

Chitinozoans of the *Margachitina margaritana* Biozone and the Llandovery–Wenlock boundary in West Estonian drill cores

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Abstract. The succession of chitinozoan taxa in the uppermost Llandovery and lowermost Wenlock of the Viki, Ohesaare, Kaugatuma, and Ruhnu drill core sections is described and correlated with the global stratotype section of the basal Wenlock in Hughley Brook, Shropshire, England. The most important biomarkers for the identification of the Llandovery–Wenlock boundary in Estonian sections are the disappearance levels of *Ramochitina nestorae*, *Conochitina acuminata*, *C. cf. flamma*, and *Angochitina longicollis*. In the West Estonian cores this boundary corresponds to a level in the middle or upper part of the *Margachitina margaritana* Biozone. In the Viki and Ohesaare cores it coincides with the bentonite layers above the accepted boundary between the Adavere and Jaani regional stages and correlates with a level in the middle of the *murchisoni* graptolite Biozone. Three new species, *Belonechitina oeselensis*, *Ancyrochitina mullinsi*, and *Eisenackitina inanulifera*, are described.

Key words: chitinozoans, correlation, Llandovery, Wenlock, Silurian, Estonia.

INTRODUCTION

The boundary between the Adavere and Jaani regional stages in Estonian sections has been considered as the Llandovery–Wenlock boundary (Kaljo 1962). In the Ohesaare drill core a metabentonite layer at a depth of 345.8 m has been treated as the boundary marker of the stratotype level between the Adavere and Jaani stages (Nestor 1997). According to Kaljo (1962) and Loydell et al. (1998),

a fragment of *Cyrtograptus* is present at 345.11–345.14 m, being indicative of the lowermost Wenlock. The interval of 352.80–345.14 m did not yield zonal graptolites. In the Ohesaare core, as in some other sections, a change in sediment colour can be traced at the boundary level. The greenish mudstones of the uppermost Llandovery (Velise Formation) are replaced by dark grey or brownish mudstones in the basal Wenlock (Riga Formation). The study of the Aizpute-41 core showed that the change in colour does not always correspond to the position of the Llandovery–Wenlock boundary (Loydell et al. 2003, figs. 2, 12). In more calcareous sections this boundary is usually lithologically indistinct. In addition, a stratigraphical gap was proven to exist at the junction of the Adavere and Jaani stages, having a considerable areal extent and stratigraphical range in southwestern Estonia and northernmost Latvia (Nestor & Nestor 2002). This also complicates the exact definition of the boundary.

The international stratotype for the base of the Wenlock Series has been defined in the Hughley Brook section in Shropshire, Welsh Borderland (Bassett et al. 1975). It is a transition between purple and grey-green mudstones, where no graptolites have been recorded and correlation with the graptolite biozonation is based on indirect evidences from other sections. The use of microfossils for correlation of the base of the Wenlock was investigated by Mabillard & Aldridge (1985), but they estimated that the base did not coincide with the base of any microfossil biozone. A re-examination of microfossils, particularly chitinozoans from the samples of the Hughley Brook section was recently undertaken by Mullins & Aldridge (2004). They describe a diverse and abundant assemblage of chitinozoans, containing also new species and forms. This study stimulated re-examination of chitinozoans from the Llandovery–Wenlock boundary interval in some Estonian drill cores with the aim of finding possibilities of more precise correlation with the international boundary stratotype in Welsh Borderland.

In the chitinozoan zonal succession the base of the *Margachitina margaritana* Biozone has gained special attention as a possible criterion for the determination of the Llandovery–Wenlock boundary. At first it was recorded just above the Wenlock boundary in the Ohesaare core (Nestor 1984), then also at the base of the Wenlock in the international boundary stratotype (Mabillard & Aldridge 1985). Later it has been used as a marker of the Llandovery–Wenlock boundary in a global biozonal scheme of chitinozoans (Verniers et al. 1995). Recent investigation of chitinozoans and graptolites in the Welsh area (Mullins 2000; Mullins & Loydell 2001) enables a detailed correlation between the graptolite and chitinozoan biozones, including the determination of a more exact position for the base of the *M. margaritana* Biozone. It appears to lie within the lowermost *insectus* Biozone in the graptolite zonal succession (Mullins & Loydell 2001), being indicative of the uppermost Llandovery.

CHITINOZOAN BIOSTRATIGRAPHY

Thirty-one biozonal units were established in the entire Silurian sequence of the East Baltic (Nestor 1990), five of which were treated as interzones, poorly characterized by chitinozoans. Later Nestor (1994) described more precisely 22 biozones from the Llandovery and Wenlock.

In this paper the chitinozoan succession in the upper Telychian and lower Wenlock beds of some West Estonian core sections (Fig. 1) is discussed. The ranges of chitinozoan species in the Viki (Fig. 2), Kaugatuma (Fig. 3), Ohesaare (Fig. 4), and Ruhnu (Fig. 5) cores are illustrated. The most characteristic biozone succession in ascending order is the following: *Angochitina longicollis*, *Conochitina proboscifera*, *C. acuminata*, and *Margachitina margaritana*. In the Ohesaare core also the *Margachitina banwyensis* Biozone is established. In some cases the zonal species may appear almost simultaneously or close to each other, for instance *C. acuminata*, *M. banwyensis*, and *M. margaritana* in



Fig. 1. Location of the studied West Estonian drill holes.

Viki core

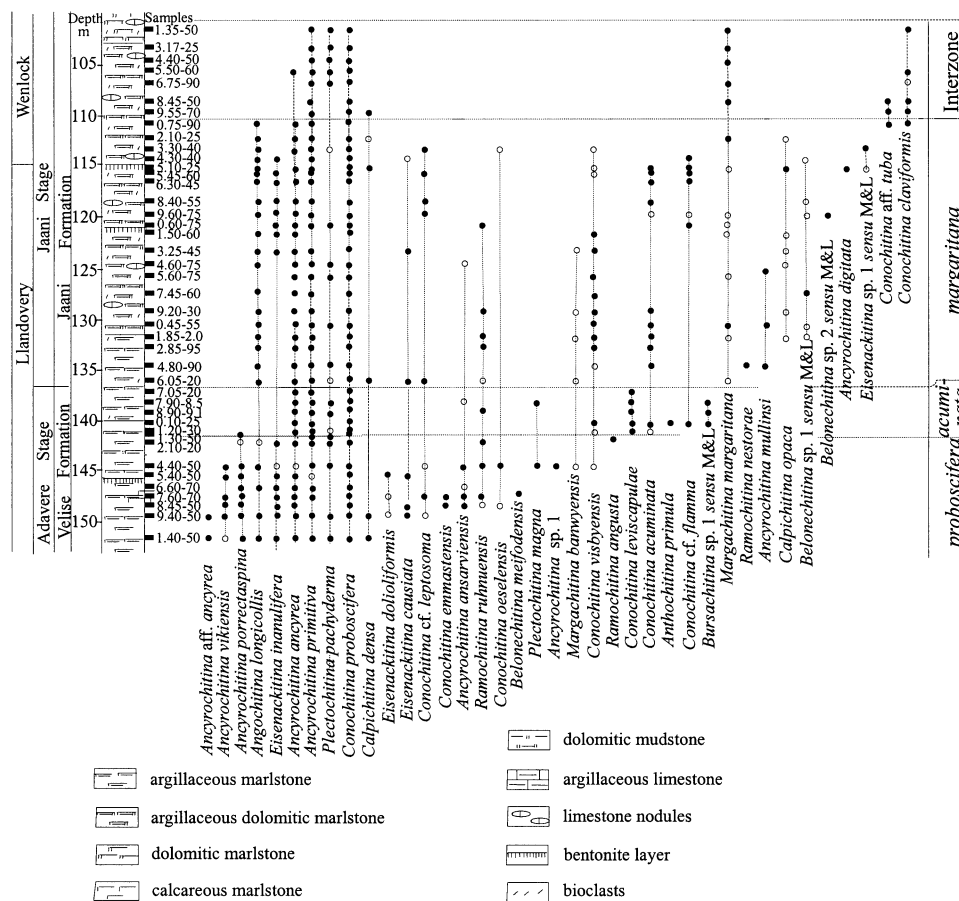


Fig. 2. Lithological log and ranges of chitinozoan species in the Llandovery–Wenlock boundary interval in the Viki drill core.

the Kaugatuma core (Fig. 3), *Margachitina banwyensis* and *M. margaritana* in the Ruhnu core (Fig. 5) or *C. proboscifera* and *M. margaritana* in the Ventspils core (Loydell & Nestor in press), which complicates the identification of several biozones.

Figures 2–5 display only the upper part of the *C. proboscifera* Biozone. The *C. acuminata* Biozone is distinguished in the Ohesaare, Viki, and Ruhnu cores, the *Margachitina banwyensis* Biozone only in the Ohesaare core. The upper boundary of the *M. margaritana* Biozone is marked in the East Baltic sections by

the disappearance of *A. longicollis*; above that level an Interzone is present, ranging up to the appearance of *Conochitina mamilla*, the index species of the covering biozone (see Nestor 1994).

