Chitinozoans in the Wenlock–Ludlow boundary beds of the East Baltic

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Abstract. The distribution of chitinozoans in the Wenlock–Ludlow boundary beds was studied in five drill core sections of the East Baltic. It was established that most of the typical Wenlock chitinozoan species became extinct in the uppermost part of the Jaagarahu Stage. In the lower part of the Rootsiküla Stage the *Sphaerochitina lycoperdoides* Biozone was identified for the first time. The *Conochitina postarmillata* and *Ancyrochitina desmea* biozones were established in the Dubysa Formation of the Paadla Stage in the Ventspils and Pavilosta cores and in the Gorstian Stage of the Gussev-1 core. Two stratigraphically important new species, *Rhabdochitina sera* and *Conochitina postarmillata*, were described, and *Eisenackitina lagena* (Eisenack) was redescribed.

Key words: chitinozoans, correlation, Wenlock, Ludlow, Silurian, East Baltic.

INTRODUCTION

Due to wide occurrence of lagoonal and shoal rocks in the very shallow-water sections of the upper Wenlock Rootsiküla Formation in Estonia (Nestor 1997), chitinozoans are very rare in that part of the stratigraphic sequence (Nestor 1994). However, in deeper-water core sections of the central part of the Baltic Basin, the distribution of chitinozoans is continuous (e.g. in the Ventspils core, see Nestor 1994).

During the last decade a large number of Silurian chitinozoan samples were investigated from the west Latvian (Kolka, Pavilosta) and Kaliningrad (Gussev-1) deep cores (Fig. 1). Additional samples were studied also from the Ohesaare core, which contained more chitinozoans than presumed earlier. This enabled distinction of the global *Sphaerochitina lycoperdoides* chitinozoan Biozone in the upper Wenlock of the Ohesaare core, but also better correlation of the northern and southern sections of the Baltic Basin. In the global chitinozoan biozonation (Verniers et al. 1995) an unzoned interval is marked above the *S. lycoperdoides* Zone. The main aim of this paper is to present more biostratigraphic information about the distribution of chitinozoans in the Wenlock–Ludlow boundary beds, but also to find stratigraphically more useful chitinozoan taxa for correlation of the East Baltic sections with other regions.

Earlier it was thought that the lowermost part of the Ludlow was lacking in the Estonian Silurian sequence (Nestor 1982; Nestor & Nestor 1991), but was represented in the West Latvian core sections (Ulst 1964). Later investigations (Viira & Einasto 2003) have shown that this gap is stratigraphically more restricted.

For independent stratigraphical control it is very important to integrate chitinozoan and graptolite biostratigraphical data. All graptolites from the Ventspils

Fig. 1. Location of the studied East Baltic drill holes.

and Pavilosta drill cores, used in this study, have been identified by R. Ulst (Gailite et al. 1987). The succession of graptolites in the Gussev-1 core has been published in Koren et al. (2005), but some graptolite identifications by D. Kaljo (pers. comm. 2006) were also used. No graptolites have been found in the Rootsiküla Stage of the Ohesaare core, and only some graptolites have been identified in the Kolka core (D. Loydell, D. Kaljo, pers. comm. 2006).

LITHOLOGY, FACIES, AND STRATIGRAPHICAL NOTES

The studied core sections represent different facies belts. The studied interval of the Ohesaare core (Fig. 2) is characterized by various carbonate rocks from open shelf limestones up to lagoonal dolomites, forming the carbonate platform of the Baltic Basin (Nestor & Einasto 1982). The Kolka core (Fig. 3) is represented by marlstones and limestones of open shelf origin. The Ventspils and Pavilosta boreholes (Figs 4, 5) are located in the depression facies of the Baltic Basin (Nestor & Einasto 1982), characterized mostly by argillaceous marlstones with graptolites. The Gussev-1 (or Gusevskaya-1 by Koren et al. 2005) core (Fig. 6) in the southernmost edge of the basin contains dolomitic mudstones.

In the present paper the distribution of chitinozoans is examined in the Wenlock–Ludlow boundary beds from the topmost Jaagarahu Stage up to the Sauvere Beds of the Paadla Stage in the Ohesaare and Kolka cores, as well as in the graptolitic sections of the Ventspils, Pavilosta, and Gussev-1 cores. The distribution of selected chitinozoan species in the East Baltic drill cores is shown in Fig. 7.

In 1978 the boundary between the Wenlock and Ludlow in Estonia was fixed at the boundary of the Rootsiküla and Paadla regional stages, i.e. at the boundary of the Soeginina and Sauvere beds (Resheniya… 1978). On the basis of recent conodont and cyclostratigraphic investigations (Viira & Einasto 2003), the stratigraphical position of the Soeginina Beds in the stratotype section as well as in the Ohesaare core was specified. It appeared that the Soeginina Beds, represented by various dolostones, belonged to the Paadla Stage.

In the uppermost Wenlock of the East Baltic the most reliable level for correlation is the base of the *nassa* graptolite Zone (Radzevičius & Paškevičius 2005). In the Latvian graptolitic sections it coincides with the thin and more carbonate Ančia Member, treated also as the base of the Rootsiküla Stage (Kaljo et al. 1984). The lower boundary of the *nassa* Zone is not clear in all studied sections because the Ančia Member has been distinguished only in the Ventspils and Pavilosta cores.

The lower boundary of the *nassa* Zone is placed at the base of or within the Ančia Member, where a number of species, including *Monograptus f. flemingii*, *Monograptus t. testis*, *Cyrtograptus lundgreni*, and *Monoclimacis flumendosae*, are replaced by *Gothograptus nassa* and *Pristiograptus parvus* (Kaljo et al. 1984). This enables recognition of the base of the *nassa* Zone in the Pavilosta and Ventspils cores. According to indirect correlation, the Mulde Event of Gotland (Calner & Jeppsson 2003; Jeppsson & Calner 2003) coincides

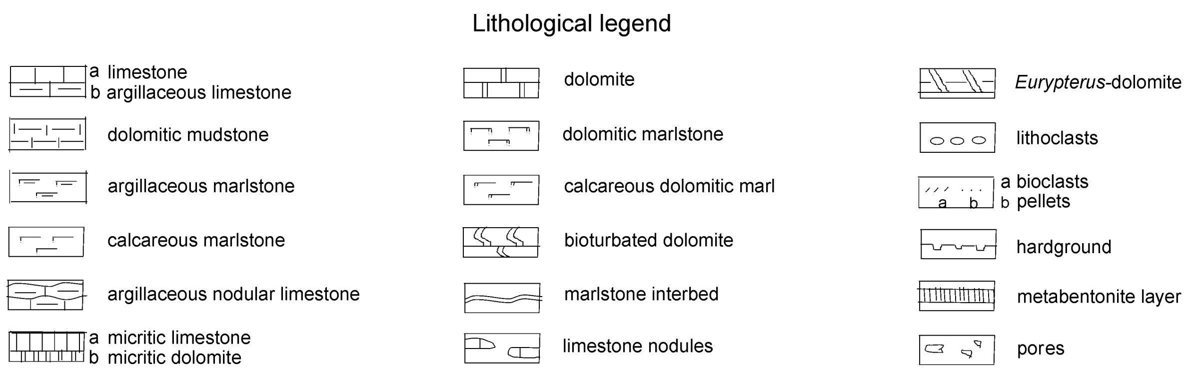
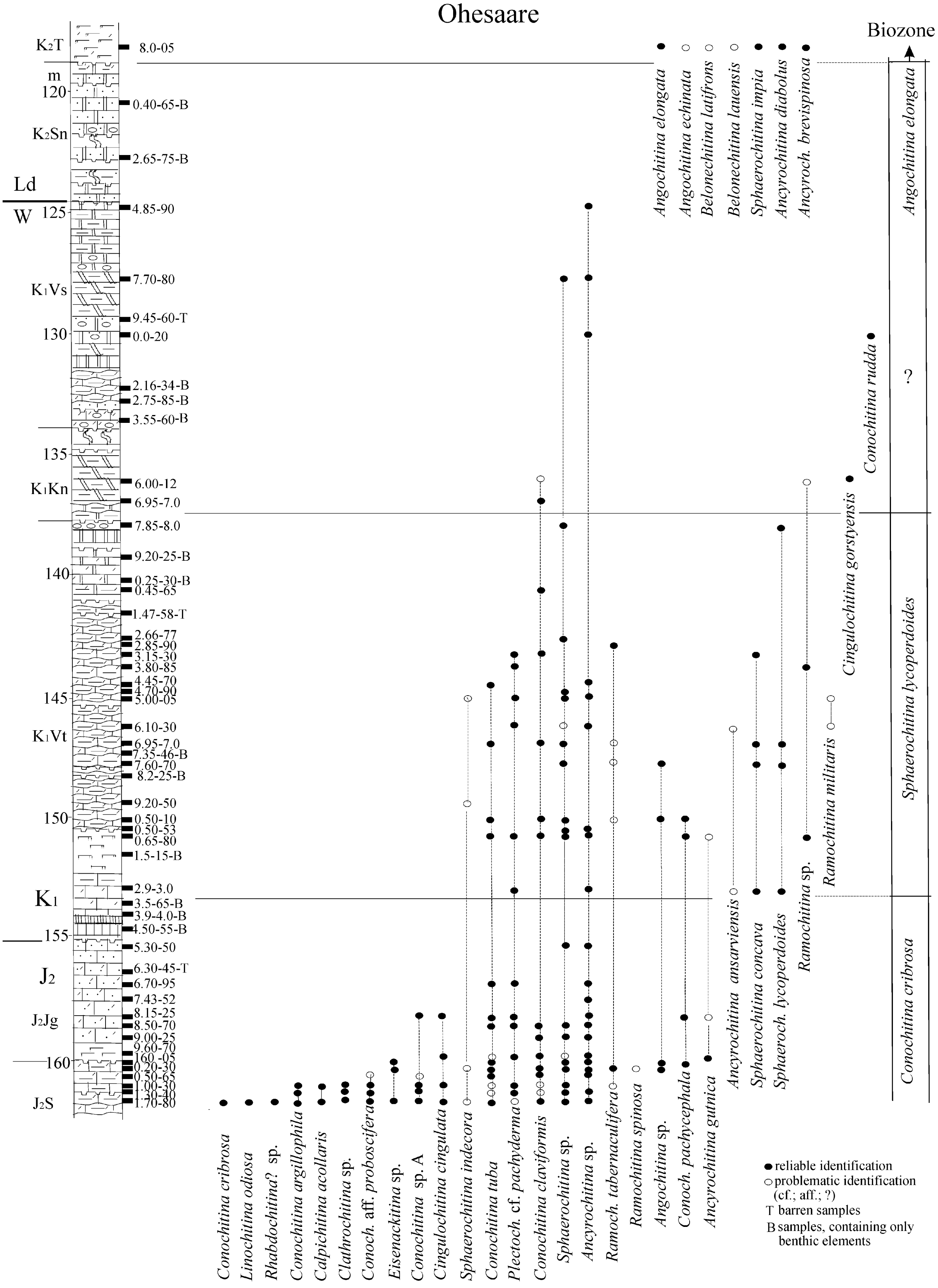


