Estonian Journal of Earth Sciences, 2012, **61**, 4, 242–260 doi: 10.3176/earth.2012.4.05

A summary and revision of the East Baltic Silurian chitinozoan biozonation

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Received 31 January 2012, accepted 5 September 2012

Abstract. The biostratigraphical data on the East Baltic Silurian chitinozoans are summarized. Based on the study of nine East Baltic drill cores, 28 regional chitinozoan zonal units, including 26 biozones and 2 interzones, are briefly characterized. In comparison with earlier publications, the Silurian chitinozoan biozonation chart is essentially updated, some biozonal units are added, some renamed and several previous subdivisions have been abolished or replaced. The ranges of the stratigraphically most important chitinozoan species throughout the East Baltic Silurian are discussed. Regional chitinozoan biozones are correlated with the global chitinozoan biozones and graptolite biozones, as well as with the regional stratigraphical units of Estonia, Latvia and the Kaliningrad district.

Key words: Silurian, East Baltic, chitinozoans, biozonation, graptolites, correlation.

INTRODUCTION

The first records of Silurian chitinozoans in Estonia were presented by Eisenack (1970) and Männil (1970). Continuous study by the present author of East Baltic Silurian chitinozoans from more than 50 outcrops and drill cores has already lasted for 35 years (Nestor 1976–2011). Biostratigraphical investigations, based on successions of chitinozoan taxa, began with the Llandovery (Nestor 1976, 1984b) and Wenlock strata (Nestor 1982, 1984a). In collaboration with other palaeontologists, some joint works concerning the ecostratigraphy of different fossil groups were published under the guidance of D. Kaljo (Kaljo et al. 1983, 1986, 1995). The first review of the entire Silurian chitinozoan biozonation with 31 zonal units and stratigraphical ranges of 60 species was given in a geological excursion guidebook (Nestor 1990), including also the preliminary correlation of chitinozoan biozones with the regional graptolite zonation (data from Ulst in Gailite et al. 1987 and Kaljo 1970). Joint studies with P. Männik (conodonts) and D. Loydell (graptolites) of the same East Baltic core sections, Aizpute (Loydell et al. 2003), Ventspils D-3 (Loydell & Nestor 2005) and Kolka-54 (Loydell et al. 2010), enabled more precise correlation of the biozones of these fossil groups in the lower Silurian. Graptolites from the lower Ludlow in the Ventspils and Pavilosta cores (Ulst in Gailite et al. 1987) helped to correlate the corresponding chitinozoan biozones with the graptolite biozonation (Nestor 2007). As graptolites are missing in the studied East Baltic Přídolí sections, correlation of the graptolite and chitinozoan biozones in this series is rather approximate.

The aims of this paper are to revise and summarize all existing biostratigraphical data on the East Baltic Silurian chitinozoans. A more precise correlation of chitinozoan and graptolite biozones (according to Loydell et al. 2003, 2010), as well as of regional and global chitinozoan biozones (Verniers et al. 1995), is presented. In addition, the ranges of the stratigraphically most important chitinozoan species throughout the East Baltic Silurian are displayed.

BIOZONATION

The distribution of chitinozoans in the Llandovery and Wenlock beds of the East Baltic drill cores has been treated in many papers (e.g. Nestor 1994), but the exact correlation between the chitinozoan and graptolite biozones is still partly obscure. Collaboration with D. K. Loydell in the study of some East Baltic drill cores (Aizpute, Ventspils, Kolka) has considerably contributed to integration of these biozones (Loydell et al. 2003, 2010; Loydell & Nestor 2005). The present paper deals with the distribution of chitinozoan species in the Kaugatuma, Ruhnu, Ohesaare, Kolka-54, Ventspils D-3, Aizpute-41, Pavilosta, Northern Gusevskaya 1 (Gussev-1, Llandovery–Wenlock) and Dubovskoye (Northern Gusevskaya 2, Ludlow–Přídolí) drill cores (Fig. 1), represented mostly by carbonate and carbonate-argillaceous shelf deposits. Some differences may occur between

Fig. 1. Location of the studied drill cores.

shallow and deep shelf chitinozoan associations, expressed by the presence or absence of certain species. The succession of Lower Silurian biozones, described formerly in the Ohesaare core (Nestor 1994), is somewhat changed here, as many new samples from several drill cores have been studied subsequently. The aim was not to increase the stratigraphical resolution of biozonation (e.g. by use of subzones), but to find out the best taxa for marking the zonal boundaries over a wider area and across facies belts.

Description of the East Baltic Silurian chitinozoan biozones is kept in general as brief as possible with references to the earlier publications. Most attention is paid to the appearing species. Only the distribution of Rhuddanian chitinozoans is discussed more thoroughly, giving an account of the species' occurrences in other regions too (see below). Like the global biozones of Verniers et al. (1995), almost all of the East Baltic chitinozoan biozones are interval zones, the lower boundaries of which are marked by the FAD of the index species. In addition, two interzones are separated, corresponding to the beds, barren of or poor in chitinozoans. Their lower boundaries are good stratigraphical markers, characterized by the LAD of the zonal species of the underlying biozones. The ranges of the stratigraphically most important chitinozoan species in the Silurian and the correlation of global and regional chitinozoan biozones are presented in Fig. 2. Correlation of the East Baltic chitinozoan biozones with graptolite biozones, Silurian stage slices (after Cramer et al. 2011), and the regional stratigraphical subdivisions of Estonia, Latvia and the Kaliningrad district (Přídolí) are shown in Fig. 3.

Llandovery

The Ordovician–Silurian boundary is lithologically well defined in all East Baltic sections studied due to marked sea level changes through the boundary interval (H. Nestor & Einasto 1997). At the end of the Ordovician the Baltic basin was subjected to a considerable regression that caused a hiatus over a wide area. The Silurian began with a glacio-eustatic rise of the sea level and deposition of pure lime muds in the central and southern East Baltic, replaced by calcareous-argillaceous muds in South Estonia and North Latvia (Õhne Formation). Still, Hints et al. (2010) showed that the hiatus might embrace also earlier parts of the Llandovery. This is in agreement with chitinozoan data referred to by Kaljo et al. (2008) – absence in the Baltic of *Ancyrochitina ellisbayensis* Soufiane & Achab, occurring elsewhere in the O/S boundary beds. It means that our oldest Silurian chitinozoan biozone could be correlated with the most part of the *Akidograptus ascensus* Biozone (see below).

The Spinachitina fragilis–Ancyrochitina laevaensis *Biozone*

The *Spinachitina fragilis–Ancyrochitina laevaensis* concurrent-range chitinozoan Biozone was erected in the lowermost Llandovery in the Juuru Regional Stage in the Ohesaare drill core (438–447.70 m, Nestor 1994). The boundary assemblage includes *Ancyrochitina laevaensis* Nestor (Fig. 4A), *Spinachitina fragilis* (Nestor) (Fig. 4B), *Plectochitina nodifera* (Nestor), *Belonechitina aspera* (Nestor), *Belonechitina postrobusta* (Nestor) and *Cyathochitina campanulaeformis* (Eisenack) (Nestor 1994). The ranges of the last three species extend beyond the limits of the biozone. Verniers et al. (1995) selected the name *Spinachitina fragilis* Biozone for the lowermost Silurian global biozone, as this species has been found more widely in other sections around the world: Bohemia (Dufka et al. 1995), Saudi Arabia (Paris et al. 1995), Mauritania (Paris et al. 1998), southern and northeastern Iran (Ghavidel-Syooki 2000; Ghavidel-Syooki & Vecoli 2007), Jordan (Butcher 2009), Illinois, USA (Butcher at al. 2010). The FAD of *Plectochitina nodifera* is stated to mark the Ordovician–Silurian boundary in the Yangtze region, China (Geng et al. 1997) and on Anticosti, Québec (Soufiane &

