

# Integrated biostratigraphy of the lower Silurian of the Kolka-54 core, Latvia

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**Abstract** – Integrated graptolite, conodont and chitinozoan biostratigraphical data are presented from the Llandovery and Wenlock of the Kolka-54 core, Latvia. Correlations between graptolite and chitinozoan biozones are consistent with those published from other East Baltic sections and the Welsh Basin. While most correlations between graptolite and conodont biozones agree with those presented in previous studies, there are important exceptions. Significantly, we report here the discovery of *Distomodus staurognathoides* Biozone conodonts in the lowest Aeronian *Demirastrites triangulatus* graptolite Biozone. The base of the *D. staurognathoides* Biozone was previously considered to lie much higher in the Aeronian. Also it is shown that *Walliserodus* survived the late Wenlock Mulde Event, during which it was considered previously to have become extinct.

Keywords: graptolites, chitinozoan, conodonts, Silurian, biostratigraphy, Llandovery, Wenlock.

## 1. Introduction

Over the past ten years, a series of papers has been published with the aim of integrating the biozonations for the Silurian System based upon graptolites, conodonts and chitinozoans. Many of these have focused upon the continuous sections provided by cores in Estonia and Latvia: Ohesaare (Loydell, Kaljo & Männik, 1998), Ruhnu (Pöldvere, 2003), Aizpute-41 (Loydell, Männik & Nestor, 2003) and Ventpils D-3 (Loydell & Nestor, 2005). Here we continue and extend this work, with a study of the Kolka-54 core, Latvia, which provides a record from the base of the Llandovery Series through to the top of the Wenlock Series.

## 2. The Kolka-54 core

Kolka is situated in northwestern Latvia (Fig. 1). The Kolka-54 core was drilled in 1967. Sampling was undertaken by V. Nestor and V. Viira in 1978. The core is deposited in Riga in the store-house of the Geological Survey of Latvia.

The chitinozoan, graptolite and conodont collections, including all figured specimens, are housed in the Institute of Geology, Tallinn Technological University (prefix GIT).

According to Nestor & Einasto (1997), the Llandovery and Wenlock strata of the Kolka-54 core belong to the deep-water transitional facies belt, except for the upper part of the Rootsiküla Stage (upper Homeric), which is represented by lagoonal dolomites.

## 3. Graptolite biostratigraphy of the Kolka-54 core

The material available for study comprised both 70 mm diameter core samples and graptolites picked from residues after processing for chitinozoans. The latter material was in some cases highly fragmented, preventing identification to species level. Graptolites from the samples are illustrated in Figures 2–4. Stratigraphical ranges are shown in Figures 5 and 6.

The lowest graptolite-bearing sample was close to the base of the Silurian, at 659.50–659.80 m, but this unfortunately yielded only the siculae and th1<sup>1</sup> of indeterminate biserials. The lowest sample to yield identifiable graptolites was at 625.0 m; the presence at this level of *Glyptograptus sinuatus* (Nicholson) (Fig. 2a) and *Rhaphidograptus toernquisti* (Elles & Wood) (Fig. 2b) indicates either the upper Rhuddanian *cyphus* Biozone or lower Aeronian *triangulatus* Biozone. Triangulate monograptid fragments appear in the 621.7–622.0 m sample, indicating the *triangulatus* Biozone. *Demirastrites triangulatus* (Harkness) (Fig. 2hh) itself occurs from 621.50 m to 612.00 m. By comparison with higher Aeronian biozones, the *triangulatus* Biozone is thus rather thick (at c. 10 m). The *simulans* Biozone (which occupies a similar stratigraphical position to the *magnus* Biozone, that is, between the *triangulatus* and *leptotheca* biozones) is recognized by the presence of the eponymous species (Fig. 2ff) at 607.80 m. ‘*Monograptus*’ *inopinatus* Törnquist (Fig. 2aa), at 605.80 m indicates the *leptotheca* Biozone, while the occurrence of ‘*Monograptus*’ *decipiens* Törnquist (Fig. 3e) in the 603.40–603.70 m sample indicates the *convolutus* Biozone.

The next highest graptolite-bearing sample (at 601.00 m), only 2.4 m above the *convolutus* Biozone

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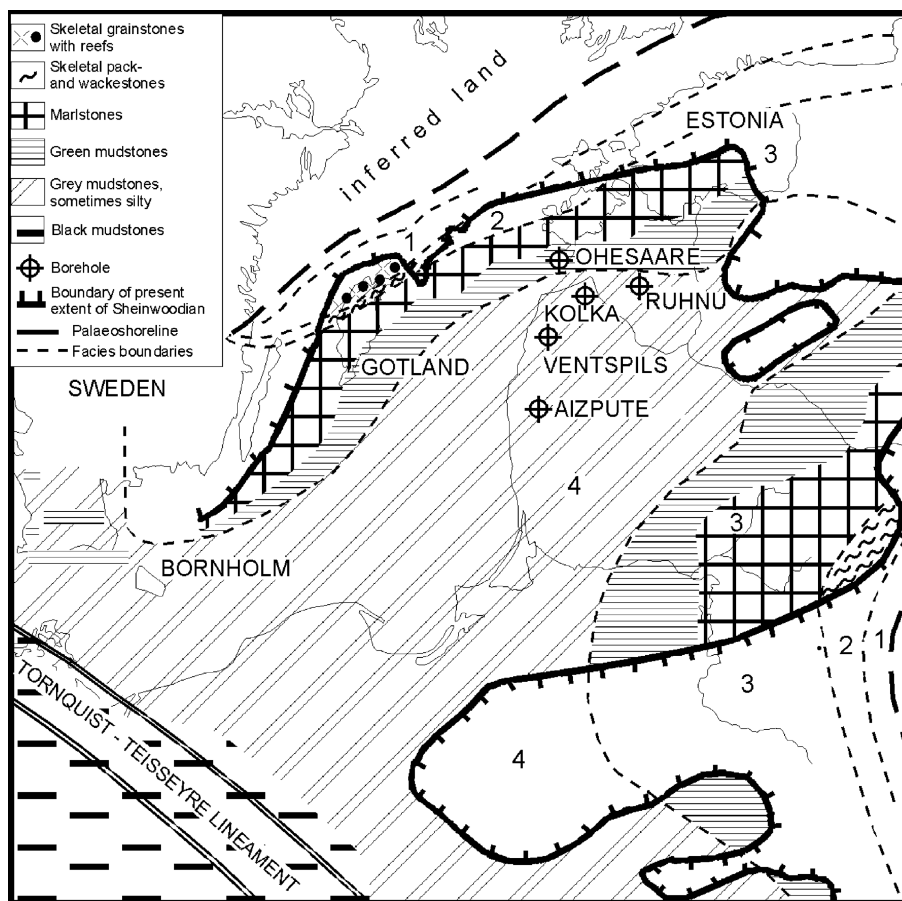


Figure 1. Location of Aizpute-41 on a map showing distribution of early Wenlock (approximately *riccartonensis* Zone) sedimentary rock types and facies belts in the northern Baltic region (modified from Bassett, Kaljo & Teller, 1989). The locations of other boreholes mentioned in the text are also indicated. Key to facies belts: 1 – nearshore, high energy shoals; 2 – shallow mid-shelf; 3 – deeper, outer shelf; 4 – deep-shelf depression.

sample, yielded abundant *Streptograptus johnsonae* Loydell (Fig. 2i), together with *Spirograptus turriculatus* (Barrande) (Fig. 2m) and *Pristiograptus bjerlingus* (Bjerreskov) (Fig. 2t) indicating the *johnsonae* Subzone of the lower part of the Telychian *turriculatus* Biozone. There is interpreted to be an unconformity in the section with the uppermost Aeronian and

lower Telychian not represented in the core. The middle Telychian is highly condensed, samples at 599.20 m and 599.0 m yielding species known from the *crispus*–lower *griestoniensis* biozones. *Pristiograptus pergratus* Přibyl (Fig. 2r), in the lower of these two samples, has been recorded previously only from the *crispus* Biozone. The lowest sample attributable to the

Figure 2. Graptolites from the Kolka-54, core, Latvia. (a) *Glyptograptus sinuatus* (Nicholson); GIT 352-2326; 625.00 m. (b) *Rhaphidograptus toernquisti* (Elles & Wood); GIT 352-2315(1); 619.40 m. (c) *Streptograptus exiguus* (Lapworth); GIT 352-2290; 599.00 m. (d) '*Monograptus*' *austerus* Törnquist *sensu lato*; GIT 352-2323; 623.30 m. (e) *Glyptograptus enodis* Packham; GIT 352-2313; 616.50 m. (f) *Pseudorthograptus insectiformis* (Nicholson); GIT 352-2315(2); 619.40 m. (g) *Atavograptus atavus* (Jones); GIT 352-2317; 621.30 m. (h) '*Monograptus*' *nobilis* Törnquist; GIT 352-2315(1); 619.40 m. (i) *Streptograptus johnsonae* Loydell; GIT 352-2293; 601.00 m. (j) *Normalograptus nikolayevi* (Obut); GIT 352-2302(2); 605.80 m. (k) *Monograptus riccartonensis* Lapworth; GIT 352-2251; 556.20 m. (l) *Oktavites excentricus* (Bjerreskov); GIT 352-2282; 589.30 m. (m) *Spirograptus turriculatus* (Barrande); GIT 352-2293; 601.00 m. (n) *Diversograptus ramosus* Manck?; GIT 352-2279; 587.30 m. (o) *Parapetalolithus altissimus* (Elles & Wood); GIT 352-2291(2); 599.20 m. (p) *Coronograptus gregarius* (Lapworth); GIT 352-2315(2); 619.40 m. (q) *Glyptograptus* sp.; GIT 352-2318; 621.50 m. (r) *Pristiograptus pergratus* Přibyl; GIT 352-2291(1); 599.20 m. (s) *Metaclimacograptus slalom* Zalasiewicz; GIT 352-2305(1); 607.80 m. (t) *Pristiograptus bjerringus* (Bjerreskov) GIT 352-2293; 601.00 m. (u) *Mediograptus vittatus* (Štorch); GIT 352-2261; 566.60 m. (v) '*Monograptus*' *communis* Lapworth; GIT 352-2312; 615.50 m. (w) *Mediograptus flexuosus* (Tullberg); GIT 352-2255(1); 560.00 m. (x, dd) *Oktavites spiralis* (Geinitz); (x) GIT 352-2287; 591.40 m; (dd) GIT 352-2274; 580.80 m. (y) *Monograptus priodon* (Bronn); GIT 352-2290; 599.00 m. (z) *Mediograptus* sp.; GIT 352-2244; 542.00 m. (aa) '*Monograptus*' *inopinus* Törnquist; GIT 352-2302(2); 605.80 m. (bb) *Streptograptus* sp.; GIT 352-2280; 588.50 m. (cc) *Cyrtograptus perneri* Bouček; GIT 352-2227; 489.50 m. (ee) *Monograptus flemingii* (Salter); GIT 352-2192; 413.20 m. (ff) *Demirastrites simulans* (Pedersen); GIT 352-2305(2); 607.80 m. (gg) *Cyrtograptus centrifugus* Bouček or *Cyrtograptus munchisoni* (Carruthers); GIT 352-2262; 567.10 m. (hh) *Demirastrites triangulatus* (Harkness); GIT 352-2318; 621.50 m.

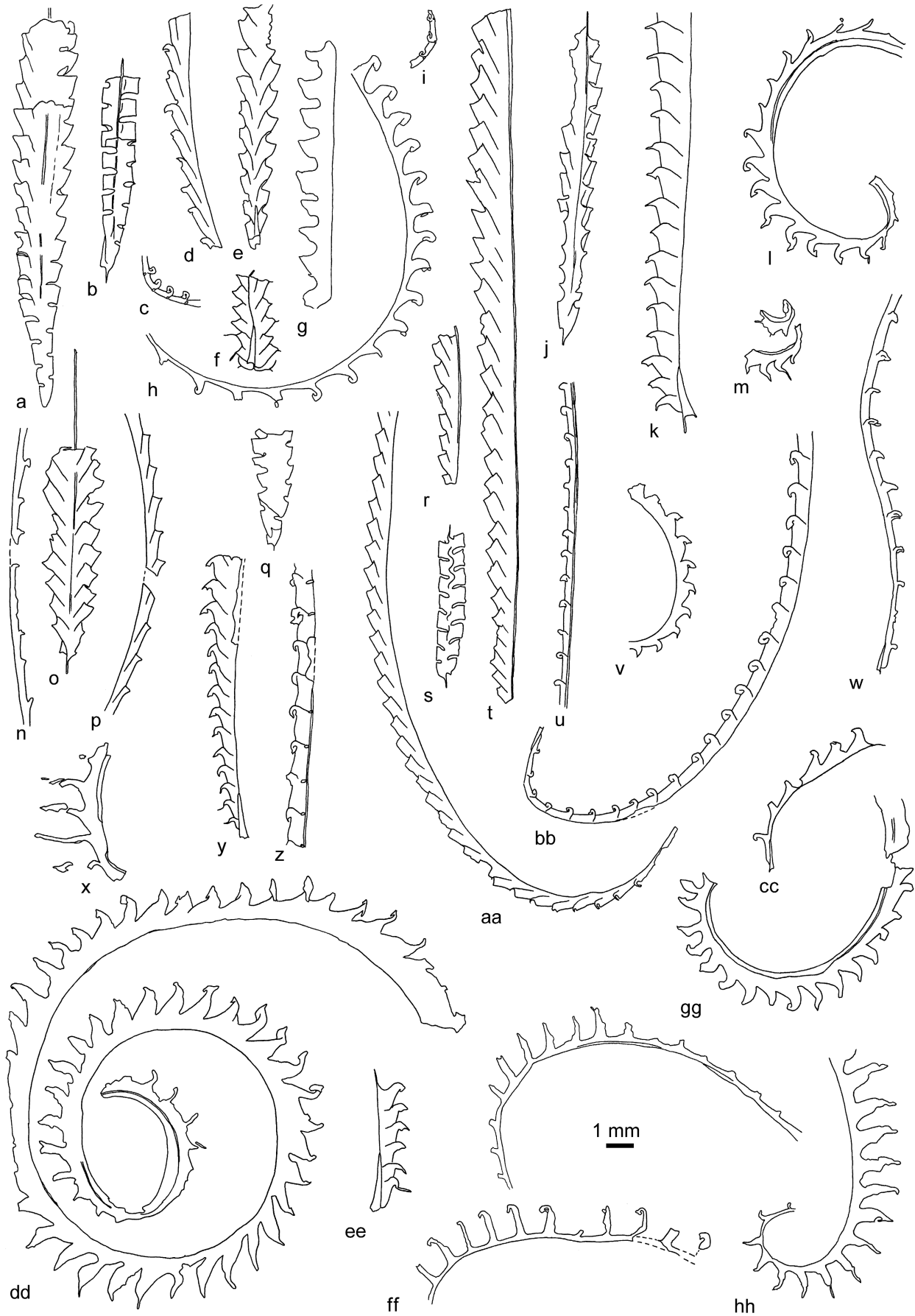


Figure 2. For caption see facing page.





