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Latest Ordovician age of the *Spinachitina fragilis* Chitinozoan Biozone in Baltoscandia

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ABSTRACT

The global *Spinachitina fragilis* Chitinozoan Biozone has been considered the lowermost Silurian zone in most publications. *S. fragilis* was first described from the Ohesaare drill core, Estonia, and utilised as a Baltic regional zonal taxon together with *Ancyrochitina laevaensis*. Despite its wide geographical occurrence, *S. fragilis* has remained poorly documented in its type region. This has created confusion in taxonomy and distribution of the species. Herein, we have restudied material from the type locality and supplementary sections in the East Baltic region. *S. fragilis* generally has a very short stratigraphic range, which, according to new data on carbon isotope chemostratigraphy, coincides with the falling limb of the Hirnantian carbon isotope excursion. This suggests the latest Hirnantian rather than the early Rhuddanian age of the *Spinachitina fragilis* Chitinozoan Biozone in Baltoscandia. Based on this view, we revise the latest Ordovician chitinozoan biozonal scheme for the region. Globally, the *S. fragilis* Biozone may span across the Ordovician–Silurian boundary.

Introduction

The identification of the base of the Silurian System is challenging in sections lacking graptolites, such as those in carbonate-dominated settings of the Baltic Palaeobasin. This is because of stratigraphic gaps and the scarcity of reliable index fossils among conodonts, ostracods, and other organisms, which were severely affected by the end-Ordovician extinction. Although chitinozoans also exhibit significantly reduced diversity in the Ordovician–Silurian boundary interval (Hints et al. 2018), they have traditionally provided some valuable reference levels. Verniers et al. (1995) established the global *Spinachitina fragilis* Chitinozoan Biozone, which has been considered the lowermost chitinozoan biozone in the Silurian, coeval with the *A. ascensus* Graptolite Biozone (Melchin et al. 2020). Many studies in previous decades have utilised this zone to identify the basal part of the Silurian in different regions (e.g., Dufka et al. 1995; Paris et al. 1995; Butcher 2009; Vandenbroucke et al. 2009; Le Hérissé et al. 2013; Ghavidel-Syooki 2022). In Baltoscandia, where *S. fragilis* was first described by Nestor (1980), the lowermost regional chitinozoan biozone in the Silurian has been the *S. fragilis–A. laevaensis* Biozone in recent compilations (Nestor 2012). However, *S. fragilis* has remained poorly illustrated and understood in the type region and elsewhere. This has created confusion and contrasting ideas regarding the taxonomy as well as the age of the *S. fragilis* Biozone and its potential to efficiently identify the base of Silurian.

The aim of this report is to review the distribution of chitinozoans in the Ohesaare drill core from western Estonia, which serves as the type section for the global *S. fragilis* Chitinozoan Biozone. We examine the topotypic specimens of *S. fragilis* and analyse the distribution of coeval chitinozoans in other East Baltic sections in order to provide insights into the taxonomic puzzle and the latest Ordovician chitinozoan biostratigraphy. The studied collection has been obtained using conventional microfossil extraction techniques (Nõlvak et al. 2022) and is deposited at the Department of Geology, Tallinn University of Technology (institutional abbreviation GIT).

Results

The Ordovician–Silurian boundary interval in the Ohesaare drill core is represented by the Saldus Formation (Fm), Porkuni Regional Stage, and the overlying Õhne Fm, Juuru Regional Stage. Conventionally, the Ordovician–Silurian boundary has been correlated with the base of the Õhne Fm and the Juuru Stage (e.g., Nestor 1994). In the lower part of the Õhne Fm, two distinct members are distinguished: the Puikule Member (Mb) of dolomitic marls and the Rūja Mb of lime mudstones, overlain by marls and marly limestones of the Rozeni Mb (Fig. 1).

The chitinozoan assemblage was studied in 47 samples from core depths of ca 437.6–449.0 m. The Saldus Fm proved to be barren of chitinozoans, but the lower Õhne Fm contained eight species, including zonal indices. The lowermost part of the Puikule Mb is characterised by the abundant occurrence of *Conochitina scabra*, marking the respective biozone. In total, more than a thousand specimens were recovered.

The first specimens of *S. fragilis* are found at a depth of 447.7 m, but the typical forms and an almost continuous range start ca 0.3 m higher and extend up to the top of the Puikule Mb at ca 446 m. That interval includes sample M-1983, from which the holotype of *S. fragilis* was derived (Fig. 1; Nestor 1980). Within the overlying Rūja Mb, the specimens of *S. fragilis* have a slightly different look, being somewhat translucent due to the thin vesicle wall. Closely similar specimens have also been observed in other Baltic sections; however, they are usually very rare. Nestor (2012, fig. 4B) has identified all these specimens as *S. fragilis*, and the name of the species also denotes 'fragile nature', referring to the thin wall and usually deformed shape. Altogether, the Ohesaare collection includes a few hundred specimens assigned to *S. fragilis*. Some examples from this collection are illustrated in Fig. 2.

