Geol. Mag. **140** (*2*)*, 2003, pp. 205–229. © 2003 Cambridge University Press*
DOI: 10.1017/S0016756802007264 *Printed in the United Kingdom*

Integrated biostratigraphy of the lower Silurian of the Aizpute-41 core, Latvia

D. K. LOYDELL*, P. MÄNNIK† & V. NESTOR†

*School of Earth and Environmental Sciences, University of Portsmouth, Burnaby Road, Portsmouth PO1 3QL, UK
†Institute of Geology, Tallinn Technical University, 7 Estonia Avenue, 10143 Tallinn, Estonia

(*Received* 20 November 2001; *accepted* 28 November 2002)

Abstract – Integrated graptolite, conodont and chitinozoan biostratigraphical data is presented from the Rhuddanian through to lower Sheinwoodian of the Aizpute-41 core, Latvia. Correlation of the biozonation schemes based upon the three groups is achieved from the *cyphus* through to lowermost *riccartonensis* graptolite biozones, except for the upper Aeronian and lower Telychian, which lack both chitinozoans and graptolites, and upper *lapworthi* through to approximately base *murchisoni* graptolite Biozone, where there is interpreted to be an unconformity. Datum 2 of the Ireviken Event is correlated with a level at the base of or within the *murchisoni* Biozone. It is possible that the changes in conodont assemblages at Datum 2 on Gotland are the result of an unconformity here. *Streptograptus*? *kaljoi* sp. nov., from the lower *spiralis* graptolite Biozone, is described.

Keywords: graptolites, Chitinozoa, Conodonta, Silurian, biostratigraphy.

1. Introduction

Recognition of the importance of integrated biostratigraphical studies in the precise cross-facies correlation required to test models of biotic and facies change in the Silurian has resulted in a recent mushrooming of studies in this field. Loydell, Kaljo & Männik (1998) presented graptolite, conodont and chitinozoan data for the Rhuddanian–Sheinwoodian of the Ohesaare core, Estonia; Verniers (1999) erected a chitinozoan biozonation for the Builth Wells region, Wales, which he correlated with Zalasiewicz & Williams' (1999) graptolite biozonation of the same area; Mullins & Loydell (2001) produced a detailed study of the Telychian–lower Sheinwoodian of the Banwy River section, Wales; Mullins & Loydell (2002) presented an integrated graptolite and chitinozoan biostratigraphy for Buttington Brick Pit, Wales; and Vandenbroucke, Verniers & Clarkson (in press) correlate the chitinozoan and graptolite biozones of the Girvan district, Scotland. Conference abstracts (e.g. Melchin *et al.* 2000: Arctic Canada) indicate that similar projects are being undertaken elsewhere, but full details have not yet been published.

This paper presents integrated graptolite, conodont and chitinozoan biostratigraphical data for the Llandovery and lower Sheinwoodian (lower Wenlock) of the Aizpute-41 core, Latvia. All material is housed in the Institute of Geology, Tallinn Technical University, Tallinn, Estonia.

2. The Aizpute-41 core

Aizpute is situated in western Latvia (Fig. 1). Aizpute-41 was cored during the 1960s. Its palaeogeographical setting is further off-shore than that of Ohesaare (Fig. 1; see Loydell, Kaljo & Männik, 1998, for details of the Ohesaare core), and the succession within the core is significantly more complete, most notably in the Aeronian.

The lithostratigraphical divisions and dominant lithologies within the core are indicated in Figure 2. The Rhuddanian Remte Formation overlies the upper Ordovician Saldus Formation unconformably. How much of the upper Ordovician and lowermost Silurian is missing is not known. The base of the Dobele Formation lies within the *cyphus* graptolite Biozone (upper Rhuddanian); that of the Jūrmala Formation lies immediately above strata yielding *sedgwickii* Biozone graptolites (upper Aeronian). The top of the core lies within the Sheinwoodian (lowermost *riccartonensis* graptolite Biozone). The entire Ordovician was cored also, the base of this system lying at 1167 m.

3. Graptolite biostratigraphy of the Aizpute-41 core

More than 150 taxa have been identified from the core, a remarkably high number given the core's diameter (63–68 mm) and the non-graptolitic nature in the core of the uppermost Aeronian–lower Telychian, an interval of high graptolite diversity (Loydell, 1992, 1993*a*). The graptolites are illustrated in Figures 3–9; stratigraphical ranges are shown in Figures 10–12. All of the graptolite biozones referred to below are interval zones in the sense of the *International Stratigraphic Guide* (Salvador, 1994), their bases being defined by the incoming of a specific taxon, either that after which the biozone is named or a well-known taxon, the

---

* Author for correspondence: david.loydell@port.ac.uk

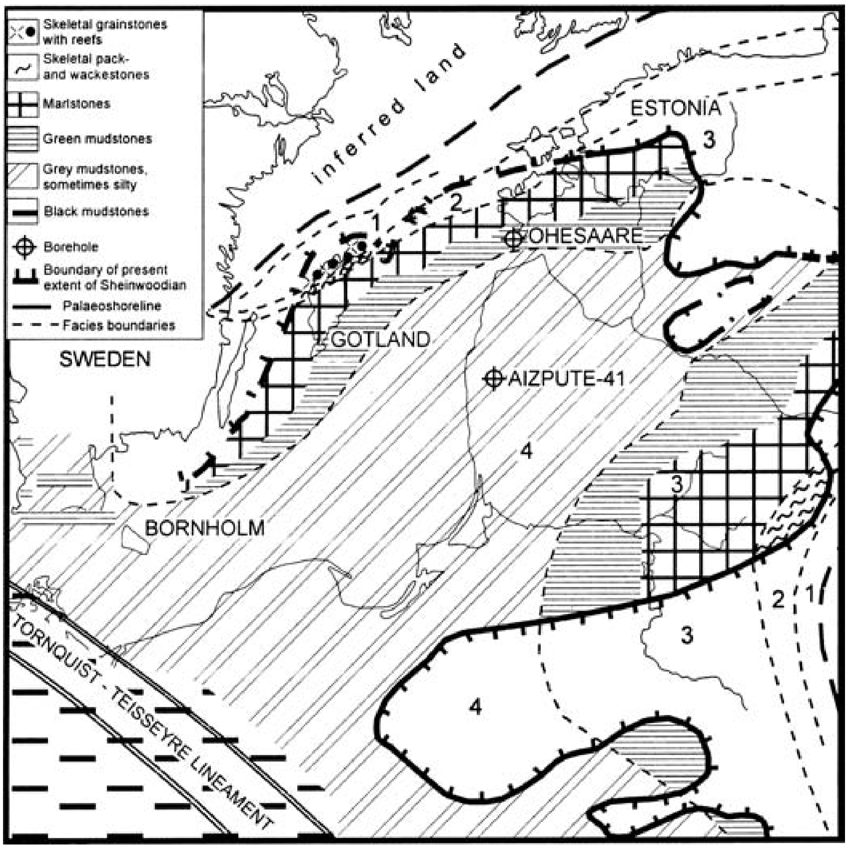

Figure 1. Location of Aizpute-41 on a map showing distribution of early Wenlock (approximately *riccartonensis* Zone) sedimentary rock types and facies belts in the northern Baltic region (modified from Bassett, Kaljo & Teller, 1989). The location of Ohesaare is also indicated. Key to facies belts: 1,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

first occurrence of which is well established as at the base of or within the biozone under discussion.

3.a. Rhuddanian–Aeronian

The lowest graptolites in the core occur in thin dark shale interbeds in the Remte Formation (samples DL1–2, Fig. 10); the assemblages indicate the uppermost Rhuddanian *cyphus* Biozone (Fig. 3). The base of the *triangulatus* Biozone (the base of the Aeronian) occurs at 975.18 m (sample DL7), 1.32 m above the base of the Dobele Formation. The condensed dark shales of the latter formation are rich in graptolites enabling recognition of all Aeronian biozones up to *sedgwickii* with the possible exception of the *magnus* Biozone. Above the *sedgwickii* Biozone strata the lowermost beds of the Jūrmala Formation are graptolitically barren, thus preventing identification of the uppermost Aeronian *halli* Biozone.

Worthy of note is the appearance of *Metaclimacograptus hughesi* (Nicholson) (Fig. 4d) low in the *triangulatus* Biozone. Zalasiewicz (1996) considered this species to occur only higher in the Aeronian, in the *leptotheca* and lower *convolutus* biozones. *Streptograptus ansulosus* (Törnquist) (Fig. 5k) also first appears somewhat earlier than has previously been recorded, in the *convolutus* Biozone. Otherwise, both the upper Rhuddanian (Fig. 3) and the Aeronian (Figs 4–6) assemblages are similar to those previously described for this interval and the ranges of individual taxa fall within their known ranges elsewhere (e.g. Hutt, 1974, 1975; Bjerreskov, 1975; Koren' & Rickards, 1996), with the ranges of several taxa in the *leptotheca*–*convolutus* biozones very similar to those recorded by Štorch (1998) in his detailed study of the graptolites of this interval in Bohemia.

3.b. Telychian

The lowest graptolitic horizons (samples DL41–42; Fig. 11) in the Jūrmala Formation yield graptolites indicative of the *proteus* Subzone of the *turriculatus* Biozone. Above this all graptolite biozones up to lower *lapworthi* are represented. Assemblages (Figs 6–8) are generally as described previously by, for example, Bjerreskov (1975), Loydell & Cave (1993, 1996) and Zalasiewicz (1994). The highest Telychian graptolitic sample (DL 104; Fig. 11) includes *Streptograptus wimani* (Bouček), indicating the lower part of the *lapworthi* Biozone (for range of *S. wimani* see Štorch, 1994, and Loydell & Cave, 1996).

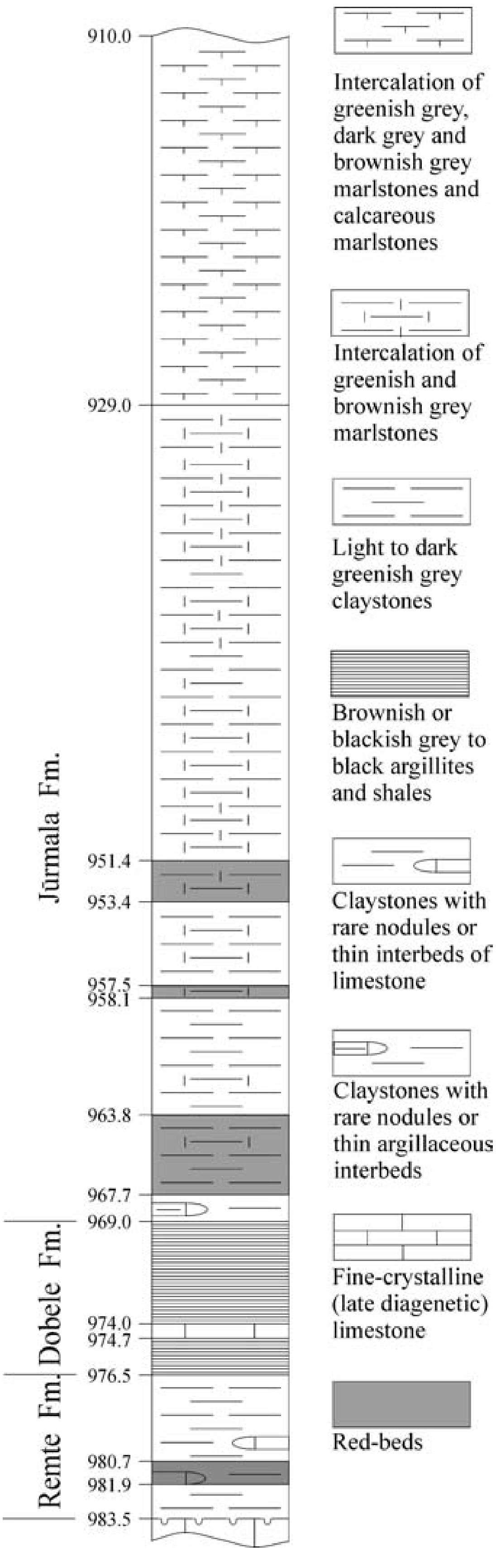

Figure 2. Simplified log of the Aizpute-41 core.

3.c. Sheinwoodian

Only 0.21 m above sample DL104 (lower *lapworthi* Biozone), sample DL105 (Figs 11–12) contains a robust *Cyrtograptus*, either *centrifugus* or *murchisoni*. The next sample (DL106), 0.39 m above DL105, contains a proximal end of *C. murchisoni* (Fig. 9f), matching precisely those described by Loydell & Cave (1994) from the species' type locality. It is clear then that the upper *lapworthi* and *insectus* biozones must either be very condensed indeed or more probably are represented by an unconformity (see also Section 5.i). It is possible that the *centrifugus* Biozone is missing also, although sample DL105 could belong to this biozone.

The *murchisoni* Biozone is the thickest in the core, at more than 15 m (Fig. 12), and is thicker than the entire Aeronian. It is succeeded by the *firmus* Biozone. The uppermost 0.89 m of the core represents the lowermost part of the *riccartonensis* Biozone.

The Sheinwoodian graptolite assemblages (Fig. 9) are typical for the stage, dominated by species (many of which are stratigraphically long-ranging) of *Cyrtograptus*, *Monoclimacis*, *Retiolites*, *Monograptus* and *Mediograptus*. The range of *Mediograptus morleyae* Loydell & Cave, 1996 (Fig. 9p) is extended into the *murchisoni* Biozone. Previously this species was known only from the uppermost Llandovery.

4. Conodont biostratigraphy of the Aizpute-41 core

Conodonts are well represented in the Aizpute-41 core. The general composition of the conodont fauna (dominance in most of samples of *Dapsilodus*, extremely rare occurrences of *Aulacognathus* and *Apsidognathus*; low numbers of *Pterospathodus amorphognathoides angulatus* Männik and *P. a. amorphognathoides* Walliser; complete lack of *Ozarkodina polinclinata* (Nicoll et Rexroad), *P. a. lennarti* Männik, and several other taxa; well represented *P. celloni* (Walliser) and *P. pennatus procerus* (Walliser); Fig. 13) is typical of off-shore environments (e.g. Aldridge & Mabillard, 1981; Männik, 1998). Many of the biostratigraphically important taxa are illustrated in Figure 14.

The lowermost part of the Aizpute-41 core (the Remte Formation) is characterized mainly by long-ranging coniform species currently not allowing precise dating of these strata. In sample C97-115 (Fig. 13), just below the upper boundary of the Remte Formation, *Aspelundia expansa* Armstrong (Fig. 14z, aa) appears. The level of appearance of *A. expansa* can be traced widely across different environments in the Baltic basin (P. Männik, pers. obs.) and is well established also in other parts of the world. This level defines the lower boundary of the *A. expansa* Biozone (Armstrong, 1990). The strata below the first appearance of *A. expansa* are assigned to the *D. kentuckyensis* Biozone, and the strata above, between the level of appearance of *A. fluegeli* (sample C00-7) up to the level of appearance of *D. staurognathoides* (Walliser) are

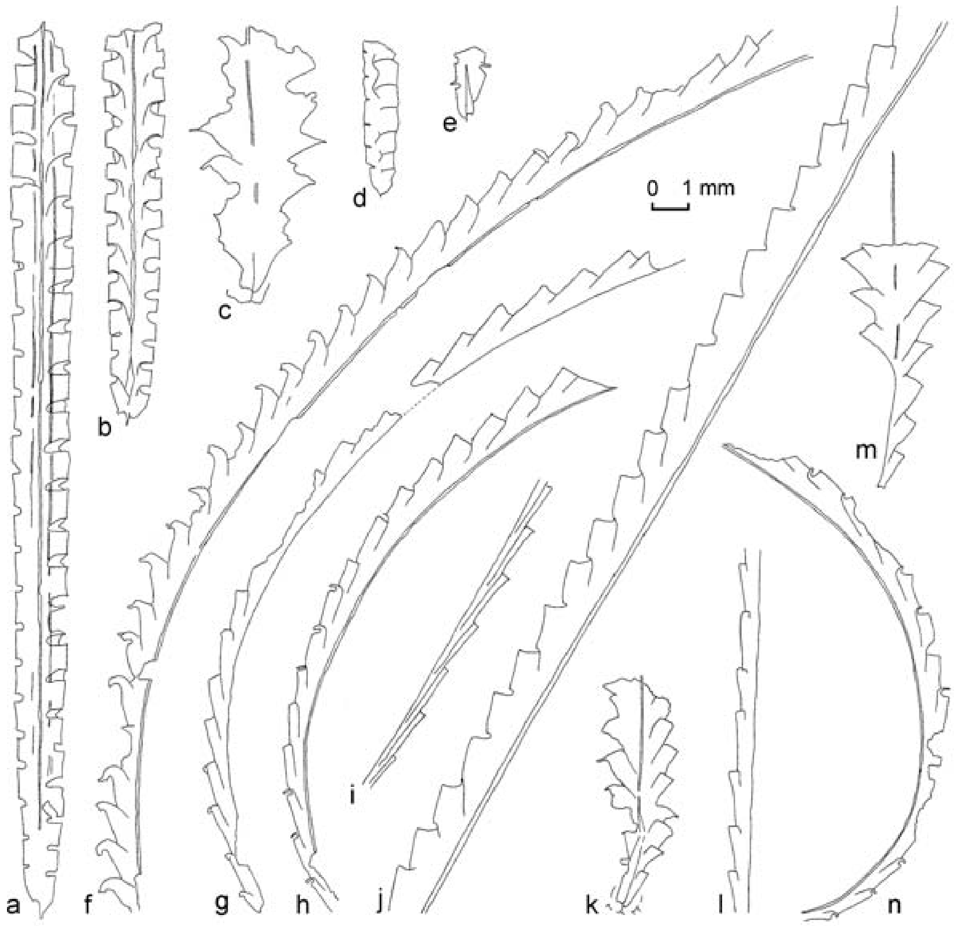

Figure 3. Rhuddanian (lower Llandovery) graptolites from the Aizpute-41 core, Latvia. (a) *Normalograptus normalis* (Lapworth); 341-1; 976.40 m. (b) *Normalograptus* sp.; 341-2; 977.92 m. (c) *Pseudorthograptus obuti* (Rickards & Koren'); 341-3; 975.33 m. (d) *Metaclimacograptus khabakovi* Koren' & Rickards; 341-4; 977.94 m. (e) *Paraclimacograptus innotatus* (Nicholson); 341-5; 977.94 m. (f) '*Monograptus*' *difformis* Törnquist; 341-6; 975.45 m. (g) '*Monograptus*' *vulgaris* Hutt; 341-7; 976.40 m. (h, n) *Huttagraptus*? sp.; 975.45 m; (h) 341-8; (n) 341-14. (i) *Huttagraptus acinaces* (Törnquist); 341-9; 977.94 m. (j) *Atavograptus atavus* (Jones); 341-10; 976.40 m. (k) *Dimorphograptoides* cf. *physophora sensu* Koren' & Rickards; 341-11; 975.33 m. (l) *Pribylograptus sandersoni* (Lapworth); 341-12; 975.3 m. (m) *Dimorphograptus confertus* (Nicholson); 341-13; 977.90 m.

correlated with the *A. fluegeli* Biozone of Armstrong (1990).

