

Chitinozoans and the age of the Soom Shale, an Ordovician black shale Lagerstätte, South Africa

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ABSTRACT – Isolated chitinozoans from the Soom Shale Member of the Cedarberg Formation, SW South Africa are described and provide a date of the latest Hirnantian–earliest Rhuddanian. The recovered chitinozoans are typical of the latest Ordovician *Spinachitina oulebsiri* Biozone, although an earliest Silurian age is possible. They indicate a very short time span (less than 1 Ma) across the Ordovician–Silurian boundary. This is currently the highest biostratigraphical resolution attainable for the Soom Shale Lagerstätte. Correlation of the Soom Shale chitinozoans with identical assemblages in post-glacial, transgressive deposits of Northern Africa is possible; both faunas occur in shales that overlie glacial diamictites of the Hirnantian glaciation. A new species, *Spinachitina verniersi* n. sp. is described. *J. Micropalaeontol.* 28(1): 53–66, May 2009.

KEYWORDS: *Hirnantian, chitinozoans, Soom Shale, Lagerstätte, Ordovician–Silurian boundary*

INTRODUCTION

Location, sedimentology and importance of the Soom Shale

The Soom Shale Member and the overlying Disa Siltstone Member comprise the Cedarberg Formation of the Table Mountain Group, which crops out in the Cape Province of South Africa. Importantly, both members of the Cedarberg Formation contain the only dateable fossils known in the whole Table Mountain Group, a sequence of sediments of latest Cambrian to Early Devonian age. The Soom Shale Member is a parallel-laminated black shale, reported to contain dropstones (Rust, 1981; Hiller, 1992), which overlies, with a gradational contact, the glaciogenic diamict of the Pakhuis Formation. Thus, it is thought to represent deposition of sediment close to a retreating ice front in a quiet water basin (Theron & Thamm, 1990). None of the fossils show signs of having been transported from outside of this basin (Gabbott, 1998).

The Soom Shale Member is famous as it hosts exceptionally well-preserved fossils, including the soft part remains of conodonts (Aldridge & Theron, 1993; Gabbott *et al.*, 1995), many arthropod groups (e.g. Braddy *et al.*, 1995, 1999; Gabbott *et al.*, 2003; Whittle *et al.*, 2007) and enigmatic taxa (Aldridge *et al.*, 2001), as well as a shelly fauna dominated by brachiopods, but most notably including orthocones with well-preserved radulae (Gabbott, 1999).

Before this investigation, the age of the Soom Shale was not very precisely known (see discussion below). This was unfortunate, not only because its important well-preserved fauna was loosely constrained in time, but also because of the potentially important role it could play in providing new insights on the post-glacial melting and climatic amelioration scenario following the Hirnantian glaciation. For example, Page *et al.* (2007) suggested that de-glacial, anoxic, transgressive black shales may have acted as significant carbon sinks, producing a negative feedback mechanism for climatic warming and aiding stabilization of the Early Palaeozoic Icehouse (EPI) conditions. They cited the Soom Shale as a potential candidate for such a carbon

sink and we can now confirm that its age is consistent with this and thus it may have played a role in climatic transition (Page *et al.*, 2007, p. 133).

The age of the Cedarberg Formation and the Soom Shale Member

Cocks & Fortey (1986) provided an overview of dating of the Cedarberg Formation. In summary, the Soom Shale Member has yielded the trilobite *Mucronaspis olini*, which is indicative of a latest Ordovician age (Rawtheyan–Hirnantian), i.e. late Katian–Hirnantian according to the new international time-scale (Bergström *et al.*, 2006). The overlying Disa Siltstone Member contains a shelly fauna that Cocks & Fortey (1986, p. 440) considered to have an overall generic aspect similar to that of the *Hirnantia* fauna, which is widespread in the latest Ordovician. However, other authors, such as Berry & Boucot (1973), have attributed the same fauna to the earliest Silurian (see overview in Cocks & Fortey, 1986). Gray *et al.* (1986) used the size of spore tetrads to suggest a Llandovery age, although they could not rule out a latest Ordovician age. Meanwhile, Rong & Harper (1988, p. 388), in considering the Disa Siltstone brachiopods, argued that ‘the Cedarberg fauna is not a typical member of the *Hirnantia* fauna but, nonetheless, may be a related assemblage of Hirnantian age’. In addition, Rong *et al.* (2002) have shown that the *Hirnantia* fauna is diachronous, ranging from the Katian (Rawtheyan) to the Rhuddanian.

In this paper, our aims are to describe and illustrate new chitinozoans from the Soom Shale Member that are age diagnostic. These fossils, for the first time, enable us to make high-resolution correlations with more precisely constrained sections elsewhere.

SOOM SHALE CHITINOZOANS

Previous chitinozoan work

Chitinozoans have been previously recovered from three localities from the Soom Shale Member (Fig. 1). Isolated chitinozoans

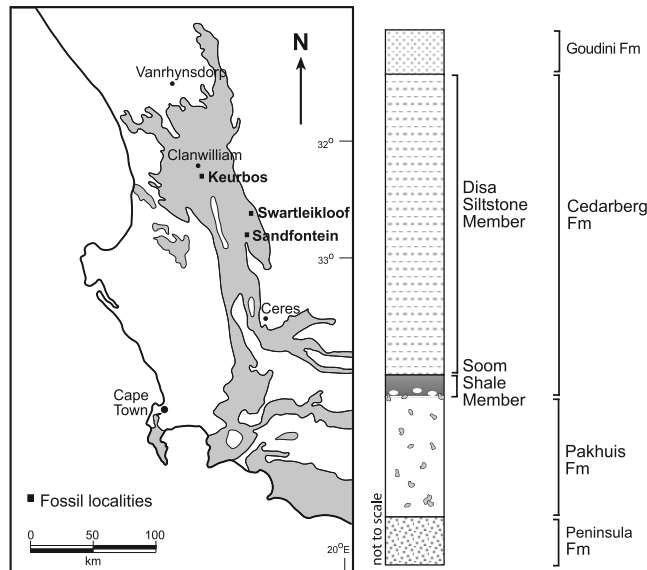


Fig. 1. Map of part of the Western Cape Province, South Africa showing the outcrop area of the Table Mountain Group (shaded grey) and the fossil-collecting localities Keurbos, Swartleikloof and Sandfontein. The core ('Keurbos 70') from which the chitinozoan samples were taken is located 1 km southwest of the main Keurbos locality. Alongside is a schematic stratigraphical section showing part of the Table Mountain Group and the position of the Soom Shale Member which has dropstones at its base. The exact depths of sample collection in the core are given in Table 1.

were first described from this unit at the Swartleikloof locality by Cramer *et al.* (1974), who listed a fauna consisting mainly of species of the genera *Ancyrochitina*, *Conochitina*, *Cyathochitina* and *Desmochitina*. The fauna, as listed by these authors, is not highly age diagnostic and they were only able to date the deposit to the 'Upper Ordovician'. No systematic descriptions were provided and no scanning electron microscope (SEM) photographs were shown, so we cannot make detailed comparisons between their material and the collections we have studied.

Chitinozoans from two other localities, Keurbos and Sandfontein (Fig. 1) were described and illustrated by Gabbott *et al.* (1998). Their specimens, mainly of the genus *Cyathochitina*, occurred on bedding planes as scattered individuals, linked chains and aggregated masses, sometimes associated with organic envelopes. These chitinozoans are conspicuous on freshly split bedding planes preserved as organic remains, clay mineral films or composites of both these preservation modes (Gabbott, 1998; Gabbott *et al.*, 2001).

Material and methods

In this study, core material (in ascending order samples K2.0, K2.3, K2.9a, K2.10, K2.14 and K 2.14A) from the 'Keurbos 70' borehole approximately 1 km southwest of Keurbos (see Fig. 1) was examined, and the samples yielded moderately well-preserved chitinozoans. The core sediment is black and relatively fresh when compared to the quarry site at Keurbos where the sediment is grey. In addition, one sample described herein (S4) comes from Swartleikloof. Here small exposures of Soom Shale can be found in the base of a stream bed, where the shale is very black and contains fresh pyrite. The samples were treated using standard palynological techniques (Paris, 1981). In addition, the residues, which were very rich in organic matter, were treated with standard household bleach (NaOCl) in order to facilitate chitinozoan hand picking. Comparison of bleached and unbleached specimens from the same sample showed that the bleaching technique did not notably change the appearance or state of preservation of the chitinozoan specimens. All studied (and illustrated) specimens are stored at the Council for Geoscience, Bellville, South Africa.