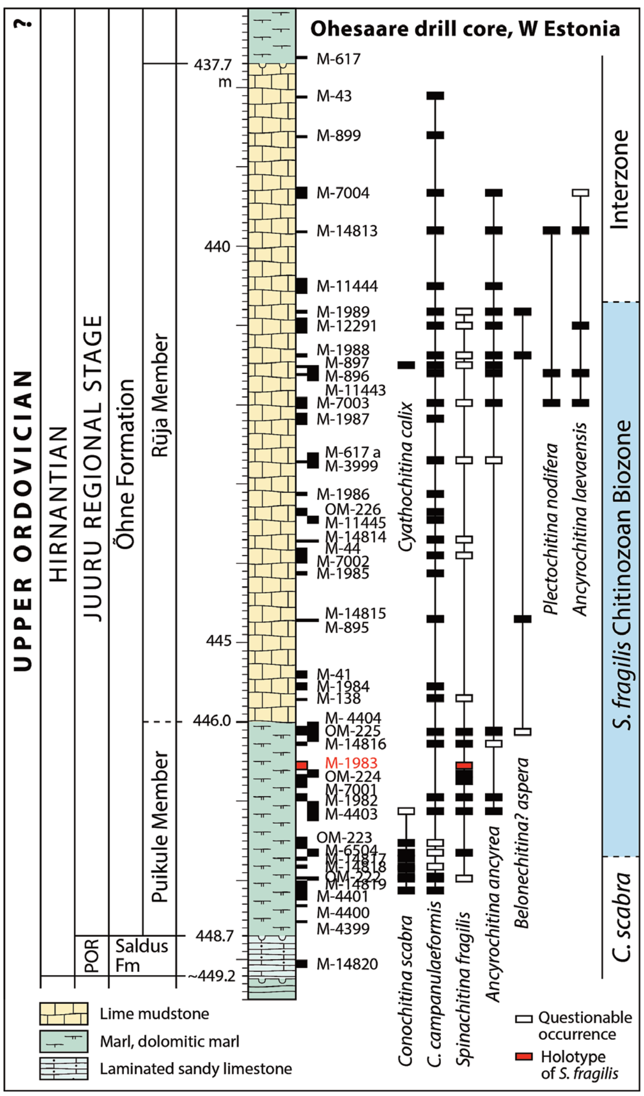

Fig. 1. Distribution of the latest Ordovician chitinozoans in the Ohesaare drill core, western Estonia. The exact position of the Ordovician–Silurian boundary remains unclear; in earlier publications, it has been drawn at the discontinuity surface at a core depth of 448.7 m, coinciding with the base of the Õhne Formation. The base of the *Spinachitina fragilis* Biozone is drawn here at a depth of 447.7 m (sample M-6504), but its top is taken at the last occurrence of *S. fragilis* in sample M-1989, following Nestor (1994, fig. 20:1). Abbreviations: POR – Porkuni Regional Stage, Roz – Rozeni Member.

The third biostratigraphically important species, *Ancyrochitina laevaensis*, was identified from the upper part of the Rūja Mb, at a depth of ca 439 to 442 m. However, it is very rare, with less than ten specimens recovered from the Ohesaare core. Additionally, *Cyathochitina campanulaeformis* and *Ancyrochitina ancyrea* are common through the Puikule and Rūja members in the Ohesaare core. In other sections, these taxa are known from older as well as younger strata and represent the survivors from the end-Ordovician extinction. Other species have been identified in a few samples only, and thus the overall diversity of the studied assemblage is low, with up to 5 species in a sample (Fig. 1).

Carbon stable isotope data from the Ohesaare drill core are currently limited, but the few bulk samples analysed from the Puikule and Rūja members show $\delta^{13}C_{carb}$ values between 2.3 and 3.5‰ below the depth of 440 m. This is on par with the falling limb of the Hirnantian carbon isotope curve (HICE) in other sections (cf. Meidla et al. 2023b).