Due to the rare occurrences and poor preservation of elements of *Distomodus* (Fig. 14cc, dd) the position of the lower boundary of the *D. staurognathoides* Zone in the Aizpute-41 core is problematical. The lowermost well-preserved Pa element of this species comes from sample C01-25 (Fig. 13). However, based on the occurrence of fragments of the Pa elements with characteristic sculpture (e.g. distinct central row of nodes/denticles) it is most probable that *D. staurognathoides* is present already in sample C00-09, and that the lower boundary of the *D. staurognathoides* Biozone lies below this sample. At the same level (in sample C00-09), *Dapsilodus* ex gr. *sparsus* Barrick, *D.* ex gr. *praecipuus* Barrick and *Pseudooneotodus bicornis* Drygant appear.

The lower boundaries of the *Pterospathodus eopennatus* ssp. n. 1 (Fig. 14r–t), *P. eopennatus* ssp. n. 2 (Fig. 14j, n–q, u) and *P. a. angulatus* biozones can be easily identified based on the appearance of the nominal taxa. It is noteworthy that in the Aizpute-41 core *P. celloni* (Fig. 14d, e, g–i) appears together with *P. a. angulatus* (Fig. 14l, m) confirming Männik's (1998) suggestion that the lower boundaries of the *P. a. angulatus* Zone and *P. celloni* Superzone coincide.

Due to the lack of characteristic taxa, the lower boundaries of the *P. a. lennarti* and *P. a. lithuanicus* biozones cannot be identified. A few specimens of *P. a. lithuanicus* have been found in one sample only (C97-77; Fig. 13), just below the level of appearance of *P. a. amorphognathoides*. The upper boundary of the *P. a. angulatus* Biozone is tentatively drawn above the uppermost sample (C 97-86) with *P. a. angulatus*. The interval above, up to the level of appearance of *P. a. amorphognathoides* (Fig. 14a,b), correlates with the *P. a. lennarti* and *P. a. lithuanicus* biozones.

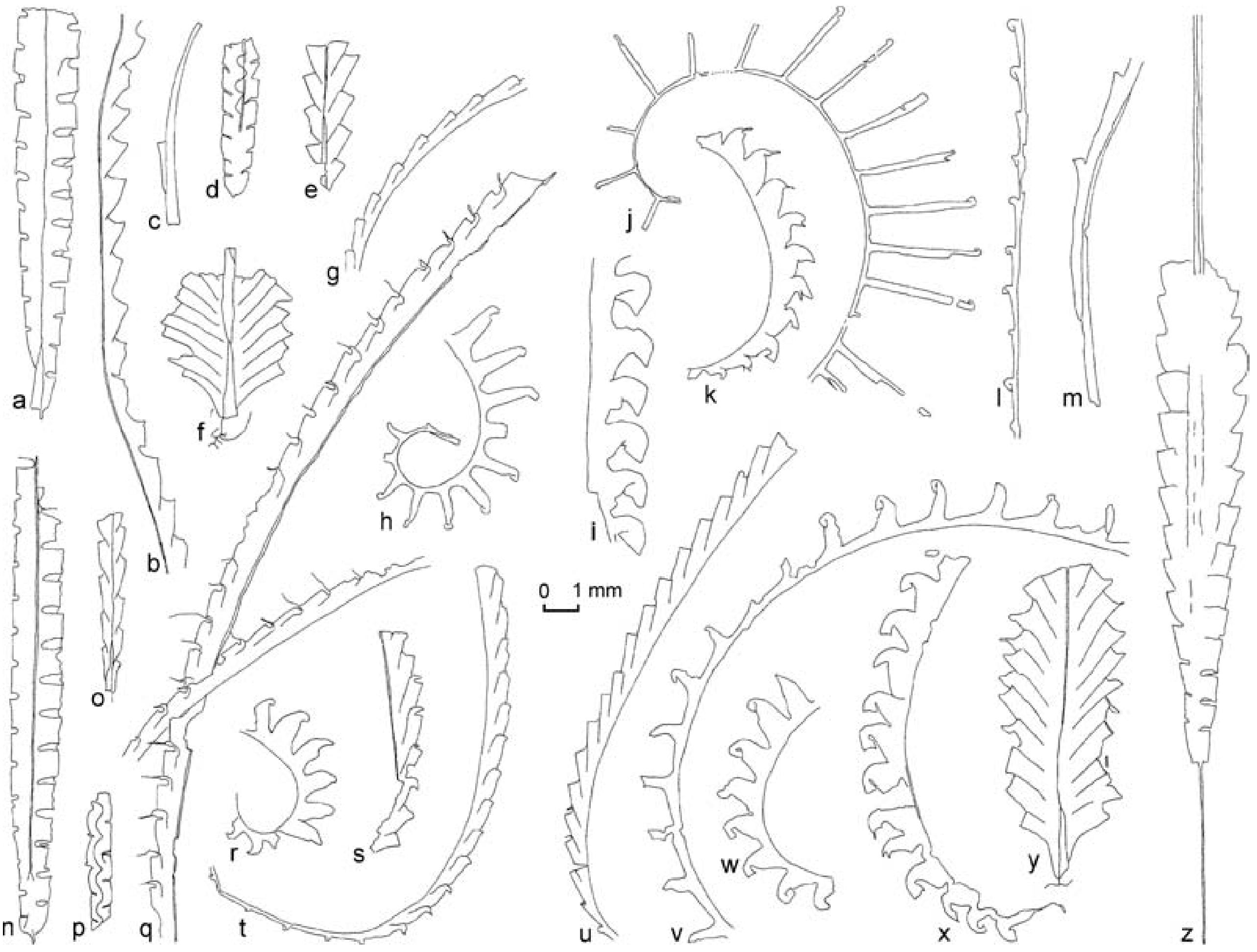

Figure 4. Aeronian (middle Llandovery) graptolites from the Aizpute-41 core, Latvia. (a) *Rhaphidograptus toernquisti* (Elles & Wood); 341-15; 975.12 m. (b) *Atavograptus atavus* (Jones); 341-16; 974.92 m. (c) *Coronograptus gregarius* (Lapworth); 341-17; 972.82 m. (d) *Metaclimacograptus hughesi* (Nicholson); 341-18; 975.06 m. (e) *Rivagraptus cyperoides* (Törnquist); 341-19; 973.65 m. (f) *Petalolithus ovatoelongatus* (Kurck); 341-20; 975.06 m. (g) *Pribylograptus argutus* (Lapworth); 341-21; 974.33 m. (h) '*Demirastrites*' *triangulatus* (Harkness); 341-22; 974.35 m. (i) *Campograptus lobiferus* (M'Coy); 341-23; 970.75 m. (j) *Rastrites geinitzii* Törnquist; 341-24; 973.83 m. (k), (x) *Campograptus millepeda* (M'Coy). (k) 341-25; 973.13 m. (x) 341-38; 972.82 m. (l) *Streptograptus* sp. 1; 341-26; 973.13 m. (m) *Neolagarograptus*? sp.; 341-27; 973.83 m. (n) *Clinoclimacograptus retroversus* Bulman & Rickards; 341-28; 970.30 m. (o) *Glyptograptus tamariscus* (Nicholson); 341-29; 973.13 m. (p) *Metaclimacograptus orientalis* (Obut & Sobolevskaya); 341-30; 973.83 m. (q) *Pribylograptus* sp.; 341-31; 974.92 m. (r) '*Demirastrites*' *pectinatus* (Richter); 341-32; 973.79 m. (s) '*Monograptus*' *argenteus* (Nicholson); 341-33; 973.75 m. (t, u) '*Monograptus*' *inopinus* Törnquist; (t) 341-34; 973.55 m; (u) 341-35; 970.75 m. (v) '*Monograptus*' sp. (aff. *simulans*) *sensu* Štorch; 341-36; 973.13 m. (w) *Campograptus rostratus* (Elles &Wood); 341-37; 973.65 m. (y) *Petalolithus praecursor* Bouček & Přibyl; 341-39; 973.13 m. (z) *Glyptograptus sinuatus* (Nicholson); 341-40; 973.20 m.

The lower boundary of the *P. a. amorphognathoides* Biozone is distinct and easily identified based on the appearance of the nominal taxon, but the position of its upper boundary remains problematical. Jeppsson (1997*a*) proposed a very detailed zonation for the uppermost Telychian and Sheinwoodian strata. The boundaries of his zones correspond to the datums of the Ireviken Event. However, as was noted by Loydell, Kaljo & Männik (1998) and Männik (1998), identification of some datums of the Ireviken Event in strata formed in off-shore environments is still very difficult.

The upper boundary of the *P. a. amorphognathoides* Biozone (= the lower boundary of the Lower *Ps. bicornis* Biozone) was defined by Jeppsson (1997*a*) as corresponding to Datum 1 of the Ireviken Event. Several criteria were proposed to identify this level (Jeppsson, 1997*b*); however, none seems to be applicable in the Aizpute-41 core. At the moment, the position of Datum 1 in the core is unidentifiable. However, the disappearance of *Daps. sparsus* lineage in the upper part of the range of *P. a. amorphognathoides* (the uppermost *Daps*. ex gr. *sparsus* comes from sample C97-68; Fig. 13) probably indicates some environmental changes connected to the Ireviken Event.

Identification of Datum 2 (= the boundary between the Lower and Upper *Ps. bicornis* biozones) in the Aizpute-41 core is also difficult. Sample C01-31

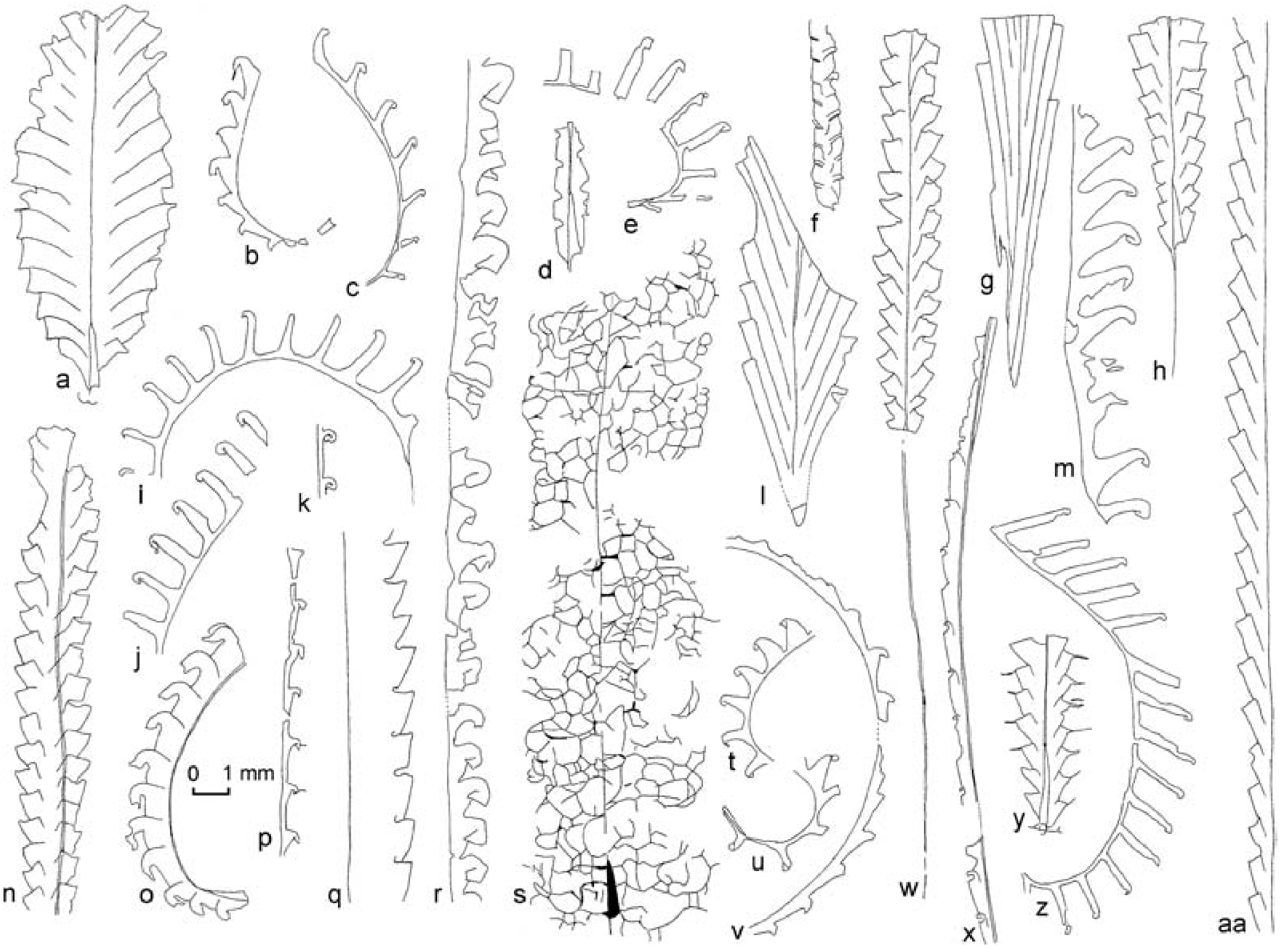

Figure 5. Aeronian (middle Llandovery) graptolites from the Aizpute-41 core, Latvia. (a) *Petalolithus dubovikovi* (Obut & Sobolevskaya); 341-41; 970.30 m. (b) *Campograptus communis* (Lapworth); 341-42; 972.00 m. (c) ‘*Monograptus*’ *decipiens* Törnquist; 341-43; 970.30 m. (d) *Metaclimacograptus hubeiensis* (NIGP); 341-44; 970.75 m. (e) *Rastrites approximatus* Perner; 341-45; 972.25 m. (f) *Metaclimacograptus minimus* (Paškevičius); 341-46; 970.30 m. (g) *Cephalograptus cometa* (Geinitz); 341-47; 970.99 m. (h) *Rivagraptus bellulus* (Törnquist); 341-48; 970.79 m. (i, j) ‘*Lituigraptus*’ *richteri* (Perner); (i) 341-49; 972.55 m; (j) 341-50; 972.47 m. (k) *Streptograptus ansulosus* (Törnquist); 341-51; 970.75 m. (l) *Petalolithus folium* (Hisinger); 341-52; 971.72 m. (m) *Torquigraptus*? *valens* (Přibyl & Münch)?; 341-53; 970.96 m. (n) *Glyptograptus* sp.; 341-54; 970.44 m. (o) *Campograptus clingani* (Carruthers); 341-55; 971.43 m. (p) ‘*Monograptus*’ *dracocephalus* Štorch; 341-56; 973.00 m. (q) *Pribylograptus leptotheca* (Lapworth); 341-57; 972.47 m. (r) *Campograptus harpago* (Törnquist); 341-58; 971.60 m. (s) *Pseudoretiolites perlatus* (Nicholson); 341-59; 970.79 m. (t, u) *Torquigraptus denticulatus* (Törnquist); (t) 341-60; 971.60 m; (u) 341-61; 969.05 m. (v) ‘*Monograptus*’ *mirificus* Štorch?; 341-62; 973.00 m. (w) *Rivagraptus* sp.; 341-63; 972.43 m. (x) *Monoclimacis imago* (Zalasiewicz); 341-64; 972.47 m. (y) *Pseudorthograptus insectiformis* (Nicholson); 341-65; 970.30 m. (z) *Rastrites peregrinus* Barrande; 341-66; 971.43 m. (aa) *Pristiograptus regularis* (Törnquist); 341-67; 970.30 m.

contains the stratigraphically highest specimen of *Apsidognathus* sp. and Datum 2 has been placed between this and sample C97-67 (Fig. 13). However, *Apsidognathus* is extremely rare in the Aizpute-41 core (found in only three samples, and only one fragment comes from the *P. a. amorphognathoides* interval), so it is possible that this level does not correspond to the true end of the range of *Apsidognathus*. What is certain, however, is that Datum 2 lies at some level above sample C01-31.

