Silurian Brachiopods from the Cappanana Formation East of Cooma, Southern New South Wales

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Strusz, D.L. (2012). Silurian brachiopods from the Cappanana Formation east of Cooma, southern New South Wales. *Proceedings of the Linnean Society of New South Wales* **135**: 1-17.

A collection of strongly tectonically distorted fossils from the Cappanana Formation east of Cooma, NSW, is treated using digital imagery and computer software to restore the better-preserved specimens to an approximation of their original shape and size, using previously published principles. The fauna is dominated by brachiopods, all as dissociated valves, but also includes some encrinurid trilobites and a few corals. Ten brachiopod species are recognised, of which seven - *Mesopholidostrophia bendeninensis, Morinorhynchus oepikensis*, cf. *Apopentamerus clarkei, Atrypa* cf. *duntroonensis, Atrypoidea australis, Howellella* aff. *elegans* and *Spirinella caecistriata* - are identical to, or closely comparable with, published species of late Wenlock to Ludlow age. Three taxa (*Coelospira* sp., a leptaenine and an eospiriferine) are very rare and could be new, but the material is insufficient, and restored images as obtained by the methods used here should not be used to erect new taxa. The fauna is enclosed in mudstone, probably a current-winnowed slump deposit, so the original environment cannot be determined.

Manuscript received 26 October 2012, accepted for publication 20 February 2013.

KEYWORDS: *Apopentamerus, Atrypa, Atrypoidea,* brachiopods, Cappanana Formation, distortion digitally removed, *Howellella*, Ludlow, *Mesopholidostrophia, Morinorhynchus* , *Spirinella*, Silurian, Wenlock.

INTRODUCTION

In 1999 the residents of 'Lara' property, 15 km east of Cooma, advised ANU geologists that abundant fossils had been turned up during regrading of the road west of the homestead. Dr Tim Munson (the then collections manager) and I visited the spot, and made a collection of the better preserved material, overwhelmingly brachiopods. Fossils in the Early Palaeozoic of southeastern New South Wales between Canberra and the Victorian border are generally moderately to strongly distorted. As many are in shales and thinly bedded muddy limestones, part of this distortion is a result of compaction, but the major component is tectonic, the result of at least one major compressional phase with consequent strong folding and faulting. In Canberra this distortion is much less, insufficient to make recognition of taxa difficult (see, e.g., Strusz 1984, 1985). This cannot be said of the region around Cooma, some 100 km to the south, an area further complicated by the formation of the Cooma Gneiss (part of the Murrumbidgee Batholith). Consequently, there have been very few taxa described from that region, and the ages of the various stratigraphic units are not well constrained. Distortion of the collected specimens is strong, as is weathering, but at the time of collecting the fauna was recognised as being clearly Silurian, and several taxa were considered comparable with those known from Canberra. The collection was therefore set aside until more was known of the better-preserved Silurian faunas in the Canberra - Yass region.

MATERIALS

The topographic map available to us at the time of collecting was the first edition Cooma 1:100 000 sheet of 1969, and this did not show 'Lara' homestead or all of its access road, so our estimate of the position was very approximate. Satellite imagery is now readily available, as is a more detailed topographic map (the Numeralla 1:25,000 sheet of 2001), and this allows

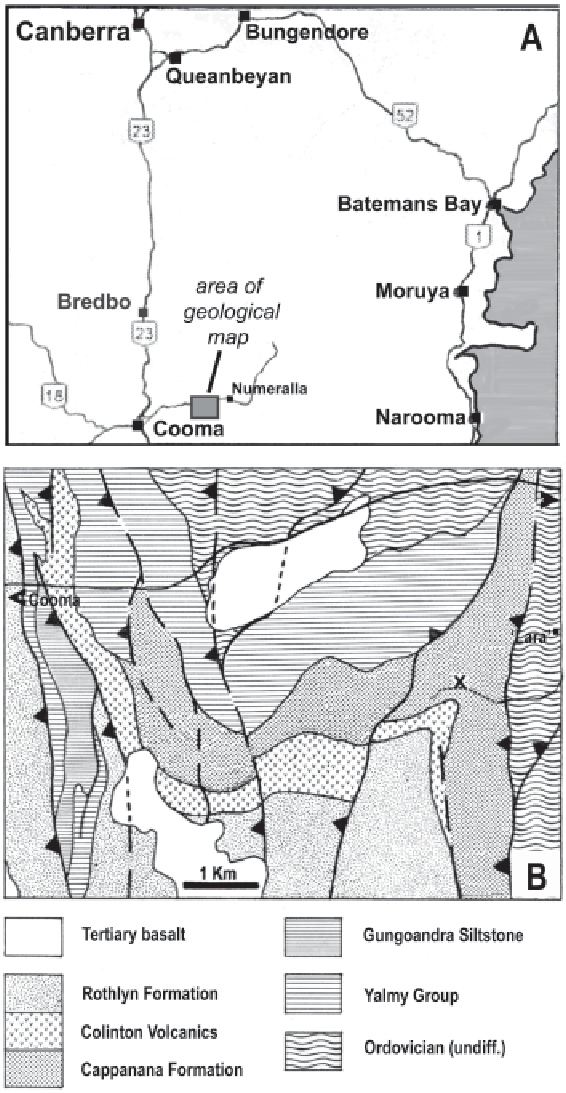

Figure 1. Location of the collection from near 'Lara' homestead, east of Cooma. A: regional map. B: geology in the vicinity of 'Lara' (derived from Lewis and Glen, 1995). The approximate position of the locality is marked by x. The undifferentiated Yalmy Group is considered to be laterally equivalent to the whole Bredbo Group (Cappanana Formation to Rothlyn Formation).

greater precision. The material came from the north side of the road on a curve, and is at approximately GA065.907. On the second edition of the Bega-Mallacoota 1:250 000 geological sheet (Lewis and Glen, 1995) this locality lies in a folded and faulted area within the Cappanana Formation (see Fig. 1). The fossils are preserved as moulds in soft, yellow- to buff-weathering pale olive-green mudstone; the extensive weathering has partly to completely obliterated fine detail. Some of the moulds are lined with clusters of small crystals of iron oxide - possibly derived from the overlying Colinton Volcanics - and limonitisation is heavy in some specimens. All the brachiopods occur as dissociated valves, the trilobites as detached parts (moults?). The valves of strophomenide and orthotetide taxa are generally parallel to the original bedding, but the more strongly biconvex atrypide and spiriferide valves can lie at moderate angles to that bedding. This means that initial compaction has had only a minor effect on the shape of the strophomenides and orthotetides, but more on the others. The appearance of the material - flat-lying weakly convex valves, more randomly oriented strongly convex valves, often in discrete layers - suggests current winnowing of soft, slumped sediment, and so the original depth inhabited by the fauna is uncertain.

PROCEDURES

Important in making reliable identifications of such strongly distorted fossils is a means to reconstruct their original appearance. Because of the fragility of the specimens from 'Lara' even after impregnation with acetone-diluted adhesive ('Tarzan's Grip' in this case), no attempt has been made to obtain latex casts, but the natural moulds, when carefully prepared, were generally quite sufficient. Specimens were photographed using a digital camera with x3 optical zoom, under a mix of natural and artificial light, without whitening. For the purposes of this paper, as fine detail is generally poorly preserved, colour has been retained. Removal of the effects of distortion followed methods outlined by Cooper (1990) and Rushton and Smith (1993), taking advantage of the digital tools available in Adobe Photoshop. In essence, the procedure is to determine the extent of distortion by determining the strain ellipse (i.e. a distorted initial circle), then calculate the factors to be applied to return that ellipse to circularity. These factors are then applied to images of individual fossils to restore their original shape.