CHITINOZOAN RESULTS

Several of the samples studied yielded moderately well-preserved chitinozoans, listed in Table 1. The dominant species belong to the genera *Ancyrochitina*, *Spinachitina* and *Cyathochitina*. The specimens of the latter genus belong to the *Cyathochitina caputoi* group, and are morphologically closest to the chitinozoans

Chitinozoan identifications	S4	K 2.0	K 2.3	K 2.9 α	K 2.10	K 2.14 A	K 2.14
Depth in core (m)	*	23.65	21.44	15.45	14.45	12.05	12.00
<i>Ancyrochitina</i> sp. A	—	65	—	—	—	—	—
<i>Ancyrochitina</i> sp. B	—	320	62	7	—	—	—
<i>Ancyrochitina</i> sp. C	—	53	—	1	—	—	—
<i>Ancyrochitina</i> spp.	—	43	5	1	5	—	—
<i>Angochitina</i> spp.	—	5	4	—	—	—	—
<i>Spinachitina oulebsiri</i>	—	103	—	—	2	—	—
<i>Spinachitina verniersi</i> n. sp.	—	57	—	1	—	—	—
<i>Spinachitina</i> spp.	—	15	—	—	—	—	—
<i>Fungochitina</i> sp.	—	—	—	1	—	—	—
<i>Cyathochitina caputoi</i> Group	—	—	—	6	72	4	—
<i>Lagenochitina</i> sp.	—	—	—	—	1	—	—
Chitinozoa indet.	—	25	2	3	—	—	—
scolecodont	—	—	x	—	—	—	—
Total number of chitinozoans	0	686	73	20	80	4	0
Sample size (g)	35.44	10.75	23.44	10.24	14.31	12.19	13.08

The top of the diamictite of the Pakhuis Formation in the core is observed at 23.82 m.

Table 1. Chitinozoan results from samples from the 'Keurbos 70' core approximately 1 km southwest of Keurbos, except sample S4 (*), which was collected in Swartleikloof.

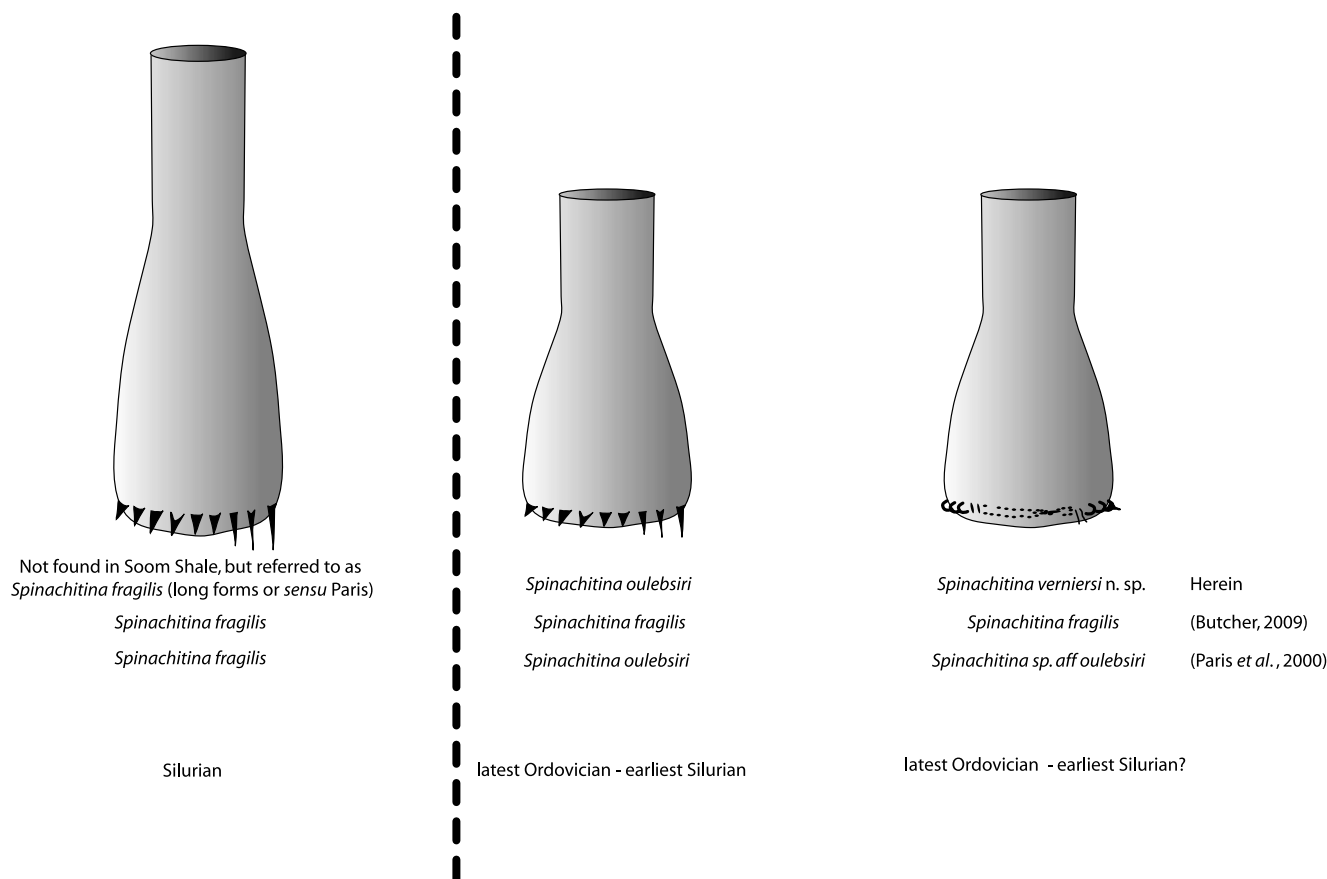


Fig. 2. A suite of three distinct but morphologically very similar *Spinachitina* species that range around the Ordovician–Silurian boundary in the N. Gondwanan realm and a summary of their recent taxonomic history.

described from bedding planes by Gabbott *et al.* (1998: 449, figs 2a, b). *Spinachitina oulebsiri* and *Spinachitina verniersi* n. sp. (Fig. 2) have been recovered from samples K2.0, K2.9a and K2.10 and are the most biostratigraphically useful species in the assemblage.

Few of the taxa originally described by Cramer *et al.* (1974) have been recognized in the material we have studied. Based on their illustrations, the *Ancyrochitina* species that they identified were left in open nomenclature in our study; *Conochitina oelandica*, as illustrated by Cramer *et al.* (1974, fig. 7), probably represents a different species: *C. oelandica* has been placed in synonymy with *Eisenackitina rhenana* by Nölvak & Grahn (1993), which is an index species for the lowest Sandbian (Nölvak & Grahn, 1993; Vandenbroucke, 2004); the specimen illustrated by Cramer *et al.* (1974) does not have the typical S-shaped flank of *E. rhenana* (cf. Vandenbroucke, 2004); in contrast, it is similar in general shape to the bursachitinids, such as those recognized by Verniers & Vandenbroucke (2006, fig 4G) in the Late Ordovician of Dob's Linn (Scotland).

DATING AND CORRELATION OF THE SOOM SHALE

In the North Gondwanan realm, the strata straddling the Ordovician–Silurian (O/S) boundary host a suite of *Spinachitina* species, enabling precise subdivision of this interval. A short overview is given in Figure 2, with special attention to the species collected from the Soom Shale Member. Although the

taxonomic history of these species is complex (Fig. 2), three distinct morphotypes can be distinguished: (i) a compact, rather short *Spinachitina* with well-differentiated spines (*Spinachitina oulebsiri*); (ii) a rather compact *Spinachitina* with poorly differentiated spines (*Spinachitina verniersi* n. sp.); and (iii) an elongated *Spinachitina* with well-differentiated spines (*Spinachitina fragilis* long forms). The first two were recovered from the Soom Shale Member.