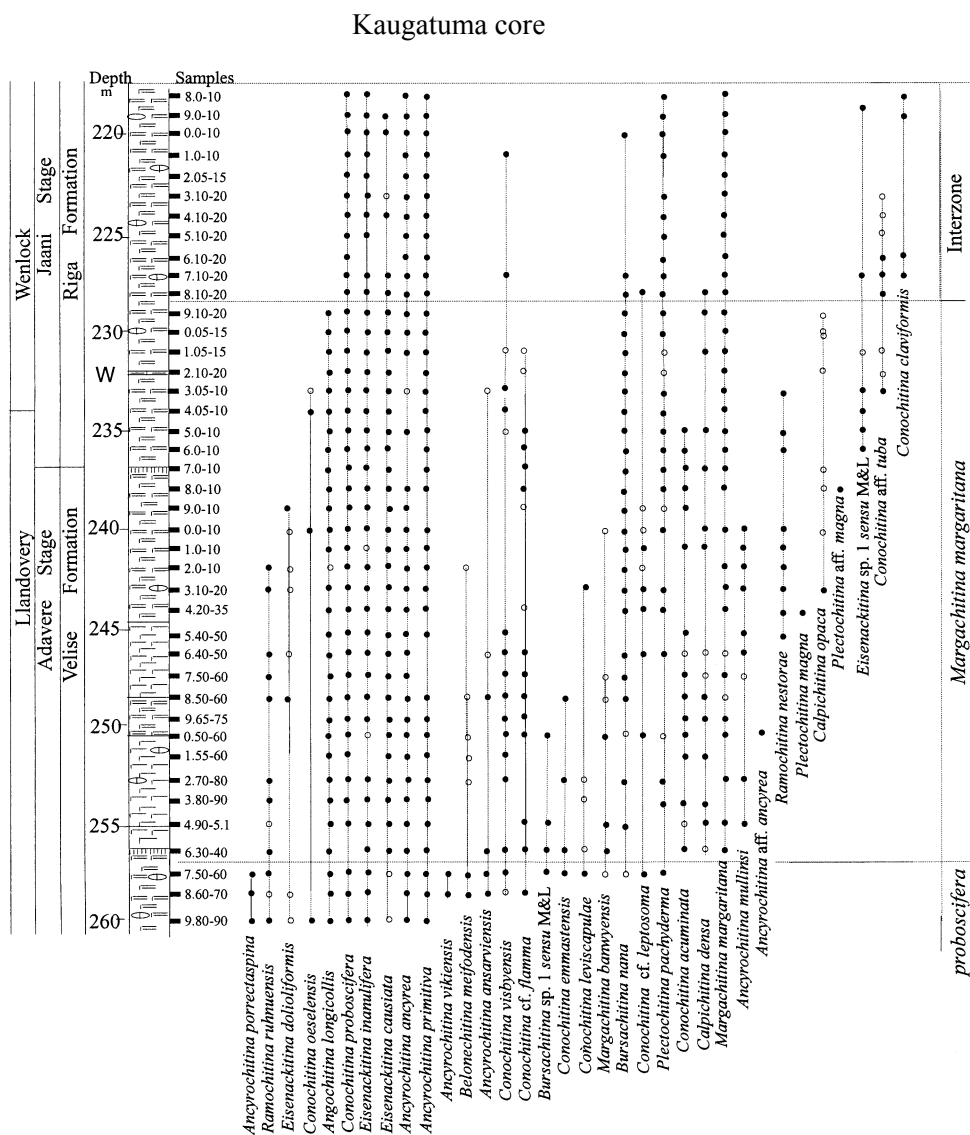


Fig. 3. Lithological log and ranges of chitinozoan species in the Llandoverly–Wenlock boundary interval in the Kaugatuma drill core. For legend see Fig. 2.

Ohesaare core

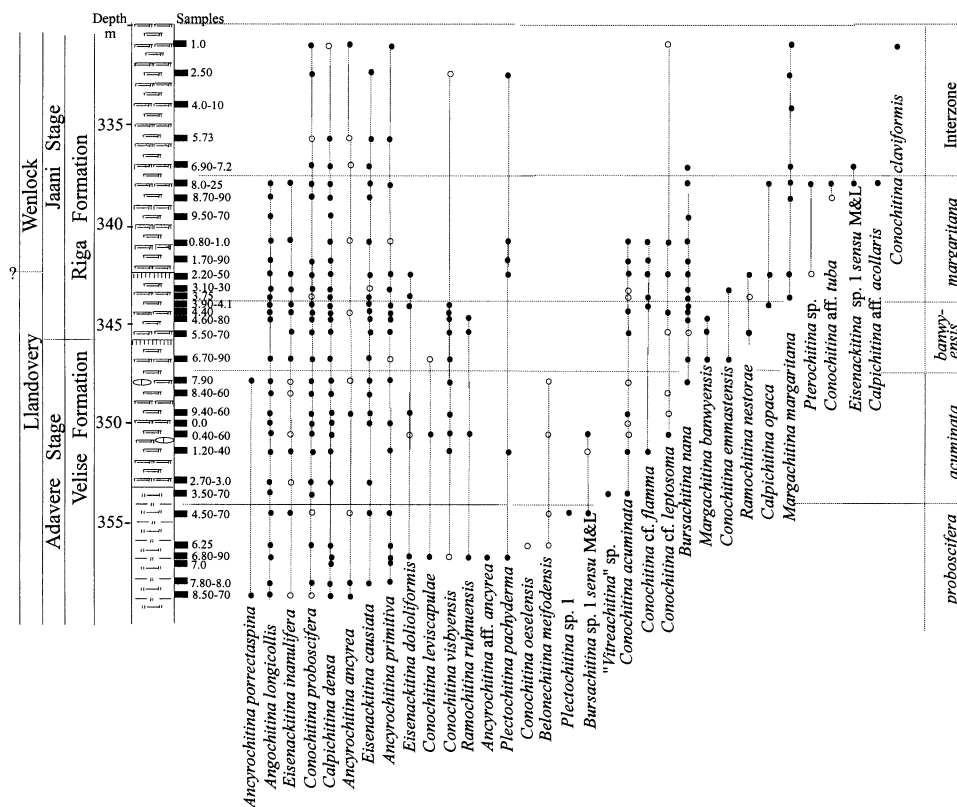


Fig. 4. Lithological log and ranges of chitinozoan species in the Llandoverly–Wenlock boundary interval in the Ohesaare drill core. For legend see Fig. 2.

Chitinozoan distribution below the *Margachitina margaritana* Biozone

Most of the chitinozoan taxa occurring in the *C. proboscifera* and *C. acuminata* biozones range from the lower or middle Telychian. The appearance level of some species has been connected with graptolite data. *Angochitina longicollis* Eisenack (Pl. I, fig. 7) is represented from the lower part of the *spiralis* graptolite Biozone (Loydell et al. 2003; Põldvere et al. 2003), *C. proboscifera* Eisenack (Pl. I, figs. 8, 9) from the middle or upper *spiralis* Biozone (Loydell et al. 2003; Loydell & Nestor in press). The appearance of *Ramochitina ruhnuensis* (Nestor) (Pl. I, fig. 3) is probably related to the lowermost *lapworthi* Biozone (Loydell et al. 1998). According to Mullins & Loydell (2001), the *Conochitina acuminata* Biozone is