Figure 3. For caption see facing page.

*spiralis* Biozone is at 591.40 m; *Oktavites excentricus* (Bjerreskov) (Fig. 2l), indicating the middle of this biozone, occurs at 589.30 m. A ventrally curved *Streptograptus* (Fig. 2bb), broader (maximum DVW 0.8 mm) than *S. kaljoi* Loydell, Männik & Nestor (maximum DVW 0.6 mm) and with apparently simpler distal thecae, occurs both 0.2 m below and 0.8 m above the *O. excentricus*-bearing level. The presence of *Streptograptus wimani* (Bouček) (Fig. 3d) in the 578.9–579.2 m and 575.00–575.30 m samples indicates the lower *lapworthi* Biozone.

Unfortunately, the next graptolitic samples, between 570.60 m and 568.0 m, yielded only indeterminate material or specimens of long-ranging taxa such as *Retiolites* and *Monograptus priodon* (Bronn). A robust, tightly coiled cyrtograptid proximal fragment (either *Cyrtograptus centrifugus* Bouček or *C. murchisoni* Caruthers) (Fig. 2gg) occurs at 567.10 m; *Mediograptus vittatus* Štorch (Fig. 2u), recorded previously only from the *murchisoni* Biozone, occurs in the next sample, at 566.60 m. The lowest sample attributable to the *firmus* Biozone is at 560.0 m; *Monograptus riccartonensis* Lapworth (Fig. 2k), indicating the *riccartonensis* Biozone, occurs in samples at 556.90 m and 556.20 m.

It is difficult to erect a graptolite biostratigraphy for the samples from higher in the Sheinwoodian for a number of reasons. The biozonal index species *Monograptus belophorus* Meneghini (= *Monograptus flexilis* Elles) is not represented and there is only one specimen of *Cyrtograptus rigidus* Tullberg (Fig. 3m; at 519.80 m). Several taxa, for example, the various species of ‘*Mediograptus*’, are in need of taxonomic revision, preventing meaningful identification of the mostly fragmentary, but otherwise well-preserved, isolated specimens encountered (e.g. Fig. 3n, o). These are referred to as ‘*Mediograptus*’ spp. in the range charts (Figs 5, 6). They are abundant in the 549.60 m, 545.0–545.30 m, 544.90 m and 542.0 m samples at a stratigraphical level consistent with the *antennularius* Biozone of Rickards (1967) and White *et al.* (1992).

The retiolitid *Sokolovograptus textor* (Bouček) (Fig. 4f, j) has a known stratigraphical range commencing in the upper *riccartonensis* Biozone (in which it was described as *Plectograptus? bouceki* by Rickards, 1967) and is common in the upper Sheinwoodian (e.g. Kozłowska-Dawidziuk, 1995). In the Kolka-54 core its first appearance is at 544.90 m in strata yielding abundant ‘*Mediograptus*’ fragments and its

range extends into the lower *lundgreni* Biozone (Fig. 6). The *Cyrtograptus perneri* Biozone has not been recognized. It may lie somewhere between 519.80 m and 510.50 m.

The lowest sample that can be assigned to the *lundgreni* Biozone is at 510.50 m. This yielded a proximal fragment of *Cyrtograptus lundgreni* Tullberg (Fig. 3q), exhibiting the characteristic, widely spaced, hooked and spinose thecae of this species. The base of the Homerian (if one takes this at the base of the *lundgreni* Biozone; see Zalasiewicz & Williams, 1999, p. 276 for discussion) thus lies between 519.80 m (sample with *C. rigidus*) and 510.50 m (lowest *C. lundgreni*). The highest (indeterminate species) *Cyrtograptus* fragment occurs at 430.8–431.1 m; the *lundgreni* Biozone is thus the thickest biozone (at a minimum of c. 80 m) in the Kolka-54 core. At the top of the *lundgreni* Biozone (430.8–431.1 m sample), *Gothograptus kozłowskii* Kozłowska-Dawidziuk (Fig. 4h) appears. This distinctive species occurs also at 427.40–427.70 m. Above this, the 415.20 m and 414.90 m samples yielded *Pristiograptus dubius* (Suess) and the 413.20 m sample *Monograptus flemingii* (Salter).

The lowest *Gothograptus nassa* (Holm) (Fig. 4d) fragments occur at 408.40–408.70 m. In the 394.20–394.50 m sample, the orientation of the virgella combined with the narrowness of the sicula enable identification of a damaged proximal end as *Colonograptus praedeubeli* (Jaeger) (Fig. 3p). The presence of *G. nassa* (Fig. 4g) in the 392.70 m and 390.0–390.40 m samples indicates that strata from 394.50–390.0 m can be assigned to the *praedeubeli* Biozone. Graptolites are very sparse higher in the Homerian and are represented only by fragmentary isolated material. Rapidly widening proximal fragments occur at 380.8–381.1 m and 353.60 m and are assigned to *Colonograptus ludensis* (Murchison) (Fig. 3h–j), indicating the uppermost Homerian *ludensis* Biozone.

#### 4. Conodont biostratigraphy of the Kolka-54 core

In total, 104 samples were processed and picked for conodonts. All samples, except one from the uppermost part of the studied interval (the 356.60–357.00 m sample; Fig. 8), yielded conodonts. More than 24,000 identifiable specimens were found. The weight of samples varied from 500 g up to 1.4 kg, the number

Figure 3. Graptolites from the Kolka-54, core, Latvia. (a) *Glyptograptus tamariscus* (Nicholson); GIT 565-5; 621.7–622.00 m. (b) *Retiolites angustidens* Elles & Wood; GIT 565-6; 563.00–563.30 m. (c) *Cyrtograptus metatheca*; GIT 565-7; 559.0–559.30 m. (d) *Streptograptus wimani* (Bouček); GIT 565-8; 578.90–579.20 m. (e) ‘*Monograptus*’ *decipiens* Törnquist, proximal theca; GIT 565-9; 603.40–603.70 m. (f) *Pribylograptus sudburiae* (Hutt); GIT 565-10; 614.20–614.55 m. (g) *Streptograptus* sp.; GIT 565-11; 603.40–603.70 m. (h–j) *Colonograptus ludensis* (Murchison); (h) GIT 565-12; 353.60–353.65 m; (i, j) GIT 565-13; 380.80–381.10 m. (k, q, r) *Cyrtograptus lundgreni* Tullberg. (k) ventral view of proximal end; GIT 565-14; 505.50–505.55 m; (q) proximal fragment; GIT 565-20; 510.50–510.55 m; (r) proximal theca; GIT 565-21; 435.0–435.55 m. (l) *Barrandeograptus* sp.; GIT 565-15; 559.0–559.30 m. (m) *Cyrtograptus rigidus* Tullberg; GIT 565-16; 519.80–519.85 m. (n, o) *Mediograptus* sp(p.); 549.60–549.65 m. (n) proximal end; GIT 565-17; (o) distal fragment; GIT 565-18. (p) *Colonograptus praedeubeli* Jaeger; GIT 565-19; 394.20–394.50 m. (s, t) *Pristiograptus dubius* var. *A. sensu* Radzevičius (this may be *Pristiograptus labiatus* Urbanek; P. Štorch, pers. comm.); (s) GIT 565-22; 470.90–470.95 m; (t) GIT 565-23; 484.60–484.65 m. Scale bars represent 1 mm (a, b, h–j, m, o, s, t) or 100 µm (others).



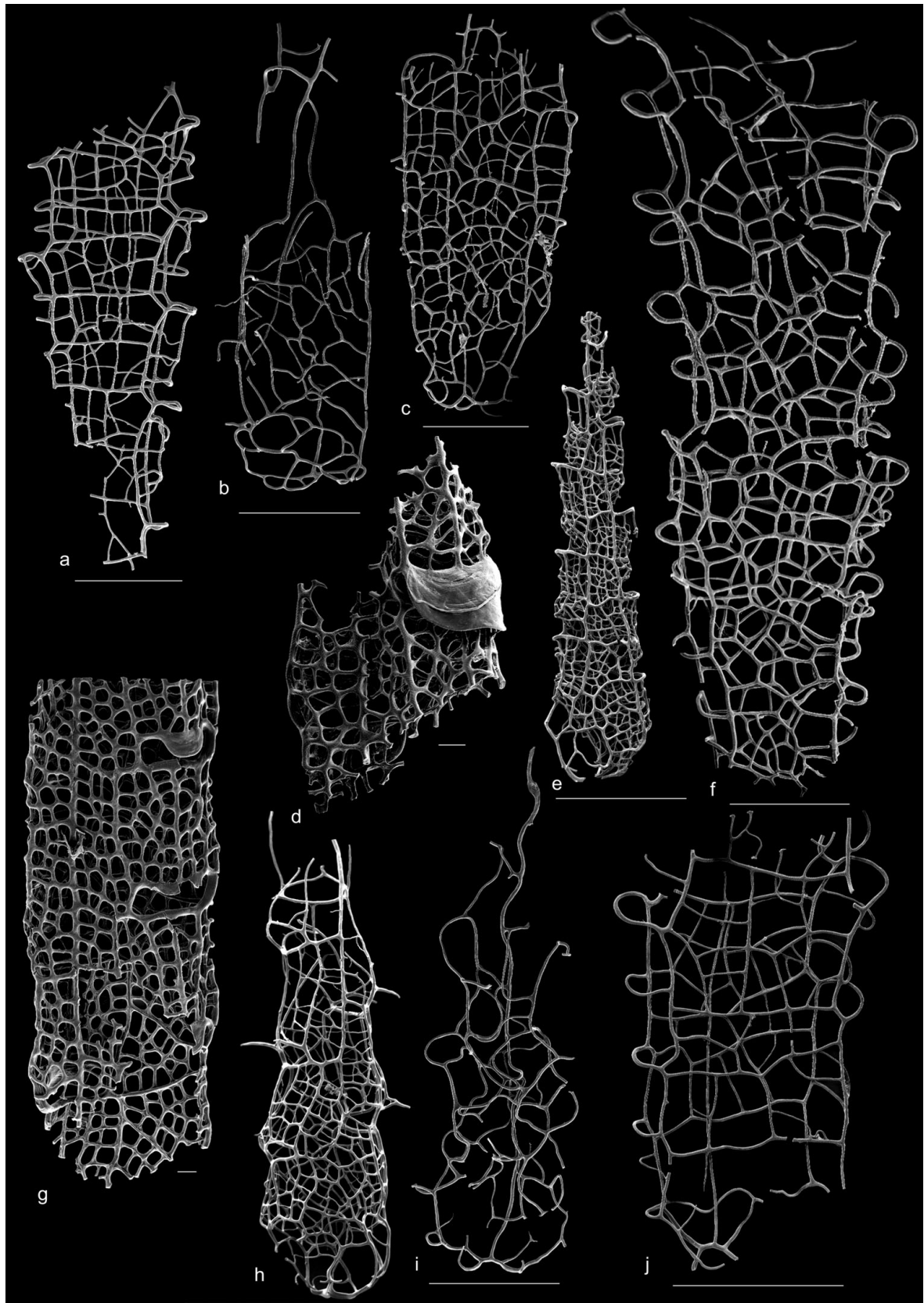


Figure 4. Graptolites from the Kolka-54, core, Latvia. (a, c) *Sokolovograptus parens* Kozłowska-Dawidziuk; (a) GIT 565-24; 519.80–519.85 m; (c) GIT 565-26; 524.70–524.75 m. (b) *Sokolovograptus?* sp.; GIT 565-25; 530.0–530.30 m. (d, g) *Gothograptus nassa* (Holm); (d) GIT 565-27; 408.40–408.70 m; (g) GIT 565-30; 392.70–392.75 m. (e) *Eisenackograptus eisenacki* (Obut & Sobolevskaya); GIT 565-28; 451.50–452.30 m. (f, j) *Sokolovograptus textor* (Bouček & Münch); (f) GIT 565-29; 534.60–534.65 m; (j) GIT 565-33; 544.90–544.95 m. (h) *Gothograptus kozłowskii* Kozłowska-Dawidziuk; GIT 565-31; 427.40–427.70 m. (i) *Pseudoplectograptus simplex* Kozłowska-Dawidziuk; GIT 565-32; 445.30–445.35 m. Scale bars represent 1 mm (a–c, e, f, h–j) or 100  $\mu$ m (d, g).

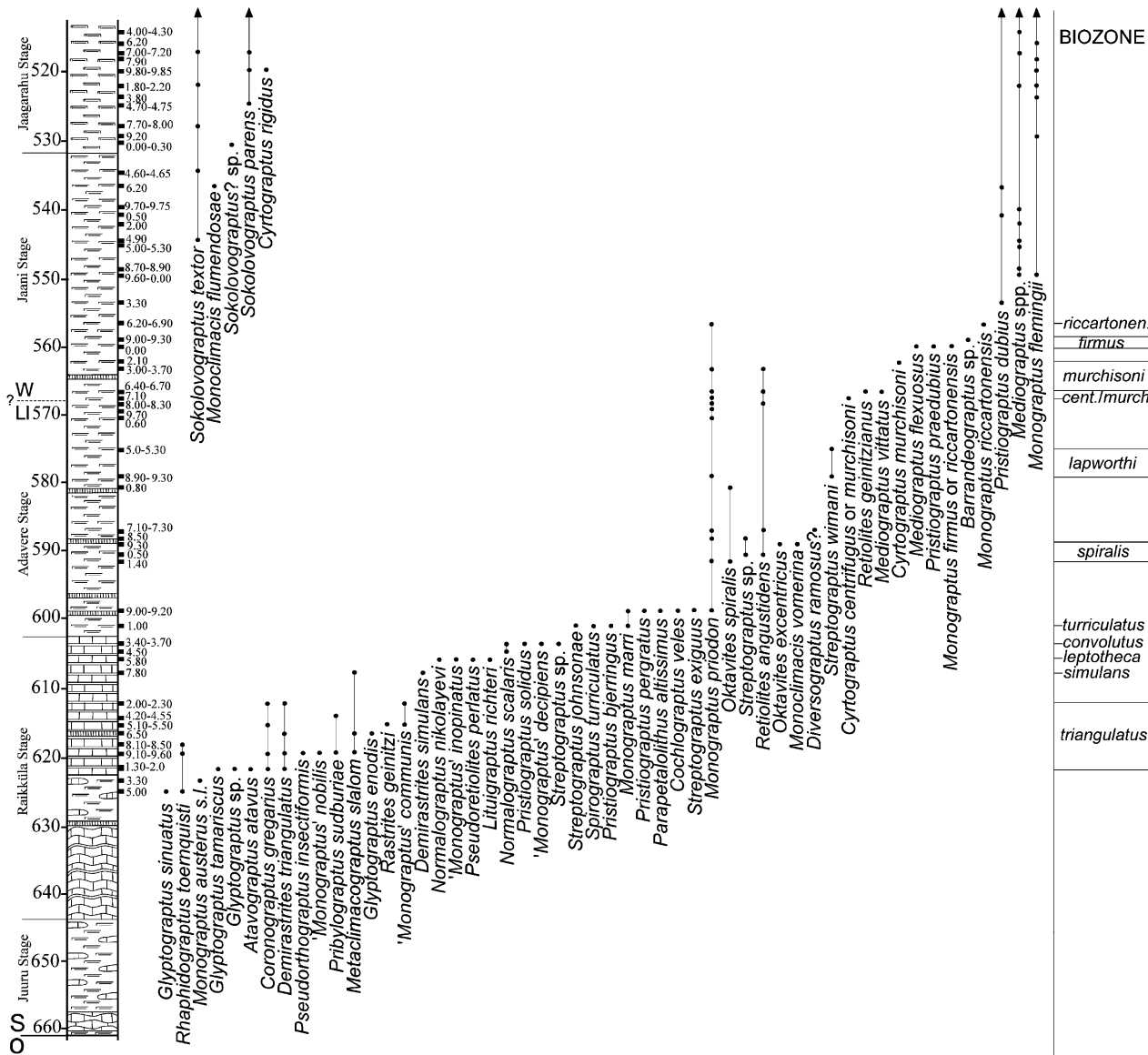


Figure 5. Stratigraphical ranges of graptolites through the Llandovery and lower Wenlock (Sheinwoodian) of the Kolka-54 core. See Figure 10 for lithological legend.

of specimens per kilogram of rock from a few tens (in the lower Raikküla Stage and in the Rootsiküla Stage) up to 4800 specimens (in the 575.0–575.3 m sample). The richest samples were from the Adavere Stage from which most samples (excluding those from the lowermost and uppermost parts of the stage) yielded more than 1000 conodont specimens per kilogram of rock. All figured conodont specimens are deposited in collection GIT 566. Stratigraphical ranges are shown in Figures 7 and 8.

