Early Ordovician lingulate brachiopods from the Emanuel Formation, Canning Basin, Western Australia

GLENN A. BROCK and LARS E. HOLMER


The lingulate brachiopods from the type section of the Emanuel Formation, Canning Basin, Western Australia are described. The fauna consists of 3 new obolid taxa, Libecoviella divaricata n. sp., Wahwahlingula emanuelensis n. sp., and Zhanatellidae n. gen? A, and two acrotretoids, Semitreta lauriei n. sp., and Ottenbyella shidertensis (Popov & Holmer, 1994). Contemporaneous trilobite and conodont faunas indicate a late Lancefieldian (La3) to mid Bendigonian (Be2) (=earliest Arenigian) age for the Emanuel Formation. The lingulate fauna is largely endemic at the species level, with minor faunal links to Kazakhstan and Bohemia.

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THE ORDOVICIAN Period in Australia was characterised by the development of widespread epicratonic seas, the establishment of the Larapintine Seaway across northern Australia, and the deposition of thick, richly fossiliferous sequences of shallow marine sediments associated with a major transgression during the Bendigonian (=early Arenigian) (Webby et al. 2000). Australia, and specifically the deposits in the Canning Basin, were located at, or very near, the palaeoequator at this time.

In an analysis of linguliformean brachiopod faunal turnover during the early Palaeozoic, Bassett et al. (1999) noted that the Arenigian was an important period in the diversification and evolution of linguliformean brachiopods. Bassett et al. (1999, p. 148) reported that during the Arenigian "acrotretide genera almost doubled...[and]...the diversity of lingulides increased up to 40 genera". It is thus remarkable that, despite a favourable biogeographic and palaeoecologic setting, coincident with a period of marked faunal recovery of the group, there has been limited investigation of lingulate brachiopods from Australian sequences of this age. Until recently, the published record of Early Ordovician lingulate brachiopods in Australia was restricted to description of some very poorly preserved, nondescript material from the graphitotic successions of Victoria (Chapman 1903, 1918; Sherrard 1930) and the report of an undescribed species of Westonia from the Pontoon Hill Siltstone Member of the Florentine Valley Formation, Tasmania (Quilty 1971; Stait & Laurie 1980; Laurie 1991). Fletcher (1964) described species of Ectenoglossa, 'Obolus' and 'Linguella' from lower Ordovician quartz arenites of the Rowena Formation, north western New South Wales. In more recent times, Percival (2000) reported a small lingulate fauna of late Lancefieldian-early Bendigonian age from the Yarrimbah Formation in the Parkes region, and indeterminate lingulellide and acrotretide taxa are known from limestones in the Hensleigh Siltstone south of Wellington, central western N.S.W. (Percival in Webby et al. 2000).

This paper aims to describe the well preserved lingulate taxa from the Lower Ordovician Emanuel Formation, Canning Basin, Western Australia and thus represents a further contribution to knowledge about the biostratigraphy and biogeography of early Ordovician linguliformean brachiopods from Australia.

GEOLOGICAL SETTING AND BIOSTRATIGRAPHY

The Prices Creek Group outcrops over an area of approximately 20 sq km on the northern margin of the Canning Basin in the vicinity of the Emanuel Ranges, Western Australia (Fig. 1). Guppy & Öpik
(1950) initially recognised two units in this region with the lower 509 m called the Emanuel Limestone and the upper 186 m of dolomite, calcareous sandstone and minor carbonates named the Gap Creek Dolomite. Guppy et al. (1958) later changed the name to Emanuel Formation due to the recognition of additional non-carbonate lithologies encountered in shallow drill holes. The type section (section 705, see Fig. 1) sensu Guppy et al. (1958) thus consisted of 595 m of dominantly interbedded limestones, siltstones and shales overlying a package of sandy dolomites and sandstones (Towner & Gibson 1983). These lower packages were subsequently recognised as separate formations (Henderson 1963) and formally named by Nicoll et al. (1993) as the Kuningan Sandstone (82 m) and the conformably overlying Kudanta Dolomite (88 m) (Fig. 1).

We follow the concept of the Emanuel Formation as set out by Nicoll et al. (1993), Shergold et al. (1995) and Laurie & Shergold (1996). The Emanuel Formation is richly fossiliferous and various faunal elements have been described including nautiloids (Teichert & Glenister 1952, 1954; see also Percival in Webby et al. 2000), gastropods (Gilbert-Tomlinson 1973; Yu 1993; Jell et al. 1984), trilobites (Laurie & Shergold 1996), ostracodes (Schallreuter 1991, 1993a, b), echinoderms (Brown 1964) and conodonts (McTavish 1973; McTavish & Legg 1976; Nicoll 1992; Nicoll et al. 1993; Ethington et al. 2000; Zhen et al. 2001). The lingulate brachiopod material described herein is derived from outcrops of samples collected by Laurie & Shergold (1996) along the type section (705; see Fig. 1) as part of their investigation of the trilobite fauna and biostratigraphy of the Emanuel Formation. The biostratigraphy of the Emanuel Formation has been documented in some detail mainly using trilobites (Laurie & Shergold, 1996, p. 69-73, text-fig. 4).

The basal 28 m of the Emanuel Formation is devoid of trilobites and essentially unzoned (Laurie & Shergold 1996, p. 69). However, ůpík (in Guppy & ůpík 1950) did recognise his “faunal assemblage 1” based on the presence of a lingulate brachiopod identified only as “Obolus”. This assemblage occurs in the Kuningan Sandstone, Kudanta Dolomite and basal 28 m of the Emanuel Formation. Despite repeated attempts to acidise samples from the Kudanta Dolomite, no examples of the brachiopod identified by ůpík as “Obolus” have been recovered.

Laurie & Shergold (1996) recognised 5 trilobite Assemblage zones within the Emanuel Formation
Fig. 2. Stratigraphic ranges, sampled horizons, distribution and abundance of lingulate brachiopods from the type section of the Emanuel Formation. Trilobite zonation after Laurie & Shergold (1996). Abbreviations: DV = dorsal valve, VV = ventral valve, P & H = Popov & Holmer, 1994. Total number of DV and VV shown in brackets for each taxon.