During the last couple of decades, *Spinachitina fragilis* has been considered as being indicative of the lowermost Silurian, and was elected as the index species for the lowest Silurian biozone in ‘the global chitinozoan biozonation for the Silurian’ by Verniers *et al.* (1995, also see references therein). In the Gondwanan realm, it therefore immediately succeeded the uppermost Ordovician biozone, the *Spinachitina oulebsiri* Biozone, defined by the range of its index fossil (Webby *et al.*, 2004). Recently, Butcher (2009) has synonymized *Spinachitina fragilis* and *Spinachitina oulebsiri*. In this scenario, *S. fragilis*, the senior synonym, and its eponymous biozone would range from the uppermost Ordovician to the lower Silurian, and would span the range of the former *S. oulebsiri* and *S. fragilis* Biozones. This would also be, as Butcher (2009) pointed out, in good agreement with earlier findings of Melchin & Holmden (2006), who suggested that placing the base of the *S. fragilis* Biozone below the O/S boundary would facilitate intercontinental correlation of sections that yielded both chitinozoan and $\delta^{13}\text{C}$ data.

However, we see merit in a continued split between the two *Spinachitina* species. We are able to see subtle differences between the two species (see systematic section) and prefer to await a direct comparison between the vast N. Gondwana assemblages and a full assemblage of the Estonian *S. fragilis* material that includes the holotype before assessing the possible synonymy of *S. oulebsiri* and *S. fragilis*. The Estonian material is from a drill core, and a large chitinozoan collection may be unavailable, but studies planned by FP may throw more light on this question.

Spinachitina oulebsiri has been reported from post-glacial deposits in the NE Algerian Sahara (Paris *et al.*, 2000) and also occurs in the Bou Ingarf section in the Moroccan Anti-Atlas (Bourahrouh *et al.*, 2004, p. 27; Elaouad-Debbaj, 1984: 61, identified as *Spinachitina bulmani*; Paris unpublished data); in both sections, *Spinachitina oulebsiri* co-occurs with species of the preceding biozone, the *Tanuchitina elongata* Biozone. The latter is usually considered typical of the glacial episode in the Hirnantian, and is often found in the Hirnantian glacial diamictites (Paris *et al.*, 2000; Bourahrouh *et al.*, 2004). Higher up in the stratigraphy, *Spinachitina oulebsiri* occurs without the *T. elongata* fauna, e.g. in the Nseirat section in Mauritania (Paris unpublished data; Paris *et al.*, 1998, in assemblage 1), and in the MKSR-1 core in Saudi Arabia, where it was originally identified as *S. aff. S. fragilis* by Paris *et al.* (1995).

Long forms of *Spinachitina fragilis* (300 µm and more), often referred to as true *S. fragilis* in previous publications dealing with N. Gondwana sections (e.g. Paris *et al.*, 1995, 1998, 2000), appear still higher in the stratigraphy as a further evolved member of the *Spinachitina fragilis* lineage (including *S. oulebsiri*, *S. verniersi* and *S. fragilis*; see Paris *et al.*, 2000 and Fig. 3). It remains to be seen whether these specimens fall within the same assemblage as the holotype, or whether they should be separated as a new species (Paris, work in progress). These forms have not been recovered from the Soom Shale and will not be dealt with in detail here.

We can calibrate these ranges with the graptolite biostratigraphy in the Nseirat section (Mauritania): *Spinachitina oulebsiri* (identified within local Nseirat assemblage 1 as *Spinachitina* sp. off. *bulmani*) and long *Spinachitina* forms (identified as *Spinachitina fragilis* within local assemblage 2 and higher) have been observed from separate levels from the *N. persculptus* graptolite Biozone (Paris unpublished data; Paris *et al.*, 1998; Underwood *et al.*, 1998) in the Nseirat section, and the long forms continue upwards into the Silurian. However, Loydell (2007) rejected some of Underwood *et al.*'s (1998) key graptolite identifications. This is crucial, as prior to Loydell's revision, the Nseirat section was one of the few sections that allowed calibration of the occurrence of *S. oulebsiri* with Hirnantian graptolites and, therefore, one of the few sections that independently demonstrated the latest Ordovician age of this chitinozoan. Strata at Nseirat dominated by *Cyathochitina* gr. *caputoi*, but also yielding other chitinozoans including *S. oulebsiri*, contain graptolites reported by Underwood *et al.* (1998) as *Normalograptus* cf. *extraordinarius*. Legrand (in press), however, included these specimens in the synonymy list of a new species of *Normalograptus*, which he assigned either to the *N. persculptus* Biozone or more probably to the lowermost part of the *ascensus–acuminatus* Biozone (Legrand, 2006). In that case, the base of the Nseirat

section (i.e. the part of it sampled for chitinozoans) is very close to the base of the Rhuddanian.

Spinachitina oulebsiri (originally identified as *S. aff. S. fragilis*) and long forms of *S. fragilis* (identified as *S. fragilis*) co-occur immediately below *acuminatus* Biozone graptolites in the MKSR-1 core in Saudi Arabia (Paris *et al.*, 1995). The latter co-occur with *C. caputoi* (Paris *et al.*, 1995; see below).

A second species of *Spinachitina*, here named *Spinachitina verniersi* n. sp., has been recovered from the Soom Shale Member. This form has also been found (under various names, see below in the systematics section) in the M'Kratra Formation of the NE Algerian Sahara (Paris *et al.*, 2000), the Hirnantian lower Second Bani Formation of the central Anti-Atlas of Morocco (Bourahrouh *et al.*, 2004), the Hirnantian Ashgill Shales Formation in the type area of the British Ashgill Series in Northern England (Vandenbroucke *et al.*, 2005; Vandenbroucke, 2008), and in the lower 'hot shale' (Mudawwara Shale Formation) of Rhuddanian age in Jordan, where it co-occurs with *S. fragilis* in the upper *ascensus–acuminatus* graptolite biozonal interval (Butcher, 2009). *Spinachitina verniersi* n. sp. is also reported from the Moussegouda Shale in Chad (Paris, unpublished data). The latter is sedimentologically very similar to the Soom Shale, and immediately overlies diamictites which yielded *Armoricochitina nigerica*, one of the key elements of the *T. elongata* Biozone fauna.

Clearly, the taxonomy of *Spinachitina* around the Ordovician–Silurian boundary is in urgent need of revision. This is not within the scope of this paper as it necessitates a world-wide investigation of the sections and taxa. Nevertheless, it is certainly possible to use the *Spinachitina* lineage to date the Soom Shale Member accurately: the presence of *S. oulebsiri* places the samples in the Hirnantian or Rhuddanian; the Soom Shale assemblage has relatively short *Spinachitina* species (*S. oulebsiri* and *S. verniersi* n. sp.) and lacks (with very few exceptions) the longer forms, which in other places appear more or less at the O/S boundary. In addition, it lacks any elements of the *Tanuchitina elongata* fauna, which places the samples high in the Hirnantian. Furthermore, *S. verniersi* n. sp. has been recorded only from Hirnantian sections in other localities, apart from the one Rhuddanian locality in Jordan (Butcher, 2009). Taken together, this evidence indicates that the Soom Shale Member can probably be dated to the late Hirnantian. However, given the rather loose constraints on the FAD of the longer forms of *S. fragilis vis-à-vis* the graptolite biozonation in some of the key sections (e.g. Nseirat, see Loydell, 2007; Underwood *et al.*, 1998), an earliest Rhuddanian age for the samples from the Soom Shale Member cannot be excluded. Nevertheless, the interval remains tightly constrained in time to the latest (post-glacial) Hirnantian and the earliest Rhuddanian.

The apparent dominance of the *C. caputoi* group in the higher samples (Table 1) is of interest as the development and proliferation of this *Cyathochitina* species usually fits well with the base of the Silurian. This can be observed in various localities, such as in Bohemia and Brittany (Bourahrouh, unpublished data), in the MKSR-1 core (see above; Paris *et al.*, 1995), and in the Nseirat section if one follows the graptolite re-assignment of Legrand (in press).