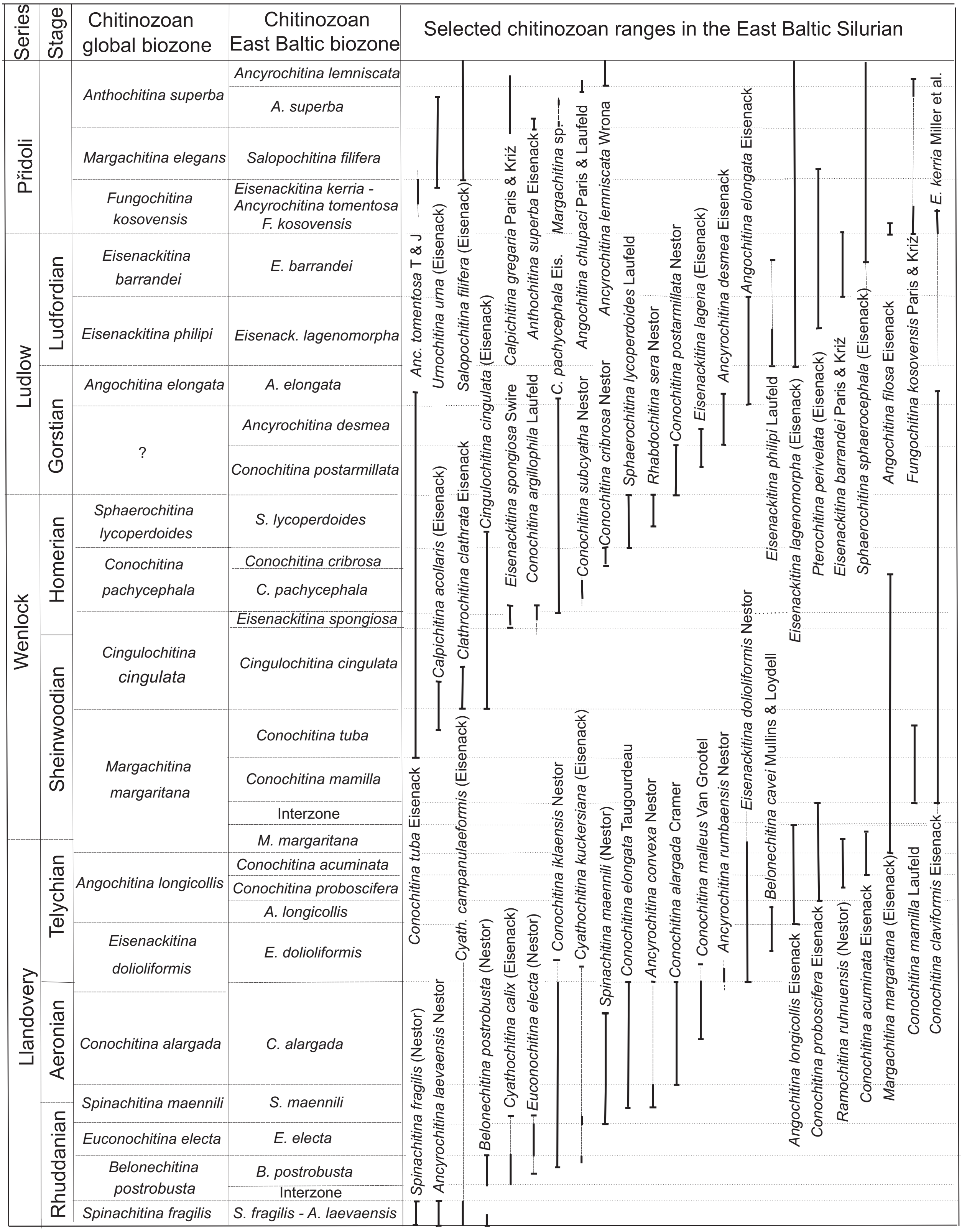


Fig. 2. The ranges of the stratigraphically most important chitinozoan species in the East Baltic Silurian and correlation of the global (Verniers et al. 1995) and regional chitinozoan biozones. Thin lines of the ranges indicate problematic identifications or scattered presence of a taxon.

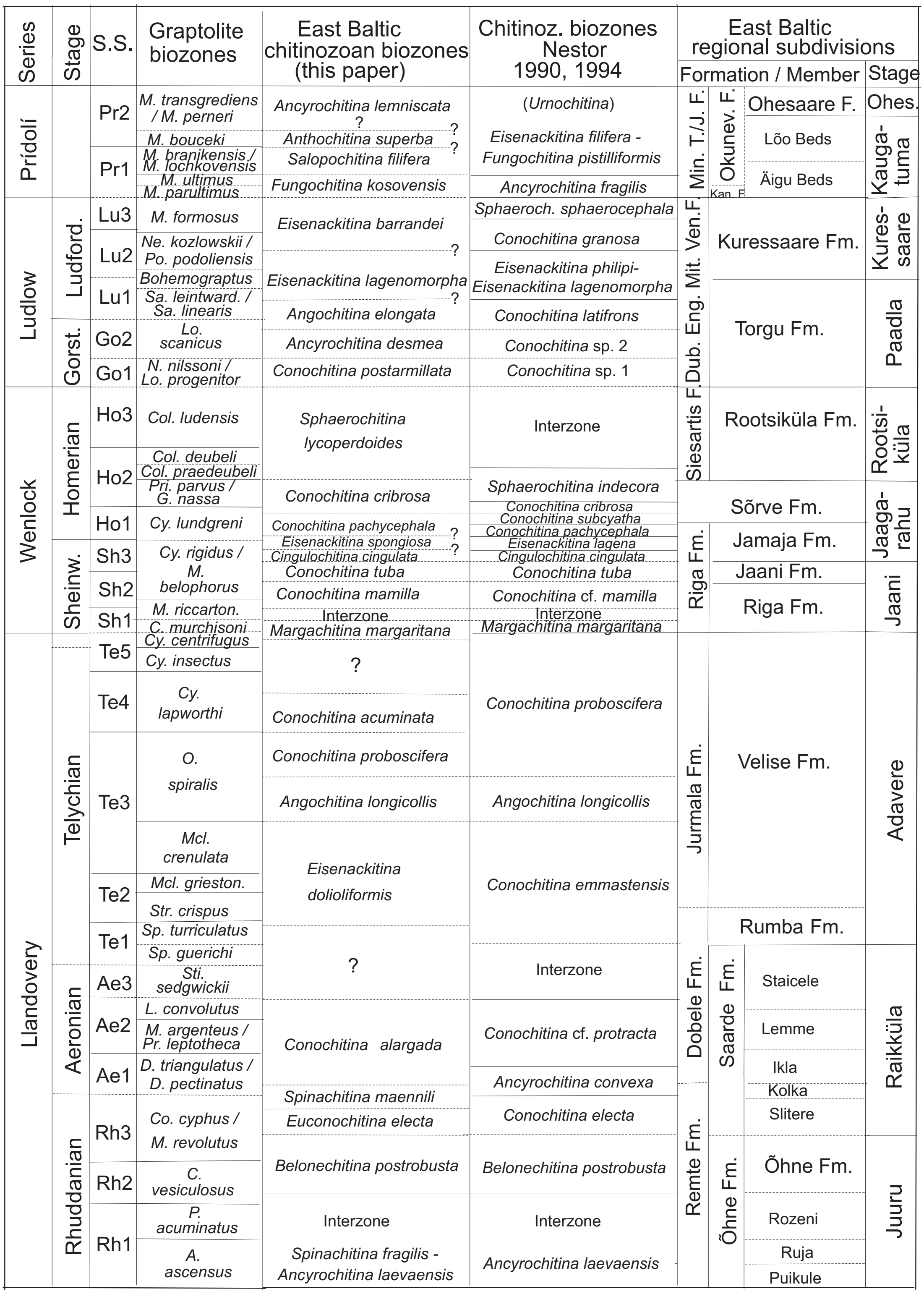


Fig. 3. Correlation of the East Baltic chitinozoan biozones with the global graptolite biozones and Silurian stage slices (S.S.) (after Cramer et al. 2011), as well as regional stratigraphical subdivisions of Estonia (after H. Nestor 1997), Latvia (after Gailite et al. 1987) and Kaliningrad district (Pridoli) (after Koren et al. 2009). Abbreviations: Dub., Dubysa; Eng., Engure; Mit., Mituva; Ven., Ventspils; Min., Minija; T., Targale; J., Jura; Kan., Kandievski; Okunev., Okunevski; Ohes., Ohesaare; Fm., F., Formation.