The basal *Kayseraspis cf. brackebuschi* Assemblage Zone ranges from 28 - 131.5 m above the base of the formation and is followed by the 42 m thick *Emanuelaspis (Emanuelaspis) nicolli* Assemblage Zone ranging from 131.5 - 152.8 m above the base of the Formation. The interval occupied by the *Kayseraspis cf. brackebuschi* and *Emanuelaspis (Emanuelaspis) nicolli* Assemblage Zones is equivalent to the Bendigonian (Be 1) stage using the Victorian graptolite zonal scheme (VandenBerg & Cooper 1992). The remaining three assemblage zones (lowest to highest) are the *Emanuelaspis (Emanuelaspis) nicolli* (35 m), *Priceaspis oepiki* - *P. rochei* (68.5 m), and *Priceaspis guppyi* (64 m) Assemblage Zones ranging over the upper 167.5 m of the formation. These Assemblage Zones are equivalent to a Bendigonian (Be2) graptolite age.

As noted by Laurie & Shergold (1996, p. 73) “the trilobite and graptolite biostratigraphic scales cannot be directly correlated” and “correlation must be achieved through conodont biostratigraphy and/or intricate overseas correlations”. Unfortunately the conodont faunas from the Emanuel Formation have not been documented in detail. Parts of the fauna have been described by McTavish (1973), McTavish & Legg (1976), Nicoll (1992), Nicoll et al. (1993), with recent...
contributions from Ethington et al. (2000) and Zhen et al. (2001). The fauna includes the index taxon Bergstroemognathus extensus, plus Jumundontus brevis, Paracordylopus gracilis, Prioniodus oepiki, Serratognathus bilobatus, Stiptognathus borealis and Rhipidognathus? yichangensis. Nicoll (1992) assigned this fauna to the Prioniodus elegans-Bergstroemognathus extensus conodont zone indicating an earliest Arenigian age for the formation, equivalent to a late Lancefieldian (L3) – mid Bendigonian (Be2) age using Australian stage scale. Nicoll et al. (1993) and Zhen et al. (2001) recognised conodont assemblages of the Oepikodus communis and Jumundontus gananda biozones in the overlying Gap Creek Formation indicating this formation can be assigned a mid – late Bendigonian (Be3 - Be4) age.

The lingulate fauna lacks diversity, so no formal biozonation has been attempted. However, some comment on the stratigraphic ranges of each taxon is warranted (see Fig. 2). Semitreta lauriei n. sp. only occurs in the lowermost sampled horizon in the type section (705/048), some 28 m above the base of the formation - coincident with the base of the Kayseraspis cf. brackebuschii trilobite Assemblage Zone. To date, S. lauriei n. sp. has not been recovered from the underlying Kudata Dolomite or the basal part of the Emanuel Formation, so its precise range remains unclear. Ottenbyella shidertensis (Popov & Holmer, 1994) is the numerically dominant taxon in the type section (Fig. 2) and ranges throughout the entire formation. The remaining three lingulide taxa, Libecoviella divaricata n. sp., Wahlwhalingula? emanuelensis n. sp., and Zhanatellidae n. gen? A occur in low numbers in the type section (Fig. 2). L. divaricata n. sp. ranges throughout the entire type section (Fig. 2). Wahlwhalingula? emanuelensis n. sp. ranges from sample 705/048, 28 m above the base of the formation to 705/157, 191 m above the base of the formation. This range equates with the lower three trilobite assemblage zones, the Kayseraspis cf. brackebuschii AZ to E. (Emanuelaspis) teichertii AZ, and correlates with a Be1 to lower Be2 age (Fig. 2). W. emanuelensis n. sp. may, in fact, range higher in the section since two fragmentary ventral valves possibly attributable to this species were also recovered from 705/232, 303.5 m above the base of the formation. Zhanatellidae n. gen? A is rare in the collections (Fig. 2) but ranges from 705/048, 28 m above the base of the formation to 705/125, 144.5 m above the base of the formation. This equates with the basal two trilobite assemblage zone and indicates a Be1 age for this taxon (Fig. 2). A single fragment of a dorsal valve questioned referred to Zhanatellidae n. gen? A was recovered slightly higher in the section in sample 705/159, 194.2 m above the base of the formation in the E. (Emanuelaspis) teichertii AZ.

CORRELATION AND BIOGEOGRAPHY

Webby et al. (2000) noted that the Canning Basin faunas (including those from the Emanuel Formation) whilst very diverse, were largely endemic. Laurie & Shergold (1996, Text-fig. 5) were able to correlate elements of the trilobite faunas from the Emanuel Formation with the Amadeus Basin (Pacoota Sandstone sequences 3 & 4) in central Australia, part of the Rollston Range Formation in northeastern Queensland, and, in part, the Pontoon Hill Member of the Florentine Valley Formation and basal horizons of the Karnberg Formation in Tasmania. On a regional scale, Zhen et al. (2001) have also noted links between the conodont fauna in the Emanuel Formation with sequences in the Amadeus Basin, and the Lachlan Fold Belt, central N.S.W. Correlation of the Emanuel Formation with the Florentine Valley Formation in Tasmania is also reinforced by the presence of the gastropod Peeleroxon oehlerti (Jell et al. 1984).

The lingulate brachiopod fauna from the Emanuel Formation is also largely endemic, at least at the species level. All taxa are reported from Australia for the first time. As such, the lingulate fauna provide little useful data for regional correlation. The presence of O. shidertensis (Popov & Holmer 1994) throughout the Emanuel Formation provides a comparative tie point with the upper part of the Olenty Formation in north-east-central Kazakhstan. Popov & Holmer (1994, p. 32, fig. 2) indicated the horizons in the upper Olenty Formation containing O. shidertensis are early Arenigian in age spanning an interval equivalent to the P. proetus – O. evae conodont zones, indicating synchronicity with the Emanuel Formation. The type species of Ottenbyella, O. carinata, from the Björkåsholmen Limestone in Sweden and O. evanda from the Batybay section in Kazakhstan correlate with a late Tremadocian-early Arenigian age (Popov & Holmer 1994, fig 2; Holmer et al. 2001) and are thus slightly older than O. shidertensis from Kazakhstan and Australia. The genus Semitreta Biernat, 1973 has a relatively widespread distribution with occurrences known in ?Cambrian and lower Ordovician (Tremadocian – Arenigian) sequences from Poland, Britain, ?Estonia, Kazakhstan and Western Australia (Popov & Holmer 1994).