Strain ellipse

Several slabs containing a number of fossils with unambiguous traces of their original hinge line and longitudinal axis of symmetry (or the equivalents in the case of trilobite cranidia) were photographed, taking care to include a linear scale. The images were then oriented with the trace of lineation horizontal. Prints were then used to analyse strain following Wellman's method (see Cooper 1990, pp. 323-324), with the 'control line' parallel to the lineation. The

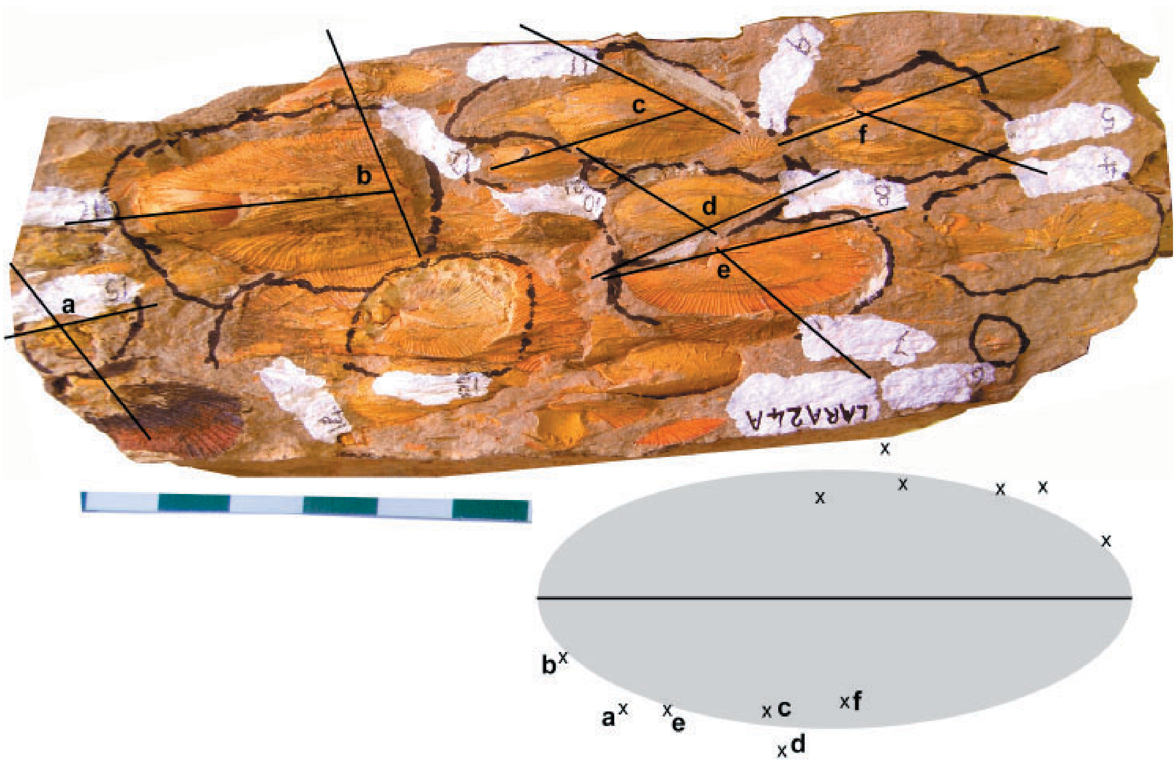

Figure 2. Specimen Lara 24A (containing MMF45320-45334) with symmetry axes (see text) superimposed on individuals labelled a to f. Scale is in centimetres. Lower right: a control line 80 mm in length is drawn parallel to the direction of maximum extension, its ends forming the control points referred to by Cooper (1990). For each individual, lines drawn through these control points, parallel to the two marked axes of symmetry, intersect at the labelled points (and their diagonally opposite counterparts). The shaded area is the ellipse which appears to best fit these intersections.

resulting points, to be used to estimate the strain ellipse, were then plotted on a millimetre grid in Photoshop. In a separate layer, an ellipse was drawn through them using the ellipse tool, adjusting the shape of the ellipse until it was seen to be a best fit for the plotted points (see Fig. 2). For each slab, the correction factors needed to restore the ellipse to circularity (on the assumption that the contained area within the original circle remained constant) were then calculated, again following the methods described by Cooper (1990).

There are steps in this procedure by which inaccuracies are inevitably introduced - determining the original axis of symmetry (not easy if ornament is uniform or internal structures are subdued or diffuse), fitting an ellipse to the plotted points, and the assumption of unchanged area occupied by the fossil during distortion. Added to these is the likelihood for the 'Lara' specimens that not all individuals were equally affected by compaction (see below) or lay precisely on the original bedding plane. Consequently, the calculated correction factors for the selected slabs varied significantly. There were insufficient suitable slabs for a calculated mean to be useful. Many fossils were on pieces with too few suitable individuals for the above procedure to be appropriate. Therefore it was decided to use correction factors rounded from the median, and see how well they worked for the majority of specimens - a potentially iterative process, but fortunately the chosen factors (reduction in the direction of lineation x0.6, extension at right angles to that of x1.4) worked well in nearly all cases, so did not need changing.

Application to individual fossils

Inevitably most of the fossils on the photographed slabs were not well oriented relative to the direction of lighting, and there were numerous fossils, not on those slabs, which were needed for reliable taxonomy. Therefore chosen fossils were photographed either individually or in small groups of similar orientation, again with the inclusion of a scale - in this case, a 6 mm diameter disc of graph paper (meaning that one diameter would always be oriented correctly relative to the direction of photography, and could be used to determine magnification during processing of the image). Care was taken to save a fresh file for each image at each step in the subsequent process. Each image was brought to an appropriate magnification, then rotated to bring the traces of lineation to either horizontal or vertical orientation. The correction factors were then applied, and their effectiveness checked. Errors arose because the direction of lineation was not always easily seen (meaning orientation of the image could be not quite right), or in the case of taxa such as globose atrypides or spiriferides because orientation before compaction was not always parallel to bedding before compaction, so that the resulting distortion was uneven. This second source of error also made orientating small specimens for photography uncertain. Where the 'restored' images were not quite symmetric, the process was repeated using the saved files, with slightly changed orientation, until an optimum result was obtained. The second source of error mentioned above meant that full symmetry could not always be attained even with several attempts. The final 'restored' images were then cropped to remove surplus background (and significantly reduce file size), and adjustments made to colour balance (the artificial light used was a 'white' LED, which resulted in very blue-biassed images), to bring the images as close as possible to the originals. Images of very dark brown fossils were made more useful by changing brightness and contrast. These images were then used for systematic study of the fauna.

Limitations

As can be seen from the above discussion, this is not a precise procedure. Provided strain was uniform across the outcrop, a fair approximation to the original proportions of symmetric fossils can be obtained. However, in most cases the strain will vary from bed to bed, depending on variations in lithology and distance from the nearest fold axis. In the case of the material from 'Lara', nearly all the specimens were loose, the result of grading of strongly weathered rock, and little bedding (let alone folding) could be seen in the road-bed, so this limitation certainly applied!

Original size is not restored using this methodology - again, because of the uncertainties in orientation and strain analysis - but the images will be a reasonable approximation of that size. Restoration of proportions (such as length to width ratio) is more accurate, but still not perfect.

As shown by Hughes and Jell (1992), and Rushton and Smith (1993), this is a very useful tool in assessing the relationships of taxa which have been described from strongly distorted specimens, particularly when there are many individuals available. As in the current case, it is also useful when dealing with a distorted fauna in which many of the taxa have been previously described from good material from other localities. Known taxa can often be identified with confidence. However, it is not reasonable to base new taxa just on images from which distortion has been removed. This is particularly so when trying to discriminate between species of the same genus, where size and proportions are often critical and not infrequently overlap.

RESULTS

Ten brachiopod species have been recognised, of which four can be confidently identified with known taxa; another three are closely comparable with known taxa but because of insufficient material cannot be identified with certainty. One species can be placed in a known genus but not species, and the final two (represented by only a few specimens) can be assigned to subfamilies. The fauna also contains encrinurid trilobite fragments, mostly librigenae, and a few moulds of rugose corals, including (Fig. 3) a small syringaxonid with a massive columella.

The fauna of the Cappanana Formation farther north, near Bredbo, has been listed previously, mostly at the generic level, but the only species described from the formation is the rugose coral *Rhizophyllum interpunctatum* de Koninck, 1876, from Rock Flat Creek southeast of Cooma. Richardson and Pickett (p. 61 in Pickett 1982) commented that 'precise correlation is not possible until identifications have been carried to specific level for as many forms as possible, but the overall aspect of the fauna resembles most closely that of the Canberra Group, and it is most likely to be of Late Wenlockian or Ludlovian age.'

Of the brachiopods described here, the known species elsewhere range in age from mid-Wenlock to

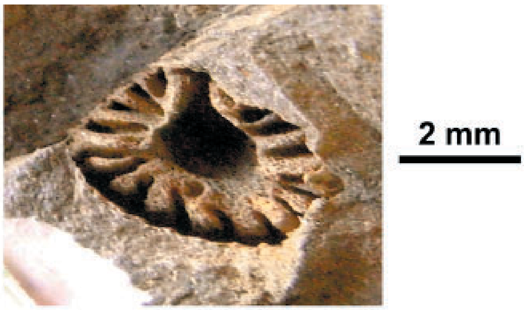

Figure 3. MMF45247, calical mould of an undetermined syringaxonid rugose coral.

early Ludfordian, with several known from Wenlock rocks in Canberra but not above, and only one not previously known below the Ludlow (it enters at Yass at about the Wenlock-Ludlow boundary). This is not enough for a definitive determination of the age of the Cappanana Formation, but a Wenlock age is more likely than not.

SYSTEMATIC PALAEONTOLOGY

Classification follows that in the six volumes of the revised Treatise on Invertebrate Paleontology, part H (Williams et al. 1997-2007). References to suprageneric taxa can be found in the relevant parts of that work.

The specimens used in this study have been lodged with the Geological Survey of New South Wales, their catalogue numbers being prefixed with MMF. Other depositories cited are the Research School of Earth Sciences, Australian National University (ANU), the Commonwealth Palaeontological Collection held by Geoscience Australia (CPC), and the Australian Museum (AMF). The dimensions quoted are for specimens as digitally restored, and are at best only a reasonable estimate of the dimensions of the original undistorted valves.