Ancyrochitina species that have been recorded from the Soom Shale Member, *Ancyrochitina* sp. A and *Ancyrochitina*

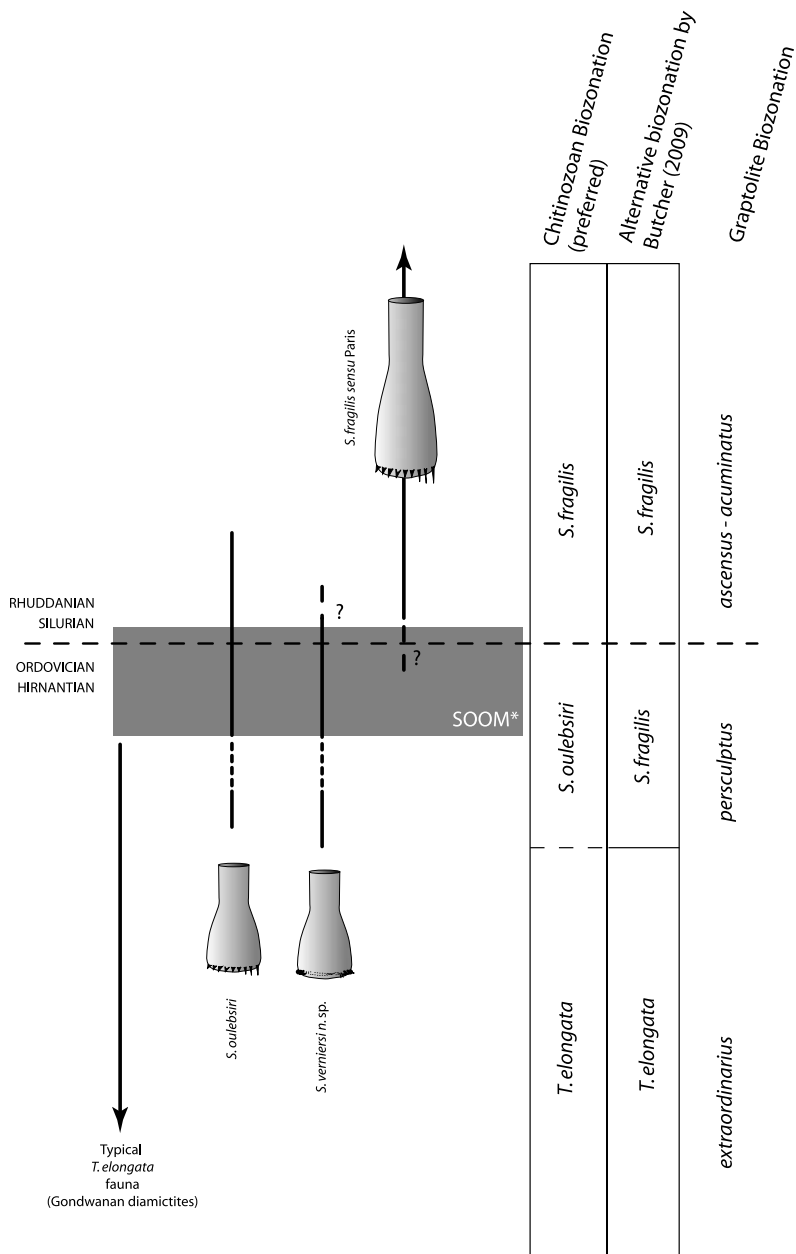


Fig. 3. A Gondwanan model that shows the stratigraphical ranges of the three key *Spinachitina* species discussed in the text. The *Tamuchitina elongata* fauna is typical of the glacial deposits in the Hirnantian; *Spinachitina oulebsiri* and *Spinachitina verniersi* n. sp. appear in the post-glacial melting phase/transgression, which occupies the transitional interval between the Ordovician and Silurian. *Spinachitina fragilis* is typical of the early Silurian. The time of deposition of the Soom Shale Member is within the grey area labelled SOOM*. A more precise calibration of these chitinozoan ranges versus the graptolite stratigraphy is work in progress (detailed in the text).

sp. C, are respectively close to *Ancyrochitina ellisbayensis* and *Ancyrochitina* cf. *corniculans*, which have both been reported from Ordovician/Silurian boundary strata of Anticosti Island, Canada (Soufiane & Achab, 2000). This corroborates the suggested Hirnantian–Rhuddanian age for the Soom Shale.

Cramer *et al.* (1974, fig. 9) illustrated a large specimen that could well be a specimen of *Armoricochitina nigerica*, a typical Katian–Hirnantian species, which ranges below and into the lower part of the *oulebsiri* Biozone. The same authors also listed

Desmochitina minor, which normally does not range above the base of the Silurian.

SYSTEMATIC DESCRIPTIONS OF SELECTED TAXA

Chitinozoan dimensions are given in micrometres, using three dash-separated values, indicating the minimum, the average and the maximum value of the parameter. The following abbreviations, from Paris (1981), are used: L, total length; Dp, maximum chamber diameter; Dc, diameter of oral tube; *n* is the number of measured specimens.

Incertae sedis Group **Chitinozoa** Eisenack, 1931

Order **Prosomatifera** Eisenack, 1972

Family **Conochitnidae** Eisenack, 1931 emend. Paris, 1981

Subfamily **Spinachitininae** Paris, 1981

Genus *Spinachitina* Schallreuter, 1963

Spinachitina oulebsiri Paris *et al.*, 2000

(Pl. 1, figs 1–12)

.pars 1984 *Spinachitina bulmani* (Jansonius); Elaouad-Debbaj: 61, pl. 3, figs 6–8, 10, 12; *non* pl. 2, figs 7–8.

v. pars 1995 *Spinachitina fragilis* (Nestor); Paris *et al.*: 77, *non* pl. 1, fig. 1. [figured specimen = long form: 340 µm long; but some other specimens of the assemblage are *S. oulebsiri*]

v. 1995 *Spinachitina* aff. *S. fragilis* (Nestor); Paris *et al.*: 77 [listed only].

v. 1998 *Spinachitina* sp. aff. *fragilis* (Nestor); Paris *et al.* [listed only].

*v. 2000 *Spinachitina oulebsiri* Paris *et al.*: 99, pl. 1, figs 2, 3.

?pars v 2008 *Spinachitina* sp. 5 Vandenbroucke: pl. 29, fig. 7; *non* pl. 21, figs 8, 11, 12.

?pars v 2008 *Spinachitina bulmani* (Jansonius); Vandenbroucke: pl. 26, fig. 3; *non* pl. 5, fig. 14; *non* pl. 23, fig. 17.

?v 2008 *Spinachitina* ?*fragilis* (Nestor); Vandenbroucke: pl. 26, fig. 9 [single specimen: identification uncertain].

?v 2008 *Spinachitina* ?*fragilis* (Nestor); Vandenbroucke *et al.* [listed only = identical to previous record].

?v 2008 *Spinachitina* sp. 5 Vandenbroucke *et al.* [listed only].

?pars v 2008 *Spinachitina bulmani* (Jansonius); Vandenbroucke *et al.* [listed only].

Diagnosis. ‘*Spinachitina* species with a short (150–250 µm) conical thin-walled vesicle; the margin bears a crown of about 20 short (less than 8 µm) conical and simple spines’ (Paris *et al.*, 2000, p. 99).

Material. 105 specimens from samples K2.0 and K2.10

Age. Latest Ordovician (late Hirnantian) to earliest Silurian (early Rhuddanian). If our suggested synonymy (see list above) of *Spinachitina oulebsiri* with *Spinachitina* sp. 5 from the Hirnant Limestone Member of Hirnantian age (Vandenbroucke *et al.* 2008) is correct, this will be important for the age attribution of the species.

Description. See Paris *et al.* (2000). Our material consists of cylindro-conical specimens with a relatively short neck and a gentle flexure. The neck is straight to slightly flaring and bears a fringe of small spines around the aperture. The vesicle wall is smooth to delicately granular. The basal margin, frequently folded during flattening, bears a crown of about 20, triangular (to rather cylindro-conical with broadened bases), well-separated spines. Transitional specimens to *Spinachitina verniersi* n. sp. have been included herein.

Dimensions. L: 105–163–270 µm; Dp: 55–72–100 µm; Dc: 25–42–60 µm (*n*=46). See Figure 4.