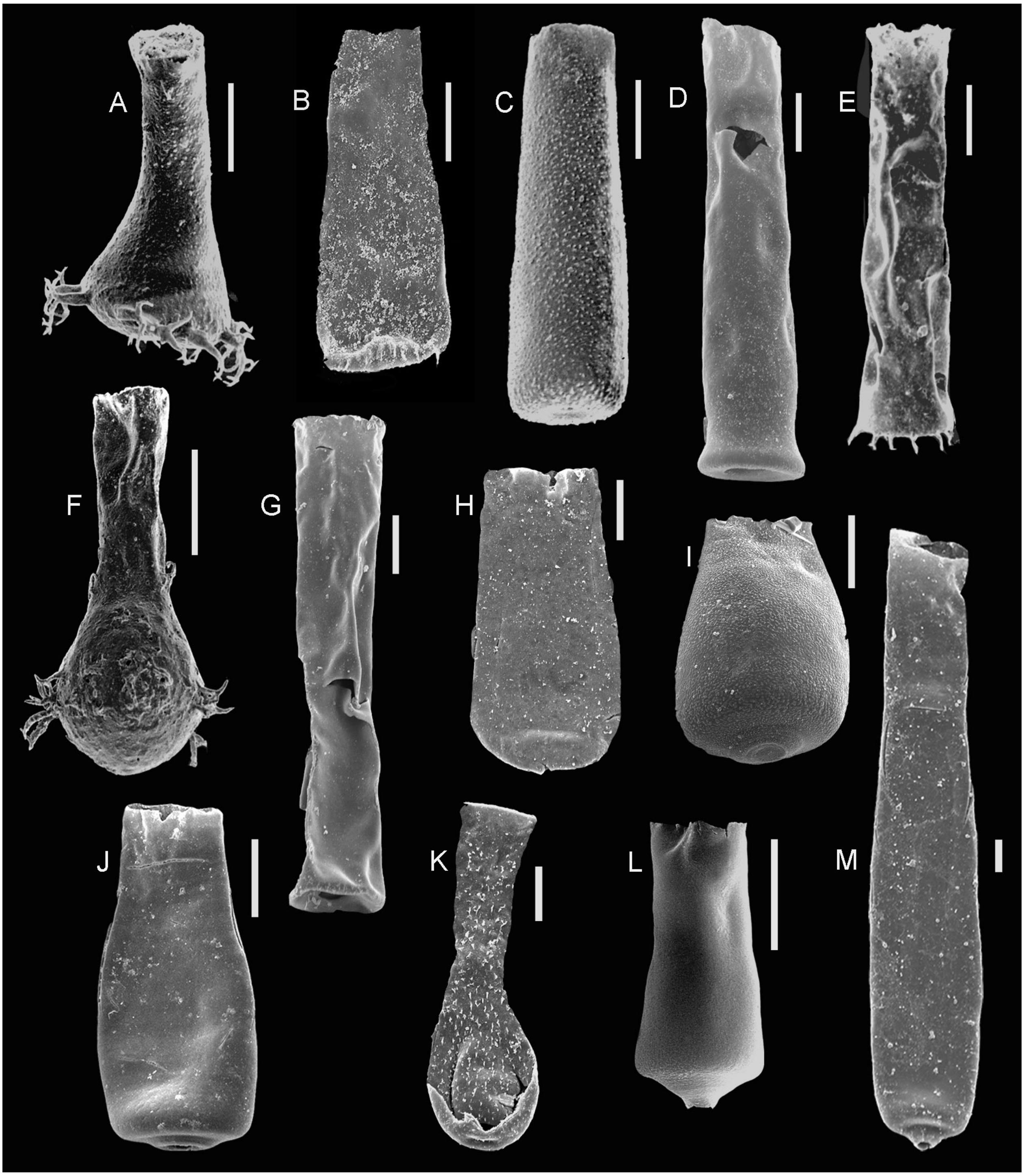


Fig. 4. Chitinozoan biozonal species in the Llandovery of the East Baltic drill cores. Scale 50 µm. **A**, *Ancyrochitina laevaensis* Nestor, GIT 212-1 (HT), Laeva-10 core, depth 122.5 m, Juuru Stage. **B**, *Spinachitina fragilis* (Nestor), GIT 546-3, Kolka-54 core, depth 660.50–661.0 m, Juuru Stge. **C**, *Belonechitina postrobusta* (Nestor), GIT 212-10 (HT), Ikla core, depth 515.70 m, Juuru Stage. **D**, *Euconochitina electa* (Nestor), GIT 546-6, Kolka-54 core, depth 643.0–643.30 m, Raikküla Stage. **E**, *Spinachitina maennili* (Nestor), GIT 213-3 (HT), Ikla core, depth 462.90 m, Raikküla Stage. **F**, *Ancyrochitina convexa* Nestor, GIT 213-1 (HT), Ruhnu core, depth 536.0 m, Raikküla Stage. **G**, *Conochitina alargada* Cramer, GIT 546-11, Kolka-54 core, depth 618.10–618.50 m, Raikküla Stage. **H**, *Conochitina malleus* Van Grootel (*nomen nudum*), GIT 546-18, Kolka-54 core, depth 614.60–614.65 m, Raikküla Stage. **I**, *Eisenackitina dolioliformis* Umnova, GIT 4272-2, Kaugatuma core, depth 246.45–246.55 m, Adavere Stage. **J**, *Conochitina emmastensis* Nestor, GIT 423-17, Ventspils D-3 core, depth 815 m, Adavere Stage. **K**, *Angochitina longicollis* Eisenack, GIT 546-33, Kolka-54 core, depth 584.90–585.20 m, Adavere Stage. **L**, *Conochitina acuminata* Eisenack, GIT 272-62, Ohesaare core, depth 349.40 m, Adavere Stage. **M**, *Conochitina proboscifera* Eisenack, GIT 546-44, Kolka-54 core, depth 581.90–582.20 m, Adavere Stage.

Achab 2000). *Ancyrochitina laevaensis* was established as an index species at the base of the Silurian in northeast Libya (Paris 1988) and in the Oslo region (Nestor 1999). *Ancyrochitina laevaensis* was also found in the Ordovician–Silurian boundary stratotype section of Dob's Linn, about 0.50 m above the Silurian boundary (Verniers & Vandenbroucke 2006). It is worth mentioning that their sample weights were there mostly between 10 and 15 g, which is clearly too little to obtain all of the species contained in the rock.

The type section for this biozone is the Ohesaare core (Nestor 1994, fig. 20), where all species of the biozonal assemblage appear at the base of the Rhuddanian, in the interval 446.90–447.70 m. In the other East Baltic sections the presence and appearance of taxa above the base of the Silurian boundary vary. In the Ventspils, Kolka and Ruhnu cores the first samples above the boundary yielded *Spinachitina fragilis* and *Belonechitina postrobusta*. In the Kolka core, about a metre higher, in the second sample also *Ancyrochitina laevaensis* and *Plectochitina nodifera* were identified. *Spinachitina fragilis* was not found in the Viki (Nestor 2010) and Kaugatuma cores, but *A. laevaensis* and *P. nodifera* occurred about a metre above the boundary. In the Gussev-1 drill section about 6.70 m of the core is missing at the O/S boundary, but after the gap *P. nodifera* was identified in the first sample. The basal Silurian samples of the Pavilosta core are barren of chitinozoans.

Thus, the chitinozoan assemblage in the lowermost Llandovery of the East Baltic is quite variable. Elsewhere this variability has increased with the description of the new species *Spinachitina oulebsiri* (Paris et al. 2000) from the NE Algerian Sahara and *Spinachitina verniersi* (Vandenbroucke et al. 2009) from South Africa, both of which cross the Ordovician–Silurian boundary. Biostratigraphical correlation and the chitinozoan biozones of the lower Llandovery were thoroughly discussed by Butcher (2009), who established all species of the biozonal assemblage in drill cores from Jordan.

In some sections the *S. fragilis* Biozone is well integrated with the graptolite biozonation. For example, in Jordan (Butcher 2009) *S. fragilis* occurs in the upper part of the *Akidograptus ascensus–Parakidograptus acuminatus* graptolite Biozone. In the Dob's Linn stratotype section *A. laevaensis*, *S. fragilis* and *P. nodifera* were established in the lower part of the *A. ascensus* graptolite Biozone (Verniers & Vandenbroucke 2006).

The Belonechitina postrobusta *Biozone and underlying interzone*

An interzone, corresponding to beds either barren (Ruhnu, Kolka, Ventspils, Pavilosta, Gussev-1) or poor (Kaugatuma, Ohesaare) in chitinozoans was distinguished above the *S. fragilis* Biozone (Figs 2, 3). These barren beds are represented mostly by redbeds. The *B. postrobusta* Biozone has not been established above the redbeds in the southernmost East Baltic cores (Kolka, Ventspils, Pavilosta, Gussev-1). In the Ohesaare core an approximately 19 m thick chitinozoan-poor interval contains mainly *Cyathochitina campanulaeformis* and *Ancyrochitina ancyrea* (Eisenack). It is succeeded by the (re)appearance of *Belonechitina postrobusta* (Fig. 4C) and *B. aspera*. In the upper part of the interzone an interval of about 5–7 m with *Cyathochitina calix* (Eisenack) occurred in the Ohesaare and Kaugatuma cores.

Butcher (2009) defined the *B. postrobusta* Biozone as a local abundance biozone in Jordan. In the Ohesaare and Kaugatuma drill cores very rare specimens of *B. postrobusta* appear at the beginning of its range, but in the upper layers this species occurs abundantly. However, in the other studied cores the abundance of the species may be moderate throughout its range. Thus, according to the East Baltic material, the use of the abundance biozone name for this subdivision is questionable and it would be better to call it a partial-range biozone. If the interzone is lacking, the lower boundary of the biozone is defined by the LAD of *Spinachitina fragilis* (see H. Nestor et al. 2003). The upper boundary of the *B. postrobusta* Biozone is marked by the LAD of the eponymous species.

Cyathochitina calix is numerous in the lower part of the *B. postrobusta* Biozone and *Cyathochitina kuckersiana* (Eisenack) in its upper part. The last specimens of *Belonechitina aspera* and the first *Ancyrochitina bifurcaspina* Nestor, *Conochitina iklaensis* Nestor and *Euconochitina electa* (Nestor) may occur in this biozone, as well as the stratigraphically long-ranging *Cyathochitina campanulaeformis* and *Ancyrochitina ancyrea*.

Belonechitina postrobusta is widely distributed around the world: Brabant Massif, Belgium (Martin 1973), northeast Libya (Hill et al. 1985; Paris 1988), southern Ohio and northern Kentucky, USA (Grahn 1985), southern Sweden (Grahn 1978, 1998), Yangtze region, China (Geng & Cai 1988; Geng et al. 1997), Quebec, Canada (Asselin et al. 1989; Soufiane & Achab 2000), Bohemia, Prague Basin (Dufka 1992; Dufka & Fatka 1993; Dufka et al. 1995), Saudi Arabia (Paris et al. 1995), subsurface of Gotland (Grahn 1995), Mauritania (Paris et al. 1998), Oslo region (Nestor 1999), southern and northeastern Iran (Ghavidel-Syooki 2000; Ghavidel-Syooki & Vecoli 2007), Dob's Linn, Scotland (Verniers & Vandenbroucke 2006), Jordan (Butcher 2009).

Kaljo et al. (1984) recognized the *Dimorphograptus confertus* graptolite Biozone in East Baltic drill cores at the level from which *B. postrobusta* was recorded. This *confertus* Biozone was originally correlated with the middle Rhuddanian *Cystograptus vesiculosus* Biozone, but Loydell et al. (2003) noted that the stratigraphical range of *D. confertus* extends into the succeeding *Coronograptus cyphus* graptolite Biozone. Elsewhere (e.g. Jordan, Butcher 2009) the *B. postrobusta* chitinozoan assemblage has been shown to occur in the *Cystograptus vesiculosus* graptolite Biozone, but the upper part of the *B. postrobusta* Biozone may extend into the upper Rhuddanian *Coronograptus cyphus* graptolite Biozone.

The Euconochitina electa *Biozone*

This partial-range and abundance biozone was defined as a global biozone by Verniers et al. (1995). The stratigraphical range of *E. electa* (Nestor) (Fig. 4D) partly overlaps that of *B. postrobusta* in most of the studied sections, except for the southernmost drill cores, where *B. postrobusta* is absent. The base is defined by the LAD of *B. postrobusta* and the abundant appearance of *E. electa* in the Ohesaare core at 410.10 m, marked also by the hardground between the Juuru and Raikküla regional stages. This biozone is perfectly represented in all East Baltic sections (Nestor 1994, 1998), but suprisingly it is lacking in subsurface sections of Gotland (Grahn 1995) and on the mainland of Sweden (Grahn 1998). Four barren samples were encountered in the Grötlingbo 1 drill core between the occurrences of *B. postrobusta* and *Spinachitina maennili* (Nestor) (V. Nestor, unpublished data). This interval possibly corresponds to the *E. electa* Biozone. *Euconochitina electa* is also found in southern Ohio, USA (Grahn 1985), the Yangtze region of China (Geng et al. 1997), in the Oslo region (Nestor 1999) and on Anticosti Island, Canada (Soufiane & Achab 2000).

The *E. electa* Biozone is one of the best-studied chitinozoan biozones in the East Baltic Silurian where some environmental control on species distribution has been observed (Nestor 1998). This concerns the occurrence of the accompanying species, especially the different species of *Cyathochitina*. Besides *Cyathochitina*, *Conochitina iklaensis* Nestor, *Ancyrochitina bifurcaspina* Nestor and rare *Clathrochitina* sp. may occur in this biozone. Previously, the stratigraphical extent of the *E. electa* Biozone was greater (Nestor 1994, 1998; H. Nestor et al. 2003), as the lowermost part of the range of *Spinachitina maennili* was not regarded as a separate *S. maennili* Biozone but as the upper part of the *E. electa* Biozone.

The thickness of the *E. electa* Biozone varies considerably in different sections, from a few metres in the Ventspils core up to 26 m in the Viki core. This biozone is missing in the southernmost drill cores (Pavilosta, Gussev-1) or is so thin (1–1.5 m) that it remains between the studied samples.

According to Loydell et al. (2003), the *E. electa* Biozone corresponds to the middle–upper part of the *Coronograptus cyphus* graptolite Biozone.

