

## Lower Silurian biostratigraphy of the Viirelaid core, western Estonia

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**Abstract.** The distribution of five groups of fossils in the upper Llandovery (Telychian) and Wenlock of the Viirelaid core section, Estonia, is presented and discussed in terms of their biozones (conodonts and chitinozoans) and mutual positions (scolecodonts, ostracods, and brachiopods). Graphical correlation of the Viirelaid and Paatsalu sections shows a stronger linear correlation for zonal conodonts than for chitinozoans and scolecodonts. In the given case, this is caused by different nature of zones: chitinozoan zones are based on appearances and/or disappearances of ordinal taxa whereas conodont zonation corresponds, as a rule, to evolutionary succeeding species in the *Pterospathodus* lineage. At the same time, the positions of chitinozoan zones in the Viirelaid, Ruhnu, Aizpute, and Paatsalu cores are oscillating with respect to conodont zones.

**Key words:** conodonts, chitinozoans, ostracods, scolecodonts, brachiopods, biostratigraphy, Silurian, Estonia.

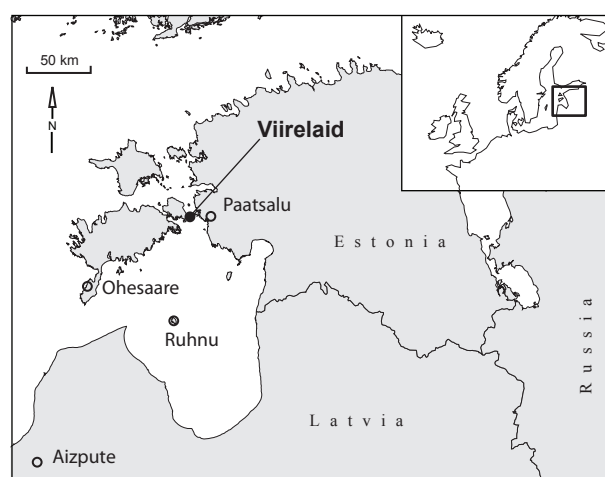
### INTRODUCTION

The early Silurian palaeontology and sedimentology of Estonia were recently summarized by Nestor (1997) and Nestor & Einasto (1997). In these works biozonal schemes of important fossil groups, including conodonts, chitinozoans, and ostracods, are discussed in great detail. Those biozones have been widely used in both regional and interregional correlations (Loydell et al. 1998, 2003; Nestor 2003). Later data, however, obtained mostly by the restudy of well-known sections, have implied changes in the taxonomy and zonality of fossils (Nestor 2005; Rubel et al. 2006; Männik 2007).

The lower–middle Silurian of the Baltic Basin is the most complete and fossiliferous in Estonia. All new data presented here complement the biostratigraphy and sedimentological history of the basin. The Viirelaid borehole was drilled in 1997 in order to study the bedrock properties below the Suur Väin Strait for tunnel connection (Fig. 1). The results of this study were summarized in the report GL-98-55 of the Geological Survey of Estonia (EGK 1998). The lithology and stratigraphy of the Viirelaid section are given here in accordance with H. Perens in this report. The palaeontological record was newly obtained by us for the present study.

This paper, focusing on Llandovery–Wenlock strata of the Viirelaid section, analyses the temporal and spatial relationships of the communities and zones

revealed in that section. To this end, chitinozoans, conodonts, scolecodonts, ostracods, and brachiopods were studied from the same set of samples. Using the detailed biostratigraphic data, we compare the fossil successions and biozones with those of other sections, particularly of the Paatsalu (Hints et al. 2006), Ohesaare (Loydell et al. 1998), Aizpute (Loydell et al. 2003), Ventspils (Loydell & Nestor 2005), and Ruhnu (Nestor 2003) cores.



**Fig. 1.** Sketch map showing the location of the Viirelaid drilling site and four other sections mentioned frequently in the text.

**MATERIAL AND METHODS**

The Viirelaid borehole, located on the Islet of Viirelaid between the Island of Muhu and the Estonian mainland (Fig. 1; geographic coordinates 58°32'40" N and 23°26'40" E), penetrates the nearly horizontal Wenlock and upper Llandovery carbonates to a depth of 85 m below the sea level. In terms of regional stratigraphy, these rocks comprise the Jaagarahu, Jaani (both Wenlock), and Adavere (upper Llandovery) stages represented by the Jaagarahu, Jaani, Velise, and Rumba formations. The Wenlock formations together consist of up to five beds or members that express the shallowing of the shelf area in the basin (see Fig. 2).

The diameter of the extracted core was 112 mm in the upper 31 m and 93 mm below 31 m. The average core recovery was 95%.

The fossils discussed in this paper come from a series of 50 samples, each representing a 5–10 cm interval. The sampling interval was, in general, about 1 m, except for the uppermost 30 m of the Maasi dolomites, which was sampled at longer intervals (Fig. 2). The samples were processed using standard laboratory methods to extract ostracods and brachiopods. Then, about 50 g of the remaining rock material was dissolved in 7% acetic acid to get chitinozoans. Finally, all rock material was dissolved and the residues (including those from where chitinozoans were picked) were examined for conodonts and scolecodonts.