Fig. 2. Lithological log and ranges of chitinozoan species in the Wenlock–Ludlow boundary interval in the Ohesaare drill core. J_2, Jaagarahu Stage; S, Sõrve Formation; Jg, Jaagarahu Formation; A, Ančia Member; K_1, Rootsiküla Stage; Vt, Viita Beds; Kn, Kuusnõmme Beds; Vs, Vesiku Beds; K_2, Paadla Stage; Sn, Soeginina Beds; T, Torgu Formation.


Ohesaare
Biozone
K2T
m
120
K2Sn
Ld
W
125
K1Vs
130
135
K1Kn
140
145
K1Vt
150
K1
155
J2
J2Jg
160
J2S
8.0-05
0.40-65-B
2.65-75-B
4.85-90
7.70-80
9.45-60-T
0.0-20
2.16-34-B
2.75-85-B
3.55-60-B
6.00-12
6.95-7.0
7.85-8.0
9.20-25-B
0.25-30-B
0.45-65
1.47-58-T
2.66-77
2.85-90
3.15-30
3.80-85
4.45-70
4.70-90
5.00-05
6.10-30
6.95-7.0
7.35-46-B
7.60-70
8.2-25-B
9.20-50
0.50-10
0.50-53
0.65-80
1.5-15-B
2.9-3.0
3.5-65-B
3.9-4.0-B
4.50-55-B
5.30-50
6.30-45-T
6.70-95
7.43-52
8.15-25
8.50-70
9.00-25
9.60-70
160 -05
0.20-30
0.50-65
1.00-30
1.30-40
1.70-80
Angochitina elongata
Angochitina echinata
Belonechitina latifrons
Belonechitina lauensis
Sphaerochitina impia
Ancyrochitina diabolus
Ancyroch. brevispinosa
Conochitina rudda
Cingulochitina gorstyensis
Ramochitina militaris
Ramochitina sp.
Ancyrochitina ansarviensis
Sphaerochitina concava
Sphaeroch. lycoperdoides
Angochitina elongata
?
Sphaerochitina lycoperdoides
Conochitina cribrosa
Conochitina cribrosa
Linochitina odiosa
Rhabdochitina? sp.
Conochitina argillophila
Calpichitina acollaris
Clathrochitina sp.
Conoch. aff. proboscifera
Eisenackitina sp.
Conochitina sp. A
Cingulochitina cingulata
Sphaerochitina indecora
Conochitina tuba
Plectoch. cf. pachyderma
Conochitina claviformis
Sphaerochitina sp.
Ancyrochitina sp.
Ramoch. tabernaculifera
Ramochitina spinosa
Angochitina sp.
Conoch. pachycephala
Ancyrochitina gutnica
● reliable identification
○ problematic identification (cf.; aff.; ?)
T barren samples
B samples, containing only benthic elements

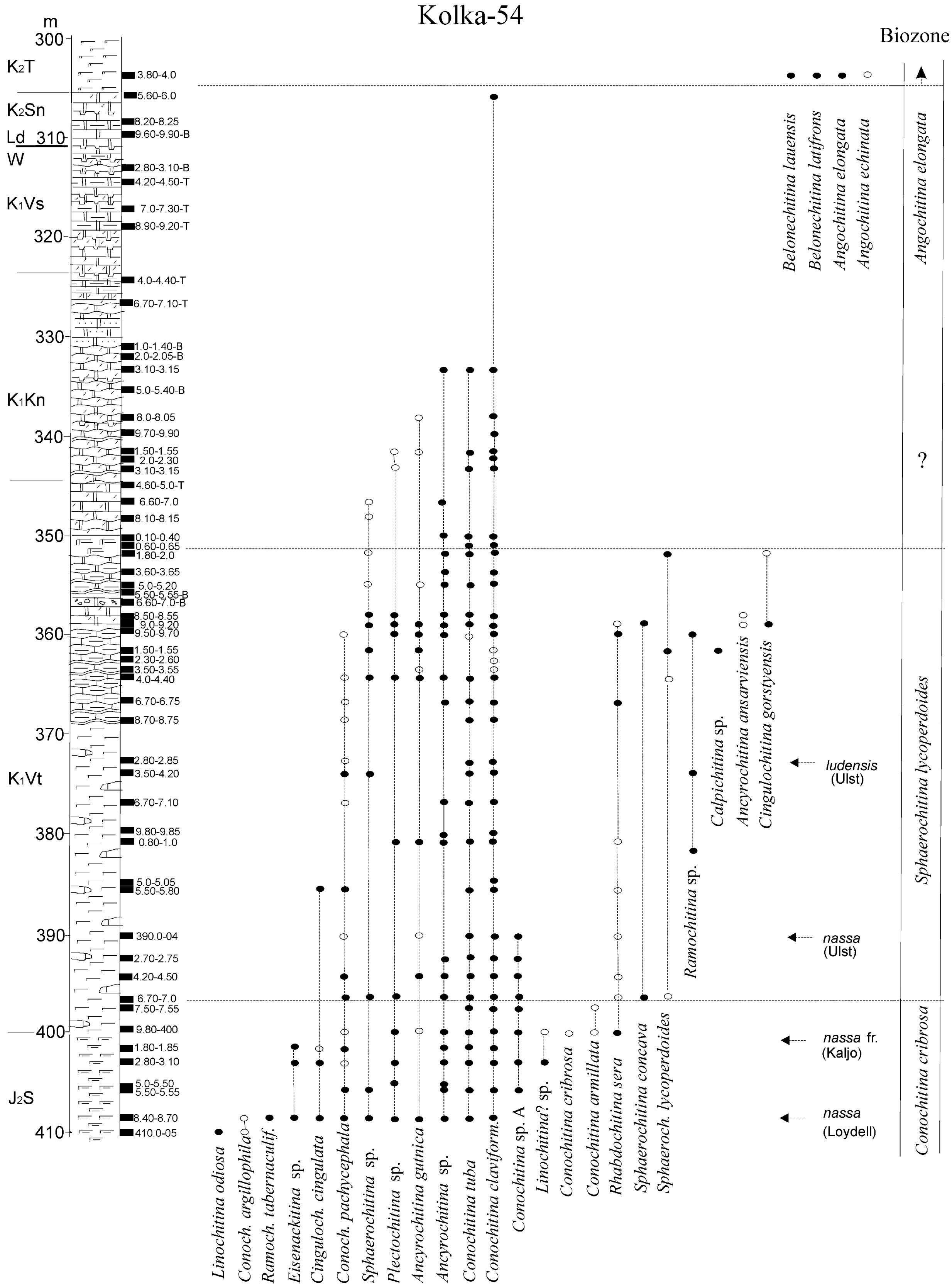


Fig. 3. Lithological log and ranges of chitinozoan species in the Wenlock–Ludlow boundary interval in the Kolka drill core. For legend see Fig. 2.