The occurrence of *Aulacognathus* cf. *chapini* Savage (Fig. 14k) in sample C97-66 (Fig. 13) suggests that Datum 2 lies higher in the sequence. According to Jeppsson (1997*b*) *Aul. chapini* became extinct at Datum 2 of the Ireviken Event, together with the other species of *Aulacognathus*. Thus, in the Aizpute-41 core Datum 2 should perhaps lie above the sample with *Aul*. cf. *chapini*. Alternatively, it is also possible that the range of *Aul. chapini* was misinterpreted (detailed studies of the Ireviken Event have been carried out only on Gotland and Estonia where *Aul. chapini* has not been found; the specimen under discussion is the first and only one found in this region and Jeppsson's interpretation of the stratigraphical range of this species was based on previously published data from other regions only) and in reality this taxon did not become extinct at Datum 2 but later, or it reappeared above this level as a Lazarus taxon.

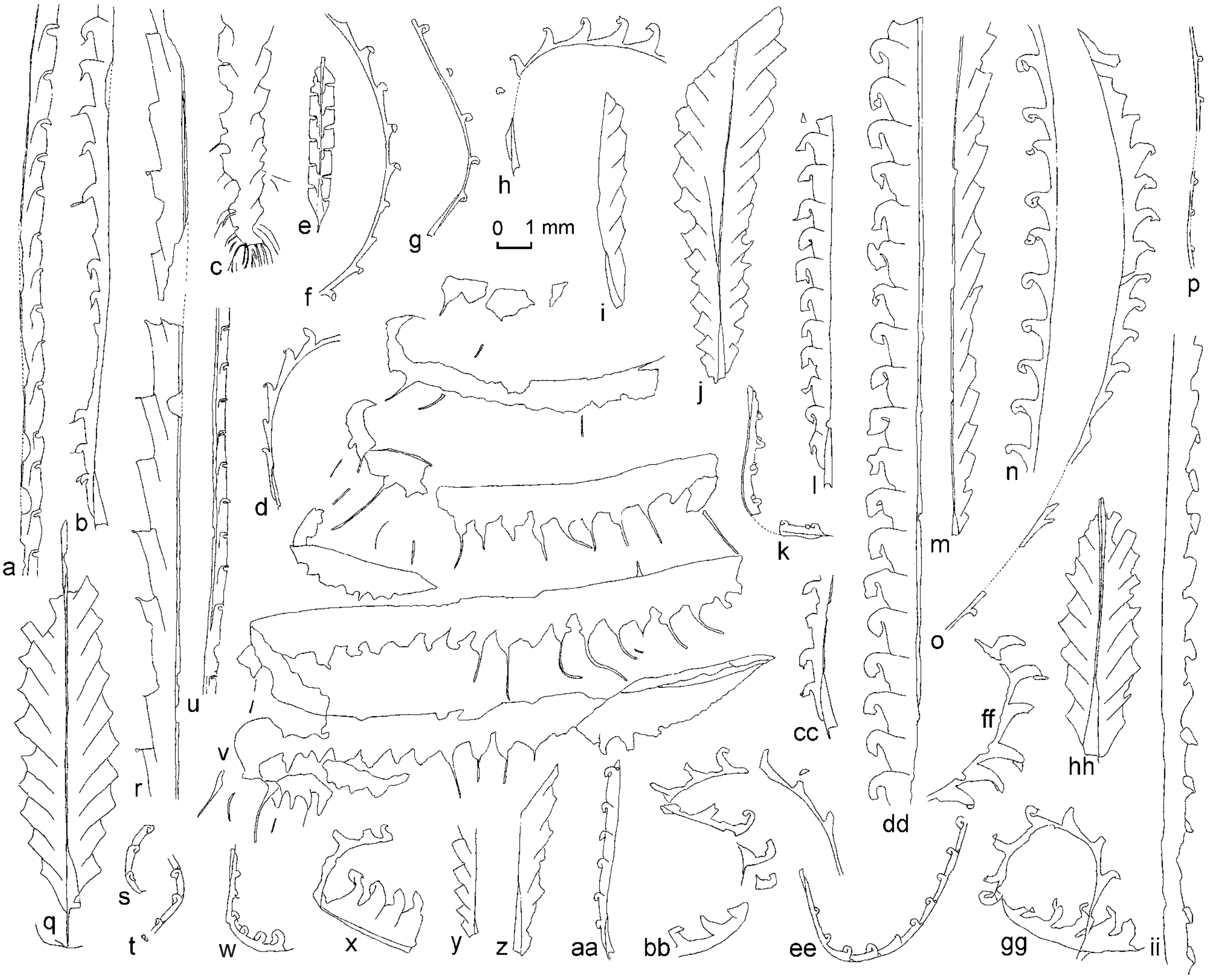

Figure 6. Aeronian and Telychian (middle and upper Llandovery) graptolites from the Aizpute-41 core, Latvia. (a) *Monoclimacis crenularis* (Lapworth); 341-68; 970.42 m. (b) *Stimulograptus sedgwickii* (Portlock); 341-69; 969.05 m. (c) *Comograptus barbatus* (Elles & Wood); 341-70; 969.53 m. (d) *Torquigraptus australis* Štorch; 341-71; 959.16 m. (e) *Metaclimacograptus* sp.; 341-72; 969.05 m. (f) *Torquigraptus involutus* (Lapworth); 341-73; 969.08 m. (g, n) *Streptograptus crispus* (Lapworth); (g) 341-74; 962.39 m; (n) 341-81; 962.31 m. (h) *Oktavites* sp.; 341-75; 958.66 m. (i) *Pristiograptus pergratus* Přibyl; 341-76; 962.39 m. (j) *Parapetalolithus altissimus* (Elles & Wood); 341-77; 964.62 m. (k) *Streptograptus*? sp. *sensu* Loydell; 341-78; 963.59 m; (l, cc, dd) *Stimulograptus clintonensis* (Hall); (l) 341-79; 961.06 m; (cc) 341-95; 963.55 m; (dd) 341-96; 960.00–960.10 m. (m) *Pristiograptus artus* (Bouček)?; 341-80; 961.06 m. (o) *Torquigraptus arcuatus* (Bouček); 341-81; 961.45 m. (p) *Streptograptus tenuis* Loydell; 341-82; 963.34 m. (q) *Petalolithus* sp.; 341-83; 969.23 m. (r) *Neolagarograptus tenuis* (Portlock); 341-84; 969.66 m. (s, t) *Streptograptus johnsonae* Loydell; 964.62 m; (s) 341-85; (t) 341-86. (u) *Monoclimacis griestoniensis* (Nicol); 341-87; 959.16 m. (v) *Spirograptus turriculatus* (Barrande); 341-88; 961.91 m. (w) *Streptograptus* aff. *loydelli sensu* Zalasiewicz; 341-89; 959.31 m. (x) *Torquigraptus proteus* (Barrande); 341-90; 963.59 m. (y) *Pristiograptus pristinus* Přibyl?; 341-91; 963.55 m. (z) *Pristiograptus* sp.; 341-92; 958.66 m. (aa) *Streptograptus storchi* Loydell; 341-93; 963.55 m. (bb, ff, gg) *Oktavites*? sp. 2; (bb) 341-94; 961.91 m; (ff) 341-98; 961.06 m; (gg) 341-99; 961.45 m. (ee) *Streptograptus exiguus* (Lapworth); 341-97; 961.45 m. (hh) *Parapetalolithus schaueri* (Loydell); 341-100; 960.00–960.10 m. (ii) *Torquigraptus pragensis* (Přibyl) *sensu lato*; 341-101; 962.31 m.

The boundary between the Upper *Ps. bicornis* and the Lower *P. p. procerus* zones corresponds to Datum 3 and the boundary between the Lower and Upper *P. p. procerus* zones to Datum 4 of the Ireviken Event (Jeppsson, 1997*a*,*b*). Datum 3 (disappearance of *P. a. amorphognathoides*) lies between samples C00-11 and C01-27 (Fig. 13). The position of Datum 4 in the Aizpute-41 core is problematical. According to Jeppsson (1997*a*,*b*, 1998) several taxa (*Oulodus petilus* (Nicoll et Rexroad), *Panderodus recurvatus* (Rhodes), *Pand. serratus* Cooper and some others became extinct or disappeared temporarily. None of these taxa has been found in the critical interval in the Aizpute-41 core. However, the distribution of *Pand. langkawiensis* Igo et Koike in this core provides some valuable information. *Pand. langkawiensis* is known to become extinct between datums 3 and 4 (Jeppsson & Männik, 1993). In the Aizpute-41 core, the uppermost specimens of this taxon come from sample C00-12 (Fig. 13), indicating that Datum 4 lies just above this level, or higher.

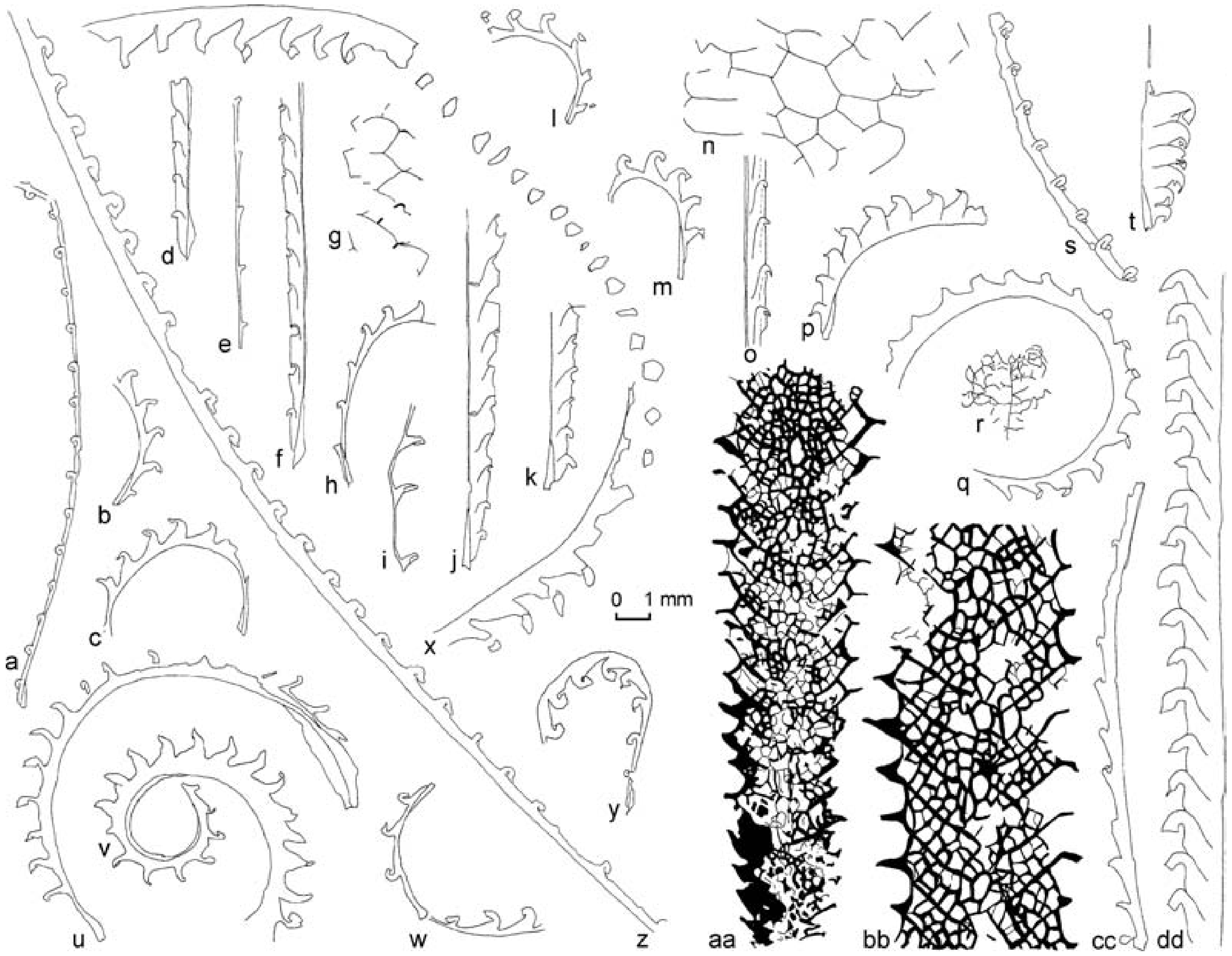

Figure 7. Telychian (upper Llandovery) graptolites from the Aizpute-41 core, Latvia. (a) *Streptograptus sartorius* (Törnquist); 341-102; 960.25 m. (b, c) *Oktavites falx* (Suess); (b) 341-103; 951.30 m; (c) 341-104; 950.33 m. (d) *Monoclimacis vomerina* ssp. *sensu* Bjerreskov; 341-105; 949.44 m. (e) *Torquigraptus pergracilis* (Bouček); 341-106; 950.16 m. (f) *Monoclimacis subgeinitzi* Fu; 341-107; 953.94 m. (g) *Pseudoplegmatograptus*? *elleswoodae* (Bouček & Münch)?; 341-108; 947.52 m. (h) *Torquigraptus tullbergi* (Bouček) *sensu lato*; 341-109; 953.54 m. (i) *Lapworthograptus singularis* (Törnquist); 341-110; 958.11 m. (j, k) *Monoclimacis crenulata* (Elles & Wood); (j) 341-111; 950.33 m; (k) 341-112; 956.77 m. (l) *Torquigraptus* sp. 2; 341-113; 957.34 m. (m, v) *Oktavites spiralis* (Geinitz); (m) 341-114; 940.64 m; (v) 341-123; 937.16 m. (n) *Pseudoplegmatograptus*? *giganteus* (Bouček & Münch); 341-115; 951.12 m. (o) *Monoclimacis hemmanni* (Přibyl); 341-116; 942.90–943.05 m. (p) ‘*Monograptus*’ *vesiculosus* Perner; 341-117; 940.64 m. (q) *Torquigraptus australis* Štorch; 341-118; 959.16 m. (r) *Pseudoplegmatograptus*? sp. 1; 341-119; 930.40–930.52 m. (s) *Streptograptus*? *nodifer* (Törnquist); 341-120; 941.60 m. (t) *Monograptus cultellus* Törnquist; 341-121; 949.11 m. (u) *Oktavites*? sp. 1; 341-122; 962.39 m. (w) *Torquigraptus*? *flagellaris* (Törnquist); 341-124; 950.10 m. (x) *Torquigraptus* sp. 1; 341-125; 961.91 m. (y) ‘*Monograptus*’ *drepanoformis* Toghill & Strachan; 341-126; 957.01 m. (z) *Streptograptus whitei* Zalasiewicz; 341-127; 963.14 m. (aa, bb) *Stomatograptus* sp.; (aa) 341-128; 949.01 m; (bb) 341-129; 949.20 m. (cc) *Torquigraptus* ex gr. *pragensis sensu* Zalasiewicz; 341-130; 957.34 m. (dd) *Monograptus priodon* (Bronn); 341-131; 950.33 m.

As the other criteria to identify Datum 4 are absent from the core, this datum (and thus also the boundary between the Lower and Upper *P. p. procerus* biozones) is placed, tentatively, between samples C00-12 and C01-28 (Fig. 13).

The boundary between the Upper *P. p. procerus* and the Lower *Kockelella ranuliformis* biozones corresponds to Datum 6 of the Ireviken Event (Jeppsson, 1997*a*,*b*). At this level *P. p. procerus* (Fig. 14c,f) became extinct. In the Aizpute-41 core this level lies between samples C97-56 and C00-17 (Fig. 13). The two samples above this level (C00-17: 70 + conodonts; and C97-55: 150+ conodonts) contain only *Ps. bicornis*, *Ps. beckmanni* (Bischoff et Sannemann), *Ps. coniformis* (Drygant), *Ozarkodina excavata* (Branson et Mehl), *K. ranuliformis* (Walliser), *Daps. obliquicostatus* (Branson et Mehl), and some fragments of *Walliserodus* (Fig. 13). The lack of elements of *D. staurognathoides* seems to indicate that these strata correspond already to the Upper *K. ranuliformis* Zone (Jeppsson, 1997*a*), but as *K. ranuliformis* is very rare above Datum 6 (Jeppsson & Männik, 1993) we assign these strata simply to the *K. ranuliformis* Superzone.