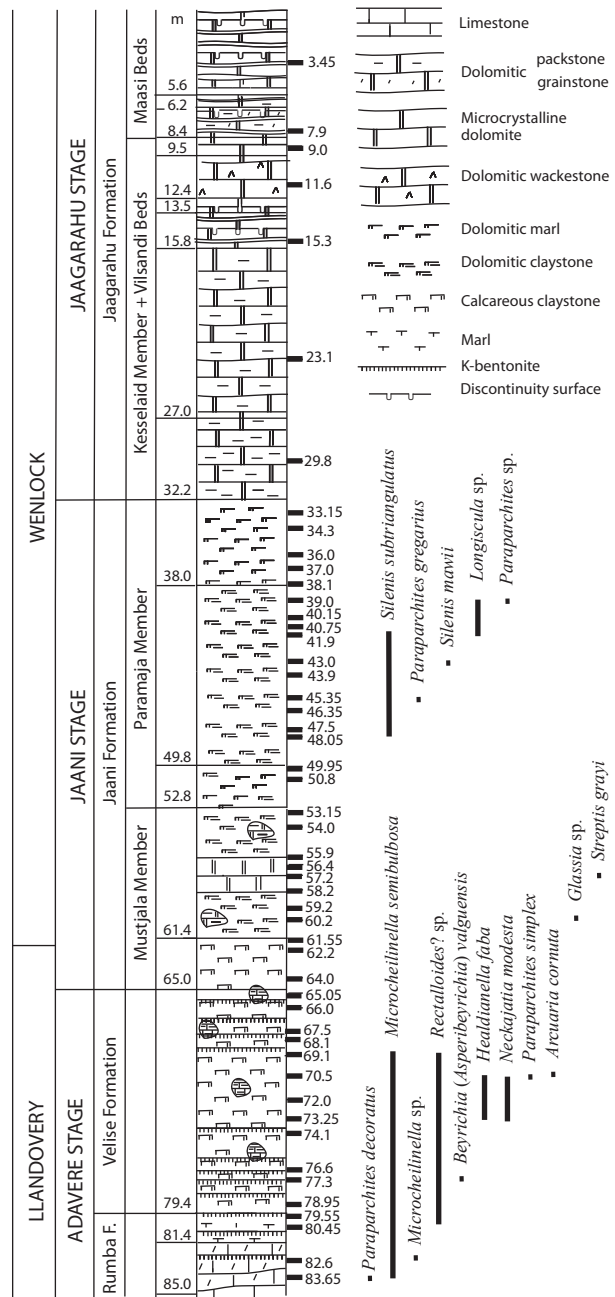
The conodonts were identified by P. Männik, chitinozoans by V. Nestor, scolecodonts by O. Hints, ostracods by L. Sarv, I. Sibul, and T. Meidla, and brachiopods by M. Rubel. The fossil groups were collected from the same samples for direct comparison of the distributional pattern and better assessment of the corresponding biozones.

The collections of ostracods and brachiopods are deposited in the Museum of Geology, University of Tartu, Estonia. The chitinozoans, conodonts, and scolecodonts are stored at the Institute of Geology at Tallinn University of Technology, Estonia.

**BIOSTRATIGRAPHY**

**Brachiopods and ostracods**

The distribution of these groups in the Silurian in the Baltic area is well known. Ostracod biozonation was proposed by Meidla & Sarv (1990) and later advanced by Sarv (Nestor 1997, p. 91). The Baltic brachiopod communities have been described in several papers (Kaljo & Rubel 1982; Männil & Rubel 1999; Musteikis & Paškevičius 1999; Musteikis & Juškute 1999). Palaeontological timescales have been elaborated for both



**Fig. 2.** Stratigraphy, general lithology, sample depths, and distribution of ostracods and brachiopods in the Viirelaid section. F., Formation.

groups using the quantitative stratigraphic correlation software (ostracods: Rubel & Sarv 1996; brachiopods: Musteikis 1989).

Ostracods are relatively rare in the Viirelaid core and occur only in two intervals (Fig. 2). Five species have been recognized in the Paramaja Member and nine in the Rumba and Velise formations. The older ostracod assemblage contains species indicative of the Adavere

Stage: *Paraparchites decoratus* (Jones) and *Beyrichia* (*Asperibeyrichia*) *valguensis* (Sarv). The occurrence of *Neckajatia modesta* (Neckaja) and *Paraparchites simplex* (Jones) supports this dating. The younger assemblage contains *Silenis subtriangulatus* Neckaja and *Paraparchites gregarius* (Sarv), which are characteristic of the Jaani Stage. These datings are based on the biozonation proposed by Sarv (see Nestor 1997, p. 91) and also concur with the composite standard of ostracods (Rubel & Sarv 1996). That two groups of ostracods are recorded in two distinct intervals is most likely due to preservational phenomena. Such a discontinuous distribution of ostracods limits characterization of the section to general terms.

The brachiopod record is considerably poor. Only one of the two brachiopods found in the Mustjala Member, *Streptis grayii* (Davidson), dates these strata as of Jaani Age (Rubel & Rõõmusoks 1970; Musteikis 1989). In terms of communities, both brachiopods (*Streptis grayii* and *Glassia* sp.) indicate offshore conditions, evidently a dysoxic environment perhaps also unsuitable for ostracods, but probably still in the limits of BA 4–5 (Musteikis & Juškute 1999).

### Chitinozoans

The distribution of chitinozoans in the uppermost Llandovery and Wenlock of western Estonia and Latvia has been discussed in a number of earlier publications (Nestor 1994, 2005; Rubel et al. 2006 and references therein). The chitinozoan record is nearly continuous throughout the Viirelaid section. Only the primary dolomites of the Jaagarahu Formation, the upper 30 m of the core, are very poor in chitinozoans (Fig. 3). The topmost sample of the Rumba Formation and the two lowermost samples of the Velise Formation also lack chitinozoans.

The most abundant chitinozoan species are *Conochitina proboscifera* Eisenack in the upper part of the Velise Formation and in the lower part of the Mustjala Member, and *C. claviformis* Eisenack in the uppermost part of the Mustjala Member and in the Paramaja Member. A similar succession of dominant species is also observed in other sections (Nestor 1994).

The chitinozoan biozones recognized in the Viirelaid core concur with data from other sections studied in the northern East Baltic (Nestor 2005). This makes the zonal succession of chitinozoan species in the Viirelaid core one of the most complete successions in the Baltic Llandovery, although the *C. acuminata*, *Margachitina banwyensis*, and *M. margaritana* biozones are nevertheless notably thin, probably due to a gap or a very low primary sedimentation rate, which similarly affects the conodont record in the same interval (see discussion on conodonts below).

The parity of the chitinozoan succession in the Viirelaid section can be expressed through comparison of this particular succession with the chitinozoan composite standard for the eastern Baltic area (Fig. 4). The chitinozoan standard by Rubel et al. (2006) showed only minor changes after the inclusion of the latest chitinozoan data from the Viirelaid section. These changes consist of a decrease in one datum plane in the composite itself and the addition of some new datum limits in the corresponding dating graph (Fig. 4). The datings of the Viirelaid section indicate no significant changes in the accumulation rates, but suggest a very low sedimentation rate in the Rumba Formation.