Remarks. Our specimens are typical of the species *Spinachitina oulebsiri*. We chose not to follow Butcher’s (2009) synonymy of

S. oulebsiri and *Spinachitina fragilis* and we refer to that paper for a discussion of *S. fragilis*. Based solely on the original descriptions of both species by Nestor (1994) and Paris *et al.* (2000), it is difficult indeed to distinguish the two species and the differences are subtle (and thus easier to observe when presented with a large assemblage): *S. oulebsiri* has conical (triangular when flattened) spines, whereas *S. fragilis* (or least its holotype) has more cylindrical spines (although the morphological variability may be greater than indicated by the limited amount of material that is available from Estonia). Another difference concerns the width of the chamber *vis-à-vis* the vesicle length: the holotype of *S. fragilis* is more slender than specimens assigned to *S. oulebsiri* here, which have a more conical chamber and a stouter general appearance (especially noticeable in flattened specimens).

In addition, we are uncertain regarding the inclusion in Butcher’s (2009) synonymy of *S. fragilis* of the larger specimens originally attributed to *S. fragilis* (e.g. by Paris *et al.*, 1995); these probably represent a new species and will need to be renamed in the future. These larger *Spinachitina* forms have been provisionally referred to as *S. fragilis* ‘long forms’ in this text. No large ‘forms’ of *S. fragilis* have been found in the Soom Shale; we interpret this to be a genuine stratigraphic signal.

Spinachitina verniersi n. sp.

(Pl. 2, figs 1–12)

v. 2000 *Spinachitina* sp. aff. *oulebsiri* Paris *et al.*: pl. 1, figs 1, 4.

v. 2004 *Spinachitina* sp. aff. *oulebsiri* Bourahrouh *et al.*: pl. 4, figs 6, 10.

?2005 *Spinachitina* sp. aff. *oulebsiri* Hints *et al.*: fig. 4 [listed only].

v. 2005 *Spinachitina* sp. 3 Vandenbroucke *et al.* [listed only].

pars v. 2008 *Spinachitina* sp. 5 Vandenbroucke: pl. 21, figs (8?.) 11, 12; ?*non* pl. 29, fig. 7.

v. 2008 *Spinachitina* sp. off. *oulebsiri* Paris *et al.*; Vandenbroucke: pl. 26, figs 5–8.

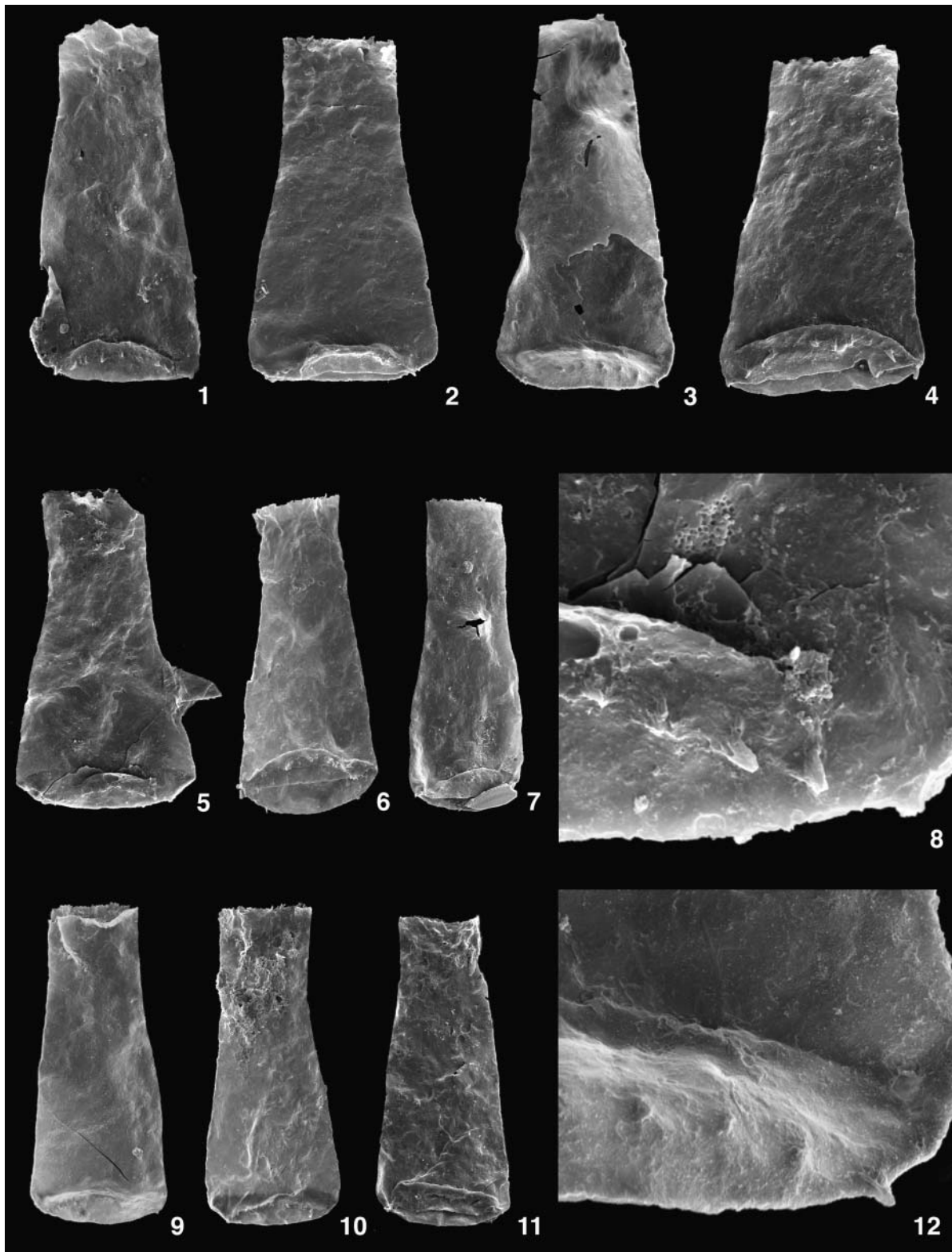
v. 2008 *Spinachitina* sp. off. *oulebsiri* Paris *et al.*; Vandenbroucke *et al.* [listed only].

.pars 2009 *Spinachitina fragilis* (Nestor); Butcher: pl. 3, figs 6–10.

Derivation of name. In honour of Prof. Jacques Verniers, who supervised TVDB’s earlier work (MSc & PhD) and who is a significant Silurian chitinozoan worker.

Diagnosis. Small, cylindro-conical *Spinachitina* species with a crown of *c.* 40 numerous, closely spaced, hardly differentiated to undifferentiated spines and/or scars at the basal margin; the latter often resembles a row of colons (::::) that are the remains of hollow short spines that were either bi-rooted or had a vertically stretched insertion.

Holotype. The specimen (IGR 70013) originally identified as *Spinachitina* sp. aff. *oulebsiri* (by Paris *et al.*, 2000), figured in Paris *et al.* (2000, pl. 1, fig. 4), from the upper member of the M’Kratra Formation in the NE Algerian Sahara, well N1-2, core 29, depth 2655.30 m. Collections of the Geological Institute of Rennes University, France, IGR 70013 (L52).



Explanation of Plate 1.

figs 1–12. *Spinachitina oulebsiri*: **1**, $160 \times 70 \times 45$, specimen C2044, sample K2.0; **2**, $130 \times 70 \times 40$, specimen C2045, sample K2.0; **3**, $195 \times 90 \times 45$, specimen C2046, sample K2.0; **4**, $120 \times 75 \times 45$, specimen C2047, sample K2.0; **5**, $150 \times 78 \times 42$, specimen C2048, sample K2.0; **6**, $140 \times 60 \times 35$, specimen C2049, sample K2.0; **7**, $180 \times 65 \times 45$, specimen C2050, sample K2.0; **8**, close up of figure 5; **9**, $140 \times 60 \times 35$, specimen C2051, sample K2.0; **10**, $150 \times 60 \times 40$, specimen C2052, sample K2.0; **11**, $140 \times 60 \times 35$, specimen C2053, sample K2.0; **12**, close up of figure 3. All measurements in μm (L \times Dp \times Dc). Abbreviations, following Paris (1981): L, total length; Dp, chamber diameter; Dc, diameter of oral tube.

