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Agglutinated Foraminifera (Silurian and Early Devonian) from Borenore and Windellama, New South Wales

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Abstract – Ten species of agglutinated foraminifers are documented from the Boree Creek Limestone and the Mirrabooka Formation (Wenlock, *ranuliformis* Zone) and the Wallace Shale (early Ludlow, *variabilis* Zone) in central New South Wales. Fifteen species of agglutinated foraminifers are documented from the Windellama Limestone (Pridoli–Lochkovian, *?eosteinhornesis–delta* zones) in southeastern New South Wales. Four species are common to both faunas; two new species, *Hyperammina leptalea* and *Hemisphaerammina crassa*, are described. The stratigraphic range of the forms described is discussed in relation to established conodont zonation.

INTRODUCTION

Australian Silurian and Early Devonian foraminiferal faunas are poorly known; with one exception, all that have been reported to date consist of agglutinated forms. Chapman (1933) suggested two species of foraminifers from localities near Melbourne could be Silurian in age; it has since been shown that at least one of these is possibly Early Devonian (Bell 1996). Sherwin (1971, 1973) reported three species from the Molong Limestone and the Mumbidgle Formation from central New South Wales; these were not described. A foraminiferal fauna of Ludlow age from the Cowombat Formation, Victoria, has been described and documented (Bell in Simpson *et al.* 1993) and the large Emsian foraminiferal fauna from Buchan and Bindi, Victoria, was described by Bell (1996). Winchester-Seeto and Bell (1994, 1999) reported on Early and Middle Devonian occurrences of the linings of agglutinated foraminifers from the Garra Formation, central New South Wales, the Taravale Formation, northern Victoria and the Shield Creek Formation, northern Queensland and the Tamworth Belt, northern New South Wales, whilst Bell and Winchester-Seeto (1999) described linings from the Darling Basin, western New South Wales, the Point Hibbs Formation, Tasmania and the Coopers Creek Limestone, Victoria. The earliest occurrence of calcareous foraminifers has been reported from late Emsian (*serotinus* Zone) horizons in the Tamworth Belt (Bell 1999).

This paper documents Silurian (Wenlock to early Ludow) faunas from Borenore, near Orange, central New South Wales (Figure 1) and from an Early Devonian (Pridoli to Lochkovian) fauna from Windellama, near Goulburn, southern New South Wales (Figure 2). As all horizons from which the foraminifers were derived have been dated using conodont data (Mawson 1986, 1987; Mawson and Talent 1994; Simpson *et al.* 1993; Cockle 1999), the utility of foraminifers as stratigraphic indicators or otherwise can be assessed.

MATERIAL AND METHODS

The samples available for foraminiferal study comprised the light flotation fraction of the acid digestion process (see Anderson *et al.* 1995 for details) of samples collected for conodont study by Peter Cockle (Borenore) and Ruth Mawson (Windellama).

BORENORE (Figure 1; Table 1)

Near Borenore, northwest of Orange, central-western New South Wales, in a Middle Silurian sequence, the Boree Creek Limestone is overlain by the Mirrabooka Formation and its lateral limestone equivalent, the Borenore Limestone (Figure 1). Based on the conodont assemblages present (Cockle 1998, 1999), the foraminiferal-bearing samples from the Boree Creek Limestone (WERR 13.0, WERR 16.2, WERR 18.3) are dated as low in the *ranuliformis* Zone. The overlying Mirrabooka Formation and the Borenore Limestone, which in this area interdigitate, are about 123 m thick (Cockle 1998, 1999); according to Cockle (1998, 1999), they span the Wenlock and extend into the Ludlow (upper *ranuliformis/amsdeni* Zone and into the *variabilis* Zone). The single foraminiferal-bearing sample from the Mirrabooka Formation, DSC 230, is dated as being close to the *ranuliformis-amsdeni* boundary

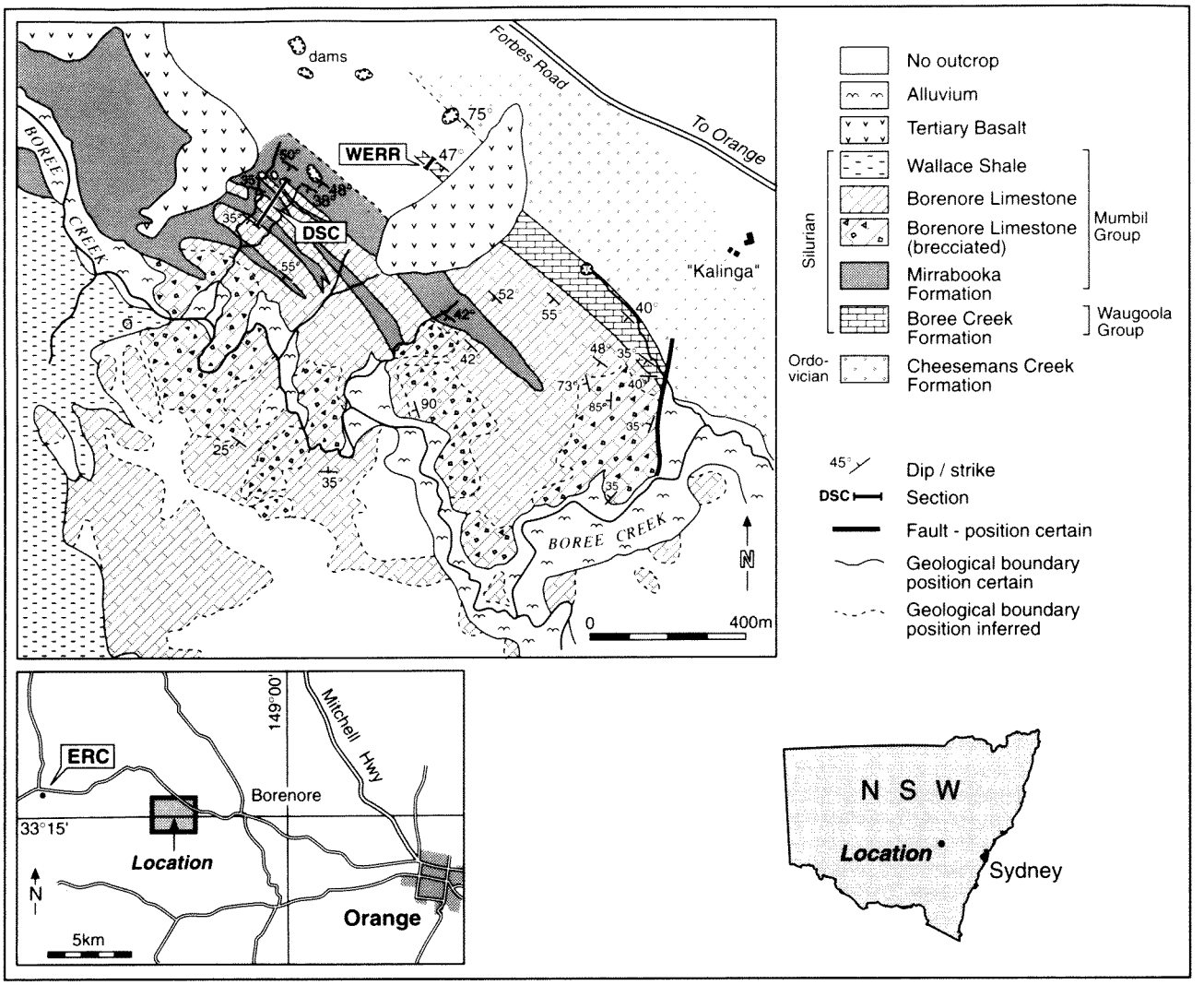

Figure 1 Geology and alignment of stratigraphic sections WERR and DSC and the location of locality EPC in the Borenore area, New South Wales (based on Cockle 1998).

	WERR 13	WERR 16.2	WERR 18.3	DSC 230	ERC 6	ERC 7
Rhabdammina sp. A	x					
Rhabdammina sp. B	x					
Sorosphaera tricella		x		x	x	
Stomasphaera globosa			x	x		
Psammosphaera cava				x		
Hemisphaerammina crassa				x		
Hyperammina leptalea				x		
'Lituotuba' exserta		x				x
Thurammina foersteri				x		
Thuramminoides sphaeroidalis			x			

Table 1 Distribution of foraminifers in sections WERR and DSC and the EPC locality in the Borenore area, New South Wales.

(early Wenlock). With the zone fossil, *Kockelella amsdeni*, occurring in one sample, approximately 8 m above the foraminiferal sample, and *K. ranuliformis* elements present in DSC 124 and DSC 181.2 (Cockle 1998, 1999), it can be no older than upper *ranuliformis* Zone.