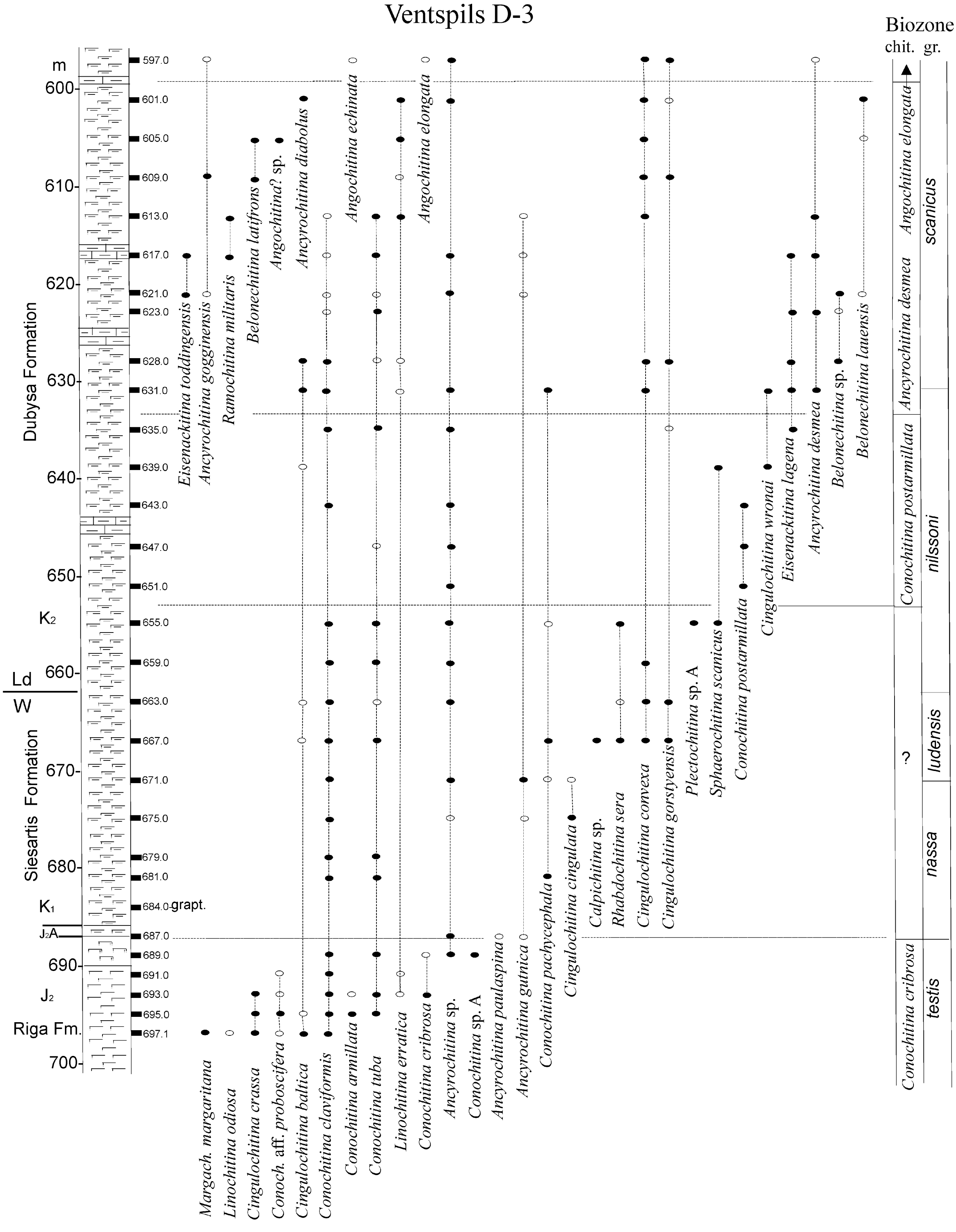


Fig. 4. Lithological log and ranges of chitinozoan species in the Wenlock–Ludlow boundary interval in the Ventspils drill core. For legend see Fig. 2.

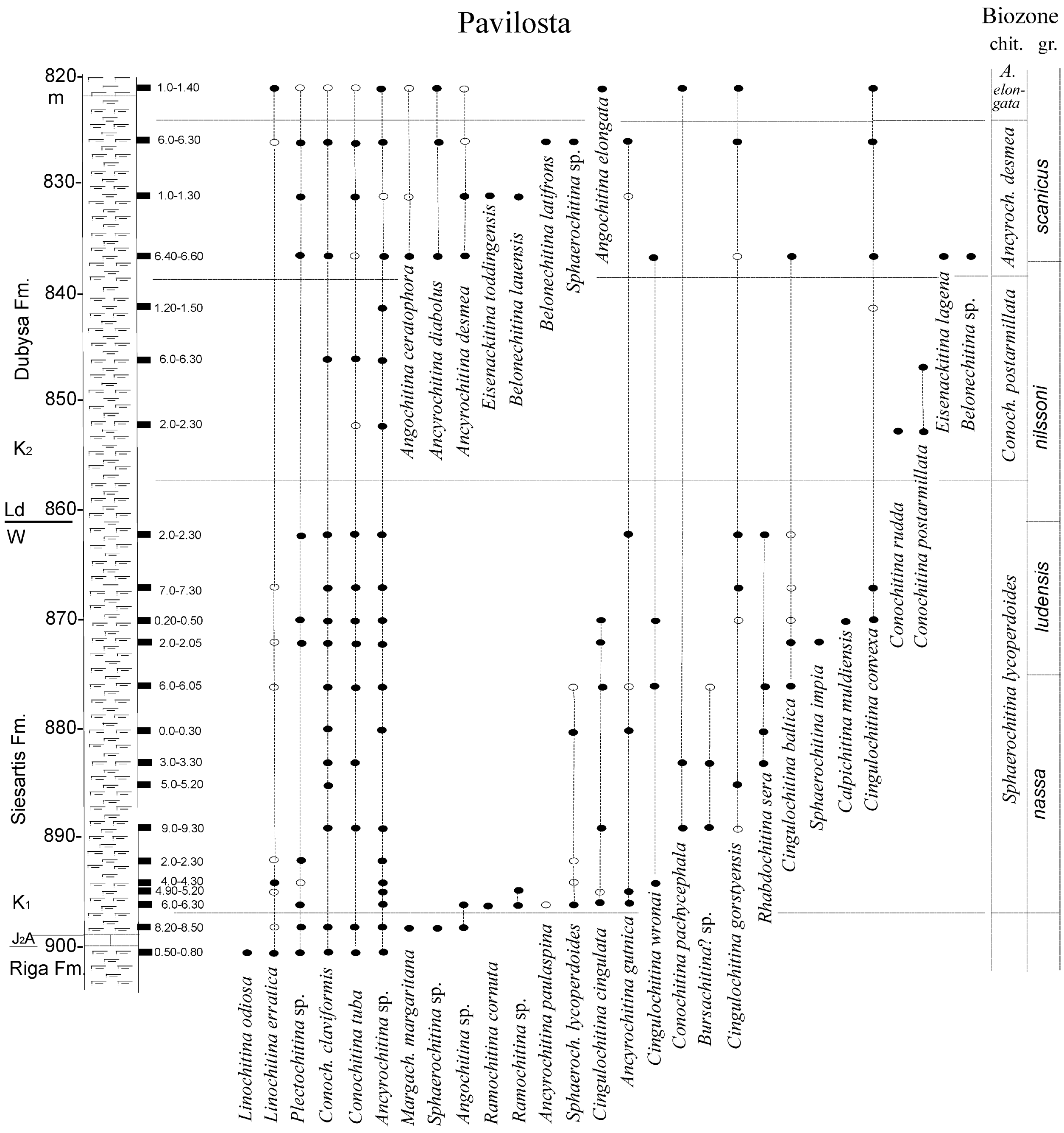


Fig. 5. Lithological log and ranges of chitinozoan species in the Wenlock–Ludlow boundary interval in the Pavilosta drill core. Lithological column after Koren et al. (2005). For legend see Fig. 2.

with the interval of 149.8–161.5 m in the Ohesaare core, including the boundary of the Jaagarahu and Rootsiküla stages, but also three conodont extinction steps (datums 1, 1.5, and 2). The hardground at the base of the Rootsiküla Stage is regarded as the sequence boundary (Calner 1999), defined in the Ohesaare core at 155.1 m. An excellent stratigraphic marker is the Grötlingbo Bentonite (Jeppsson & Calner 2003), which in the Ohesaare core has been determined at a depth of 154.25–154.5 m (Kiipli & Kallaste 2006). A strong positive shift in the $\delta^{13}C$ stable isotope curve, peaked at 154 m in the Ohesaare core (Kaljo et al. 1997), just above the Grötlingbo bentonite, is another good stratigraphic marker (Jeppsson & Calner 2003). According to Calner et al. (2006),

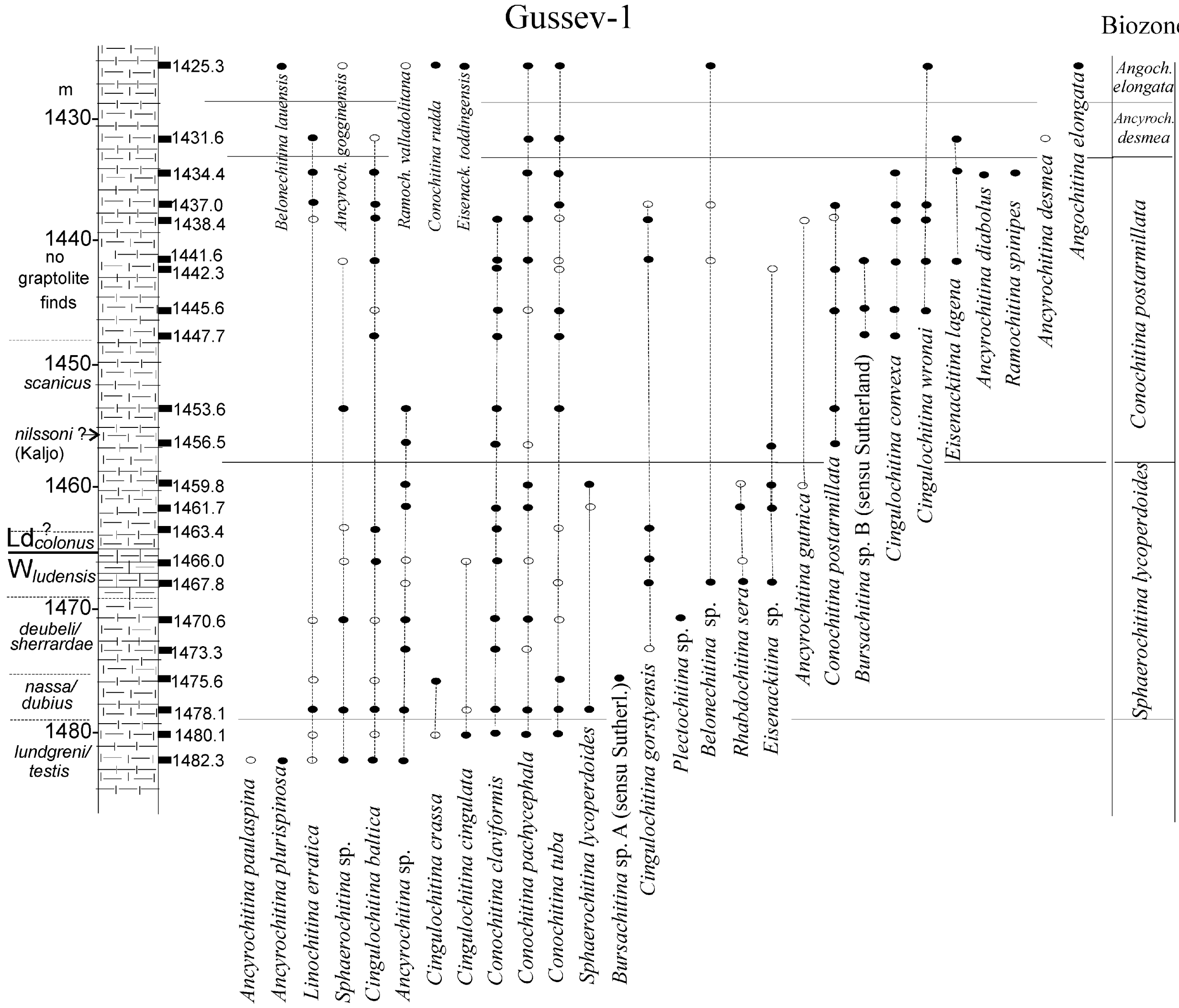


Fig. 6. Lithological log and ranges of chitinozoan species in the Wenlock–Ludlow boundary interval in the Gussev-1 drill core. For legend see Fig. 2.