The most common taxa in the faunas are those with coniform elements, particularly *Panderodus*. The almost continuous occurrence of *Dapsilodus*, but also the rare occurrences of several taxa known from nearer shore environments (e.g. *Apsidognathus*), and lack of *Ozarkodina polinclinata* (Nicoll & Rexroad) and some other taxa, indicate that the strata studied formed in

distal, deeper shelf environments. The rare, sporadic occurrences of many stratigraphically diagnostic taxa complicates considerably the dating of some intervals in the core.

The conodont biostratigraphy of the strata below the level of appearance of *Distomodus staurognathoides* (Walliser) is highly problematical in the Kolka-54 core. In this interval the conodont fauna is dominated by simple-cone taxa, mainly by *Panderodus* ex gr. *equicostatus* (Rhodes) (Fig. 9a, e, f) and *Dapsilodus* sp. n. R (Fig. 9b, g). However, the occurrence of *Oulodus?* cf. *panuarensis* Bischoff (Fig. 9o) and *Ozarkodina* ex gr. *excavata* (Branson & Mehl) (Fig. 9i, n) in the 640.80–641.00 m sample (Fig. 7) indicates that these strata are not older than late Rhuddanian; both taxa are known to appear in the uppermost Juuru Stage in the Baltic region (e.g. Nestor *et al.* 2003). The only

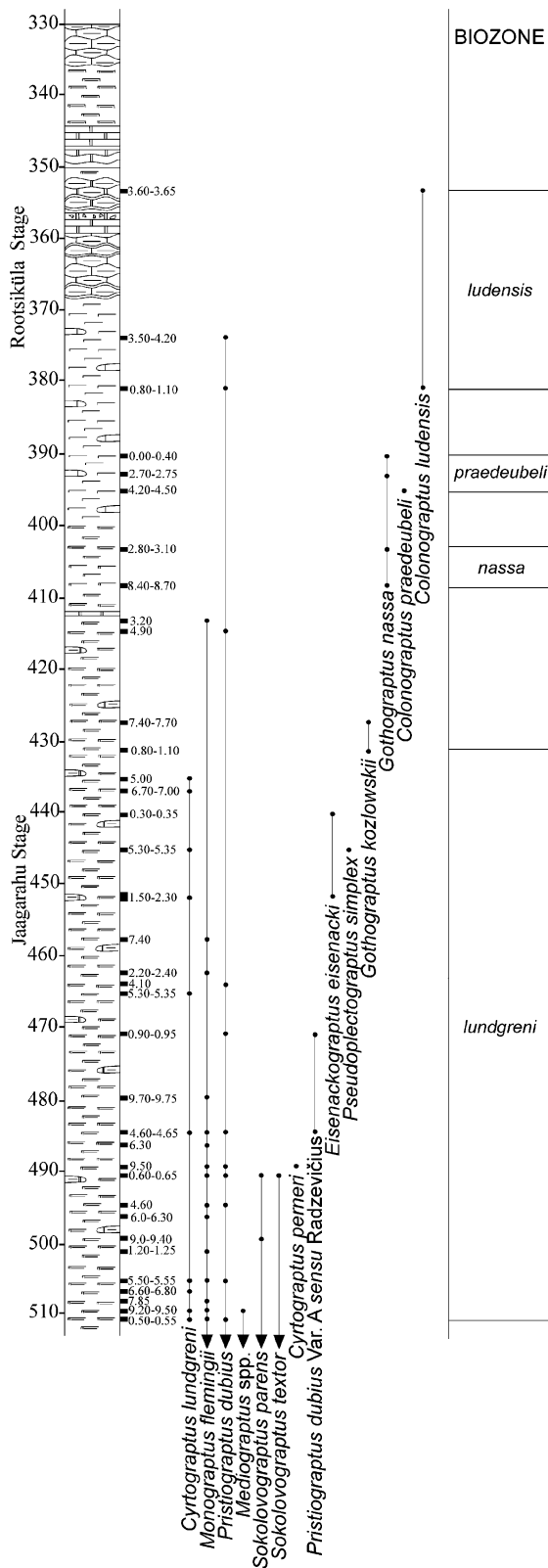


Figure 6. Stratigraphical ranges of graptolites through the upper Wenlock (Homerian) of the Kolka-54 core. See Figure 10 for lithological legend.

identifiable *Distomodius* in this interval comes from the 654.50–654.80 m sample. The Pa elements found here (e.g. Fig. 9j) are morphologically quite similar to *D. combinatus* Bischoff (Bischoff, 1986, pl. 7, fig. 19,

pl. 8, figs 1–7), although the processes, particularly the anterior and posterior ones, on our specimens are shorter. The specimens from the Kolka-54 core (identified as *D. ex gr. combinatus* on Fig. 7) probably are from the earlier part of the *D. combinatus* lineage.

In the Kolka-54 core, *Aspelundia? expansa* Armstrong (Fig. 9c, d, h) appears in the 621.70–622.00 m sample and, above this level, is continuously present up to the 601.00–601.20 m sample (Fig. 7). The appearance of *A.? expansa* normally marks the lower boundary of the *A.? expansa* Biozone (Armstrong, 1990). However, based on published data on the distribution of conodonts and other faunas in the Baltic region, the real level of the lower boundary of this biozone in the Kolka-54 core should most probably be looked for at a lower level, close to the lowermost *O.? panuarensis* in the basal Raikküla Stage (Fig. 7). This conclusion is based on the following: (1) in the Aizpute-41 core, *A.? expansa* appears in the topmost *Belonechitina postrobusta* chitinozoan Biozone and *O.? panuarensis* in the lowermost *Euconochitina electa* chitinozoan Biozone; in the graptolite biostratigraphy, both appear in the upper *cyphus* Biozone (Loydell, Männik & Nestor, 2003); (2) in the Heimtali and Põltsamaa cores, *O.? panuarensis* makes its first appearance again in the *E. electa* chitinozoan Biozone, although the lowermost specimen of *A.? expansa* in the Heimtali core was found at a considerably higher level (Nestor *et al.* 2003); (3) in the Ikla and Ruhnu-500 cores the oldest specimens of *A.? expansa* again come from the *E. electa* chitinozoan Biozone; based on data from the Ruhnu-500 core, this is from the upper *Coronograptus cyphus* graptolite Biozone (Kaljo, Männik, Nestor *in* Pöldvere, 2003; Nestor *et al.* 2003). Considering these data, it is evident that in the Kolka-54 core only the upper part of *A.? expansa*'s stratigraphical range has been recognized and, in this paper, the lower boundary of the *A.? expansa* Biozone (and of the *Aspelundia?* Superzone) is therefore tentatively drawn below the level of the lowermost *O.? panuarensis* (Fig. 7). Such an interpretation of this boundary agrees with data from New South Wales. According to Bischoff (1986), in that region *O.? panuarensis* and *Aspelundia? expansa* (identified by Bischoff as *Oulodus planus planus* (Walliser)) appear almost at the same level, with the stratigraphically lowest specimens stated to be from the *C. cyphus* graptolite Biozone, the same graptolite biozone as their first occurrences in the Baltic region.

The reason for the stratigraphically late appearance of *Aspelundia?* in the Kolka-54 core is not clear, but it may be an artefact resulting from the rarity of conodonts in the interval from 620 m to 645 m; the number of specimens per kilogram of rock is generally between ten and 40 and the faunas are strongly dominated by (up to 95 %) or in many cases are exclusively of taxa with coniform elements. Starting from the level of appearance of *Aspelundia?*, the number of specimens per kilogram of rock increases









Figure 9. For caption see next page.



considerably and in most samples above this level reaches several hundreds. Also, it is evident that if there is too great an interval between samples (generally more than 3 m) and sample size is limited, this hampers the biostratigraphical resolution of conodonts considerably (see also below; Figs 7, 8).

The lowermost *A.?* *fluegeli* (Fig. 9k–m) was found in the 607.60–607.70 m sample, well into the *D. staurogathoides* conodont Biozone. Previously, the oldest specimens of *A.?* *fluegeli* reported from the Baltic region were from the *Conochitina alargada* chitinozoan Biozone (Nestor *et al.* 2003), and the oldest identifiable specimens of *D. staurogathoides* were also from the *C. alargada* chitinozoan Biozone but above the level of appearance of *A.?* *fluegeli* (Loydell, Männik & Nestor, 2003). In the Kolka-54 core, both of these taxa again have their lowest occurrence in the *C. alargada* chitinozoan Biozone: identifiable *D. staurogathoides* about 7 m below the lowermost *A.?* *fluegeli* (Fig. 7). These data indicate that our ideas about the succession of appearances of these taxa in a sequence, and the conodont biozonation proposed for this interval (e.g. Männik, 2007a), need further studies and that the conodont biozonation of the Rhuddanian and Aeronian is still problematical.

The lower boundary of the *Pterospathodus eopennatus* ssp. n. 2 Biozone lies between the 601.00–601.20 m and 596.90–597.20 m samples (Fig. 7). The *P. eopennatus* ssp. n. 1 Biozone cannot be identified in the Kolka-54 core. Most probably it corresponds to a part of the 2.8 m thick unsampled interval between these samples. In all studied Baltic sections, the appearance of the *Pterospathodus* faunas is accompanied

by considerable changes in the taxonomic composition of conodont assemblages and a sharp increase in the number of taxa and specimens in samples (Männik *in* Pöldvere, 2003; Männik, 2008). In the Kolka-54 core the number of conodont specimens increases almost ten times: from about 345 specimens per kilogram of rock below this level up to 3300 specimens per kilogram above it.

The appearance of *P. amorphognathoides angulatus* (Walliser) (Fig. 9p, r) in the 593.10–593.30 m sample indicates that the lower boundary of the *P. a. angulatus* conodont Biozone (and that of the *P. celloni* conodont Superzone *sensu* Männik, 2007b) lies below this level (Fig. 7). In the same sample the lowermost *P. celloni* (Walliser) (Fig. 9s, u) was found. As in the Aizpute-41 core (Loydell, Männik & Nestor, 2003), in the Kolka-54 core *P. a. lennarti* Männik has not been found and *P. a. lithuanicus* Brazauskas (Fig. 9x) is rare (occurring in only one sample, 581.90–582.20 m; Fig. 7). For this reason, the upper boundary of the *P. a. angulatus* Biozone is drawn tentatively above the uppermost sample yielding *P. a. angulatus*. The lower boundary of the *P. a. amorphognathoides* Biozone is marked by the appearance of *P. a. amorphognathoides* Walliser (Fig. 9aa) in the 578.90–579.20 m sample (Fig. 7). The interval between this sample and that with the uppermost *P. a. angulatus* probably corresponds to the *P. a. lennarti* and *P. a. lithuanicus* biozones.

Two subzones, Lower and Upper, were recognized in the *P. a. amorphognathoides* Biozone by Männik (2007b). The boundary between these subzones is defined as the level of disappearance of *A.?* *fluegeli* ssp. n., the youngest known representative of the