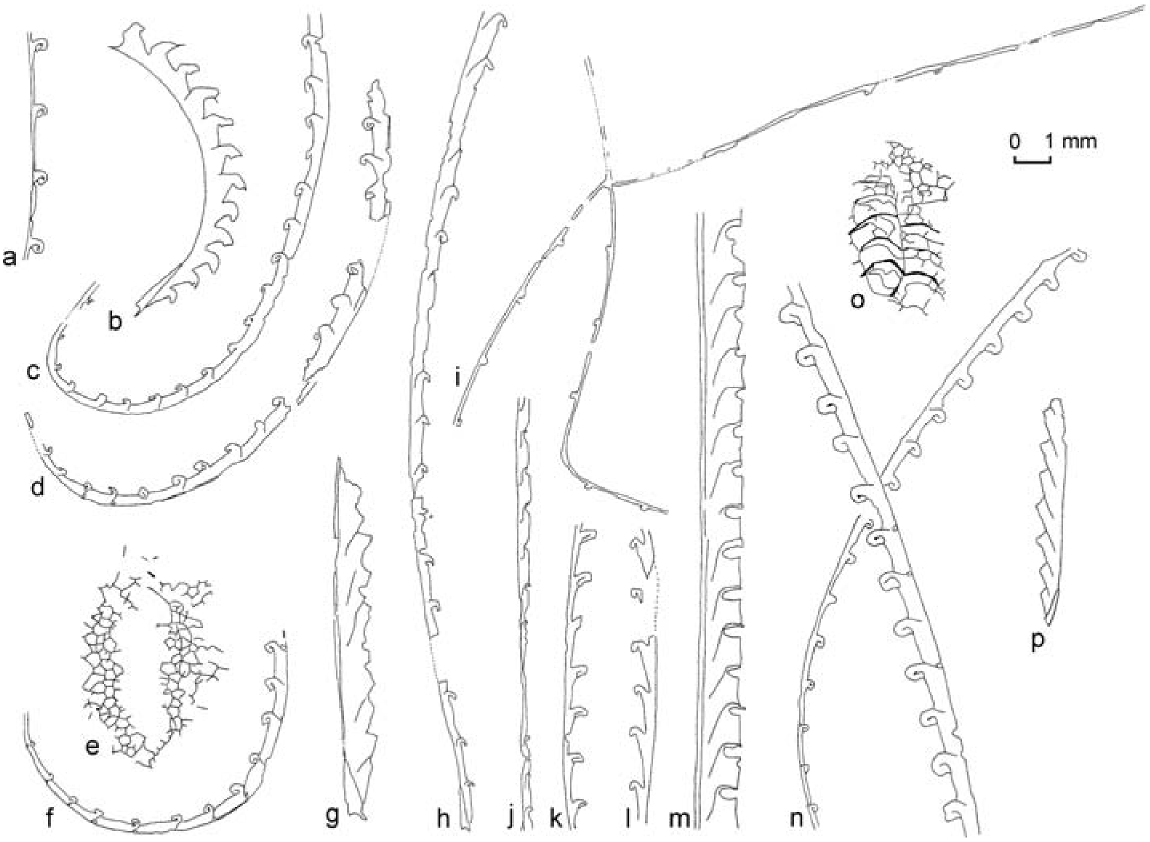

Figure 8. Telychian (upper Llandovery) graptolites from the Aizpute-41 core, Latvia. (a) *Streptograptus wimani* (Bouček); 341-132; 935.55–935.65 m. (b) '*Monograptus*' *vesiculosus* Perner; 341-133; 940.64 m. (c, d, f) *Streptograptus*? *kaljoi* sp. nov.; (c) holotype, 341-134; 947.52 m; (d) 341-135; 947.52 m; (f) 341-137; 948.51 m. (e, o) *Pseudoplegmatograptus*? sp. 2; 930.40 m; (e) 341-136; (o) 341-146. (g) *Pristiograptus prantli* Přibyl; 341-138; 935.55–935.65 m. (h) '*Monograptus*' *speciosus* Tullberg; 341-139; 935.55–935.65 m. (i) *Barrandeograptus*? *bornholmensis* (Laursen); 341-140; 933.55 m. (j) *Monoclimacis linnarssoni* (Tullberg); 341-141; 930.45 m. (k) *Lapworthograptus grayae* (Lapworth); 341-142; 946.39 m. (l) *Diversograptus ramosus* Manck; 341-143; 942.40–942.50 m. (m) *Monoclimacis geinitzi* (Bouček); 341-144; 942.90–943.05 m. (n) *Streptograptus* sp. 2; 341-145; 937.50 m. (p) *Pristiograptus praedubius* (Bouček); 341-147; 950.33 m.

5. Chitinozoan biostratigraphy of the Aizpute-41 core

Chitinozoans exhibit a patchy distribution through the Aizpute-41 core, with several processed samples yielding no specimens (Interzones I–III). Ranges and biozones are shown on Figure 15. Many of the biostratigraphically important taxa are illustrated in Figure 16. It is important to note that in some cases the sample containing the first appearance of a biozonal indicator species, for example *Angochitina longicollis* and *Conochitina proboscifera*, is succeeded by a number of samples lacking this species. This emphasizes the value of taking such a large number of samples from the core (the bases of these biozones could have appeared significantly higher had a smaller number of samples been analysed) and of course highlights the fact that in any biostratigraphical study (and especially one where sample size is limited by core diameter) the chances of encountering the 'true' first occurrence of any taxon are extremely slim. It also highlights the value in this core of the very high graptolite diversity (in comparison with that of the conodonts and chitinozoans), which enables recognition of some graptolite biozones even when the biozonal name-bearing taxon is absent.

5.a. The *Spinachitina fragilis* Biozone

This is equivalent to the *Ancyrochitina laevaensis* Biozone of Nestor (1994). In the Aizpute-41 core the lowermost Silurian chitinozoan biozone is represented by a single sample (LH982.60–982.70 m). Samples above and below are barren of chitinozoans. The zonal index species are not present, but an assemblage with abundant *Cyathochitina campanulaeformis* (Eisenack) (Fig. 16b) and *Ancyrochitina ancyrea* (Eisenack) and scarce *Plectochitina* cf. *spongiosa* (Achab) (Fig. 16h) is characteristic of many studied lowermost Silurian sections, which usually contain also the biozonal index species (Viki, Laeva, Ohesaare, Kolka). Unfortunately the shortage of core material did not allow us to resample this part of the core. In the south Estonian and north Latvian cores this biozone corresponds to

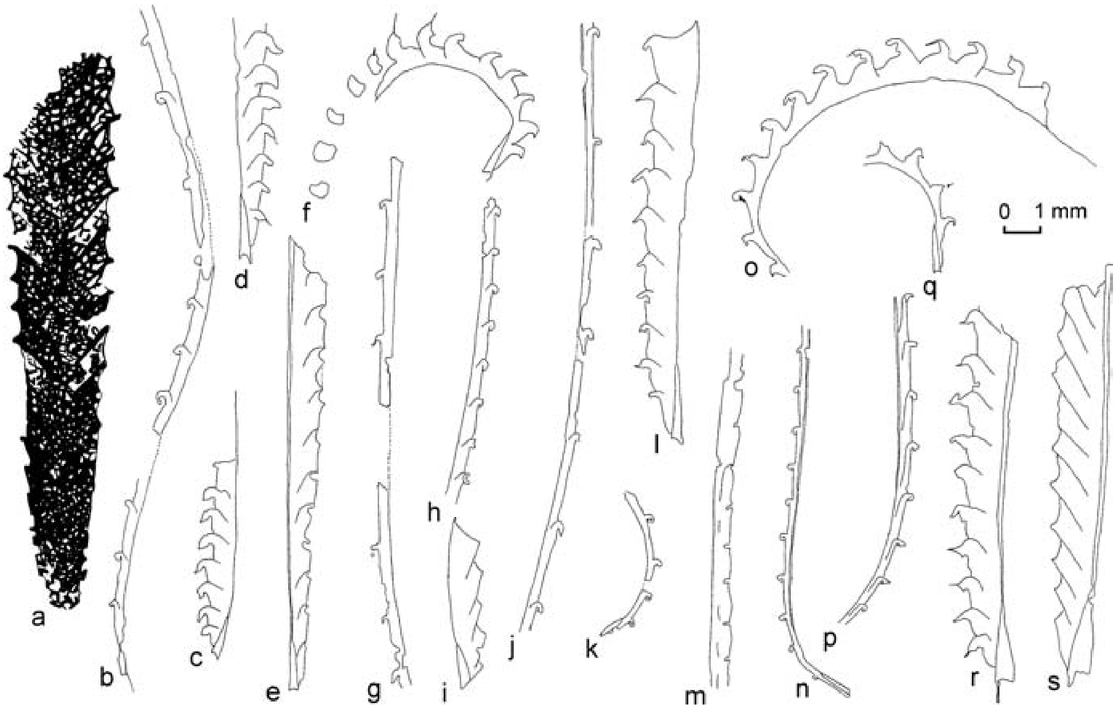

Figure 9. Sheinwoodian (lower Wenlock) graptolites from the Aizpute-41 core, Latvia. (a) *Retiolites angustidens* Elles & Wood; 341-148; 914.75–914.85 m. (b) *Mediograptus flexuosus* (Tullberg); 341-149; 911.79 m. (c) *Monograptus pseudocultellus* Bouček; 341-150; 927.00 m. (d) *Monograptus priodon* (Bronn); 341-151; 914.74 m; (e) *Monoclimacis vomerina* (Nicholson); 341-152; 927.01 m. (f) *Cyrtograptus murchisoni* (Carruthers); 341-153; 929.81 m. (g) *Mediograptus? minor* (Bouček); 341-154; 914.95 m. (h, n) *Mediograptus vittatus* (Štorch); (h) 341-155; 919.44 m; (n) 341-161; 924.70 m. (i) *Pristiograptus dubius* (Suess)?; 341-156; 914.75–914.85 m. (j) *Mediograptus? remotus* (Elles & Wood); 341-157; 914.74 m. (k) *Mediograptus inconspicuus* (Bouček); 341-158; *c.* 920 m. (l) *Monograptus firmus* Bouček; 341-159; 911.52 m. (m) *Monoclimacis kettneri* (Bouček); 341-160; 927.01 m. (o) *Cyrtograptus bohemicus* Bouček; 341-162; 910.96 m. (p) *Mediograptus morleyae* Loydell & Cave; 341-163; 927.01 m. (q) *Cyrtograptus centrifugus* Bouček; 341-164; *c.* 920 m. (r) *Monograptus riccartonensis* Lapworth; 341-165; 910.60 m. (s) *Pristiograptus dubius* (Suess); 341-166; 910.60 m.

the Puikule and Ruja members in the lowermost Õhne Formation of the Juuru Regional Stage.

The red, mottled clays and mudstones above this biozone are barren of chitinozoans, as in many other sections of the laterally equivalent Rozeni Member (Ohesaare, Ruhnu, Kolka, Ventspils).

5.b. The *Belonechitina postrobusta* Biozone

B. postrobusta (Nestor) (Fig. 16a) appears in Sample C97-117 and is abundant in Sample C97-116 (Fig. 15). The accompanying species, *Belonechitina aspera* (Nestor) (Fig. 16o), *Euconochitina electa* (Nestor) (Fig. 16e), *Cyathochitina* cf. *kuckersiana* (Eisenack) (Fig. 16c) and *Spinachitina* sp. (Fig. 16d), are present also in this biozone in most previously studied sections, except for the last taxon, which is less frequent in this interval of the uppermost Õhne Formation (Nestor, 1994).

5.c. The *Euconochitina electa* Biozone

In the Aizpute-41 core the lower boundary of the *E. electa* Biozone is marked only by the disappearance of *B. postrobusta* (sample C00-2; Fig. 15); *E. electa* is present already in the preceding biozone. The graptolitic shales of the *cyphus* graptolite Biozone in the Aizpute-41 core contain very few specimens of chitinozoans in contrast with the corresponding beds in other East Baltic sections which are characterized by abundant *E. electa* and associated species (Nestor, 1994, 1998). In the carbonate sections of Estonia and northernmost Latvia the *E. electa* Biozone corresponds to the Slitere Member and lower Kolka Member of the Saarde Formation in the lowermost part of the Raikküla Stage.

5.d. The *Ancyrochitina convexa* Biozone

In addition to the index species (questionably identified because the processes have broken off; Fig. 16j), the biozonal assemblage in the Aizpute-41 core includes also *Ancyrochitina ancyrea* (Eisenack) and *Conochitina iklaensis* Nestor (Fig. 16p). In south Estonian and north Latvian core sections the *A. convexa* Biozone corresponds to the upper part of the Kolka Member and to the lowermost part of the Ikla Member of the Saarde Formation.

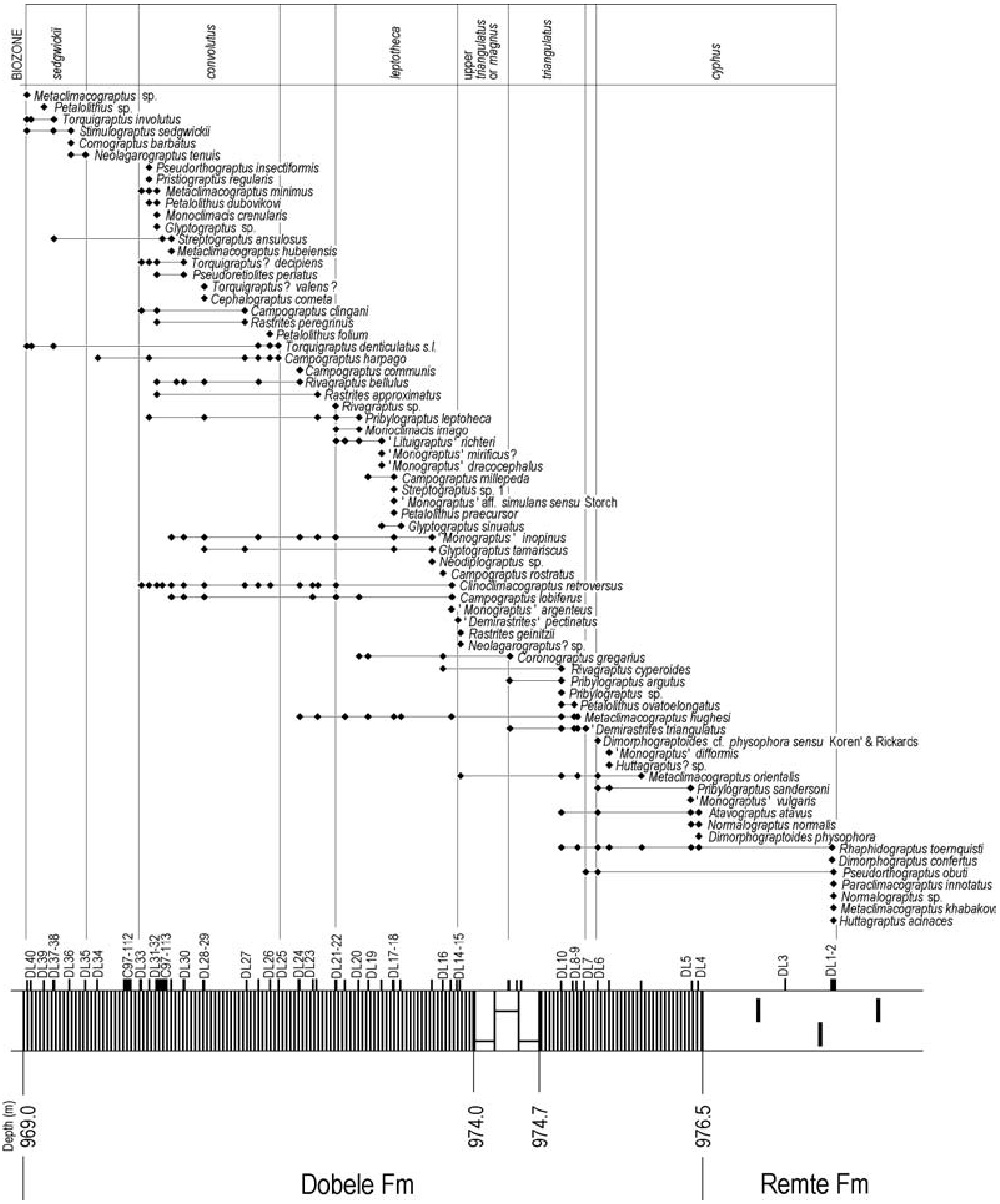

Figure 10. Range chart for graptolites through the Rhuddanian and Aeronian of the Aizpute-41 core. For lithological legend see Figure 2. In the BIOZONE column, boxes left blank indicate that the strata at this level could belong in either of the named biozones, above or below.