Libecoviella has thus far only been described from the Lower Ordovician (Tremadocian), Trench Formation in the northern part of the Prague Basin, as part of the Westominasca community (Mergl 1997, 1999, 2002). Mergl (2002) recognised a specific
Libecoviella Community in the Prague Basin characterised by the presence of two shallow water (limnetic) endobenthic species of Libecoviella, L. arachne and L. ovata. No acroretids are reported in association with this community. Mergl (2002) commented that linguliformean brachiopods with terrace lines are usually present in fine grained sandstones and siltstones in monospecific assemblages. The presence of a divaricate ornament in Libecoviella divaricata n. sp. and Zhanatellidae n. gen? A is consistent with the interpretation that these forms were adapted to a burrowing life habit (Savazzi 1986). Similar terraced obolids, pseudolingulids and glossinellines are known from the Prague Basin (Mergl 2002).

SYSTEMATICAL PALEONTOLOGY

The classification follows Holmer & Popov (2000). Type and toptype material are housed in the Commonwealth Palaeontological Collection at Geoscience Australia, Canberra. CPC numbers for type material can be found in the figure captions. Abbreviations for measurements in Tables 1-4: L, W, H, LI, WI = length, width, height, length of pseudointerarea and width of pseudointerarea; LM1, WM1 = length and width of cardinal muscle scars; WMP = width of median plate; LS = length of median septum/ridge; WG = width of pedicle groove; WV = width of visceral area; LP, WP = length and width of larval shell.

Subphylum LINGULIFORMEA Williams et al., 1996
Class LINGULATA Holmer & Popov, 2000
Order LINGULIDA Waagen, 1885
Superfamily LINGULOIDEA Menke, 1828
Family OBOLIDAE King, 1846
Subfamily OBOLINAE King, 1846

Genus Libecoviella Mergl, 1997

Type species. Lingula arachne Barrande, 1879; Lower Ordovician (Tremadocian), Třenice Formation, Bohemia; original designation.

Species included. Lingula arachne Barrande, 1879; Westonisca ovata Havlíček, 1982; L. brthohicensis Mergl, 1997; Libecoviella divaricata n. sp.

Occurrence. Lower Ordovician (Tremadocian): Třenice Formation, Prague Basin, Bohemia; Lower Ordovician (Bendigonian, Be1 – Be2); Emanuel Formation, Canning Basin, Western Australia.


Discussion. As noted by Mergl (1997, p. 132; 2002, p. 22) Libecoviella is one of a number of relatively large ovoid obolid genera with a divaricate external ornament similar to Westonisca Walcott. Libecoviella can be distinguished by the presence of subparallel divaricate terrace lines on the lateral slopes of the shell with zig zag lines only developed in the postero-median sector of the shell. This contrasts with Westonisca, which has zig zag terrace lines developed across the entire posterior part of the shell (see Holmer & Popov 2000, fig. 21a-d). The terrace lines in Libecoviella occur over the entire shell surface, but are less distinct in the antero-median section of the shell. Internally, the ventral pseudointerarea in Libecoviella is considerably smaller than in Westonisca, though L. divaricata n. sp. from the Emanuel Formation has a well developed ventral pseudointerarea. In the dorsal valve, Libecoviella does not develop the median projection found in Westonisca (see Mergl 1997, 2002; Holmer & Popov 2000).

Westonisca Havlíček, 1982 is also similar to Libecoviella in general shape and size, but the external ornament of Westonisca consists of concentric rugae crossed by transverse lines (Holmer & Popov 2000). In addition, like Westonisca, the dorsal valve of Westonisca has a long anterior projection that extends almost to the anterior margin of the shell. No such feature is developed in Libecoviella.

The genus Josephobolus, based on J. regificus from the uppermost part of the Arenigian Klabava Formation, Bohemia, is similar to Libecoviella in terms of external ornament, but Mergl (1997, p. 137) noted that Josephobolus is unique because it has numerous large pits crowded anteriorly on the interior of both valves. In addition, the distinct secondary pallial canals developed in Westonisca, Westonisca and Libecoviella are absent in Josephobolus.

Another oboline taxon with distinct terraced ornamentation is Spinilngula Cooper, 1956. However, this taxon is distinguished by the presence of short spine projections along the anterior edge of concentric lainellae (Holmer 1989; Holmer & Popov 2000).

In his original description of Libecoviella, Mergl (1997) makes no mention of a pitted external microornament on any of the described species. Apart from the presence of a pitted larval and postlarval shell, the external and internal features of L. divaricata n. sp. clearly fall within the concept of Libecoviella. The presence of larval and postlarval shell pitting on L. divaricata n. sp. (see below) thus raises some questions about the oboloid affinities of Libecoviella. The lack of a pitted microornament in the Czech species,
Fig. 3. A-R, Libecoviella divaricata n. sp. A-B, Holotype, CPC 37402 from 705/97, interior and exterior of holotype ventral valve, both x 11; C-E, CPC 37403 from 705/117, interior (x 11), exterior (x 11) and pseudointerarea (x 22) of dorsal valve; F, CPC 37404 from 705/212, interior of fragmentary ventral valve, x 16; G, CPC 37405 from 705/97, interior of ventral valve, x 12; H, CPC 37406 from 705/212, interior of fragmentary dorsal valve, x 14; I-O, all CPC 37407 from 705/97, I-K, exterior (x 10), oblique lateral (x 12), & larval shell (x 30) of dorsal valve, L-M, close up of larval shell – note indistinct pitting, x 260 and x 1000, respectively, N-O, close up of circular flat-bottomed pits on lateral flanks of post larval shell, x 1400 and x 700, respectively; P-R, CPC 37408 from 705/48, exterior (x 10), close up of divaricate ornament of ventral valve, x 120 and x 41, respectively.
including the type species, may simply reflect inadequate preservation of microornament from the host terrigenous conglomerates, sandstones and siltstones in the Barrandian area of the Prague Basin (Mergl 1997, 2002). Interestingly, the postlarval shell pitting in *L. divaricata* n. sp. is very similar to that found in the oboloid *Lingulella* sp. a from the Middle Ordovician of Västergötland, Sweden (Holmer 1986, fig. 4H, I), indicating this type of pitting may be more common in ‘obolids’ than previously appreciated.