Samples from the ERC section in the Wallace Shale, contained either fragmentary conodonts or ones too poorly preserved for identification. *Kockelella variabilis* from high in the Borenore Limestone (interbedded with the Wallace Shale), provides a maximum age for the Wallace Shale, early Ludlow *variabilis* Zone. Some conodonts from within the Wallace Shale give a slightly younger age, *siluricus–crispa* zones in accord with graptolite data (Sherwin 1971). Where no diagnostic conodonts can be determined for conodont faunas derived from clasts as is the case for samples from the ERC section, the only time constraint is the maximum age: they can be no younger than *variabilis* Zone.

WINDELLAMA (Figures 2, 3; Table 2)

The ?Late Silurian to Early Devonian carbonate sequence at Windellama, 224 km southwest of Sydney, consists of approximately 286 m of richly fossiliferous limestone (Mawson 1975, 1986). It unconformably overlies a Late Ordovician turbiditic sequence and, in turn, is overlain by the clastics and volcaniclastics of the Tangerong Formation (Mawson and Talent 1999). Conodonts from the limestone have been documented by Mawson (1986) and the brachiopod fauna described by Mawson and Talent (1999). The location of the sections and foraminifer samples are shown on Figures 2 and 3.

Conodont samples came from two sections (Figure 2) – a lower section (S section) of 128 m, and, in the vicinity of the quarry, an upper section (Q, QU section) of 161 m. These produced contrasting numbers of conodonts: 4 in the lower section and 6657 in the upper one. From the lower S section, a juvenile specimen of *O. remscheidensis costeinhornensis* was recovered suggesting a Late Silurian (Pridoli, *costeinhornensis* Zone) age for the lowermost horizons. The only foraminifer recovered from this part of the section is long-ranging. The boundary between the Pridoli and Lochkovian therefore cannot be located with precision. The lower 180.7 m of the Quarry section is assumed by Mawson (1986) to be *eurekaensis* Zone but she indicated that the incoming of *Amydrotaxis corniculans* at 143.2m above the base of the section suggests that samples Q7 and QU23 may be of *hesperius* age. Based on the conodont faunas, Mawson (1986) suggests that most of the Quarry section is Lochkovian spanning at least the *eurekaensis* and *delta* zones and perhaps ranging into the *pesavis* Zone towards the top of the section, possibly from QU259.

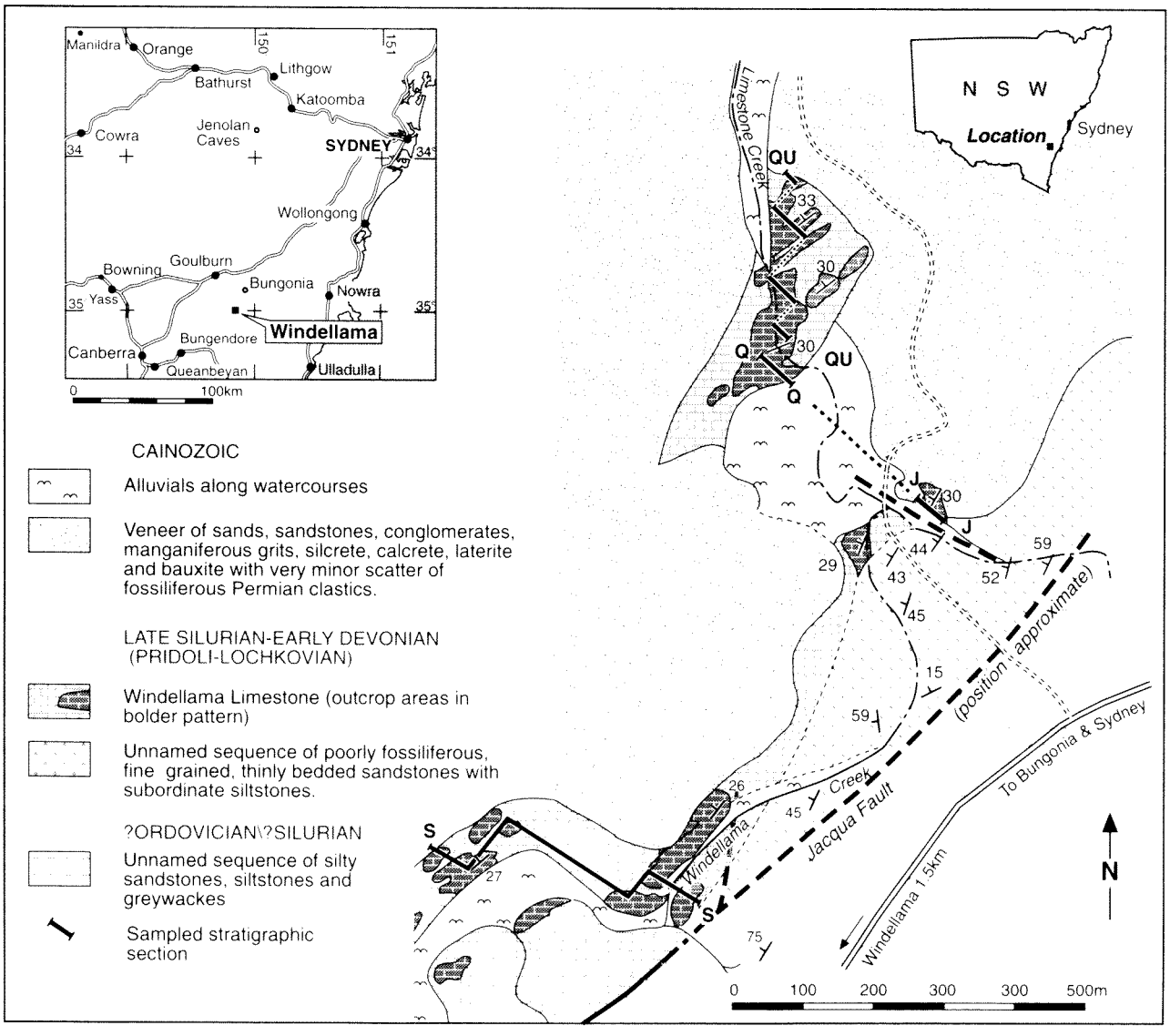

Figure 2 Geology and alignment of stratigraphic sections S, Q and QU in the vicinity of the junction of Limestone and Windellama Creeks, Windellama, New South Wales (based on Mawson 1975, 1986; Mawson and Talent 1999).