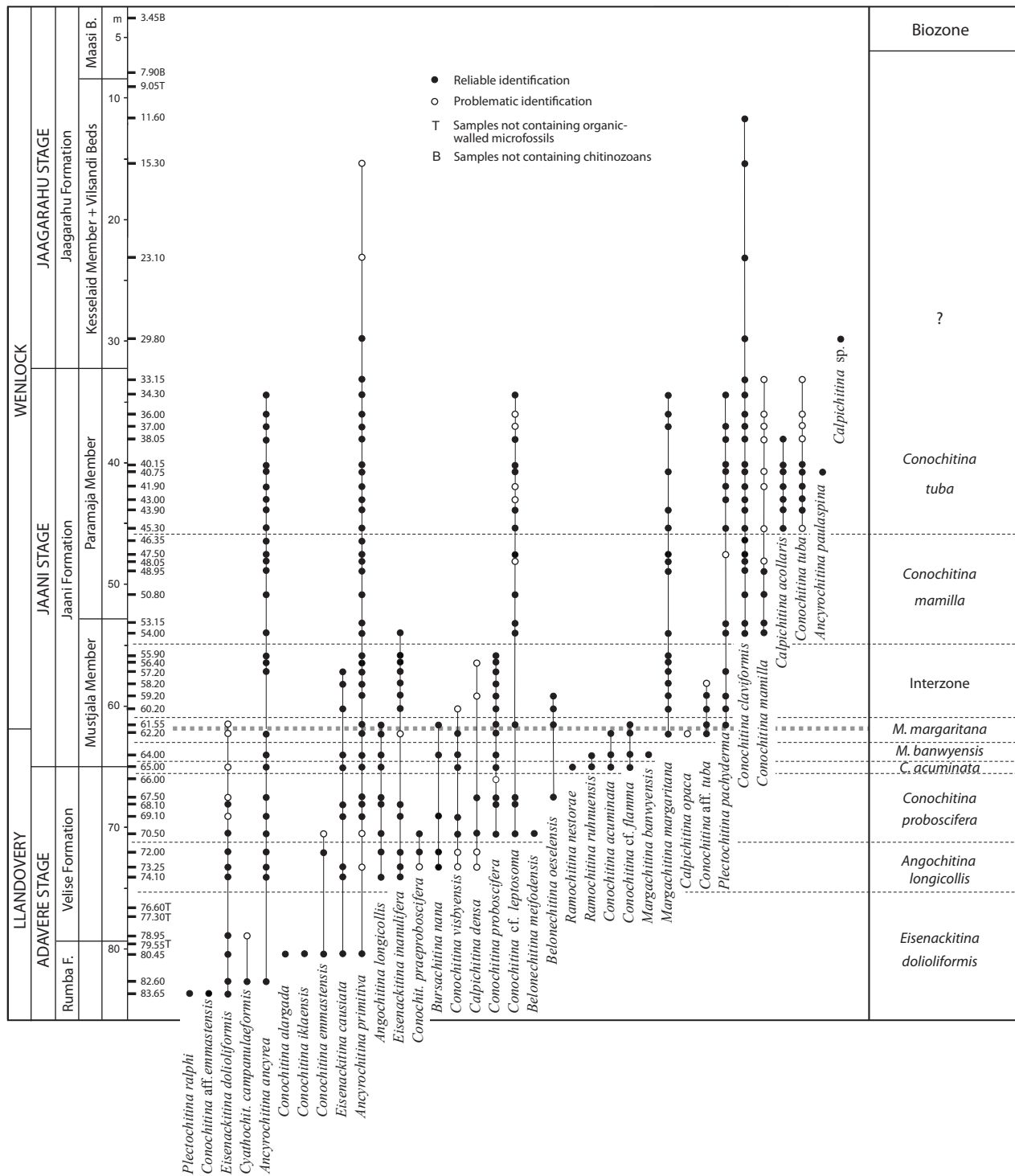
### Conodonts

The conodont record from the Viirelaid section is good and allows very detailed stratigraphy (see Fig. 5).

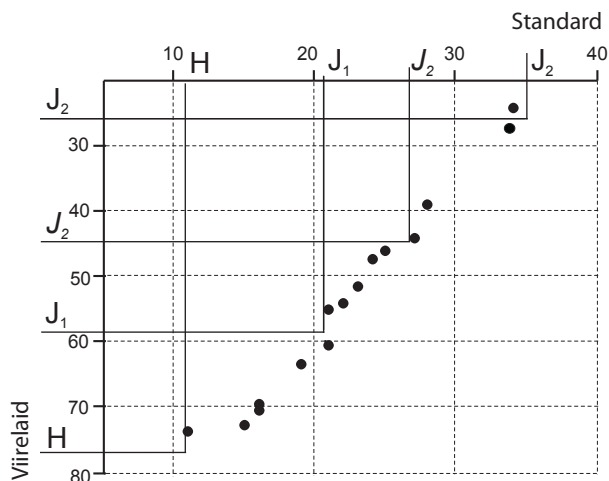
The nodular argillaceous limestones below 81.4 m are evidently older than the *Pterospirifer eopennatus* ssp. n. 1 Biozone and most probably represent the *Distomodus staurognathoides* Biozone. Both samples from these strata (Fig. 5) yielded only a few conodont specimens.

At 81.4 m the nodular limestones are replaced by calcareous marlstones. The lowermost sample above this contact, at 80.45 m, contains *Aulacognathus kuehni* Mostler, *Ozarkodina polinclinata estonica* Männik, and some rare fragments of *P. eopennatus* Männik, all taxa characteristic of the *P. eopennatus* Superzone (Männik 2007). The lack of *Astropentagnathus irregularis* Mostler in this association indicates that this sample originates from the upper part of the superzone and probably corresponds to the *P. eopennatus* ssp. n. 2 Biozone. Well-preserved specimens of *P. eopennatus* ssp. n. 2 appear in the next sample (at 79.55 m). The characteristic fauna of the underlying *P. eopennatus* ssp. n. 1 Biozone has not been identified. This biozone may either correspond to a gap in the section or lie between 82.60 and 80.45 m.

Based on the conodont data, the sequence between 80.45 and 62.20 m seems to be continuous. All conodont biozones (from the *P. eopennatus* ssp. n. 2 Biozone below to the *P. amorphognathoides amorphognathoides* Biozone above), known from the Telychian in the Baltic area (Männik 2007), are present (Fig. 5). The lower boundary of the *P. a. amorphognathoides* Biozone (drawn according to the appearance of the nominal taxon) lies between 67.50 and 66.00 m (Fig. 5). The occurrence of *Aspelundia fluegeli* ssp. n. in the sample at 65.00–65.05 m indicates that the boundary between the Lower and Upper subzones of the *P. a. amorphognathoides* Biozone lies above this level (between 65.00–65.05 and 64.00 m).



**Fig. 3.** Stratigraphy, sample depths, distribution, and biozones of chitinozoans in the Viirelaid section. The dotted line within the *M. margaritana* Zone marks a possible gap or a very condensed interval. F., Formation; B., Beds.