Williams et al. (1998), Cusack et al. (1999) and Williams (2003) have demonstrated the taxonomic significance of microscopic imprints on linguliformean brachiopods. As noted by Holmer & Popov (2000) members of the family Obolidae are normally characterised by a smooth larval and postlarval shell. Oboloid-like shells with a well developed pedicle groove, ventral interarea and pitted microornament (e.g. *Fossulielia, Thyssanotes* and *Tropidoglossa*) are generally referred to the family Zhanattellididae Koneva (see Holmer & Popov 2000). It could thus be argued that *Libecoviella* should be placed in the Zhanattellidae. However, Popov & Holmer (2003) have noted that at least some species of *Obolus* have a finely pitted first formed shell. The taxonomic utility of pitted microstructure in the Obolidae is under investigation by one of us (LEH).

Until the presence of a pitted microornament can be demonstrated on the larval and postlarval shell of the type species, *L. arachne*, it would be premature to realign *Libecoviella* to the Zhanattellidae. The lack of an emarginate in the ventral valve of *Libecoviella* also place some doubt about affinities with the zhanattellids. The presence of distinct microornament on *L. divaricata* n. sp. may also have implications for the classification of a number of other poorly known or poorly preserved taxa (e.g. *Westonia, Westonisca* and *Josepholobus*) currently assigned to the Obolidae (see Holmer & Popov 2000; Mergl 1997, 2002). Future investigation of the microornament of these taxa should result in a better understanding of the phylogeny of the Obolidae and related families.

*Libecoviella divaricata* n. sp. (Fig. 3A-R)

*Etymology.* Latin, *divaricatus*, spread apart. In reference to the divaricate external ornament.

*Type locality.* Emanuel Formation, Prices Creek Group, Canning Basin, Western Australia. Early Ordovician, Bendigonian Be1-Be2, *Kayseraspis cf. brackebushi* to *Priceaspis guppyi* trilobite Assemblage Zones of Laurie & Shergold (1996).

*Type stratum.* Type section 705, sample 097, 101.2 metres above the base of the Emanuel Formation.

*Material.* Holotype, ventral valve, CPC 37402 (Fig. 3A-B); Paratypes: CPC 37403, dorsal valve; CPC 37404, ventral valve; CPC 37405, ventral valve; CPC 37406, dorsal valve; CPC 37407, dorsal valve; CPC 37408, ventral valve. Unfigured topotype material includes 80 dorsal valves and 19 ventral valves from the type section (see Fig. 2).

*Diagnosis.* Smaller than normal species of *Libecoviella*, distinguished by ventral pseudointerarea occupying more than 50% valve width but not raised or anteriorly excavated. Larval shell with fine, weakly developed shallow pitting. Postlarval shell completely covered by microornament of circular, flat bottomed pits (2 μm in diameter). Pedicle groove short, relatively shallow with subparallel sides. Middle lateral muscle scars in ventral valve transversely elongate, tapering laterally to join with small ovoid central muscle scars.

*Description.* Shell with maximum shell length of 6 mm, elongately ovoid in outline, average length/ width = 142%, acuminate, weakly biconvex in lateral profile with greatest convexity in posterior 1/3 of the shell. Larval shell small (average width 0.8 mm), circular, with fine, weakly developed, hemispherical pits (uniformly about 0.08 μm in diameter). External ornament consists of closely spaced concentric filae crossed, on lateral shell slopes, by raised, irregular transverse lines, spaced at regular (~170-180 μm) intervals. From the lateral shell margins, transverse lines curve in a posterior direction towards the median plane. Junction of the transverse lines in the median sector of the shell form distinct zig zag pattern which widens anteriorly. Entire postlarval shell covered by microornament of closely spaced, in some cases imbricated or overlapping, circular, flat bottomed pits (2 μm in diameter).

Ventral pseudointerarea well defined, orthocline to anacline occupying more than 50% valve width. Flexure lines well developed, clearly delineating pseudointerarea. Anterior edge of ventral pseudointerarea merges with posterior valve floor. Pedicle groove short, shallow with subparallel sides, average width 0.3 mm. Middle lateral muscle scars in ventral valve transversely elongate, tapering laterally to join with small ovoid central muscle scars. Some specimens with well developed (0.4 mm long) anterolateral muscle scars. Type specimen also appears to have a pair of arcuate umbal muscle scars preserved on the valve floor immediately anterior of the pseudointerarea and pedicle groove. *Vascula*
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Table 1. A, summary statistics for dorsal valves and B, summary statistics for ventral valves of *Libecoviella divaricata* n. sp.

*bilateria* weakly impressed, baculate.

Dorsal pseudointerarea simple, relatively narrow (ave. length 0.2 mm), arcuate, aspacialine occupying more than 50% of shell width. Median plate poorly defined. Anterior edge of pseudointerarea merges with valve floor. A pair of small, circular, anterior muscle scars situated at approximately 50% valve length. Very thin, low, median ridge extends to about 75% valve length in some specimens. Interiors of both valves with randomly placed circular pits (10-15 μm in diameter).

**Measurements.** See Table 1.

**Discussion.** With an average length of 4.7 mm and width 3.3 mm, *L. divaricata* n. sp. is considerably smaller than the other species of *Libecoviella*. The ventral pseudointerarea of *L. divaricata* occupies more than 50% of the valve width and is thus considerably larger than in the other 3 species of the genus (see Mergl 1997). The type species, *L. arachne* can be further distinguished from *L. divaricata* by its dorsiconvex profile and, internally by its distinct radial striations (Mergl 1997). In addition, *L. divaricata* does not have the raised, anteriorly excavated ventral pseudointerarea present in *L. arachne*, *L. ovata* and *L. brilohicensis*. The presence of fine, weakly expressed, hemispherical pits on the larval shell and circular, flat-bottomed, 2 μm diameter, overlapping and imbricated pits on the postlarval shell (Fig. 3N-O) also distinguishes *L. divaricata* from other members of the genus, though this may simply be preservational bias.

Family ZHANATELLIDAE Koneva, 1992

Genus *Wahwahlingula* Popov, Holmer & Miller, 2002

**Type species.** *Lingula antiquissima* Jeremejew, 1856; Upper Cambrian-Lower Ordovician Tosna Formation, northwestern Russia.

**Species included.** *Lingula antiquissima* Jeremejew, 1856; *Wahwahlingula* sp. Popov, Holmer & Miller, 2002; *W. emanuelensis* n. sp.

**Occurrence.** Upper Cambrian – Lower Ordovician (Tremadocian): Tosna Formation, northwestern Russia and Notch Peak Formation and House Limestone, Ibex area, Utah, USA; Lower Ordovician (Tremadocian): Leetse Formation, northwestern Russia; Lower Ordovician (Bendigonian, Bel 1 – Be2): Emanuel Formation, Canning Basin, Western Australia.