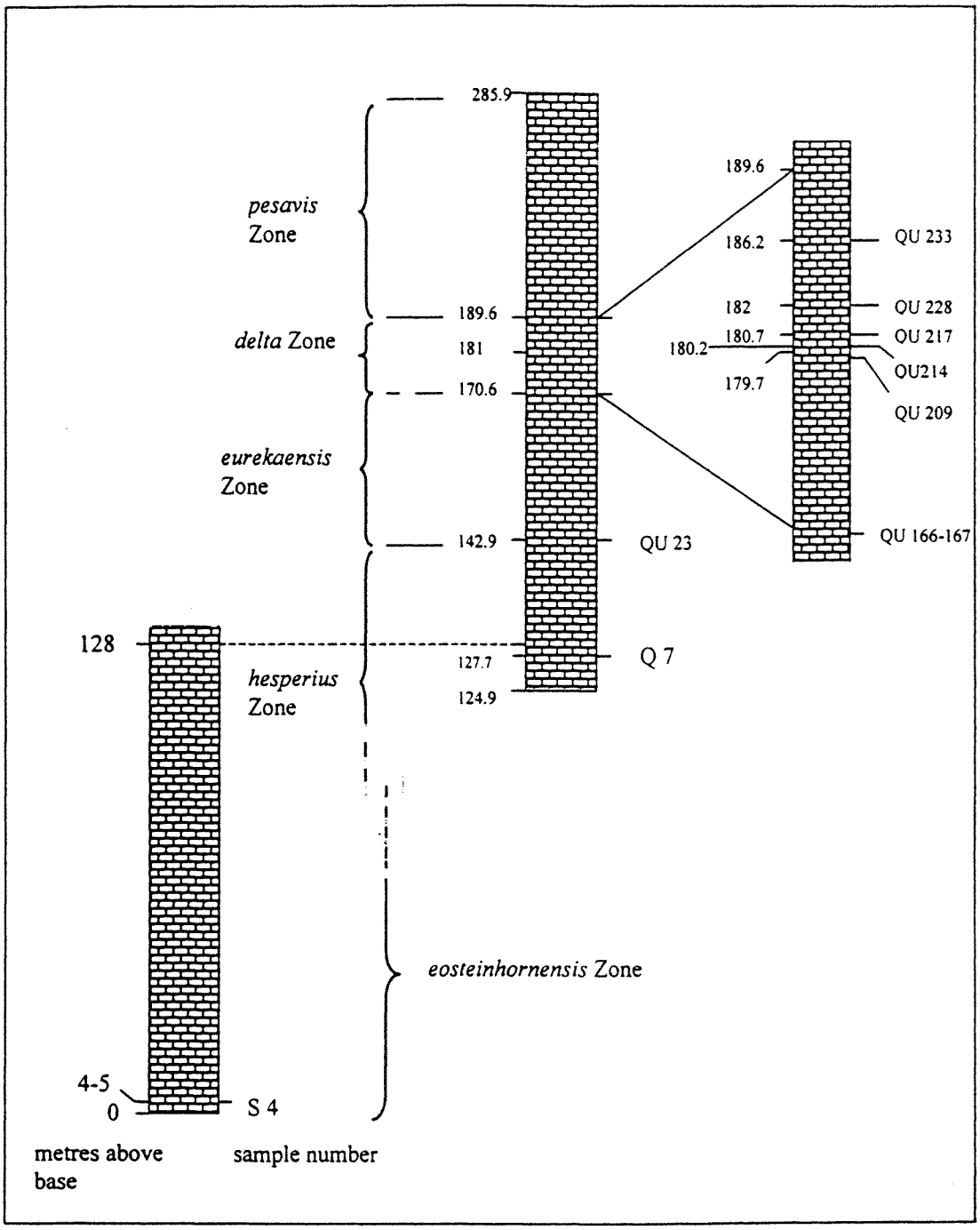

Figure 3 Windellama stratigraphic sections, showing position and age of foraminiferal samples in S, Q and QU sections. Sample numbers are prefixed with S, Q or QU.

RESULTS AND DISCUSSION

Of the 21 species of foraminifers recovered from the light flotation fraction of material prepared for conodont studies, 10 were found in the Borenore samples (Wenlock-early Ludlow) and 15 from the Windellama Limestone (Pridoli-Lochkovian). The distribution of the foraminiferal fauna from Borenore is shown in Table 1 and from Windellama on Table 2.

Occurrences of similar foraminiferal forms at Cowombat, Victoria (Bell in Simpson *et al.* 1993) and at Buchan, Victoria (Bell 1996) are included in discussion of their stratigraphic distribution and shown on Table 3.

- Four species appear to be restricted to the Silurian: *Rhabdammina* sp. A occurs only in WERR 13 and *Stomasphaera globosa* in WERR 18.3 at Borenore (lower *ranuliformis* Zone), and at Cowombat, Victoria (*crispa* Zone) as documented by Bell (in Simpson *et al.* 1993), *'Lituotuba' exserta* occurs in WERR 16.2 (lower *ranuliformis* Zone) and ERC 7 (no younger than

	eosteinhornensis	*hesperius*		*eurekaensis*					*delta*	
	S4	Q7	QU23	QU166/7	QU209	QU212	QU214	QU217	QU228	QU233
Astrorhiza triquetra					x					
Rhabdammina sp. B						x	x			
Bathysiphon sp.				x						
Psammosphaera cava				x		x				x
P. aspera										x
Sorosphaera confusa	x		x	x	x	x	x		x	x
S. tricella										x
Stegnammina cylindrica					x					x
Stomasphaera cyclops					x					x
Hemisphaerammina crassa			x							x
Tolypammina anguinea				x				x	x	
Ammovertella sp.				x						
Ammovolummina bostryx		x								
Serpenulina aulax		x								
S. uralica		x		x						

Table 2 Distribution of foraminifers in section S, Q and QU through the Windellama Limestone, Windellama, New South Wales.

variabilis Zone), and *Hyperammina leptalea* occurs in DSC 230 (upper *ranuliformis* zone).

- *Sorosphaera tricella* and *Rhabdammina* sp. B co-occur in the WERR section (lower *ranuliformis* Zone) and in the Devonian (*delta* Zone) at Windellama. *Hemisphaerammina crassa* occurs in DSC230 (upper *ranuliformis* zone) at Borenore as well as a number of horizons at Windellama (*eurekaensis–delta* zones).
- Two species (*Thurammina foersteri* and *Thuramminoides sphaeroidalis*) are long-ranging as they are known from Borenore (lower *ranuliformis Zone* and upper *ranuliformis* Zone) as well as the Emsian faunas at Buchan and Bindi, Victoria (Bell 1996). *Th. sphaeroidalis* also occurs in the Tamworth Belt as foraminiferal linings in successions that range from *costatus* Zone to *australis* Zone (Winchester-Seeto and Bell 1999). It is also known from the Permian (V. Palmeri pers. comm. 1999).
- *Psammosphaera cava*, which co-occurs with *H. crassa* in Borenore (upper *ranuliformis* zone) and at Windellama (*eurekaensis–delta* zones), is also found as linings from the *pesavis-sulcatus* zones in the Garra Formation and Darling Basin in New South Wales, Martins Well in north Queensland, and Coopers Creek Formation in southeast Victoria (Winchester-Seeto and Bell 1994; Bell and Winchester-Seeto 1999); *P. cava* also in the form of linings in the Tamworth Belt, in nothern New South Wales, spanning the *costatus-australis* zones (Winchester-Seeto and Bell 1999).
- *Sorosphaera confusa* occurs in the Silurian (*?eosteinhornensis* Zone) and extends through the *?hesperius, eurekaensis,* and *delta* zones at

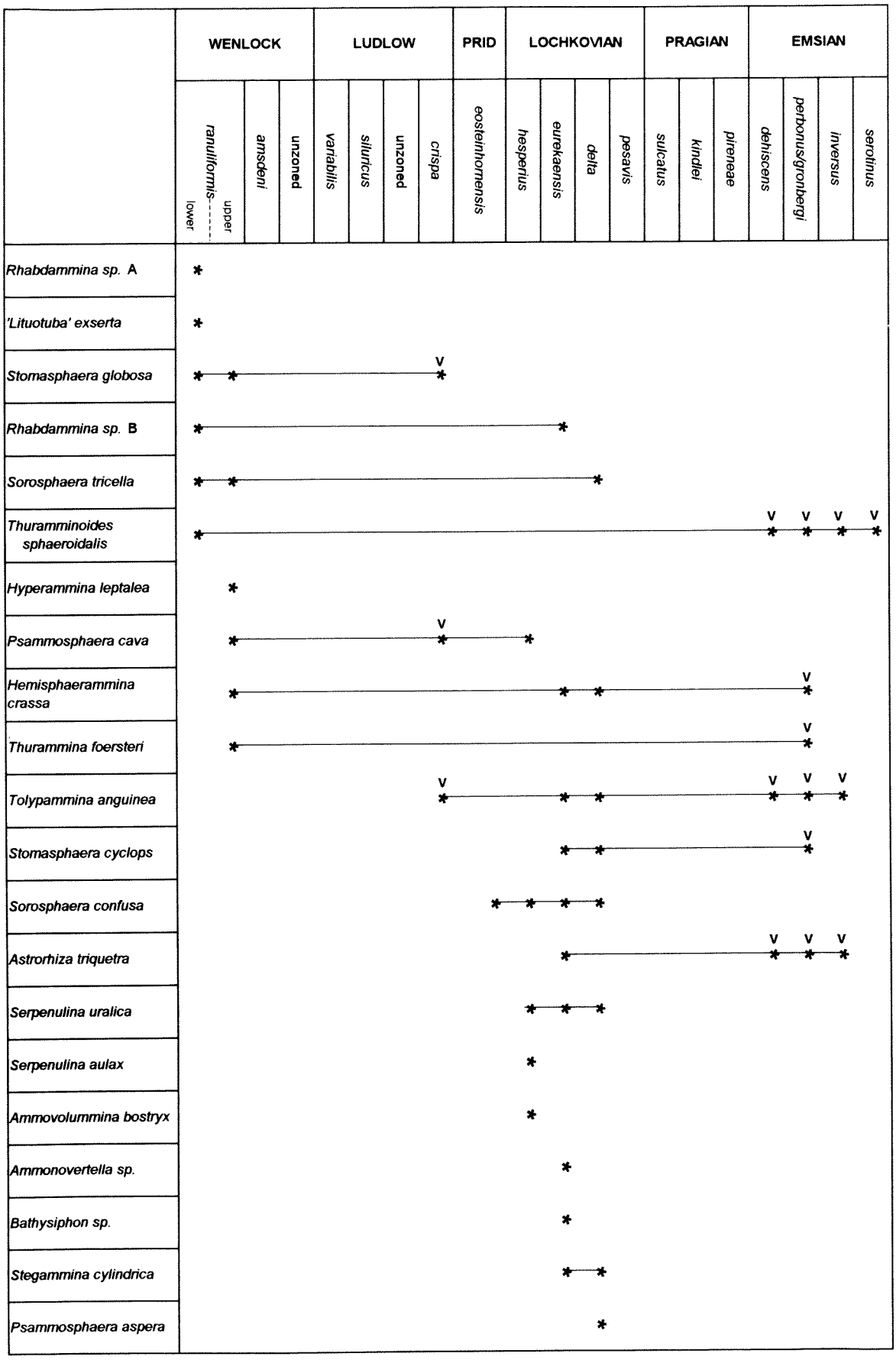

Table 3 Stratigraphic ranges of foraminifers from New South Wales localities, Borenore and Windellama, and those that also occur at Victorian localities, Cowambat and Buchan. Those from Victoria are marked with a "V".