in the Hunninge-1 core *G. nassa* appears about 0.6 m above the Grötlingbo Bentonite and in the Grötlingbo-1 core just below the bentonite. This obviously places the base of the *nassa* Zone in the Ohesaare core between 153 and 153.5 m, above the bentonite and samples containing only fragments of benthic organisms (Fig. 2).

CHITINOZOAN BIOSTRATIGRAPHY

The chitinozoan assemblage below the *Sphaerochitina lycoperdoides* Biozone

Nestor (1994) distinguished the *Sphaerochitina indecora* chitinozoan Biozone in the uppermost part of the Jaagarahu Stage and the lower part of the Rootsiküla Stage in the Ohesaare core. Later investigations, however, showed that the occurrences of *S. indecora* Nestor are rather scattered. This species has not been found in the Kolka, Ventspils, Pavilosta, and Gussev-1 cores. In the global chitinozoan biozonal scheme (Verniers et al. 1995) the *Conochitina pachycephala* Biozone is differentiated below the *S. lycoperdoides* Zone (Fig. 8), but in deeper-water sections (Ventspils, Pavilosta), in the uppermost Jaagarahu Stage, the former species has only limited distribution. More frequent *Conochitina cribrosa*, occurring together with *S. indecora* (Nestor 1994), is a better index species for the biozone. The *Conochitina cribrosa* Biozone, corresponding to the upper part of the *M. testis* graptolite Zone (Nestor 1994), has been distinguished in the Ohesaare, Kolka,

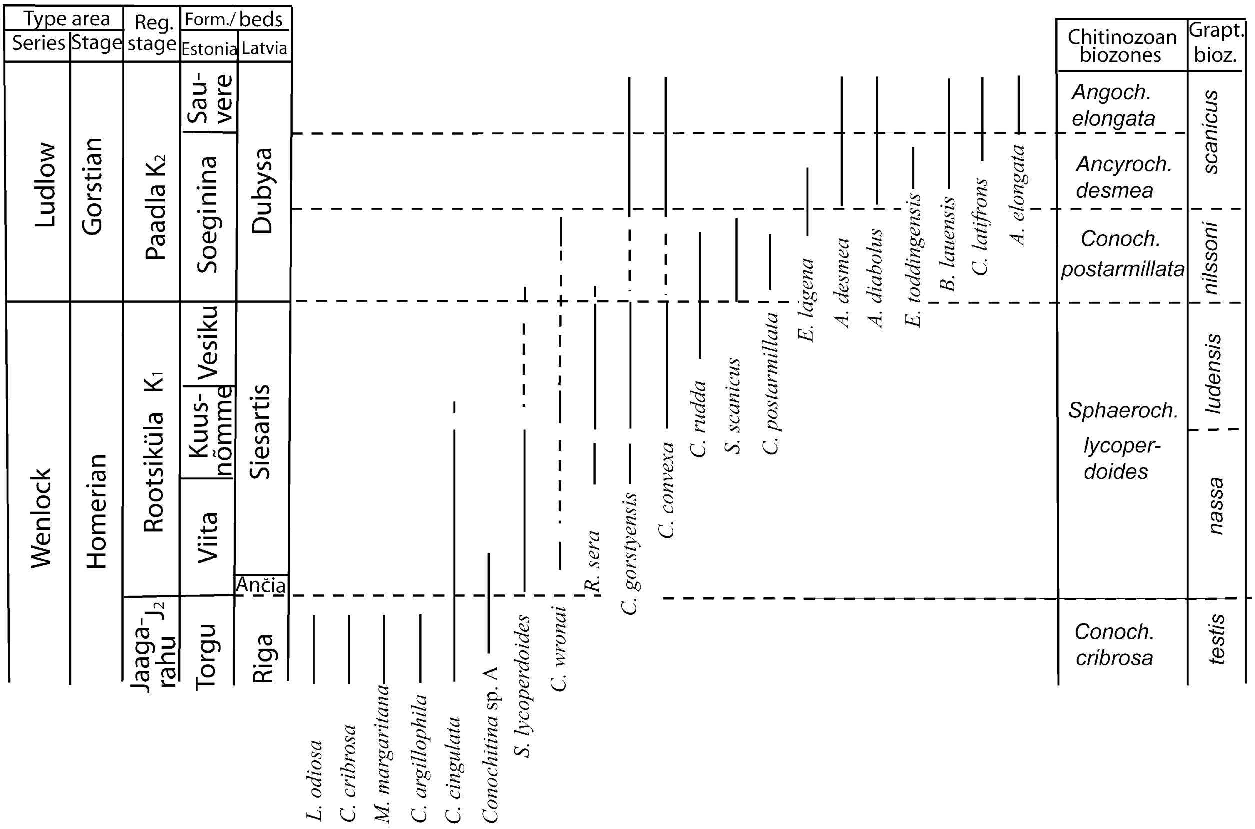


Fig. 7. Distribution of selected chitinozoan species in the Wenlock–Ludlow boundary interval in the East Baltic drill cores.

and Ventspils cores (Figs 2–4). The last occurrence of *Margachitina margaritana* (Eisenack) coincides with the beginning of the *nassa* Zone in the Pavilosta core at the base of the Rootsiküla Stage, but in the Ventspils and Ohesaare cores, *M. margaritana* disappears already in the upper part of the Jaagarahu Stage, about 10 m below the boundary of the Rootsiküla Stage. In the Kolka and Gussev-1 cores this species was not found in the upper part of the Jaagarahu Stage. Along with *M. margaritana* (Eisenack) a number of other species disappear in the uppermost part of the Jaagarahu Stage: *Linochitina odiosa* Laufeld (Fig. 9S), *Cingulochitina crassa* Nestor, *Conochitina cribrosa* Nestor (Fig. 9O), *Con. argillophila* Laufeld (Fig. 9E), *Con.* aff. *proboscifera* Eisenack (Fig. 9B), *Calpichitina acollaris* (Eisenack) (Fig. 9M), *Ramochitina spinosa* (Eisenack) (Fig. 9F), *Clathrochitina* sp. (Fig. 9D), *Eisenackitina* sp. (Fig. 9R). Most of these species become extinct in the Ohesaare core at 160–161.5 m, between the datum points 1 and 1.5 of the Mulde Event (see Jeppsson & Calner 2003). Of transitional species, *Conochitina claviformis* Eisenack (Fig. 9A) and *Con. tuba* Eisenack (Fig. 10L), in the Ohesaare and Kolka cores also *Con. pachycephala* (Fig. 9C), are more numerous. Probably due to facies difference the genera *Sphaerochitina*, *Ramochitina*, and *Plectochitina* are missing in the deepest-water Ventspils section. The species diversity is higher in the Ohesaare and Kolka sections, representing the shallower-water carbonate platform environment.

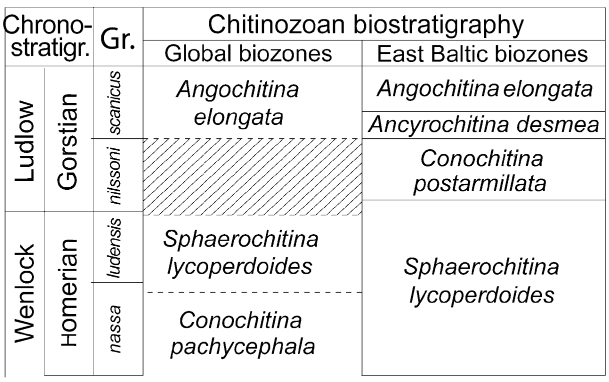


Fig. 8. Correlation of the global chitinozoan biozones (Verniers et al. 1995) and the East Baltic chitinozoan biozones (this paper).