**Diagnosis.** See Popov et al. (2002, p. 218).

**Discussion.** The elongate tear-drop shaped outline, equibiconvex profile and, at first glance, smooth shell with simple concentric growth lines invariably invite close comparison with the ‘catch all’ genus *Lingulella* Salter (see discussion by Krause & Rowell 1975, Popov & Holmer 1994, Sutton et al. 1999, 2000). Sutton et al. (2000) have recently redescribed toptotypic material of the type species of *Lingulella, L. davisi* M’Coy, 1851, from the Upper Cambrian of North Wales. The Emanuel Formation specimens are very similar in both external and internal morphology to *L. davisi*, but *L. davisi* is 4-6 times larger, with ventral valves ranging in length from 8-16.6 mm (mean 12.2 mm) compared to a maximum shell length of 2.4 mm in the Emanuel specimens. Sutton et al. (2000, p. 429) also indicate specifically in the diagnosis of *Lingulella* that the “external shell is without pitting” with a “surface ornament of growth lines only”. Cusack et al. (1999, p. 810) also indicate no pitting is found on well preserved shells of *L. davisi* at high magnification.

The Emanuel specimens have a microornament
consisting of closely packed, often overlapping and/or imbricating circular to crescentic, flat bottomed pits, uniformly 1-2 µm in diameter covering the entire shell surface (Fig. 4H, I, L). Sutton et al. (2000) indicate that Lingulella-like taxa with a pitted microornament (e.g. Lingulella antiquissima) should be excluded from Lingulella sensu stricto.

Popov et al. (2002) erected the new genus Wahwaltingula, with L. antiquissima as the type species, for Lingulella-like taxa that have a microornament consisting of finely pitted subcircular to suboval pits on the larval and postlarval shell. Popov et al. (2002) also described Wahwaltingula sp. from the Upper Cambrian to Tremadocian sequence of Utah. It seems likely that a number of taxa previously referred with question to Lingulella have a fine pitted microornament and should probably be referred to Wahwaltingula. Examples include the Upper Ordovician Lingulella? sp. from Ontario, Canada illustrated by Cusack et al. (1999, pl. 1, fig. 8) and Lingulella? sp. a from Middle-Upper Ordovician boundary beds in Västergötland illustrated by Holmer (1986, figs 4A-I). However, a complete revision of Wahwaltingula is beyond the scope of this paper.

Wahwaltingula? emanuelensis n. sp. (Fig. 4A-P)

Etymology. After the type stratum, the Emanuel Formation.

Type locality. Emanuel Formation, Prices Creek Group, Canning Basin Western Australia. Early Ordovician, Bendigonian Be1–Be2. Kayseraspis cf. brackebuschi trilobite Assemblage Zone to Priceaspis guppi Assemblage Zone of Laurie & Shergold (1996).

Type stratum. Type section 705, sample 097, 101.2 metres above the base of the Emanuel Formation.

Type material. Holotype. CPC 37409: dorsal valve (Fig. 4A-B); Paratypes: CPC 37410: dorsal valve; CPC 37411: dorsal valve; CPC 37412: dorsal valve; CPC 37413: dorsal valve; CPC 37414: ventral valve; CPC 37415: dorsal valve. Unfigured toptype material includes 19 dorsal valves and 12 ventral valves plus many fragments from the type section (see Fig. 2).

Diagnosis. Shell small with teardrop-shaped outline. Larval shell is smooth. Postlarval shell with microornament of closely packed, often overlapping and/or imbricating circular to crescentic, flat bottomed pits, uniformly 1-2 µm in diameter covering entire shell surface. Pits tend to be more closely spaced and overlapping on slopes of individual concentric fila.

Description. Shell teardrop-shaped in outline, posterior margin subacuminate. Average shell length 2.2 mm, average shell width 1.4 mm. In lateral profile, shell is evenly but weakly equibiconvex. Larval shell totally smooth, relatively large, circular, averaging 0.5 mm in diameter for both valves. Postlarval shell ornament consists of closely spaced, rounded concentric growth fila, ranging from 7-10 µm in width. Microornament consists of closely packed, often overlapping and/or imbricating circular to crescentic, flat bottomed pits, uniformly 1-2 µm in diameter covering entire shell surface. Pits tend to be more closely spaced and overlapping on slopes of individual concentric fila. Pitting commences at the larval-postlarval shell boundary and increases in size away from the smooth larval shell.

Ventral valve pseudointerarea large, lying flat on the floor of the valve and occupying more than 50% valve width. Pedicle groove is shallow, narrow, acutely triangular, averaging 0.25 mm in length and 0.2 mm in width, and well defined laterally by low flexure lines. Propareas are curved, wide and broadly triangular in outline. Posterolateral shell margins adjacent to propareas distinctly enrolled, forming a distinct groove at the posterolateral junction with each proparea. Enrolled edges widen anterolaterally but become less distinct at 30-35% shell length and gradually merge with lateral valve margin. Muscle scars and vascular markings not readily discernible.

Dorsal valve pseudointerarea simple, a relatively broad arcuate strip along the posterior shell margin. Median groove not preserved. Posterior lateral shell margins of pseudointerarea with enrolled edges similar to ventral valve. Visceral area poorly impressed; some valves with random scatter of round bottomed circular pits preserved on valve floor, in front of pseudointerarea. Pits extend anteriorly in median sector of valve to ~60% valve length. Vascula lateralia, narrow, arched and marginal.

Measurements. See Table 2.