Windellama. *Tolypammina anguinea*, documented from Cowombat (Bell in Simpson *et al.* 1993), is also recorded from Windellama (*eurekaensis–delta* zones) and from the Emsian (*dehiscens–inversus* zones) at Buchan, Victoria.

- At Windellama, two new species, *Ammovolummina bostryx* and *Serpenulina aulax*, occur only low in the Quarry section at Windellama (*?hesperius* Zone) while *Serpenulina uralica* range from Q7 to QU233 (*?hesperius* Zone to *delta* Zone).
- *Bathysiphon* sp. and *Ammovertella* sp. are recorded only from QU 166/167 (*eurekaensis* Zone).
- Two species, *Astrorhiza triquetra* and *Stomasphaera cyclops*, occurring at Windellama (*eurekaensis–delta* zones) have also been recorded from the early Emsian (*dehiscens–inversus* zones) at Buchan (Bell 1996).

SYSTEMATIC PALAEONTOLOGY

All type and figured specimens have been deposited in the Palaeontological Collections of the National Museum of Victoria, registered numbers prefixed NMV P. Classification follows Loeblich and Tappan (1988).

Order Foraminiferida Eichwald, 1831

Suborder Textulariina Delage and Hérouard, 1896

Family Astrorhizidae Brady, 1881

Astrorhiza Sandahl, 1858

Type Species
Astrorhiza limnicola Sandahl 1858

Astrorhiza triquetra Bell, 1996

Astrorhiza triquetra Bell 1996: 80, fig. 5A,B

Distribution and Age
QU209, Windellama Limestone, Windellama, NSW; Lochkovian, *eurekaensis* Zone.

Material
4 specimens.

Remarks
The specimens found have short, but equally long, stolons and fall within the range shown by specimens from the Emsian (*dehiscens–inversus* zones) from Buchan, Victoria, (Bell 1996).

Family Rhabdamminidae Rhumbler, 1895

Rhabdammina M. Sars in Carpenter, 1869

Type Species
Rhabdammina abyssorum M. Sars in Carpenter 1869

Rhabdammina sp. A

Figure 4 I

Description
Test free; large, Y-shaped, bifurcating tube, with arms forming an angle of 120°; no inflation at arm junction; arms thin (narrow), evenly cylindrical; wall, thin, fine grained, surface smoothly finished; apertures simple, circular opening at ends of arms.

Distribution and Age
WERR 13, Boree Creek Limestone, Borenore, NSW; early Wenlock, lower *ranuliformis* Zone.

Material
8 specimens.

Measurements (in mm)
Figured specimen NMV P208054 average arm diameter 0.2-0.275;
longest arm 1.2;
wall thickness 0.025;
wall thickness/wall diam. = 0.1

Remarks
There appears to be no inflation at the junction of the arms that would indicate a prolocular chamber as is usual in *Rhabdammina*, but this feature is not always apparent in Recent specimens (cf. *R. linearis*) figured by Brady (1884) or in Silurian forms figured by McClellan (1966).The arms are usually slightly curved and often show increased swelling just after the junction. Features that indicate this to be a separate species are the narrow arms that are not inflated at the arm junction.

Rhabdammina sp. B

Figure 4 J

Description
Test free; long, Y-shaped, bifurcating tube with at least 3 arms; arms narrow with one arm usually much wider than the other two; angle between the narrower arms greater than 120°; wall thin, coarsely formed and finished; apertures are narrow openings at the ends of the arms.

Distribution and Age
WERR 13, Boree Creek Limestone, Borenore, NSW; early Wenlock, lower *ranuliformis* Zone; QU 212, QU 214, Windellama Limestone, Windellama, NSW; Lochkovian, *eurekaensis* Zone.

Material
7 specimens.

Measurements (in mm)
Figured specimen NMV P208055 average arm

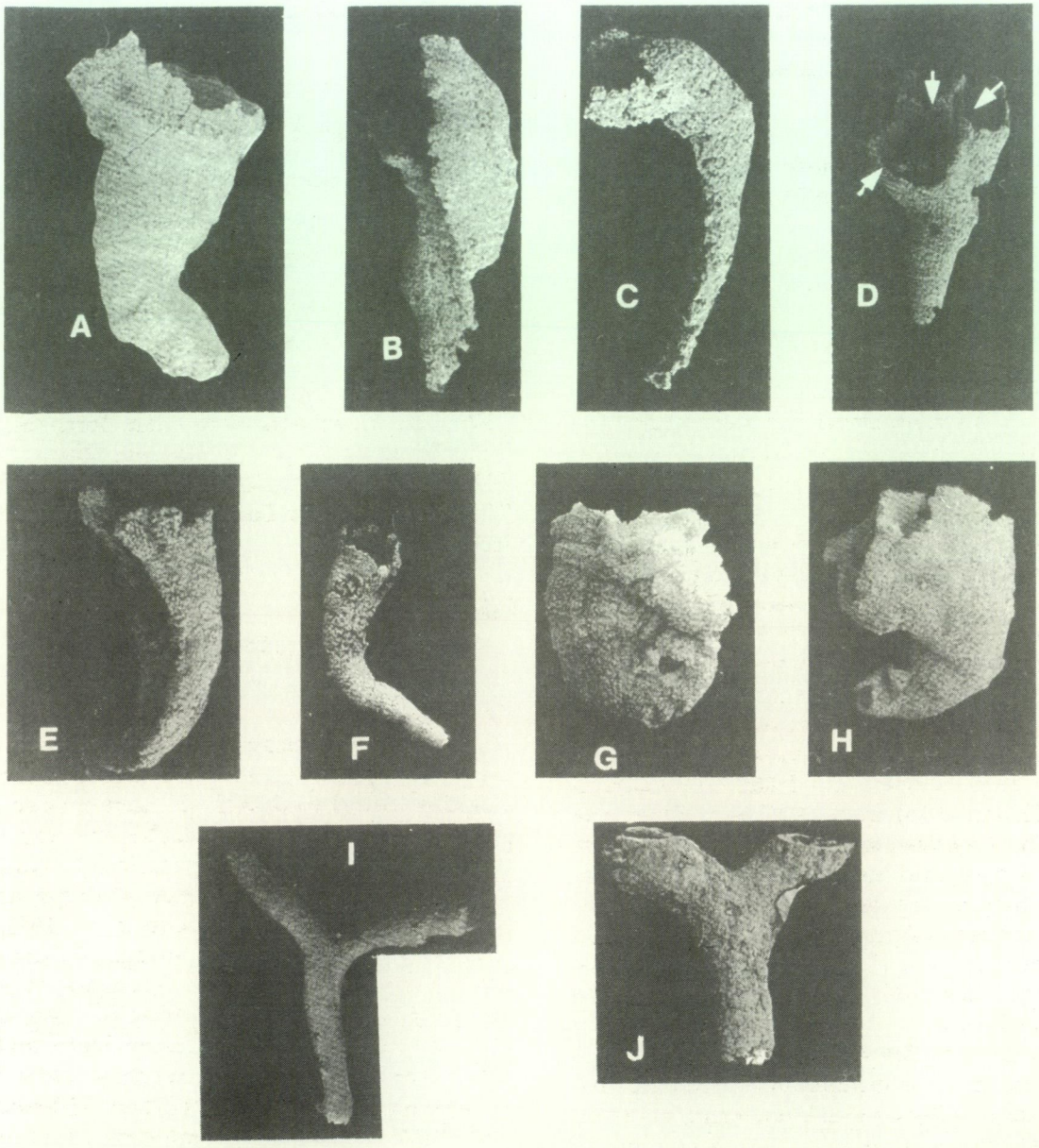

Figure 4 **A–D**, *Serpenulina uralica* Tschernich. **A**, figured specimen NMV P208019, x30, Q7. **B**, figured specimen NMV P208020, x30, Q7. **C**, Figured specimen NMV P208021, x30, Q7. **D**, Figured specimen NMV P208022, x20, Q7, showing multichambered aperture, arrows indicate intercameral apertures. **E–F**, *Serpenulina aulax* n. sp. **E**, Holotype NMV P208023, x25, Q7. **F**. Paratype NMV P208024, x15, Q7. **G–H**, *Ammovolumina bostryx* n. sp. **G**, holotype NMV P208025, x30, Q7. **H**, paratype NMV P208026, x25, Q7. **I**, *Rhabdammina* sp. A. Figured specimen NMV P208054, x25, WERR 13. **J**, *Rhabdammina* sp. B. Figured specimen NMV P208055, x25, WERR 13.

diameter 0.4–0.5;
longest arm 1.1;
wall thickness 0.075
wall thickness/wall diam. = 0.15

Remarks

This is a much stouter species than *Rhabdammina* sp. A in both overall size and relative arm thicknesses. Features that indicate this to be a separate species are that there at least 3 arms, one of which is usually much wider than the other two. One four armed specimen has been found. A prolocular inflation is present rarely.