Figure 9. Selected conodonts from the Kolka-54 core section. (a, e, f) *Panderodus* ex gr. *equicostatus* (Rhodes); (a) GIT 566-1, lateral view of aequaliform element, 648.20–648.40 m; (e) GIT 566-2, furrowed face of falciform element, 648.20–648.40 m; (f) GIT 566-3, unfurrowed face of high-based graciliform element, 648.20–648.40 m. (b, g) *Dapsilodus* sp. n. R; (b) GIT 566-4, inner lateral view of high-based element, 659.50–659.80 m; (g) GIT 566-5, lateral view of symmetrical element, 659.50–659.80 m. (c, d, h) *Aspelundia?* *expansa* Armstrong; (c) GIT 566-6, inner lateral view of M element, 618.10–618.50 m; (d) GIT 566-7, inner lateral view of Pb? element, 618.10–618.50 m; (h) GIT 566-8, inner lateral view of Sc element, 614.20–614.55 m. (i, n) *Ozarkodina* ex gr. *excavata* (Branson & Mehl); (i) GIT 566-9, inner lateral view of M element, 640.80–641.00 m; (n) GIT 566-10, inner lateral view of Sc element, 640.80–641.00 m. (j) *Distomodus* ex gr. *combinatus* Bischoff; GIT 566-11, upper view of Pa element, 654.50–654.80 m. (k–m) *Aspelundia?* *fluegeli* (Walliser); (k) GIT 566-12, lateral view of Pa? element, 601.90–602.00 m; (l) GIT 566-13, inner lateral view of Sc element, 601.90–602.00 m; (m) GIT 566-14, inner lateral view of M element, 601.90–602.00 m. (o) *Oulodus?* *panuarensis* Bischoff; GIT 566-15, inner lateral view of Sc element, 640.80–641.00 m. (p, r) *Pterospathodus amorphognathoides angulatus* (Walliser); (p) GIT 566-16, outer lateral view of Sc<sub>1</sub> element, 588.90–589.20 m; (r) GIT 566-17, inner lateral view of Pa element, 593.10–593.30 m. (q, t) *Aspelundia?* *fluegeli* ssp. n.; (q) GIT 566-18, inner lateral view of Pb? element, 575.00–575.30 m; (t) GIT 566-19, inner lateral view of M element, 575.00–575.30 m. (s, u) *Pterospathodus celloni* (Walliser); (s) GIT 566-20, (u) GIT 566-21, inner lateral views of Pa elements, 584.90–585.20 m. (v) *Panderodus* sp. n. N; GIT 566-22, unfurrowed face of falciform element, 568.60–568.80 m. (w) *Pseudooneotodus tricornis* Drygant; GIT 566-23, upper view, 563.00–563.30 m. (x) *Pterospathodus amorphognathoides lithuanicus* Brazauskas; GIT 566-24, inner lateral view of Pa element, 581.90–582.20 m. (y) *Pterospathodus pennatus procerus* (Walliser); GIT 566-25, upper view of Pa element, 575.00–575.30 m. (z) *Panderodus* cf. *langkawiensis* Igo & Koike; GIT 566-26, unfurrowed face of low-based graciliform element, 559.00–559.30 m. (aa) *Pterospathodus amorphognathoides amorphognathoides* Walliser; GIT 566-27, upper view of Pa element, 578.90–579.20 m. (bb) *Ozarkodina excavata* (Branson & Mehl); GIT 566-28, inner lateral view of Pa element, 419.80–420.10 m. (cc) *Kockelella amsdeni* Barrick & Klapper; GIT 566-29, upper view of Pa element, 530.00–530.30 m. (dd) *Pseudooneotodus linguicornis* Jeppsson; GIT 566-30, upper view, 434.60–434.90 m. (ee, ii) *Walliserodus* sp. n. C; (ee) GIT 566-31, inner lateral (ee1) and outer lateral (ee2) views of deboltiform element, 419.80–420.10 m; (ii) GIT 566-32, inner lateral view of multicostatiform element, 419.80–420.10 m. (ff) *Ozarkodina sagitta sagitta* (Walliser); GIT 566-33, lateral view of Pa element, 436.70–437.00 m. (gg) *Ozarkodina bohemica longa* Jeppsson; GIT 566-34, lateral (gg1) and lower (gg2) views of Pa element, 362.30–362.60 m. (hh) *Dapsilodus praecipuus* Barrick; GIT 566-35, inner lateral view of high-based element, 427.40–427.70 m. (jj) *Kockelella ortus absidata* Barrick & Klapper; GIT 566-36, lateral view of Pa element, 402.80–403.10 m. Scale bars represent 100 µm.

*Aspelundia?* lineage. In the Kolka-54 core, *A.?* *fluegeli* ssp. n. (Fig. 9q, t) occurs in two samples, the higher of which is at 568.60–568.80 m (Fig. 7). From the same sample the uppermost probable specimens of *P. a. amorphognathoides* in the core have been identified. In general, the distribution of *P. a. amorphognathoides* in the Kolka-54 core is similar to that in the Aizpute-41 core (Loydell, Männik & Nestor, 2003; conodont biostratigraphy revised in Männik, 2007c), that is, the taxon becomes rare, or is missing, in the Upper Subzone of the *P. a. amorphognathoides* Biozone. This is due to ecology: *P. a. amorphognathoides* is common in nearshore environments (Männik, 1998). In deeper, graptolite-bearing environments it becomes rare and is replaced by *P. pennatus procerus* (Walliser) (Fig. 9y). In the Kolka-54 core *P. pennatus procerus* appears in the Lower Subzone of the *P. a. amorphognathoides* Biozone (Fig. 7).

Two samples, from 566.40–566.70 m and 563.00–563.30 m, probably come from the Upper Subzone of the *P. a. amorphognathoides* Biozone. The position of the upper boundary of this subzone, and, accordingly, also of the upper boundary of the *P. a. amorphognathoides* Biozone, in the Kolka-54 core is problematical. However, considering the results of the highly detailed analysis of faunal changes during the Ireviken Event carried out by Jeppsson (1997a), it is quite possible that the continuous occurrence of *Pseudooneotodus tricornis* Drygant (Fig. 9w) up to and including the 563.00–563.30 m sample indicates that this sample lies below Datum 1 of the event (and, accordingly, below the upper boundary of the *P. a. amorphognathoides* Biozone) (Fig. 7). From the same sample comes the uppermost *Panderodus* sp. n. N (Fig. 9v), indicating also that Datum 3 of the Ireviken Event, marking the boundary between the *Ps. bicornis* and *P. pennatus procerus* superzones *sensu* Jeppsson (1997b), lies between this and the next sample. Thus, at least two biozones, the Lower and Upper *Ps. bicornis* biozones, correspond to the 3.7 m thick unsampled interval between the 563.00–563.30 m and 559.00–559.30 m samples (Fig. 7). Also, as the Llandovery/Wenlock boundary in its type section at Hughley Brook correlates approximately with Datum 2 of the Ireviken Event (Jeppsson, 1997b), the series boundary in the Kolka-54 core should be looked for in the same interval.

A single specimen of *Panderodus* cf. *langkawiensis* Igo & Koike (Fig. 9z) occurring with *P. pennatus procerus* in the 559.00–559.30 m sample indicates that this sample most probably comes from the Lower *P. pennatus procerus* Biozone (Fig. 7). This is the highest sample with *P. pennatus procerus* and *D. staurognathoides*. These data indicate that the Upper *P. pennatus procerus* and the Lower *Kockelella ranuliformis* conodont biozones evidently correspond to the unsampled interval between this and the overlying (555.00–555.30 m) sample. However, as *D. staurognathoides* becomes very rare in the topmost part of its range (e.g. Jeppsson & Männik, 1993) and as our

samples are small, it is quite possible that, in reality, the boundary between the Lower and Upper *K. ranuliformis* biozones lies higher in the core.

The strata above this level, up to the upper Jaagarahu Stage, are dominated by simple-cone taxa: *Pseudooneotodus*, *Panderodus* and *Decoriconus*. *Dapsilodus* is quite common. Ramiforms are represented mainly by *Ozarkodina excavata* (Branson & Mehl) (Fig. 9bb). Although the coniform fauna is quite diverse in this interval, current knowledge of these taxa does not allow reliable recognition in the Kolka-54 core of any of the conodont biozones described from the Wenlock by Jeppsson (1997b). However, a single specimen of *Kockelella amsdeni* Barrick & Klapper (Fig. 9cc) in the 530.00–530.30 m sample suggests that this sample comes from the Lower *K. walliseri* Biozone. In North America the range of *K. amsdeni* coincides with that of *Ozarkodina sagitta rhenana* and with part of the range of *K. walliseri* (Barrick & Klapper, 1976). According to Jeppsson (1997b), the Lower *K. walliseri* Biozone is the only unit characterized by co-occurrences of *K. walliseri* and *O. s. rhenana*. Unfortunately, no specimens of *O. s. rhenana* and *K. walliseri* have been found in the Kolka-54 core samples.

The next level well dated by conodonts lies in the upper Jaagarahu Stage. Based on the occurrence in the 436.70–437.00 m sample of *Pseudooneotodus linguicornis* Jeppsson (Fig. 9dd) and of *O. s. sagitta* (Walliser) (Fig. 9ff), this level definitely lies in the *O. s. sagitta* Biozone. A single broken Pa element of *O. s. sagitta* in the 448.00–448.30 m sample suggests that the lower boundary of the biozone most probably lies below this sample (Fig. 8).

*Ps. linguicornis* is continuously present up to the 419.8–420.10 m sample. This sample also contained the uppermost specimens of *Walliserodus* sp. n. C (Fig. 9ee, ii). According to Jeppsson & Calner (2003), both of these taxa disappear at Datum 1.5 of the Mulde Event, in the middle part of Subzone 0 of the *Ozarkodina bohémica longa* Biozone. Starting from Datum 1.5 of the Mulde Event the number of conodont specimens in samples decreases considerably in the Kolka-54 core. In the strata from just below the *O. s. sagitta* Biozone through to the lowermost *O. b. longa* Biozone (below Datum 1.5) the number of conodonts varied from several hundreds up to more than 1500 (in the 448.00–448.30 sample), whereas above this interval the number of specimens rarely reaches more than just a few tens, and in many samples it is less than ten. Only in three samples from the uppermost part of the studied interval of the core (the 355.00–355.20 m, 351.80 m and 350.10–350.40 m samples) does the number of specimens reach more than 200 or 300.

By the definition of Jeppsson & Calner (2003), Datum 1 of the Mulde Event, and the boundary between the *O. s. sagitta* and *O. b. longa* biozones, corresponds to the level of extinction of *O. s. sagitta*. At this level also *K. ortus ortus* (Walliser), *Dapsilodus praecipuus* Barrick and *D. sparsus* Barrick became extinct. As

all of these taxa are very rare and have a sporadic distribution in the Kolka-54 core, recognition of Datum 1 is difficult, but most probably it lies (and is tentatively drawn in Fig. 8) above the 427.40–427.70 m sample from which the uppermost specimen of *D. praecipuus* (Fig. 9hh) was found.

According to Calner & Jeppsson (2003), the upper boundary of the *O. b. longa* Biozone corresponds to the level of appearance of *Kockelella ortus absidata* Barrick & Klapper, the nominal taxon of the following conodont biozone. In the Kolka-54 core *K. o. absidata* (Fig. 9jj) occurs only in the 402.80–403.10 m sample, probably indicating that the level of this sample lies already in the *K. o. absidata* Biozone (Fig. 8). This agrees with the graptolite dating of these strata, although *O. b. longa* (Fig. 9gg) appears higher in the section, in the 399.80–400.00 m sample (Fig. 8). Based on data from Gotland, the lower boundary of the *K. o. absidata* Biozone lies very close to the boundary between the *G. nassa* and *Co. praedeubeli* graptolite biozones (Calner & Jeppsson, 2003). In the Kolka-54 core the only specimen of *K. o. absidata* comes from an undated interval between these graptolite biozones (Figs 6, 8). Accordingly, it is most probable that the lowermost *O. b. longa* in the Kolka-54 core is not from the lowermost part of the total stratigraphical range of this taxon, evidently due to small sample size. Five subzones were defined in the *O. b. longa* Biozone (Calner & Jeppsson, 2003) but, due to inadequate information, these units cannot be recognized in the studied section. The conodont biostratigraphy of the strata above the level of appearance of *K. o. absidata* is highly problematical.

In the uppermost part of the studied interval, in the 359.00–359.20 m and 350.10–350.40 m samples, the youngest specimens of *Walliserodus* sp. known from the East Baltic region have been found (Fig. 8). Previously (Jeppsson & Calner, 2003), it was considered that in the Baltic basin *Walliserodus* became extinct during the Mulde Event (at Datum 1.5).

### 5. Chitinozoan biostratigraphy of the Kolka-54 core

The assemblages of lower Silurian chitinozoans in the Kolka 54 core are similar to those of the Ohesaare (Nestor, 1994) and Ruhnu (Nestor in Pöldvere, 2003) cores, with the argillaceous limestones and predominantly argillaceous marlstones containing abundant chitinozoans.

Chitinozoan ranges and biozones (mainly interval zones) are shown in Figures 10 and 11. Most of the identified taxa are illustrated in Figures 12–15. Alongside the well-known taxa are many new and obscure forms, which are left in open nomenclature. Because of the argillaceous nature of the entombing sedimentary rocks, some of the chitinozoans are flattened.

The *Spinachitina fragilis* Biozone assemblage is typical of the lowermost Silurian. In the Ohesaare core the corresponding biozone was named the

*Ancyrochitina laevaensis* Biozone (Nestor, 1994), but the latter species was not found in Aizpute and Ruhnu, although it is present in the Kolka-54 core. In addition to *S. fragilis* Nestor (Fig. 12c), the biozonal assemblage also contains *Plectochitina nodifera* (Nestor) (Fig. 12d), *Belonechitina postrobusta* (Nestor) (Fig. 12a), *B. aspera* (Nestor) (Fig. 12b), *Plectochitina spongiosa* Achab (Fig. 12h) and abundant *Cyathochitina campanulaeformis* (Eisenack) (Fig. 12e). The overlying, red-coloured strata (the Rozeni Member) represent an Interzone, which is empty of chitinozoans.

The *Belonechitina postrobusta* Biozone, which has been recognized in many regions (see Verniers *et al.* 1995), was not identified in the Kolka-54 core. However, it is not excluded that it is actually present in this core, within the unsampled interval between 643.30 m and 647.30 m. The *B. postrobusta* Biozone can be represented by a condensed interval; for instance, in the Ruhnu core it is represented by only one sample.

The *Euconochitina electa* Biozone is treated here in a restricted sense, as in its former upper part the *Spinachitina maennili* Biozone (of Verniers *et al.* 1995) has been distinguished. The most important species associated with *E. electa* (Nestor) (Fig. 12f) are *Conochitina iklaensis* Nestor (Fig. 12j), *Ancyrochitina bifurcaspina* Nestor (Fig. 12i) and *Cyathochitina calix* (Eisenack) (Fig. 12g).

The *Spinachitina maennili* Biozone encompasses the upper part of the Slitere Member and most of the Kolka Member in the Kolka-54 core, but is quite thin in some other sections, corresponding only to the upper part of the Kolka Member (Nestor, 1994). *S. maennili* (Nestor) (Fig. 12l) has not been found in the shallower water sections of Estonia (Nestor, 1998). The associated species in the *S. maennili* Biozone of the Kolka-54 core are the same as in the underlying biozone, including *E. electa*. In most of the studied East Baltic sections, *Ancyrochitina ramosaspina* Nestor (Fig. 12q) occurs together with *S. maennili*, indicating that this biozone is present also in shallower water sections where the biozonal species is lacking (Nestor, 1994).

*Ancyrochitina convexa* Nestor (Fig. 12p) is a rather rare species in the East Baltic cores and found seldom in other regions. It appears to be similar in stratigraphical occurrence to *Conochitina edjelensis* Taugourdeau (Fig. 12n) and *Conochitina elongata* Taugourdeau (Fig. 12o). As the latter species occurs more commonly than *C. edjelensis*, this new biozone is named after *C. elongata*. The abundant occurrence of *Cyathochitina kuckersiana* (Eisenack) (Fig. 12m) is quite characteristic of this interval (see Nestor, 1994). *C. elongata* is known from many areas of the world, but has never been used before as a biozonal species.