**Fig. 4.** Datum points (base for the line of correlation) according to the upgraded chitinozoan composite standard in the Viirelaid section (see text for further explanation). H, Adavere; J<sub>1</sub>, Jaani; J<sub>2</sub>, Jaagarahu. Compatible positions of the lower boundaries of the stages by H. Perens in the Viirelaid section and in the standard excluding J<sub>2</sub>, which corresponds to the position of the base of the Jaagarahu Stage according to the composite standard.

The upper boundary of the *P. a. amorphognathoides* Biozone, as defined by Jeppsson (1997), cannot be positively identified in the Viirelaid core. The boundary between the Lower and Upper *Pseudooneotodus bicornis* biozones (Datum 2 of the Ireviken Event) lies in the 62.20–61.55 m depth interval. As the upper sample contains fauna characteristic of the Lower *Kockelella ranuliformis* Biozone, it is evident that the strata between these samples are either strongly condensed or there is a gap in the section corresponding to the interval from the *P. a. amorphognathoides* Biozone below to the Lower *Kockelella ranuliformis* Biozone above (i.e. four conodont biozones may be missing in this section).

The occurrence of *D. staurogathoides* (Walliser) in the sample at 61.55 m indicates that this level is still within the Lower *K. ranuliformis* Biozone. As *D. staurogathoides* has not been found higher in the section, the boundary between the Lower and Upper *K. ranuliformis* biozones evidently lies just above this sample.

The strata above the level of disappearance of *D. staurogathoides* are dominated by *Panderodus* ex gr. *equicostatus* (Rhodes). Other taxa are relatively rare. The finds of *Ozarkodina sagitta rhenana* (Walliser) at 54.00 m indicate that this level, together with the overlying strata, correspond to the *O. s. rhenana* Superzone sensu Jeppsson (1997). The presence of *O. confluens*

*bucerus* (Viira) in the sample at 7.90 m is indicative of the upper part of the Jaagarahu Stage (Viira 1983).

### Scolecodonts

Scolecodonts in the Silurian strata of Estonia were noted already by Eichwald (1854), but until recently (Hints et al. 2006) only little was known about the distribution and taxonomic composition of jawed polychaetes. Silurian scolecodonts have, however, been studied intensively on Gotland, Sweden (Eriksson et al. 2004 and references therein) and in erratic boulders in Poland (Kielan-Jaworowska 1966).

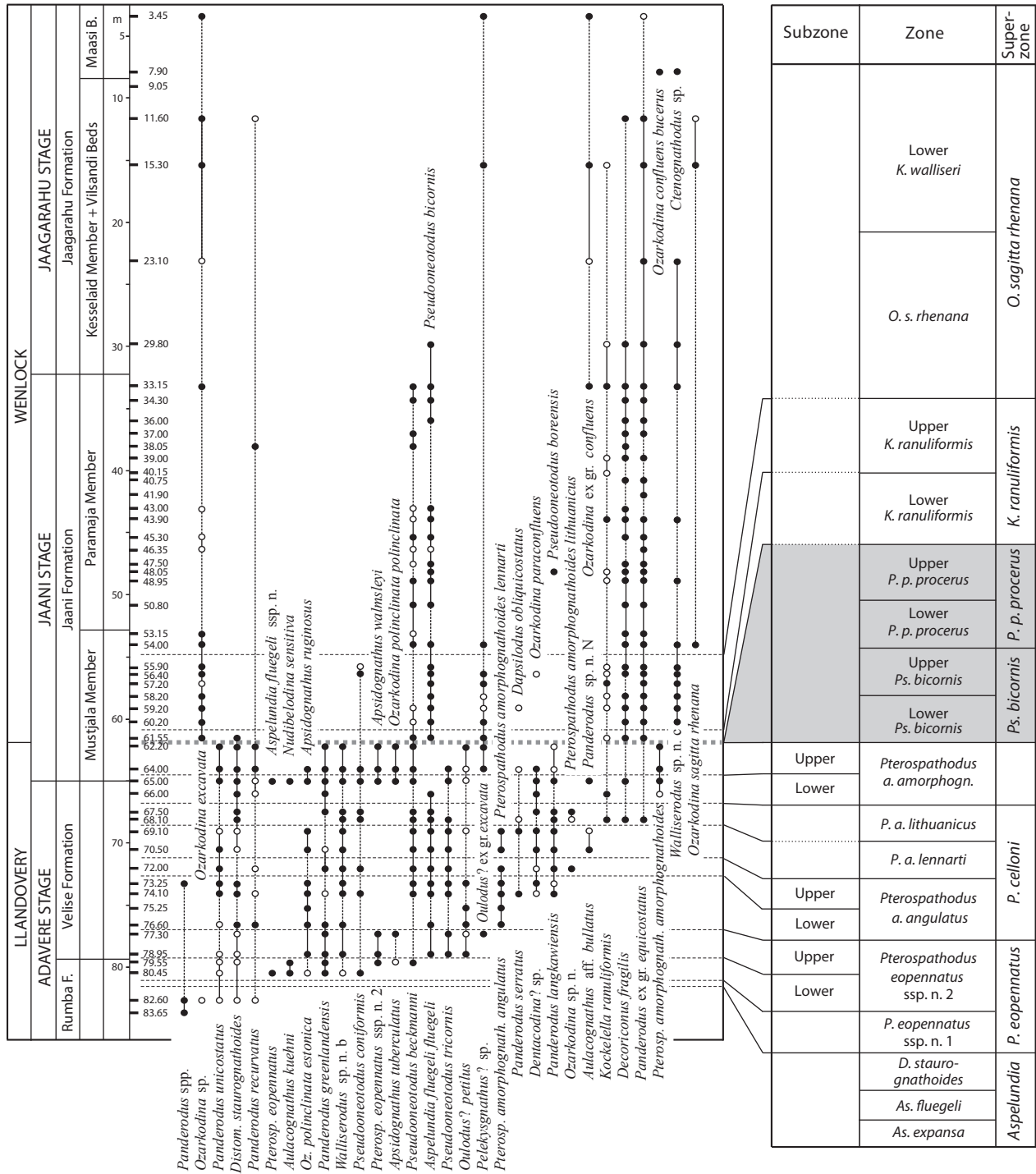
Scolecodonts were found in most of the 50 samples of the Viirelaid section, studied for chitinozoans and conodonts (Fig. 6). Nearly 40 apparatus-based species were identified. The most common scolecodont species were polychaetaspids, paulinitids, and mochttyellids.