Ruhnu core

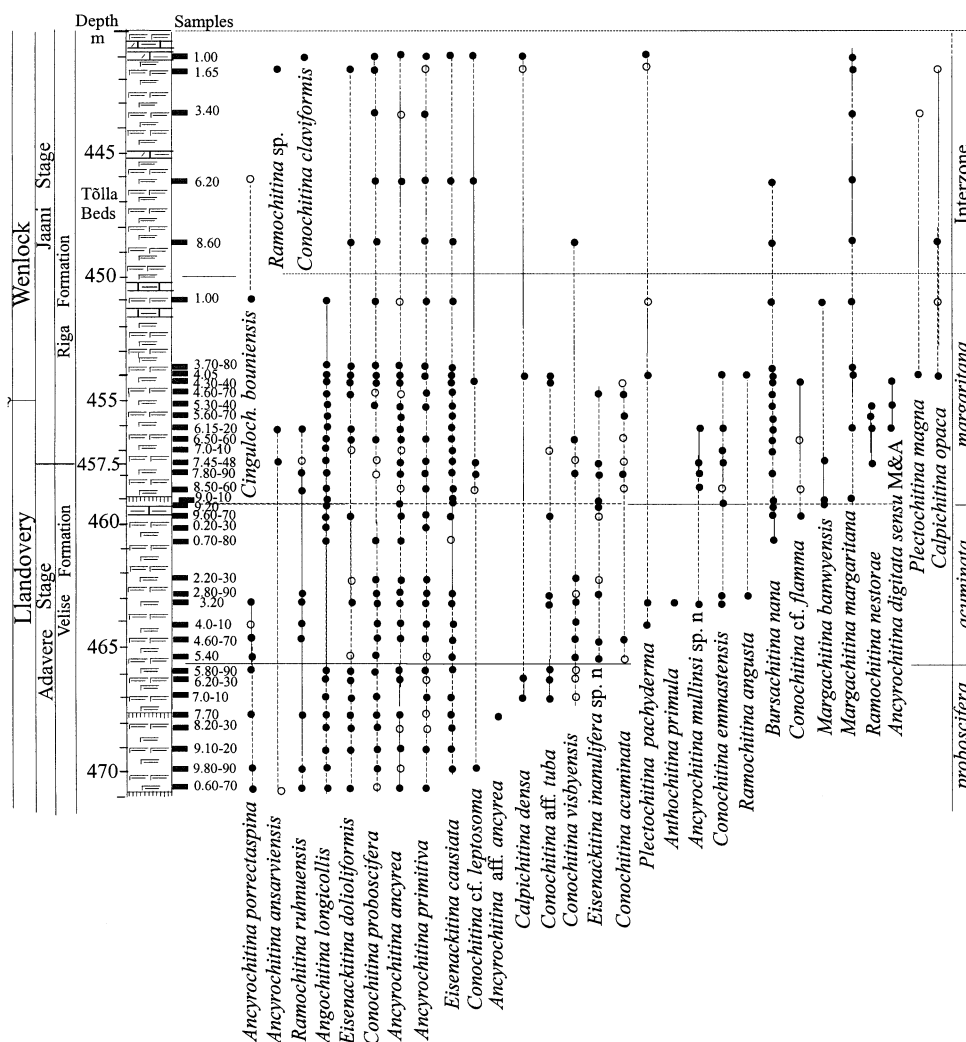
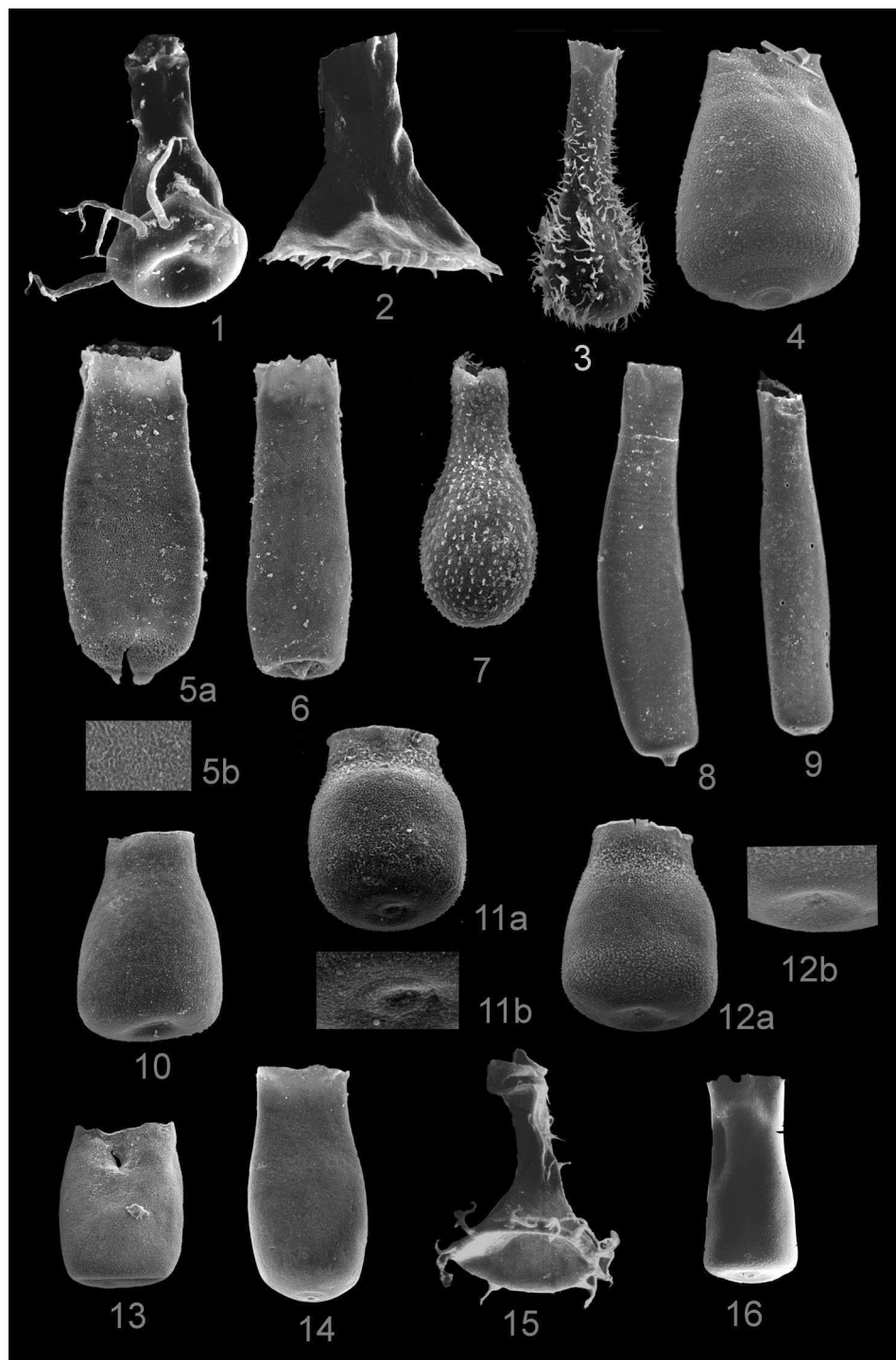


Fig. 5. Lithological log and ranges of chitinozoan species in the Llandoverly–Wenlock boundary interval in the Ruhnu drill core. For legend see Fig. 2.

correlated with the *lapworthi* Biozone in the Banwy River section. In the Ohesaare core the *lapworthi* Biozone has been established at 356.14 and 352.80–352.88 m (Loydell et al. 1998). The latter interval corresponds to the lower part of the *C. acuminata* Biozone (Fig. 4). Besides *C. acuminata* Eisenack (Pl. II, fig. 9), there occur more frequently *C. proboscifera* and *C. visbyensis* Laufeld (Pl. I, fig. 16).

PLATE I



In the upper part of this zone *Conochitina* cf. *flamma* Laufeld (Pl. II, fig. 1) and *Bursachitina nana* (Nestor) make their appearance (Pl. II, figs. 4–6). Quite unique are the findings of *Anthochitina primula* Nestor (Pl. III, fig. 6) in the *C. acuminata* Biozone of the Viki and Ruhnu cores. Below the *M. margaritana* Biozone, *Ancyrochitina porrectaspina* Nestor (Pl. I, fig. 1) disappears, as do *A. vikiensis* Nestor (Pl. I, fig. 15), *Belonechitina* cf. *meifodensis* Mullins & Loydell (Pl. I, fig. 14) and *Bursachitina* sp. 1 by Mullins & Loydell (2001).

Margachitina banwyensis Mullins (Pl. II, fig. 11) has been described from the Wenlock type area (Mullins 2000) as a predecessor of *M. margaritana*. In the

Explanation of Plate I

Fig. 1. *Ancyrochitina porrectaspina* Nestor 1994, GIT 272-39, Ruhnu core, depth 464.60–464.70 m, Adavere Stage, ×250.

Fig. 2. *Ancyrochitina ansarviensis* Laufeld 1974, GIT 272-27, Viki core, depth 148.45–148.50 m, Adavere Stage, ×440.

Fig. 3. *Ramochitina ruhnuensis* (Nestor 1982), GIT 427-1, Kaugatuma core, depth 242.0–242.10 m, Adavere Stage, ×200.

Fig. 4. *Eisenackitina dolioliformis* Umnova 1976, GIT 427-2, Kaugatuma core, depth 246.45–246.55 m, Adavere Stage, ×180.

Figs. 5, 6. *Belonechitina oeselensis* sp. nov., Adavere Stage. 5, Holotype GIT 427-3, Kaugatuma core, depth 234.05–235.10 m: 5a, ×180; 5b, close-up of the ornament, ×400. 6, GIT 427-4, Kaugatuma core, depth 240.0–240.10 m, ×145.

Fig. 7. *Angochitina longicollis* Eisenack 1959, GIT 427-5, Kaugatuma core, depth 235.0–235.10 m, Adavere Stage, ×185.

Figs. 8, 9. *Conochitina proboscifera* Eisenack 1937, Kaugatuma core, depth 245.40–245.50 m, Adavere Stage, ×140. 8, GIT 427-6; 9, GIT 427-7.

Figs. 10–12. *Eisenackitina inanulifera* sp. nov., Kaugatuma core, Adavere Stage. 10, GIT 427-8, depth 235.0–235.10 m, ×160. 11, Holotype GIT 427-9, depth 242.0–242.10 m: 11a, ×160; 11b, close-up of the mucron, ×700. 12, GIT 427-10, depth 242.0–242.10 m: 12a, ×160; 12b, close-up of the mucron, ×700.

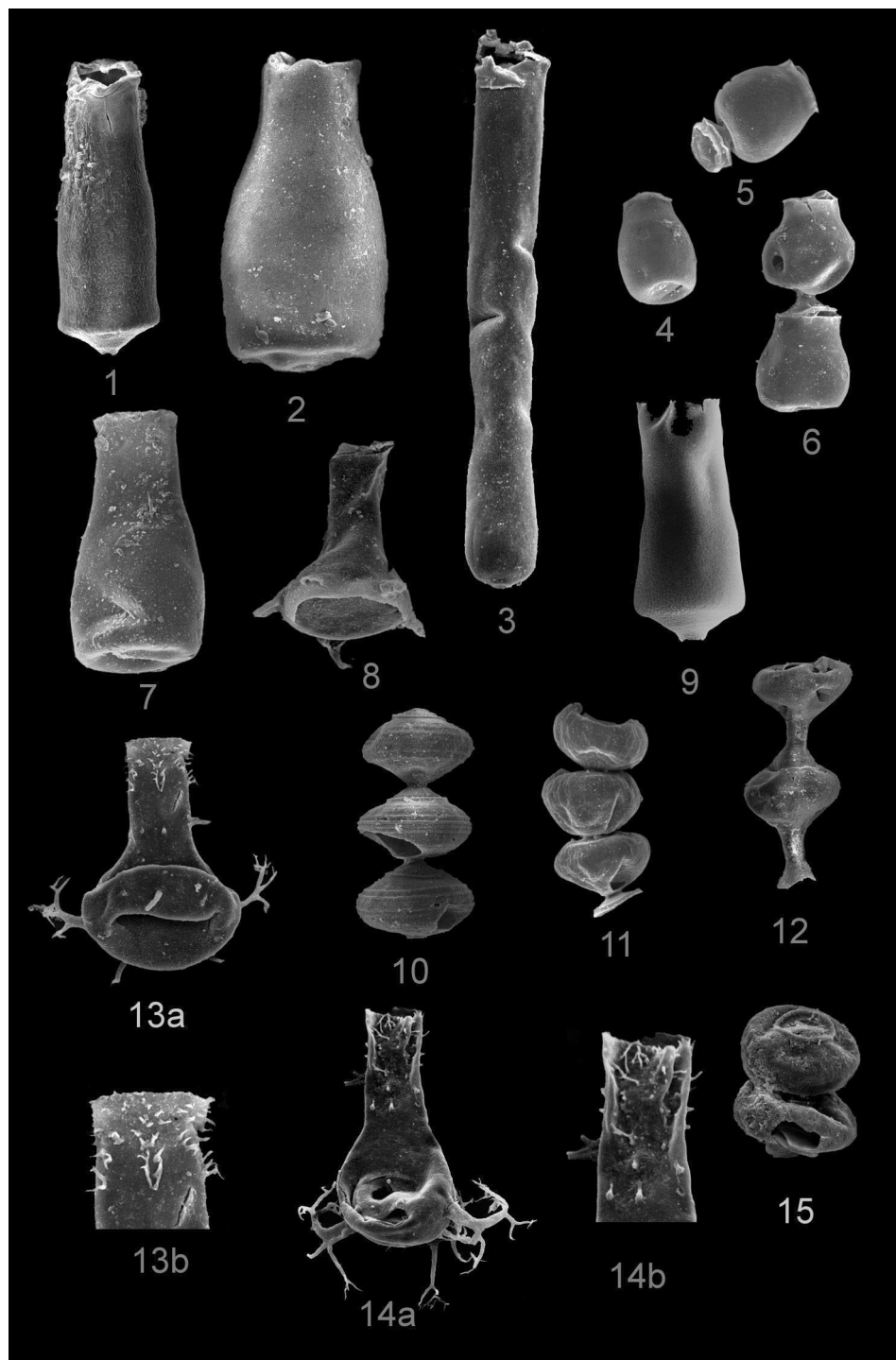
Fig. 13. *Eisenackitina causiata* Verniers 1999, GIT 427-11, Kaugatuma core, depth 237.0–237.10 m, Adavere Stage, ×160.