Abbreviations used are:

Ls - length of shell (normally the ventral valve)
Ld - length of dorsal valve
Lwmax - length to position of maximum width
Ws - shell width (except for alate species)
Wc - width of corpus (i.e. of the main body of alate taxa)
Wh - width of hinge (including alae where relevant) in strophic shells
CM - width of cardinal margin in nonstrophic shells

In lists of dimensions, italicised numbers indicate estimated values (e.g. doubled from measured half-width).

Class STROPHOMENATA Williams et al., 1996
Order STROPHOMENIDA Öpik, 1934
Superfamily STROPHOMENOIDEA King, 1846
Family RAFINESQUINIDAE Schuchert, 1893
Subfamily LEPTAENINAE Hall and Clarke, 1894

Leptaeninae, gen. et sp. indet.

Fig. 4

Material.

MMF45315 - ventral internal and dorsal external moulds.

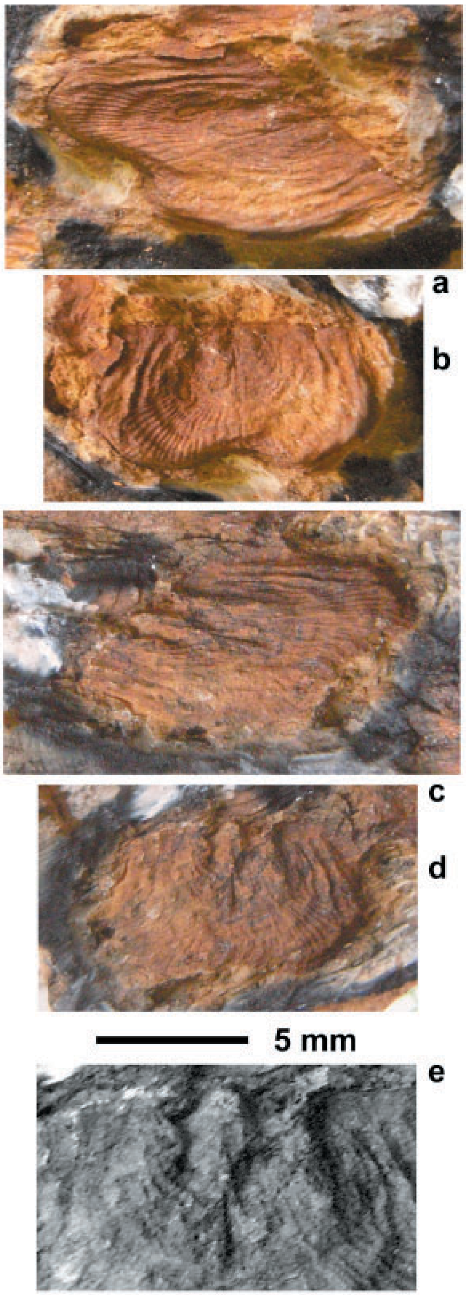

Figure 4. Leptaeninae, gen. et sp. indet., MMF 45315; a, b, dorsal external mould as collected, and restored; c, d, ventral internal mould as collected, and restored; e, posteromedian area of 4d, in grey-scale with increased contrast, enlarged to show the unusually shaped ventral muscle field.

Description.

Outline transverse, subquadrate with rounded margins, concave anteromedially; maximum width at about 2/3 length. Ventral valve convex, dorsal valve gently resupinate, with abrupt dorsal geniculation; trail short. Dorsal surface radially ribbed, relatively irregularly rugate; ribs rounded, 4-5 per mm marginally. Ventral beak broad, fairly low; interarea narrow, concave; delthyrium triangular, open, pseudodeltidium obscure; foramen not seen.

Teeth narrow, diverge from median line at about 50°. Muscle field subquadrate, with strong anterior and lateral reentrant, extends to about 1/3 valve length; in cross-section trough-shaped, gently impressed medially and moderately raised laterally. Adductor scars small, elongate elliptical, smooth. Floor of field not strongly ridged. Low, narrow myophragm starts at mouth of anterior reentrant in muscle field, extends to a little beyond mid-length. No other details visible. Dorsal interior unknown.

Dimensions Ls 5.0 mm, Ws 9.5 mm, Wh c. 8.6 mm, Ls/Ws 0.53, Wh/Ws c. 0.9.

Remarks

This single individual cannot be easily assigned to a leptaenine genus, particularly in the absence of details of the dorsal interior. It does not closely resemble any described species of *Leptaena*. A weakly concave anteromedian margin is unusual but not unknown in *Leptaena* - see Hoel (2005, Figs 2K, P). The Siluro-Devonian leptaenine *Glossoleptaena* Havlíček, 1967, has a concave anterior margin, but this is associated with a distinct sulcus; also it has much weaker shell ornament. The outline of the ventral muscle field in the 'Lara' specimen is quite distinctive (see Fig. 4e), perhaps approached only by that of *Glossoleptaena pixis* (Kelly, 1967).

Very few leptaenids have been described from the Australian Silurian, none being similar to the present species. An indeterminate *Leptaena* from the Walker Volcanics in Canberra was figured by Strusz (1982, p. 119). The single ventral internal mould has a semi-oval outline and a small subtriangular ventral muscle field. *Bracteoleptaena pannucea* Rickards and Wright, 1997 has a weakly developed trail, and a fairly large cordate ventral muscle field with evenly curved muscle-bounding ridges to either side of but not anterior to the field. The valve floors are noticeably papillate. *Leptaena compitalis* Strusz, 2003 has a fairly strong trail, and the ventral muscle field is small, rhomboid in outline with a concave front contained within the well developed muscle-bounding ridges.

Family EOPHOLIDOSTROPHIIDAE Rong and Cocks, 1994

Genus MESOPHOLIDOSTROPHIA Williams, 1950

Type species

Pholidostrophia (*Mesopholidostrophia*) *nitens* Williams, 1950. Wenlock, Gotland.

Mesopholidostrophia bendeninensis (Mitchell, 1923)

Fig. 5

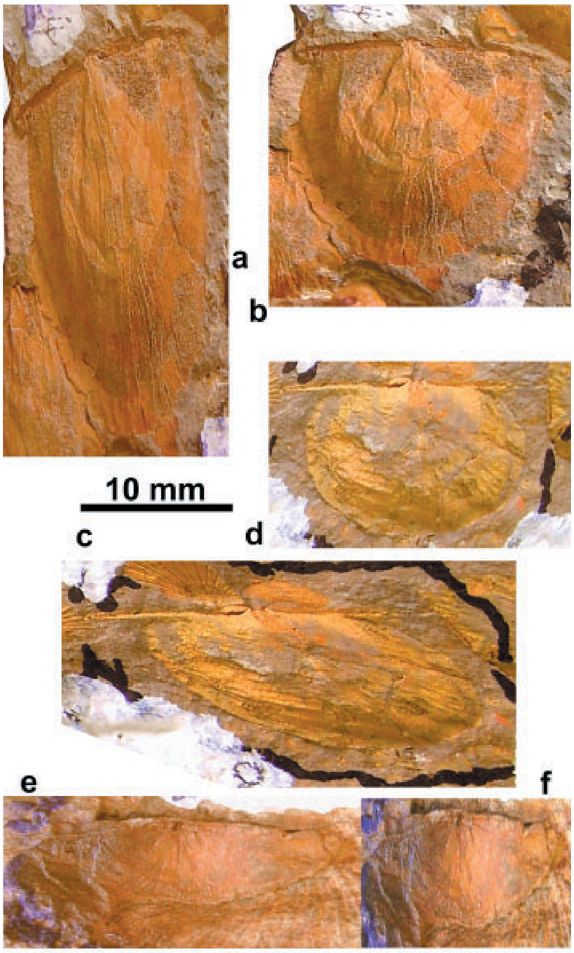

Figure 5. *Mesopholidostrophia bendeninensis* (Mitchell, 1923); a, b, MMF45238, ventral internal mould with well defined muscle field, as collected, and restored; c, d, MMF45329a, ventral internal mould with poorly defined muscle field, distinct ventral process, and strong reentrants in front of narrow alae, as collected, and restored; e, f, MMF45250, incomplete dorsal internal mould as collected, and restored.

Synonymy

Mesopholidostrophia bendinensis (Mitchell, 1923); Strusz, 2003, pp. 10-17, figs 7-10, cum syn.; Strusz, 2010b, pp. 149-150, figs 3Q-S..

Type material

Lectotype AM F28789. Bowning Creek, near Bowning, NSW. “Lower Trilobite Bed” = Black Bog Shale; Ludfordian (Upper Silurian).

New material

MMF45233, 45236-45238, 45243, 45244, 45250, 45260-45262, 45273, 45303, 45310-45314, 45329-45331.