The lowermost part of the sampled succession corresponding to the Rumba Formation is distinct in the abundance of *Pistoprion serrula* (Hinde) sensu Bergman (1979). This species is found in different parts of the world, including Gotland (Bergman 1979), Severnaya Zemlya (Männil & Zaslavskaya 1985), and Canadian Arctic (Hints et al. 2000). The occurrence of *Tetraprion* sp. A sensu Hints et al. (2006), recovered from the sample at 82.6 m, is typical of the Rumba Formation. A particular feature of this part of the succession is also the lack of paulinitids that become very common in the overlying strata.

The 79.75–62.20 m interval is characterized by a relatively low yield and diversity of scolecodonts, the fauna consisting of long-ranging species of *Oeononites* and *Kettnerites*, but also *Skalenoprion bugensis* Szaniawski and *Oeononites* aff. *varsoviensis* Kielan-Jaworowska. Notable is also the occurrence of *Pistoprion* at 62.2 m. The same form was recorded very close to the Llandovery–Wenlock boundary in the Viki core (Olle Hints, unpublished data) and could perhaps be taken as an indicator of the shallowing of the palaeobasin.

The Ireviken Event interval, including the Llandovery–Wenlock boundary, is between 62.20 and 61.55 m (see discussion on chitinozoans and conodonts above). This level is distinct in jawed polychaete succession. As in the Paatsalu section, it is marked by the appearance of “*Mochtyella*” sp. b sensu Szaniawski (1970), *Oeononites* sp. A sensu Hints et al. (2006), *Mochtyella* sp. A sensu Hints et al. (2006), and *Kettnerites sisyphi* Bergman.

Higher in the Jaani Formation “*Mochtyella*” cf. *trapezoidea* Kielan-Jaworowska becomes abundant. Some problematic specimens of *Lanceolatites gracilis* Bergman



**Fig. 5.** Stratigraphy, sample depths, and distribution of conodont biozones in the Viirelaid section. Dashed parts of the ranges indicate scattered presence of a taxon. Black circle – undoubted identification, white circle – problematic identification (cf. or with “?”). The grey interval is a very condensed or missing interval. Abbreviations: B., Beds; F., Formation; Superz., Superzone; *As.*, *Aspelundia*; *D.*, *Distomodus*; *P.*, *Pterosp. a.*, *Pterosp. a. lithuanicus*; *amorphogn.*, *amorphognathoides*; *Ps.*, *Pseudooneotodus*; *P. p.*, *Pterosp. p. pennatus*; *K.*, *Kockelella*; *O. s.*, *Ozarkodina sagitta*.

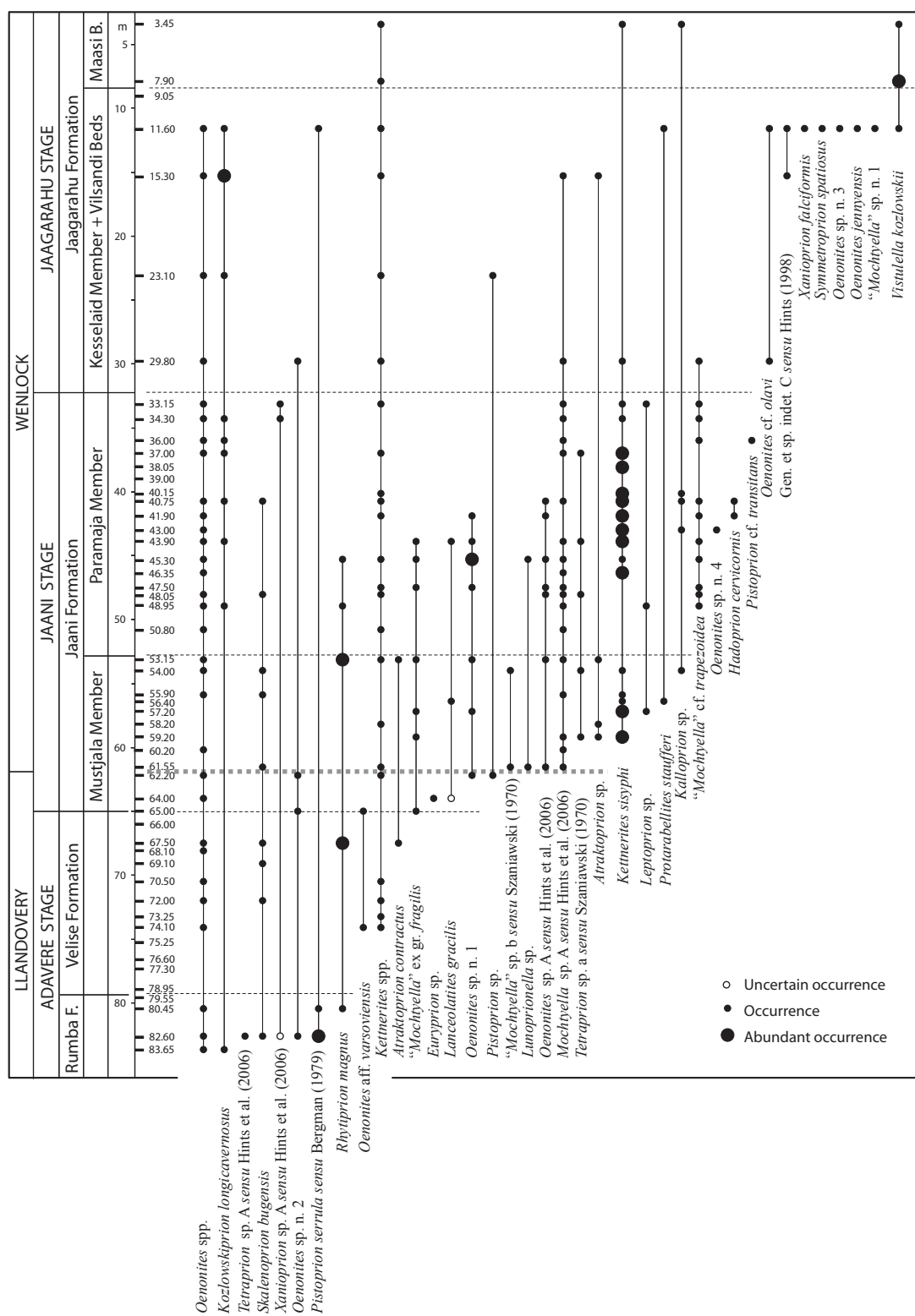


Fig. 6. Stratigraphy, sample depths, and distribution of scolecodonts in the Viirelaid section. F., Formation; Mb., Member; B., Beds.

are found in the upper part of the Velise Formation, although the first definite identification of this species comes from the 56.4 m sample. In the Paatsalu core, *L. gracilis* also occurs in the lower part of the Jaani Formation. *Kettnerites sisyphi* is especially abundant in the 46.35–37.0 m interval. On Gotland the continuous distribution of *K. sisyphi* begins in the Upper Visby Formation (Bergman 1989), thus conforming well with our data from the Viirelaid core.