Fig. 14. *Belonechitina* cf. *meifodensis* Mullins & Loydell 2001, GIT 427-12, Kaugatuma core, depth 242.0–242.10 m, Adavere Stage, ×150.

Fig. 15. *Ancyrochitina vikiensis* Nestor 1994, GIT 272-27, Viki core, depth 147.45–147.60 m, Adavere Stage, ×300.

Fig. 16. *Conochitina visbyensis* Laufeld 1974, GIT 272-135, Ohesaare core, depth 349.40–349.60 m, Adavere Stage, ×230.

PLATE II



East Baltic sections the *M. banwyensis* Biozone is usually hardly distinguishable from the *M. margaritana* Biozone as the index species occurs sporadically and appears usually very close (0.2–1.0 m) to the base of the *M. margaritana* (Pl. II, fig. 12) Zone. In the Ohesaare core this biozone is identified in the interval of about 343.80–347.40 m, embracing at least the lowest part of the *murchisoni* graptolite Biozone (Loydell et al. 1998). In the Banwy River section the *M. banwyensis* Biozone correlates with the upper part of the *lapworthi* and lower part of the *insectus* graptolite biozones, but the zonal species ranges up to the topmost *centrifugus* Biozone (Mullins & Loydell 2001).

Explanation of Plate II

Fig. 1. *Conochitina flamma* Laufeld 1974, GIT 427-13, Kaugatuma core, depth 237.0–237.10 m, Adavere Stage, ×170.

Fig. 2. *Conochitina emmastensis* Nestor 1982, GIT 427-14, Kaugatuma core, depth 252.70–252.80 m, Adavere Stage, ×115.

Fig. 3. *Conochitina* cf. *leptosoma* Laufeld 1974, GIT 427-15, Kaugatuma core, depth 241.0–241.10 m, Adavere Stage, ×120.

Figs. 4–6. *Bursachitina nana* (Nestor 1994), Kaugatuma core, Adavere Stage. 4, 5, depth 237.0–237.10 m, ×130. 4, GIT 427-16; 5, GIT 427-17. 6, GIT 427-17, depth 240.0–240.10 m, ×120.

Fig. 7. *Conochitina* cf. *leviscapulae* Mullins & Loydell 2001, GIT 427-18, Kaugatuma core, depth 243.10–243.20 m, Adavere Stage, ×120.

Fig. 8. *Plectochitina pachyderma* (Laufeld 1974), GIT 427-19, Kaugatuma core, depth 236.0–236.10 m, Adavere Stage, ×235.

Fig. 9. *Conochitina acuminata* Eisenack 1959, GIT 272-62, Ohesaare core, depth 349.40 m, Adavere Stage, ×290.

Fig. 10. *Calpichitina densa* (Eisenack 1962), GIT 427-20, Kaugatuma core, depth 250.50–250.60 m, Adavere Stage, ×140.

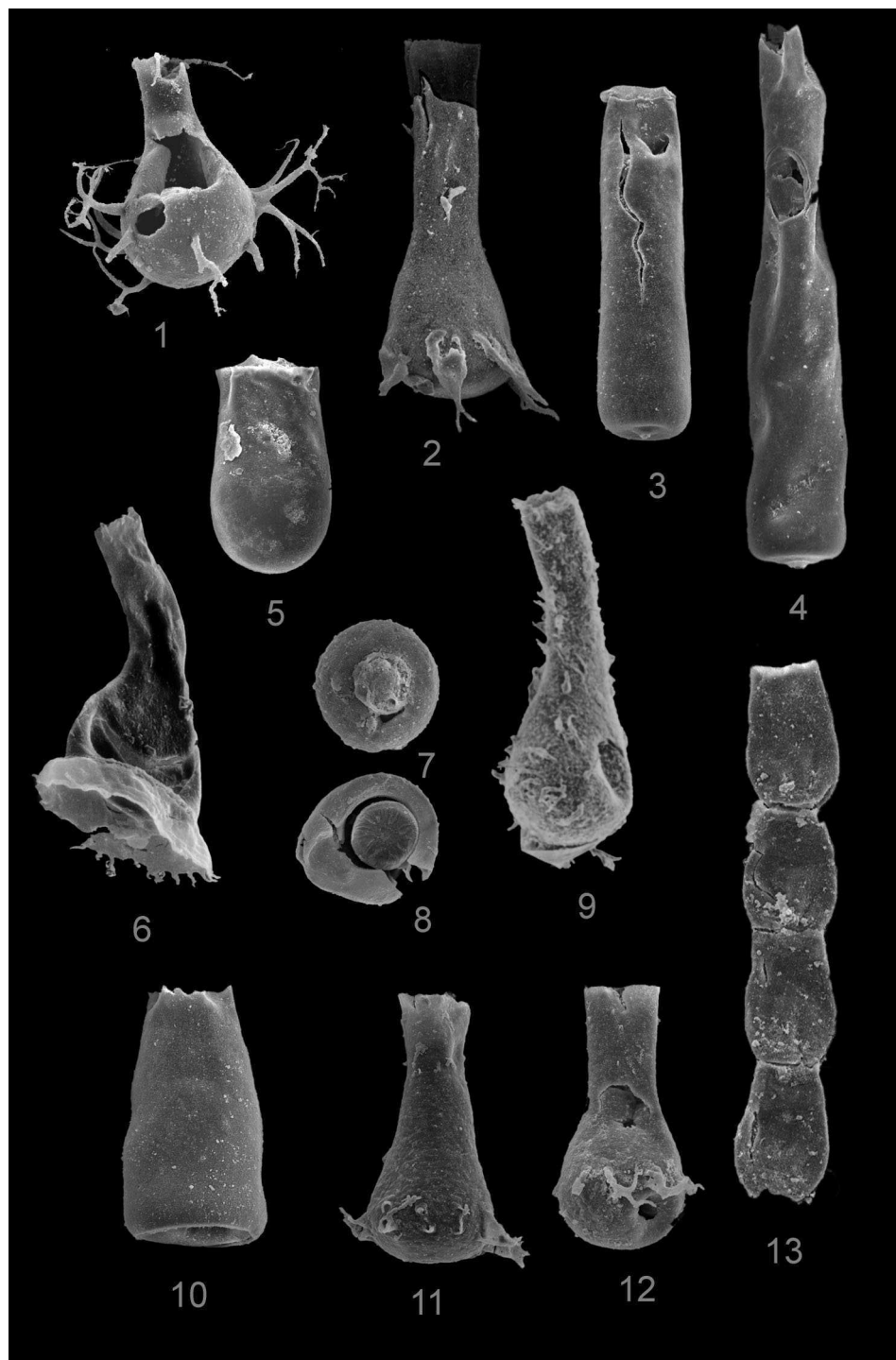
Fig. 11. *Margachitina banwyensis* Mullins 2000, GIT 427-21, Kaugatuma core, depth 240.0–240.10 m, Adavere Stage, ×140.

Fig. 12. *Margachitina margaritana* (Eisenack 1937), GIT 427-22, Kaugatuma core, depth 240.0–240.10 m, Adavere Stage, ×140.

Figs. 13, 14. *Ancyrochitina mullinsi* sp. nov., Kaugatuma core, Adavere Stage. 13, Holotype GIT 427-23, depth 242.0–242.10 m: 13a, ×220; 13b, close-up of the neck ornament, ×400. 14, GIT 427-24, depth 246.40–246.50 m: 14a, ×200; 14b, close-up of the neck ornament, ×330.

Fig. 15. *Calpichitina opaca* (Laufeld 1974), GIT 427-25, Ohesaare core, depth 342.20 m, Adavere Stage, ×140.

PLATE III



The *Margachitina margaritana* Biozone

In the East Baltic core sections this biozone is defined from the appearance level of the zonal species up to the disappearance of *Angochitina longicollis* (Nestor 1990, 1994). The thickness of this biozone is quite different in the studied cores: it is thicker in the Kaugatuma (28.3 m) and Viki (27.2 m) cores, but thinner in the Ohesaare (6.15 m) and Ruhnu (9.0 m) cores. The most diverse assemblage of chitinozoans (30 species) occurs in the Kaugatuma core. Twenty-six species have been distinguished in the Ruhnu and Viki cores and 21 species in the Ohesaare core. In this biozone some levels of chitinozoan extinction as the “datums” of the Ireviken Event were recognized. The disappearance of *C. acuminata* and

Explanation of Plate III

Fig. 1. *Ramochitina nestorae* Grahn 1995, GIT 427-26, Kaugatuma core, depth 243.10–243.20 m, Adavere Stage, ×175.