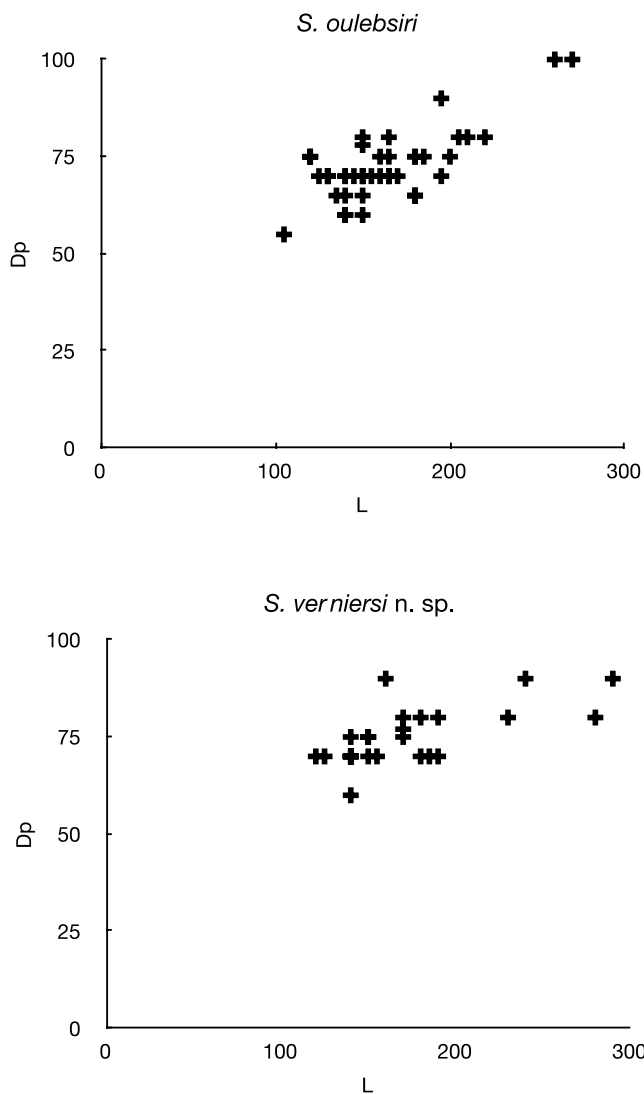


Fig. 4. Length–width diagrams of the specimens of *Spinachitina oulebsiri* and *Spinachitina verniersi* n. sp. from the Soom Shale Member. Abbreviations, following Paris (1981): L, total length; Dp, chamber diameter.

Paratype. Paris *et al.* (2000, pl. 1, fig. 1, IGR 70011); well N1-2, core 29, depth 2656.00 m; collections of the Geological Institute of Rennes University, France, IGR 70011 (O40/3).

Material. 58 specimens from samples K.2.0 and K.2.9a. Stored at the Council for Geoscience, Bellville, South Africa, collection numbers C2044-2086.

Age. Latest Ordovician (late Hirnantian). Sporadically observed in earliest Silurian strata (early Rhuddanian, Butcher, 2009).

Description. The general vesicle shape is the same as that of *Spinachitina oulebsiri*. The material consists of cylindro-conical specimens with a gentle to somewhat more pronounced flexure. The neck is slightly flaring and bears a fringe of small spines around the aperture. The base bears a series of poorly separated spines and scars of spines; the latter often occur in two closely

spaced, parallel rows (Pl. 2, fig. 12), as witnesses of broken, bi-rooted spines, or of hollow short spines with stretched bases (insertion on the margin) that were broadly parallel to the longitudinal axis of the vesicle. The bi-rooted spines have varied morphologies and, for instance, can be arch-shaped or lambda-shaped.

Dimensions. L: 120–173–290 μm ; Dp: 60–75–90 μm ; Dc: 30–45–60 μm ($n=25$). See Figure 4.

Stratigraphic range/occurrence. To date, known from the Soom Shale Member of the Cedarberg Formation in South Africa (this study), the M’Kratra Formation in the NE Algerian Sahara (Paris *et al.*, 2000), the lower Second Bani Formation in the central Anti-Atlas of Morocco (Bourahrouh *et al.*, 2004), the Moussegouda post-glacial shale in northern Chad (Paris, pers. obs.), the Ashgill Shales Formation in Northern England (Vandenbroucke *et al.*, 2005), the Cwmere Formation and the Cerig Gwynion Grit facies of the Caban Conglomerate Formation in central Wales (Vandenbroucke *et al.*, 2008) and the Mudawwara Shale Formation in Jordan (Butcher, 2009).

Remarks. Although we may become convinced of Butcher’s (2009) synonymy of *Spinachitina oulebsiri* with *S. fragilis*, we do not follow his attribution of *S. sp. aff. oulebsiri* (*sensu* Paris *et al.*, 2000) to the same species. We have erected a new species, *Spinachitina verniersi* n. sp. for those specimens with a crown of very numerous and poorly separated spines. Although a lot of transitional forms between *S. oulebsiri* and *S. verniersi* n. sp. can be observed (with a growing number of spines, and/or different degrees of spine separation), the two end-members are considered distinctive enough to support the split into two species. Until now, no specimens have been found that show the characteristics of both species on a single specimen. In the Soom Shale samples, doubtful (intermediate) specimens have in most cases been attributed to *S. oulebsiri* (Pl. 1, fig. 10). Vandenbroucke (2008) reported the species from the UK, as *Spinachitina sp. 5* (pars, excluding the specimen figured on his pl. 29, fig. 7, which seems to be closer to *S. oulebsiri*).