The Spinachitina maennili *Biozone*

This global interval biozone was first defined by Verniers et al. (1995) as the interval between the FAD of the biozonal species and the FAD of *Conochitina alargada*. In the East Baltic *Spinachitina maennili* (Nestor) (Fig. 4E) occurs only in the deeper parts of the basin, in south-westernmost sections (Ventspils, Ohesaare, Kolka, Ruhnu). It is missing in the eastern- and northernmost cores, in strata representing more shallow shelf sediments (Nestor 1998), partly due to a subregional hiatus. *Spinachitina maennili* is rather widely distributed: southern Ohio, USA (Grahn 1985), Brabant Massif, Belgium (G. Van Grootel, unpublished data), subsurface of Gotland (Grahn 1995), Saudi Arabia (Paris et al. 1995), southern Baltic Sea (Samuelsson et al. 2001), Girvan area, Scotland (Vandenbroucke et al. 2003).

In the East Baltic sections almost all accompanying species occur also in the underlying *E. electa* Biozone, only *Ancyrochitina ramosaspina* Nestor has its FAD. Abundant *Cyathochitina kuckersiana* and the LAD of *E. electa* occur in the uppermost part of the *S. maennili* Biozone. The *A. ramosaspina* total range Biozone has been regarded as a separate biozone above the *E. electa* Biozone in Anticosti (Soufiane & Achab 2000) and above the range of *A. bifurcaspina* in sections in northeastern Iran (Ghavidel-Syooki & Vecoli 2007).

In the East Baltic drill cores the *Ancyrochitina convexa* Biozone was established below the *Conochitina alargada* Biozone (Nestor 1994; Nestor et al. 2003; Loydell et al. 2003). However, the former contains rather few specimens and in some sections *Conochitina elongata* Taugourdeau appears below *Ancyrochitina convexa* Nestor (Fig. 4F) (Kolka, Loydell et al. 2010). Anyway, the *A. convexa* Biozone is quite thin and in some sections *A. convexa*, as well as *C. elongata* and *Conochitina edjelensis*, appear together with *C. alargada* (Kaugatuma, Ventspils). Sometimes all of these species are absent (Pavilosta, Gussev-1), which does not enable differentiation of the *C. alargada* Biozone. The *A. convexa* Biozone is not shown on the chitinozoan range chart (Fig. 2), but corresponds to the uppermost part of the *S. maennili* Biozone.

The *S. maennili* Biozone corresponds to the uppermost part of the *Coronograptus cyphus* and the lower part of the *Demirastrites triangulatus* graptolite biozones (Loydell et al. 2003).

The Conochitina alargada *Biozone*

The index species of this interval biozone was first described as subspecies, *Conochitina edjelensis alargada* Cramer 1967, from the Aeronian Stage in Leon, Spain. Nestor (1994) treated *Conochitina edjelensis* Taugourdeau 1963 (*s.l.*), including *C. alargada* (Fig. 4G), as a complex of co-occurring variable forms. According to Cramer (1967), all (sub)species of the 'edjelensis complex' occur together, yet, this is only partly true. *Conochitina edjelensis* and *C. elongata* appear usually simultaneously (Põltsamaa, Ikla, Kolka), in some drill cores also with *C. alargada* (Ruhnu, Ventspils), but more often *C. alargada* appears 2–10 m higher (Viki, Ohesaare, Kolka). Besides the above-named species, *Conochitina iklaensis* and *S. maennili* are numerous in this biozone and the latter species has its LAD there. The global *C. alargada* Biozone was defined by Verniers et al. (1995) as an interval from the FAD of *C. alargada* up to the FAD of *Eisenackitina dolioliformis* Umnova. In some East Baltic drill cores the *Conochitina malleus* Biozone has been established between the *C. alargada* and *E. dolioliformis* biozones (H. Nestor et al. 2003), but usually it is regarded as the upper part of the *C. alargada* Biozone (Loydell et al. 2003, 2010). *Conochitina malleus* Van Grootel *nomen nudum* (Fig. 4H) was described in his unpublished Ph.D. thesis, from the Llandovery of the Brabant Massif and was first used as a biozonal species in Bohemia (zone C in Dufka 1992).

Conochitina alargada is widely distributed in Middle Llandovery sections on different palaeoplates (see Verniers et al. 1995). In the Aizpute and Kolka cores the *C. alargada* Biozone corresponds to the upper part of the *Demirastrites triangulatus* graptolite Biozone through to the top of the *Lituigraptus convolutus* graptolite Biozone (Loydell et al. 2003, 2010).

A barren interval in the Aizpute core occurs in the upper part of the *C. alargada* Biozone. This interval is correlated with *Stimulograptus sedgwickii*, *Sti. halli*, *Spirograptus guerichi* and the lower part of the *Spirograptus turriculatus* graptolite biozones (Loydell et al. 2003) and with the stratigraphical gap in the Kolka (Loydell et al. 2010), Viki (Nestor 2010) and Kaugatuma cores (unpublished data by V. Nestor).

The Eisenackitina dolioliformis *Biozone*

This global interval biozone was first described as the *Conochitina emmastensis* Biozone (Nestor 1994), but was later changed to the *Eisenackitina dolioliformis* global Biozone (Verniers et al. 1995). In the East Baltic drill cores both species appear at almost the same level (Nestor 1984b, 1994; Loydell et al. 2010). *Eisenackitina dolioliformis* (Fig. 4I) was first described by Umnova (1976) from the Virtsu core of western Estonia. *Ancyrochitina rumbaensis* Nestor, *Belonechitina oeselensis* Nestor, *B. cavei* Mullins & Loydell, *Conochitina emmastensis* Nestor (Fig. 4J), *C. leviscapulae* Mullins & Loydell, *C. leptosoma* Laufeld, *Calpichitina densa* (Eisenack), *Eisenackitina causiata* Verniers, '*Vitreachitina*' sp. and some other taxa appear in this biozone.

The *E. dolioliformis* Biozone has been established on several palaeocontinental plates (Verniers et al. 1995). It is described in detail from the Banwy River section in Wales (Mullins & Loydell 2001). In some Estonian sections (Ohesaare, Ruhnu) a stratigraphical hiatus has been recorded at this level.

The *E. dolioliformis* Biozone correlates with the upper *Spirograptus turriculatus* through to *Monoclimacis crenulata* graptolite biozones in the East Baltic (Loydell et al. 2003, 2010), but extends to a stratigraphically higher level, within the overlying *Oktavites spiralis* Biozone, in the Banwy River section, Wales (Mullins & Loydell 2001).

The Angochitina longicollis *Biozone*

Angochitina longicollis Eisenack (Fig. 4K) is very widely distributed geographically (Verniers et al. 1995). In the East Baltic drill cores this global interval biozone contains mostly the same accompanying species as the underlying *Eisenackitina dolioliformis* Biozone. In some drill cores *Belonechitina meifodensis* Mullins & Loydell and *Conochitina praeproboscifera* Nestor appear at this level. This biozone is lacking in the Gussev-1 and Kaugatuma cores, where *A. longicollis* and *Conochitina proboscifera* Eisenack appear together, probably because of a stratigraphical gap. In the Ruhnu core this biozone is quite thin.

Graptolites have been identified from the same biozone in the Aizpute (Loydell et al. 2003), Ventspils D-3 (Loydell & Nestor 2005) and Kolka (Loydell et al. 2010) cores. In all three cores the *A. longicollis* Biozone has been correlated with the lower part of the *Oktavites spiralis* graptolite Biozone.

The Conochitina proboscifera *Biozone*

The index species (Fig. 4M) of this interval biozone was described by Eisenack (1937), and was later found also in the Adavere and Jaani stages in Estonia (Eisenack 1971). This regional biozone is easily identified in all East Baltic drill cores because of the appearance and abundant occurrence of the index species, which also dominates assemblages from the three succeeding chitinozoan biozones. Only a few new species appear in the biozone: *Ramochitina ruhnuensis* Nestor, *Ancyrochitina porrectaspina* Nestor, *A. ansarviensis* Laufeld, *A. vikiensis*

Nestor. According to Verniers et al. (1995), this regional biozone corresponds to the upper part of the *A. longicollis* global Biozone.

Graptolites in the *C. proboscifera* Biozone have been studied from the Aizpute, Ventspils D-3 and Kolka drill cores, correlating in all sections with the upper part of the *Oktavites spiralis* Biozone.

The Conochitina acuminata *Biozone*

This interval biozone was first distinguished in the Banwy River section, Wales (Mullins & Loydell 2001). The range of *C. acuminata* Eisenack (1959) (Fig. 4L) as a characteristic chitinozoan species between the *A. longicollis* and the *Margachitina margaritana* biozones had been demonstrated already by Verniers et al. (1995). The *C. acuminata* Biozone has not been recognized in the deepest-water East Baltic sections (Pavilosta, Aizpute, Gussev-1), but has been easily identified in other drill cores (Nestor 2005; Loydell at al. 2010).

Conochitina flamma Laufeld, *Plectochitina pachyderma* Laufeld, *Anthochitina primula* Nestor, *Ramochitina nestorae* Grahn, *Bursachitina nana* (Nestor) and *Ancyrochitina mullinsi* Nestor appear in this biozone, although the occurrence of these species is rather sporadic. According to Nestor (2005), *C. acuminata* disappears very close to the Llandovery–Wenlock boundary or coincides with it.

In the Banwy River section the *C. acuminata* Biozone is correlated with the lower part of the *Cyrtograptus lapworthi* Biozone up to the upper part of this biozone at which level lies the base of the *Margachitina banwyensis* Biozone. In the Kolka core (Loydell et al. 2010) biozonal graptolites are missing above the lower part of the *C. lapworthi* Biozone, the base of which corresponds to that of the *C. acuminata* Biozone.