5.e. The *Conochitina alargada* Biozone

In the Aizpute-41 core the lower boundary of this biozone is tentatively identified by the questionable identification of the index species in sample C00-5 (Fig. 15). In the lower part of the biozone *C.* aff. *tuba* Eisenack (Fig. 16k), *Sphaerochitina* sp. (Fig. 16i) and *Spinachitina* sp. also occur. Precise identification of the *Spinachitina* species is difficult in the Aizpute-41 samples as specimens are poorly preserved and occur

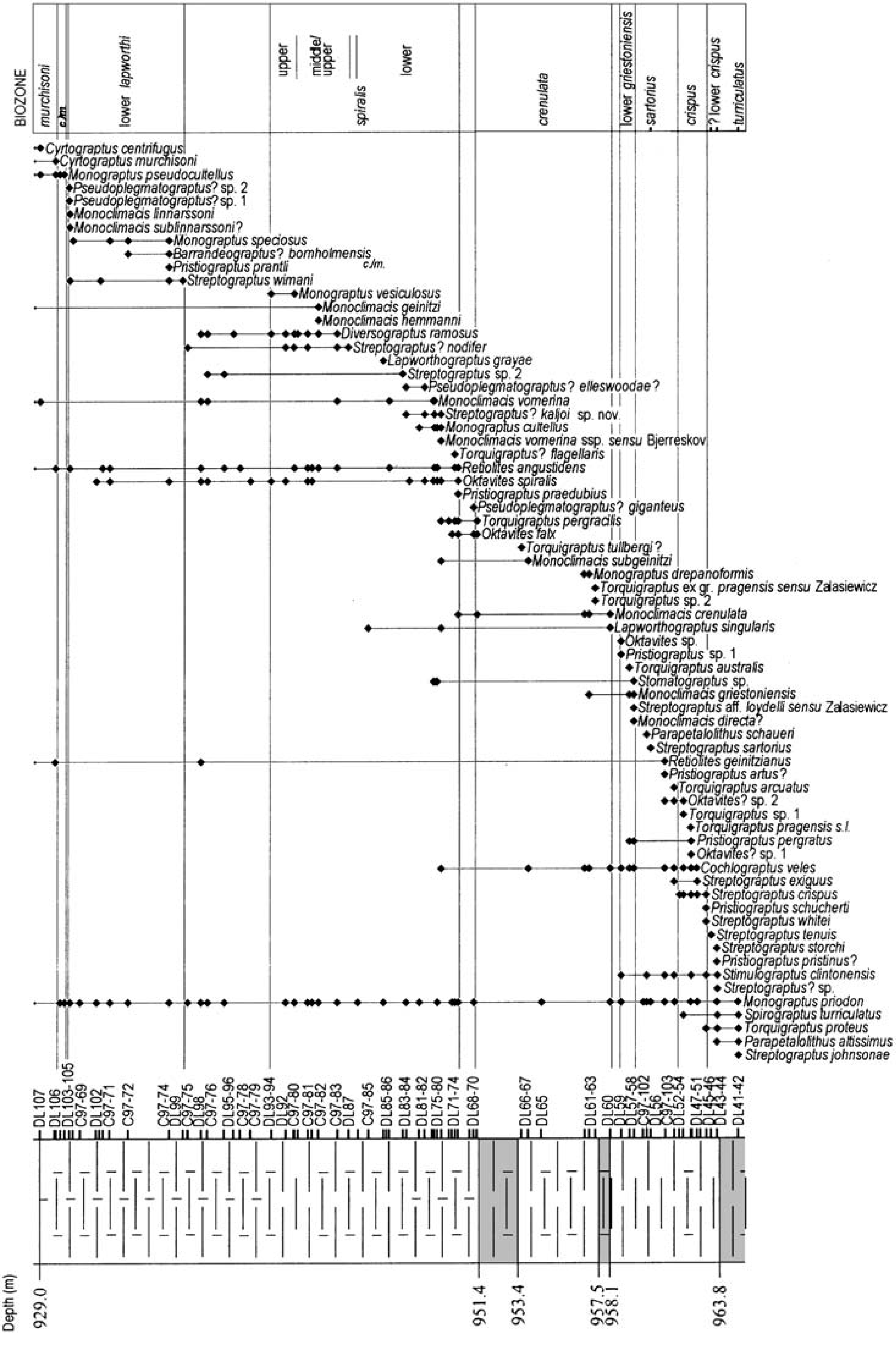

Figure 11. Range chart for graptolites through the Telychian and lowermost Sheinwoodian of the Aizpute-41 core. *c./m.* = *centrifugus* or *murchisoni* Biozone. For lithological legend see Figure 2. In the BIOZONE column, boxes left blank indicate that the strata at this level could belong in either of the named biozones, above or below.

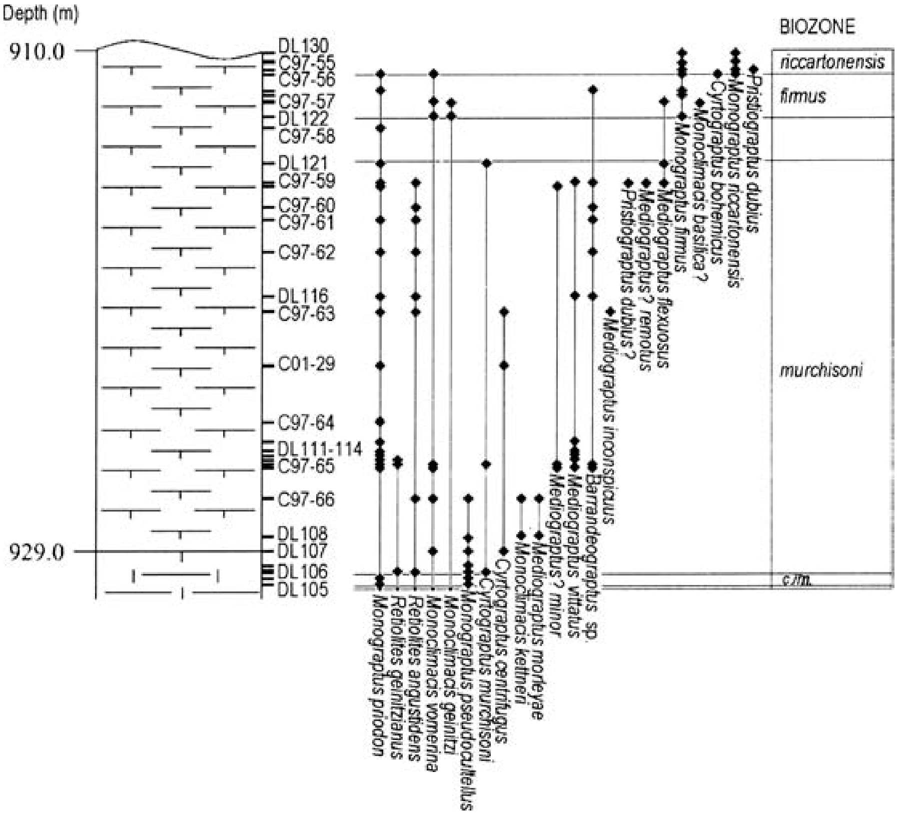

Figure 12. Range chart for graptolites through the Sheinwodian of the Aizpute-41 core. *c./m.* = *centrifugus* or *murchisoni* Biozone. For lithological legend see Figure 2. In the BIOZONE column, boxes left blank indicate that the strata at this level could belong in either of the named biozones, above or below.

only in small numbers from the upper part of the Rhuddanian up to the middle Aeronian. Aeronian specimens probably belong to *S. maennili* (Nestor). In the upper part of the *C. alargada* Biozone the most representative species is *Conochitina* cf. *malleus*. (Fig. 16l), which is present also in the Brabant Massif (G. Van Grootel, unpub. Ph.D. thesis, Rijksuniversiteit, Gent, 1990) and elsewhere in Latvia (Staicele core). In the Staicele core (unpub. data) the ranges of *A. convexa* and *C.* cf. *malleus* overlap in the Middle Aeronian. In the Aizpute-41 core, in addition to *C.* cf. *malleus* and *C. alargada* Cramer (Fig. 16q), *C. edjelensis* Taugourdeau (Fig. 16m), *C. elongata* Taugourdeau and *C. iklaensis* Nestor (Fig. 16p) occur and also the last representatives of *Cyathochitina* and the first *Bursachitina*. According to G. Van Grootel (unpub. Ph.D. thesis, Rijksuniversiteit, Gent, 1990) and Dufka (1992), *C. alargada* was not found in the Brabant Massif and Prague Basin, but the beds with *C.* cf. *malleus* correspond to the Aeronian or its upper part, the species being most abundant in the *convolutus* graptolite Biozone. In south Estonian and north Latvian core sections the *C. alargada* Biozone corresponds mostly to the Ikla and Lemme members of the middle part of the Saarde Formation.

The upper Aeronian and lower Telychian are devoid of chitinozoans (barren samples) in the Aizpute-41 core (Interzone II).

5.f. The *Eisenackitina dolioliformis* Biozone

This is equivalent to the *Conochitina emmastensis* Biozone of Nestor (1994). In the Aizpute-41 core this biozone is characterized by a low diversity of chitinozoans, with seven barren samples within this interval. In addition to the index species (Fig. 16r), there are only occasional occurrences of other species, of which *Rhabdochitina* sp. and *Eisenackitina causiata* Verniers (Fig. 16w) were the most numerous. In Estonian core sections this biozone embraces most of the Rumba Formation and the lower part of the Velise Formation of the Adavere Regional Stage (Nestor, 1994).

5.g. The *Angochitina longicollis* Biozone

In the Aizpute-41 core the index species (Fig. 16x) is the most abundant species in this biozone. *Conochitina visbyensis* Laufeld (Fig. 16t), *C. praeproboscifera* Nestor (Fig. 16y) and *Conochitina* sp. 6 (of Nestor, 1994; Fig. 16u) are common among the associated species. *Bursachitina* sp. occurs in the lower part and *Ramochitina angusta* (Nestor) (Fig. 16aa) in the upper part of the biozone. In Estonian and Latvian core sections this biozone corresponds respectively to the middle part of the Velise Formation and Irlava Beds of the Adavere Regional Stage.

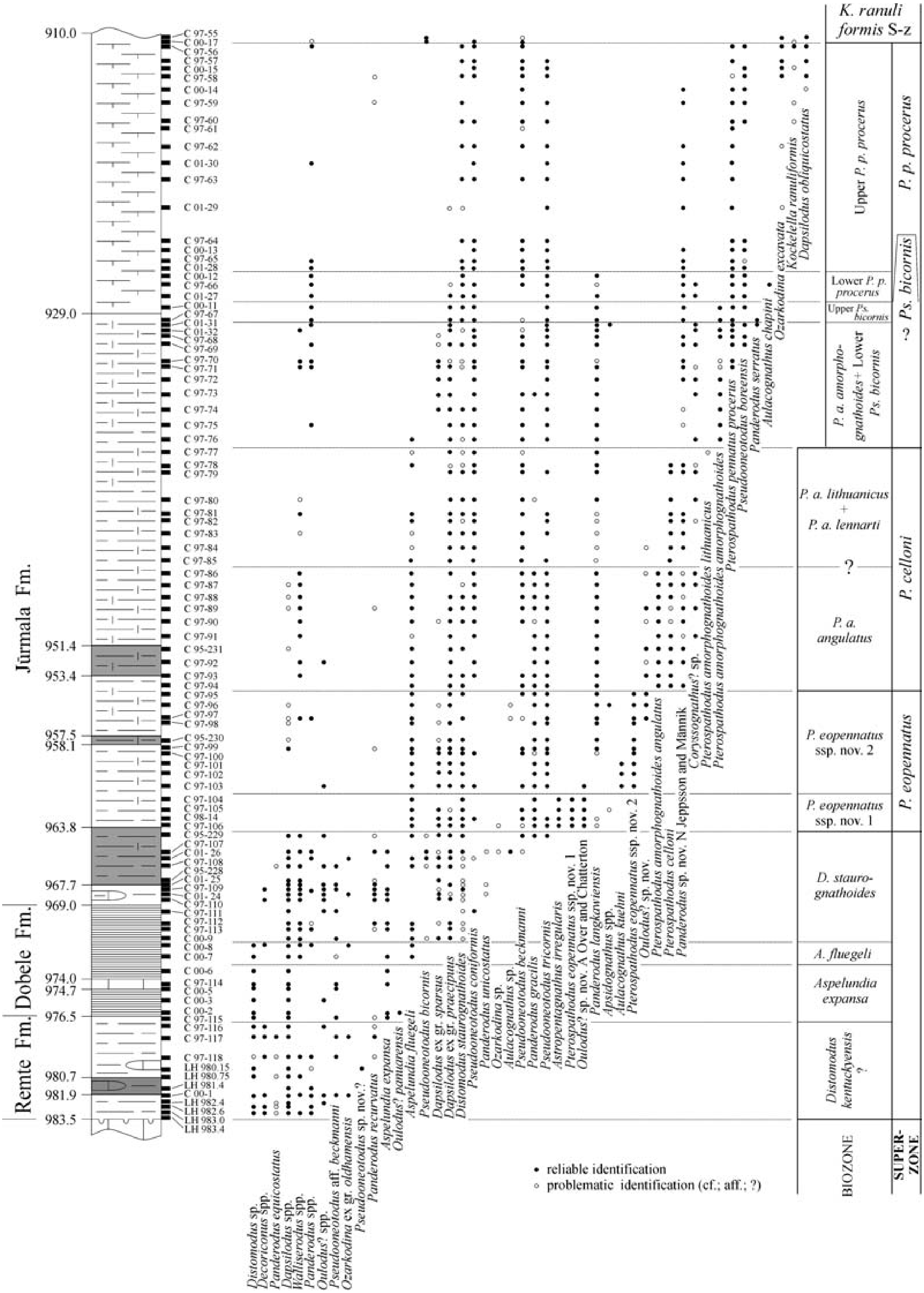

Figure 13. Range chart for conodonts through the Aizpute-41 core. For lithological legend see Figure 2.

5.h. The *Conochitina proboscifera* Biozone

Besides the index species (Fig. 16ab), this biozone is characterized by the presence of *A. longicollis* and *Conochitina emmastensis* Nestor (Fig. 16v), as well as sporadic occurrence of *Eisenackitina dolioliformis*, *E. causiata*, *Conochitina visbyensis, Conochitina* sp. 6 (of Nestor, 1994) and the appearance of *Ramochitina ruhnuensis* (Nestor) (Fig. 16ac).

It is likely that *Conochitina proboscifera* has been confused in the past with *Conochitina praeproboscifera* (Nestor, 1994) which appears significantly earlier than *C. proboscifera*. In all studied East Baltic sections *C. proboscifera* makes its appearance stratigraphically higher than the appearance of *A. longicollis*. Thus, most probably, the *C. proboscifera* Biozone is a good stratigraphical tool not only in Baltic regional geology.

The *C. proboscifera* Biozone corresponds to the uppermost part of the Velise Formation in Estonian sections and to the uppermost part of the Irlava Beds in Latvia.

5.i. The *Margachitina margaritana* Biozone

Recently, Mullins (2000) described a new species, *Margachitina banwyensis*, from the upper *lapworthi* to upper *centrifugus* graptolite biozones of the Banwy River section, Wales. This species was not found in the Aizpute-41 core, its absence being consistent with the existence of an unconformity at this level in the core.

In the Aizpute-41 core the dominant species within the *M. margaritana* Biozone is *Conochitina proboscifera*. *Cingulochitina bouniensis* Verniers occurs in the uppermost sample within the *margaritana* Biozone. The disappearance of *Angochitina longicollis* at 912.85 m indicates the boundary level between the *M. margaritana* Biozone and succeeding Interzone (Nestor, 1994). In the local stratigraphy the *M. margaritana* Biozone embraces the lowermost part of the Jaani and Rīga formations of the Jaani Regional Stage.

5.j. Additional chitinozoan data from the Ohesaare core

Since the publication of Loydell, Kaljo & Männik (1998), examination of previously studied and additional samples has provided new data, particularly on the chitinozoans of the core.

The questionable *Angochitina longicollis* in the Ohesaare core, at a depth 372.10 m, upon which the base of the biozone was founded (Nestor, 1994, fig. 20/1; Loydell, Kaljo & Männik, 1998) has been re-examined and is a *Sphaerochitina* sp. This apparently unusually early occurrence of *A. longicollis* can thus be disregarded.

A. longicollis appears in the Ohesaare core at 369.62–369.66 m, immediately below strata yielding lower *spiralis* Biozone graptolites. However, it is important to bear in mind the absence of biostratigraphically diagnostic graptolites between 370.2 m and 369.62 m in the core, an interval that should comprise the upper *griestoniensis* and *crenulata* biozones (assuming that there is no unconformity present). Thus the level of the base of the *longicollis* Biozone with respect to the graptolite biozones in the Ohesaare core remains uncertain.

6. Correlation of graptolite and conodont biozones

The correlation of conodont and graptolite biozones in the Aizpute-41 core is shown in Figure 17.