Description

Outline weakly to moderately transverse, semi-oval, alate; alae narrow, reentrant at junction with corpus of shell shallow or absent. Largest shell 16.3 mm long. Greatest width at 0.35-0.4 Ls. Profile concavo-convex, ventral valve moderately to strongly convex, dorsal valve weakly to moderately concave. Ornament absent, or weak with moderately irregular rounded ribs, and sometimes sparse, irregular, weak concentric wrinkles. Ventral interarea low, flat, apsacline; dorsal interarea not seen. Delthyrium open; notothyrial structures not seen. Cardinal margin on both valves denticulate to 0.4-0.5Wc.

Ventral muscle field variably well expressed, moderately to strongly impressed into valve floor posteriorly, extends to about 0.4Ls; outline anteriorly poorly defined, subtriangular to bilobed. Adductor scars obscure, or weak, small, elongate, subparallel. Muscle-bounding ridges divergent, straight, faintly to moderately tuberculate, little if at all raised above posterolateral valve floor. Ventral process small, divided by shallow triangular furrow. Myophragm fine to obscure. Valve floor outside muscle field variably tuberculate.

Cardinal process lobes elongate, narrowly triangular, nearly parallel, separated by narrow slot and supported by small, low notothyrial platform; other details obscure. Notothyrial platform continuous with socket ridges, muscle-bounding ridges and myophragm. Inner socket ridges low, slightly curved, tuberculate, weakly divergent from cardinal margin. Muscle-bounding ridges curved, initially fairly strongly divergent then anteriorly only moderately so (at about 25-30°), tuberculate. Myophragm long, narrow, may be slightly swollen anteriorly. Notothyrial platform, muscle-bounding ridges and myophragm combine to form anchor-shaped structure posteriorly enclosing moderately divergent, oval, smooth adductor scars. Remainder of valve floor moderately tuberculate.

<u>Dimensions</u>

specimen	Ls	Wc	Wh	Ls/Wc	Ls/Wh	Wh/Wc
MMF45311	16.3	17.3	≥21	0.94	≤0.78	≥1.2
MMF45329	10.5	14.5	16.3	0.72	0.64	1.12
MMF45238	15.0	16.3	≥16.7	0.92	≤0.9	≥1.02

Remarks

There are three fairly similar species of ‘stropheodontid’ brachiopods in the Silurian of southeastern Australia which had to be considered when identifying this form: *Mesoleptostrophia* (*Mesoleptostrophia*) *quadrata* (Mitchell, 1923), *Mesoleptostrophia* (*M.*) *oepiki* Strusz, 1985, and *Mesopholidostrophia bendeninensis* (Mitchell, 1923). The first of these (from the Ludlow of Yass) is fairly small, and can be recognised externally by its subquadrate outline and the usually strong reentrants where the relatively short alae join the sides of the shell corpus; its ribs are fine and subdued. Internally it has a large, triangular, posteriorly impressed ventral muscle field bounded by straight tuberculate muscle-bounding ridges. The notothyrial platform, inner socket ridges, dorsal muscle-bounding ridges, and myophragm are all well developed. *Mesoleptostrophia* (*M.*) *oepiki* (Wenlock, Canberra) can be distinguished from it by its longer, thinner alae separated from the valve corpus by weaker reentrants, coarser ornament, a fine ventral myophragm, and curved dorsal muscle-bounding ridges. It also tends to be larger. *Mesopholidostrophia bendeninensis* is closer to the latter in size, and in having long slender alae and weak reentrants. It differs from both species of *Mesoleptostrophia* in its very weak external ornament, a ventral muscle field which is less obviously triangular and is often bilobed, weak ventral myophragm and muscle-bounding ridges, weak inner socket ridges, notothyrial platform and muscle-bounding ridges, and a longer myophragm which may expand slightly anteriorly.

The material from ‘Lara’, where many features are not well preserved, is so similar to both *Mesoleptostrophia* (*M.*) *quadrata* and *Mesopholidostrophia bendeninensis* that it is very unlikely to be a new species of either genus. The very weak external ornament and often significant convexity alone suggest the latter, and internal features, particularly the form of the ventral muscle field and the relatively weak dorsal structures, confirm the specific identity.

Since the revision of this species was published, a locality low in the Bowspring Limestone Member at Yass (locality GOU57 - see Strusz 2005) yielded a few specimens. This locality is below the *Ancoradella ploeckensis* zone, and could be either earliest Ludlow or latest Wenlock.

Order ORTHOTETIDA Waagen, 1884
Suborder ORTHOTETIDINA Waagen, 1884
Superfamily CHILIDIOPSOIDEA Boucot, 1959
Family CHILIDIOPSIDAE Boucot, 1959
Subfamily CHILIDIOPSINAE Boucot, 1959
Genus MORINORHYNCHUS Havlíček, 1965

Type species

Morinorhynchus dalmanelliformis Havlíček, 1965. Ludlow, Bohemia.

Morinorhynchus oepiki Strusz, 1982
Fig. 6

Synonymy

Morinorhynchus oepiki Strusz, 1982; Strusz 2003, pp. 31-33, figs 20-21, cum syn.; Strusz, 2010b, pp. 140-150, figs 3K'-M'.

Type material

Holotype CPC20987, paratypes CPC20415-20419, 20988-20994. Molonglo Valley, Canberra, ACT. Walker Volcanics; probably Homerian, Wenlock.

New material

MMF45234, 45240, 45246, 45249, 45252-45255, 45264-45267, 45271, 45274, -45277, 45298-45302, 45304, 45320-45327, 45335-45340, 45348-45353, 45355.

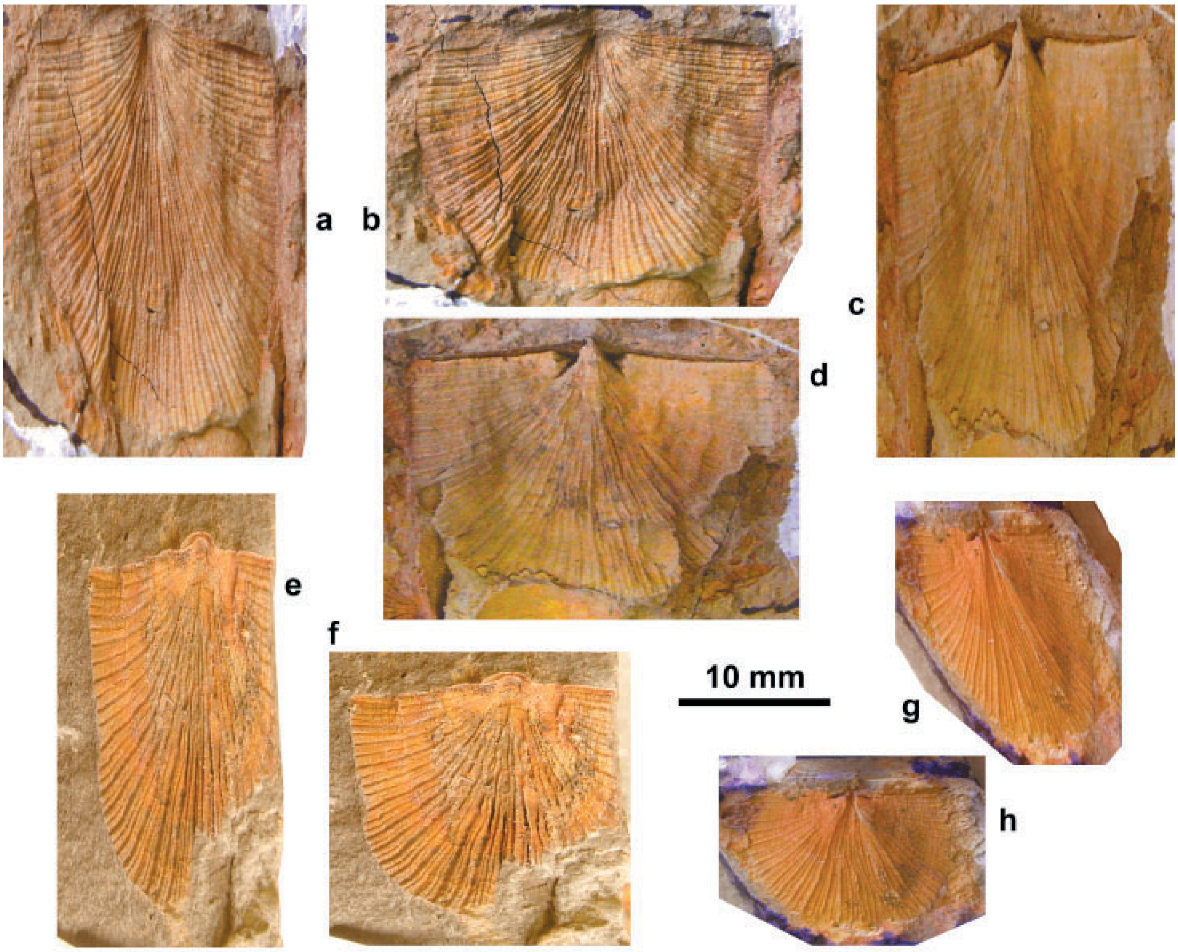

Figure 6. ***Morinorhynchus oepiki*** **Strusz, 1982; a-d, MMF45298, a, b, ventral external mould as collected, and restored; c, d, ventral internal mould as collected, and restored; e, f, MMF45255, incomplete dorsal external mould showing large chilidium extending posterior to hinge line, as collected and restored; g, h, MMF45264b, dorsal internal mould as collected, and restored.**

Description

Shell gently to moderately biconvex, ventral valve moderately more convex than dorsal valve; outline semi-elliptical, Wh ca 0.95Ws, Ls ca 0.75Ws but very variable, greatest width at about 0.4Ls. Anterior margin rectimarginate to moderately sulcate, dorsal sulcus most prominent in large shells. Ventral umbo low, interarea low, flat, strongly apsacline; pseudodeltidium large, moderately convex; foramen small, apical. Dorsal umbo low, interarea very low, chilidium broad, convex, projects posteriorly. Ornament unequally parvicostellate, with strong, rounded ribs separated by wider flat-bottomed interspaces crossed by fine growth lines; at 5 mm radius, at least 20 ribs in 5 mm.