The *Sphaerochitina lycoperdoides* Biozone

The *S. lycoperdoides* Biozone was erected by Paris (1981) in Portuguese sections. Definition of this total range global biozone is presented in Verniers et al. (1995) and Grahn (1996). The biozone in the East Baltic sections is first described in the present paper. Earlier (Nestor 1994) this interval was distinguished as Interzone. It is relevant to note that the zonal species itself is rather sparsely represented throughout the biozone, whereas it was not found in the Ventspils core. The lower boundary of the biozone coincides roughly with the lower boundary of the Viita Beds and the Siesartis Formation of the Rootsiküla Stage, lying a few metres above it. Together with *Sphaerochitina lycoperdoides* Laufeld (Fig. 9J, K), *S. concava* Laufeld (Fig. 9I) appears in the Ohesaare and Kolka cores. One of the most characteristic species in this biozone is *Rhabdochitina sera* sp. nov. (Fig. 10M–P), occurring in all studied cores except Ohesaare. In the Kolka core it appears at the base of the Rootsiküla Stage, in the Pavilosta and Gussev-1 cores in the middle or upper part of the *S. lycoperdoides* Biozone, and in the Ventspils core, where *Sphaerochitina* is lacking, in the upper part of the Siesartis Formation. The range of *Cingulochitina gorstyensis* Sutherland (Fig. 10F–G) partly coincides with those of the zonal species and *Rhabdochitina sera* sp. nov. Within this biozone also *Cingulochitina wronai* Paris & Křiž, (Fig. 10D, E), *Cin. cingulata* (Laufeld), *Cin. baltica* Nestor (Fig. 9U), and *Cin. convexa* (Laufeld) (Fig. 10H, I) were identified in more off-shore sections; *Ancyrochitina ansarviensis* Laufeld (Fig. 9G) was found in Ohesaare and Kolka; and *Plectochitina pachyderma* (Laufeld) (Fig. 9L), *Angochitina* sp. (Fig. 9P), *Ramochitina militaris* (Laufeld) (Fig. 10B), and *R. tabernaculifera* (Laufeld) (Fig. 10A) in Ohesaare. As appendices were frequently broken, it was difficult to identify precisely the species of *Ancyro*-, *Ramo*-, and *Plectochitina*, but *Ancyrochitina gutnica* Laufeld (Fig. 9N, V) was established in all studied sections. In the Ohesaare core the last Wenlock species disappear within this biozone. In more off-shore sections some Wenlock species (*Conochitina claviformis*, *Con. tuba*, *Con. pachycephala* Eisenack) range up to the Ludlow. It is important to note that in deep-water sections, where *Sphaerochitina* is lacking, the range of *Rhabdochitina sera* usually coincides with the upper part of the *S. lycoperdoides* Biozone.

According to graptolite data from Pavilosta (Gailite et al. 1987), the *Sphaerochitina lycoperdoides* Biozone corresponds to the *nassa* and *ludensis* graptolite zones. The graptolite finds from Kolka (Fig. 3) also refer to the correspondence of the *S. lycoperdoides* and *nassa–ludensis* zones. Concerning the position of the boundary between the *colonus* and *scanicus* zones, some graptolite data from the Gussev-1 core (Koren et al. 2005) seem to be insufficiently detailed and there was no evidence presented to place the bottom of the *scanicus* Zone at a depth of 1464 m (Fig. 6). Some unpublished graptolite data by D. Kaljo refer to a 7–8 m higher position of this boundary. Considering these data, *S. lycoperdoides* may be present also in the *nilssoni* graptolite Zone. It should be noted that the zonal graptolites *Pristiograptus praedeubeli* and *P. deubeli* have not been identified in the Ventspils and Pavilosta cores (Gailite et al. 1987).

In the Pavilosta core the *S. lycoperdoides* Biozone corresponds to the uppermost Wenlock Siesartis Formation, in the Ohesaare and Kolka cores to the Viita Beds of the Rootsiküla Stage. In the last two sections the uppermost Wenlock (Kuusnõmme and Vesiku beds of the Rootsiküla Stage) is mostly represented by lagoonal dolomites, containing an impoverished assemblage of only scarce specimens of long-ranging species of *Ancyro*- and *Conochitina.* An exception is the occurrence of *Conochitina rudda* Sutherland (Fig. 10J) in the Ohesaare core, in the middle of the Vesiku Beds. This interval could be treated as a continuation of the *S. lycoperdoides* Zone or treated as an Interzone (see Nestor 1994).

The *Conochitina postarmillata* Biozone

This biozone is an interval zone of *Conochitina postarmillata* sp. nov. (Fig. 11A–C). The base of the zone is defined at the first occurrence of the index species and the top by the first occurrence of the index species of the succeeding biozone. It is distinguished only in the southern, deeper-water Ventspils, Pavilosta, and Gussev-1 sections and characterizes the lowermost beds of the Ludlow. In the Ohesaare and Kolka cores this biozone is lacking due to sparse, only scattered distribution or absence of chitinozoans. Beside long-ranging species (*Con. claviformis*, *Con. tuba*), only a few species associate with *Con. postarmillata*: *Sphaerochitina scanicus* Grahn (in the Ventspils core), *Cingulochitina wronai* Paris & Křiž and *Eisenackitina lagena* (Eisenack) (Fig. 11F–H; Ventspils and Gussev-1 cores), *Conochitina rudda* (Pavilosta core), *Cingulochitina convexa*, *Cin. gorstyensis*, *Cin. baltica*, and *Cin. wronai* (Gussev-1 core). It is worth mentioning that Grahn (1996) dis-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tinguished the *Sphaerochitina scanicus* Subzone as the uppermost part of the *S. lycoperdoides* Zone in Skåne, southern Sweden.

In the Ventspils and Pavilosta cores the *Conochitina postarmillata* Biozone corresponds to the lower part of the Dubysa Formation, and to the *nilssoni* graptolite Zone (Gailite et al. 1987).

The *Ancyrochitina desmea* Biozone

The *Ancyrochitina desmea* Interval Biozone was first described by Grahn (1996) as the lower subzone of the *Angochitina echinata* Zone in Skåne, Sweden. In the East Baltic sections *Anc. desmea* Eisenack occurs below the appearance of *Angochitina echinata* Eisenack, but has some overlap with the latter within the *Angochitina elongata* Biozone. The lower boundary of the *Anc. desmea* Biozone is determined by the appearance of *Anc. desmea* (Fig. 11D, E). In the Ohesaare and Kolka cores the zonal species was not found. A number of newcomers characterize this zone in Ventspils and Pavilosta: *Belonechitina lauensis* (Laufeld) (Fig. 11O), *B. latifrons* (Eisenack) (Fig. 11N), *Angochitina ceratophora* Eisenack, *Ancyrochitina gogginensis* Sutherland, *Anc. diabolus* Eisenack, *Eisenackitina toddingensis* Sutherland (Fig. 11K), *Ramochitina militaris* (Laufeld) (Fig. 10C). In the Gussev-1 core this biozone contains besides uncharacteristic *Anc. desmea* only long-ranging transitional species. In all deep-water sections *E. lagena*, *Cin. baltica*, *Anc. gutnica*, and *Cin. wronai* disappear from this biozone.

According to graptolite data (Gailite et al. 1987), in the Pavilosta and Ventspils cores the *Ancyrochitina desmea* Biozone corresponds to the lower part of the *scanicus* graptolite Zone, which coincides with the middle part of the Dubysa Formation.

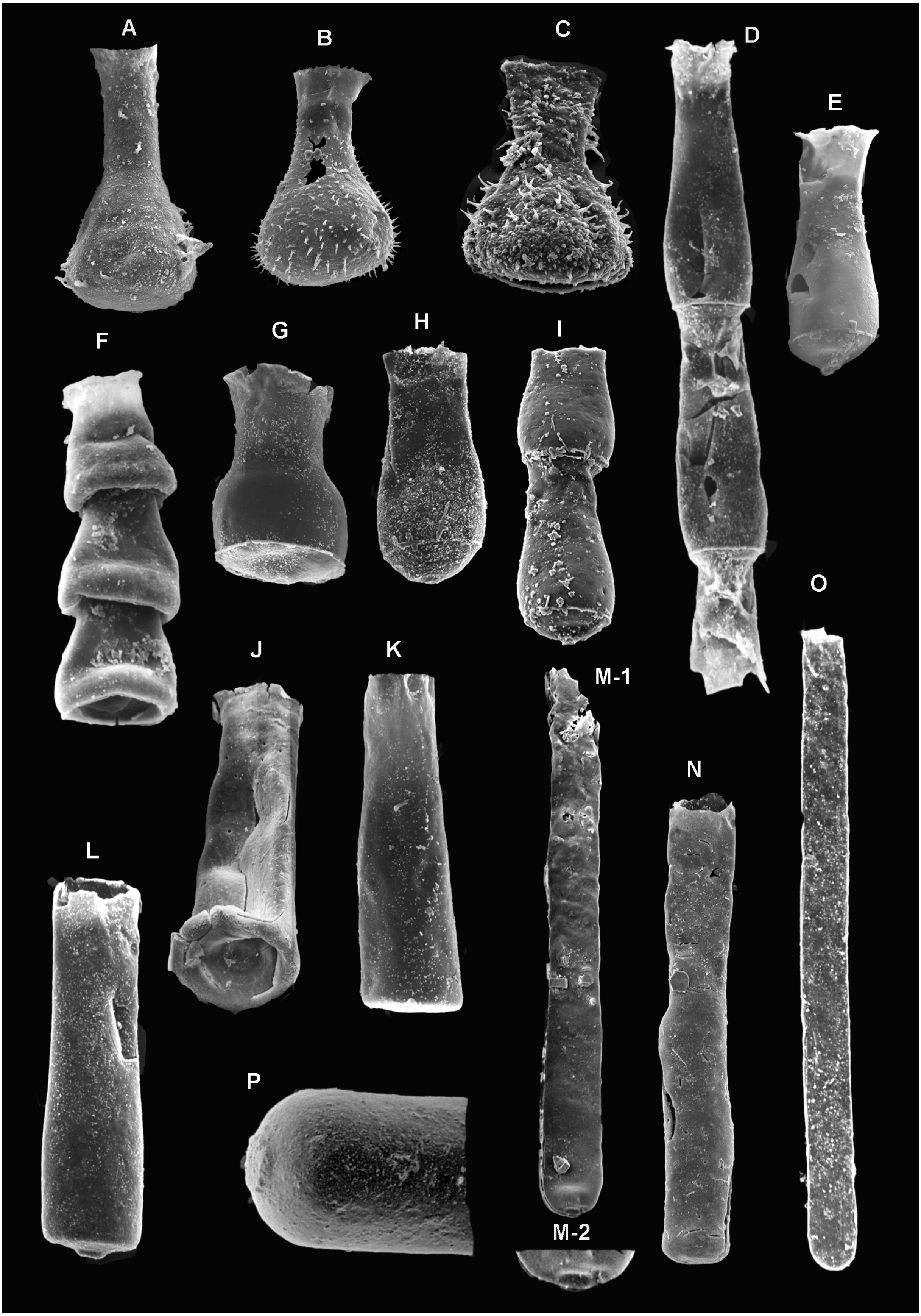
Many new species appear in the succeeding *Angochitina elongata* Biozone (Verniers et al. 1995). Besides the zonal species (Fig. 11P) also *Ancyrochitina brevispinosa* Eisenack (Fig. 11M), *Ramochitina valladolitana* Schweineberg (Fig. 11I), and *Sphaerochitina* cf. *impia* Laufeld (Fig. 11L) appear in the Torgu Formation of the Paadla Stage, as well as in the upper part of the Dubysa Formation. This zone, however, is not considered in this paper.