Family Bathysiphonidae Avnimelech, 1952

***Bathysiphon* M. Sars in G.O. Sars, 1872**

Type Species

Bathysiphon filiformis M. Sars *in* G.O. Sars 1872

***Bathysiphon* sp.**

Figure 5 K–L

Description

Tubular pieces; thick wall formed of two layers – an inner layer formed of equiangular grains, closely

fitted together with little cement, and overlain by a thin glaze (?cement) resulting in a smooth exterior; interior smooth; surface may show wrinkles.

Distribution and Age

QU166, Windellama Limestone, Windellama, NSW; Lochkovian, *eurekaensis* Zone.

Material

7 specimens.

Remarks

The wall varies in thickness from specimen to specimen but is usually about one-sixth of the tube diameter. The two layered wall structure is found in some Recent *Bathysiphon* (Gooday and Claugher 1989). Moreman (1930) and Stewart and Priddy (1941) have each described *Bathysiphon* species from Ordovician and Silurian rocks from Oklahoma, Ohio and Indiana respectively. The present specimens differ from those of Moreman (1930) in size and wall thickness; as there is insufficient material, the Windellama specimens are left in open nomenclature.

Bathysiphon has been recorded from the Ordovician and numerous species in the Silurian (Moreman 1930; Stewart and Priddy 1941; Dunn 1942; McClellan 1966) from Oklahoma, Ohio and Indiana. The American forms are described as thin walled, narrow and usually curved; in these characters they closely resemble the distal tubular section of species of *Hyperammina*, a fact also noted by these authors and also by Mound (1968). The present specimens differ from these species in size and wall thickness.

One specimen of *Bathysiphon* sp. (Figure 5 K–L) shows a foraminifer embedded in the wall. Epizoal activity of foraminifers is well known and, in Recent and Cretaceous sediments, seem restricted to calcareous rotaliid genera (Nyholm 1961; Sliter 1965; Todd 1965; Banner 1971; Baumfalk *et al.* 1982; Alexander and DeLaca 1987; Smyth 1988; Collen 1998). In discussing epizoans on Silurian-Devonian crinoids from Gotland Franzen (1974), reported that in many pits on the crinoid stems small, flattened, agglutinated vesicles which in all respects resembled the foraminiferal genera *Psammosphaera* and *Saccammina*. In the present case the epizoan foraminifer is clearly an agglutinated form. It has a bulbous proloculum followed by a coiled second chamber; this type of growth is characteristic of both *Tolypammina* and *Lituotuba*.

Family Psammosphaeridae Eimer and Fickert, 1899

Psammosphaera Schulze, 1875

Type Species

Psammosphaera fusca Schulze 1875

Psammosphaera cava Moreman, 1930

Figure 5 H

Psammosphaera cava Moreman 1930: 48, pl.6, fig. 12.

Psammosphaera sp.: Simpson *et al.* 1993: 146.

Psammosphaera cava: Bell 1996: 88, fig. 6J.

Psammosphaera cava: Bell and Winchester-Seeto 1999: 32, pl. 1, figs 2, 3.

Psammosphaera cava: Winchester-Seeto and Bell 1999: 155–175, figs 7 B–C.

Distribution and Age

DSC 230, Mirrabooka Formation, Borenore, NSW; early Wenlock, upper *ranuliformis* Zone; QU166, QU167, QU212, QU233, Windellama Limestone, Windellama, NSW; Lochkovian, *eurekaensis–delta* zones

Material

More than fifty specimens.

Remarks

Depending on the size of the grains used in the test wall, specimens may be either smooth or slightly roughly finished. Some specimens showed evidence of an attachment scar in the form of a narrow linear depression. In Australia, this species occurs in horizons of *crispa* Zone at Cowombat, Victoria (Simpson *et al.* 1993) and what are considered to be linings of the species have been recovered from horizons of *pesavis* and *sulcatus* Zone in the Wellington area, central New South Wales (Winchester-Seeto and Bell 1994), the Darling Basin, western New South Wales, Martins Well Limestone, Queensland, and from the *kindlei* conodont zone of the Coopers Creek Limestone, Victoria (Bell and Winchester-Seeto 1999), and also from the *costatus-australis* conodont zones in the Tamworth Belt, northern New South Wales (Winchester-Seeto and Bell 1999).

Psammosphaera cava is long-ranging and cosmopolitan in its distribution. It is commonly found in horizons of Silurian age in North America, for example, in Missouri (Dunn 1942), Ohio (Stewart and Priddy 1941), and Indiana (Browne and Schott 1963; McClellan 1966; Mound 1968), and it has been reported from the Devonian of Ohio (Summerson 1958). It has also been reported from the Silurian in England (Mabillard and Aldridge 1982) and the Austrian Alps (Kristan-Tollmann 1971), from Late Silurian–Early Devonian sequences in Sardinia (Gnoli and Serpagli 1985). Olempska (1983) has found *Psammosphaera cava* in a Late Devonian fauna from the Holy Cross Mountains, Poland.

Psammosphaera aspera Summerson, 1958
Figure 5 I

Psammosphaera aspera Summerson 1958: 550, pl. 18, figs 10,11.

Description
Spherical to subglobular; large; wall single grain thickness and coarsely constructed; surface rough; no visible aperture.

Distribution and Age
QU233, Windellama Limestone, Windellama, NSW; Lochkovian, *delta* Zone.

Material
More than twenty specimens.

Remarks
P. aspera is distinguished by its large size and coarse construction. Although similar to single chambers of *Sorosphaera tricella* Moreman, the specimens do not show any evidence of remains of formerly attached chambers but often show narrow attachment scars as if they could have once been attached to algal stems.

Mound (1968) placed *P. aspera* into synonymy with *P. fusca* without comment.

Sorosphaera Brady, 1879

Type Species
Sorosphaera confusa Brady 1879

Remarks
The determination of species within *Sorosphaera* is difficult. The number of chambers joined together has, in the past, been a character used to distinguish separate species (Dunn 1942; McClellan 1966) even though McClellan (1966) considered that it was highly likely that several species were only various chamber combinations of the one species and he used the number of chambers for convenience. Gutschick and Treckmann (1959) found polythalamous forms in their material and thought it futile to attempt to split these into separate species. Kristan–Tollmann (1971) revised the early Palaeozoic sorosphaerid foraminifers and showed that using only the arrangement of chambers (planar or three-dimensional), five species could be distinguished (*S. tricella, S. bicella, S. confusa, S. subconfusa, S. papilla*). This classification is not useful for Australian material; although some samples may only have one form present, in many samples various groupings of chambers can occur and merge from one form to another and only two forms can consistently be separated: *S. tricella* and *S. confusa.*

Single chambered specimens of *Sorosphaera* are distinguished from *Psammosphaera* in having a much thinner test wall and in having one or more flattened surfaces.

Sorosphaera confusa Brady, 1879

Sorosphaera confusa Brady 1879: 28

Distribution and Age
S4, QU23, QU166, QU167, QU209, QU212, QU214, QU228, QU233, Windellama Limestone, Windellama, NSW; Pridoli-Lochkovian, *?eosteinhornensis-delta* zones.

Material
More than fifty specimens.

Remarks
Kristan-Tollmann (1971) has revised the early Palaeozoic species in the genus *Sorosphaera* and concluded that, on the basis of chamber shape and mode of aggregation of the chambers, there are only five species. She did not accept that the number of chambers present should be a specific character. However in the present samples the forms showing multithalamous grouping are not as easily separable as Kristan-Tollmann suggests. Whilst most samples contain forms typical of *S. confusa* (i.e. small, smooth tests, loosely arranged in clusters) there are other variants present; in samples QU212 and S4 the tests are all flattened to some degree; in sample QU214 the test wall is extremely finely grained and in sample QU228 many linear arrangements (of up to 6 chambers) are found. These latter could be placed in *S. tricella* following Kristan-Tollmann but, apart from this different growth habit, they are otherwise similar to *S. confusa.* Mound (1961) reported this species from Silurian horizons in Indiana.

Many form variants co-exist with *S. confusa*; these are not separated herein as different species.

Sorosphaera tricella Moreman, 1930
Figure 5 F–G

Sorosphaera tricella Moreman 1930: 47, pl. 5, figs 12, 14.