Discussion. Wahwaltingula? emanuelensis can be distinguished from the type species W. antiquissima by its smaller size (maximum length 2.4 mm, maximum width 1.9 mm compared to max. length 13.2 mm and max. width 10 mm in W. antiquissima – see Popov & Holmer 1994, tables 1-4). W? emanuelensis is further distinguished from W. antiquissima, and Wahwaltingula sp. from Utah (Popov et al. 2002), by its smooth larval shell. The pits on the postlarval shell of W?
Fig. 4. A-P, Wahwahingula? emanuelensis n. sp. A-B, Holotype, CPC 37409 from 705/97, interior and exterior of dorsal valve, both x 17; C-D, CPC 37410 from 705/97, exterior of dorsal valve (x 13) and close up of postlarval shell showing conspicuous 'drapes' (x 61); E-I, CPC 37411 from 705/97, exterior (x 12), oblique posterolateral (x 25) and close up of surface pitting on postlarval shell of dorsal valve, x 364, x 1375 and x 936, respectively; J-L, CPC 37412 from 705/97, exterior (x 19), oblique posterolateral (x 50) of dorsal valve and close up of postlarval shell pitting (x 820); M, CPC 37413 from 705/97, interior of fragmentary dorsal valve, x 21; N, CPC 37414 from 705/97, interior of fragmentary ventral valve, x 25; O-P, CPC 37415 from 705/97, interior (x 23) and oblique interior (x 25) of fragmentary dorsal valve.
Table 2. A, summary statistics for dorsal valves and B, summary statistics for ventral valves of *Wahlwahlingula? emanuelensis* n. sp.

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emanuelensis are uniformly about 1-2 μm in diameter and are thus larger than those on *Lingulella?* sp. from Ontario (600 nm - Cusack et al. 1999, pl. 1, fig. 8), but smaller than the 6-8 μm diameter pits on *W. antiquissima* (Popov et al. 2002) and the same size as the 2 μm diameter pits on *Lingulella?* sp. a from Sweden (Holmer 1986).

Zhanatellidae n. gen.? A (Fig. 5A-P)

**Material.** 15 dorsal valves and 3 fragmentary ventral valves from the type section of the Emanuel Formation.

**Description.** Shell often fragmented, but generally subcircular to transversely oval in outline with estimated shell width ~2 mm. Larval shell circular, ~600 μm in diameter, with microornament of radial arrays of tiny (~2-3 μm diameter), hemispherical pits excavated into larval shell. Hemispherical pits completely surrounded by shallow, circular, flat-bottomed pits with shared walls forming a dimpled surface. Flat-bottomed pits uniformly 2 μm in diameter. Postlarval shell ornamented by undulatory, draping, concentric rugae, 20-40 μm in length, that become somewhat chaotic in the median sector of the shell. Microornament is dominated by well developed, closely packed, circular, hemispherical pits excavated into the postlarval shell. Pits vary in size from 3-12 μm and are randomly scattered. Occasionally bands (10-20 μm wide) of postlarval shell occur with uniformly fine pits (2-3 μm in diameter) that arise directly from the larval shell and radiate anteriorly to form distinct margins to the bands with multi-sized pits. This produces bands of microornament with distinctive radial arrays.

Ventral valve with long and wide, orthoclinal pseudointerarea cleft medianly by a narrow, anteriorly widening pedicle groove. Proporaeas long, narrow and weakly concave in profile, but subtriangular in outline, extending along the lateral shell margins for up to 30% valve length. Umbo broken in most shells, but some specimens show evidence of a relatively small apical emarginature. Visceral field not preserved.

Dorsal valve interior with relatively wide and long pseudointerarea, flattened to floor of valve and merging laterally to form a pair of narrow, sharply triangular, laterally tapering proporaeas. Apex of pseudointerarea with small but distinctive notch. Flexure lines weakly expressed. Musculature and vascular system unknown.

**Discussion.** The presence of a pitted postlarval shell microornament and the possible presence of a small apical emarginature in the ventral valve indicates this taxon has a close alliance to the family Zhanatellidae. As presently defined (Holmer & Popov 2000) there is no zhanatellid genus currently known that has an external ornament of undulose, divaricate rugae. The genus *Fossuliella*, erected by Popov & Ushtatsynkaya (1992) from the Middle Cambrian of northeastern Central Siberia, has an ornament of fine concentric rugellae, (see also Popov & Holmer 1994, fig. 66) but these are not as well defined as the undulatory, medianly chaotic, concentric rugae of Zhanatellidae n. gen.? A. It thus seems likely that this taxon represents a new zhanatellid genus.

However, the paucity and fragmentary nature of the material (especially of the ventral valve), and poorly expressed musculature, make it difficult to define the taxon accurately, and thus a cautious taxonomic approach is taken here. The external concentric rugae of Zhanatellidae n. gen.? A is very similar to that described in *Westonisca* (Holmer & Popov 2000, p. 54, fig. 21, 2a-c; Mergl 1997, fig. 3A-C; F; Mergl 2002, pl. 8, figs 1-6). However, recent description of toptype material of the type species *W. lamellosa* by Mergl (1997) does not mention the presence of a pitted microornament.
Fig. 5. A-P. Zhanelildae n. gen. A-F. CPC 37416 from 705/48, exterior (x 15), oblique postero-lateral (x 18), interior (x 15), and close up of postlarval shell ornament and pitting of fragmentary dorsal valve, x 30, x 55 and x 460, respectively; G-P. CPC 37417 from 705/48, exterior (x 24), oblique posterior showing larval shell (x 28), oblique posterior showing postlarval shell ornament (x 26), interior (x 24), and close up views of distinctive postlarval shell (K-M) and larval shell (N-P) ornament and pitting of ventral valve, K and N, x 69, L, x 139, M, x 287, O, x 540, P, x 164.
Mergl (2002, p. 28) notes that while *W. lamellosa* is common in the Tremadocian Trenice Formation in the Barrandian area, most specimens are "imperfectly preserved in sandstone". It is thus possible that the microornament in *Westoniscus* is not preserved. However, until a pitted microornament is demonstrated in the obolid *Westoniscus*, and more morphologic information is available about the taxon from the Emanuel Formation, we prefer to recognize this taxon as a probable new genus in the Zhanatellidae.

The discontinuous radial array of pits in Zhanatellidae n. gen.? A (Fig. 5E, K, L) is very similar, though not identical, to the microornament in the discinid *Orbiculoides?* sp. from the Middle Ordovician (Llandelio) Gullhögö Formation illustrated by Holmer (1989, fig. 45, E-F).

Order ACROTRETIDA Kuhn, 1949
Superfamily ACROTRETOIDEA Schuchert, 1893
Family ACROTRETDÆA Schuchert, 1893

Genus *Semitreta* Biernat, 1973

*Type species*. *Semitreta maior* Biernat, 1973; Tremadocian Chalcedonites, Holy Cross Mountains, Poland.

*Species included*. *Semitreta maior* Biernat, 1973; *Torynelasma? magnum* Goryansky, 1969; *Hansotreta acrobela* Krause & Rowell, 1975; *Semitreta kotujensis* Ushatinskaya, 1994; *Semitreta lauriei* n. sp.