Dolomites of the Jaagarahu Formation contain a microfossil assemblage strongly dominated by the benthic element, scolecodonts and melanoscleritoids in particular. *Symmetrion prion spatiosus* (Hinde), *Oeonites jennyensis* Eriksson, and *Protarabellites cf. staufferi* Eriksson have been found at 11.6 m. The scolecodont assemblage in the sample at 7.9 m is strongly dominated by *Vistulella kozlowskii* Kielan-Jaworowska.

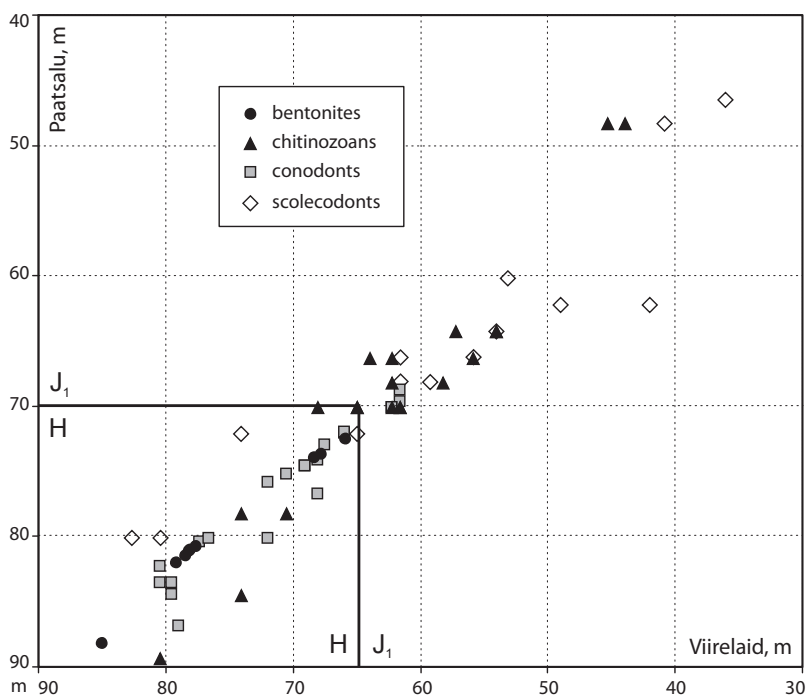
## DISCUSSION

Brachiopods and ostracods of the Viirelaid section have a lower biostratigraphic potential than other groups, first of all, due to destructive preservational conditions. Although the material is sparse, the distinction of major stratigraphic units (stages) was still possible and the overall distribution of these groups matches the generally accepted biostratigraphic framework.

Chitinozoans, conodonts, and, to some extent, scolecodonts show high diversity in the Viirelaid section. Recent data from the Llandovery–Wenlock boundary

interval of the nearby Paatsalu core section (Hints et al. 2006) allow estimation of the temporal component (zonality) in the distribution of chitinozoans, conodonts, and scolecodonts in the Viirelaid section. For this purpose we plotted the first occurrences (FO) and the last occurrences (LO) of the taxa common in both sections on an XY-graph (Fig. 7). For scolecodonts the acmes (levels of the highest relative frequency) were sometimes included. Additionally, eight bentonite layers distinguishable by distinct composition of pyroclastic sanidine (Kiipli et al. 2001; Kallaste & Kiipli 2006) were included in this graph. All used data according to which the dating points can be easily identified on the graph are summarized in Table 1.

As expected, the bentonites present in both sections show a strong linear correlation, which for much of the interval could serve as a proxy for the line of correlation (LOC). The distribution of fossils agrees rather well with the bentonite-based LOC. Among others, conodonts show the best alignment around this LOC. Chitinozoan points are slightly more scattered than those of conodonts and discrepancies from the LOC are observed for several taxa, including some zonal species. Thus, the FOs of *Margachitina margaritana*, *M. banwyensis*, and *Conochitina acuminata* are stratigraphically so high in the Paatsalu core that the *M. margaritana* and *M. banwyensis* zones can be considered absent in the Viirelaid core, and the *C. acuminata* Zone is also thinner in this section. On the other hand, *C. proboscifera* and *Eisenackitina inanulifera* appear higher in Paatsalu than suggested by their LOs in the Viirelaid core and



**Fig. 7.** Graphical correlation of the Viirelaid and Paatsalu sections showing the first and/or last occurrences of selected chitinozoans, conodonts, and scolecodonts. Data from the Paatsalu core after Hints et al. (2006) and from authors' unpublished data. Bentonites and their correlation is shown according to Kiipli et al. (2001) and Kallaste & Kiipli (2006). H and J<sub>1</sub>, Adavere and Jaani stages; the boundary positions between these stages are drawn according to H. Perens (EGK 1998) and Hints et al. (2006).



**Table 1.** Common events in the Viirelaid and Paatsalu core sections. Bentonite ID numbers, names, and depths according to Kallaste & Kiipli (2006) and Kiipli et al. (2001). AC, acme; FO, appearance; LO, disappearance