Sorosphaera tricella: Dunn 1942: 324, pl. 42, fig. 15.

Sorosphaera tricella: Browne and Schott 1963: 212, pl. 49, fig. 15,

Sorosphaera tricella: McClellan 1966: 472, pl. 37, fig. 10; pl. 41, fig. 10.

Sorosphaera tricella: Kristan-Tollmann 1971: 173, Table 1.

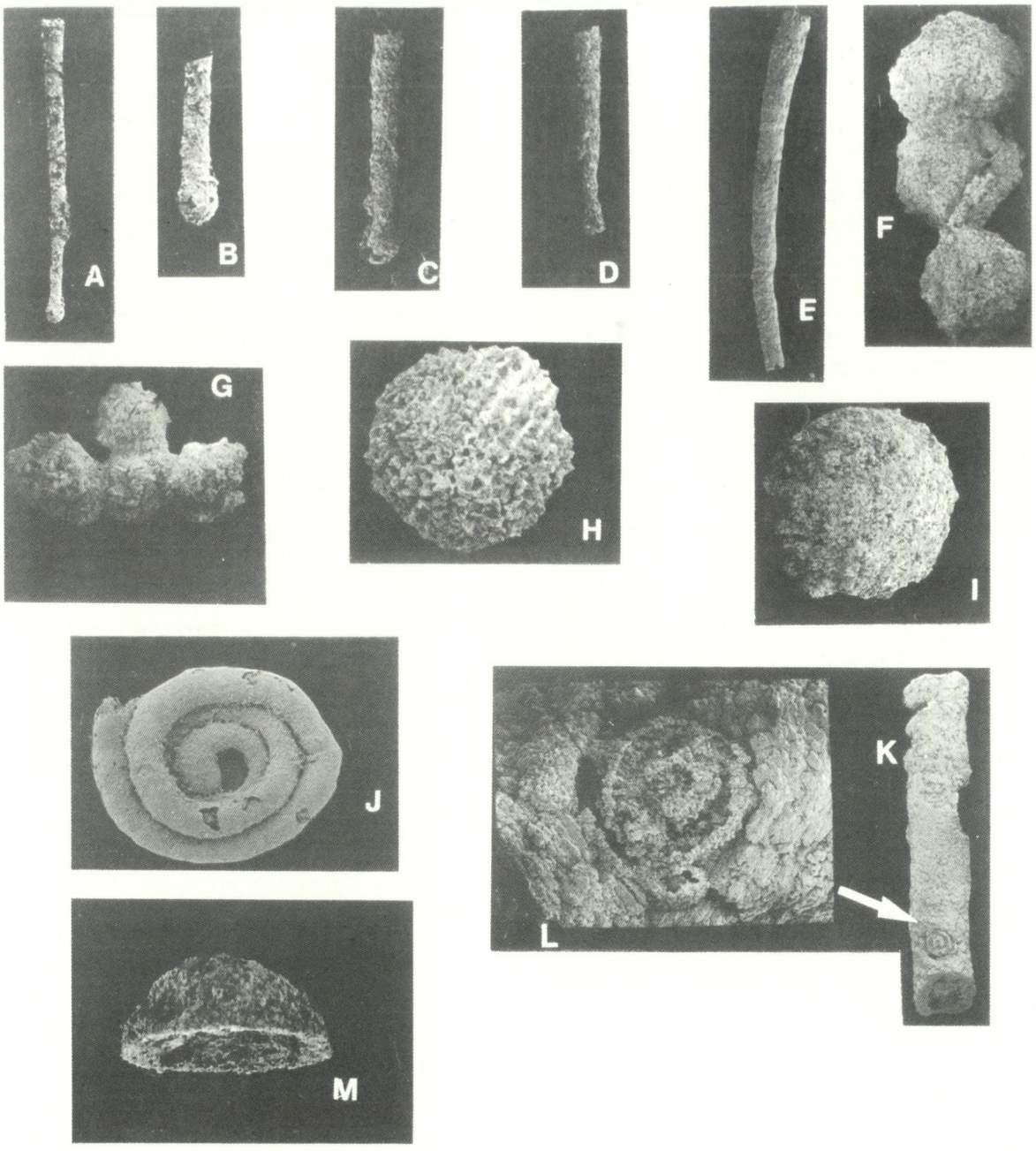

Figure 5 **A–E**, *Hyperammina leptalea* n.sp. **A**, holotype NMV P208072, x60, DSC 230. **B**, closeup of proloculum of Holotype, x150. **C**, paratype NMV P208073, x80, DSC 230. **D**, paratype NMV P208074, x70, DSC 230. **E**, paratype NMV P208075, x65, DSC 230. **F–G**, *Sorosphaera tricella* Moreman. **F**, figured specimen NMV P208070, x24, WERR 16.2. **G**, figured specimen NMV P208071, x24, QU 166. **H**, *Psammosphaera cava* Moreman. Figured specimen NMV P208076, x130, DSC 230. **I**, *Psammosphaera aspera* Summerson. Figured specimen NMV P208077, x24, QU 233. **J**, *'Lituotuba' exserta* Moreman. Figured specimen NMV P208078, x400, WERR 16.2. **K–L**, *Bathysiphon* sp. **K**, figured specimen NMV P208032, x15, QU 166, arrow points at epizoan. **L**, closeup of epizoan on figured specimen NMV P208032, x110. **M**, *Hemisphaerammina crassa* Bell. Holotype NMV P199599, x26, OTRC 7, Taravale Formation (re-illustrated from Bell, 1996, fig. 8N).

Description

Test free; globular chambers, varying numbers, joined in a plane; moderately loosely combined; wall thickness variable, finely to coarsely arenaceous; no apparent aperture.

Distribution and Age

WERR 16.2, Boree Creek Limestone, Borenore, NSW, early Wenlock, lower *ranuliformis* Zone; DSC 230, Mirrabooka Formation, Borenore, NSW, early Wenlock, upper *ranuliformis* Zone; ERC, clast in the Wallace Shale, Borenore, NSW, early Ludlow no younger than *variabilis* Zone; QU 233, Windellama Limestone, Windellama, NSW; Lochkovian, *delta* Zone.

Material
More than fifty specimens.

Measurements (in mm)
Figured specimen NMV P208070 chamber diameters 0.7–0.75
Figured specimen NMV P208071 chamber diameters 0.8–0.9.

Remarks
Included in this taxon are specimens with from one to five large and subequal chambers, loosely arranged in a more or less linear manner; in all these characters they differ from the smaller, smoother and agglomerate form *confusa*. Because various sized chambers are grouped together, the variation between specimens is often marked but only one species is present. Although isolated specimens do have chambers smaller at one end and apparently enlarging in sequence, the variation of the chamber sizes within the specimens, taken over the whole population , does not seem to show any apparent growth direction. The wall thickness is variable even within the one sample. Specimens from WERR 16.2 were much thicker than those from elsewhere ranging up to 100 µm.

Sorosphaera tricella has been reported from Silurian and Early Devonian sequences in Europe and North America (e.g. Moreman 1930; Summerson 1958; Browne and Schott 1963; Mound 1968; Kristan-Tollmann 1971)

Stegnammina Moreman, 1930

Type Species
Stegnammina cylindrica Moreman 1930

Stegnammina cylindrica Moreman, 1930

Stegnammina cylindrica Moreman 1930: 49, pl.7, fig. 12.

Stegnammina cylindrica: Bell 1996: 90, fig. 6K.

Distribution and Age
QU209, QU233, Windellama Limestone, Windellama, NSW; Lochkovian, *eurekaensis–delta* zones.

Material
More than fifty specimens.

Remarks
Specimens are usually cylindrical in shape; some, especially in sample QU209, become attenuated at one end. In North America, *S. cylindrica* has been reported from Silurian sequences (e.g., Moreman 1930; Dunn 1942; Mound 1968).

Thuramminoides Plummer, 1945 *emend.* Conkin, 1961

Type Species
Thuramminoides sphaeroidalis Plummer 1945.

Thuramminoides sphaeroidalis Plummer, 1945

Thuramminoides sphaeroidalis Plummer 1945: 218, pl.15, figs 4–10.

Thuramminoides sphaeroidalis: Conkin and Conkin 1964: 71, pl. 12, figs 36–38 (with synonymy).

Thuramminoides sphaeroidalis: Conkin *et al.* 1981: 344, pl. 1, figs 4–7 (with extensive synonymy).

Thuramminoides sphaeroidalis: Bell 1996: 103, fig. 10 L.

Thuramminoides sphaeroidalis: Riegraf and Niemeyer 1996: 26, figs 4–6, 8–11, 14–15, 17, 20–23, 25–31, 45, 58–60, 63.

Trochammina bursaria Chapman: 1933: 246, pl. 11, fig. 3.