Discussion and correlation with other areas

Gotland and Skåne

The chitinozoan assemblages of Gotland (Laufeld 1974) and Skåne (Grahn 1996) partly coincide with those determined from the Wenlock–Ludlow boundary beds in the East Baltic area. *Sphaerochitina lycoperdoides* was found in the *dubius–nassa* Zone in the När-1 core (graptolites identified by Jaeger 1991) and in the *ludensis*

Fig. 9. Selected chitinozoan species. **A**, *Conochitina claviformis* Eisenack 1931, GIT 527-1, Ohesaare core, depth 160.50–160.60 m, Jaagarahu Stage, ×230. **B**, *Conochitina* aff. *proboscifera* Eisenack 1937, GIT 527-2, Ohesaare core, depth 161.70–161.80 m, Jaagarahu Stage, ×130. **C**, *Conochitina pachycephala* Eisenack 1964, GIT 527-3, Kolka core, depth 450–450.05 m, Jaagarahu Stage, ×210. **D**, *Clathrochitina* sp., GIT 527-4, Ohesaare core, depth 161.70–161.80 m, Jaagarahu Stage, ×280. **E**, *Conochitina argillophila* Laufeld 1974, GIT 527-5, Ohesaare core, depth 161.20–161.30 m, Jaagarahu Stage, ×260. **F**, *Ramochitina* cf. *spinosa* (Eisenack 1932), GIT 527-6, Ohesaare core, depth 160.20–160.30 m, Jaagarahu Stage, ×360. **G**, *Ancyrochitina* cf. *ansarviensis* Laufeld 1974, GIT 527-7, Ohesaare core, depth 152.90–153 m, Rootsiküla Stage, ×330. **H**, *Sphaerochitina*? sp., GIT 527-8, Ohesaare core, depth 161.20–161.30 m, Jaagarahu Stage, ×230. **I**, *Sphaerochitina concava* Laufeld 1974, GIT 527-9, Ohesaare core, depth 152.90–153 m, Rootsiküla Stage, ×400. **J**, **K**, *Sphaerochitina lycoperdoides* Laufeld 1974, Ohesaare core, depth 147.60–147.70 m, Rootsiküla Stage. J, GIT 527-10, ×230, K, GIT 527-11, ×250. **L**, *Plectochitina* cf. *pachyderma* (Laufeld 1974), GIT 527-12, Ohesaare core, depth 144.70–144.90 m, Rootsiküla Stage, ×290. **M**, *Calpichitina acollaris* (Eisenack 1959), GIT 527-13, Ohesaare core, depth 161.20–161.30 m, Jaagarahu Stage, ×400. **N**, **V**, *Ancyrochitina gutnica* Laufeld 1974, Ohesaare core, depth 159.60–159.70 m, Jaagarahu Stage. N, GIT 527-14, ×310, V, GIT 527-21, ×280. **O**, *Conochitina cribrosa* Nestor 1994, GIT 527-15, Ohesaare core, depth 166.90–166.05 m, Jaagarahu Stage, ×260. **P**, *Angochitina* sp., GIT 527-16, Ohesaare core, depth 160–160.05 m, Jaagarahu Stage, ×240. **R**, *Eisenackitina* sp., GIT 527-17, Ohesaare core, depth 160.20–160.30 m, Jaagarahu Stage, ×230. **S**, *Linochitina odiosa* Laufeld, GIT 527-18, Pavilosta core, depth 900.50–900.80 m, Riga Formation, ×200. **T**, *Linochitina erratica* (Eisenack 1931), GIT 527-19, Pavilosta core, depth 900.50–900.80 m, Riga Formation, ×100. **U**, *Cingulochitina baltica* Nestor 1994, GIT 527-20, Gussev-1 core, depth 1441.6 m, Gorstian Stage, ×160. **W**, *Conochitina* sp. A, GIT 527-22, Kolka core, depth 399.80–400 m, Rootsiküla Stage, ×240.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Zone in the Järrestadsån-4 core (Grahn 1996, fig. 2). On Gotland, Laufeld (1974, fig. 77) recorded this species from the upper part of the Mulde and throughout the Klinteberg beds. According to the correlation of Jeppsson et al. (2006), this interval coincides also with the *nassa–ludensis* zones, similarly to the East Baltic core sections. *Sphaerochitina scanicus* occurs in the *nilssoni* Zone in the Ventspils core, but has also been established in the *colonus* Zone in the sections of Skåne (Grahn 1996, fig. 3). *Conochitina postarmillata* sp. nov. is not found in Swedish sections. *Ancyrochitina desmea* has been recorded in the middle part of the Hemse Beds (Laufeld 1974) of the Gotland sequence, correlating with the *scanicus* Zone (Jeppsson et al. 2006), and also in the sections of Skåne (Grahn 1996, fig. 4), where its occurrences correspond to the *chimaera* Zone.

There are some differences in the stratigraphical ranges of several species in Gotland (Laufeld 1974) and East Baltic sections. For example, the range of *Anc. gutnica* ends in the uppermost Wenlock on Gotland, but in the lower Ludlow in the East Baltic sections. *Cingulochitina convexa* has been recorded on Gotland only from the Ludlow (Hemse and Eke beds), whereas in the Ventspils and Pavilosta sections this species appears already in the upper Wenlock (Siesartis Formation). The appearance level of *Belonechitina latifrons* and *Angochitina elongata* at the top of the Klinteberg Marl on Gotland (Laufeld 1974), corresponding to the top of the *ludensis* Zone (Jeppsson et al. 2006), does not coincide with the appearance of these species in the Ventspils and Pavilosta cores in the middle of the Dubysa Formation, correlating with the middle part of the *scanicus* Zone. In the Ohesaare and Kolka cores these species appear at the base of the Torgu Formation of the Paadla Stage, which is barren of graptolites. In Skåne, Grahn (1996, fig. 5) identified *B. latifrons* and *Ang. elongata* at the base of the Klinta Formation from the Bjärsjölagård 1 section, above the *scanicus* Zone.

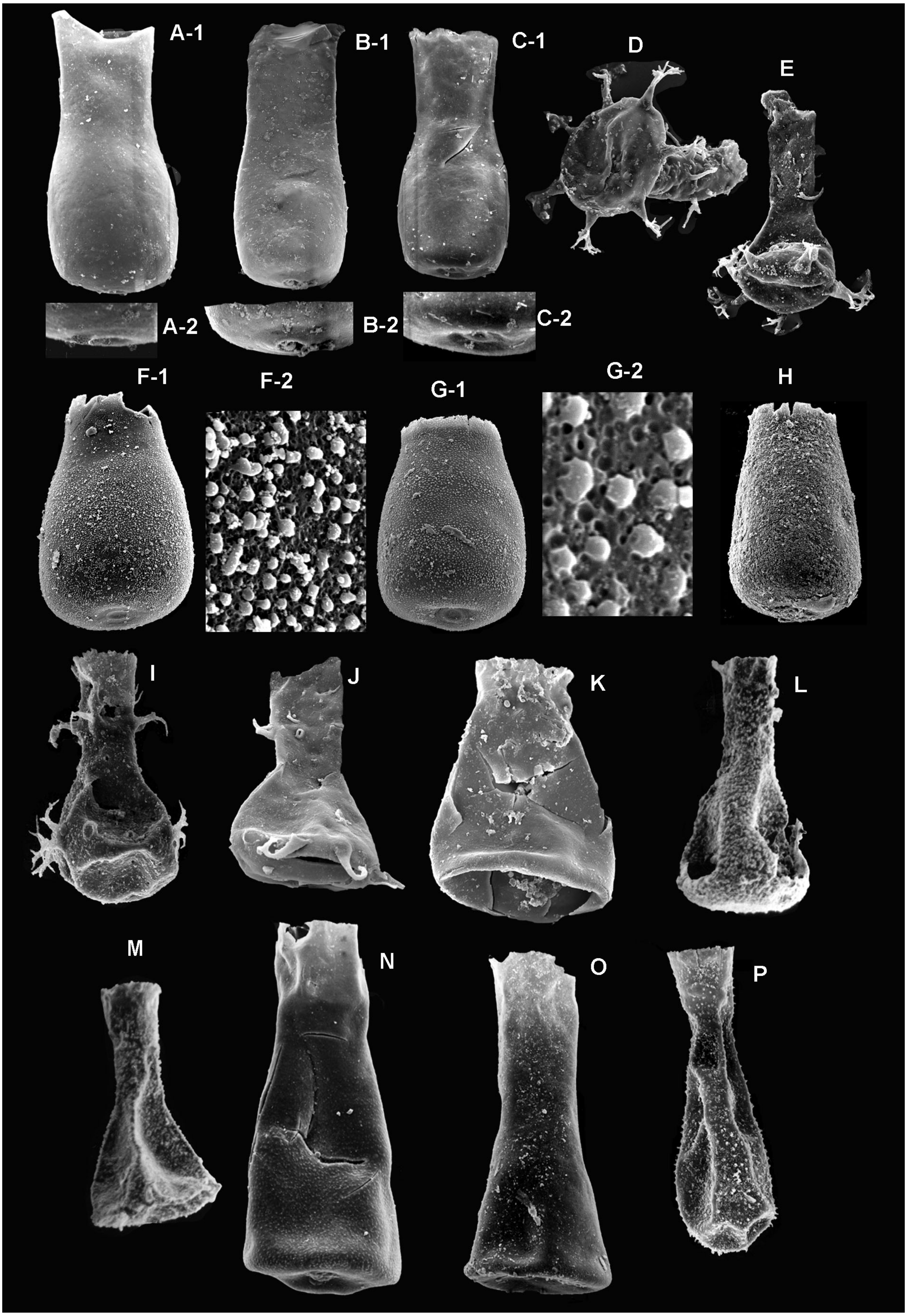
Such differences are difficult to explain. These may be induced by the lithology and facies of the sampled beds, but also by gaps in sedimentation.