Family **Lagenochitinidae** Eisenack, 1931, emend. Paris, 1981

Subfamily **Ancyrochitinae** Paris, 1981

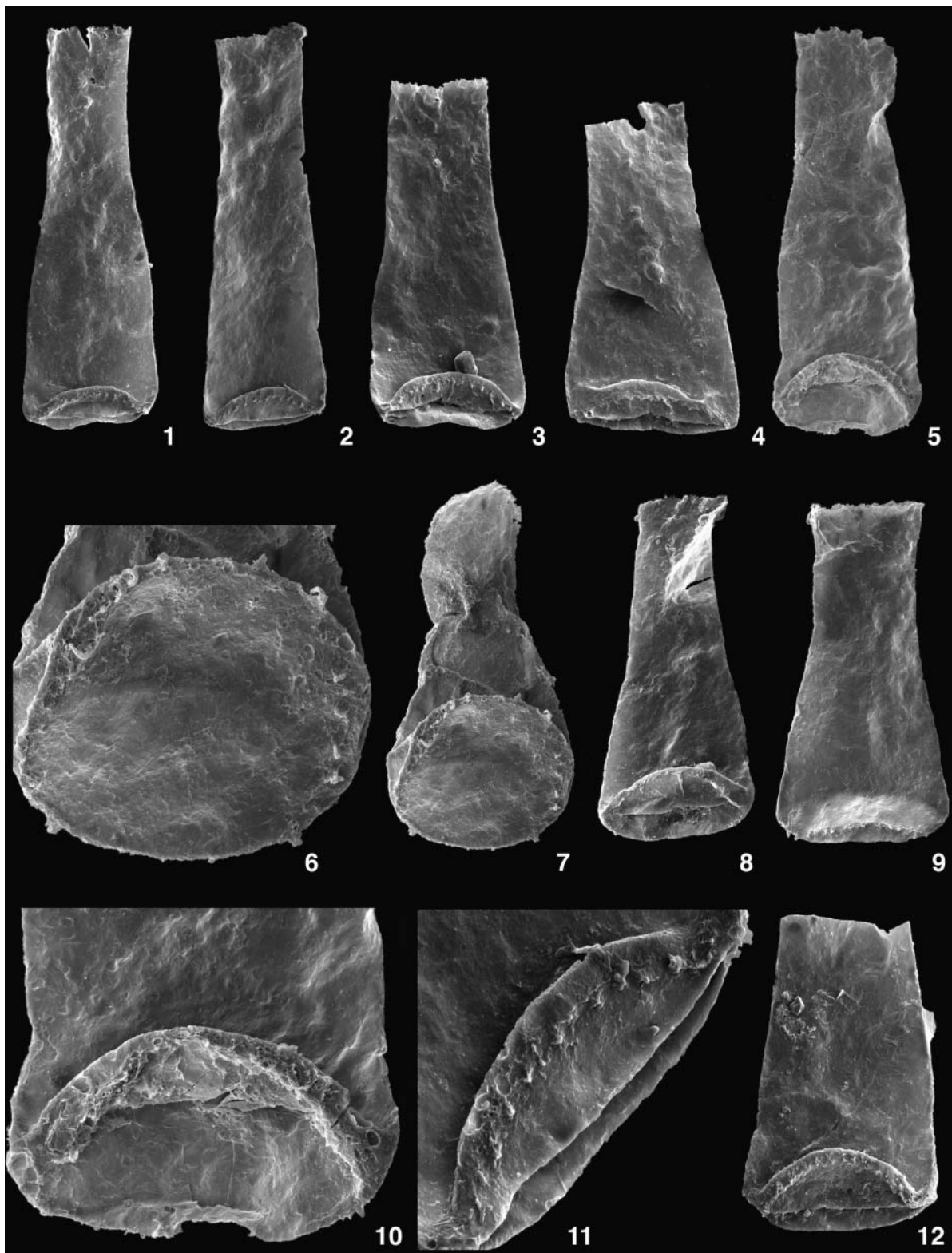
Genus *Ancyrochitina* Eisenack, 1955

Ancyrochitina sp. A
(Pl. 3, figs 1–7)

Description. Compact, wide *Ancyrochitina* species with a very short, flaring neck, spiny ornamentation on the test and multi-branched appendices.

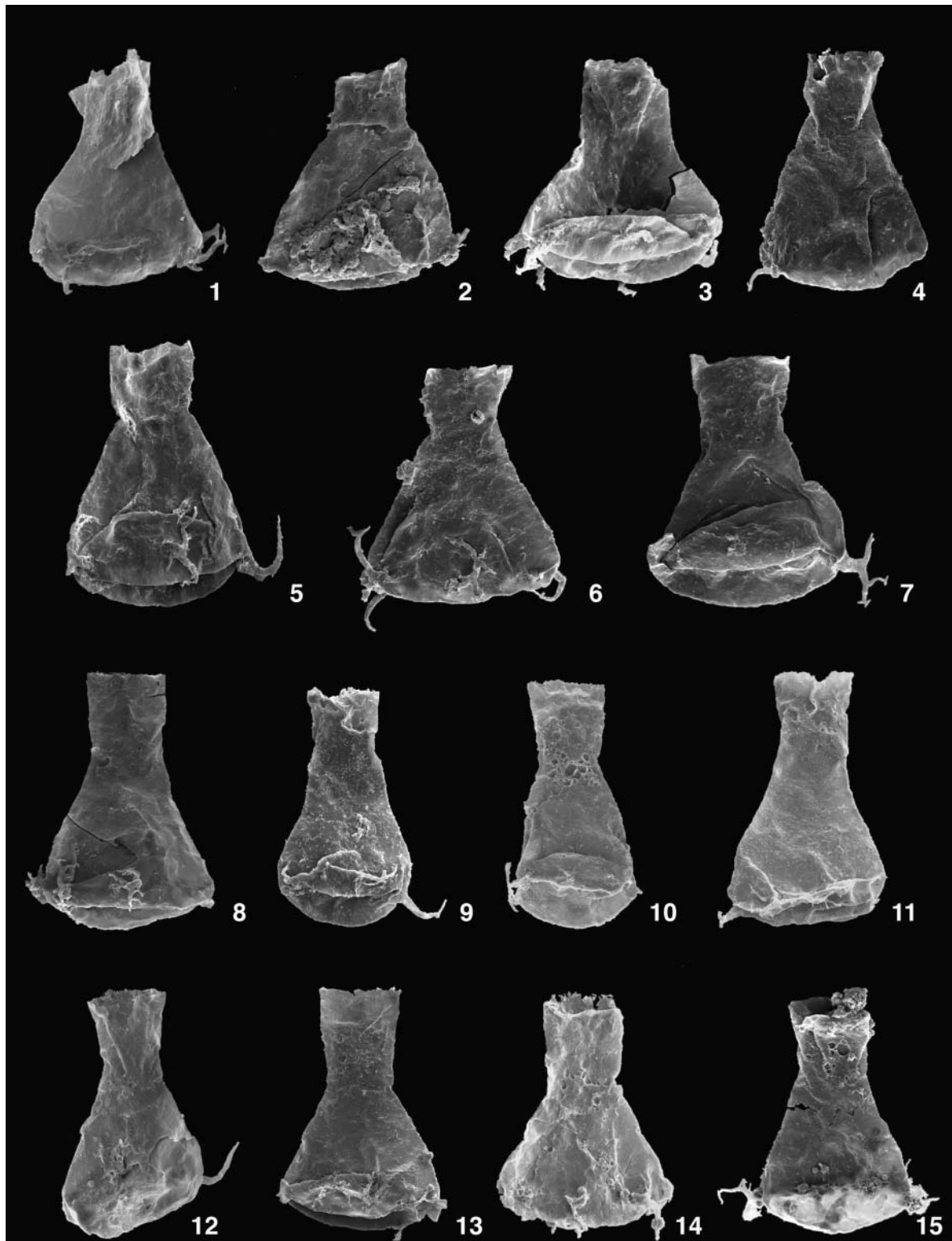
Dimensions. L: 90–100–115 μm ; Dp: 65–75–85 μm ; Dc: 25–31–40 μm ($n=32$).

Remarks. The species is morphologically close to *Ancyrochitina ellisbayensis*, which has been reported from Ordovician/Silurian boundary strata of Anticosti Island, Canada (Soufiane &



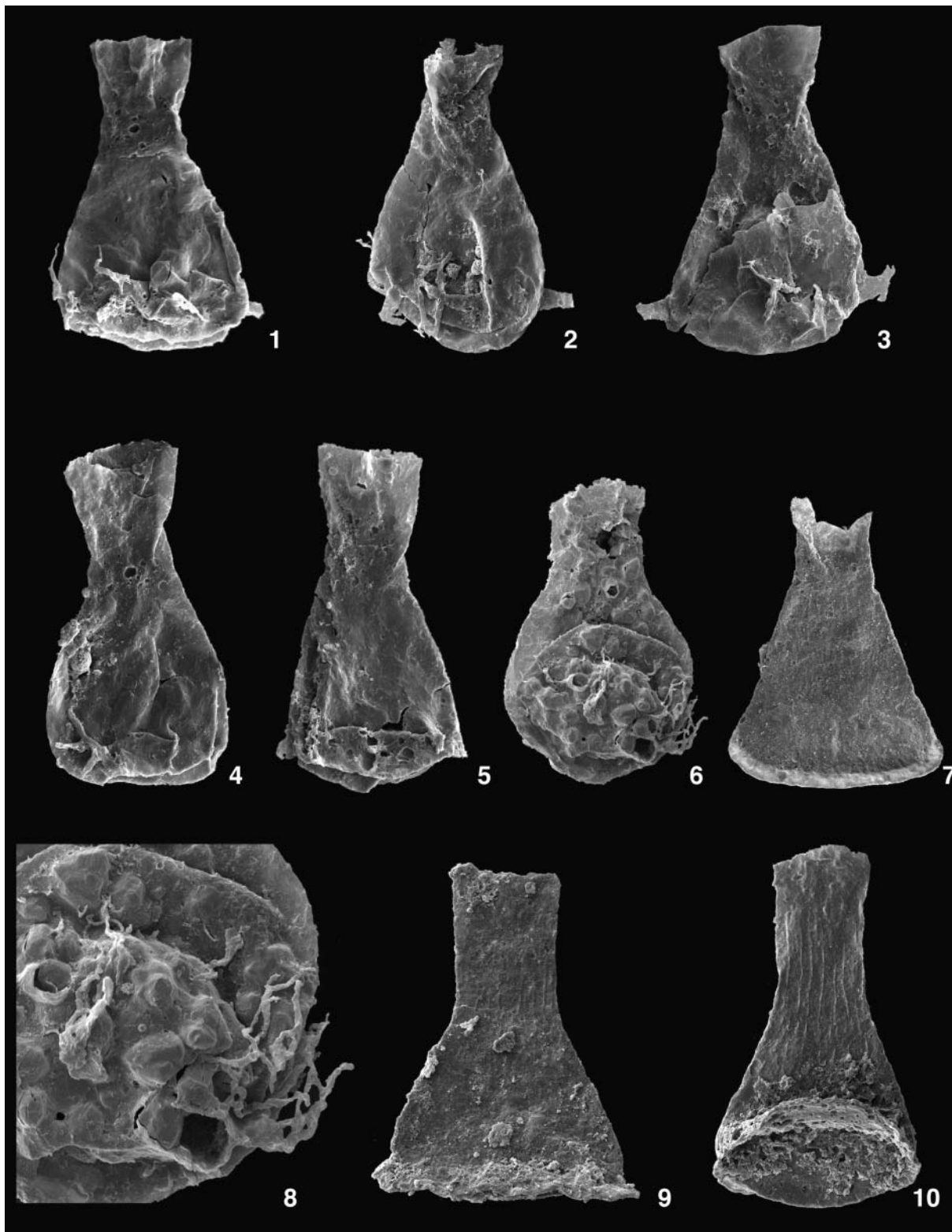
Explanation of Plate 2.