The *Aspelundia expansa* conodont Biozone correlates with the upper *cyphus* through to upper *leptotheca* graptolite biozones. The *Aspelundia fluegeli* conodont Biozone correlates with the uppermost *leptotheca* and lower part of the *convolutus* graptolite biozones. This seems to be in agreement with the situation in Washington Land, north Greenland (Armstrong, 1990), where the base of the *fluegeli* conodont Biozone appears to lie within the *argenteus* (stratigraphically equivalent to the *leptotheca*) graptolite Biozone. The base of the *Distomodus staurognathoides* conodont Biozone lies within the *convolutus* graptolite Biozone, and sample C95-229, which lies above *turriculatus* Biozone (*proteus* Subzone) graptolitic strata, is still within the *staurognathoides* Biozone. The base of the *Pterospathodus eopennatus* conodont Superzone correlates approximately with the base of the *crispus* graptolite Biozone; the base of the *P. eopennatus* ssp. 2 Biozone is close to the *crispus*/*sartorius* graptolite Biozone boundary. The base of the *Pterospathodus amorphognathoides angulatus* conodont Biozone (and also of the *P. celloni* Superzone) occurs within the *crenulata* graptolite Biozone. This is the first time that correlation of the base of the *celloni* Superzone with the graptolite biozonation has been achieved. It is interesting to note that the base of the superzone lies approximately at the level within the graptolite biozonation that the Subcommission on Silurian Stratigraphy (1995) had placed the base of the succeeding *amorphognathoides* Biozone. As in the Ohesaare core (Loydell, Kaljo & Männik, 1998), the base of the *Pterospathodus amorphognathoides amorphognathoides* Biozone occurs close to the base of the *lapworthi* graptolite Biozone.

As indicated above, placement of Ireviken Event Datum Point 2 (the boundary between the Lower and Upper *Pseudooneotodus bicornis* conodont biozones) is problematical. It is placed between samples C01-31 and C97-67, but could lie above sample C97-66 or higher. This level lies either at the base of or within the *murchisoni* graptolite Biozone. It is possible that Datum 2 at Ireviken 3 on Gotland, where the sequence of Datum Points comprising the Ireviken Event was established, ‘shows the most significant conodont changes within the Ireviken Event’ (Aldridge, Jeppsson

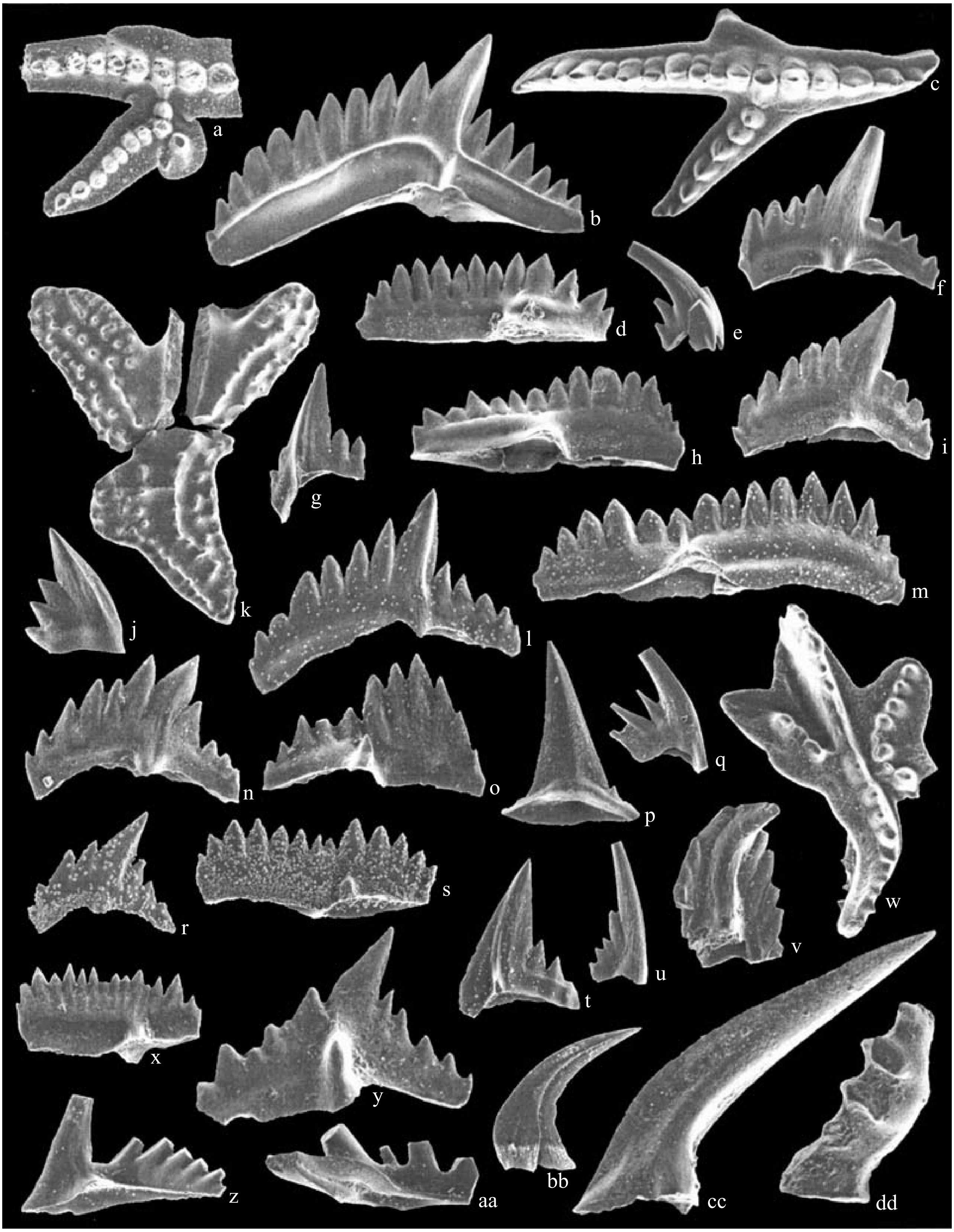

Figure 14. For legend see facing page.

& Dorning, 1993, p. 509) simply because there is a significant unconformity immediately beneath this Datum Point. This is worthy of consideration for several reasons. First, within the Aizpute-41 core the unconformity is recognizable primarily on graptolite biostratigraphical grounds; there is no obvious eroded or mineralized surface. A similar unconformity could easily be overlooked in an area, such as northwestern Gotland, where biostratigraphically useful graptolites are rare. Second, if there is an unconformity present in the relatively deep water facies represented by the Aizpute-41 core, one is likely also in the shallower waters of Silurian Gotland (see Fig. 1 for palaeogeographical reconstruction of Baltic region). There is, for example, a considerable gap across the Llandovery–Wenlock boundary recognized, and well dated based on conodonts, in western mainland Estonia (to the east of the town Pärnu). Here, strata corresponding to the interval from the upper part of the *P. a. amorphognathoides* Biozone up to the Upper *K. ranuliformis* Biozone are missing (P. Männik, unpub. Ph.D. thesis, Univ. Tartu, 1992 and later obs.). Third, it is interesting to note that in the even deeper (than Aizpute-41) marine sections cored in Lithuania neither the upper *lapworthi* (characterized by *Monograptus probosciformis* Bouček) nor the *insectus* biozones have been recognized (despite considerable study of the graptolites: e.g. Paškevičius, 1979) and the *centrifugus* Biozone is known from one core only (Paškevičius, 1997, p. 122). This suggests that this unconformity may be of regional extent. An explanation for the unconformity is provided by Loydell's (1998) eustatic sea-level curve for the early Silurian which shows a major sea-level fall in the late *lapworthi* Zone.

The base of the *Pterospathodus pennatus procerus* Superzone lies within the *murchisoni* Biozone, as it does also in the Ohesaare core (Loydell, Kaljo & Männik, 1998). However, the base of the succeeding *Kockelella ranuliformis* Superzone (Ireviken Event Datum 6) lies one graptolite biozone higher (near the base of the *riccartonensis* graptolite Biozone) in the Aizpute-41 core than it did in the Ohesaare core. Datum 6 is marked by the disappearance of the conodont genus *Pterospathodus*, the last species being the diminutive *P. p. procerus*. In the Ohesaare core the last *P. p. procerus* were found in the 338.0–338.20 m sample (they were absent from the next sample at 337.0–337.20 m). Thus Datum 6 appeared to lie within the *firmus* graptolite Biozone (Loydell, Kaljo & Männik, 1998, p. 781). In the Aizpute-41 core, however, *P. p. procerus* is present in the lowermost sample from the *riccartonensis* Biozone, but does not occur in any higher samples. This suggests either that the extinction of *Pterospathodus* occurred later further off-shore, or that the absence of *P. p. procerus* in the upper *firmus* and lowermost *riccartonensis* biozones of the Ohesaare core was a result of insufficient sample size rather than genuine absence from this area.

7. Correlation of graptolite and chitinozoan biozones

The correlation of chitinozoan and graptolite biozones in the Aizpute-41 core is shown in Figure 17.

The *Conochitina postrobusta* chitinozoan Biozone clearly correlates, in part at least, with the *cyphus* graptolite Biozone, but not with the latter's uppermost part (see below). Below sample C97-117 there are several metres of core barren of both chitinozoans and graptolites, so it is possible that the lower part

Figure 14. Conodonts from the Aizpute-41 core, Latvia. (a, b) *Pterospathodus amorphognathoides amorphognathoides* Walliser; (a) 301-1; upper view of dextral Pa element; sample C97-74, 935.4–935.5 m; (b) 301-2; outer lateral view of a sinistral Pb_1 element; sample C97-73, 934.4–934.5 m. (c, f) *Pterospathodus pennatus procerus* (Walliser); sample C97-69, 930.9–931.0 m; (c) 301-3; upper view of a dextral Pa element; (f) 301-4; outer lateral view of a sinistral Pb element. (d, e, g–i) *Pterospathodus celloni* (Walliser); sample C97-83, 943.95–944.05 m; (d) 301-5; inner lateral view of a dextral Pa element; (e) 301-6; outer lateral view of a dextral Sb_2 element; (g) 301-7; outer lateral view of a sinistral Pc element; (h) 301-8; inner lateral view of a sinistral Pa element; (i) 301-9; outer lateral view of a sinistral Pb_1 element. (j, n–q, u) *Pterospathodus eopennatus* Männik ssp. nov. 2; (j) 301-10; outer lateral view of a dextral Pb_2 element; (n) 301-11; outer lateral view of a sinistral Pb_1 element; (o) 301-12; inner lateral view of a sinistral Pa element; (p) 301-13; inner lateral view of a sinistral carniciform element; (q) 301-14; inner lateral view of a sinistral Sc_2 element; (u) 301-15; outer lateral view of a dextral Sc_3 element. (j, n–q) from sample C97-97, 956.25–956.35 m; (q, u) from sample C97-96, 955.45–955.55 m. (k) *Aulacognathus* cf. *chapini* (Savage); 301-16; upper view of a sinistral Pa element; sample C97-66, 926.9–927.0 m. (l, m) *Pterospathodus amorphognathoides angulatus* (Walliser); (l) 301-17; outer lateral view of a sinistral Pb_1 element; sample C97-87, 947.3–947.4 m; (m) 301-18; inner lateral view of a sinistral Pa element; sample C97-90, 949.85–949.95 m. (r–t) *Pterospathodus eopennatus* Männik ssp. nov. 1; sample C97-104, 961.9–962.0 m; (r) 301-19; outer lateral view of a sinistral Pb_1 element; (s) 301-20; inner lateral view of a dextral Pa element; (t) 301-21; outer lateral view of a sinistral Pc element. (v, w) *Astropentagnathus irregularis* Mostler; sample C97-106, 963.45–963.60 m; (v) 301-22; posterior view of a sinistral Sb? element; (w) 301-23; upper view of a sinistral Pa_1 element. (x) *Ozarkodina* ex gr. *oldhamensis* (Rexroad); 301-24; inner lateral view of a dextral Pa element; sample C00-8, 971.75–971.85 m. (y) *Aulacognathus* sp.; 301-25; outer lateral view of a sinistral Pb element; sample C97-107, 965.40–965.55 m. (z, aa) *Aspelundia expansa* Armstrong. (z) 301-26; inner lateral view of a dextral M element; sample C97-115, 976.45–976.55 m. (aa) 301-27; inner lateral view of a sinistral Pb? element; sample C97-113, 970.45–970.60 m. (bb) *Panderodus* n. sp. N Jeppsson and Männik; 301-28; furrowed face of a falciform element; sample C97-81, 942.4–942.5 m. (cc–dd) *Distomodus* sp.; 980.75–980.80 m. (cc) 301-29; inner lateral view of a dextral M element. (dd) 301-30; upper view of a fragment of a Pa element. (k) and (w) × 50, others × 80.

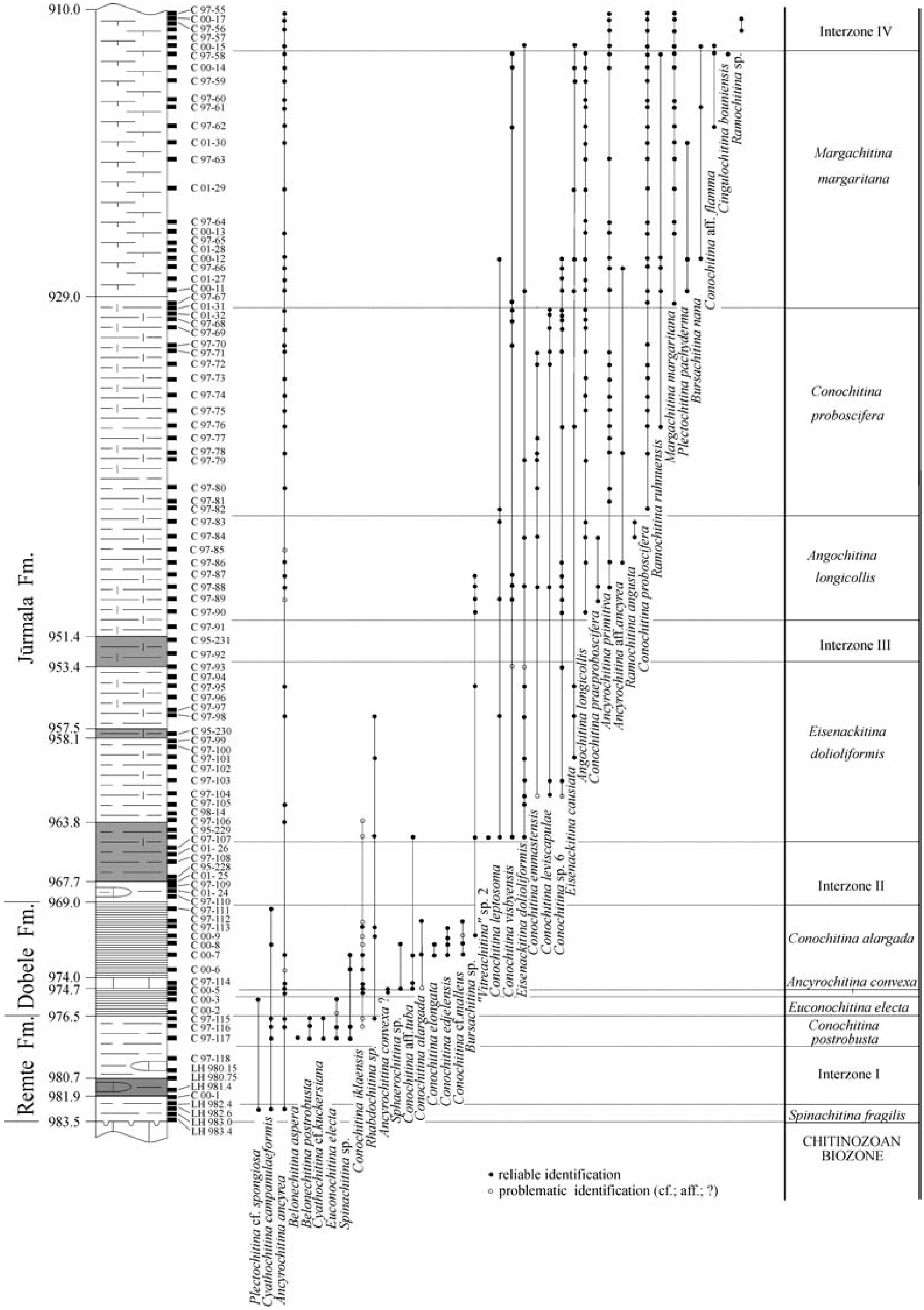

Figure 15. Range chart for chitinozoans through the Aizpute-41 core. For lithological legend see Figure 2.

of the *postrobusta* Biozone correlates with the *vesiculosus* graptolite Biozone. Verniers *et al*. (1995) had suggested that the *postrobusta* Biozone correlated with the *vesiculosus* graptolite Biozone, based on the correlation of the local *confertus* graptolite Biozone with the *vesiculosus* graptolite Biozone. *Dimorphograptus confertus* (Nicholson) occurs also in the *cyphus* Biozone, however (e.g. Hutt, 1974, 1975), the biozone in which it occurs in the Aizpute-41 core together with typical *cyphus* Biozone taxa, such as *Pseudorthograptus obuti* (Rickards & Koren').

The *Euconochitina electa* Biozone correlates with the upper part of the *cyphus* graptolite Biozone. This broadly agrees with previous correlations, although Verniers *et al*. (1995, p. 654) stated that the base of the biozone correlated with a level low in the *cyphus* Biozone. Re-examination (by Loydell, Kaljo & Männik, 1998) of the graptolites upon which this suggestion was based indicated that the sparse assemblages from this level were insufficient for precision biozonal assignment.

The *Ancyrochitina convexa* chitinozoan Biozone is represented, questionably, only by sample C00-4, correlating approximately with the base of the *triangulatus* graptolite Biozone. This agrees with Nestor's (1994, p. 123) suggested correlation.