Fig. 2. *Plectochitina magna* (Nestor), GIT 427-27, Kaugatuma core, depth 244.20–244.35 m, Adavere Stage, ×110.

Fig. 3. *Conochitina* aff. *tuba* Eisenack 1932, GIT 427-28, Kaugatuma core, depth 233.05–233.15 m, Jaani Stage, ×110.

Fig. 4. *Conochitina claviformis* Eisenack 1931, GIT 427-29, Viki core, depth 110.75–110.90 m, Jaani Stage, ×110.

Fig. 5. *Eisenackitina* sp. 1 *sensu* Mullins & Loydell 2001, GIT 427-30, Kaugatuma core, depth 231.05–231.15 m, Jaani Stage, ×190.

Fig. 6. *Anthochitina primula* Nestor 1994, GIT 272-31, Viki core, depth 140.10–140.25 m, Adavere Stage, ×240.

Figs. 7, 8. *Calpichitina* aff. *acollaris* (Eisenack 1959), GIT 427-31, Ohesaare core, depth 338.25–338.30 m, Jaani Stage, ×290.

Fig. 9. *Ramochitina angusta* (Nestor 1982), GIT 219-3, Ruhnu core, depth 454.05 m, Jaani Stage, ×180.

Fig. 10. *Belonechitina* sp. 2 *sensu* Mullins & Loydell 2001, GIT 427-32, Viki core, depth 119.60–119.75 m, Adavere Stage, ×170.

Figs. 11, 12. *Ancyrochitina digitata* Mullins & Aldridge 2004, Ruhnu core, depth 454.05 m, Jaani Stage. 11, GIT 427-33, ×200. 12, GIT 427-34, ×170.

Fig. 13. *Cingulochitina bouniensis* Verniers 1999, chain of four vesicles GIT 427-35, Ruhnu core, depth 451.0 m, Jaani Stage, ×140.

C. cf. flamma characterizes the second event level, correlating with a level between conodont datums 2 and 3 (see Nestor et al. 2002). The most important level (8) in the chitinozoan succession is the disappearance of *A. longicollis*, corresponding to the conodont datum 6.2 in the Ireviken 3 section (Jeppsson & Männik 1993; Nestor et al. 2002). In addition to *M. margaritana*, in this biozone there appear *Ramochitina nestorae* Grahn (Pl. III, fig. 1), *Ancyrochitina mullinsi* sp. nov. (Pl. II, figs. 13, 14), *Plectochitina magna* (Nestor) (Pl. III, fig. 2), *Calpichitina opaca* (Laufeld) (Pl. II, fig. 15), *Ancyrochitina digitata* Mullins & Aldridge (Pl. III, figs. 11, 12), *Belonechitina* sp. 2 *sensu* Mullins & Loydell (Pl. III, fig. 10). The uppermost part of the biozone is characterized by the appearance of *Eisenackitina* sp. 1 *sensu* Mullins & Loydell (Pl. III, fig. 5) and *Conochitina* aff. *tuba* Eisenack (Pl. III, fig. 3) in most of the studied sections, but also tiny *Calpichitina* aff. *acollaris* (Eisenack) (Pl. III, figs. 7, 8) are found in the Ohesaare core and *Cingulochitina bouniensis* Verniers (Pl. III, fig. 13) in the Ruhnu core. Most of the species, occurring more or less numerous in the lower and middle Telychian, disappeared in the *M. margaritana* Biozone and following Interzone, among them *Eisenackitina dolioliformis* Umnova (Pl. I, fig. 4), *E. causiata* Verniers (Pl. I, fig. 13), *E. inanulifera* sp. nov. (Pl. I, figs. 10–12), *Calpichitina densa* (Eisenack) (Pl. II, fig. 10), *Ancyrochitina ansarviensis* Laufeld (Pl. I, fig. 2), *Conochitina emmastensis* Nestor (Pl. II, fig. 2), *C. oeselensis* sp. nov. (Pl. I, figs. 5, 6), *C. cf. leviscapulae* Mullins & Loydell (Pl. II, fig. 7), and also *C. proboscifera*, the dominant species for the uppermost Llandovery and lowermost Wenlock strata. Only a few species, such as *Plectochitina pachyderma* (Laufeld) (Pl. II, fig. 8), *Conochitina* cf. *leptosoma* Laufeld (Pl. II, fig. 3), *Ancyrochitina ancyrea* (Eisenack), and *A. primitiva* Eisenack, continue their range upwards. The index species of the succeeding biozone, *C. claviformis* Eisenack (Pl. III, fig. 4), appears within or just above the Interzone. It is worth mentioning that the Interzone corresponds to the *firmus* and *riccartonensis* graptolite biozones (Loydell et al. 2003).

The Llandovery–Wenlock transition

Chitinozoans from 20 samples of the boundary stratotype section of Hughley Brook were recently re-examined by Mullins & Aldridge (2004). Thirty-three species (including different formas) were distinguished (Fig. 6), 16 of which are also identified in the boundary beds of West Estonian core sections. All four formas of *C. proboscifera*, distinguished by Mullins and Aldridge, are present also in the studied Estonian cores, but their occurrence seems to be irregular. The ranges of stratigraphically most important species at the Llandovery–Wenlock transition are shown in Fig. 7. The topmost part of the range of *C. acuminata* is also included in Fig. 7, as the disappearance level of this species as well as

C. cf. flamma may indicate the approximate position of the Llandovery–Wenlock boundary, determined by conodonts as Datum 2 in the Ireviken 3 locality (Jeppsson & Männik 1993; Nestor et al. 2002). The interval covered by the studied samples is about 0.1 m in the Hughley Brook section, but about 1 m in the Estonian cores. The thickness of the displayed part of the Hughley Brook section is 1.28 m, corresponding to 10 m in the Estonian cores. This probably indicates substantial compaction of shales and mudstones in the stratotype section. An approximate supposed position of the Llandovery–Wenlock boundary and its depth in metres in the cores are also shown in Fig. 7. The ranges of the chitinozoan taxa more useful in the correlation with the boundary stratotype are listed below: *Angochitina longicollis* (in Viki 110.75–1780? m, Kaugatuma 229.10–269.10 m, Ohesaare 338.0–369.66 m, Ruhnu 451.0–487.70 m), *Ramochitina nestorae* (in Viki 134.80–134.90 m, Kaugatuma 233.05–245.50 m, Ohesaare 342.20–345.70 m, Ruhnu 455.30–457.48 m), *Conochitina acuminata* (in Viki 115.10–140.30 m, Kaugatuma 235.0–256.40 m, Ohesaare 340.80–353.70 m, Ruhnu 454.30–465.40 m), *C. cf. flamma* (in Viki 114.30–140.30 m, Kaugatuma 231.05–258.70 m, Ohesaare 340.80–351.40 m, Ruhnu 454.05–459.70 m). Actually, even more significant are the disappearances of these species at the Llandovery–Wenlock boundary or close to it (Fig. 7). Among other species, appearing below the boundary and crossing it in the Hughley Brook section, *Eisenackitina* sp. 1 should be noted in the Viki (113.30–115.25 m), Kaugatuma (219.0–236.10 m), and Ohesaare (336.70–338.20 m) cores. In the stratotype section *Ancyrochitina digitata* and *A. ansarviensis* appear directly above the boundary. In the Estonian cores *A. ansarviensis* occurs mostly in the lowermost beds, and *A. digitata* near the boundary in the Viki (515.10–515.25 m) and Ruhnu (454.30–456.20 m) cores. Unfortunately, a new species *Pterochitina hughleyensis sensu* Mullins & Aldridge, which appears just above the boundary at Hughley Brook (Fig. 6), was not found in Estonian cores. The first occurrence of *Cingulochitina bouniensis* was reported in the stratotype in sample 25/40, 25.6 cm above the base of the Wenlock. The biozone of the same name was distinguished already in the Banwy River section, where it correlates with the uppermost part of the *murchisoni* graptolite Biozone (Mullins & Loydell 2001). This species was found also in the Ruhnu core in the interval of 446.20–451.0 m. Earlier *C. bouniensis* was recognized in the Aizpute-41 core, at a level assigned also to the topmost part of the *murchisoni* Biozone (Loydell et al. 2003). *Conochitina* aff. *tuba* was present upward from sample 25/42. In Estonian cores this species has a similar position in the Viki (108.45–110.90 m), Kaugatuma (223.10–233.10 m), and Ohesaare (238.0–238.90 m) cores. In Ruhnu this species was recognized lower, at the level of the supposed Llandovery–Wenlock boundary (454.05–467.10 m). *Salopochitina bella*, the index species of the succeeding biozone in Hughley Brook, has not been found in Estonian cores.