Ludlow type area

Chitinozoans from the Ludlow type area were recorded by Dorning (1981) and Sutherland (1994). The former author listed 35 taxa from the type Wenlock and Ludlow localities and gave their stratigraphical ranges. The most important events are the disappearance of *Cin. cingulata* and *Anc. gutnica* in the Much Wenlock Limestone Formation (uppermost Wenlock) and the appearance of *B. latifrons* and *Ang. elongata* in the Middle Elton Formation (lower Ludlow).

In his monograph Sutherland (1994) described chitinozoans from the type Ludlow Series, showing also the species coming from the Much Wenlock Limestone Formation (Sutherland 1994, text-fig. 36). The most important species is *Conochitina rudda*, which is present also in the Lower Elton Formation and at 130.0–130.20 m in the Ohesaare core, in the Vesiku Beds of the Rootsiküla Stage. *Conochitina* sp. A Sutherland (pl. 9, figs 12, 13) from the Lower Elton Formation (*nilssoni* graptolite Zone) is probably identical with the new zonal species *Con. postarmillata.* In the uppermost part of the Middle Elton Formation, corresponding to the *scanicus* graptolite Zone, there appear *B. lauensis*, *Ang. elongata*, and *E. toddingensis.* These data correlate well with the occurrences of the same species in the East Baltic core sections.

Fig. 10. Selected chitinozoan species. **A**, *Ramochitina tabernaculifera* (Laufeld 1974), GIT 527-23, Ohesaare core, depth 143.15–143.30 m, Rootsiküla Stage, ×240. **B**, *Ramochitina* cf. *militaris* (Laufeld 1974), GIT 527-24, Ohesaare core, depth 146.20–146.30 m. Rootsiküla Stage, ×250. **C**, *Ramochitina militaris* (Laufeld 1974), GIT 527-25, Ventspils core, depth 613 m, Dubysa Formation, ×330. **D**, **E**, *Cingulochitina wronai* Paris & Křiž 1984. D, GIT 527-26, Gussev-1 core, depth 1441.6 m, Gorstian Stage, ×310, E, GIT 527-27, Pavilosta core, depth 836.40–836.60 m, Dubysa Formation, ×230. **F**, **G**, *Cingulochitina gorstyensis* Sutherland 1994. F, GIT 527-28, Pavilosta core, depth 862–862.30 m, Siesartis Formation, ×280, G, GIT 527-29, Gussev-1 core, depth 1441.6 m, Gorstian Stage, ×360. **H**, **I**, *Cingulochitina convexa* (Laufeld 1974). H, GIT 527-30, Gussev-1 core, depth 1441.6 m, Gorstian Stage, ×300, I, GIT 527-31, Ventspils core, depth 663 m, Siesartis Formation, ×250. **J**, **K**, *Conochitina rudda* Sutherland 1994. J, GIT 527-32, Ohesaare core, depth 130–130.20 m, Rootsiküla Stage, ×300, K, GIT 527-33, Gussev-1 core, depth 1431.6 m, Gorstian Stage, ×300. **L**, *Conochitina tuba* Eisenack 1932, GIT 527-34, Gussev-1 core, depth 1431.6 m, ×220. **M**–**P**, *Rhabdochitina sera* sp. nov. M-1, Holotype GIT 527-35, Ventspils core, depth 655 m, Dubysa Formation, ×90, M-2, ×180; N, GIT 527-36, Kolka core, depth 366.70 m, Rootsiküla Stage, ×180; O, GIT 527-37, Gussev-1 core, depth 1467.8 m, Homerian Stage, ×100; P, The aboral part of GIT 527-38, Ventspils core, depth 655 m, Dubysa Formation, ×260.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Differences are observed in the stratigraphical ranges of some species as well. In the type Ludlow area *Cingulochitina gorstyensis* and *Cin. convexa* appear in the Middle Elton Formation (*scanicus* graptolite Zone), but in the uppermost Wenlock in the East Baltic cores (*nassa* and *ludensis* zones). However, we should note here that not all members of the species assemblage, contained in the studied beds, may be recorded if too small rock samples (15–25 g) are used for analysis (Hints et al. 2006).

Prague Basin (Bohemia)

The Wenlock–Ludlow boundary beds in the Prague Basin have been studied in great detail by Křiž et al. (1993). Chitinozoans (identified by P. Dufka) are represented by a rather few species. Among some long-ranging species *Eisenackitina pregranosa* and *Cingulochitina wronai* were determined. The former species, identical with *E. lagena*, occurred in the *dubius parvus* and *chimaera* graptolite zones. *Cingulochitina wronai* was reported from the *colonus* and *chimaera* zones. The ranges of these species partly coincide with the ranges of the same species in the East Baltic cores.

Palencia Province (Spain)

Schweineberg (1987) investigated chitinozoans in the uppermost Wenlock to lowermost Devonian sediments of North Spain, including the Wenlock–Ludlow boundary beds. In addition to many exotic species, missing in the East Baltic sections, there occur also more widespread species, useful for interregional correlation. The range of *Anc. desmea* coincides with the *nilssoni* Zone and the range of *Ang. elongata* with the *scanicus* Zone. In the Gussev-1 core *Ancyrochitina valladolitana* Schweineberg was found, appearing here together with *Ang. elongata* as in Palencia.

Mehaigne and Ronquières-Monstreux areas (Brabant Massif, Belgium)

Verniers (1982) and Verniers et al. (2002) present the results of chitinozoan studies in the Brabant Massif. *Sphaerochitina lycoperdoides* was recorded in the *nassa* and lower–middle part of the *ludensis* graptolite zones in the Mehaigne area (Verniers 1982). Verniers et al. (2002) recorded a number of species in the Ludlow sections, corresponding to the undifferentiated *nilssoni* and *scanicus* zones, but presented no data on the top-most Wenlock, probably lacking chitinozoans. Besides the long-ranging species, appearing jointly in the lower-most Ludlow, a more important event is the occurrence of *Cin. wronai* (zone F of Verniers et al. 2002).

CONCLUSIONS

1. Facies dependence of chitinozoans is well expressed by the scarcity or lack of chitinozoans in shallow-water sparitic limestones and dolomites (Kuus-nõmme, Vesiku, and Soeginina beds of the Ohesaare and Kolka cores), compared to their diverse and continuous presence in deeper-water marl- and mud-stones (Siesartis and Dubysa formations in the Ventspils and Pavilosta cores).

Fig. 11. Selected chitinozoan species. **A–C**, *Conochitina postarmillata* sp. nov. A, C, Gussev-1 core, depth 1456.5 m, Gorstian Stage; A, GIT 527-39, A-1, ×280, A-2, ×700; C, GIT 527-40, C-1, ×260, C-2, ×700; B, holotype GIT 527-40, Ventspils core, depth 647 m, Dubysa Formation, B-1, ×330, B-2, ×700. **D**, **E**, *Ancyrochitina desmea* Eisenack 1964, Dubysa Formation. D, GIT 527-42, Ventspils core, depth 613 m, ×300, E, GIT 527-43, Ventspils core, depth 617 m, ×240. **F–H**, *Eisenackitina lagena* (Eisenack 1968). F–G, Gussev-1 core, depth 1431.6 m, Gorstian Stage; F, GIT 527-44, F-1, ×180, F-2, ×2000; G, GIT 527-45, G-1, ×200, G-2, ×5000; H, GIT 527-46, Ventspils core, depth 631 m, Dubysa Formation, ×190. **I**, *Ancyrochitina* cf. *valladolitana* Schweineberg 1987, GIT 527-47, Gussev-1 core, depth 1425.3 m, Gorstian Stage, ×340. **J**, *Ancyrochitina* sp. GIT 527-48, Pavilosta core, depth 880–880.3 m, Siesartis Formation, ×250. **K**, *Eisenackitina toddingensis* Sutherland 1994, GIT 527-49, Pavilosta core, depth 831–831.3 m, Dubysa Formation, ×210. **L**, *Sphaerochitina impia* Laufeld 1974, GIT 527-50, Ohesaare core, depth 118–118.05 m, Paadla Stage, ×320. **M**, *Ancyrochitina brevispinosa* Eisenack 1968, GIT 527-51, Ohesaare core, depth 118–118.05 m, Paadla Stage, ×240. **N**, *Belonechitina latifrons* (Eisenack 1964), GIT 527-52, Ohesaare core, depth 118–118.05 m, Paadla Stage, ×230. **O**, *Belonechitina lauensis* (Laufeld 1974), GIT 527-53, Gussev-1 core, depth 1425.3 m, Gorstian Stage, ×300. **P**, *Angochitina elongata* Eisenack 1931, GIT 527-54, Gussev-1 core, depth 1425.3 m, Gorstian Stage, ×300.