Discussion

The distribution of *S. fragilis* in the East Baltic region is stratigraphically consistent. It occurs above or sometimes together with *C. scabra* and has a very short stratigraphic range. Usually it is found in one or a few samples closely above the base of the Õhne or Stačiūnai formations. Examples come from the Seliste, Ristiküla, Laeva-13, Taagepera, Tartu-554, Likenai and Ketrzyn IG-1 drill cores in Estonia, Lithuania and Poland. In the proximal part of the Baltic basin, for instance, in the Viki reference core, *S. fragilis* has not been recovered, probably due to a more extended stratigraphic gap. The unusually long stratigraphic range of *S.* cf. *fragilis* in the Heimtali core reported by Nestor et al. (2003) requires further analysis. *S. fragilis* and the corresponding biozone have been identified by several authors around the world; for review, see Butcher (2009), Thusu et al. (2013) and Ghavidel-Syooki (2022).

Paris et al. (2000) erected a closely similar species, *Spinachitina oulebsiri*, from the latest Ordovician of Algeria. That species was later discussed and considered synonymous with *S. fragilis* by Butcher (2009). Vandenbroucke et al. (2009), however, applied the name *S. oulebsiri* and erected another similar form – *S. verniersi* – from the Soom Shale of South Africa. The latter species is characterised by less

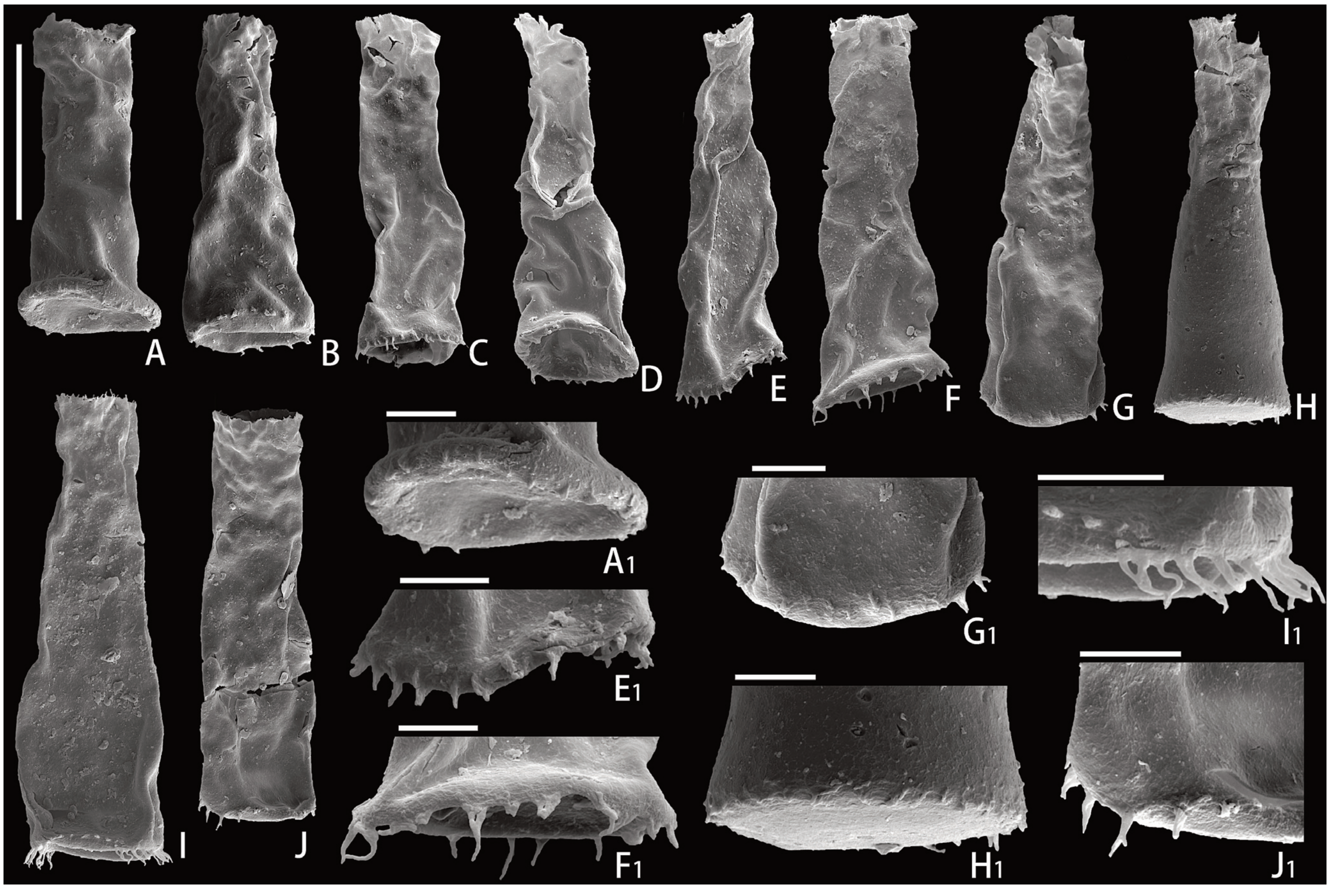

Fig. 2. SEM images of *Spinachitina fragilis*. All specimens are from the Ohesaare drill core, sample M-4403 from a core depth of 447.0–447.25 m, Õhne Formation, Puikule Member. The scale bar corresponds to 100 μm, except in detail photos where it corresponds to 20 μm. The specimens have been assigned consecutive collection numbers from GIT 891-1 to 891-10.