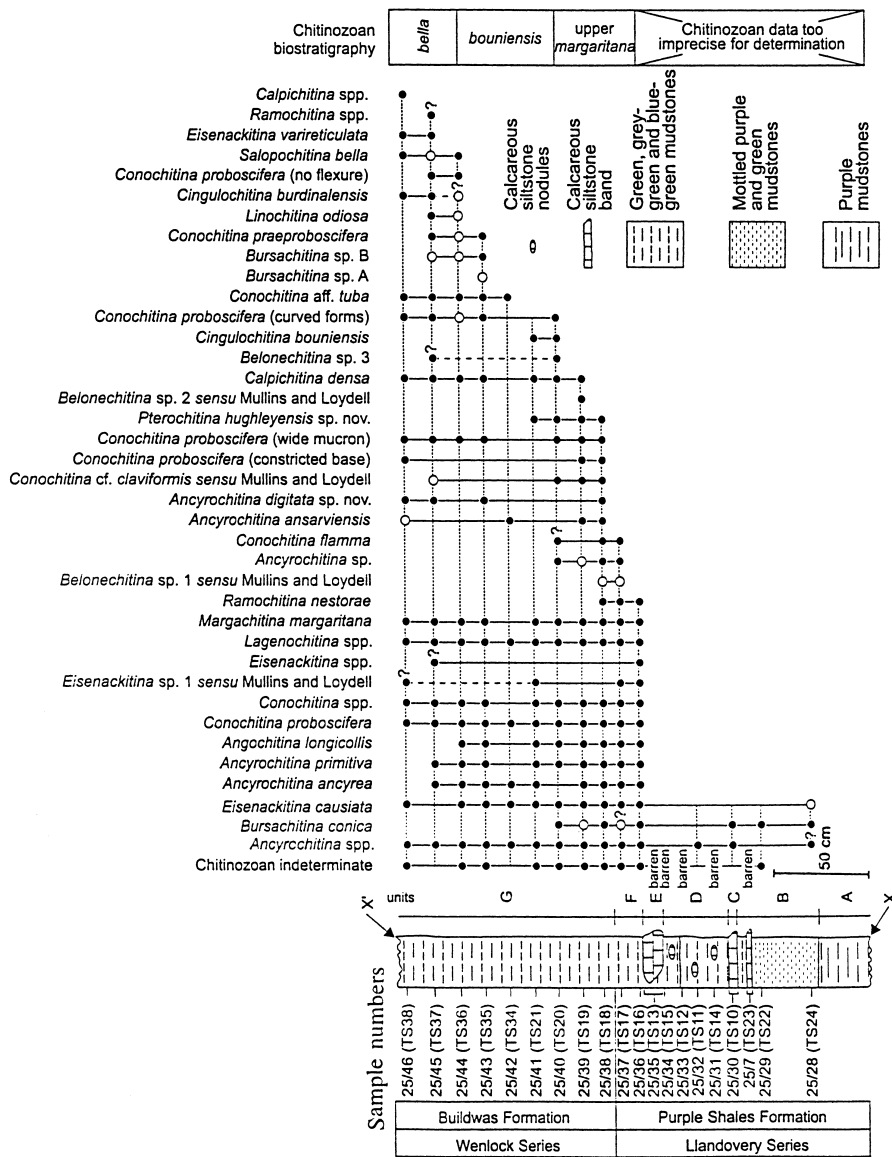


Fig. 6. The distribution of chitinozoans across the type Llandovery–Wenlock series boundary in the Hughley Brook stratotype section, Shropshire (after Mullins & Aldridge 2004). Units A–G after Bassett et al. (1975).

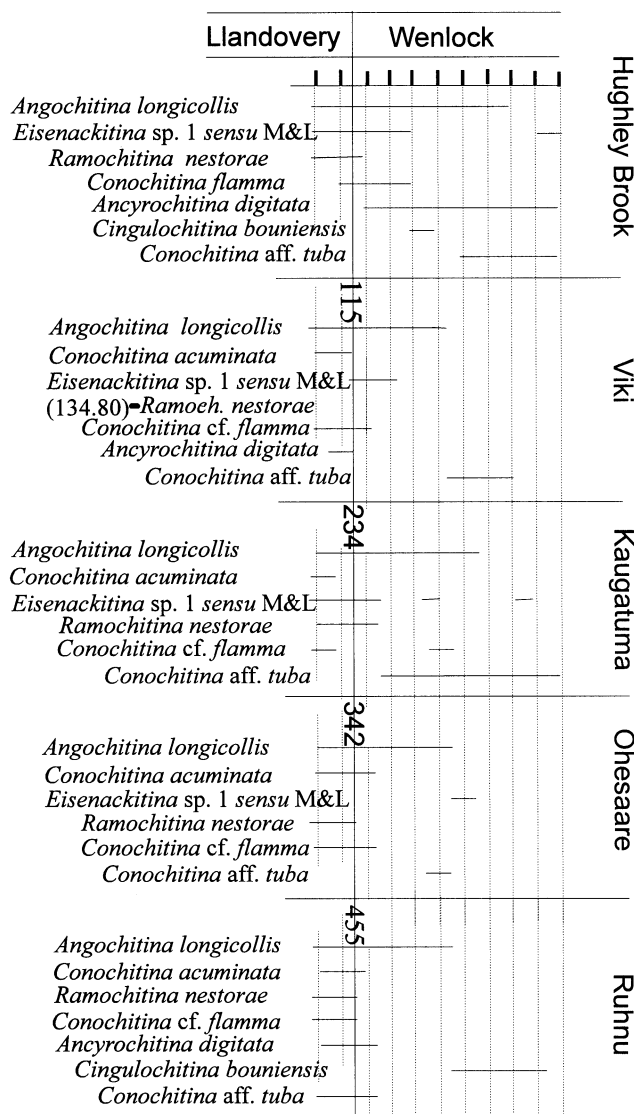


Fig. 7. The ranges of chitinozoan species stratigraphically most important in the correlation with the Llandovery–Wenlock boundary stratotype in Hughley Brook and the supposed position of the boundary in the studied West Estonian cores.

DISCUSSION

On the basis of published chitinozoan data Mullins & Loydell (2001) and Mullins & Aldridge (2004) present detailed reviews of correlation problems concerning the upper Llandovery and lower Wenlock strata around the world.

Below, some remarks concerning disappearance levels of more common and stratigraphically more important species at the Llandovery–Wenlock boundary interval are added.

A. longicollis has been identified from the Telychian of different palaeocontinents (Verniers et al. 1995), but the upper limit of its range is disputable. It is correlated with the topmost Telychian in Bohemia (Dufka et al. 1995), Shropshire, England (Dorning 1981), and in the Yangtze Region, China (Geng et al. 1997). In Quebec, Canada, *A. longicollis* has been recovered from the *centrifugus* graptolite Zone (Asselin et al. 1989). Its disappearance has been related to the *murchisoni* Biozone in subsurface sections of Gotland (Grahm 1995), mainland of Sweden (Grahm 1998), Girvan area, Scotland (Vandenbroucke et al. 2003), Ronquières-Monstreux area, Belgium (Verniers et al. 2002), Buttington Brick, Wales (Mullins & Loydell 2002), Ventspils core (Nestor 1994) and Aizpute-41 core, West Latvia (Loydell et al. 2003), Ohesaare core (Nestor 1994) and Ruhnu core, West Estonia (Pöldvere et al. 2003). In the Banwy River section (Mullins & Loydell 2001), as well as in the Builth Wells district, Wales (Verniers 1999) and in the Mehaigne area, Belgium (Verniers 1982; Verniers et al. 2002), the disappearance of *A. longicollis* has been recorded at some level within the *riccartonensis* graptolite Zone.

Thus, the disappearance of *A. longicollis* is most often related to the *murchisoni* Biozone. Its earlier disappearance may be caused by gaps in sedimentation, insufficient data or unfavourable life conditions for this taxon. The reasons for the prolongation of its range remain unclear, but it is most likely that chitinozoan occurrences are not always precisely related to the graptolite zonation as graptolite data may be incomplete.

The disappearance level of *C. acuminata* has often been correlated with that of *A. longicollis*, for example, in Scotland (Vandenbroucke et al. 2002), Québec (Asselin et al. 1989), Builth Wells district (Verniers 1999), the Mehaigne area (Verniers 1982), Sweden (Grahm 1995, 1998), and China (Geng et al. 1997). In the Ireviken 3 section of Gotland (Nestor et al. 2002), *C. acuminata* disappears about 1 m above the Llandovery–Wenlock boundary determined by conodonts (Jeppsson & Männik 1993). In the Banwy River section *C. acuminata* ranges up to the top of the Llandovery sequence and in the *insectus* Biozone. In the Estonian cores this species disappears just at the boundary or closely above it, being related to the middle part of the *murchisoni* Biozone (this study).

Ramochitina nestorae (= *Gotlandochitina magnifica* Nestor 1982) was identified by Y. Grahm from the *spiralis* Zone in the När core 1 and Rosendal core 1 in the subsurface of Gotland, ranging there up to the Llandovery–Wenlock boundary (Grahm 1995). The species was found also from the *spiralis* Zone in the Kallholn 1 core in the mainland of Sweden (Grahm 1998). Among all Estonian cores, *R. nestorae* has its longest range in the Kaugatuma core (233.05–245.50 m), but no graptolite datings are available from this core. Graptolites were not found from the Viki core either, but the single occurrence of *R. nestorae* in the sample from 134.80–134.90 m remains probably at a level below the Llandovery–Wenlock boundary. A sparse occurrence of *R. nestorae* is caused very likely

by environmental conditions, being related to relatively deep-water sediments (Nestor 1994). In all studied East Baltic sections where this species was found (Nestor 1994) it disappears around the Llandovery–Wenlock boundary interval. The presence of *R. nestorae* at the boundary in the Hughley Brook section (Mullins & Aldridge 2004) makes it a good marker for identification of the Llandovery–Wenlock boundary elsewhere, except in shallow-water and deepest-water graptolite sediments.

A bentonite layer is recognized in the Viki, Ohesaare, and Aizpute cores at depths of 115.0, 342.10, and 917.10 m, respectively (Kiipli & Kallaste 2002). This level is regarded by chitinozoans as the boundary between the Llandovery and Wenlock. It lies a couple of metres lower than the boundary established by conodonts (see Männik et al. 2002). In the Kaugatuma and Ruhnu cores a bentonite layer is recorded at depths of 236.90 and 458.90 m, respectively, i.e. 3–4 m lower than the supposed Series boundary. It may be another bentonite layer, corresponding to that occurring in the Ohesaare core at a depth of 345.80 m. The bentonite layer is considered as the lower boundary stratotype of the Jaani Regional Stage (see Nestor 1997).