Teeth small, dental plates well developed, upright, gently curved outward, divergent at about 90°. Muscle field obscure. Socket plates well developed, curved outwards, strongly divergent, fused with bilobed cardinal process; myophragm weak, broad. Further details obscure.

Dimensions

specimen	Ls	Ws	Wh	Ls/Ws	Wh/Ws
MMF45266	11.5	18.0	17.5	0.64	0.97
MMF45298	17.5	23.5	22.8	0.74	0.97
MMF45326	22.0	25.0	23.0	0.88	0.92
MMF45353	15.8	20.5	18.8	0.77	0.92

Remarks

The specimens from east of Cooma are morphologically (allowing for the poorer preservation) the same as Wenlock specimens from the Canberra Formation (Strusz, 1985) and those from the Ludlow of Yass (Strusz, 2003). As noted by Strusz (2003), *M. oepiki* is now known to reach a larger size than the type specimens from the Walker Volcanics indicated. The largest new specimen is MMF45326, with Ls 22 mm, Ws 25 mm, comparable with MMF610 (Ls 17 mm, Ws 26.1 mm) from Bowning. Rib spacing is on the low side, but within the previously known range.

Unlike elsewhere, where *Morinorhynchus oepiki* is a minor part of the fauna, the collection from 'Lara' is dominated by this species.

Class RHYNCHONELLATA Williams et al., 1996
Order PENTAMERIDA Schuchert and Cooper, 1931
Suborder PENTAMERIDINA Schuchert and Cooper, 1931
Superfamily PENTAMEROIDEA M'Coy, 1844
Family PENTAMERIDAE M'Coy, 1844
Genus APOPENTAMERUS Boucot and Johnson, 1979

Type species

Apopentamerus racinensis Boucot and Johnson, 1979. Wenlock, Wisconsin.

cf. *Apopentamerus clarkei* Strusz, 2011
Fig. 7

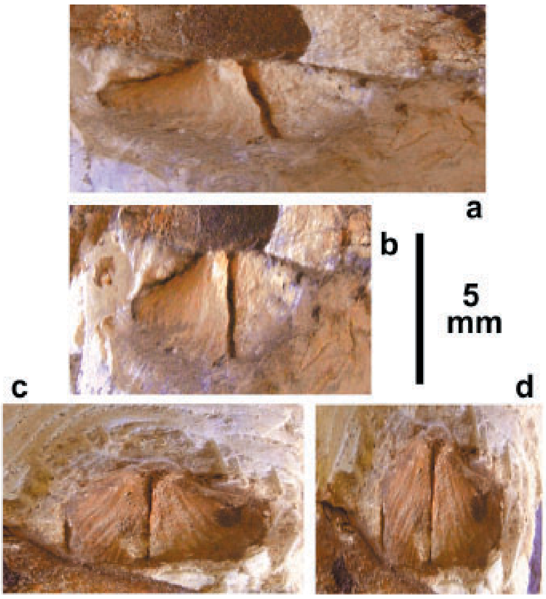

Figure 7. cf. *Apopentamerus clarkei* Strusz, 2011; a, b, MMF45256, ventral internal mould as collected, and restored; c, d, MMF45305, ventral internal mould as collected, and restored.

Synonymy

cf. *Apopentamerus clarkei* Strusz, 2011, pp. 36-39, fig. 5.

Material

MMF45256, 45305, 45306, 45328.

Discussion

These four small shells are clearly a smooth pentameroid, but only the exterior (completely lacking ribs, but one has a few concentric wrinkles) and the ventral interior are known. The ventral median septum is very long, and supports a narrow and upwardly flaring spondylium. There is considerable similarity with smaller specimens of *Apopentamerus clarkei*, recently described from the Canberra Formation, although the specimens from 'Lara' are even smaller (compare especially MMF45305 with Strusz 2011, figs 5e, h, and MMF45256 with fig. 5c). I am reasonably confident that this is the same species, but the material from 'Lara' is insufficient for certainty.

Order ATRYPIDA Rzhonsnitskaya, 1960
Suborder ATRYPIDINA Moore, 1952
Superfamily ATRYPOIDEA Gill, 1871
Family ATRYPIDAE Gill, 1871
Subfamily ATRYPINAE Gill, 1871
Genus ATRYPA Dalman, 1828
Subgenus ATRYPA Dalman, 1828

Type species

Atrypa reticularis Linnaeus, 1758. Ludlow, Gotland.

Atrypa (Atrypa) sp. cf. *duntroonensis* Mitchell and Dun, 1920
Fig. 8

Synonymy

cf. *A. (Atrypa) duntroonensis* Mitchell and Dun, 1920; Strusz, 2011, pp. 39-44, figs 6-9, cum syn.

Material

MMF45269, 45281, 45302, 45318, 45319.

Discussion

Available material is very limited, with no well preserved ventral valves. Until the recent redescription of *A.* (*Atrypa*) *duntroonensis* by Strusz (2011), based on abundant new material from the Wenlock of Canberra, only one species of *Atrypa* was reasonably well known from the Silurian of southeastern Australia: *A.* (*A.*) sp. cf. *dzwinogrodensis* Kozłowski, 1929 of Strusz (1984, 2007) from the Late Wenlock? to Ludlow of Yass. The two highly variable species are very similar externally, *A.* (*A.*) *duntroonensis* tending to be somewhat more elongate, with the dorsal valve more often anteromedially extended as a broad ventrally directed tongue. Rib shape, density and mode of increase are the same in the two species. In the dorsal valve, *A.* (*A.*) *duntroonensis* has a deeper cardinal pit, the sockets have distinct median ridges, and diverge at about 110-120°, and the myophragm is less prominent than in *A.* (*A.*) sp. cf. *dzwinogrodensis*. MMF45318 is the only available dorsal internal mould, and has a broad but rather low myophragm. The socket plates are short but robust, and the sockets (whose finer details are obscure) diverge at more than 140°. On this basis, the few specimens from 'Lara' are most comparable with *A.* (*A.*) *duntroonensis*, but specific identity must remain uncertain.

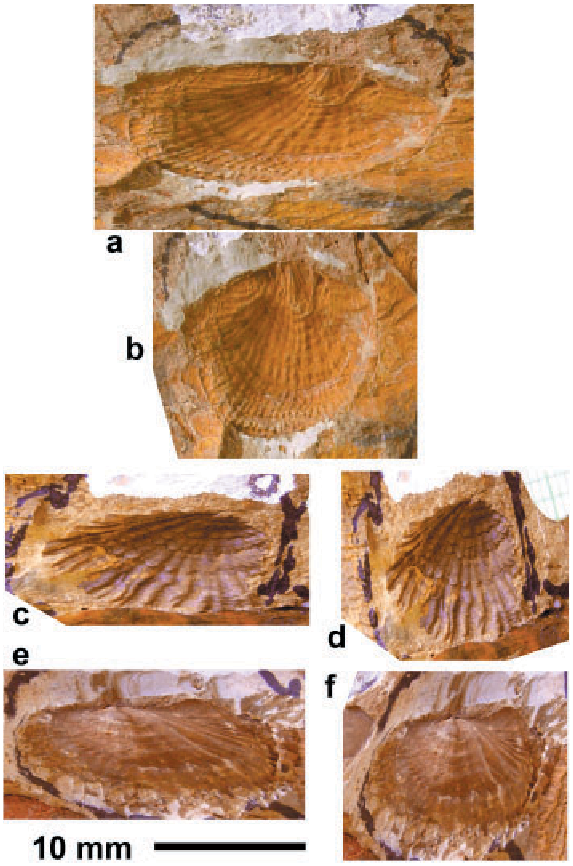

Figure 8. *Atrypa* (*Atrypa*) sp. cf. *duntroonensis* Mitchell and Dun, 1920; a, b, MMF45302b, dorsal external mould as collected, and restored; c-f, MMF45318, c, d incomplete dorsal external mould as collected, and restored, e, f, dorsal internal mould as collected, and restored.