The base of the *Conochitina alargada* chitinozoan Biozone is correlated tentatively with a level in the middle or upper part of the *triangulatus* graptolite Biozone. The absence of chitinozoans from Interzone II (Fig. 15) means that the level in the graptolite biozonation of the upper boundary of the biozone remains uncertain, but the entire *convolutus* graptolite Biozone appears to be encompassed by the *alargada* Biozone. This correlation agrees in part with that of Verniers *et al.* (1995), but in the present paper the level of the base of the biozone is lowered by approximately two and one-half graptolite biozones.

Sample, C97-111, from the lowermost *sedgwickii* graptolite Biozone yielded only *Cyathochitina campanulaeformis* (Eisenack). As this species occurs sporadically in the *Eisenackitina dolioliformis* Biozone (Nestor, 1994, p. 121) as well as in the *alargada* Biozone, its presence is of little biostratigraphical significance. Above sample C97-111 all samples were barren until the lower Telychian, *turriculatus* graptolite Biozone.

The earliest *Eisenackitina dolioliformis* Umnova occur within the upper *turriculatus* graptolite Biozone. There is, however, no chitinozoan data from the *sedgwickii* through to lower *turriculatus* graptolite biozones, so correlation of the base of the *dolioliformis* Biozone with the graptolite biozonation (discussed at length by Mullins & Loydell, 2001, 2002) remains uncertain.

In the Aizpute-41 core *Angochitina longicollis* first appears close to the base of the *spiralis* graptolite Biozone, above strata barren of chitinozoans. The lower part at least of these barren strata correlates with the upper *crenulata* graptolite Biozone. This level of first appearance in the Aizpute-41 core (and in the Ohesaare core; see Section 5.j) differs somewhat from that in the Banwy River and Buttington sections, where *Angochitina longicollis* first occurs in the upper part of the *spiralis* graptolite Biozone, but is similar to that in the Girvan District, Scotland, from which Vandenbroucke, Verniers & Clarkson (in press) record *A. longicollis* from the Lauchlan Formation (lower *spiralis* Biozone; see Loydell, in Floyd, 1999, p. 40). Mullins & Loydell (2001, 2002) discussed at length the correlation of the *Angochitina longicollis* Biozone with the graptolite biozonation. The apparent early appearance of *A. longicollis* in the Ohesaare core (in the *turriculatus* graptolite Biozone) is explained above (Section 5.j), however, the apparently equally early (lower Telychian) occurrence in the southern part of the Oslo region (Nestor, 1999) has been re-examined and confirmed as *A. longicollis*. The specimens of *A. longicollis* come from the upper half of the Rytteråker Formation of the Solhaugveien section (Nestor, 1999). Although the Rytteråker Formation has traditionally been dated as late Aeronian–early Telychian (e.g. Worsley *et al*. 1983, p. 12), the formation has yielded conodonts that suggest a rather later age: Aldridge & Mohamed (1982, p. 111) recorded *Pterospathodus celloni* (Walliser) from the uppermost part of the Rytteråker Formation at Skien. Elsewhere (e.g. on Malmøya), however, the Rytteråker Formation must be either early Telychian or late Aeronian in age as the overlying Vik Formation is older than *Pterospathodus eopennatus* Superzone (older than *crispus* graptolite Zone using the Aizpute-41 biozonal correlation). It thus appears that the top of Rytteråker Formation may be highly diachronous. A study of the Solhaugveien section is needed to determine the conodont biostratigraphy in this part of the Oslo region. If the upper Rytteråker Formation at Solhaugveien does lie within the *celloni* Biozone and the Aizpute-41 core correlation of the *celloni* conodont Biozone with the graptolite biozonation is equally applicable to the southern part of the Oslo region, then the occurrence of *A. longicollis* ceases to be anomalous; the material would most probably come from a level correlating with the *spiralis* graptolite Biozone.

Regardless of the situation in the Oslo region, the base of the *longicollis* chitinozoan Biozone does appear to be diachronous, correlating with different levels within the *spiralis* graptolite Biozone (and possibly into the *crenulata* graptolite Biozone, represented by the barren Interzone III in the Aizpute-41 core). The *spiralis* graptolite Zone has been interpreted to be the longest in duration of all Llandovery graptolite zones (Loydell, 1993*b*, p. 333), so this diachronism may represent a significant time interval.

The base of the *Conochitina proboscifera* chitinozoan Biozone correlates with a level in the middle or

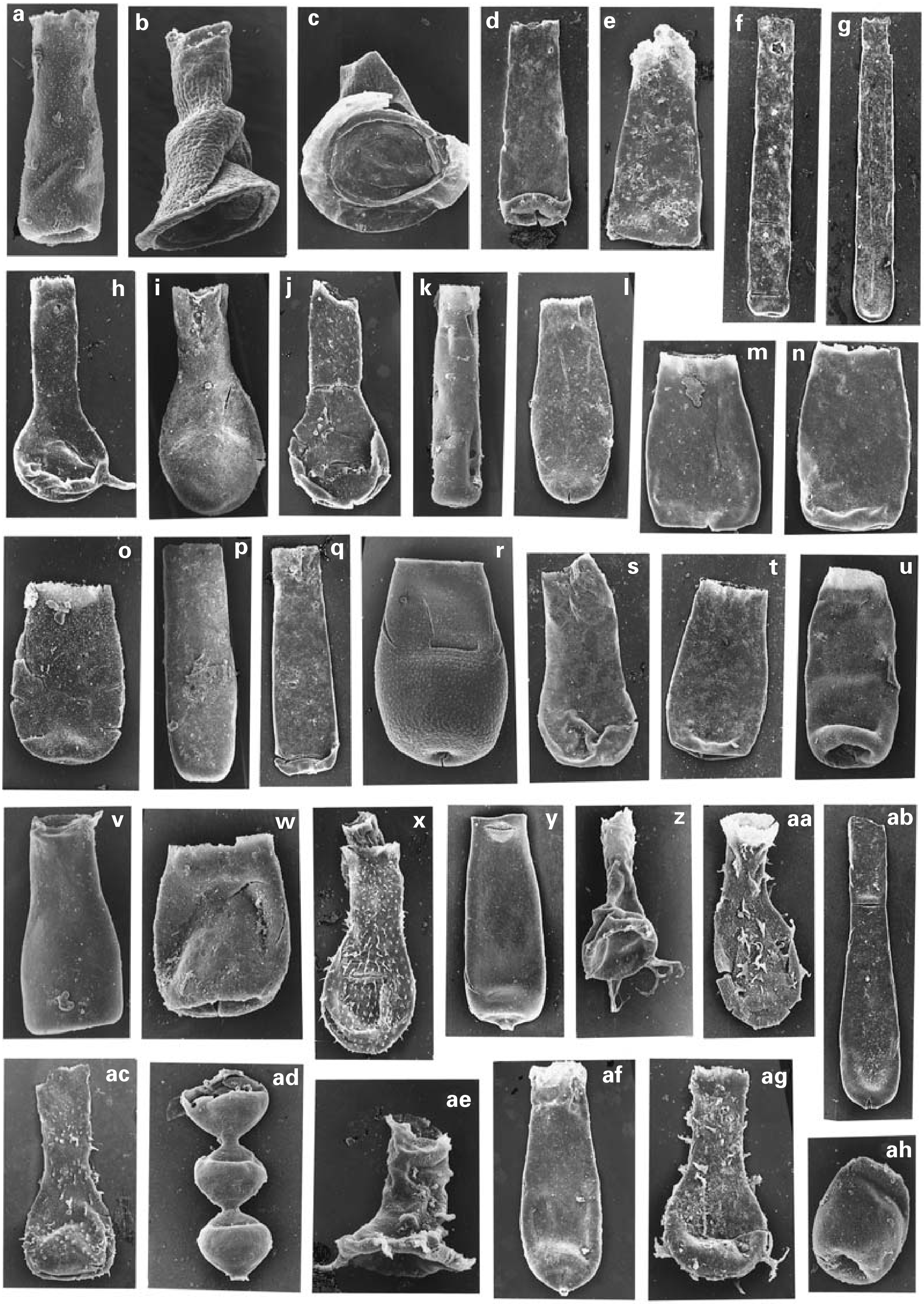

Figure 16. For legend see facing page.

upper *spiralis* Biozone in the Aizpute-41 core, but with a somewhat higher level (probably *lapworthi* Biozone) in the Ohesaare core (Loydell, Kaljo & Männik, 1998). The earliest *C. proboscifera* in the Banwy River section occur in the upper *spiralis* Biozone where it is rare; it becomes abundant in the *lapworthi* Biozone (Mullins & Loydell, 2001, p. 776). It is possible, therefore, that the apparently higher level for the base of the *proboscifera* Biozone in the Ohesaare core is a result of it being rare or having a patchy distribution during the lower part of its range and thus was not encountered in *spiralis* graptolite Biozone samples.

Mullins & Loydell (2001) recognized a *Conochitina acuminata* chitinozoan Biozone above the *longicollis* Biozone in the Banwy River section. This nominal species is not present in the Ohesaare core.

An unconformity is interpreted below the first appearance of the *Margachitina margaritana* (Eisenack); see Section 5.i. The occurrence of *Cingulochitina bouniensis* in the uppermost *murchisoni* graptolite Biozone agrees well with the first appearence of this taxon in the Banwy River section, Wales (Mullins & Loydell, 2001, p. 769).

The base of Interzone IV (which, unlike the earlier interzones, is not barren of chitinozoans) correlates approximately with the base of the *firmus* graptolite Biozone in both the Aizpute-41 and Ohesaare cores (Loydell, Kaljo & Männik, 1998, fig. 1). Interzone IV is characterized by a low diversity of chitinozoans and begins immediately above the extinction of *Angochitina longicollis*. In the Banwy River section this interval is named the *Salopochitina bella* chitinozoan Biozone and contains *A. longicollis* in both the *firmus* and *riccartonensis* graptolite biozones. *S. bella* was not encountered in the Aizpute-41 core.

8. Systematic palaeontology

Streptograptus? *kaljoi* sp. nov.

Figure 8c, d, f

1975 *Monograptus anguinus* Přibyl, 1941; Bjerreskov, pp. 63–64, pl. 9, figs E–G.

Name. After Prof. D. Kaljo, of the Institute of Geology, Tallinn Technical University, Estonia.

Material. More than 20 specimens, from the lower part of the *spiralis* Biozone (Fig. 11), Aizpute-41 core, Latvia. Most are flattened; the remainder are preserved in three dimensions, but have suffered from 'pyrite disease' (decomposition).

Holotype. Specimen 341-134 (Fig. 8c), a flattened specimen retaining some original periderm, from sample DL83 (depth 947.52 m).

Diagnosis. Ventrally curved, fish-hook shaped rhabdosome, increasing in dorso-ventral width moderately rapidly from 0.2 mm at th1 to a distal maximum of 0.6 mm. Sicula small, apex reaching approximately the top of th1. Thecae increase in complexity distally: proximal thecae appear to be of *Streptograptus*-like form; distal thecae are laterally expanded.

Description. The rhabdosome is ventrally curved, except at the extreme proximal and distal ends which are straight. Degree of curvature is variable (compare Fig. 8c with Fig. 8f). Measurements of proximal dorso-ventral width are given in Table 1; a distal maximum of 0.6 mm is achieved, although the width may appear greater in specimens preserved slightly obliquely to bedding (e.g. Fig. 8d). 2TRD is highly variable proximally, 1.2–1.9 mm, but is generally 1.4–1.6 mm.

Figure 16. Silurian chitinozoans from the Aizpute-41 core, Latvia. (a) *Belonechitina postrobusta* (Nestor); Ch 551/11924; 977.95–978.10 m; × 220. (b) *Cyathochitina campanulaeformis* (Eisenack); Ch 549/12103; 982.60–982.70 m; × 200. (c) *Cyathochitina* cf. *kuckersiana* (Eisenack); Ch 552/11924; 977.95–978.10 m; × 140. (d) *Spinachitina* sp.; Ch 553/11925; 977.00–977.15 m; × 125. (e) *Euconochitina electa* (Nestor); Ch 555/12105; 975.45–975.55 m; × 175. (f) *Rhabdochitina* sp.; Ch 554/11926; 976.45–976.55 m; × 105. (g) *Conochitina leptosoma* Laufeld; Ch 565/12112; 964.60–964.65 m; × 65. (h) *Plectochitina* cf. *spongiosa* (Achab); Ch 550/12103; 982.60–982.70 m; × 200. (i) *Sphaerochitina* sp.; Ch 556/12107; 974.65–974.73 m; × 220. (j) *Ancyrochitina convexa* Nestor?; Ch 557/12106; 974.80–974.90 m; × 200. (k) *Conochitina* aff. *tuba* Eisenack; Ch 558/11927; 974.15–974.25 m; × 120. (l) *Conochitina* cf. *malleus*; Ch 559/12109; 972.40–972.50 m; × 110. (m) *Conochitina edjelensis* Taugourdeau; Ch 563/12110; 971.15–971.25 m; × 200. (n) *Bursachitina* sp.; Ch 564/12110; 971.15–971.25 m; × 230. (o) *Belonechitina aspera* (Nestor); Ch 584/11924; 977.95–978.10; × 240. (p) *Conochitina iklaensis* Nestor; Ch 562/12109; 972.40–972.50 m; × 120. (q) *Conochitina alargada* Cramer; Ch 561/12109; 972.40–972.50 m; × 120. (r) *Eisenackitina dolioliformis* Umnova Ch 568/11933; 961.90–962.00 m; × 155. (s) '*Vitreachitina*' sp. 2 (of Nestor, 1994); Ch 566/12112; 964.60–964.65 m; × 210. (t) *Conochitina visbyensis* Laufeld; Ch 566/12112; 964.60–964.65 m; × 200. (u) *Conochitina* sp. 6 (of Nestor, 1994); Ch 569/11934; 960.95–961.05 m; × 190. (v) *Conochitina emmastensis* Nestor; Ch 572/11942; 948.10–948.20 m; ×175. (w) *Eisenackitina causiata* Verniers; Ch 578/11954; ∼ 937.50 m; × 270. (x) *Angochitina longicollis* Eisenack; Ch 570/11940; 949.85–949.95 m; × 190. (y) *Conochitina praeproboscifera* Nestor; Ch571/11941; 949.00–949.10 m; × 110. (z) *Ancyrochitina* aff. *ancyrea* (Eisenack); Ch 573/11944; 946.55–946.60 m; × 240. (aa) *Ramochitina angusta* (Nestor); Ch 574/11947; 943.95–944.05 m; × 200. (ab) *Conochitina proboscifera* Eisenack; Ch 576/11948; 942.90–943.05 m; × 85. (ac) *Ramochitina ruhnuensis* (Nestor); Ch 577/11954; ∼ 937.50 m; × 180. (ad) *Margachitina margaritana* (Eisenack); Ch 579/11963; ∼ 929.50 m; × 155. (ae) *Plectochitina* cf. *pachyderma* Laufeld; Ch 580/12113; ∼ 928.0 m; × 300. (af) *Conochitina* aff. *flamma* Laufeld; Ch 582/12117; 912.45–912.55; × 140. (ag) *Ramochitina* sp.; Ch 583/12119; 910.50–910.60; × 180. (ah) *Bursachitina nana* (Nestor); Ch 581/12114; ∼ 926.0 m; × 250.