Wenlock

The Margachitina margaritana *Biozone and overlying interzone*

The lower boundary of this global interval biozone is defined by the FAD of *Margachitina margaritana* (Eisenack) (Fig. 5A). In Verniers et al. (1995) it marks the lower boundary of the Wenlock Series, but later investigations have demonstrated that the biozonal boundary is in the uppermost Llandovery (Mullins & Loydell 2001; Mullins & Aldridge 2004; Nestor 2005). Below the range of *M. margaritana* in the Banwy River section, Mullins & Loydell (2001) established the *Margachitina banwyensis* Biozone. In the East Baltic the *M. banwyensis* Biozone is well identified only in the Ohesaare core (Nestor 2005). The other sections contain only a few specimens of *M. banwyensis* Mullins & Loydell 2001 and it appears together with *M. margaritana* or only a metre below it. *Calpichitina opaca* (Laufeld), *Ancyrochitina digitata* Mullins & Aldridge and *Conochitina* aff. *tuba* Eisenack appear in the *M. margaritana* Biozone. Mullins & Loydell (2001) erected also the *Cingulochitina bouniensis* Biozone above the *M. margaritana* Biozone in the Banwy River section. In the East Baltic only a few specimens of this species were found in the Aizpute (Loydell et al. 2003) and Ruhnu (Nestor 2005) cores.

The appearance level of *M. margaritana* is still problematic. It is probably controlled by some environmental factors (Loydell & Nestor 2005). According to Mullins & Loydell (2001), its appearance is coincident with the upper Telychian *Cyrtograptus insectus* graptolite Biozone in the Banwy River section, but in the East Baltic drill cores, where the uppermost Telychian graptolite biozones are missing, its FAD generally corresponds to the *Cyrtograptus murchisoni* graptolite Biozone (Ulst in Gailite et al. 1987; Loydell et al. 2003, 2010). An exception is the Ventspils D-3 core in which both *M. margaritana* and *M. banwyensis* first appear in the Telychian upper *spiralis* graptolite Biozone (Loydell & Nestor 2005).

In the East Baltic drill sections the total diversity of chitinozoan species is highest in the *M. margaritana* Biozone (Nestor 2009b). The extinction of species was also highest in this biozone, as it correlates partly with the Ireviken Event (Nestor et al. 2002).

The following interval, from the disappearance of *Angochitina longicollis* to the abundant appearance of *Conochitina claviformis* Eisenack and *Conochitina mamilla* Laufeld and coincidental disappearance of *Conochitina proboscifera*, is treated in the East Baltic sections as an interzone (Nestor 1994). The diversity of chitinozoans is very low in this interval (Nestor 1994). Graptolite diversity also declines at about the same level (Kaljo et al. 1995). The interzone corresponds to the *Monograptus firmus* and lower part of the *Monograptus riccartonensis* graptolite biozones (Loydell et al. 2010).

The Conochitina mamilla *Biozone*

This regional interval biozone was erected by Nestor (1994), but the index species was first described from the Högklint Beds of Gotland (Laufeld 1974). *Conochitina mamilla* Laufeld (Fig. 5C) has been identified from the East Baltic drill cores and the Builth Wells sections in Wales, UK (Verniers 1999).

In the southernmost drill cores (Ventspils, Pavilosta) *C. mamilla* occurs only sporadically and is missing in the Gussev-1 core. The dominant species in this biozone

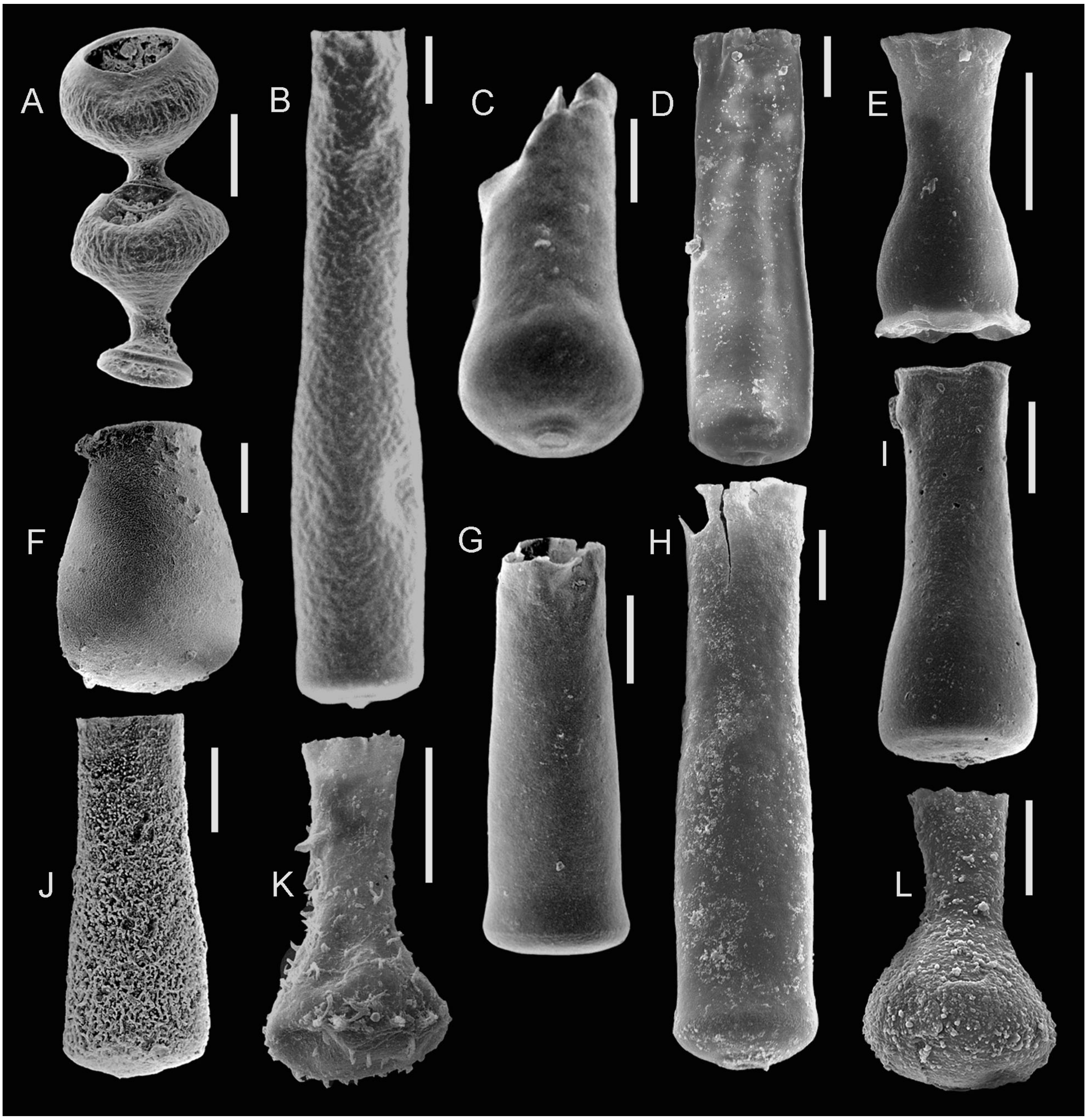


Fig. 5. Chitinozoan biozonal species in the Wenlock of the East Baltic drill cores. Scale 50 µm. **A**, *Margachitina margaritana* (Eisenack), GIT 220-9, Ohesaare core, depth 300.70 m, Jaani Stage. **B**, *Conochitina claviformis* Eisenack, GIT 272-69, Ohesaare core, depth 192.90 m, Jaagarahu Stage. **C**, *Conochitina mamilla* Laufeld, GIT 220-27, Pulli 2 core, depth 0.50 m, Jaani Stage. **D**, *Conochitina tuba* Eisenack, GIT 350-17, Staicele core, depth 274.50 m, Jaani Stage. **E**, *Cingulochitina cingulata* (Eisenack), GIT 189-20, Ruhnu core, depth 359.25 m. **F**, *Eisenackitina spongiosa* Swire, GIT 272-103, Ohesaare core, depth 260.30 m, Jaagarahu Stage. **G**, *Conochitina argillophila* Laufeld, GIT 220-45, Ohesaare core, depth 260.30 m, Jaagarahu Stage. **H**, *Conochitina pachycephala* Eisenack, GIT 546-78, Kolka-54 core, depth 486.29–486.50 m, Jaagarahu Stage. **I**, *Conochitina subcyatha* Nestor, GIT 217-18, Ruhnu core, depth 333.0 m, Jaagarahu Stage. **J**, *Conochitina cribrosa* Nestor, GIT 217-7, Ohesaare core, depth 188.20 m, Jaagarahu Stage. **K**, *Sphaerochitina indecora* Nestor, GIT 272-203, Ohesaare core, depth 165.90 m, Jaagarahu Stage. **L**, *Sphaerochitina lycoperdoides* Laufeld, GIT 527-11, Ohesaare core, depth 147.60–147.70 m, Rootsiküla Stage.

is the long-ranging *Conochitina claviformis* (Fig. 5B); other species, including the index species, are less numerous.

According to Verniers et al. (1995), the *C. mamilla* Biozone constitutes the middle part of the *M. margaritana* Biozone *s.l.* In the Ventspils and Kolka cores the *C. mamilla* Biozone corresponds to the upper half of the *M. riccartonensis* graptolite Biozone (Ulst in Gailite et al. 1987; Loydell et al. 2010). Verniers (1999) has also demostrated the correlation of the *C. mamilla* Biozone with the *M. riccartonensis* Biozone in the Builth Wells district, Wales.

The Conochitina tuba *Biozone*

This regional interval biozone was erected by Nestor (1994). Besides *Conochitina tuba* Eisenack (Fig. 5D), *Calpichitina acollaris* (Eisenack), *Ancyrochitina paulaspina* Nestor, *Ancyrochitina ansarviensis* Laufeld and *A.* cf. *clathrospinosa* Eisenack appear in this biozone in the Ohesaare core (Nestor 1994). The diversity of chitinozoans is higher in the Kolka core (Loydell et al. 2010), where *Ancyrochitina gutnica* and some other species appear in the uppermost part of the biozone, while *Conochitina claviformis* is still dominating. Deeper-water sections (Ventspils, Pavilosta, Gussev-1) show a somewhat lower diversity of species, containing in addition to *C. tuba* and *C. claviformis* only *M. margaritana.*

The *C. tuba* Biozone constitutes the upper part of the *M. margaritana* global Biozone in Verniers et al. (1995). In the Ventspils core this biozone corresponds to the middle Sheinwoodian *Streptograptus antennularius* graptolite Biozone (Ulst in Gailite et al. 1987). In the Ohesaare core the base of the *C. tuba* Biozone lies immediately below the level with *Monograptus flexilis* (= *M. belophorus*), but above the *Pristiograptus dubius* Interzone (Loydell et al. 1998). It thus correlates with at least part of the interval referred to as the ‘middle Wenlock’, as it does also in the Kolka core (Loydell et al. 2010).