In conclusion, the correlation of chitinozoan distribution in some West Estonian core sections and in the Llandovery–Wenlock boundary stratotype in the Hughley Brook section shows that the boundary corresponds to a level in the middle or in the upper part of the *M. margaritana* Biozone. In the Viki and Ohesaare cores the boundary coincides with a bentonite layer above the hitherto accepted boundary between the Adavere and Jaani regional stages, which correlates with a level in the middle of the *murchisoni* graptolite Biozone in the Ohesaare core.

SYSTEMATIC PALAEOLOGY

In this paper only the new species are described. The taxonomy follows the revised classification by Paris et al. (1999). The abbreviations used are: L, total length of the vesicle; ln, length of the neck; lapp, length of the appendices; D, maximum vesicle diameter; dap, diameter of the aperture.

All figured chitinozoan specimens are deposited in collections Nos. 272 and 427 of the Institute of Geology at Tallinn University of Technology, Estonia.

Group CHITINOZOA Eisenack, 1931

Order PROSOMATIFERA Eisenack, 1972

Family CONOCHITINIDAE Eisenack, 1931 emend. Paris, 1981

Subfamily BELONECHITININAE Paris, 1981

Genus *Belonechitina* Jansonius, 1964 emend. Paris, Grahn, Nestor & Lakova, 1999

Type species. *Conochitina micracantha* subsp. *robusta* Eisenack, 1959, pl. 3, fig. 4.

Belonechitina oeselensis sp. nov.

Plate I, figures 5, 6

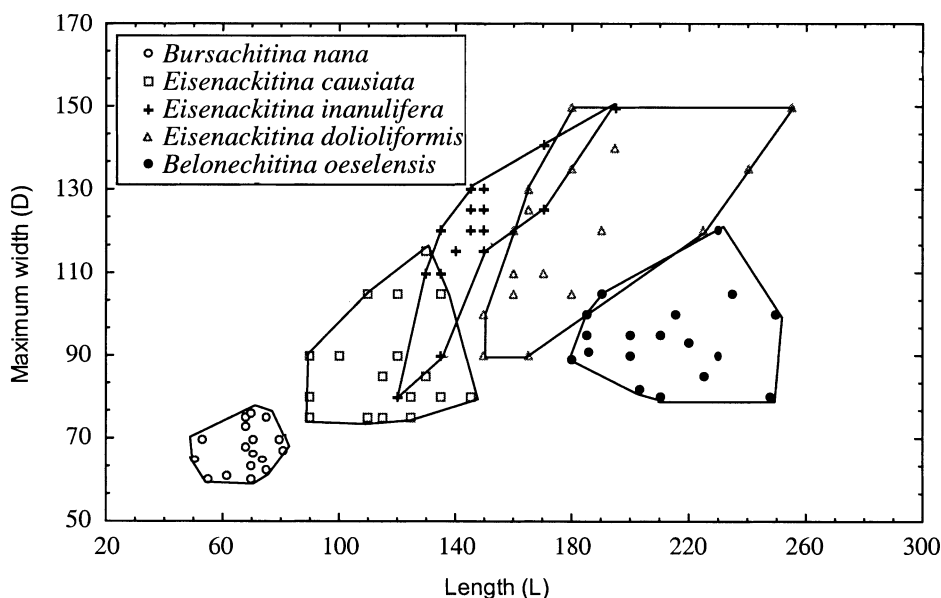
1994 *Conochitina* sp. 6 Nestor, p. 42, pl. 21, figs. 1, 2.2003 *Conochitina* sp. 6 Nestor; Loydell et al., fig. 16-u.**Derivation of name.** From Oesel, the old name of Saaremaa Island.**Holotype.** GIT 427-3, Pl. I, figs. 5a, 5b, Kaugatuma core, depth 234.05–235.10 m, Velise Formation, Adavere Stage, Upper Llandoverly.**Diagnosis.** Vesicle conical, with concave or convex base and broadly to bluntly rounded basal margin. The vesicle flanks are slightly convex, tapering towards the aperture, where a thin-walled collerette occurs. The neck is not distinguished from the chamber, neither shoulder nor flexure is present. The central part of the base carries a wide conical mucron, formed by a thin membrane or wall. The vesicle wall has dense fine rugose or granular ornamentation, somewhat coarser at the base.**Dimensions.** L, 180–250 μm ; D, 75–120 μm ; L/D = 2–2.5 : 1 (18 specimens in Fig. 8).

Fig. 8. Variation of the vesicle length (L) and maximum vesicle width (D) in μm in *Bursachitina nana*, *Eisenackitina causiata*, *Eisenackitina inanulifera* sp. nov., *Eisenackitina dolioliformis*, and *Belonechitina oeselensis* sp. nov.

Remarks. Fine rugose or microgranular ornamentation is the most characteristic feature of *B. oeselensis*. The mucron is often hidden at the centre of the concave base (see Loydell et al. 2003, fig. 16-u) and not seen in the case of flattened vesicles. The maximum diameter is attained in the lower third of the vesicle. *Conochitina visbyensis* Laufeld has subcylindrical vesicle and is smaller: L = 96–125 µm, D = 38–52 µm (see Laufeld 1974, p. 74, fig. 37). *Bursachitina nestorae sensu* Mullins & Loydell (2001) is similar to *B. oeselensis* in the overall shape of the vesicle, but its wall is smooth and its mucron “arises from a hemispherical mound” on the base (p. 738). *Belonechitina parvispinata* Soufiane & Achab (2000) has a vesicle covered with short (less than 4 µm), simple, lambda-shaped or multi-rooted spines.

Occurrence. Upper Llandovery: Velise and Jurmala formations of the Adavere Stage. Viki core, 144.40–172.0 m; Kaugatuma core, 240.05–270.10 m; Ohesaare core, 356.26 m; Ruhnu core, 486.20–487.70 m; Nagli core, 612.0–642.0 m; Aizpute-41 core, 926.0–961.0 m; Ventspils core, 798.0?–842.80 m.

Family LAGENOCHITINIDAE Eisenack, 1931, emend. Paris, 1981
 Subfamily ANCYROCHITININAE Paris, 1981
 Genus *Ancyrochitina* Eisenack, 1955

Type species. *Conochitina ancyrea* Eisenack, 1931 (holotype lost, neotype: Eisenack, 1955, pp. 163–164, pl. 2, fig. 7).

Ancyrochitina mullinsi sp. nov.
 Plate II, figures 13, 14

2001 *Ancyrochitina gutnica* Laufeld; Mullins & Loydell, pl. 11, figs. 9, 10.

?2001 *Ancyrochitina desmea* Eisenack, 1964; Mullins & Loydell, pl. 11, figs. 4–8.

Derivation of name. Named after the palynologist Gary Mullins.

Holotype. GIT 427-23, Pl. II, figs. 13a, 13b, Kaugatuma core, depth 242.0–242.10 m, Velise Formation, Adavere Stage, Upper Llandovery.

Diagnosis. Vesicle cylindro-conical with slightly developed flexure and shoulder. The base is flat or convex and broadly rounded basal edge carries 5–8 appendices, branching 4–5 times. The neck comprises about half the total length. The oral part of the neck bears very short simple or twice branching and vertically orientated spines. The middle part of the neck is sometimes provided with gently branching solitary spine(s). The aperture is smooth or finely fringed. Vesicle wall is smooth or finely granulated.

Dimensions. L, 110–180 µm; lapp, 15–50 µm; D, 60–85 µm; L/l_n = 1 : 1.

Remarks. *Ancyrochitina mullinsi* sp. nov. is similar to *A. gutnica* Laufeld, 1974, but appendices of the latter species have a long unbranched proximal part as well

as long and well-developed curved spines in the aboral part of the neck, which decrease in size towards the aperture. Densely distributed tiny spines of *A. mullinsi* in the oral part of the neck are lacking in *A. gutnica*. *Ancyrochitina desmea* Eisenack, 1964 has strongly branching thick appendices at the basal edge, 156 µm in length, and in the middle part of the neck, 105 µm in length (Eisenack 1964, pp. 325, pl. 29, figs. 1–3). *Ancyrochitina ramosaspina* Nestor, 1994 has straight and rigid appendices but lacks tiny spines in the oral part of the neck.

Occurrence. Upper Llandoverly: the uppermost part of the Velise Formation of the Adavere Stage. Kaugatuma core, 240.0–255.1 m; Viki core, 125.0–134.0 m; Ruhnu core, 456.15–463.20 m. In the Banwy River section in Wales *A. mullinsi* occurs in the *spiralis*, *lapworthi*, and *insectus* graptolite zones of the uppermost Llandoverly.

Order OPERCULATIFERA Eisenack, 1972
Family DESMOCHITINIDAE Eisenack, 1931, emend Paris, 1981
Subfamily EISENACKITININAE Paris, 1981
Genus *Eisenackitina* Jansonius, 1964

Type species. *Eisenackitina castor* Jansonius, 1964

Eisenackitina inanulifera sp. nov.
Plate I, figures 10–12

?1982 *Eisenackitina* sp. A, Verniers 1982, pl. 5, fig. 92.

?2001 *Eisenackitina* aff. *anulifera* Verniers; Mullins & Loydell, pl. 3, figs. 5, 6.

Derivation of name. Refers to the lack of the ring-like thickenings of the vesicle wall as well as to similarity of the vesicle shape of the new species to *E. anulifera* Verniers, 1999.

Holotype. GIT 427-9, Pl. I, fig. 11, Kaugatuma core, 242.0–242.10 m, Velise Formation, Adavere Stage, Upper Llandoverly, Saaremaa Island, Estonia.

Diagnosis. Vesicle (cylindro-)conical or (cylindro-)ovoid, with slightly convex flanks and broadly rounded basal edge. The flexure and shoulders are more or less developed. The neck is short or missing. The base is slightly convex or flat with a little button-like mucron in the centre. The vesicle wall is felt-like, rugose or finely granulated. The ornamentation is best developed at the shoulders and at the aboral part of the body.