*Conochitina alargada* Cramer (Fig. 12k) is the index species of a global biozone (Verniers *et al.* 1995). In addition to the index species, the *C. alargada* Biozone contains numerous *Conochitina iklaensis*, *C. elongata*, *C. edjelensis* and *Spinachitina maennili*. A newcomer



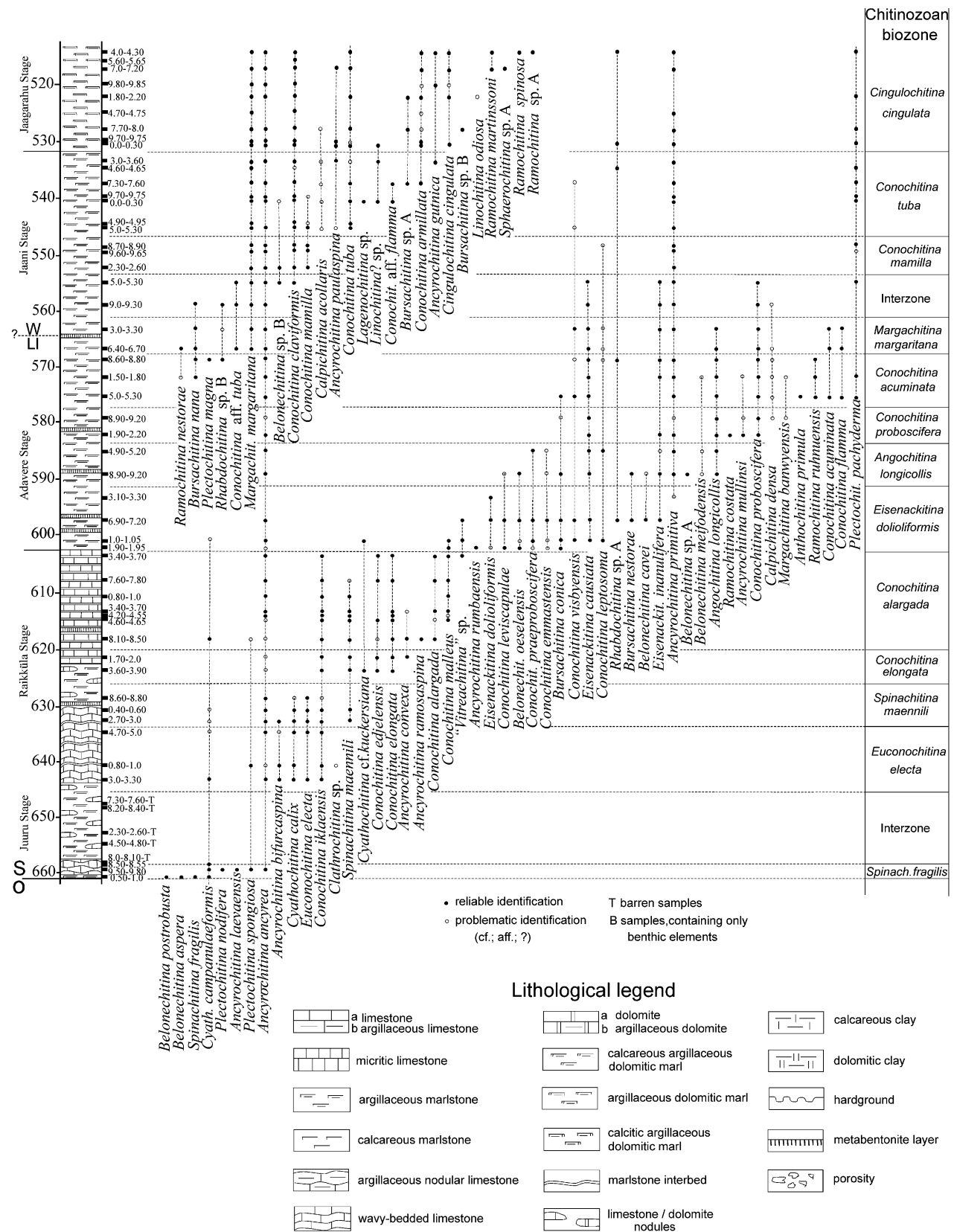


Figure 10. Distribution of chitinozoans in the lower part of the Kolka-54 core. From left to right: regional stage, depth (in metres), lithological log of the core, sample, sample interval, distribution of taxa. Note that the barren interval (Interzone) in the nodular argillaceous marlstones in the Juuru Stage is characterized by red coloration.

is ‘*Vitreachitina*’ sp. (Fig. 12s) in the uppermost sample from this interval (603.40–603.70 m). The biozone corresponds to the middle and upper parts of the Raikküla Stage.

Interzone (II), which is devoid of chitinozoans in many East Baltic cores and separates the *C. alargada* and *Eisenackitina dolioliformis* biozones, is missing in the Kolka-54 core. Most likely this indicates an

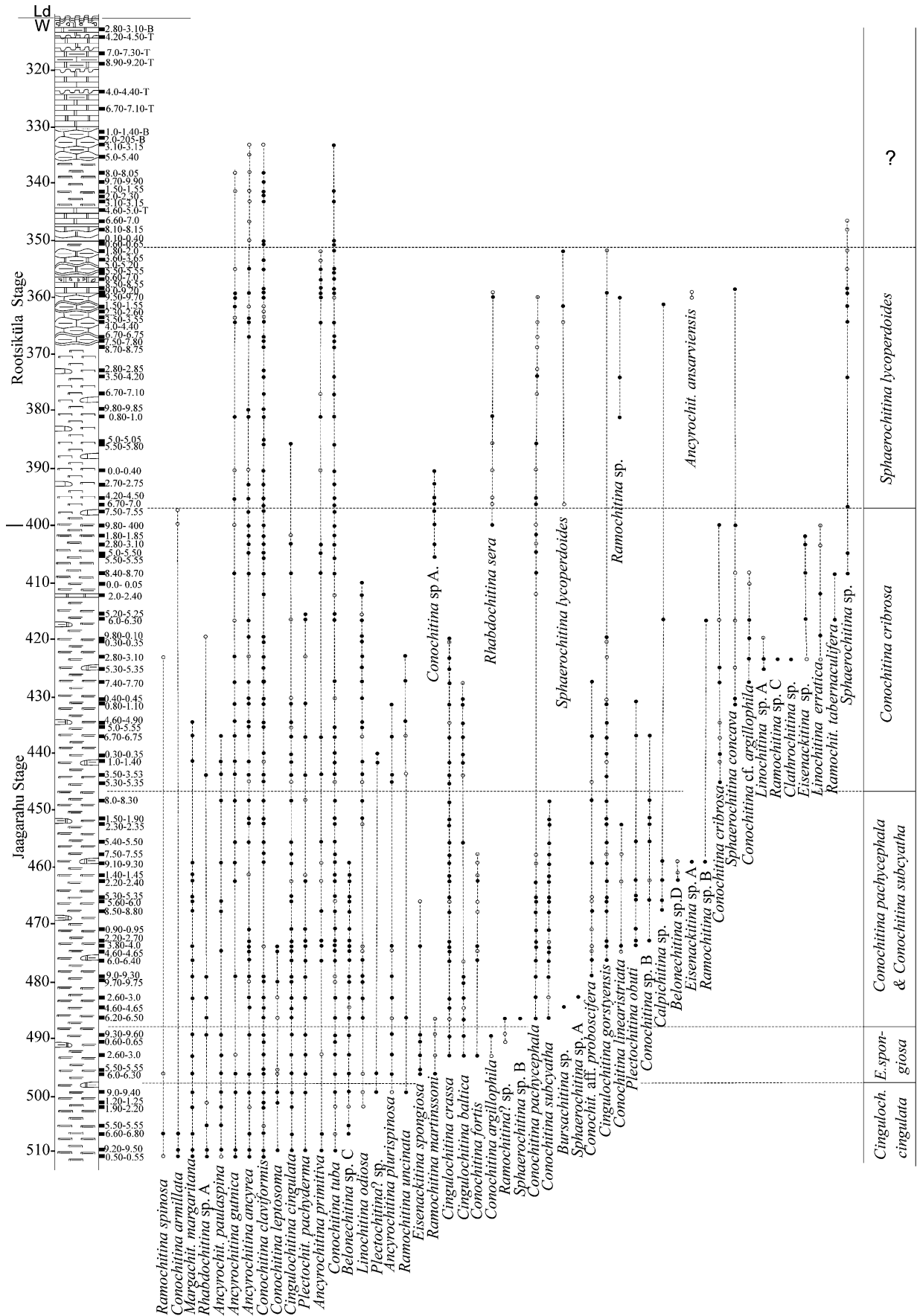


Figure 11. Distribution of chitinozoans in the upper part of the Kolka-54 core. From left to right: regional stage, depth (in metres), lithological log of the core, sample, sample interval, distribution of taxa, biozone. See Figure 10 for lithological legend. W – Wenlock; Ld – Ludlow.

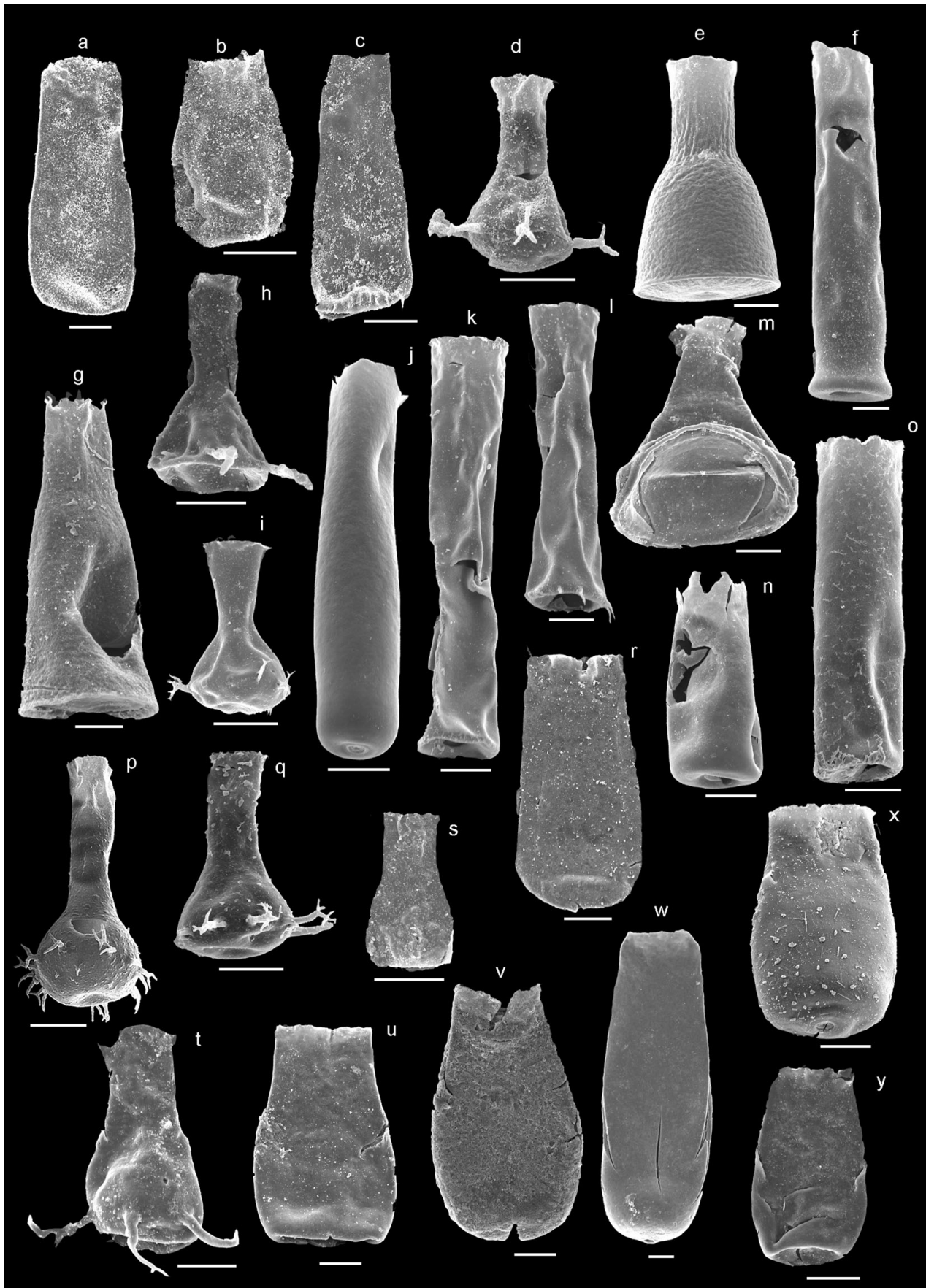


Figure 12. For caption see next page.



unconformity in this section; the lower *Stimulograptus sedgwickii* graptolite Biozone, established in the Aizpute-41 core (see Loydell, Männik & Nestor, 2003), is also missing in this interval in Kolka-54.

The lower boundary of the *Eisenackitina dolioliformis* Biozone is sharp, probably because of the underlying gap in the section. Seven species appear together at the base of the Adavere Stage: the index species *E. dolioliformis* Umnova (Fig. 12x), *Ancyrochitina rumbaensis* Nestor (Fig. 12t), *Conochitina leviscapulae* Mullins & Loydell (Fig. 12u), *Belonechitina oeselenensis* Nestor (Fig. 12v), *Conochitina praeproboscifera* Nestor (Fig. 12w), *Bursachitina conica* (Taugourdeau & de Jekhowsky, *sensu* Mullins & Loydell, 2001) (Fig. 13a) and *Conochitina emmastensis* Nestor (Fig. 13g).

The next sample, at a depth of 601.0–601.05 m, yielded also *Conochitina visbyensis* Laufeld (Fig. 12y), *Conochitina leptosoma* Laufeld (Fig. 13c) and *Eisenackitina causiata* Verniers (Fig. 13d). *Rhabdochitina* sp. A (Fig. 13b), *Eisenackitina inanulifera* Nestor (Fig. 13e), *Belonechitina cavei* Mullins & Loydell (Fig. 13f) and *Bursachitina nestorae* Mullins & Loydell (Fig. 13i) appear in the middle of the biozone (in the 596.90–597.20 m sample). The uppermost sample from the biozone (593.10–593.30 m) contained only a few chitinozoans, including *Ancyrochitina primitiva* Eisenack. The *E. dolioliformis* Biozone corresponds to the lower part of the Adavere Stage and is recognized worldwide (Verniers *et al.* 1995).

*Angochitina longicollis* Eisenack (Fig. 13h), indicative of the succeeding biozone, appears in the Kolka-54 core, together with *Belonechitina* cf. *meifodensis* Mullins & Loydell (Fig. 13r) and *Belonechitina* sp. A (Fig. 13y). It is important to note that the questionably identified specimens of *A. longicollis* in the lowermost Telychian of the Ohesaare (Nestor, 1994) and Ruhnu (Nestor *in* Pöldvere, 2003) cores have been re-examined and identified as *Angochitina* cf. *hansonica* Soufiane & Achab, 2000. Six chitinozoan species have their last occurrences in this biozone, in the middle part of the Adavere Stage. The *A. longicollis* Biozone is known worldwide (Verniers *et al.* 1995; Grahn, 2005, 2006).