The Cingulochitina cingulata *Biozone*

The *Cingulochitina cingulata* Biozone is a global interval biozone (Verniers et al. 1995). In the East Baltic drill cores *C. cingulata* (Eisenack) (Fig. 5E) occurs in deeper-water sections (Ohesaare, Ruhnu, Ventspils, Pavilosta, Gussev-1). *Clathrochitina clathrata* Eisenack is found in more shallow-water sections (Viki, Kaugatuma), but is missing in deep-water sections (Kolka, Ventspils, Pavilosta, Gussev-1). In the Ohesaare and Ruhnu cores these species appear together, at the same level.

The rate of origination of chitinozoan species increases considerably within this biozone (Nestor 2009b): 9–10 species appear in the Kolka, Ohesaare, Ruhnu and Kaugatuma cores, fewer in the others. In addition to the index species, the most important newcomers are *Ramochitina martinssoni* (Laufeld), *R. spinosa* (Eisenack), *R. uncinata* (Laufeld), *Ancyrochitina plurispinosa* Nestor and *Conochitina* aff. *pachycephala* Eisenack.

Mid-Wenlock graptolite occurrences in East Baltic drill cores are sparse, so the correlation with graptolite biozones in different sections may be rather difficult. Ulst (in Gailite et al. 1987) identified graptolite species in the Ventspils and Pavilosta drill cores. In both sections *Monograptus flemingii* occurs more or less continuously and a single specimen of *Cyrtograptus* cf. *rigidus* was recognized. In addition, in the Pavilosta core *Cyrtograptus perneri* was found in the middle–upper part of the *C. cingulata* Biozone. In the Kolka core a fragment of *Cyrtograptus lundgreni* has been identified from the upper part of the *C. cingulata* Biozone (Loydell et al. 2010), indicating that this chitinozoan biozone extends into the Homerian.

The Eisenackitina spongiosa *Biozone*

The *E. spongiosa* regional interval Biozone described by Loydell et al. (2010) was earlier (Nestor 1994, 2007) shown by the name of *Eisenackitina lagena* (Eisenack), as the index species was misidentified. *Eisenackitina spongiosa* (Fig. 5F) was first described by Swire (1990) from the middle Wenlock Coalbrookdale Formation, Shropshire. In the East Baltic drill cores this biozone is well represented in deeper-water sections, with a usual thickness of about 10 m, only in the Ruhnu core does the thickness extend to more than 20 m. In the Kaugatuma and Viki cores *E. spongiosa* has been found only in one sample, but *Conochitina argillophila* Laufeld (Fig. 5G), co-occurring with the index species, is more common. There are only a few newcomers in this biozone, of which *Ramochitina valbyttiensis* (Laufeld), *Cingulochitina baltica* Nestor and *Conochitina argillophila* are more widely geographically distributed. Verniers et al. (1995) incorporated this regional biozone within the *C. cingulata* global Biozone.

In the Kolka core this biozone correlates with the lower–middle part of the *Cyrtograptus lundgreni* graptolite Biozone (Loydell et al. 2010). In the Ventspils and Pavilosta cores some *Cyrtograptus radians* have been identified below the FAD of *C. lundgreni* (Ulst in Gailite et al. 1987). *Cyrtograptus radians* characterizes the lower part of the *lundgreni* raptolite Biozone (Williams & Zalasiewicz 2004, fig. 3).

The Conochitina pachycephala *Biozone*

This global chitinozoan interval biozone (Verniers et al. 1995) is represented in all studied East Baltic drill cores, except the Viki core, which contains only barren samples at that stratigraphic interval. Nestor (1994) established the *Conochitina subcyatha* Biozone above the *C. pachycephala* Biozone, but later investigations (Nestor 2003; Loydell et al. 2010) confirmed the simultaneous appearance of these species in some drill cores (Ruhnu, Kolka). Therefore in the present paper I have combined the above-named biozones. The diversity of species increases considerably in the *C. pachycephala* Biozone (Nestor 2009b).

In addition to *Conochitina pachycephala* Eisenack (Fig. 5H), *C. subcyatha* Nestor (Fig. 5I), *C. linearistriata* Nestor, *C. fortis Nestor*, *Plectochitina obuti* Nestor, *Cingulochitina crassa* Nestor, *C. gorstyensis* Sutherland and many other species in open nomenclature appear in this biozone (see Loydell et al. 2010).

In the Pavilosta and Ventspils cores the FAD of *C. pachycephala* coincides with the FAD of *Cyrtograptus lundgreni* (Ulst in Gailite et al. 1987). In the Kolka core the *C. pachycephala* Biozone correlates with the middle–upper part of the *Cyrtograptus lundgreni* Biozone (Loydell et al. 2010).

The Conochitina cribrosa *Biozone*

The index species *C. cribrosa* Nestor (Fig. 5J) of this regional interval biozone occurs in almost all studied drill cores, except for the Viki and Pavilosta cores. Nestor (1994) established the *Sphaerochitina indecora* Biozone above the *C. cribrosa* Biozone, but as *S. indecora* (Fig. 5K) is a rare species, later (Nestor 2007; Loydell et al. 2010) the *S. indecora* Biozone was included in the lower biozone. In the global biozonation scheme (Verniers et al. 1995) the *C. cribrosa* Biozone corresponds to the upper part of the *C. pachycephala* Biozone. *Conochitina cribrosa* has not been found in the southernmost sections (Pavilosta, Gussev-1) but the accompanying species are represented there.

Sphaerochitina concava Laufeld, *Conochitina* cf. *argillophila* Laufeld, *Linochitina erratica* Eisenack, *Ramochitina tabernaculifera* (Laufeld) and some other species (see Nestor 1994; Loydell et al. 2010) appear in this biozone. Many Wenlock species disappear in the uppermost part of the biozone, probably due to the Mulde Event (see Nestor 2007).

The *C. cribrosa* Biozone is correlated with the upper part of the *Cyrtograptus lundgreni* graptolite Biozone and the *Gothograptus nassa* Biozone in the Kolka core (Loydell et al. 2010).

The Sphaerochitina lycoperdoides *Biozone*

This is a global total-range biozone (Verniers et al. 1995), the index species of which is present in all studied East Baltic drill cores except the Ventspils core (Nestor 2007). Laufeld (1974) described *Sphaerochitina lycoperdoides* from the upper part of the Mulde and the Klinteberg Beds of Gotland. The biozone was erected by Paris (1981). During earlier investigations *S. lycoperdoides* was not found in the Ohesaare core (Nestor 1994), but later studies confirmed its presence in that section (Nestor 2007).

The northernmost drill cores (Kaugatuma, Ohesaare) are mostly characterized by transitional species, only *Ramochitina* cf. *militaris* (Laufeld) appears as scattered specimens. In other sections the FAD of *Rhabdochitina sera* Nestor is more remarkable. The richest assemblage occurs in the Pavilosta core, where *Cingulochitina wronai* Paris & Kříž, *Sphaerochitina impia* Laufeld and *Calpichitina muldiensis* (Laufeld) appear. The uppermost layers of the Wenlock in the Ohesaare, Ruhnu and Kolka cores are very poor in or barren of chitinozoans. The chitinozoan diversity curve displays a lowstand within this biozone (see Nestor 2009b).

According to Loydell et al. (2010), the *Sphaerochitina lycoperdoides* Biozone is correlated with the *Colonograptus praedeubeli*, *C. deubeli* and *C. ludensis* graptolite biozones.

Ludlow

The Conochitina postarmillata *Biozone*

The index species (Fig. 6A) was described and this regional interval biozone was erected by Nestor (2007). From the studied East Baltic drill cores the *C. postarmillata* Biozone has been established in the Ventspils, Pavilosta and Gussev-1 cores (Nestor 2007). In the northern sections (Kaugatuma, Ruhnu, Ohesaare, Kolka) the core interval between the *S. lycoperdoides* and *Angochitina elongata* biozones is represented mostly by barren samples. *Conochitina postarmillata* has not yet been identified in other regions.

In addition to transitional species, the *C. postarmillata* Biozone is characterized by the FAD of *Conochitina rudda* Sutherland, *Sphaerochitina scanicus* Grahn, *Eisenackitina lagena* (Eisenack) and *Ramochitina spinipes* (Eisenack).

In Verniers et al. (1995) no global chitinozoan biozone is erected in the lowermost Ludlow, at the level of the *Neodiversograptus nilssoni* graptolite Biozone. In the East Baltic sections the co-occurrence of chitinozoans and *N. nilssoni* has been established in the Ventspils and Pavilosta cores (Ulst in Gailite et al. 1987). The

C. postarmillata Biozone correlates well with the *N. nilssoni* Biozone in the Pavilosta core. In the Ventspils core *N. nilssoni* appears some metres below the records of *C. postarmillata* (Nestor 2007).

The Ancyrochitina desmea *Biozone*

This regional interval biozone was erected by Nestor (2007). Eisenack (1964) and Laufeld (1974) described the index species (Fig. 6B) from the lower–middle part of the Hemse Beds on Gotland. The *A. desmea* Biozone is well represented in the Ventspils and Pavilosta cores. In the Gussev-1 core the index species was found in only one sample.

Many species, characteristic also of the middle part of the Ludlow, appear in this biozone: *Belonechitina lauensis* (Laufeld), *B. latifrons* (Eisenack) (Fig. 6G), *Eisenackitina toddingensis* Sutherland*, Ancyrochitina gogginensis* Sutherland, *A. diabolus* Eisenack and *Angochitina ceratophora* Eisenack.

According to graptolite data (Ulst in Gailite et al. 1987), in the Ventspils and Pavilosta cores the *A. desmea* Biozone corresponds to the lowermost part of the *Lobograptus scanicus* graptolite Biozone (see Nestor 2007).