*Discussion*. The genus *Semitreta* includes those acrötretid taxa with an essentially *Eurytrema*-like dorsal valve but with a distinctive, high conical and erect ventral valve with a procline (rare) to commonly apsacine pseudointerearea. The genus *Hansotreta* Krause & Rowell (1975) from the Lower Ordovician Meiklejohn Mudmound (Pogonip Group) from Nevada is here considered a junior subjective synonym of *Semitreta* Biernat, 1973.

The external and internal features of both valves of *Hansotreta* conform with the current understanding of *Semitreta* as outlined by Popov & Holmer (1994) and Holmer & Biernat (2002). Krause & Rowell (1975, p. 47) recognised the close similarity between *Hansotreta* and *Semitreta*, but suggested that the two genera could be separated based on the fact that the dorsal surface of the interridge in the ventral valve of *Semitreta* is not concave apically, and the dorsal valve of *Semitreta* lacks the "strongly incurved apex characteristic of *Hansotreta*". Biernat (1973), Popov & Holmer (1994) and Holmer & Biernat (2002) have commented that the development of the ventral valve pseudointerearea and the degree of geniculation in the dorsal valve is quite variable and thus it is difficult to recognise *Hansotreta* as a valid genus.

As noted by Popov & Holmer (1994, p. 122) the single ventral valve illustrated and identified as "*Torynelasma?*" by Rushton & Bassett (in Owens *et al.* 1982, pl. 6m-p) from the Tremadocian of North Wales is also very similar to *Semitreta*. Sutton *et al.* (2000, pl. 19, figs 11, 12) have recently documented more specimens of this taxon and have referred the species to *Semitreta*.

*Semitreta lauriei* n. sp. (Fig. 6A-T)

*Etymology*. For Dr. John Laurie in recognition of his continued work on Ordovician faunas from Australia and his previous work in establishing a trilobite biozonation for the Emanuel Formation.

*Type locality*. Emanuel Formation, Prices Creek Group, Canning Basin, Western Australia. Early Ordovician, Bendigonian Be1, *Kayseraspis* cf. *brackebuschi* trilobite Assemblage Zone of Laurie & Shergold (1996).

*Type stratum*. Type section 705, sample 048, 28 metres above the base of the Emanuel Formation.

*Type material*. Holotype, CPC 37418, ventral valve (Fig. 6A-C). Paratypes: CPC 37419, ventral valve; CPC 37420, ventral valve; CPC 37421, ventral valve; CPC 37422, ventral valve; CPC 37423, dorsal valves; CPC 37424, dorsal valve. Unfigured toptype material includes 23 dorsal valves and 34 ventral valves from sample 705/048.

*Diagnosis*. Species of *Semitreta* distinguished by having a very high, narrow conical ventral valve with distinctly apsacine, never procline pseudointerearea. Foramen apical, truncated; external pedicle tube lacking. In lateral profile,
Fig 6. A-T, *Semitreta laurie* n. sp., all specimens from 705/48. A-C, CPC 37418, posterior (x 21), lateral (x 21) and foramen (x80) of holotype ventral valve; D, CPC 37419, lateral view of ventral valve, x 18; E-F, CPC 37420, anterior and apical views of ventral valve, both x 25; G-I, CPC 37421, oblique anterior (x 22), larval shell and foramen (x 192) and larval shell pitting of ventral valve (x 727); J-M, CPC 37422, posterior, oblique apical, oblique lateral and close up of inter-ridge of ventral valve, J-L, x 15, M, x 30; N-O, CPC 37423, interior and oblique lateral interior of dorsal valve, both x 34; P-S, CPC 37424, exterior, oblique lateral exterior, larval shell and larval shell pitting of dorsal valve, P-Q, x 17, R, x 123, S, x 512; T, CPC 37425, exterior of fragmentary dorsal valve, x 16.
anterior slope of ventral valve gently concave from edge of larval shell to approximately 50% valve height where profile becomes gently convex. Dorsal valve weakly curved to geniculate with weak median sulcus in anterior half of the valve. Median ridge arises some distance anterior of dorsal pseudointerarea.

Description. Shell outline transversely oval, on average 76% wider than long. Ventral valve a very high, relatively narrow cone, antero-ventrally flattened, 50% as high as long with small (50 μm diameter) apical foramen at terminal apex of valve lacking external pedicle tube. Foramen completely enclosed by larval shell. External ornament of subdued concentric lines.

Ventral pseudointerarea flattened, distinctly aspacle, never procline, with poorly defined narrow intertrough. In lateral profile, anterior slope gently concave from edge of larval shell to approximately 50% valve height where profile becomes gently convex. Apical process poorly defined. Mantle canal pattern unknown.

Dorsal valve gently convex to geniculate with weak median sulcus in anterior half of the valve. Larval shell small, circular, averaging 140 μm in diameter. Dorsal pseudointerarea narrow, raised, occupying 48% valve width with broad, triangular median groove and strongly anacline propareas. Cardinal muscle scars transversely oval, occupying 58% valve width. Median buttress weakly expressed. Low, narrow (0.2 μm wide) median ridge arises some distance anterior of dorsal pseudointerarea and extends (on average) to 75% valve length. Mantle canal pattern not preserved, though fine anterior radiate terminal canals are present in well preserved specimens.

Measurements. See Table 3.

Discussion. The dorsal valve of S. lauriei and the type species, S. maior described by Biernat (1973) (see also Holmer & Biernat 2002) are very similar in general shape and geniculation except that in most valves of S. lauriei n. sp. the median ridge originates some distance in front of the anterior edge of median depression (Fig. 6N, O), whereas in S. maior the median ridge begins immediately in front of the median depression (Holmer & Biernat 2002, fig. 8B, H, I, K). Holmer & Biernat (2002, p. 152) also report that in dorsal valves of S. maior, the shallow median sulcus originates at the umbo; in S. lauriei n. sp., the dorsal sulcus is confined to the anterior half of the valve (Fig. 6Q). The ventral valve of S. lauriei n. sp. is narrower and more tapered than S. maior and, in lateral profile, the anterior margin in the apical 50% of the valve is distinctly, but gently, concave. In this regard, S. lauriei n. sp. is more similar to S? aff. magna described by Popov & Holmer (1994) from the Lower Ordovician Alimbet and Akbukaksai formations from the South Urals. However, S. lauriei n. sp. has more subdued concentric fila and lacks an external pedicle tube that serves to distinguish it from S. magna described by Goryansky (1969) from the Lower Ordovician of Estonia and the Ural Mountains and S? aff. magna described by Popov & Holmer (1994). Both of these taxa also have a more pronounced concentric ornament and have a small pedicle sheath on the ventral valve (see Popov & Holmer 1994, p. 123, fig. 99A-D). Dorsal valves of S. magna and S? aff. magna have not been recovered, making further comparison with S. lauriei n. sp. impossible at present.