figs 1–12. *Spinachitina verniersi* n. sp: 1, 230 × 80 × 50, specimen C2054, sample K2.0; 2, 290 × 90 × 60, specimen C2055, sample K2.0; 3, 170 × 75 × 49, specimen C2056, sample K2.0; 4, 140 × 70 × 43, specimen C2057, sample K2.0; 5, 240 × 90 × 55, specimen C2058, sample K2.0; 6, close up of figure 7; 7, 140 × 70 × 35, specimen C2059, sample K2.0; 8, 170 × 77 × 35, specimen 2060, sample K2.0; 9, 150 × 75 × 45, specimen C2061, sample K2.0; 10, close up of figure 5; 11, close up of figure 12; 12, 140 × 85, specimen C2062, sample K2.0. All measurements in μm (L × Dp or L × Dp × Dc). See Plate 1 for abbreviations.



Explanation of Plate 3.

figs 1–7. *Ancyrochitina* sp. A: **1**, $110 \times 80 \times 30$, specimen C2063, sample K2.0; **2**, $95 \times 80 \times 30$, specimen C2064, sample K2.0; **3**, $90 \times 80 \times 35$, specimen C2065, sample K2.0; **4**, $105 \times 70 \times 25$, specimen C2066, sample K2.0; **5**, $105 \times 70 \times 25$, specimen C2067, sample K2.0; **6**, $105 \times 85 \times 28$, specimen C2068, sample K2.0; **7**, $100 \times 75 \times 30$, specimen C2069, sample K2.0. **figs 8–15.** *Ancyrochitina* sp. B: **8**, $110 \times 70 \times 30$, specimen C2070, sample K2.0; **9**, $130 \times 70 \times 35$, specimen C2071, sample K2.3; **10**, $140 \times 65 \times 35$, specimen C2072, sample K2.3; **11**, $130 \times 80 \times 35$, specimen C2073, sample K2.3; **12**, $110 \times 70 \times 25$, specimen C2074, sample K2.0; **13**, $120 \times 80 \times 30$, specimen C2075, sample K2.0; **14**, $105 \times 80 \times 30$, specimen C2076, sample K2.0; **15**, $110 \times 70 \times 30$, specimen C2077, sample K2.0. All measurements in μm (L \times Dp \times Dc). See Plate 1 for abbreviations.



Explanation of Plate 4.

figs 1–5. *Ancyrochitina* sp. C: **1**, 115 × 70 × 25, specimen C2078, sample K2.0; **2**, 120 × 70 × 25, specimen C2079, sample K2.0; **3**, 110 × 65 × 25, specimen C2080, sample K2.0; **4**, 130 × 65 × 30, specimen C2081, sample K2.0; **5**, 125 × 70 × 28, specimen C2082, sample K2.0. **figs 6, 8.** *Angochitina* sp.: **6**, 100 × 65 × 30, specimen C2083, sample K2.0; **8**, close up of figure 6. **figs 7, 9–10.** *Cyathochitina caputoi* group: **7**, 230 × 170 × 60, specimen C2084, sample K2.10; **9**, 250 × 180 × 80, specimen C2085, sample K2.10; **10**, 310 × 150 × 60, specimen C2086, sample K2.10. All measurements in μm (L × Dp × Dc). See Plate 1 for abbreviations.

Achab, 2000) and Dob's Linn, Scotland (Verniers & Vandenbroucke, 2006). The specimens from the Soom Shale Member have not been attributed to the species cited above, as they lack the bell-shaped (to hemispherical) chamber, which is typical of *Ancyrochitina ellisbayensis*. In addition, the specimens from South Africa are a little larger, and their ornamentation is slightly less well developed, although the latter may be due to their less than perfect preservation.

Ancyrochitina sp. B
(Pl. 3, figs 8–15)

Description. Small, cylindro-conical *Ancyrochitina* species with multi-branched appendices and a spiny test.

Dimensions. L: 90–113–170 µm; Dp: 60–74–120 µm; Dc: 20–30–55 µm ($n=73$).

Remarks. The species has a rather generalized appearance. Because of the imperfect preservation, it has been restricted to open nomenclature. This most probably is the same species that has been referred to *Ancyrochitina merga* by Cramer *et al.* (1974), and a specimen has also been reported by F.P. in a reprocessed sample from Cramer *et al.*'s (1974) collection, not included in Table 1. Though possibly caused by the imperfect preservation of its specimens, *Ancyrochitina* sp. B does not display the characteristic shape of *A. merga*; the latter typically has very straight flanks and a well-rounded hemispherical base. *Ancyrochitina* sp. B differs from *Ancyrochitina* sp. A in having a longer, cylindrical neck, and a narrower chamber (compared to its total vesicle length) that is more conical (or ovoidal in some cases).

Ancyrochitina sp. C
(Pl. 4, figs 1–5)

Description. *Ancyrochitina* species with a flaring neck and conical to ovoid chamber. The test bears small spines and the base bears a couple of well-developed, rather thick appendices.

Dimensions. L: 110–126–160 µm; Dp: 60–70–80 µm; Dc: 25–29–40 µm ($n=25$).

Remarks. The species is morphologically very close to *Ancyrochitina* cf. *corniculans sensu* Soufiane & Achab (2000), which has been reported from Ordovician/Silurian boundary strata of Anticosti Island, Canada (Soufiane & Achab, 2000). It has not been formally synonymized with the latter species as the imperfect preservation hampers detailed comparison of the appendices between the two species. Species of ancyrochitids are difficult to identify with certainty if the preservation of the specimens is not excellent, as is illustrated by the exclusively open nomenclature used in this study; specific distinction is often restricted to subtle differences in appendices, chamber morphology or ornament. *Ancyrochitina* sp. C has been separated from the other two *Ancyrochitina* species in this study based on its slightly larger dimensions, its conical-ovoid chamber (rather than strictly conical in sp. B) and the larger width of its appendices.

CONCLUSIONS

Despite taxonomic problems with the *Spinachitina* species, the Soom Shale fauna is interpreted as a typical '*S. oulebsiri* Biozone assemblage'. In other localities, this assemblage is known to overlie Hirnantian glaciomarine diamictites that contain the classic *elongata* fauna and to underlie unequivocal Silurian (Rhuddanian) strata with *S. fragilis* chitinozoans and *acuminatus* zone graptolites. The cited taxonomic problems are not much more than a classic 'split or lump' discussion, and this revolves around whether or not to include *S. oulebsiri* in the diagnosis of *S. fragilis*. For this study, we have chosen the pragmatic approach of maintaining the split between the two morphotypes; if, in the future, some of the Soom Shale specimens need to be renamed, this will not change the latest Hirnantian to earliest Rhuddanian age assignment we suggest here for this unit. Although we cannot attribute this fauna without doubt to either the Ordovician or the Silurian, the proposed age represents a very narrow time slice (less than 1 Ma, conservatively counting: the interval probably represents much less time) straddling the system boundary.

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