Chitinozoan species diversity in the *Conochitina proboscifera* Biozone of the Kolka-54 core is lower than that in Estonian cores (Nestor, 2005). In the Kolka-54 core, besides the index species (Fig. 13s), *Ancyrochitina mullinsi* Nestor (Fig. 13k) and *Ramochitina costata* (Umnova) (Fig. 13j) appear. *C. proboscifera* is a dominant species for this and the next three biozones, but large numbers of *E. causiata* and *A. longicollis* are also found. In the upper part of the *C. proboscifera* Biozone, *Calpichitina densa* (Eisenack) (Fig. 13t) and *Margachitina banwyensis* Mullins & Loydell (Fig. 13w) appear. The *M. banwyensis* Biozone (see Mullins & Loydell, 2001) is not differentiated in the Kolka-54 core, as the eponymous species is represented here by only a few, questionably identified, specimens. *C. proboscifera* is an easily identified and widely distributed species, but as a biozonal species it has only been used in East Baltic cores (Nestor, 1994, 2005; Nestor *in* Pöldvere, 2003).

The *Conochitina acuminata* Biozone was first defined by Mullins & Loydell (2001) in the Banwy River section and is well distinguished also in the Estonian cores (Nestor, 2005). At the base of the biozone, *Ramochitina ruhnuensis* (Nestor) (Fig. 13n), *Anthochitina primula* Nestor (Fig. 13m), *Conochitina flamma* Laufeld (Fig. 13p) and *Plectochitina pachyderma* (Laufeld) (Fig. 13u) appear along with the index species (Fig. 13o). In the middle and uppermost parts of the biozone, *Bursachitina nana* (Nestor) (Fig. 13l), *Ramochitina nestorae* Grahn (Fig. 13v), *Rhabdochitina* sp. B (Fig. 13q) and *Plectochitina magna* (Nestor) (Fig. 13x) make their appearance. According to Laufeld (1974), typical populations of *Conochitina acuminata* Eisenack occur only in the Lower Visby Beds and below. This corresponds well with data from the Estonian cores (Nestor, 2005) and from the Banwy River section, where the range of this species correlates with the *Cyrtograptus lapworthi* graptolite Biozone (Mullins & Loydell, 2001).

The lower boundary of the *Margachitina margaritana* Biozone has caused much debate (Mullins & Loydell, 2001; Loydell & Nestor, 2005; Nestor, 2005). In the Kolka-54 core, *M. margaritana* (Eisenack) (Fig. 13z) appears above the base of the Wenlock. In addition to the index species, *Conochitina* aff. *tuba* Eisenack

Figure 12. Chitinozoans from the Kolka-54 core. (a) *Belonechitina postrobusta* (Nestor); GIT 546-1; 660.50–661.0 m. (b) *Belonechitina aspera* (Nestor); GIT 546-2; 660.50–661.0 m. (c) *Spinachitina fragilis* (Nestor); GIT 546-3; 660.50–661.0 m. (d) *Plectochitina nodifera* (Nestor); GIT 546-4; 659.50–659.80 m. (e) *Cyathochitina campanulaeformis* (Eisenack); GIT 546-5; 660.50–661.0 m. (f) *Euconochitina electa* (Nestor); GIT 546-6; 643.0–643.30 m. (g) *Cyathochitina calix* (Eisenack); GIT 546-7; 640.80–641.0 m. (h) *Plectochitina spongiosa* Achab; GIT 546-8; 659.50–659.80 m. (i) *Ancyrochitina bifurcaspina* Nestor; GIT 546-9; 643.0–643.30 m. (j) *Conochitina iklaensis* Nestor; GIT 546-10; 643.0–643.30 m. (k) *Conochitina alargada* Cramer; GIT 546-11; 618.10–618.50 m. (l) *Spinachitina maenili* (Nestor); GIT 546-12; 632.70–633.0 m. (m) *Cyathochitina kuckersiana* (Eisenack); GIT 546-13; 623.60–623.90 m. (n) *Conochitina edjelensis* Taugourdeau; GIT 546-14; 621.70–622.0 m. (o) *Conochitina elongata* Taugourdeau; GIT 546-15; 621.70–622.0 m. (p) *Ancyrochitina convexa* Nestor; GIT 546-16 (HT- Ch 248/9795); 621.70–622.0 m. (q) *Ancyrochitina ramosaspina* Nestor; GIT 546-17; 618.10–618.50 m. (r) *Conochitina malleus* Van Grootel (*nomen nudum*); GIT 546-18; 614.60–614.65 m. (s) '*Vitreachitina*' sp.; GIT 546-19; 603.40–603.70 m. (t) *Ancyrochitina rumbaensis* Nestor; GIT 546-20; 601.90–601.95 m. (u) *Conochitina* cf. *leviscapulae* Mullins & Loydell; GIT 540-21; 603.40–603.70 m. (v) *Belonechitina oeselenensis* Nestor; GIT 546-22; 603.40–603.70 m. (w) *Conochitina praeproboscifera* Nestor; GIT 546-23; 601.0–601.05 m. (x) *Eisenackitina dolioliformis* Umnova; GIT 546-24; 596.90–597.20 m. (y) *Conochitina visbyensis* Laufeld; GIT 546-25; 601.0–601.05 m. Scale bars represent 50 µm.



Figure 13. For caption see next page.



(Fig. 13aa) is the only newcomer in this biozone. The disappearance levels of two species are the most important events for this biozone: that of *Ramochitina nestorae* Grahn at the Llandovery/Wenlock boundary (Grahn, 1998; Mullins & Aldridge, 2004; Nestor, 2005) and that of *A. longicollis* which identifies the upper boundary of the biozone (Nestor, 1994, 2005). This biozone and the next Interzone correspond to most of the Ireviken Event (Nestor, Einasto & Loydell, 2002), within which 11 species disappear in the Kolka-54 core.

*Cingulochitina bouniensis* Verniers, which was not found in the Kolka-54 core, has been identified above the *M. margaritana* Biozone in the Banwy River section (Mullins & Loydell, 2001), as well as in the Aizpute-41 core (Loydell, Männik & Nestor, 2003) and Ruhnu core (Nestor, 2005). The Interzone between the *M. margaritana* and *Conochitina mamilla* biozones is characterized by a gradual disappearance of species, but *Belonechitina* sp. B (Fig. 13ab) and *Conochitina claviformis* Eisenack (Fig. 14a) appear in the topmost part of this interval. The latter is one of the most abundant and long-ranging Silurian species (Nestor, 1994, 2007).

*Conochitina mamilla* Laufeld (Fig. 14b) is the index species of the next biozone. It is less common than, and is sometimes difficult to differentiate from, *C. claviformis*. The biozone contains only a few, mostly long-ranging species. This and the next biozone have been established and used up to now only in East Baltic chitinozoan biostratigraphy (Nestor, 1994), correlating there with the middle of the Jaani Stage.

The diversity of species increases considerably in the *Conochitina tuba* Biozone. In addition to *C. tuba* Eisenack (Fig. 14c), *Ancyrochitina paulaspina* Nestor (Fig. 14e) and *Calpichitina acollaris* appear in its lowermost part, followed by *Lagenochitina* sp. (Fig. 14d), *Linochitina?* sp. (Fig. 13ac), *Conochitina* aff. *flamma* (Fig. 14f), *Bursachitina* sp. A (Fig. 14g) and *Conochitina armillata* Tougeourdeau & Jekhowsky (Fig. 14j). In the uppermost part, *Ancyrochitina gutnica* Laufeld (Fig. 14k) appears. This biozone embraces the upper part of the Jaani Stage.

Many newcomers (11 taxa) occur in the *Cingulochitina cingulata* Biozone. One after another there appear *Cingulochitina cingulata* (Eisenack) (Fig. 14l), *Bursachitina* sp. B (Fig. 14m), *Linochitina odiosa* Laufeld (Fig. 14t), *Ramochitina martinssoni* (Laufeld) (Fig. 14n), *Sphaerochitina* sp. A (Fig. 14h), *Ramochitina spinosa* (Laufeld) (Fig. 14i), *Ramochitina* sp. A (Fig. 14o), *Belonechitina* sp. C (Fig. 14p), *Plectochitina?* sp., *Ancyrochitina plurispinosa* Nestor (Fig. 14q) and *Ramochitina uncinata* Laufeld (Fig. 15m). The biozonal index species is widely distributed around the world (Verniers *et al.* 1995).

*Eisenackitina spongiosa* (Fig. 14u), originally described from the Coalbrookdale Formation, Shropshire (Swire, 1990), is the index species of the next biozone. In the middle Wenlock beds of the East Baltic, Nestor (1994) identified *Eisenackitina lagena*, which Eisenack (1968) described originally from graptolitic erratic boulders of early Ludlow age. High-resolution SEM study has revealed differences in the ornamentation of the vesicle wall of these two species that are usually identical in overall shape. Like the East Baltic Wenlock species, *E. spongiosa* has a spongy ornamentation of the vesicle wall (Nestor, 1994, this paper), whereas *E. lagena* has a porous vesicle wall, covered with granules or tubercles (Nestor, 2007). Thus, it is not the *E. lagena* Biozone, but the *E. spongiosa* Biozone that occurs above the *C. cingulata* Biozone in the East Baltic Wenlock succession. In addition to the index species, the biozone yields an abundant assemblage of transitional species, while *C. claviformis* is still the most numerous. In addition to *C. cingulata*, *C. crassa* Nestor (Fig. 14r) and *C. baltica* Nestor (Fig. 14s) appear in the upper part of the biozone, together with *Conochitina fortis* Nestor (Fig. 14v) and *Conochitina argillophila* Laufeld (Fig. 14w).

In the Ohesaare core the interval between the appearance level of *Conochitina pachycephala* Eisenack (Fig. 14x) and *Conochitina subcyatha* (Fig. 15b) is more than 20 m (Nestor, 1994), whereas in the Kolka-54 core these (biozonal) species appear at the same level. In the lower-middle part of this joint biozone appear *Conochitina* aff. *proboscifera* Eisenack (Fig. 14y),

Figure 13. Chitinozoans from the Kolka-54 core. (a) *Bursachitina conica* (Taugourdeau & de Jekhowsky, *sensu* Mullins & Loydell, 2001); GIT 546-26; 603.40–603.70 m. (b) *Rhabdochitina* sp. A; GIT 546-27; 596.90–597.20 m. (c) *Conochitina leptosoma* Laufeld; GIT 546-28; 601.0–601.05 m. (d) *Eisenackitina causiata* Verniers; GIT 546-29; 596.90–597.20 m. (e) *Eisenackitina inanulifera* Nestor; GIT 546-30; 596.90–597.20 m. (f) *Belonechitina cavei* Mullins & Loydell; GIT 546-31; 596.90–597.20 m. (g) *Conochitina emmastensis* Nestor; GIT 546-32; 588.90–589.0 m. (h) *Angochitina longicollis* Eisenack; GIT 546-33; 584.90–585.20 m. (i) *Bursachitina nestorae* Mullins & Loydell; GIT 546-34; 596.90–597.20 m. (j) *Ramochitina costata* (Umnova); GIT 546-35; 581.90–582.20 m. (k) *Ancyrochitina mullinsi* Nestor; GIT 546-36; 578.90–579.20 m. (l) *Bursachitina nana* (Nestor); GIT 546-37; 568.60–568.80 m. (m) *Anthochitina primula* Nestor; GIT 546-38; 575.0–575.30 m. (n) *Ramochitina ruhnuensis* (Nestor); GIT 546-39; 575.0–575.30 m. (o) *Conochitina acuminata* Eisenack; GIT 546-40; 575.0–575.30 m. (p) *Conochitina flamma* Laufeld; GIT 546-41; 575.0–575.30 m. (q) *Rhabdochitina* sp. B; GIT 546-42; 568.60–568.80 m. (r) *Belonechitina* cf. *meifodensis* Mullins & Loydell; GIT 546-43; 588.90–589.0 m. (s) *Conochitina proboscifera* Eisenack; GIT 546-44; 581.90–582.20 m. (t) *Calpichitina densa* (Eisenack); GIT 546-45; 578.90–579.20 m. (u) *Plectochitina pachyderma* (Laufeld); GIT 546-46; 575.0–575.30 m. (v) *Ramochitina nestorae* Grahn; GIT 546-47; 566.40–566.70 m. (w) *Margachitina banwyensis* Mullins; GIT 546-48; 578.90–579.20 m. (x) *Plectochitina magna* (Nestor); GIT 546-49; 568.60–568.80 m. (y) *Belonechitina* sp. A; GIT 546-50; 588.90–589.20 m. (z) *Margachitina margaritana* (Eisenack); GIT 546-51; 566.40–566.70 m. (aa) *Conochitina* aff. *tuba* Eisenack; GIT 546-52; 566.40–566.70 m. (ab) *Belonechitina* sp. B; GIT 546-53; 552.30–552.60 m. (ac) *Linochitina?* sp. GIT 546-54; 540.0–540.30 m. Scale bars represent 50 µm.



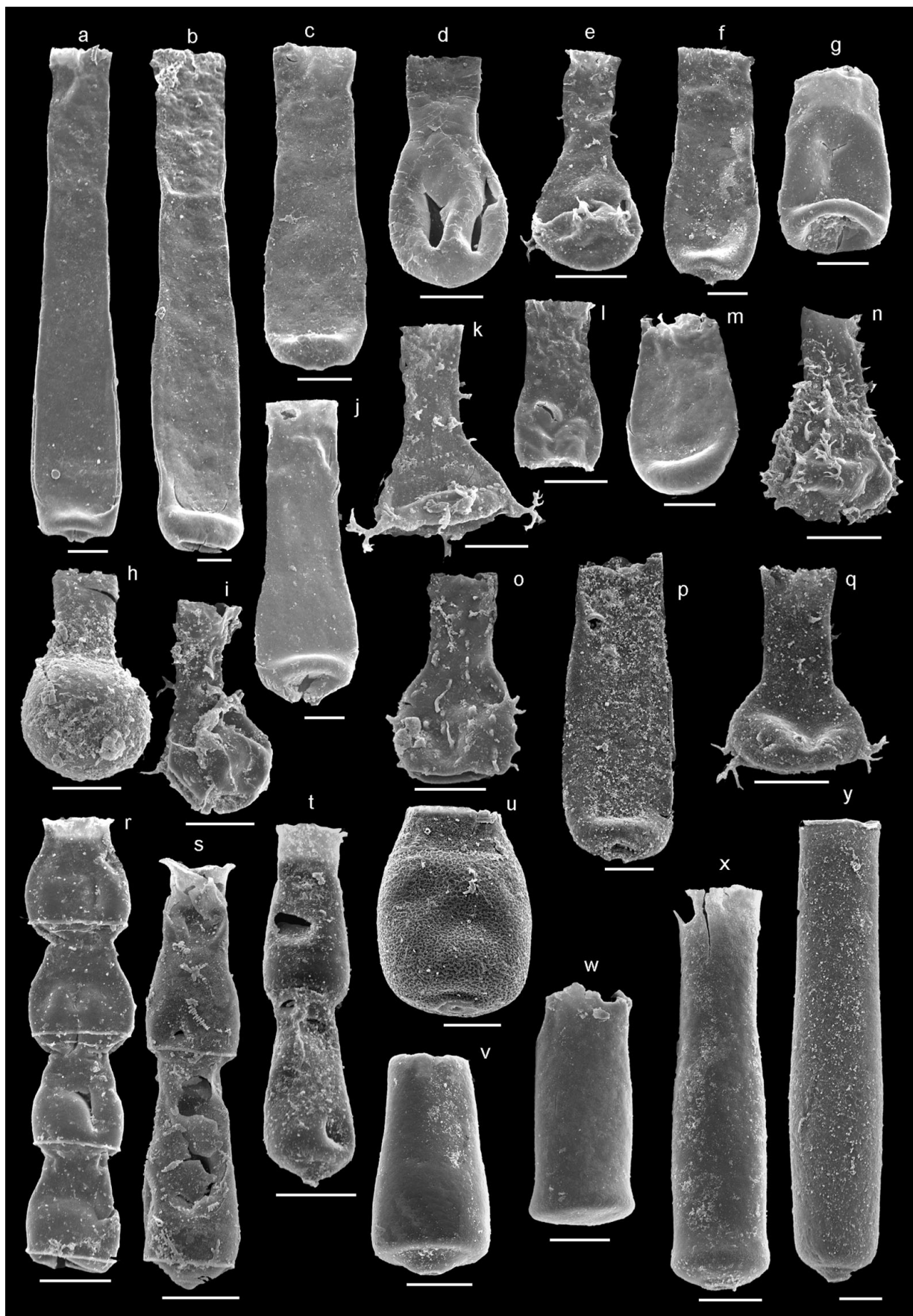


Figure 14. For caption see next page.