Dimensions. L, 120–190 µm; D, 80–150 µm; dap., 50–75 µm (16 specimens in Fig. 8).

Remarks. In overall shape *E. inanulifera* is quite similar to *E. anulifera* Verniers, 1999, but lacks the ring-like thickenings on the chamber and base as well

as circular-membrane type of mucron (or impression) of the latter species. *E. inanulifera* is similar to *E. aff. anulifera sensu* Mullins & Loydell 2001 in having a circular scar, but it usually has also ring-like thickenings and its aperture is somewhat narrower (36.3–50.0 µm). *E. dolioliformis* Umnova, 1976 has a wide short mucron and is larger (141.0–255.0 µm). *E. causiata* Verniers, 1999 is smaller and has neither neck nor shoulders.

Occurrence. Upper Llandovery and Lower Wenlock: Velise Formation of the Adavere Stage and Riga and Jaani formations of the Jaani Stage. Ohesaare core, 338.0–358.70 m; Viki core, 114.40–158.50 m; Kaugatuma core, 214.0–269.10 m; Ruhnu core, 454.60–465.40 m.

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REFERENCES

- Asselin, E., Achab, A. & Bourque, P. A. 1989. Chitinozoaires du Silurien inferieur dans la région de la baie des Chaleurs en Gaspésie, Québec, Canada. *Can. J. Earth Sci.*, **26**, 2435–2449.
- Bassett, M. G., Holland, C. H., Rickards, R. B. & Warren, P. T. 1975. The type Wenlock Series. *Rep. Inst. Geol. Sci.*, **75**, 1–19.
- Dorning, K. J. 1981. Silurian Chitinozoa from the type Wenlock and Ludlow of Shropshire, England. *Rev. Palaeobot. Palynol.*, **34**, 205–208.
- Dufka, P., Kříž, J. & Štorch, P. 1995. Silurian graptolites and chitinozoans from the Uranium Industry boreholes drilled in 1968–1971 (Prague Basin, Bohemia). *Bull. Czech Geol. Surv.*, **70**, 5–14.
- Eisenack, A. 1964. Mikrofossilien aus dem Silur Gotlands. Chitinozoen. *Neues Jb. Geol. Paläont. Abh.*, **120**, 308–342.
- Geng Liang-Yu, Qian Zhe-Shu, Ding Lian-Shen, Wang Yue, Wang Gen-Xian & Cai Xi-Yao. 1997. Silurian chitinozoans from the Yangtze Region. *Palaeoworld*, **8**, 1–152.
- Grahn, Y. 1995. Silurian Chitinozoa and biostratigraphy of subsurface Gotland. *GFF*, **117**, 57–65.
- Grahn, Y. 1998. Lower Silurian (Llandovery–Middle Wenlock) biostratigraphy of the mainland of Sweden. *GFF*, **120**, 273–283.
- Jeppsson, L. & Männik, P. 1993. High resolution correlations between Gotland and Estonia near the base of the Wenlock. *Terra Nova*, **5**, 348–358.
- Kaljo, D. 1962. On the boundary of the Llandoveryan and Wenlockian in the East Baltic. *ENSV Tead. Akad. Geol. Inst. Uurimused*, **10**, 97–113.
- Kiipli, T. & Kallaste, T. 2002. Correlation of Telychian sections from shallow to deep sea facies in Estonia and Latvia based on sanidine composition of bentonites. *Proc. Estonian Acad. Sci. Geol.*, **51**, 143–156.
- Laufeld, S. 1974. Silurian Chitinozoa from Gotland. *Fossils and Strata*, **5**, 1–130.
- Loydell, D. K. & Nestor, V. Integrated graptolite and chitinozoan biogeography of the upper Telychian (Llandovery, Silurian) of the Ventspils D-3 core, Latvia. *Geol. Mag.* (in press).

- Loydell, D. K., Kaljo, D. & Männik, P. 1998. Integrated biostratigraphy of the lower Silurian of the Ohesaare core, Saaremaa, Estonia. *Geol. Mag.*, **135**, 769–783.
- Loydell, D. K., Männik, P. & Nestor, V. 2003. Integrated biostratigraphy of the lower Silurian of the Aizpute-41 core, Latvia. *Geol. Mag.*, **140**, 205–229.
- Mabillard, J. E. & Aldridge, R. J. 1985. Microfossil distribution across the base of the Wenlock Series in the type area. *Palaeontology*, **28**, 89–100.
- Männik, P., Kallaste, T. & Martma, T. 2002. Dating of the Ireviken Event and the problem of the Llandovery–Wenlock boundary, some possible developments. In *The Fifth Baltic Stratigraphical Conference “Basin Stratigraphy – Modern Methods and Problems”, Sep 22–27, 2002, Vilnius, Lithuania: Extended Abstracts*, pp. 114–116. Vilnius.
- Mullins, G. L. 2000. A chitinozoan morphological lineage and its importance in Lower Silurian stratigraphy. *Palaeontology*, **43**, 359–373.
- Mullins, G. L. & Aldridge, R. J. 2004. Chitinozoan biostratigraphy of the basal Wenlock Series (Silurian) global stratotype section and point. *Palaeontology*, **47**, 745–773.
- Mullins, G. L. & Loydell, D. K. 2001. Integrated Silurian chitinozoan and graptolite biostratigraphy of the Banwy River section, Wales. *Palaeontology*, **44**, 731–781.
- Mullins, G. L. & Loydell, D. K. 2002. Integrated lower Silurian chitinozoan and graptolite biostratigraphy of Buttington Brick Pit, Wales. *Geol. Mag.*, **139**, 89–96.
- Nestor, H. 1997. Silurian. In *Geology and Mineral Resources of Estonia* (Raukas, A. & Teedumäe, A., eds.), pp. 89–106. Estonian Academy Publishers, Tallinn.
- Nestor, H. & Nestor, V. 2002. Upper Llandovery to middle Wenlock (Silurian) lithostratigraphy and chitinozoan biostratigraphy in southwestern Estonia and northernmost Latvia. *Proc. Estonian Acad. Sci. Geol.*, **51**, 67–87.
- Nestor, V. 1984. Zonal distribution of chitinozoans in the Wenlockian Jaani Stage of Estonia and the problem of its upper boundary. In *Stratigraphy and Early Paleozoic Sediments of East Baltic* (Männik, R. & Mens, K., eds.), pp. 119–127. Institute of Geology, Academy of Sciences of ESSR, Tallinn (in Russian).
- Nestor, V. 1990. Silurian chitinozoans. In *Field Meeting, Estonia. An Excursion Guidebook* (Kaljo, D. & Nestor, H., eds.), pp. 80–83. Tallinn.
- Nestor, V. 1994. *Early Silurian Chitinozoans of Estonia and North Latvia*. Academia, Vol. 4.
- Nestor, V., Einasto, R. & Loydell, D. K. 2002. Chitinozoan biostratigraphy and lithological characteristics of the Lower and Upper Visby boundary Beds in the Ireviken 3 section, Northwest Gotland. *Proc. Estonian Acad. Sci. Geol.*, **51**, 215–226.
- Paris, F., Grahn, Y., Nestor, V. & Lakova, I. 1999. A revised chitinozoan classification. *J. Paleont.*, **73**, 549–570.
- Pöldvere, A. (ed.). 2003. Ruhnu (500) drill core. *Estonian Geol. Sections*, 5.
- Soufiane, A. & Achab, A. 2000. Upper Ordovician and Lower Silurian chitinozoans from central Nevada and Arctic Canada. *Rev. Palaeobot. Palynol.*, **113**, 165–187.
- Vandenbroucke, T., Verniers, J. & Clarkson, E. N. K. 2003. A chitinozoan biostratigraphy of the Upper Ordovician and lower Silurian strata of the Girvan area, Midland Valley, Scotland. *Trans. Roy. Soc. Edinburgh: Earth Sci.*, **93**, 111–134.
- Verniers, J. 1982. The Silurian Chitinozoa of the Mehaigne Area (Brabant Massif, Belgium). *Prof. Pap. Geol. Surv. Belgium*, **192**, 1–76.
- Verniers, J. 1999. Calibration of Chitinozoa versus graptolite biozonation in the Wenlock of Built Wells district (Wales, U.K.), compared with other areas in Avalonia and Baltica. *Boll. Soc. Paleontol. Italiana*, **38**, 359–380.
- Verniers, J., Nestor, V., Paris, F., Dufka, P., Sutherland, S. & Van Grootel, G. 1995. A global Chitinozoa biozonation for the Silurian. *Geol. Mag.*, **132**, 651–666.
- Verniers, J., Van Grootel, G., Louwye, S. & Diependaele, B. 2002. The chitinozoan biostratigraphy of the Silurian of the Ronquières-Monstreux area (Brabant Massif, Belgium). *Rev. Palaeobot. Palynol.*, **118**, 287–322.

***Margachitina margaritana* biotsooni kitiinikud ja Llandovery–Wenlocki piir Lääne-Eesti läbilõigetes**

Viiu Nestor

On esitatud andmed kitiinikute leviku kohta Ülem-Llandovery ja Alam-Wenlocki piirialal Viki, Kaugatuma, Ohesaare ning Ruhnu puursüdamikes, mille põhjal on neid läbilõikeid korreleeritud rahvusvahelise Llandovery–Wenlocki piir-stratotüübiga Hughley Brookis Inglismaal. On selgitatud stratigraafiliselt olulisemad taksonid selle piiri määramiseks Lääne-Eesti läbilõigetes. Ohesaare ja Viki puursüdamikes langeb piir kokku bentoniidikihtidega, mis asuvad kõrgemal Adavere ja Jaani lademete ametlikust piirist, vastates ligikaudu *murchisoni* graptoliidi tsooni keskosale Ohesaare puuraugu andmetel. Töös on kirjeldatud kolme uut liiki.