S. kotujensis Ushatinskaya (1994) from the Late Cambrian of the northern Siberian Platform is based on limited specimens, but the dorsal valve illustrated by Ushatinskaya (1994, pl. 8, figs 1-2) are similar to S. lauriei n. sp., except that the median ridge does not extend to 50% valve length. As noted by Biernat & Holmer (2002) the ventral valve in S. kotujensis is poorly known, but in contrast with S. lauriei n. sp. the apex in S. kotujensis appears to be slightly recurved and the foramen is posteriorly directed and raised on
Fig. 7. A-Q, Ottenbyella shidertensis (Popov & Holmer, 1994). A, CPC 37426 from 705/212, interior of dorsal valve showing vascular markings, x 20; B, CPC 37427 from 705/212, exterior of dorsal valve, x 18; C-E, CPC 37428 from 705/97, apical, lateral and lateral larval shell and foramen of ventral valve, C, x 28, D, x 29, E, x 87; F-H, CPC 37429 from 705/97, oblique anteroapical, lateral, and foramen of ventral valve, F & G, x 15, H, x 147; I-J, CPC 37430, 705/97, interior (x 16), close up of apical process of ventral valve (x 50); K-L, CPC 37431, 705/97, interior (x 17), close up of apical process of ventral valve (x 48); M, CPC 37432, from 705/117, oblique posterior of ventral valve, x 20; N, CPC 37433 from 705/117, oblique posterior view of conjoined specimen, x 33, O, CPC 37434, 705/97, exterior of dorsal valve, x 19; P-Q, CPC 37435, 705/97, interior and oblique anterior of dorsal valve, both x 18.
a short external tube (Ushatsinskaya 1994, pl. 8, figs 3-4).

Semitreta acrobeia (Krause & Rowell 1975) can be distinguished from S. lauriei n. sp. by its less transverse outline, procline to apscaline ventral pseudointerarea and the development of a median interridge as opposed to an intertrough. In the dorsal valve, cardinal muscle scars of S. acrobeia are directed antero-laterally (Krause & Rowell 1975, pl. 6, figs 2, 11), whilst in S. lauriei n. sp. they tend to be more transverse and laterally directed (Fig. 6N-O).

Genus Ottenbyella Popov & Holmer, 1994

Type species. O. carinata (Moberg & Segerberg, 1906) from the Lower Ordovician (Tremadocian) Björkåsholmen Limestone, Fågelsång, Sweden.


Occurrence. Lower Ordovician (Tremadocian): Björkåsholmen Limestone, Fågelsång, Sweden; Batyrbay section, Szechuanella-Apatokcephalus beds, Malay Karatau, Kazakhstan; Olenty Formation, Sasyksor Lake, northeast central Kazakhstan; Lower Ordovician (Bendigonian, Bel – Be2): Emanuel Formation, Canning Basin, Western Australia.

Ottenbyella shidertensis (Popov & Holmer, 1994) (Fig. 7A-Q)

1994 Conotreta shidertensis Popov & Holmer, p. 90-91, Fig. 77A-K.

Material. 1363 dorsal valves and 1016 ventral valves from the type section of the Emanuel Formation (see Fig. 2).

Description. See Popov & Holmer (1994, p. 90)

Measurements. See Table 4.

Discussion. Conotreta shidertensis was originally described by Popov & Holmer (1994) from the Lower Ordovician Olenty Formation in northeastern central Kazakhstan. The species was originally referred to Conotreta because of the similarity in overall external form and the presence of a robust apical process. According to Holmer (2000) and Holmer & Popov (2000, p. 107), Conotreta is characterised (among other features) by having a high conical ventral valve and, in the dorsal valve, a high, triangular medium septum often with terminal denticles or spines. Popov & Holmer (1994, p. 91) noted that C. shidertensis was unusual for the genus because it possessed a less conical ventral valve with features such as a catacline to procline pseudointerarea, distinct, but low, narrow interridge, characteristic anterior bulge of the larval shell, foramen on a short external pedicle tube and the presence of a pair of straight vascula lateralia. In the dorsal valve, C. shidertensis has a lower dorsal medium ridge that lacks septal rods. All these features favour placement of the species shidertensis in Ottenbyella Popov & Holmer (1994) rather than Conotreta sensu stricto (see Holmer 2000 for revision of the type material of Conotreta).

The specimens from the Emanuel Formation are very close to the type material. The large collection of shells from the Emanuel Formation provides additional information about the morphology of this species. For instance, some mature ventral valves have a well preserved pinnate mantle canal system and some larger dorsal valves have well preserved, fine radiating terminal mantle canals not obvious in the Kazakh material (Fig. 7A). Some of these larger specimens also have a pair of well preserved small, circular central muscle scars straddling the median ridge between 30-40 % valve length (Fig. 7A).
Ottenbyella shidertensis is very similar to the type species O. carinata (Moberg & Segerberg, 1906) from the Tremadocian of Sweden, but can be distinguished by having a more prominent apical process in the ventral valve and a median ridge in the dorsal valve that originates directly under the pseudointerarea as an extension of the median buttress (Fig. 7A, P, Q) in contrast to O. carinata where the median ridge originates some distance anterior to the pseudointerarea (Popov & Holmer 1994, fig. 93B, C, N, O; fig. 94C, H). In addition, the shell outline in O. shidertensis is not as transverse as in O. carinata (89% as long as wide in O. shidertensis compared to 84% in O. carinata).

Ottenbyella evanda (Popov in Koneva & Popov 1988) is known only from a few specimens, but the very narrow dorsal valve interarea and thin median ridge which extends only to 50% valve length serve to distinguish this taxon from O. shidertensis.

O. shidertensis is the most numerically dominant species in the Emanuel Formation (Fig. 2) and apart from some questionable fragments of ventral valves in the lowest sample (705/048) it ranges throughout the entire type section of the formation.

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