prominent spines, and it co-occurs with *S. oulebsiri* in several sections. Considering the range of variability of the re-examined Baltic material (Fig. 2) and the occurrence of various transitional forms, it is possible that both *S. oulebsiri* and *S. verniersi* are junior synonyms of *S. fragilis*. This would indirectly support the late Hirnantian age of the *S. fragilis* Biozone in the East Baltic region, which is otherwise indicated by carbon isotope stratigraphy (Meidla et al. 2020, 2023a, 2023b). The possibility of the Hirnantian age of the *S. fragilis* Biozone was argued by Melchin and Holmden (2006), also based on the chemostratigraphic evidence.

Additionally, Vandenbroucke et al. (2008, 408, fig. 5) reported a single specimen designated as *S. ?fragilis* near the top of the *M. persculptus* Biozone, from the historical type area of the Hirnantian in Wales. However, in the subsurface of Jordan, *S. fragilis* is dated by graptolites and appears to belong to the *ascensus*/*acuminatus* Graptolite Biozone (Butcher 2009). Thus, it seems that globally the *S. fragilis* Biozone spans the Ordovician–Silurian boundary.

In Estonia, the lowermost Silurian chitinozoan zone was the *A. laevaensis* Zone (Nestor 1994), later upgraded to the *S. fragilis–A. laevaensis* regional concurrent range biozone. A thorough discussion on *A. laevaensis* is beyond the scope of this report, but it is necessary to stress that the definition of the species is based on very limited material (Nestor 1980). It is scarce in the type locality and type region, and in case of poorly preserved material, it is difficult to distinguish it from some other taxa, including the co-occurring *A. ancyrea s.l.* These issues have been discussed, e.g., by Ghavidel-Syooki and Vecoli (2007) and Butcher (2009). Moreover, *A. laevaensis* is also closely similar to *A. ellisbayensis* (cf. Verniers and Vandenbroucke 2006, figs 4A, C), which makes its usage in high-resolution biostratigraphy further problematic.

Based on the restudied material, we propose the following revision of the Baltic regional biostratigraphic scheme:

Conochitina scabra **Biozone** is defined as a partial range zone from the first appearance (FAD) of the nominal species to the FAD of *S. fragilis*. When the latter species is not present, the top of the zone can be approximated with the last appearance (LAD) of *C. scabra*.

Spinachitina fragilis **Biozone** is defined as a range zone based on the nominal species. We suggest abandoning the usage of *A. laevaensis* as a nominal index species due to its scarcity and taxonomically problematic nature; however, if present, it may be used as an additional criterion for distinguishing the regional *S. fragilis* Biozone.

The interval above the *S. fragilis* Biozone was designated as an interzone by Nestor (2012) to represent the strata between the LAD of *S. fragilis* and the FAD of *Belonechitina postrobusta*. This interval is not entirely barren of chitinozoans, but is characterised by low abundance and the lack of suitable index taxa. In the global biozonal scheme (Verniers et al. 1995), the top of the *S. fragilis* Biozone is defined by the FAD of *B. postrobusta*, the nominal taxon of the overlying biozone. However, here we prefer to retain the 'interzone' in the regional scheme in order to keep the LAD of

S. fragilis as a formal marker horizon. The Ordovician–Silurian boundary most likely falls into this interval in the East Baltic region. The innovations among most groups of acid-resistant microfauna, including the first chitinozoans with Silurian affinity, appear in this area in Rhuddanian–Aeronian boundary beds near the base of the *Spinachitina maennili* Biozone (Männik et al. 2015).

Conclusions

The restudy of chitinozoans from the Ohesaare drill core and complementary sections from southern Estonia showed that *Spinachitina fragilis* is most likely of late Hirnantian age, corresponding at least partly to the *M. persculptus* Graptolite Biozone. This allowed revision of the chitinozoan biozonation in the Ordovician–Silurian boundary interval and has implications for global correlations. The *S. fragilis* Biozone appears to be a valuable correlation tool for the latest Ordovician strata in Baltoscandia. Further studies are necessary to identify the *B. postrobusta* Biozone and apply a high-resolution carbon isotope chemostratigraphy in the Ohesaare reference drill core to find criteria for delineating the base of the Silurian System in the East Baltic region.

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