The Angochitina elongata *Biozone*

Eisenack (1931) described the index species from an erratic boulder, later correlated with the Hemse Beds (Eisenack 1964). This global interval biozone is well represented in the Ohesaare, Ventspils and Pavilosta cores (Nestor 2009a). In the Kolka core chitinozoans, including *A. elongata* Eisenack (Fig. 6C), have been identified only in two samples, whereas barren intervals of more than 20 m occurred below and above that level. In the Kaugatuma core only the lowermost part of the biozone is present, samples from the upper part were barren. This biozone is missing (barren samples) in the Ruhnu core (Nestor 2003). In the Dubovskoye (Gussev-2) core the beds below the *Eisenackitina lagenomorpha* Biozone have not been studied (Nestor 2009a).

Many new species appear in the Ventspils and Pavilosta cores, including *Angochitina echinata* Eisenack, *Belonechitina intermedia* (Eisenack), *B. mortimerensis* Sutherland, *Angochitina ambrosi* Schweineberg, *A. crassispina* Eisenack, *Eisenackitina clunensis* Miller, Sutherland & Dorning, *E. kerria* Miller, Sutherland & Dorning, *Ancyrochitina brevis* Taugourdeau & Jekhowsky, *Calpichitina hemsiensis* Laufeld, as well as species in open nomenclature. This level is related to one of the highstands in chitinozoan biodiversity in the Silurian (Nestor 2009b). Because of the barren interval, corresponding to the lowermost Ludlow, almost all of these species, which in the Ventspils and Pavilosta cores were present in the lower biozones already, appear for the first time in the *A. elongata* Biozone in the Ohesaare core (Nestor 2007, 2009a).

Verniers et al. (1995) correlated the *A. elongata* global Biozone with the *Lobograptus scanicus* Biozone and the lower part of the *Saetograptus leintwardinensis* Biozone. Based on the graptolite data (Ulst in Gailite et al. 1987) from the East Baltic drill cores, this biozone is correlated with the uppermost part of the *L. scanicus* Biozone and lower part of the *S. leintwardinensis* Biozone (Nestor 2009a).

The Eisenackitina lagenomorpha *Biozone*

This is a regional interval biozone used instead of the *Eisenackitina philipi* global Biozone in Verniers et al. (1995). *Eisenackitina philipi* Laufeld (Fig. 6F) is rare in the East Baltic drill cores, but *E. lagenomorpha* (Eisenack) (Fig. 6D) is well represented in almost all of the studied sections. The exceptions are the Kaugatuma and Kolka cores (Nestor 2009a), where the index species is found in the lower part of the *E. lagenomorpha* Biozone, while the upper part contains only barren samples. It is worth mentioning that Eisenack (1931) described *E. lagenomorpha* as abundantly distributed in the upper Silurian erratics.

The chitinozoan assemblage is better represented in the Pavilosta and Gussev-2 cores. *Cingulochitina hedei* Laufeld, *Eisenackitina oviformis* (Eisenack), *E. philipi* Laufeld, *E.* cf. *elongata* Eisenack, *Ramochitina villosa* (Laufeld), *Angochitina paucispinosa* Miller, Sutherland & Dorning, *A. ceratophora* Eisenack, *Ancyrochitina pedavis* Laufeld, *Sphaerochitina acanthifera* Eisenack, *Calpichitina squamosa* (Laufeld), *Pterochitina perivelata* (Eisenack) and several species in open nomenclature appear in this biozone. In the Ventspils core nine chitinozoan species disappear at the boundary with the overlying biozone, corresponding to the beginning of the Lau Event (Nestor 2009a).

As graptolites are scarce in the Upper Ludlow of the East Baltic drill cores (Ulst in Gailite et al. 1987), precise identification of the graptolite biozone boundaries is not possible. Thus, the *E. lagenomorpha* Biozone correlates approximately with the lower–middle part of the Ludfordian Stage, lying between the *Saetograptus leintwardinensis* and *Monograptus formosus* graptolite biozones.

The Eisenackitina barrandei *Biozone*

According to Verniers et al. (1995), this is a global interval biozone. The index species was described by Paris & Kříž (1984) from the stratotype sections of

Bohemia (Prague Basin). *Eisenackitina barrandei* (Fig. 6I) is well represented in the studied East Baltic drill cores (Nestor 2009a), with the exception of the Kaugatuma, Ruhnu and Kolka cores, which contain mainly barren samples in that interval.

Within the *E. barrandei* Biozone appear *Sphaerochitina sphaerocephala* (Eisenack) (Fig. 6E), *Belonechitina*? cf. *granosa* (Laufeld) (Fig. 6H)*, Calpichitina gregaria* (Paris & Kříž) and many species in open nomenclature (Nestor 2009a). It is important to mention that in all studied drill cores the index species disappears at the base of the succeeding biozone, as it does also in some sections of the Přídolí stratotype area (Kříž et al. 1986). The uppermost Ludlow chitinozoan succession and the *E. barrandei* Biozone in the Dubovskoye core are described in Nestor (2011).

On the basis of indirect correlation with the Lau Event level in the Ventspils core (Kaljo et al. 1998; Nestor 2009a) and the corresponding global carbon isotope curve for the Silurian System (Cramer et al. 2011), the *E. barrandei* Biozone corresponds to the *Neocucullograptus kozlowskii* and *M. formosus* graptolite biozones.

Přídolí

The Fungochitina kosovensis *and the* Eisenackitina kerria–Ancyrochitina tomentosa *biozones*

The *Fungochitina kosovensis* Biozone is a global interval biozone. Its index species was identified just above the base of the Přídolí Series in the global stratotype sections in Bohemia (Paris & Kříž 1984; Kříž et al. 1986) and recently also in the Dubovskoye core in the Kaliningrad district (Nestor 2011) (Fig. 6K). *Fungochitina kosovensis* is not found in the East Baltic northern drill cores, where its position has been taken by *Eisenackitina kerria* Miller, Sutherland & Dorning (Fig. 6L) and *Ancyrochitina tomentosa* Taugourdeau & de Jekhowsky (Fig. 6M). The latter two species have partly overlapping ranges in the interval, probably corresponding to the *F. kosovensis* Biozone in the Dubovskoye core. This may represent some ecological or palaeogeographical differentiation of the East Baltic chitinozoan assemblages in Přídolí time. The lower boundary of the biozone is marked by the LAD of *E. barrandei* in all studied drill cores (Nestor 2011). In addition, just above the boundary there appear and occur in a short interval *Ancyrochitina fragilis* Eisenack (Fig. 6J), *Angochitina filosa* Eisenack and *A. ceratophora* Eisenack (Nestor 2011).

The appearances of other taxa also differ between the Dubovskoye and northern drill cores. Some typically Gondwanan species, *Urnochitina urna* (Eisenack) (Fig. 6O), *Linochitina klonkensis* Paris, Laufeld & Chlupáč, *Fungochitina pistilliformis* (Eisenack) (Fig. 6N), *Eisenackitina cupellata* Wrona, *E. invenusta* (Wrona) and *Angochitina* aff. *chlupaci* Paris & Laufeld appear in the Dubovskoye core. In the Kaugatuma and Kolka cores the chitinozoan assemblage is more impoverished (Nestor 2011).

In the stratotype sections of Bohemia the biozonal graptolites *Monograptus parultimus* and *M. ultimus* are present in the lowermost part of the *F. kosovensis* Biozone (Kříž et al. 1986).

The Salopochitina filifera *Biozone*

Eisenack (1931, 1955) described the index species from the Beyrichia Limestone of the South Baltic erratics. This is a regional interval biozone, well represented in most of the studied East Baltic sections (Nestor 2011). However, it is impoverished in the Kolka core and the index species has not been found in the Kaugatuma core.

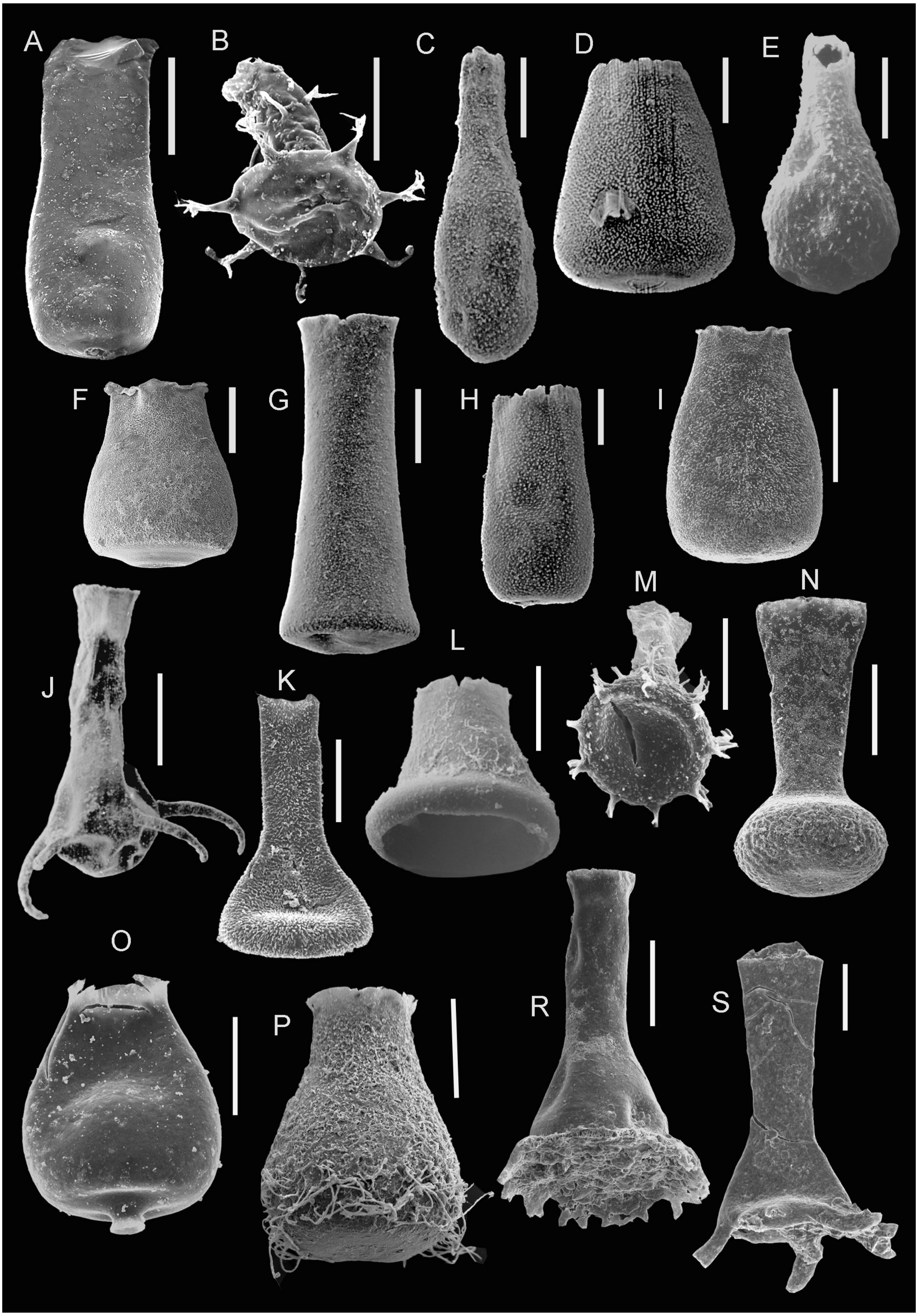
Besides the FAD of *S. filifera* (Fig. 6P), *Angochitina lebaica* Eisenack, *Eisenackitina sphaerica* (Eisenack) and *Bursachitina bursa* (Taugourdeau & Jekhowsky) appear in different drill cores and at different levels within this biozone. In addition, many appearing species are left in open nomenclature (Nestor 2003, 2011).