2. Most of the Wenlock chitinozoan species become extinct in the upper part of the Sõrve, Jaagarahu, and Riga formations of the Jaagarahu Stage (Mulde Event of the conodont succession).
3. The top Wenlock *Sphaerochitina lycoperdoides* global chitinozoan Biozone was for the first time established in the East Baltic Ohesaare, Kolka, and Pavilosta sections, where it occurs in the Viita Beds and Siesartis Formation of the Rootsiküla Stage, corresponding to the *nassa* and *ludensis* graptolite zones. The *S. lycoperdoides* Biozone was determined also in the Gusev-1 core of the Kaliningrad district, in the Homerian and lowermost Gorstian stages.
4. A new *Conochitina postarmillata* Biozone, corresponding to the *nilssoni* graptolite Zone, was established in the Dubysa Formation of the Paadla Stage in the Ventspils and Pavilosta cores. This biozone was determined also in the Gorstian Stage of the Gussev-1 core. The zonal species occurs very likely also in the sections of the Ludlow type area (= *Conochitina* sp. A in Sutherland 1994).
5. The *Ancyrochitina desmea* Biozone was established in the Dubysa Formation of the Ventspils and Pavilosta cores, corresponding to the lower part of the *scanicus* graptolite Zone. *Ancyrochitina desmea* has been recorded from the Hemse Beds of Gotland and Skåne (Laufeld 1974; Grahn 1996), corresponding also to the *scanicus* Zone. It is also known from the sections of the Ludlow type area (Dorning 1981) and from Palencia, North Spain (Schweineberg 1987). *Ancyrochitina* cf. *desmea* has been identified in the Ludlow of western Gondwana (Grahn 2006). Considering the wide distribution of the zonal species, the *Anc. desmea* Biozone might be a good candidate for a global biozone in the future, filling partly a gap in the chitinozoan biozonal succession.
6. The appearance of *Angochitina elongata*, marking the lower boundary of the respective global chitinozoan biozone in the middle Ludlow, was observed in all studied East Baltic core sections.

DESCRIPTION OF SELECTED TAXA

Most of the chitinozoan taxa, reported from the Wenlock–Ludlow boundary beds in the course of the present study, have been described from Gotland (Eisenack 1964; Laufeld 1974), Skåne (Grahn 1996), Bohemia (Paris & Kříž 1984), Palencia (Schweineberg 1987), Shropshire (Sutherland 1994), erratic boulders in the Baltic Sea (Eisenack 1968), and Estonia (Nestor 1994).

Two new species and *Eisenackitina lagena* (Eisenack) are described below. Dimensions of vesicles are denoted as follows: L = total length, D = maximum diameter, dap = diameter of aperture.

All figured specimens of chitinozoans are deposited in collection No. 527 of the Institute of Geology (GIT) at Tallinn University of Technology, Estonia.

Group CHITINIZOA Eisenack, 1931
Order PROSOMATIFERA Eisenack, 1972
Family CONOCHITINIDAE Eisenack, 1931 emend. Paris, 1981
Subfamily CONOCHITININAE Eisenack, 1931
Genus *Conochitina* Eisenack, 1931, emend. Paris et al., 1999.

Conochitina postarmillata sp. nov.
Figure 11A–C

1982 *Conochitina* sp. 1; Nestor, pp. 92–93.
?1994 *Conochitina* sp. A; Sutherland, p. 49, pl. 9, figs 12, 13.

Derivation of name. Refers to similarity with the overall shape of *Conochitina armillata*, occurring in the Wenlock.

Holotype. GIT 527-40, Fig. 11B-1, B-2, Ventspils core, depth 647 m. Dubysa Formation, Lower Ludlow, Latvia.

Diagnosis. Vesicle cylindro-ovoidal with more or less differentiated chamber and neck. Flexure and shoulder slightly developed, base weakly convex with broadly rounded basal margin. Chamber flanks slightly convex with the maximum diameter at or near the middle part of the chamber. Neck cylindrical and slightly shorter than the chamber. Base carries a wide low callus with depression at the centre, where discrete mucron is situated. Vesicle wall smooth, but shows faint rugose ornamentation at high magnifications.

Dimensions (15 specimens measured). L: 165–280 µm (holotype 166); D: 70–115 µm (holotype 71); dap: 50–75 µm (holotype 57); L/D: 1.8–2.7 (holotype 2.3); D/dap: 1.2–1.8 (holotype 1.2).

Remarks. In flattened specimens the base is flat and the mucron is not seen. *Conochitina postarmillata* has similar features with some other species. The holotype of *Con. armillata* Taugourdeau & Jekhowsky (1960) has a clear protruding mucron and its basal margin is not developed. *Conochitina pumilio* Verniers et al. (2002) is smaller (105–154 µm) and without a mucron. *Conochitina subcyatha* Nestor 1982 has a conical chamber, the basal edge is better developed and the neck of the vesicle is longer than the chamber.

Occurrence. Lower Ludlow of the East Baltic: the lower part of the Dubysa Formation of the Paadla Stage and the lower part of the Gorstian Stage. Ventspils core, 643–651 m; Pavilosta core, 846–852.3 m; Gussev-1 core, 1437–1456.5 m. ?Lower Elton Formation of the Goggin Road, England.

Genus *Rhabdochitina* Eisenack, 1931

Rhabdochitina sera sp. nov.
Figure 10M–P

1982 *Rhabdochitina* sp. 1; Nestor, pp. 92–93.
1982 *Rhabdochitina* sp. 2; Nestor, pp. 92–93.
1987 *Rhabdochitina* sp. A; Schweineberg, pp. 49–50, pl. 3, figs 5, 10, 11.
2001 *Rhabdochitina conocephala*? Grahn & Guitiérrez, p. 40, fig. 10J.

Derivation of name. Refers to belated appearance of *Rhabdochitina* species in the Ludlow. Representatives of this genus are mostly of Ordovician age.

Holotype. GIT 527-35, Fig. 10M-1, M-2, Ventspils core, depth 655 m, Dubysa Formation, Lower Ludlow, Latvia.

Diagnosis. Long cylindrical vesicles with convex base, which may be indented. Basal edge is widely rounded or inconspicuous. Mucron wide and button-like. Vesicle wall smooth.

Dimensions (28 specimens measured). L: 500–1300 µm (mean 830 µm), holotype 1260 µm; D: 50–90 µm (mean 74 µm), holotype 87 µm (corrected by 0.7); L/D: 11.2 (mean).

Remarks. The mucron is usually not seen in flattened specimens and in those with an indented base. *Rhabdochitina conocephala* Eisenack has a flat base and it is shorter. *Rhabdochitina magna* Eisenack is long, but lacks a mucron.

Occurrence. Uppermost Wenlock and Lower Ludlow of the East Baltic: Viita Beds of the Rootsiküla Stage in the Kolka core, 359–400 m; Siesartis Formation of the Rootsiküla Stage and the lowermost part of the Dubysa Formation in the Ventspils core, 655–667 m; Siesartis Formation in the Pavilosta core, 862–883.3 m; boundary beds of the Homerian and Gorstian stages in the Gussev-1 core, 1459.8–1467.8 m.

Family DESMOCHITINIDAE Eisenack, 1931
Subfamily DESMOCHITININAE Paris, 1981
Genus *Eisenackitina* Jansonius, 1964

Eisenackitina lagena (Eisenack 1968)
Figure 11F–H

1968 *Conochitina lagena* Eisenack, p. 165, pl. 26, figs 1–5.
1982 *Conochitina* cf. *lagena* Nestor, pp. 92–93.
non 1990 *Eisenackitina lagena* Nestor, pl. 14, fig. 32.
non 1994 *Eisenackitina lagena* Nestor, pp. 17–18, pl. 14, figs 9–11; p. 15, figs 1, 2.
1993 *Eisenackitina pregranosa* Dufka, pp. 381–382, pl. 3, figs 1–5.
?2002 *Eisenackitina lagena* Verniers et al., pl. II, figs 1, 2.

Description. Barrel-shaped vesicles with more or less developed flexure. The centre of the base is slightly concave, with a wide and low mucron. The basal margin in inconspicuous. The neck is not developed, but the aperture is slightly widening. The porous vesicle wall is densely covered by granules or tubercles.

Remarks. In earlier papers the author misidentified the species *Eisenackitina lagena* (Eisenack 1968) and described it from the middle Wenlock sequence of Estonia and North Latvia (Nestor 1994). High-resolution SEM study, however, revealed differences in the ornamentation of the vesicle wall in the Wenlock and Ludlow material of two species that are usually identical in the overall shape of the vesicles. Eisenack (1968) described the original material of *Conochitina lagena* from the graptolitic erratic boulders of Early Ludlow age. Swire (1990) described *Eisenackitina spongiosa* from the

Middle Wenlock Coalbrookdale Formation, Shropshire. It had spongy ornamentation of the vesicle wall like that in well-preserved Wenlock specimens of the East Baltic (Nestor 1994, pl. 15, fig. 2). Thus, not *Eisenackitina lagena* but *E. spongiosa* occurs in the East Baltic Wenlock sections and the regional biozone between the *Cin. cingulata* and *Con. pachycephala* zones (see Nestor 1990, 1994) has to be renamed the *E. spongiosa* Biozone.

Occurrence. Lower Ludlow of the East Baltic: middle part of the Dubysa Formation of the Paadla Stage – in the Ventspils core at 617–635 m, in the Pavilosta core at 836.40–836.60 m; lower–middle part of the Gorstian Stage in the Gussev-1 core, 1431–1441 m.

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Kitiinikud Ida-Balti Wenlocki–Ludlowi piirikihtides

Viiu Nestor

Kitiiniku liikide levik ja biotsoonid on kindlaks tehtud viies Ida-Balti puuraugu Wenlocki–Ludlowi piirikihtides. Esmakordselt on eristatud *Sphaerochitina lycoperdoides*'e, *Conochitina postarmillata* ja *Ancyrochitina desmea* biotsoonid, mis on rööbistatud samade tasemetega teistes regioonides. On kirjeldatud kolme liiki, millest kaks on uued: *Rhabdochitina sera* sp. nov. ja *Conochitina postarmillata* sp. nov.