Event	Viirelaid, m	Paatsalu, m	Event	Viirelaid, m	Paatsalu, m
<b>Conodonts</b>			<i>Conochitina acuminata</i> LO		
<i>Ozarkodina excavata</i> FO	61.55	69.70	<i>Conochitina</i> aff. <i>tuba</i> FO	62.20	68.23
<i>Distomodus staurogathoides</i> LO	61.55	68.80	<i>Margachitina margaritana</i> FO	62.20	66.32
<i>Ozarkodina polinclinata polinclinata</i> LO	62.20	70.14	<i>Margachitina banwyensis</i> FO	64.00	66.32
<i>Pterospathodus amorphognathoides amorphognathoides</i> LO	62.20	70.08	<i>Conochitina acuminata</i> FO	65.00	70.14
<i>Ozarkodina polinclinata polinclinata</i> FO	65.00	72.10	<i>Ramochitina nestorae</i> FO	65.00	70.14
<i>Pterospathodus amorphognathoides amorphognathoides</i> FO	66.00	72.10	<i>Eisenackitina dolioliformis</i> LO	68.10	70.14
<i>Aspelundia fluegeli</i> LO	66.00	72.00	<i>Conochitina proboscifera</i> FO	70.50	78.30
<i>Pterospathodus amorphognathoides lithuanicus</i> FO	68.10	74.10	<i>Angochitina longicollis</i> FO	74.10	78.30
<i>Kockelella ranuliformis</i> FO	68.10	76.70	<i>Eisenackitina inanulifera</i> FO	74.10	84.50
<i>Ozarkodina polinclinata estonica</i> LO	69.10	74.55	<i>Conochitina iklaensis</i> LO	80.45	93.48
<i>Pterospathodus amorphognathoides lennarti</i> LO	69.10	74.55	<i>Conochitina alargada</i> LO	80.45	89.42
<i>Pterospathodus amorphognathoides lennarti</i> FO	70.50	75.25	<b>Scolecodonts</b>		
<i>Pterospathodus amorphognathoides angulatus</i> LO	72.00	75.85	<i>Pistoprion</i> cf. <i>transitans</i> FO	36.00	46.52
<i>Pterospathodus amorphognathoides angulatus</i> FO	76.60	80.10	<i>Hadoprion cervicornis</i> LO	40.75	48.32
<i>Pterospathodus eopennatus</i> ssp. n. 2 LO	77.30	80.40	<i>Hadoprion cervicornis</i> FO	41.90	62.32
<i>Aspelundia fluegeli</i> FO	78.95	86.90	“ <i>Mochtyella</i> ” cf. <i>trapezoidea</i> AC, FO	48.95	62.32
<i>Pterospathodus eopennatus</i> ssp. n. 2 FO	79.55	84.41	<i>Rhytiprion magnus</i> AC	53.15	60.28
<i>Aulacognathus kuehni</i> LO	79.55	82.25	<i>Mochtyella</i> sp. B LO	54.00	64.31
<i>Ozarkodina polinclinata estonica</i> FO	80.45	83.55	<i>Lanceolatites gracilis</i> FO, LO	55.90	66.32
<i>Aulacognathus kuehni</i> FO	80.45	83.55	<i>Kettnerites sisyphi</i> AC, FO	59.20	68.23
<b>Chitinozoans</b>			<i>Mochtyella</i> sp. B FO	61.55	68.23
<i>Conochitina tuba</i> LO	43.90	48.32	<i>Mochtyella</i> sp. A AC, FO	61.55	68.23
<i>Conochitina tuba</i> FO	45.30	48.32	<i>Oeononites</i> sp. A FO	61.55	66.32
<i>Conochitina mamilla</i> FO	54.00	64.31	<i>Oeononites</i> aff. <i>varsoviensis</i> LO	65.00	72.15
<i>Eisenackitina inanulifera</i> LO	54.00	64.31	<i>Oeononites</i> aff. <i>varsoviensis</i> FO	74.10	72.15
<i>Conochitina proboscifera</i> LO	55.90	66.32	<i>Pistoprion serrula</i> LO	80.45	80.18
<i>Eisenackitina causiata</i> LO	57.20	64.31	<i>Tetraprion</i> sp. A LO	82.60	80.18
<i>Conochitina</i> aff. <i>tuba</i> LO	58.20	68.23	<b>K-bentonites</b>		
<i>Angochitina longicollis</i> LO	61.55	70.14	475 (Viki)	65.90	72.50
<i>Eisenackitina</i> cf. <i>dolioliformis</i> LO	61.55	70.14	518 (Viirelaid)	67.75	73.70
			520 (Lõetsa)	68.30	74.00
			719 (Virtsu)	77.60	80.80
			731 (Nurme)	78.11	81.05
			744 (Tehumardi)	78.20	81.09
			755 (Paatsalu)	78.48	81.50
			772 (Pahapilli)	79.13	82.00
			851 (Osmundsberg)	85.00	88.20

thus their ranges are clearly incomplete in this section in contrast to the Paatsalu core. The FOs of *Angochitina longicollis* and *C. mamilla*, and LOs of *C. acuminata*, *C. proboscifera*, and *C. aff. tuba*, nevertheless, conform very well to the bentonite- and conodont-based LOC.

Scolecodonts display a more variable pattern than conodonts or chitinozoans. A number of species still show a good match between the two sections, especially *Mochtyella* sp. B *sensu* Hints et al. (2006), *Lanceolatites gracilis*, and *Pistoprion* cf. *transitans*, and acmes of “*Mochtyella*” cf. *trapezoidea* and *Kettnerites sisyphi*.

That suggests a good stratigraphical potential of scolecodonts as well, although formal biozones have not yet been distinguished.

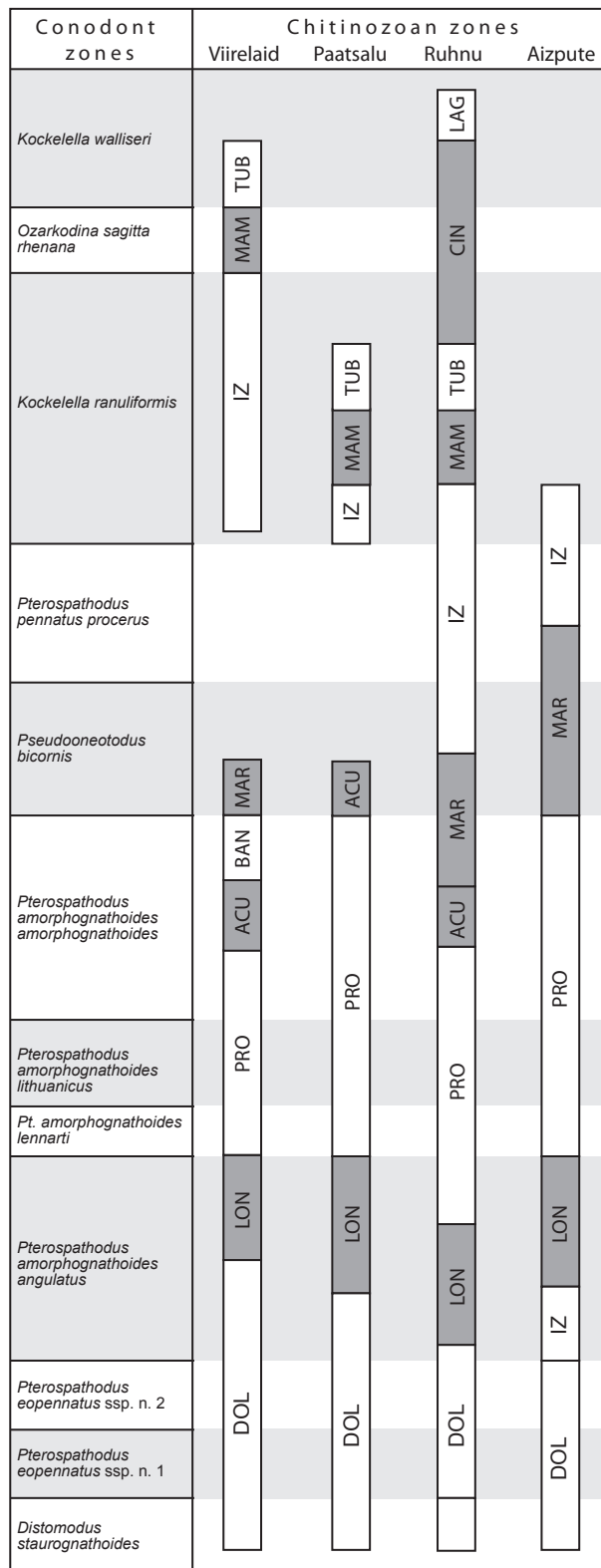
Published data from several other East Baltic sections (Paatsalu – Hints et al. 2006, Ohesaare – Loydell et al. 1998, Aizpute-41 – Loydell et al. 2003, Ventpils – Loydell & Nestor 2005, and Ruhnu – Nestor 2003) allow estimation of the mutual positions of conodont and chitinozoan zones as well as their relationships to graptolite zones in some sections. Such an integrated approach traditionally serves as a base for correlation