The *S. filifera* Biozone likely corresponds to the *Margachitina elegans* global Biozone, as the appearance levels of these species coincide in the range chart of index and characteristic species (Verniers et al. 1995).

In the East Baltic drill cores graptolites have not been found above the *M. ultimus* Biozone. In the sections of Bohemia Kříž et al. (1986) identified the chitinozoan species *U. urna* and *S. sphaerocephala* together with *Neocolonograptus lochkovensis*, whereas *S. filifera* is not recognized.

The Anthochitina superba *Biozone*

The index spcies (Fig. 6R) of this global interval biozone was described by Eisenack (1971) from the Beyrichia Limestone of the South Baltic erratics. According to Verniers et al. (1995), it is the highest chitinozoan biozone in the Silurian, while the range of *A. superba* extends over the Silurian–Devonian boundary. The top of the biozone is marked by the FAD of *Eisenackitina bohemica*, the index of the first Devonian chitinozoan biozone, defined in the global stratotype section at Klonk, Bohemia (Paris 1981). In the East Baltic drill cores the *A. superba* Biozone has been identified only in a short interval in the middle–upper Přídolí part of the Ventspils section (Nestor 2011). It is the most problematic chitinozoan biozone as it is very thin. Therefore, the core interval above the range of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the index species up to the FAD of *Ancyrochitina lemniscata* Wrona is also provisionally included in the *A. superba* Biozone (Nestor 2011).

The index species is lacking in the Ohesaare and Pavilosta drill cores, probably due to pre-Devonian erosion of the corresponding strata. In the Dubovskoye core its position seems to be occupied by *Margachitina* sp. and *Plectochitina* sp. (Nestor 2011). In the Ventspils core, in addition to *A. superba*, *Eisenackitina clunensis* Miller, Sutherland & Dorning appears in the lower part of the biozone and *Fungochitina kosovensis* is present in its upper part. In the Dubovskoye core *Calpichitina velata* (Wrona) appears above the range of *Margachitina* sp. (Nestor 2011). In both drill cores the LAD of *Fungochitina pistilliformis* occurs within this biozone.

Verniers et al. (1995) correlated the *A. superba* Biozone approximately with the *Monograptus boučeki*–*M. transgrediens* graptolite biozones.

The Ancyrochitina lemniscata *Biozone*

Wrona (1980) described the index species (Fig. 6S) of this interval biozone from the uppermost Přídolí in the drill cores of Poland. The biozone was erected by Nestor (2011) and it is represented in the Dubovskoye and Ventspils cores.

Angochitina chlupaci, a characteristic species of the basal Devonian (Paris et al. 1981), occurs at the boundary with the underlying *Anthochitina superba* Biozone in the Dubovskoye core and *Eisenackitina sphaerica* at the same level in the Ventspils core, together with some species in open nomenclature (Nestor 2011). It is worth mentioning that only *Ancyrochitina* spp., *Sphaerochitina sphaerocephala* and *Salopochitina filifera* range up to the Devonian boundary in both sections, whilst in the Ventspils core also *Eisenackitina lagenomorpha* and *E. oviformis* do so.

The *A. lemniscata* Biozone correlates probably with the uppermost Silurian graptolite biozone – the *M. transgrediens* Biozone.

A few studied samples from the Lower Devonian silt- and sandstones were barren of chitinozoans.

CONCLUSIONS

In the present paper previous biostratigraphical study of the East Baltic Silurian chitinozoans has been summarized. In comparison with earlier publications (Nestor 1990, 1994), the chitinozoan biozonation chart is essentially changed: some biozonal names are new, some subdivisions were abolished and some replaced. According to Verniers et al. (1995), the *Spinachitina maennili* Biozone was distinguished at the boundary of the Rhuddanian and Aeronian and the *Conochitina alargada* Biozone in the Aeronian. Following Mullins & Loydell (2001), the *Conochitina acuminata* Biozone was differentiated in the Telychian. The *Sphaerochitina lycoperdoides* Biozone was identified in the uppermost Wenlock and the *Conochitina postarmillata* and *Ancyrochitina desmea* biozones were recognized in the lowermost Ludlow. The *Ancyrochitina lemniscata* Biozone was erected in the upper Přídolí. In all, 28 chitinozoan zonal units have been distinguished in the East Baltic Silurian, including 26 biozones and 2 interzones based on samples barren of or poor in chitinozoans.

The distribution of some chitinozoan taxa was subject to certain environmental or palaeogeographical control. This is expressed in the variable abundance and diversity of species, and also in the absence of several

Fig. 6. Chitinozoan biozonal species in the Ludlow and Přídolí of the East Baltic drill cores. Scale 50 µm. **A**, *Conochitina postarmillata* Nestor, GIT 527-40, Ventspils D-3 core, depth 647.0 m, Paadla Stage. **B**, *Ancyrochitina desmea* Eisenack, GIT 527-42, Ventspils D-3 core, depth 613.0 m, Paadla Stage. **C**, *Angochitina elongata* Eisenack, GIT 189-28, Kaugatuma core, depth 81.10 m, Paadla Stage. **D**, *Eisenackitina lagenomorpha* (Eisenack), GIT 189-30, Kolka-54 core, depth 282.90 m, Kuressaare Stage. **E**, *Sphaerochitina sphaerocephala* (Eisenack), GIT 576-60, Ohesaare core, depth 72.95–73.0 m, Kuressaare Stage. **F**, *Eisenackitina philipi* Laufeld, GIT 576-33, Pavilosta core, depth 746.70–747.0 m, Paadla Stage. **G**, *Belonechitina latifrons* (Eisenack), GIT 576-16, Ohesaare core, depth 110.44 m, Paadla Stage. **H**, *Belonechitina*? granosa (Laufeld), GIT 189-34, Ohesaare core, depth 79.20 m, Kuressaare Stage. **I**, *Eisenackitina barrandei* Paris & Křiž, GIT 576-54, Pavilosta core, depth 695.30–695.50 m, Kuressaare Stage. **J**, *Ancyrochitina fragilis* Eisenack, GIT 607-30, Ohesaare core, depth 65.70 m, Kaugatuma Stage. **K**, *Fungochitina kosovensis* Paris & Křiž, GIT 607-13, Dubovskoye core, depth 1184.0 m, Kandievski Formation. **L**, *Eisenackitina kerria* Miller, Sutherland & Dorning, GIT 607-7, Ohesaare core, depth 63.0–63.10 m, Kaugatuma Stage. **M**, *Ancyrochitina tomentosa* Taugourdeau & de Jekhowsky, GIT 607-23, Dubovskoye core, depth 1160.0 m, Okunevski Formation. **N**, *Fungochitina pistilliformis* (Eisenack), GIT 607-14, Dubovskoye core, depth 1059.0 m, Okunevski Formation. **O**, *Urnochitina urna* (Eisenack), GIT 607-39, Dubovskoye core, depth 1101.0 m, Kandievski Formation. **P**, *Salopochitina filifera* (Eisenack), GIT 607-50, Dubovskoye core, depth 1008.0 m, Okunevski Formation. **R**, *Anthochitina superba* Eisenack, GIT 607-53, Ventspils D-3 core, depth 335.10 m, Kaugatuma Stage. **S**, *Ancyrochitina lemniscata* Wrona, GIT 607-66, Ventspils core, depth 296.0 m, Kaugatuma? Stage.

taxa due to unfavourable conditions (e.g. *Spinachitina*, *Ramochitina*, *Cingulochitina*, *Fungochitina* and *Urnochitina* in shallow-water shelf sedimentary rocks).

The correlation of chitinozoan and graptolite biozones has been much improved (see Loydell et al. 2003, 2010), as well as the correlation with global chitinozoan biozones (see Verniers et al. 1995). Many chitinozoan biozonal boundaries coincide with the boundaries of the East Baltic regional stratigraphic subdivisions, global graptolite biozones and the Silurian stage slices (after Cramer et al. 2011).

The ranges of the 54 stratigraphically most important chitinozoan species throughout the East Baltic Silurian have been presented.

Acknowledgements. I thank D. Kaljo and H. Nestor for the critical reading of the manuscript and valuable suggestions, and G. Baranov for technical help. I am very grateful to the referees D. K. Loydell and J. Verniers for essential comments and improvements. The study was supported by the Estonian Research Council (project SF0140020s08).

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Ida-Balti Siluri kitiinikute biotsonaalsuse kokkuvõte ja revisjon

Viiu Nestor

On kokku võetud autori poolt erinevatel aegadel teostatud biostratigraafilised uuringud. Ida-Balti Siluri läbilõikes on kirjeldatud 26 kitiinikute biotsooni koos kahe intertsooniga, mis on korreleeritud Siluri kitiinikute globaalse biotsonaalse skaalaga ja graptoliitide globaalse kronostratigraafilise skaalaga. On näidatud ka stratigraafiliselt olulisemate kitiinikuliikide levikuintervallid Ida-Balti Siluris.