Suborder LISSATRYPIDINA Copper, 1996
Superfamily LISSATRYPOIDEA Twenhofel, 1914
Family LISSATARYPIDAE Twenhofel, 1914
Genus ATRYPOIDEA Mitchell and Dun, 1920
Subgenus ATRYPOIDEA Mitchell and Dun, 1920

Type species

Meristina (?) *australis* Dun, 1904. Ludlow, Molong, NSW.

Atrypoidea (*Atrypoidea*) *australis* (Dun, 1904)
Fig. 9

Synonymy

Atrypoidea (*Atrypoidea*) *australis* (Dun, 1904); Strusz 2007, pp. 322-331, figs 16-21, cum syn.

Material

MMF45258, 45263, 45270, 45272, 45280, 45307-45309, 45232, 45233.

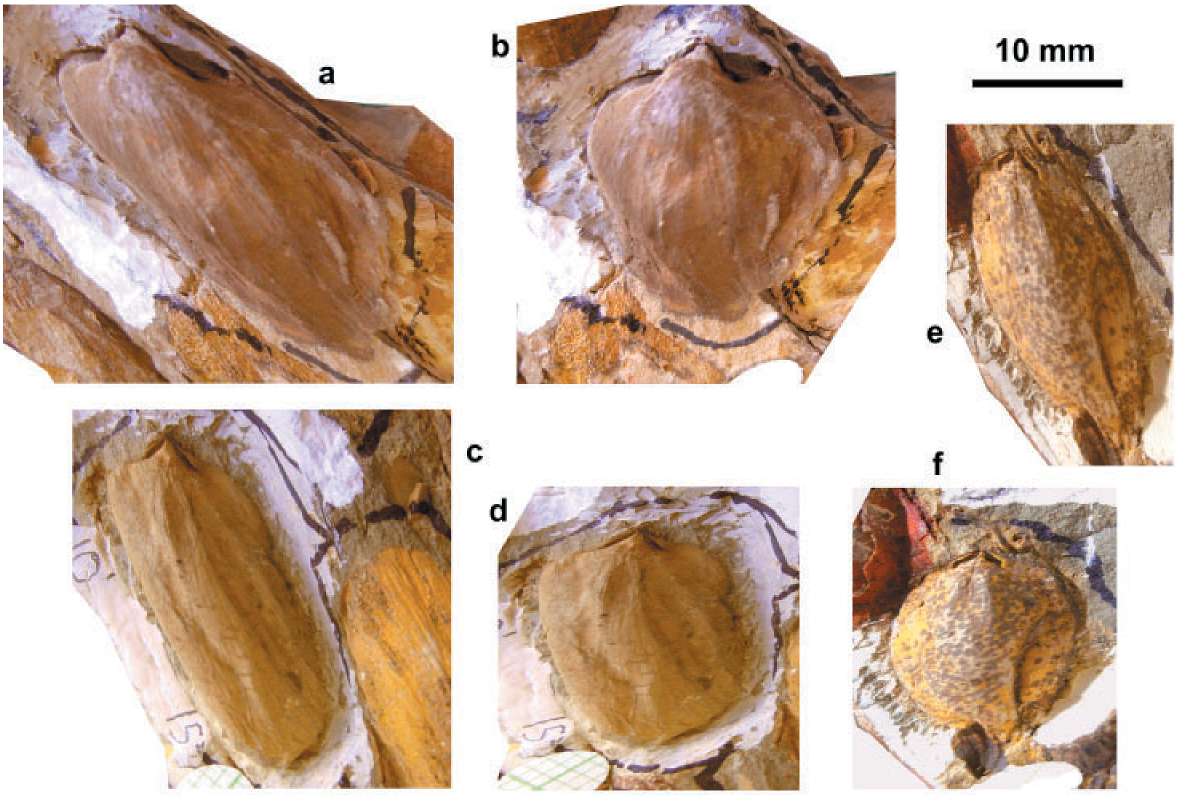

Figure 9. ***Atrypoidea* (*Atrypoidea*) *australis* (Dun, 1904); a, b, MMF45263, ventral internal mould as collected, and restored; c, d, MMF45308a, dorsal internal mould as collected, and restored; e, f, MMF45309, dorsal internal mould as collected, and restored.**

Discussion

The limited available material is mostly not well preserved, but fits well within the morphological limits of this highly variable species, and there can be little doubt of its identity. The one good ventral internal mould, MMF45263, is very like AMF17432 (Strusz 2007, Fig. 18C) in outline. With Ls = 18.5 mm, Ws = 17.0 mm, CM = 10.5 mm and Lwmax ≈ 7mm, it fits well within the published plots of Ls: Ws and CM:Ws, and differs only in the relatively posterior position of maximum width (it is just within the limits of the published plot of Lwmax: Ls). Its internal structures are also quite comparable with the few known interiors (e.g. ANU9736, Strusz 2007, fig. 17L). The same can be said of the dorsal valves - MMF45308 is close to the dorsal valves of AMF29186 and 29195 (Strusz 2007, figs 17G,19C), and MMF45309 to AMF29183, 29184 (Strusz 2007, figs 17E, F) and 29188 (fig. 18B).

Order ATHYRIDIDA Boucot, Johnson and Staton, 1964
Suborder Incertae Sedis

Superfamily ANOPLOTHECOIDEA Schuchert, 1894
Family ANOPLETHECIDAE Schuchert, 1894
Subfamily COELOSPIRINAE Hall and Clarke, 1895
Genus COELOSPIRA Hall, 1863

Type species

Leptocoelia concava Hall, 1857. Lochkovian, New York.

Coelospira sp. indet.
Fig. 10

Material

MMF45317, 45334.

Discussion

The two diminutive specimens are damaged and incomplete ventral valves of undoubted anoplothecid morphology. Both show strong curved ribs flanking a more finely ribbed fold. The one internal mould is not well enough preserved to show details. Nevertheless the basic morphology indicates this form could only belong to *Coelospira*.

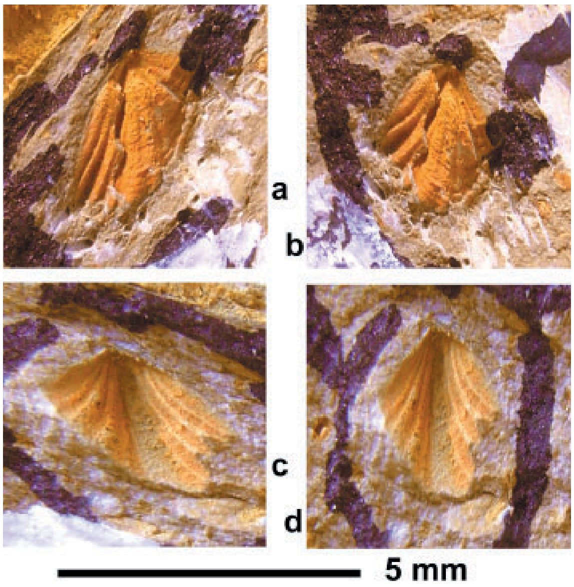

Figure 10. *Coelospira* sp. indet.; a-d, MMF45334, a, b, incomplete ventral internal mould as collected, and restored, c, d, incomplete ventral external mould as collected, and restored.

Coelospira has been recorded from the late Wenlock to early Ludlow of the Yass-Canberra region (*C. cavata* Strusz, 1982), and Cadia in central NSW (*Coelospira* sp. Percival in Rickards et al., 2001). The one incomplete ventral valve from Cadia differs from those of *C. cavata* only in having fewer, stronger ribs on the fold. In this respect the specimens from 'Lara' more closely resemble the Cadia form, but lack of material displaying the range of morphological variability means the specific relationships of the Cadia and 'Lara' forms remain unknown.

Order SPIRIFERIDA Waagen, 1883
Suborder SPIRIFERIDINA Waagen, 1883
Superfamily CYRTIOIDEA Frederiks, 1924
Family CYRTIIDAE Frederiks, 1924
Subfamily EOSPIRIFERINAE Schuchert, 1929

Eospiriferinae gen. et sp. indet.
Fig. 11

Material

MMF45282-45286.