*C. linearistriata* Nestor (Fig. 15e), *Cingulochitina gorstyensis* Sutherland (Fig. 15d) and *Plectochitina obuti* Nestor (Fig. 15f). *Sphaerochitina* sp. B (Fig. 15c), *Bursachitina* sp. (Fig. 15a), *Conochitina* sp. B (Fig. 15g), *Calpichitina* sp. (Fig. 15h), *Belonechitina* sp. D (Fig. 15i), *Eisenackitina* sp. A (Fig. 15j) and *Ramochitina* sp. B (Fig. 15k) are newcomers. *C. pachycephala* is the index taxon of a global biozone (Verniers *et al.* 1995), while the geographical distribution of *C. subcyatha* is restricted to the East Baltic (Nestor, 1994), Wales (Verniers, 1999) and the Brabant Massif, Belgium (Verniers *et al.* 2002).

In the Kolka-54 core the *Conochitina cribrosa* Biozone embraces also the *Sphaerochitina indecora* Biozone, which was erected for strata above the *C. cribrosa* Biozone in the Ohesaare core (Nestor, 1994). According to Laufeld (1974), *Sphaerochitina* is a facies-controlled genus, not occurring in deep-water sections. Nevertheless, some species of *Sphaerochitina*, *S. concava* Laufeld (Fig. 15n) and *Sphaerochitina* sp., do appear in this biozone in the Kolka-54 core. Within the stratigraphical range of *C. cribrosa* Nestor (Fig. 15l), many Wenlock chitinozoan species disappear, including *Margachitina margaritana*. The *C. cribrosa* Biozone, recognized only in East Baltic cores, is characterized also by the appearance of *Conochitina* cf. *argillophila* Laufeld (Fig. 15o), *Conochitina* sp. A (Fig. 15x), *Linochitina erratica* (Eisenack) (Fig. 15r), *Linochitina* sp. A (Fig. 15p), *Clathrochitina* sp. (Fig. 15q), *Eisenackitina* sp. (Fig. 15u), *Ramochitina tabernaculifera* (Laufeld) (Fig. 15t), *Ramochitina* sp. C (Fig. 15s) and *Rhabdochitina sera* Nestor (Fig. 15v).

*Sphaerochitina lycoperdoides* Laufeld (Fig. 15z) is the index species of the uppermost chitinozoan biozone in the Wenlock. In addition to long-ranging species, *Ancyrochitina* cf. *ansarviensis* Laufeld and *Ramochitina* sp. (Fig. 15y) are also present. The number of chitinozoans in samples varies, but decreases upwards within the biozone. The index species itself is rare, being sometimes represented by uncharacteristic specimens. The *S. lycoperdoides* Biozone has been established also in other East Baltic cores, for example, Ohesaare, Ventpils, Pavilosta and Gussev-1 (Nestor, 2007). In more offshore sections, some Wenlock species (*C. claviformis*, *C. pachycephala*, *C. tuba*)

range without interruption up to the Ludlow, but in the Kolka-54 and Ohesaare cores, all Wenlock species disappear in the uppermost part of the Rootsiküla Stage (Nestor, 2007). There is an interval, lacking chitinozoans, which has previously (Nestor, 1994) been distinguished as Interzone (V). The *S. lycoperdoides* Biozone has been included in the Silurian chitinozoan global biozonation scheme (Verniers *et al.* 1995).

## 6. Correlation of graptolite and conodont biozones

As the lowest graptolite biozone to be identified confidently is the *Demirastrites triangulatus* Biozone, we begin our discussion of graptolite–conodont biozone correlation (and of graptolite–chitinozoan biozone correlation, below) at the base of the Aeronian.

The lower and middle *Demirastrites triangulatus* graptolite Biozone correlates with the upper part of the *Aspelundia? expansa* conodont Biozone. The lowest *Distomodus staurogathoides* occurs in the 614.60–614.80 m sample, in the upper part of the *D. triangulatus* graptolite Biozone. This is at a significantly lower stratigraphical level than previously recorded. In the Aizpute-41 core, the base of the *D. staurogathoides* conodont Biozone lay within the *Lituigraptus convolutus* graptolite Biozone, more than two graptolite biozones higher than its Kolka-54 level (Loydell, Männik & Nestor, 2003, their fig. 17). *Distomodus* was, however, rare and poorly preserved in the Aizpute-41 core. It is clear that the *D. staurogathoides* conodont Biozone represents a very long period of time, comprising almost all of the Aeronian, plus the early part (*guerichi*–*turriculatus* graptolite zones) of the Telychian.

Wide conodont sample spacing in the lower Telychian part of the Kolka-54 core means that the base of the *Pterospathodus eopennatus* ssp. n. 2 Biozone (between 601.00–601.20 m and 596.90–597.20 m) cannot be tied to the graptolite biostratigraphy with any great precision. It is clearly above the *Streptograptus johnsonae* Subzone of the *Spirograptus turriculatus* Biozone, which is consistent with its level in the Aizpute-41 core (base of *Streptograptus sartorius* graptolite Biozone: Loydell, Männik & Nestor, 2003, their fig. 17).

Figure 14. Chitinozoans from the Kolka-54 core. (a) *Conochitina claviformis* Eisenack; GIT 546-55; 552.30–552.60 m. (b) *Conochitina mamilla* Laufeld; GIT 546-56; 552.30–552.60 m. (c) *Conochitina tuba* Eisenack; GIT 546-57; 545.0–545.30 m. (d) *Lagenochitina* sp.; GIT 546-58; 540.0–540.30 m. (e) *Ancyrochitina paulaspina* Nestor; GIT 546-59; 533.0–533.60 m. (f) *Conochitina* aff. *flamma* Laufeld; GIT 546-60; 540.0–540.30 m. (g) *Bursachitina* sp. A; GIT 546-61; 537.30–537.60 m. (h) *Sphaerochitina* sp. A; GIT 546-62; 517.0–517.30 m. (i) *Ramochitina spinosa* (Eisenack); GIT 546-63; 514.0–514.30 m. (j) *Conochitina armillata* Taugourdeau & Jekhowsky; GIT 546-64; 537.30–537.60 m. (k) *Ancyrochitina gutnica* Laufeld; GIT 546-65; 533.0–533.60 m. (l) *Cingulochitina cingulata* (Eisenack); GIT 546-66; 530.0–530.30 m. (m) *Bursachitina* sp. B; GIT 546-67; 527.70–528.0 m. (n) *Ramochitina martinsoni* (Laufeld); GIT 546-68; 517.0–517.20 m. (o) *Ramochitina* sp. A; GIT 546-69; 514.0–514.30 m. (p) *Belonechitina* sp. C; GIT 546-70; 506.60–506.70 m. (q) *Ancyrochitina plurispinosa* Nestor; GIT 546-71; 496.0–496.30 m. (r) *Cingulochitina crassa* Nestor; GIT 546-72; 489.0–489.30 m. (s) *Cingulochitina baltica* Nestor; GIT 546-73; 486.20–486.50 m. (t) *Linochitina odiosa* Laufeld; GIT 546-74; 486.20–486.50 m. (u) *Eisenackitina spongiosa* Swire; GIT 546-75; 496.0–496.30 m. (v) *Conochitina fortis* Nestor; GIT 546-76; 492.60–493.0 m. (w) *Conochitina argillophila* Laufeld; GIT 546-77; 489.30–489.60 m. (x) *Conochitina pachycephala* Eisenack; GIT 546-78; 486.20–486.50 m. (y) *Conochitina* aff. *proboscifera* Eisenack; GIT 546-79; 476.0–476.40 m. Scale bars represent 50 µm.



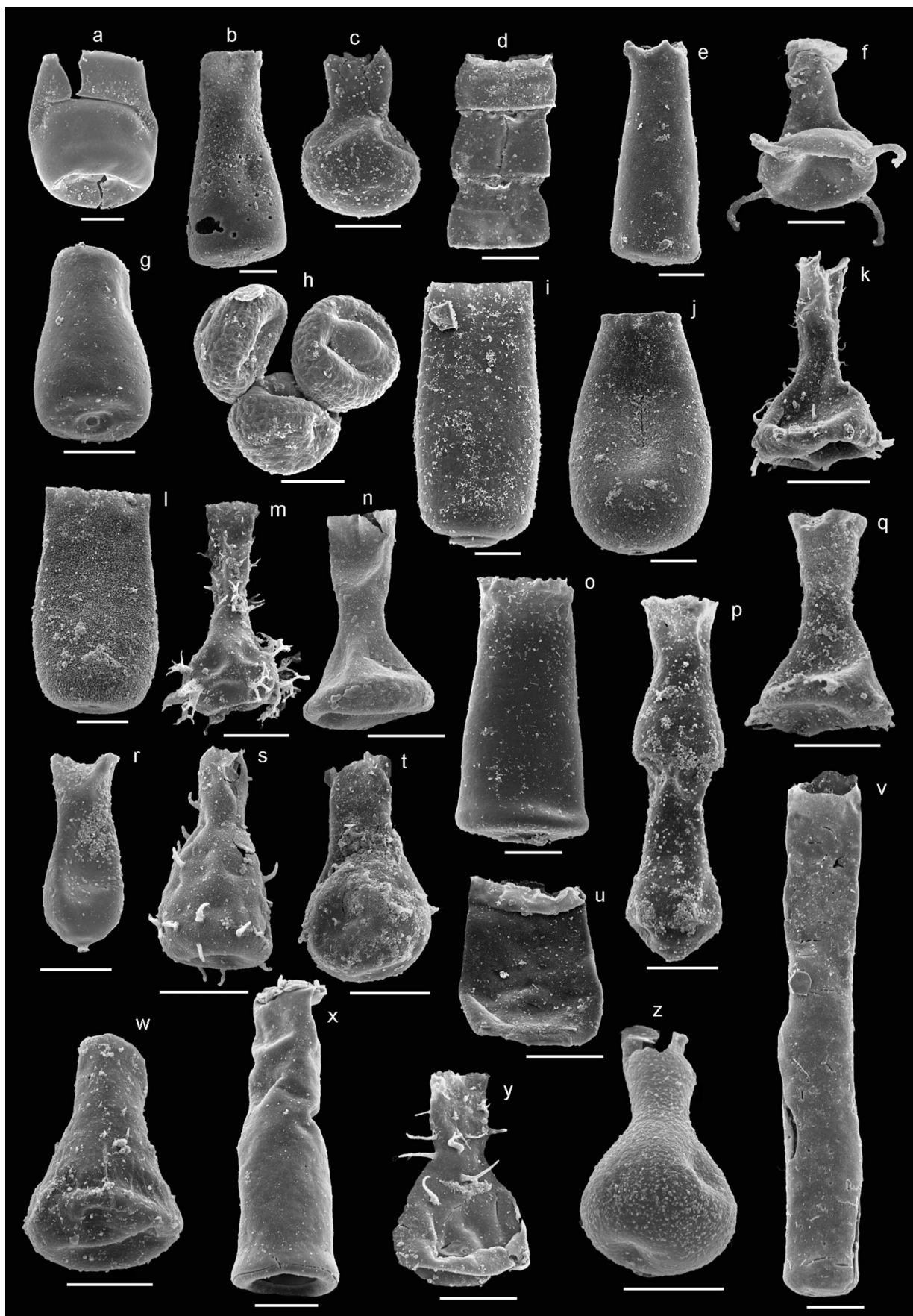


Figure 15. For caption see next page.



The base of the *P. amorphognathoides angulatus* conodont Biozone (and *P. celloni* conodont Superzone *sensu* Männik, 2007b) in the Kolka-54 core lies between graptolitic samples of middle Telychian (*crispus* to lower *griestoniensis* graptolite Zone) age and the base of the *Oktavites spiralis* graptolite Biozone. This is consistent with its position in the Aizpute-41 core, in which the base lay in the middle of the *crenulata* graptolite Biozone (Loydell, Männik & Nestor, 2003, their fig. 17).

The base of the *P. a. amorphognathoides* conodont Biozone is at the same level as that of the *Cyrtograptus lapworthi* graptolite Biozone in the Kolka-54 core. This is in agreement with data from the Ohesaare (Loydell, Kaljo & Männik, 1998), Aizpute-41 (Loydell, Männik & Nestor, 2003) and Ruhnu (Kaljo, Männik *in* Pöldvere, 2003) cores, indicating consistent correlation of these two important biozones throughout the East Baltic region. As noted above, recognition of the top of the *P. a. amorphognathoides* conodont Biozone is problematical in the Kolka-54 core. It would appear that the top of this biozone, plus the entire Lower and Upper *Ps. bicornis* biozones, lie within the upper *Cyrtograptus purchisoni* and/or *Monograptus firmus* graptolite Biozone(s).

The single sample (559.00–559.30 m) identified as belonging probably to the Lower *P. pennatus procerus* conodont Biozone is from a level within the *firmus* graptolite Biozone. In the Aizpute-41 core, Loydell, Männik & Nestor (2003) tentatively placed the Lower/Upper *P. pennatus procerus* conodont Biozone boundary within the upper *murchisoni* graptolite Biozone. The Kolka-54 core data suggest that this boundary probably lies higher in the graptolite biozonation, within the *Monograptus firmus* Biozone. In the Ruhnu core (Kaljo, Männik *in* Pöldvere, 2003), the base of the *P. p. procerus* conodont Biozone lies in a condensed interval between 448.70 m (upper *Cyrtograptus purchisoni* graptolite Biozone) and 447.0 m (*Monograptus riccartonensis* Biozone).