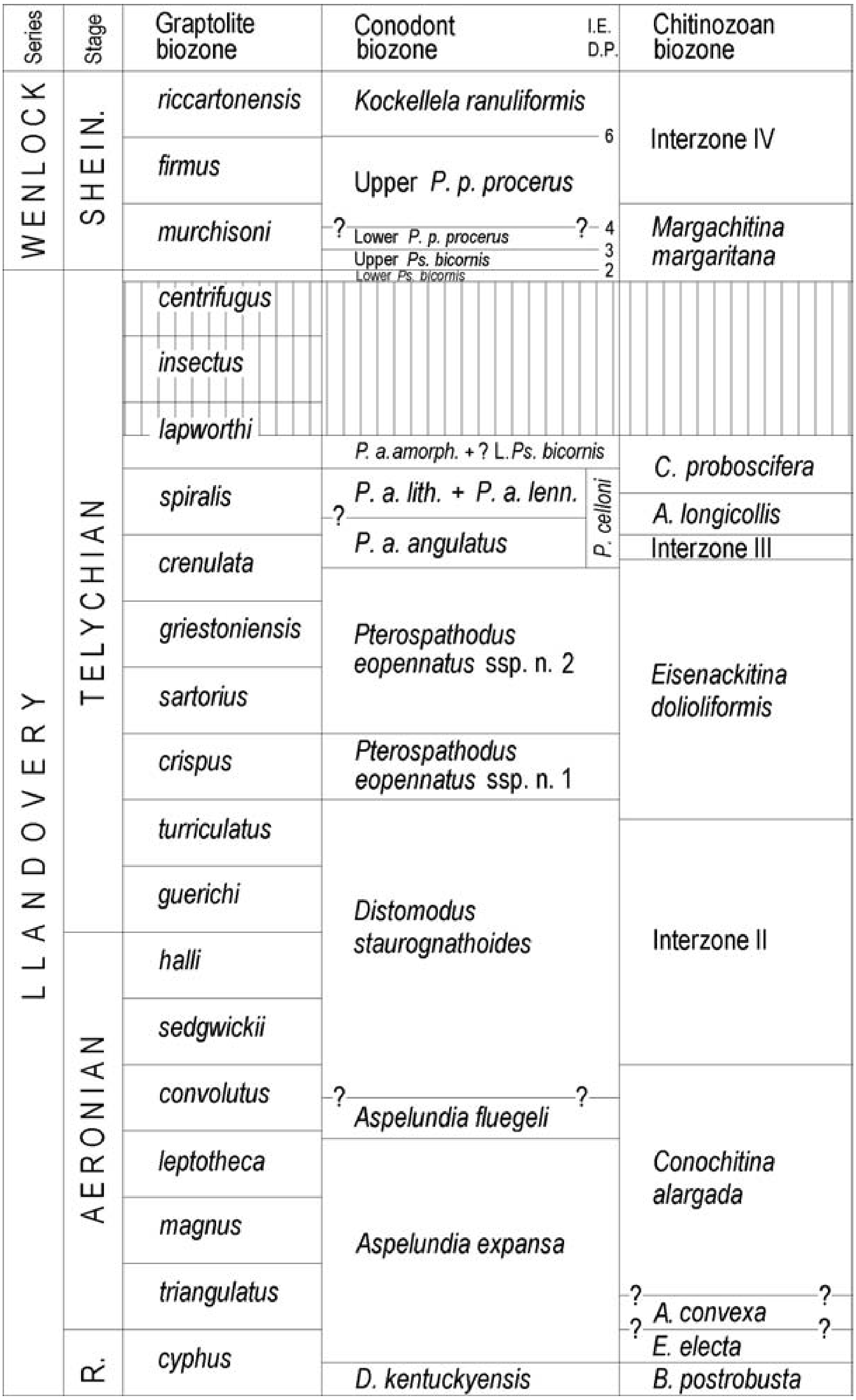

Figure 17. Correlation of graptolite, conodont and chitinozoan biozones as demonstrated by the Aizpute-41 core. R. = Rhuddanian; SHEIN. = Sheinwoodian; I.E.D.P. = Ireviken Event Datum Point. Missing biozones in the Telychian are indicated by shading of vertical lines. The base of the Wenlock (Ireviken Event Datum Point 2) is shown at the lowest level within the graptolite biozonation with which it could correlate. It is possible that I.E.D.P. 2 correlates with a level somewhat higher in the *murchisoni* graptolite Biozone (see text for discussion).

Table 1. Comparison of dorso-ventral widths (in mm) in *Streptograptus*? *kaljoi* sp. nov. and *Streptograptus*? *anguinus* (Přibyl, 1941)

Specimen no.	Th 1	2	3	5	10	15	20
Streptograptus? *kaljoi* sp. nov.							
341-134 (holotype)	0.2	–	0.3	0.3	0.5	0.6	
341-167	0.2	0.2	0.25	0.4	0.55	0.55	
Bornholm specimens (Bjerreskov, 1975)	0.2	–	–	–	–	0.6	0.6
Streptograptus? *anguinus* (Přibyl, 1941)							
L30966 (type slab)	0.2	0.2	0.25	0.3	0.35	0.45	
L30966 (type slab)	0.25	0.25	0.25	0.4	0.45	0.45	
L31055 (Bouček & Přibyl, 1942, fig. 3k, l)	0.25	–	0.3	0.3	0.4	–	0.45

Distal to th10 2TRD ranges between 1.85 mm and 2.05 mm. The sicula is preserved in only two specimens and in both is damaged aperturally. Its apex reaches the top of th1 or just below. Thecae appear to be of typical *Streptograptus*-like form proximally, but by th5 lateral expansion is apparent and all more distal thecae are laterally expanded; precise details of the metathecal morphology cannot be determined. Ventral prothecal walls are very gently inclined to the rhabdosome axis proximally; distally the prothecae are parallel-sided, comprising approximately two-thirds the dorso-ventral width of the rhabdosome. Throughout there are small, but prominent, prothecal folds at the base of each theca. Thecal overlap is very low throughout.

Remarks. Material of *S.*? *kaljoi* was assigned to Přibyl's (1941) species *anguinus* by Bjerreskov (1975). *S.*? *anguinus* has a ventrally curved rhabdosome like that of *S.*? *kaljoi* and appears also to have thecae of a modified 'streptograptid' form. *S.*? *anguinus* is, however, both distally narrower and more gradually widening than *S.*? *kaljoi* (see Table 1). In addition, the thecae of *S.*? *anguinus* are more widely spaced: 2TRD measurements taken from Přibyl's (1941) and Bouček & Přibyl's (1942) specimens, housed in the National Museum, Prague, are 1.6–2.2 mm proximally, 2.2–2.6 mm distally.

Bjerreskov's specimens are also from the lower part of the *spiralis* Biozone, suggesting that *S.*? *kaljoi* may have a very limited stratigraphical range. Bjerreskov (1975) gave a full description of well-preserved (including three-dimensional) material from Bornholm and illustrated (pl. 9E) one mesial theca under the SEM showing clearly the lateral expansion. From both stratigraphical and morphological viewpoints *S.*? *kaljoi* would appear to be a likely ancestor of one of the taxa from higher in the *spiralis* Biozone which also have thecae of a modified 'streptograptid' form: *S.*? *anguinus* and *S.*? *nodifer* (Törnquist). Examination of chemically isolated material will be required to elucidate the relationships between these taxa.

9. Conclusions

The main significance of the biostratigraphical data from the Aizpute-41 core presented here is that several graptolite, conodont and chitinozoan biozones can be correlated within the same core. With regard to graptolite–conodont biozonal correlation, the bases of the *Aspelundia expansa* and *Pterospathodus celloni* conodont biozones are tied to the graptolite scheme for the first time. The bases of the *Pterospathodus a. amorphognathoides* and *P. p. procerus* conodont superzones occur at the same level with respect to the graptolite biozonation as they did in the Ohesaare core (Loydell, Kaljo & Männik, 1998). The base of the *Kockella ranuliformis* conodont Biozone occurs one graptolite biozone higher in the Aizpute-41 core than it did in Ohesaare.

From a graptolite–chitinozoan biozonal correlation viewpoint greater precision is provided in correlating the upper Rhuddanian and lower–middle Aeronian biozones. The position of the base of the *Eisenackitina dolioliformis* chitinozoan Biozone with respect to the graptolite biozonation remains uncertain, however. The base of the *Angochitina longicollis* Biozone appears to be diachronous, occurring at a different level in Baltic sections (Aizpute-41, Ohesaare; base *spiralis* Biozone or lower) from that in Wales (Banwy, Buttington; upper *spiralis* Biozone). The base of Interzone IV in both Aizpute-41 and Ohesaare occurs at the same level, approximately at the base of the *firmus* Biozone.

The recognition of Datum 2 of the Ireviken Event within strata at or near the base of the *murchisoni* graptolite Biozone in the Aizpute-41 core may have considerable stratigraphical significance. However, it is possible that the changes in conodont assemblages marking Datum 2 are, on Gotland at least, an artefact, resulting from an unconformity which may be of regional extent.

Acknowledgements. P. Männik's studies were supported by ETF Grant No. 4070, V. Nestor's by Estonian Science Foundation Grant No. 3749. We thank Prof. J. E. Barrick (Texas Tech University) for valuable comments on the taxonomy of simple-cone conodonts in the Aizpute-41 core. We thank also Lennart Jeppsson and Petr Štorch for their thorough reviews of this paper and Gary Mullins who commented on the chitinozoan sections prior to submission.

References

ALDRIDGE, R. J., JEPPSSON, L. & DORNING, K. J. 1993. Early Silurian oceanic episodes and events. *Journal of the Geological Society, London* **150**, 501–13.

Aldridge, R. J. & Mabillard, J. E. 1981. Local variations in the distribution of Silurian conodonts: an example from the *amorphognathoides* interval of the Welsh Basin. In *Microfossils from recent and fossil shelf seas* (eds J. W. Neale and M. D. Brasier), pp. 10–17. Chichester, England: Ellis Horwood Ltd.

Aldridge, R. J. & Mohamed, I. 1982. Conodont biostratigraphy of the early Silurian of the Oslo region. In *IUGS Subcommission on Silurian Stratigraphy. Field Meeting, Oslo Region 1982* (ed. D. Worsley), pp. 109–20. Palaeontological Contributions from the University of Oslo no. 278.

Armstrong, H. A. 1990. Conodonts from the upper Ordovician–lower Silurian carbonate platform of North Greenland. *Grønlands Geologiske Undersøgelse* **159**, 1–151.

Bassett, M. G., Kaljo, D. & Teller, L. 1989. The Baltic region. In *A Global Standard for the Silurian System* (eds C. H. Holland and M. G. Bassett), pp. 158–70. National Museum of Wales, Geological Series no. 9.

Bjerreskov, M. 1975. Llandoverian and Wenlockian graptolites from Bornholm. *Fossils and Strata* **8**, 1–94, pls 1–13.

Bouček, B. & Přibyl, A. 1942. Über böhmische Monograpten aus der Untergattung *Streptograptus* Yin. *Mitteilungen der Tschechischen Akademie der Wissenschaften* **52**(1), 1–23, pls 1–3.

Dufka, P. 1992. Lower Silurian chitinozoans of the Prague Basin (Barrandian, Czechoslovakia). Preliminary results. *Revue de Micropaléontologie* **35**, 117–26.

Floyd, J. D. 1999. *Geology of the Carrick–Loch Doon district. British Geological Survey Memoir for 1:50,000 Geological sheets 8W and 8E.* London: The Stationery Office.

Hutt, J. E. 1974. The Llandovery graptolites of the English Lake District. Part 1. *Palaeontographical Society Monograph* **128**(540), 1–56, pls 1–10.

Hutt, J. E. 1975. The Llandovery graptolites of the English Lake District. Part 2. *Palaeontographical Society Monograph* **128**(542), 57–137, pls 11–26.

Jeppsson, L. 1997*a*. A new latest Telychian, Sheinwoodian and Early Homerian (early Silurian) standard conodont zonation. *Transactions of the Royal Society of Edinburgh: Earth Sciences* **88**, 91–114.

Jeppsson, L. 1997*b*. The anatomy of the mid-early Silurian Ireviken Event and a scenario for P–S events. In *Paleontological events. Stratigraphic, ecological, and evolutionary implications* (eds C. E. Brett and G. C. Baird), pp. 451–92. New York: Columbia University Press.

Jeppsson, L. 1998. Silurian oceanic events: summary of general characteristcs. In *Silurian cycles: linkages of dynamic stratigraphy with atmospheric, oceanic, and tectonic changes. James Hall Centennial Volume* (eds E. Landing and M. E. Johnson), pp. 239–57. *New York State Museum Bulletin* **491**.

Jeppsson, L. & Männik, P. 1993. High-resolution correlations between Gotland and Estonia near the base of the Wenlock. *Terra Nova* **5**, 348–58.

Koren', T. N. & Rickards, R. B. 1996. Taxonomy and evolution of Llandovery biserial graptolites from the southern Urals, western Kazakhstan. *Special Papers in Palaeontology* **54**, 1–103.

Loydell, D. K. 1992. Upper Aeronian and lower Telychian graptolites from western mid-Wales. Part 1. *Palaeontographical Society Monograph* **146**(589), 1–55, pl. 1.

Loydell, D. K. 1993*a*. Upper Aeronian and lower Telychian graptolites from western mid-Wales. Part 2. *Palaeontographical Society Monograph* **147**(592), 56–180, pls 2–5.

Loydell, D. K. 1993*b*. Worldwide correlation of Telychian (Upper Llandovery) strata using graptolites. In *High resolution stratigraphy* (eds E. A. Hailwood and R. B. Kidd), pp. 323–40. Geological Society of London, Special Publication no. 70.

Loydell, D. K. 1998. Early Silurian sea-level changes. *Geological Magazine* **135**, 447–71.

Loydell, D. K. & Cave, R. 1993. The Telychian (Upper Llandovery) stratigraphy of Buttington Brick Pit, Wales. *Newsletters on Stratigraphy* **29**, 91–103.

Loydell, D. K. & Cave, R. 1994. Distinguishing between the Wenlock biozonal indices *Cyrtograptus centrifugus* and *Cyrtograptus murchisoni. Paläontologische Zeitschrift* **68**, 437–41.

Loydell, D. K. & Cave, R. 1996. The Llandovery–Wenlock boundary and related stratigraphy in eastern mid-Wales with special reference to the Banwy River section. *Newsletters on Stratigraphy* **34**, 39–64.

Loydell, D. K., Kaljo, D. & Männik, P. 1998. Integrated biostratigraphy of the lower Silurian of the Ohesaare core, Saaremaa, Estonia. *Geological Magazine* **135**, 769–83.

Männik, P. 1998. Evolution and taxonomy of the Silurian conodont *Pterospathodus. Palaeontology* **41**, 1001–50.

Melchin, M. J., Heath, R. J., Jowett, D. M. S., Senior, S. H., Barnes, C. R. & Marshall, J. D. 2000. Correlation of the graptolite and conodont zonations and carbon isotope signal through the late Llandovery and early Wenlock, Cornwallis Island, Arctic Canada. In *Palaeontology Down-Under 2000, Geological Society of Australia Abstracts* (eds P. Cockle, G. A. Wilson, G. A. Brock, M. J. Engelbretsen, A. Simpson and T. Winchester-Seeto), pp. 64–5. Geological Society of Australia, Sydney.

Mullins, G. L. 2000. A chitinozoan morphological lineage and its importance in lower Silurian stratigraphy. *Palaeontology* **43**, 359–73.

Mullins, G. L. & Loydell, D. K. 2001. Integrated Silurian chitinozoan and graptolite biostratigraphy of the Banwy River section, Wales. *Palaeontology* **44**, 731–81.

Mullins, G. L. & Loydell, D. K. 2002. Integrated lower Silurian chitinozoan and graptolite biostratigraphy of Buttington Brick Pit, Wales. *Geological Magazine* **139**, 89–96.

Nestor, V. 1994. Early Silurian chitinozoans of Estonia and north Latvia. *Academia* **4**, 1–163.

Nestor, V. 1998. Chitinozoan biofacies of late early Llandovery (*Coronograptus cyphus*) age in the East Baltic. *Proceedings of the Estonian Academy of Sciences, Geology* **4**, 219–28.

Nestor, V. 1999. Distribution of chitinozoans in the Llandovery of the Oslo region. *Bolletino della Società Paleontologica Italiana* **38**, 227–38.

Paškevičius, J. 1979. *Biostratigraphy and graptolites of the Lithuanian Silurian*. Vilnius: Mokslas Publishers, 230 pp., 33 pls.

Paškevičius, J. 1997. *The geology of the Baltic Republics.* Vilnius: Vilnius University and Geological Survey of Lithuania, 388 pp.

Přibyl, A. 1941. O několika nových druzích graptolitů z českého siluru. *Rozpravy II. Třídy České Akademie* **51**(7), 1–9, pls 1–2.

SALVADOR, A. (ed.) 1994. *International stratigraphic guide.* Second edition. Geological Society of America, Boulder, Colorado, 214 pp.

ŠTORCH, P. 1994. Graptolite biostratigraphy of the lower Silurian (Llandovery and Wenlock) of Bohemia. *Geological Journal* **29**, 137–65.

ŠTORCH, P. 1998. Graptolites of the *Pribylograptus leptotheca* and *Lituigraptus convolutus* biozones of Tmaň (Silurian, Czech Republic). *Journal of the Czech Geological Society* **43**, 209–72.

THE SUBCOMMISSION ON SILURIAN STRATIGRAPHY. 1995. Left hand column for correlation charts. *Silurian Times, a Newsletter of the Silurian Subcommission* **3**, 7–8.

VANDENBROUCKE, T., VERNIERS, J. & CLARKSON, E. N. K. in press. A chitinozoan biostratigraphy of the upper Ordovician and lower Silurian strata of the Girvan area, Midland Valley, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*.

VERNIERS, J. 1999. Calibration of Chitinozoa *versus* graptolite biozonation in the Wenlock of the Builth Wells district (Wales, U.K.), compared with other areas in Avalonia and Baltica. *Bollettino della Società Paleontologica Italiana* **38**, 359–80.

VERNIERS, J., NESTOR, V., PARIS, F., DUFKA, P., SUTHERLAND, S. & VAN GROOTEL, G. 1995. A global Chitinozoa biozonation for the Silurian. *Geological Magazine* **132**, 651–66.

WORSLEY, D., AARHUS, N., BASSETT, M. G., HOWE, M. P. A., MØRK, A. & OLAUSSEN, S. 1983. The Silurian succession of the Oslo region. *Norges Geologiske Undersøkelse* **384**, 1–57.

ZALASIEWICZ, J. A. 1994. Middle to late Telychian (Silurian: Llandovery) graptolite assemblages of central Wales. *Palaeontology* **37**, 375–96.

ZALASIEWICZ, J. 1996. Aeronian (Silurian: Llandovery) graptolites from central Wales. *Geologica et Palaeontologica* **30**, 1–14.

ZALASIEWICZ, J. & WILLIAMS, M. 1999. Graptolite biozonation of the Wenlock Series (Silurian) of the Builth Wells district, central Wales. *Geological Magazine* **136**, 263–83.