Description

Only ventral valves are known, represented by relatively small external and internal moulds. Outline transverse spiriferoid, length 3/4 - 7/8 width, with

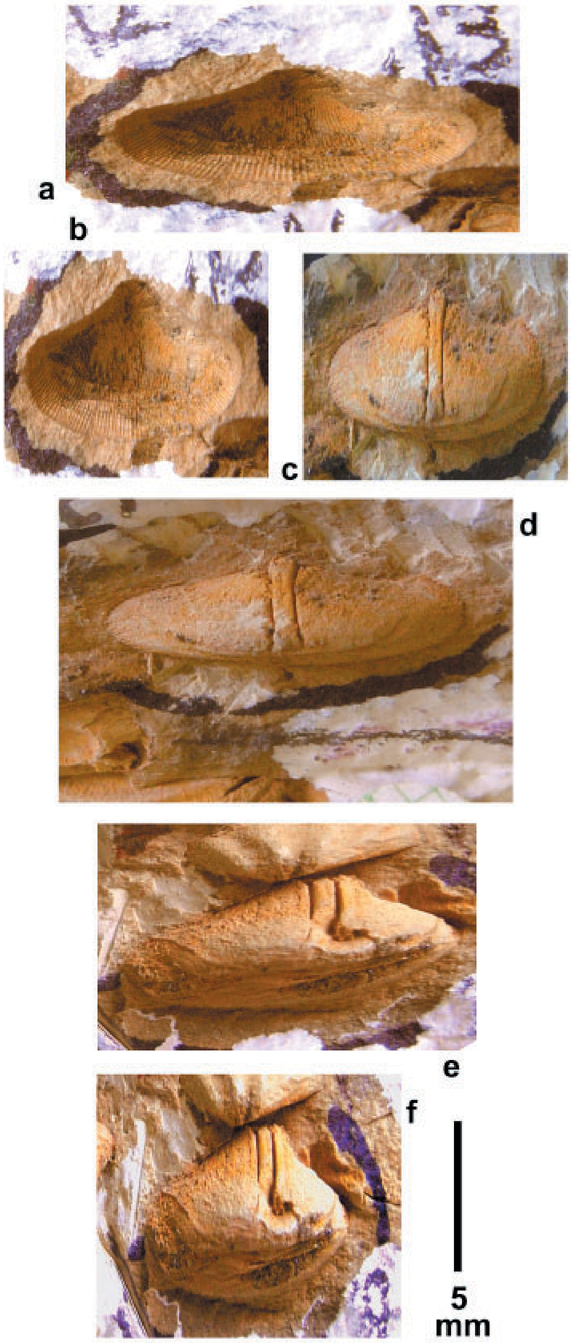

Figure 11. Eospiriferinae gen. et sp. indet.; a-d, MMF45285, a, b, ventral external mould showing well developed capillate ornament, as collected, and restored, c, d, ventral internal mould with very long parallel dental plates, restored, and as collected, e, f, MMF45284a, damaged ventral internal mould with shorter parallel dental plates, as collected, and restored.

prominent umbo, incurved beak, rounded lateral and anterior margins; greatest width somewhat anterior to mid-length. Valve strongly convex, without sulcus or ribs; anterior margin rectimarginate. Micro-ornament of rounded capillae separated by somewhat wider interspaces, *Eospirifer*-like, increasing by intercalation. Concentric micro-ornament absent or too fine to be preserved.

Dental plates parallel, long, extending to or beyond mid-length. Muscle field obscure, but weak myophragm between dental plates in some specimens, starting anterior to apex. Teeth small, triangular. One internal mould shows a small delthyrial plate. No visible pallial markings.

Dimensions

specimen	Ls	Ws	Ls/Ws
MMF45284	6.0	*6.8*	*0.88*
MMF45285	5.3	7.2	0.74
MMF45286	*6.5*	*8.4*	*0.77*

Discussion

In the absence of dorsal valves the generic identity of this form cannot be determined, but it is clearly a smooth eospiriferine. It is close to *Eospirifer* Schuchert, 1913, especially in the form of the micro-ornament, but species of that genus generally have robust divergent extrasinal dental plates, and usually have at least a shallow sulcus. In the absence of a sulcus, it cannot be said whether the dental plates in the 'Lara' form are intrasinal or extrasinal. Moreover, *Eospirifer* lacks a delthyrial plate or deltidium. Close to *Eospirifer* is *Endospirifer* Tachibana, 1981, which is known from the Silurian of Canberra and Yass, differing in having a well developed deltidium. It has fairly long and only moderately divergent dental plates which, however, lie outside a narrow but generally well developed sulcus. *Nurataella* Larin, 1973 (= *Baterospirifer* Rong, Su and Li, 1984) lacks a sulcus and has a rudimentary delthyrial plate, but the dorsal valve is of low convexity, and there are short extrasinal dental plates. Moreover, its capillae are more like those of *Myriospirifer* Havlíček, 1978, which are broadly rounded to flattened, and increase exclusively by splitting. The only eospiriferine known to me with parallel dental plates is the diminutive *Nanattegia* Strusz, 2010a, from the Silurian of Yass, but that has concave flanks on the very convex ventral valve, a deep, narrow sulcus, and no apical delthyrial structures.

Suborder DELTHYRIDINA Ivanova, 1972
Superfamily DELTHYRIDOIDEA Phillips, 1841
Family DELTHYRIDIDAE Phillips, 1841
Subfamily HOWELLELLINAE Johnson and Hou, 1994
Genus HOWELLELLA Kozłowski, 1946

Type species

Terebratula crispa von Hisinger, 1826. Wenlock, Gotland.

Howellella sp. aff. *elegans* (Muir-Wood, 1925)

Fig. 12

Synonymy

Howellella sp. aff. *elegans* (Muir-Wood, 1925); Strusz, 1982, pp. 132-134, figs 27A, C-E; Strusz, 1985, p. 117, figs 12A, 13; Strusz 2010b, figs 6, 8A-C

Material

MMF45239, 45241, 45242, 45259, 45279, 45287-45297, 45341-45344, 45345-45347.

Description

Ventral valve fairly strongly convex, outline spiriferoid, umbo wide and fairly prominent, lateral and anterior margins rounded; Ls/Ws and Wh/Ws both about 0.8. Ventral sulcus well developed, defined by two strong, sharply rounded ribs; At most, one pair of subdued lateral ribs arises anterior to beak. Dorsal valve moderately convex; beak low, fold prominent, rounded to slightly flattened medially, flanked by strong furrows. Inner pair of lateral ribs lower but well developed, rounded, slightly curved laterally. Outer pair of lateral ribs low, developed only anterolaterally; there can be a very faint third pair of ribs developed only marginally. Ventral interarea concave, apsacline; delthyrium open - structures otherwise obscure. Dorsal interarea very low, weakly anacline. Micro-ornament of fimbriate growth lines.

Teeth small, dental plates robust, upright, divergent forward, extra-sulcal, extend forward to 0.3-0.4Ls. Myophragm low, commences at about level of cardinal margin, extends forward to about mid-length. Muscle field obscure. Sockets small, widely divergent; inner socket ridges well developed, outer hinge plates narrow, steep, crural bases short, supported by triangular crural plates convergent on low notothyrial platform. Cardinal process small, its ventral face bilobed (MMF45290, 45341, 45346) or trilobed (MMF45342). Myophragm weak or absent; muscle scars obscure.