Distribution and Age
WERR 18.3, Boree Creek Limestone, Borenore, NSW; early Wenlock, lower *ranuliformis* Zone.

Material
More than twenty specimens.

Remarks
Rare specimens, usually flattened, occurred in one sample. They were smaller and had thinner walls than is usual for this species but otherwise showed no significant differences to specimens found in many Early Devonian localities at Buchan (*dehiscens–serotinus* zones) in Victoria (Bell 1996) and from Permian horizons in Western Australia, Tasmania and New South Wales (Crespin 1958). The species has been reported from Silurian horizons in Texas (Plummer 1945), from Ordovician localities in Germany (Riegraf and Niemeyer 1996) and from Late Devonian–Early Carboniferous horizons in Indiana and Kentucky (Conkin *et al.* 1981). Linings of this species have also been reported from the Middle Devonian of the Tamworth Belt (Winchester-Seeto and Bell 1999)

Family SACCAMMINIDAE Brady,1884

Stomasphaera Mound, 1961, *emend.* Bell (in Simpson *et al.*, 1993)

Type Species
Stomasphaera brassfieldensis Mound 1961

Stomasphaera cyclops Bell, 1996

Stomasphaera cyclops Bell 1996: 92, figs 9 A–D.

Distribution and Age
QU209, QU233, Windellama Limestone, Windellama, NSW; Lochkovian, *eurekaensis – delta* zones.

Material
More than twenty specimens.

Remarks
The rare specimens of this species found at Windellama were somewhat smaller than those from horizons dated as *perbonus* Zone at Bonanza Gully, Bindi, Victoria (Bell 1996).

Stomasphaera globosa Bell, 1993

Stomasphaera globosa Bell 1993: 146, fig. 3I.

Description
Test free; finely arenaceous; two – three globular chambers arranged roughly rectilinearly; chambers firmly attached to each other but with no apparent openings between them; sutures may or may not be clearly defined; aperture a small arcuate to oval opening in each chamber; wall smooth.

Distribution and Age
WERR 18.3, Boree Creek Limestone, Borenore, NSW; early Wenlock, lower *ranuliformis* Zone; DSC 230, Mirrabooka Formation, Borenore, NSW, early Wenlock, upper *ranuliformis* Zone

Material
More than twenty specimens.

Remarks
Specimens recovered at Borenore are smaller than those from Cowombat Plain on the Victoria–New South Wales border (Simpson *et al.* 1993), but do not differ in other respects.

Thurammina Brady, 1879

Type Species
Thurammina papillata Brady 1879

Thurammina foersteri Dunn, 1942

Thurammina foersteri Dunn 1942: 331, pl. 43, fig. 27.

Thurammina foersteri: Browne and Schott 1963: 219, pl. 50, fig. 13.

Thurammina foersteri: Bell 1996: 96, fig. 8F.

Description
Test free; globular, with two low, dome-shaped papillae almost diametrically opposed; test wall made from even sized, very small grains, smoothly finished; aperture a simple opening at the summit of each papilla.

Distribution and Age
DSC 230, Mirrabooka Formation, Borenore, NSW; early Wenlock, upper *ranuliformis* Zone.

Material
2 specimens.

Remarks
Specimens were smaller (0.175–0.225 mm diam.) than those found at Buchan, Victoria (0.39 mm; Bell 1996) in a horizons dated as *perbonus Zone,* and Dunn's (1942) original specimen from the Silurian in Missouri (0.29 mm) but otherwise showed no differences.

Family Hemisphaeramminidae Loeblich and Tappan, 1984

Subfamily Hemisphaeramminae Loeblich and Tappan, 1961

Hemisphaerammina Loeblich and Tappan, 1957

Type Species
Hemisphaerammina batalleri Loeblich and Tappan 1957

Remarks
It should be noted that the possibility exists that some specimens placed within the genus *Hemisphaerammina* may not belong within the Foraminiferida but actually represent gastropod egg-capsules (Adegoke *et al.* 1969; Bell and Burn 1979).

Mound (1968) emended Loeblich and Tappan's original description to include forms with a basal flange but these forms were placed in the new genus *Metamorphina* by Browne (Browne and Schott 1963). The diagnosis was further emended by Conkin and Conkin (1981) to include multichambered forms including those with or without a basal flange. McClellan (1966) restricted *Hemisphaerammina* to single hemispherical forms as distinct to the multichambered, flanged *Metamorphima.* Loeblich and Tappan (1988) synonymised *Hemisphaerammina* and *Metamorphina.* Forms without a basal flange but with one or two (or very seldom three) joined chambers have been referred herein to the genus *Hemisphaerammina* while those with a flange and are multichambered are considered to belong to *Metamorphina.*

Hemisphaerammina crassa Bell, n. sp.
Figure 7 M

Hemisphaerammina sp. Bell 1996: 97, fig. 8N.

Diagnosis
A species of *Hemisphaerammina* with a thick , rough wall.

Description
Test attached; hemispherical, with a thick wall; attachment surface flat, smooth with no flanges and no evidence of a basal membrane; wall coarse and roughly finished.

Holotype
NMV P199599, Fig. 8N, Bell 1996.

Type locality and horizon
Old Taravale Road cutting, Buchan, Victoria, sample OTRC 7, Taravale Formation, Emsian, *perbonus* Zone.

Distribution and Age
DSC 230, Mirrabooka Formation, Borenore, NSW, early Wenlock, upper *ranuliformis* Zone; QU 23, QU 233, Windellama Limestone, NSW, Lochkovian, *eurekaensis – delta* zones.

Material
9 specimens from Buchan, more than twenty specimens from Borenore and more than twenty specimens from Windellama.

Measurements (in mm)
diameter of test 0.4 – 0.6; wall thickness – ± 0.075.

Remarks
Whilst the external surface of this species can vary from quite rough to relatively smooth, the thick wall is always characteristic. Double chambered forms were common in species from the Mirrabooka Formation; the chambers, however, could be easily separated.

Derivation of name
crassa (Lat.) = thick; referring to the thickness of the wall of the test.

Family Ammodiscidae Reuss, 1862

Tolypammina Rhumbler, 1895

Type Species
Hyperammina vagans Brady 1879

Tolypammina anguinea Bell, 1996

Tolypammina sp., Simpson *et al.* 1993: 149, fig. 3 L,M.

Tolypammina anguinea Bell 1996: 99, figs 10 A,B.

Distribution and Age
QU167, QU217, QU228, Windellama Limestone, Windellama, NSW; Lochkovian, *eurekaensis – delta* zones.

Material
2 specimens – 1 each from Borenore and Windellama.

Remarks
This is a very rare species in the fauna at Windellama occurring only as single specimens in each horizon. None showed the proloculum but otherwise seemed identical with the Buchan Emsian species that were recovered from horizons dated as *dehiscens–inversus* zones. The species has also been reported from the *crispa* Zone at Cowombat, Victoria (Bell in Simpson *et al.* 1993).

Ammovertella Cushman, 1928

Type Species
Ammodiscus (Psammophis) inversus Schellwien 1898

Ammovertella sp.

Distribution and Age
QU166, Windellama Limestone, Windellama, NSW; Lochkovian, *eurekaensis* Zone.

Material
1 specimen.

Remarks
One small specimen comprising the proloculum and part of the encircling tubular chamber is tentatively placed here. It is quite similar to the initial part of the specimen figured in Bell (1996, Figure 10 I), but the precise relationship to *A. calyx* must await more material.

Ammovolummina Tschernich, 1967

Type Species
Ammovolummina saumensis Tschernich 1967

Ammovolummina bostryx Bell, n. sp.
Figure 4 G–H

Diagnosis
A species of *Ammovolummina* showing an initial spiral then a rectilinear growth habit.

Description

Test free (?); tubular, non-septate, slightly curved to tightly coiled; rapidly dilating; initially forming a spiral of about one whorl, then more or less straight; wall thin, consisting of a single layer of closely cemented quartz grains, smoothly finished; interior smooth; aperture simple at end of tube; proloculum not known.

Holotype

NMV P208025, the specimen illustrated herein on Figure 6G.

Type locality and horizon

Windellama Limestone, Windellama, NSW, sample Q 7.

Distribution and Age

Known only from the type locality; Lochkovian, *?hesperius* Zone.

Material

Twenty-six specimens.

Measurements (in mm)

	maximum length	apertural diameter
Holotype NMV P208025	1.0	0.63
Paratype NMV P208026	2.6	0.7

Remarks

Some specimens show a small attachment scar on the prolocular end. In all cases the proloculum has been broken away. The variation in shape is great: specimens maybe rectilinear or strongly spiral with the inner margins varying from being contiguous to being separate. Only in the more tightly coiled form, where after 1–2 whorls a floor forms in the initial tube, does *A. bostryx* show the formation of secondary chambers. The new chambers are interconnected with each other and the initial chamber by small pores. There is only a single wall between the chambers. *A. bostryx* is similar to *A. saumensis* Tschernich but differs in showing contiguous margins within the growth pattern, and differs from *A. pseudotuba* Tschernich in not having a reflexed growth pattern.