The 530.00–530.30 m sample suggested to be from the Lower *K. walliseri* Biozone is within the ‘middle Wenlock’ graptolitic interval, between the *Monograptus riccartonensis* and *Cyrtograptus lundgreni* graptolite biozones.

The next confidently recognized conodont biozone is the *O. s. sagitta* Biozone, which clearly correlates with part of the upper *Cyrtograptus lundgreni* graptolite Biozone. Jeppsson (1997b, fig. 3) had proposed that the *O. s. sagitta* conodont Biozone and *C. lundgreni* graptolite Biozone were broadly correlative. Unfortunately, few biostratigraphically useful graptolites were recovered from between 430.8 m (*Cyrtograptus lundgreni* graptolite Biozone) and 408.70 m (*Gothograptus nassa* graptolite Biozone). The base of the *Ozarkodina bohemia longa* conodont Biozone is tentatively placed above the 427.40–427.70 m sample. Jeppsson & Calner (2003, fig. 2) show the base of the *O. b. longa* conodont Biozone as correlating with a level high in the *C. lundgreni* graptolite Biozone (within the *Testograptus testis* Subzone). The Kolka-54 data are consistent with this proposal. As noted above, the conodont biozonation of the Kolka-54 core above the appearance of *O. b. longa* is problematical and for this reason we do not discuss possible correlations with the graptolite biostratigraphy.

#### 7. Correlation of graptolite and Chitinozoan biozones

The lowest sample assignable to the basal Aeronian *triangulatus* graptolite Biozone lies within the upper part of the newly erected *Conochitina elongata* chitinozoan Biozone. The base of the *Conochitina alargada* chitinozoan Biozone lies within the *triangulatus* graptolite Biozone in the Kolka-54 core at a level similar to that at which it was tentatively identified in the Aizpute-41 core (Loydell, Männik & Nestor, 2003, p. 215) and confidently recognized in the Ruhnu core (Kaljo, Nestor *in* Pöldvere, 2003). The biozone includes also the *simulans* to *convolutus* biozones in the Kolka-54 core as it did also in the Aizpute-41 core (Loydell, Männik & Nestor, 2003). The base of the *Eisenackitina dolioliformis* Biozone lies above a stratigraphical gap and thus, as in other East Baltic sections, the level of the true base of this biozone with respect to the graptolite biozonation is unknown.

As in the Aizpute-41 core, the base of the *Angochitina longicollis* chitinozoan Biozone is close to that of the *spiralis* graptolite Biozone. The base of the *Conochitina proboscifera* Biozone in the Aizpute-41

Figure 15. Chitinozoans from the Kolka-54 core. (a) *Bursachitina* sp.; GIT 546-80; 484.60–484.65 m. (b) *Conochitina subcyatha* Nestor; GIT 546-81; 486.20–486.50 m. (c) *Sphaerochitina* sp. B; GIT 546-82; 486.20–486.50 m. (d) *Cingulochitina gorstyensis* Sutherland; GIT 546-83; 472.20–472.70 m. (e) *Conochitina linearistriata* Nestor; GIT 546-84; 473.80–474.10 m. (f) *Plectochitina obuti* Nestor; GIT 546-85; 473.80–474.10 m. (g) *Conochitina* sp. B; GIT 546-86; 455.40–455.50 m. (h) *Calpichitina* sp.; GIT 546-87; 468.50–468.80 m. (i) *Belonechitina* sp. D; GIT 546-88; 462.20–462.40 m. (j) *Eisenackitina* sp. A; GIT 546-89; 459.10–459.30 m. (k) *Ramochitina* sp. B; GIT 546-90; 459.10–459.30 m. (l) *Conochitina cribrosa* Nestor; GIT 546-91; 445.30–445.35 m. (m) *Ramochitina uncinata* Laufeld; GIT 546-92; 422.80–423.0 m. (n) *Sphaerochitina concava* Laufeld; GIT 546-93; 430.80–431.10 m. (o) *Conochitina* cf. *argillophila* Laufeld; GIT 546-94; 427.40–427.70 m. (p) *Linochitina* sp. A; GIT 546-95; 422.80–423.0 m. (q) *Clathrochitina* sp.; GIT 546-96; 422.80–423.0 m. (r) *Linochitina erratica* Eisenack; GIT 546-97; 422.80–423.0 m. (s) *Ramochitina* sp. C; GIT 546-98; 422.80–423.0 m. (t) *Ramochitina tabernaculifera* Laufeld; GIT 546-99; 408.40–408.70 m. (u) *Eisenackitina* sp.; GIT 546-100; 416.0–416.30 m. (v) *Rhabdochitina sera* Nestor; GIT 527-36; 366.70–366.75 m. (w) *Sphaerochitina* sp.; GIT 546-101; 408.40–408.70 m. (x) *Conochitina* sp. A; GIT 546-102; 405.50–405.55 m. (y) *Ramochitina* sp.; GIT 546-103; 380.80–381.0 m. (z) *Sphaerochitina lycoperdoides* Laufeld; GIT 546-104; 361.50–361.55 m. Scale bars represent 50 µm.

core was in the upper *Oktavites spiralis* graptolite Biozone (Loydell, Männik & Nestor, 2003); this is also consistent with the Kolka-54 biostratigraphical data and first appearance of *C. proboscifera* in the Banwy River section, Wales (Mullins & Loydell, 2001). In the Ruhnu core, however, the base of the *C. proboscifera* chitinozoan Biozone appears to be slightly lower, in the lower or middle part of the *O. spiralis* graptolite Biozone (Kaljo, Nestor in Pöldvere, 2003).

*Conochitina acuminata* Eisenack was not found in the Aizpute-41 core samples. In the Banwy River section the *acuminata* Biozone correlated with the lower *lapworthi* graptolite Biozone (Mullins & Loydell, 2001). The base of the *acuminata* biozone is at the base of the lower *lapworthi* Biozone in the Kolka-54 core, as it is also in the Ohesaare core (base between 353.70 m and 354.50 m; Nestor, 2005; see Loydell, Kaljo & Männik, 1998 for graptolite biostratigraphy).

The first appearance of *Margachitina margaritana* lies 0.4 m above the lowest graptolitic sample to yield a robust *Cyrtograptus* (*centrifugus* or *murchisoni*). This is the stratigraphical level at which *M. margaritana* typically appears in the East Baltic. Loydell & Nestor (2005), however, illustrated stratigraphically older material of *M. margaritana*, from the Telychian *O. spiralis* graptolite Biozone of the Ventspils core, demonstrating the diachronous appearance of this species.

The base of an 'interzone', lacking stratigraphically diagnostic chitinozoans, correlates approximately with the base of the *firmus* graptolite Biozone in the Kolka-54 core, as it does also in the Ohesaare and Aizpute-41 cores (Loydell, Männik & Nestor, 2003, p. 225) and Ruhnu core (Kaljo, Nestor in Pöldvere, 2003).

Previous integrated biostratigraphical studies in the East Baltic region have terminated in the lower Sheinwoodian, so discussion here of stratigraphically higher graptolite–chitinozoan biozone correlation focuses on comparison with the 'global Chitinozoa biozonation' of Verniers *et al.* (1995) and with the work of Verniers (1999), who erected a chitinozoan biostratigraphy for the Wenlock of Buihth area of Wales and integrated this with the graptolite biozonation of Zalasiewicz & Williams (1999) using samples from the same localities and horizons.

*Conochitina mamilla* occurs in only two samples in the Buihth area (Verniers, 1999, fig. 2). The lower of these (sample K27) is immediately below the lowest sample (K28) to yield the biozonal index *Monograptus riccartonensis* (Zalasiewicz & Williams, 1999, fig. 6); the other *C. mamilla*-bearing sample in the Buihth region was from within the *M. riccartonensis* graptolite Biozone. In the Kolka-54 core the first *C. mamilla* occur in the 552.30–552.60 m sample above the *M. riccartonensis*-bearing core sample at 556.20 m, but below the lowest *Mediograptus*-rich sample at 549.60 m. *C. mamilla* ranges into the 'middle Wenlock' graptolitic interval. Thus the Kolka-54 and Buihth

area occurrences of *C. mamilla* are at broadly similar stratigraphical levels.

*Cingulochitina burdinalensis* Verniers, index species of the succeeding chitinozoan biozone in the Buihth area, is not present in the Kolka-54 samples. *Conochitina tuba* is present, however; its first appearance is at 545.0–555.30 m, towards the top of the *Mediograptus*-rich interval in the Kolka-54 core. As noted above, this *Mediograptus*-rich level has been termed previously the *antennularius* Biozone; this includes the upper *riccartonensis* Biozone of standard usage. Verniers' lowest *C. tuba* (from sample N33C) is from the lowest sample assigned by Zalasiewicz & Williams (1999) to their *Pristiograptus dubius* Biozone, which immediately overlies the *riccartonensis* Biozone. In the Ohesaare core, the base of the *tuba* Biozone lies immediately below a sample bearing *Monograptus flexilis*, but above the *dubius* Interzone (Loydell, Kaljo & Männik, 1998). Thus the base of *C. tuba* chitinozoan Biozone appears to lie at a level low within the 'middle Wenlock' with slight variation between localities as to the precise stratigraphical level.

The lowest *Cingulochitina cingulata* occurs low in the *dubius* Biozone in the Buihth area, somewhat lower stratigraphically than suggested by Verniers *et al.* (1995, fig. 2). Its first appearance is probably a little higher stratigraphically in the Kolka-54 core than in the Buihth area, but is still within the middle Wenlock (includes *dubius* and *rigidus* graptolite biozones of Zalasiewicz & Williams, 1999). *Eisenackitina spongiosa* was not recorded in the Buihth area. The succeeding *pachycephala* and *subcyatha* biozones are combined in the Kolka-54 core as the two index species first appear at the same level (486.20–486.50 m), in the lower third of the *lundgreni* graptolite Biozone. In the Buihth area, *Conochitina pachycephala* makes its first appearance only a little lower, in the upper Sheinwoodian *rigidus* graptolite Biozone (at the same level as shown by Verniers *et al.* 1995, fig. 2), while *Conochitina subcyatha* appears a little higher, close to the base of the *lundgreni* graptolite Biozone. The base of the *Conochitina cribrosa* chitinozoan Biozone is at the same stratigraphical level in both the Kolka-54 core and the Buihth area, in the upper *lundgreni* graptolite Biozone. The *cribrosa* chitinozoan Biozone was the highest Wenlock chitinozoan biozone recognized in the Buihth area; neither of the upper Homeric samples studied by Verniers (1999) yielded *Sphaerochitina lycoperdoides*. The *S. lycoperdoides* Biozone is the highest Wenlock chitinozoan biozone recognized within the 'global Chitinozoa biozonation for the Silurian' (Verniers *et al.* 1995). From the limited Kolka-54 core graptolite data, the *lycoperdoides* Biozone appears to correlate with the *praedeubeli* to *ludensis* graptolite biozones. Overall, the correlations between graptolite and chitinozoan biozones within the Wenlock of the Kolka-54 core are similar to those proposed by Verniers *et al.* (1995) in their 'global Chitinozoa biozonation'.

Stage	Graptolite biozone	Conodont biozone	Chitinozoan biozone
TELYCHIAN	<i>centrifugus</i>		
	<i>insectus</i>		
	<i>lapworthi</i>		
	<i>spiralis</i>	<i>P.a.amorphognathoides</i>	<i>C. acuminata</i>
	<i>crenulata</i>	<i>(P.a.lith.)+P.a.lenn.</i>	<i>P. celloni</i> <i>C. proboscifera</i> <i>A. longicollis</i>
	<i>griestoniensis</i>	<i>P. a. angulatus</i>	
	<i>sartorius</i>	<i>Pterospathodus eopennatus</i> ssp. n. 2	<i>Eisenackitina dolioliformis</i>
	<i>crispus</i>	<i>(Pterospathodus eopennatus</i> ssp. n. 1)	
	<i>turriculatus</i>	<i>D. staurognathoides</i>	
	<i>guerichi</i>		
AERONIAN	<i>halli</i>		
	<i>sedgwickii</i>		
	<i>convolutus</i>		
	<i>leptothea</i>	<i>Distomodus staurognathoides</i>	<i>Conochitina alargada</i>
	<i>simulans</i>		
<i>triangulatus</i>	<i>Aspelundia? expansa</i>	<i>C. elongata</i>	

Figure 16. Correlation of Aeronian (Middle Llandovery) and Telychian (Upper Llandovery) graptolite, conodont and chitinozoan biozones as demonstrated by the Kolka-54 core. Missing biozones are indicated by shading of vertical lines. Dashed lines indicate correlations derived from the Aizpute-41 core (Loydell, Männik & Nestor, 2003), with which the Kolka-54 core data are consistent. Biozones in parentheses have not been identified in the Kolka-54 core samples.

8. Conclusions

In terms of correlating the graptolite and conodont biozonations (Figs 16, 17), the main conclusions from the Kolka-54 core project are: (1) that the base of the *Distomodus staurognathoides* conodont Biozone is at a lower level, in the upper *Demirastrites triangulatus* graptolite Biozone, than previously thought; (2) that the conodont biostratigraphy of the Rhuddanian and Aeronian requires much further study; and (3) that

Stage	Graptolite biozone	Conodont biozone	Chitinozoan biozone
HOMERIAN	<i>ludensis</i>	Insufficient conodont data	<i>Sphaerochitina lycoperdoides</i>
	<i>deubeli</i>		
	<i>praedeubeli</i>		
	<i>nassa</i>		<i>Conochitina cribrosa</i>
SHEINWOODIAN	<i>lundgreni</i>	<i>O.s.sagitta+O.b.longa</i>	<i>C.pachyceph.+C.subcyatha</i> <i>E. spongiosa</i> <i>Ci. cingulata</i>
	?	Insufficient conodont data	
	middle Wenlock	<i>K. walliseri</i>	<i>Conochitina tuba</i>
	<i>riccartonensis</i>	<i>(K. ranuliformis)</i>	<i>Conochitina mamilla</i>
	<i>firmus</i>	<i>P.penn.procerus</i>	Interzone IV
<i>murchisoni</i>	<i>(Ps.bicornis)</i> <i>+P.a.amorphognath.</i>	<i>Margachitina margaritana</i>	

Figure 17. Correlation of Wenlock graptolite, conodont and chitinozoan biozones as demonstrated by the Kolka-54 core. Dashed lines indicate that there are generally insufficient useful conodont biostratigraphical data to delimit biozonal boundaries precisely. Biozones in parentheses have not been identified in the Kolka-54 core samples.

the base of the Upper *Pterospathodus pennatus procerus* conodont Biozone lies slightly higher, in the *Monograptus firmus* graptolite Biozone, than previously thought. Other graptolite–conodont biozone correlations within the Kolka-54 core are consistent with those proposed previously.

It is very encouraging that the correlations between the chitinozoan and graptolite biozonations in the Kolka-54 core (Figs 16, 17) are generally in agreement with those demonstrated previously in the East Baltic and, for the Wenlock, with the ‘global Chitinozoa biozonation’ of Verniers *et al.* (1995).

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