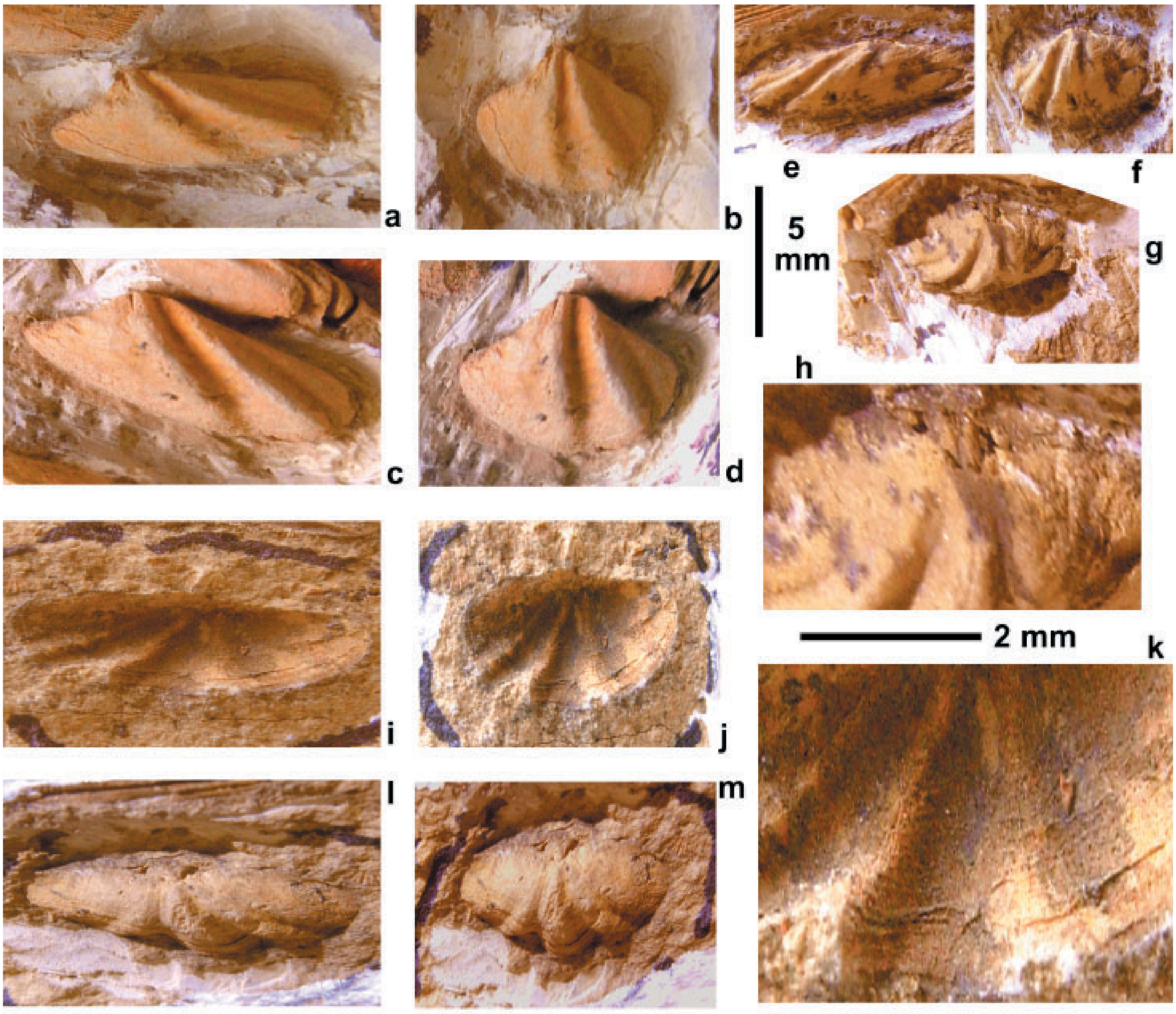

Figure 12. ***Howellella*** **sp. aff.** ***elegans*** **(Muir-Wood, 1925) Strusz, 1982; a, b, MMF45287a, ventral internal mould as collected, and restored; c, d, MMF45288a, ventral internal mould as collected, and restored; e-h, MMF45342a, dorsal internal mould, e, f, as collected, and restored, g, tilted posteriorly (restored) to show cardinalia, enlarged in h; i-m, MMF45344, i, j, dorsal external mould as collected and restored, and k, enlargement showing fimbriate ornament, l, m, dorsal internal mould as collected, and restored; 5 mm scale bar applies to a-g, i, j, l, m, 2 mm scale bar applies to h, k.**

Discussion

While preservation of detail in these small specimens is rather poor, in all that can be seen they are the same as the material from the Walker Volcanics and Canberra Formation of Canberra .

Superfamily RETICULARIOIDEA Waagen, 1883
Family RETICULARIIDAE Waagen, 1883
Subfamily RHENOTHYRIDINAE Gourvennec, 1994
Genus SPIRINELLA Johnston, 1941

Type species

Spirinella caecistriata Johnston, 1941. Late Wenlock, Yass, NSW.

Spirinella caecistriata Johnston, 1941
Fig. 13

Synonymy

Spirinella caecistriata Johnston, 1941; Strusz 2011, pp. 45-46, fig. 12, cum syn.

Material

MMF45245, 45248, 45268, 45278, 45316, 45354, 45356, 35357.

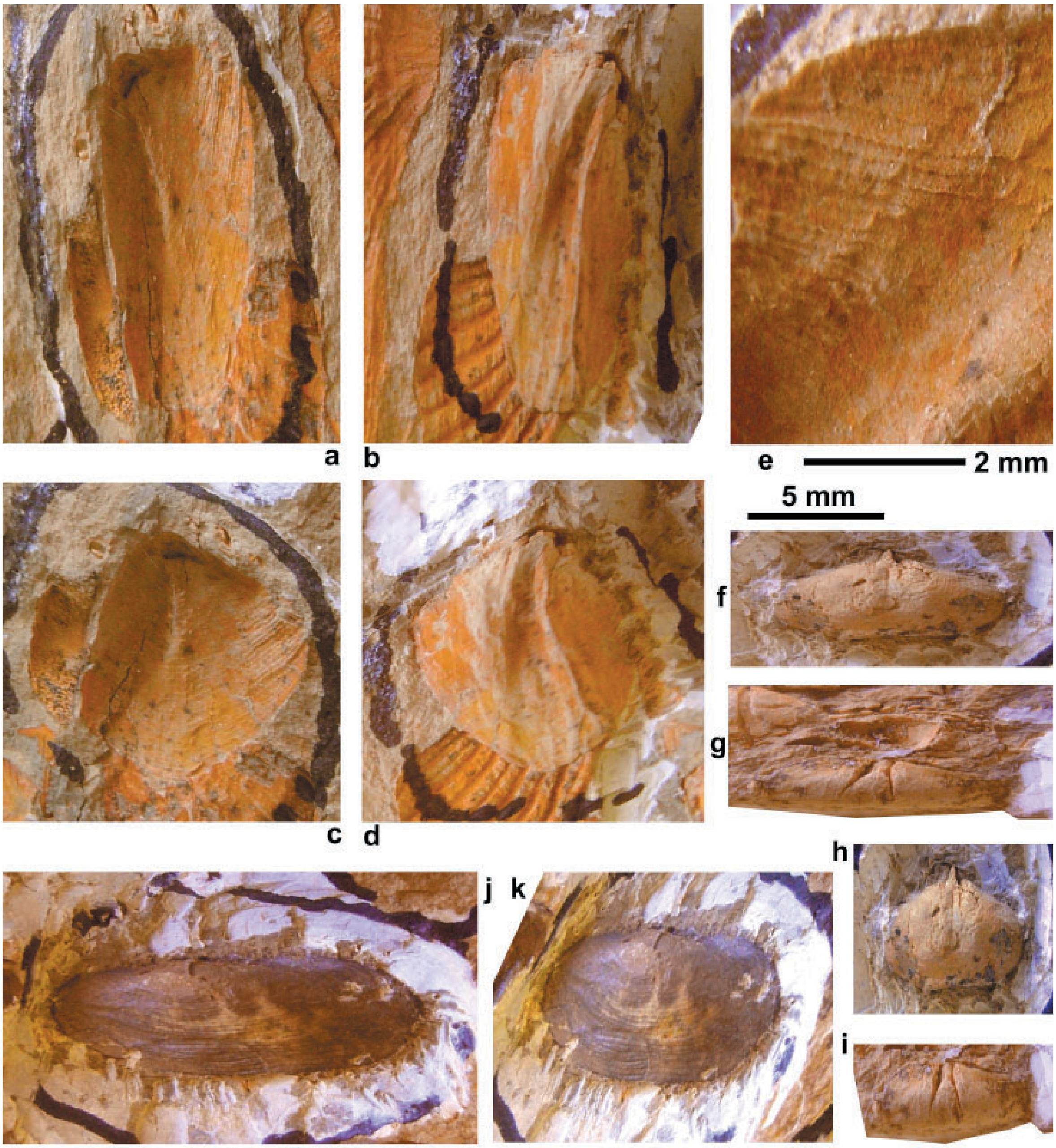

Figure 13. ***Spirinella caecistriata*** **Johnston, 1941; a-e, MMF45278, ventral valve external and internal moulds, a, b, as collected, c, d restored, e portion of c reoriented and enlarged to show fimbriate ornament; f, h, MMF45354a, incomplete ventral internal mould as collected, and restored; g, j, MMF45357, incomplete ventral mould with large apical callist, viewed postero-ventrally, as collected and restored; j, k, MMF45316a, dorsal internal mould as collected, and restored; 5 mm scale bar applies for all except e, to which 2 mm scale bar applies.**

Remarks

These few small specimens are not well preserved, most showing evidence of post-burial compaction prior to tectonic distortion. Nevertheless they show all the characteristics of the species, and the proportions fit well within the limits of variability reported by Strusz (2010a). Ventral valves have a weak ventral sulcus, fairly prominent beak, fimbriate micro-ornament, strong, divergent dental plates and a weak myophragm; two internal moulds show a well-developed apical callist - e.g. compare MMF35357 with Strusz (2010a, fig. 18G). The one dorsal internal mould is damaged by compaction, so no useful comparison can be made.

Dimensions

specimen	Ls	Ws	Wh	Ls/Ws	Wh/Ws
MMF45278	9.0	*12.0*	*11.5*	*0.75*	*0.96*
MMF45354	4.8	*5.5*	4.5	*0.87*	*0.82*

ACKNOWLEDGEMENTS

This paper was prepared in the Research School of Earth Sciences (ANU) in my capacity as a School Visitor, and also as a Research Associate of the Australian Museum, Sydney, and is a contribution to IGCP591. I would like to thank Dr T. Munson (now with the Northern Territory Geological Survey) for his assistance in collecting the material, Dr I. Percival and Dr R.A. Glen (New South Wales Geological Survey) for assistance in sourcing an appropriate geological map of the area, and Dr J. Laurie (Geoscience Australia) for his careful review of the first draft of the paper.

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