Derivation of Name

bostrychos (Greek) = curly; referring to the coiling form of the test.

Serpenulina Tschernich, 1967

Type Species

Serpenulina uralica Tschernich 1967

Serpenulina uralica Tschernich, 1967

Figure 4 A–D

Serpenulina uralica Tschernich 1967: 32, pl. 3, figs 8–11.

Description

Test attached; proloculum oval; second tubular chamber slightly curved, flattened on attached side; second chamber gradually expanding with growth; wall closely cemented quartz grains, only one grain thick, but may be partially destroyed on attached side; aperture terminal, rounded.

Distribution and Age

Q 7, QU 166, QU 233, Windellama Limestone, Windellama, NSW; Lochkovian, *?hesperius–delta* zones.

Material

Thirty-eight specimens.

Measurements (in mm)

	maximum length	apertural diameter
Figured specimen NMV P208019	1.75	1.0
Figured specimen NMV P208020	2.03	0.5
Figured specimen NMV P208021	2.37	0.35
Figured specimen NMV P208022	1.7	ch 1-0.6; ch 2-0.4; ch 3- 0.3

Remarks

The present specimens differ slightly from those originally described (Tschernich 1967) in that the surface is smooth and does not show external wall constrictions. The proloculum is normally missing but one specimen shows a fairly large hemispherical chamber which is slightly constricted from the tubular part. The initial end may be slightly coiled, about one-quarter of a revolution, then almost straight growth with no twisting of the test. The attached wall is very flat and wide giving an almost hemitubular look to the test cross-section. One specimen showed the development of two smaller chambers (?tubes); on the attachment side two small chambers form and apparently grow independently giving a splayed shape to the top of the specimen. These chambers are connected by a pore in the wall between them and by a pore to the initial tubular section which has a transverse floor forming at this junction.

Serpenulina uralica, originally described from the northern Urals (Tschernich 1967) came from horizons dated as Ludlow.

Serpenulina aulax Bell, n. sp.

Figure 4 E–F

Diagnosis

A species of *Serpenulina* with a long narrow attachment scar along the wall of the conical test.

Description
Test attached; tubular undivided chamber widening rapidly but uniformly with growth; more or less rectilinear; wall thin (one grain), formed of quartz grains closely cemented; proloculum indeterminate; aperture more or less circular at end of tube.

Holotype
NMV P208023, the specimen illustrated on Figure 6E.

Type locality and horizon
Windellama, NSW, sample Q 7.

Distribution and Age
Q 7, Windellama Limestone, Windellama, NSW; Lochkovian, *?hesperius* Zone.

Material
Fifteen specimens.

Measurements (in mm)

	maximum length	apertural diameter
Holotype NMV P208023	1.48	0.55
Paratype NMV P208024	2.63	0.65

Remarks
Serpenulina aulax differs from *S. uralica* in having a narrow, elongate attachment scar along the entire test length rather than the wide, flat attachment surface and in being more conical and wider. Also it does not show the development of secondary chambers as in *S. uralica.* The test is usually rectilinear but rarely shows a slight open coil near the initial end, as if at the beginning the test coiled partly about the substrate. The initial end is broken in all specimens but in many cases this end is quite narrowly pointed and a proloculum, if at all present, must be very small. The external surface is often wrinkled.

Derivation of Name
aulax (Lat.) = furrow; referring to the long, narrow attachment scar.

Family Hippocrepinidae Rhumbler, 1895

Hyperammina Brady, 1878

Type Species
Hyperammina elongata Brady 1878

Hyperammina leptalea Bell, n. sp.
Figure 5 A–E

Diagnosis
A species of *Hyperammina* with a small elliptical proloculum followed by a narrow, very slowly expanding tubular second chamber.

Description
Test free; small; elliptical to subglobular proloculum followed by a relatively long, narrow cylindrical second chamber which only slowly expands from a constriction at the proloculum to the aperture; wall fine grained, smooth; aperture circular, simple, at end of the tubular part.

Holotype
NMV P208072, the specimen illustrated on Figure 5A.

Type locality and horizon
DSC 230, Mirrabooka Formation, Borenore, NSW; early Wenlock, upper *ranuliformis* Zone.

Distribution and Age
Sample DSC 230, Early Silurian, upper *ranuliformis* Zone.

Material
Eleven complete specimens, plus more than twenty linear segments.

Measurements (in mm)

	Proloculum diameter	Tube diameter at proloculum	Tube diameter at aperture	Total length
Holotype NMV P208072	0.05	0.037	0.050	0.8
Paratype NMV P208073	0.075	0.037	0.65	0.5
Paratype NMV P208074	0.05	0.050	0.75	0.525
Paratype NMV P208075	–	0.050	0.1	1.0

Remarks
H. leptalea differs from *H. teres* from the Late Silurian at Cowombat (Bell in Simpson *et al.* 1993) in the wall structure, shape of the proloculum and in being much smaller. Only very few specimens have a proloculum which apparently is easily fractured away from the tube at the constriction at their junction. Rare specimens show the 'hourglass' constrictions common in many species of *Hyperammina*. The slow rate of increase in the tubular section is clearly apparent from the table.

Derivation of Name
leptaleos (Gk.) = fine, delicate; referring to the narrow test.

Family Lituotubidae Loeblich and Tappan, 1984

Lituotuba Rhumbler, 1895

Type Species
Serpula filum Schmid 1867

Diagnosis
Test free; initially a glomospirally coiled tube, followed by an uncoiling rectilinear section; wall agglutinate; aperture terminal.

Remarks
Loeblich and Tappan (1988: 69) stated, without giving reasons, that the Palaeozoic forms previously placed in *Lituotuba* are not congeneric with that genus. As there appears to be no reason for this change, the original genus is retained for Silurian and Early Devonian species from eastern Australia but is expressed as *'Lituotuba'*.

'Lituotuba' exserta Moreman, 1930
Figure 5 J

Lituotuba exserta Moreman 1930: 57, pl. 7, figs 5,6.

Lituotuba exserta: Stewart and Priddy 1941: 374, pl. 54, figs 20, 21.

Lituotuba exserta: Mound 1968: 37, pl. 2, figs 42, 43.

Lituotuba elongata Dunn 1942: 340, pl. 44, fig. 36.

Lituotuba chileana Todd and Kniker 1952 (part): 5, pl. 1, figs 6a,b,

Involutina exserta: Conkin 1961: 286, pl. 26, fig. 16.

Description
Test attached; small globular proloculum followed by a cylindrical tube which makes several complete volutions about the proloculum and then becomes rectilinear in the same plane as the spiral section and more or less at right angles to it; the tubular section has a constant diameter; wall finely agglutinated, thin, surface fairly smooth; aperture circular at end of tube.

Distribution and Age
WERR 16.2, Boree Creek Limestone, Borenore, NSW; early Wenlock, lower *ranuliformis* Zone, and ERC 7, Ludlow, no younger than *variabilis* Zone.

Material
More than twenty specimens.

Measurements (in mm)
Proloculum diameter: 0.075; tube diameter: 0.15; total length of test: 1.125.

Remarks
The tube is often flattened on one side which may indicate an site of attachment. In none of the specimens did the rectilinear section show any meandering growth.

The placement of this species within *'Lituotuba'* is based on the early plectospiral coiling about the proloculum. In the early growth stages *'Lituotuba'* is similar to *Ammodiscus* but in species of that genus the early spiral growth about the proloculum is described as being planispiral (*e.g.* Gutschick and Treckman 1959; Mound 1968; McClellan 1966; Loeblich and Tappan 1964, 1988). The present Australian specimens cannot be placed in the genus *Tolypammina* as species of this genus have no encirclement of the proloculum nor in the genus *Ammovertella* in which species have a meandering growth. As the degree of non-planispirality in the present specimens is small, this would exclude them from being placed in the genus *Glomospira*, species of which show a high degree of irregular to streptospiral initial coiling.

The specimens from Borenore are larger than the figured specimens of Moreman (1930) from Okalahoma, those from Indiana (Mound 1968) and Stewart and Priddy (1941) from the Silurian of Indiana and Ohio, but otherwise are indistinguishable. Gutschick and Treckman (1959) described *Tolypammina rotula* from a sequence in Indiana as having two irregular coils about the proloculum before a straight section and *T. cyclops* with a similar initial coiling but then becoming sinuous; both would seem to be better placed in *'Lituotuba'*. The present specimens do not have the large, prominent proloculum of *'L.' cyclops*.

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