between the Baltic Regional Silurian Standard, established in a shallow shelf succession with poor graptolite record and the International Silurian Standard, which is based mainly on the distribution of graptolites. Comparison of chitinozoan and conodont zonations in several sections revealed that in different sections the same chitinozoan zones are not in the same positions with regard to conodont zones (Fig. 8). The deviations in relative positions of these zones emphasize the differences in positions of local ranges of the corresponding taxa in different sections. Such differences are due to random or environmentally controlled fluctuations in the local ranges of particular taxa. These fluctuations are likely also very much dependent on temporal changes in the population density, and on variations in the deposition rates (see, e.g., Jaanusson 1976). In our case certain discrepancies may be explained (1) by inadequately small samples (50 g or less) for extraction of chitinozoans in the Viirelaid and Paatsalu cores or (2) by different interpretation of sampling depths by different persons in incomplete core intervals in the Ruhnu core. One reason for these discrepancies may lie in differences in the identification of zones: lower boundaries of chitinozoan zones are based on the first appearances of single taxa, whereas boundaries in conodont zonation correspond, as a rule, to levels at which one taxon was replaced by a next one in a continuous evolutionary lineage.

Various algorithms can be used to estimate the mutual positions (temporal succession) of the taxa after their reconstructed (summarized) total ranges (Agterberg 1990; Guex 1990; Sadler et al. 2003). Palaeontological timescales, the composite or optimal standards, are designed to eliminate irregularities caused by fluctuations in local ranges. Such composite standards have been developed for several groups in the Silurian of the East Baltic: for ostracods (Rubel & Sarv 1996), brachiopods (Musteikis 1989), and chitinozoans (Rubel et al. 2006). All these standards operate as dating tools, but only for a limited number of included sections. Therefore, only the chitinozoan composite is directly applicable to the Viirelaid section.

**Fig. 8.** Chitinozoan biozonations in the Viirelaid, Paatsalu, Ruhnu, and Aizpute core sections plotted against the conodont biozonation. The vertical axis is relative and does not correspond to the real thicknesses in any section or to the time intervals. Abbreviations: DOL, *Eisenackitina dolioliformis* Biozone; LON, *Angochitina longicollis* Biozone; IZ, Interzone; BRO, *Conochitina proboscifera* Biozone; ACU, *Conochitina acuminata* Biozone; BAN, *Margachitina banwyensis* Biozone; MAR, *Margachitina margaritana* Biozone; MAM, *Conochitina mamilla* Biozone; TUB, *Conochitina tuba* Biozone; LAG, *Eisenackitina lagena* Biozone; CIN, *Cingulochitina cingulata* Biozone.

All chitinozoan zones established in the Viirelaid core occur in a standard succession of the North East Baltic Silurian, at least according to the order of their index taxa appearances. However, in comparison with



the conodont zones, the relative positions of several chitinozoan zones, e.g. *Conochitina proboscifera* and *Margachitina margaritana*, fluctuate. First of all this concerns the diachronous appearances of *M. margaritana* (see also discussion in Loydell & Nestor 2005).

## CONCLUSIONS

The palaeontological record from the Viirelaid section agrees with the generally accepted biostratigraphic framework of the Silurian and shows that the section is rather complete. However, the distribution of both chitinozoans and conodonts suggests a possible gap or condensed interval in the upper part of the Rumba Formation as well as in the uppermost Velise Formation. Detailed comparative analysis of the mutual positions of biozones in a number of sections shows that conodonts (their zonal species) have better alignment to a nearly linear correlation than chitinozoans and scolecodonts, and indicates a number of discrepancies in the ranges of the last two groups, apparently caused by the fluctuations in local ranges of taxa.

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## Alam-Siluri biostratigraafia Viirelaiu puuraugus Lääne-Eestis

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Viirelaiu läbilõike jaoks vahemikus Adaverest kuni Jaagarahu lademeni on esitatud ostrakoodide, brahhiopoodide, kitiinikute, konodontide ja skolekodontide levikupilt prooviti ning kitiinikute ja konodontide biotsoonid. Viirelaiu kitiinikute, konodontide ja skolekodontide levikut koos samas vahemikus sagedaste, kuid identifitseeritavate K-bentoniidi kihtidega on võrreldud Paatsalu sama graafilise korrelatsiooni abil, mis näitab ühiste konodontide ilmumise ning kadumise suhteliselt head ühtimist K-bentoniitide peaaegu lineaarse korrelatsioonijoonega, mõnevõrra hajutatumat pilti kitiinikute samade sündmuste osas ja ainult üksikute skolekodontide järgi ajalist järjestatust võrreldavasis läbilõigetel. Võrdlus näitab, et mis tahes liikide paiksed levikuintervallid (*local range*) on mittetäielikud ja erinevais läbilõigetel ajaliselt mittekattuvad. Viimast näitab samuti Viirelaiu, Paatsalu, Ruhnu ja Aizpute läbilõigetel kitiinikute tsoonide asendi võrdlus samas kindlaks tehtud konodontide tsoonide suhtes.