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Searching for the Ordovician–Silurian boundary in Estonia, Latvia and Lithuania

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ABSTRACT

The present study focuses on determining the position of the lower boundary of the Silurian System in the eastern Baltic region. To achieve this, we conducted a comprehensive analysis of stable isotopic curves, combined with previously published data on the graptolite record. Our isotopic correlations are primarily based on the $\delta^{13}C_{org}$ curve of the Dob's Linn section, the GSSP of the Silurian System, and the $\delta^{13}C_{carb}$ curve of the Monitor Range section in Nevada. Our results provide robust evidence for correlating the basal Varbola Formation, the lower part of the Õhne Formation and the Stačiūnai Formation, and suggest their latest Ordovician age. The integration of stable isotopic data and graptolite records allows for a more accurate characterisation of the Ordovician–Silurian boundary in this region.

Introduction

Until the 2000s, the lower boundary of the Silurian System in the Baltic region was correlated with a major gap and turnover in shelly faunas. A major hiatus is observable in nearly all outcrop and subsurface sections of the eastern Baltic area. The formation of the hiatus was ascribed to the glacioeustatic sea-level fall already in the 1970–80s (e.g., Jaanusson 1979; Kaljo et al. 1988). The most remarkable change in fossil assemblages in the Ordovician–Silurian transition interval is confined to this particular level (see Nestor et al. 1991 for a summary). The post-extinction interval is characterised by the gradual appearance of new species in all fossil groups. The first new taxa were usually regarded as the 'Silurian fauna' in most papers. Even in the offshore sections, the hiatus marks a complete turnover, and the overlying strata are characterised by an impoverished fossil assemblage that was formerly regarded as of Silurian age, such as in the Jurmala core section in western Latvia (see Meidla et al. 2020). The occurrence of a hiatus in the deep-shelf Jurmala section proves that the drop in sea level was prominent, compared to other less remarkable sea-level fluctuations recorded in the Ordovician succession of the region (Kiipli and Kiipli 2020).

During the last decade, research advances, particularly new data from stable isotopic geochemistry, have questioned the traditional concept of the lower boundary of the Silurian System, and this is also causing problems for Ordovician stratigraphy.

The general understanding that the latest Hirnantian, after the second Hirnantian extinction wave, is characterised by a survival fauna has long been reflected in research papers (e.g., Brenchley et al. 1994; Marshall et al. 1997; Hammarlund et al. 2012, etc.). However, it did not affect the correlations in the Ordovician–Silurian boundary interval in Estonia, Latvia and Lithuania. The position of the system boundary in the regional succession was first challenged on the basis of the stable carbon isotopic record, after the discovery of a long falling limb of the Hirnantian Carbon Isotopic Excursion (HICE), reaching the strata traditionally attributed to the Silurian in several sections (Meidla et al. 2011; Bauert et al. 2014; Ainsaar et al. 2015). A later study (Meidla et al. 2020) on the comparison of the regional succession with the North American Monitor Range section suggests that in the middle-lower ramp sections the system boundary occurs more than 10 m higher than previously believed. However, because of the lack of diagnostic graptolites and conodonts, a proper biostratigraphic marker for this boundary could not be identified in the particular succession (Meidla et al. 2016). This view added new aspects to earlier interpretations of the stable carbon isotopic profiles of the region (e.g., Brenchley et al. 2003, fig. 13), but did not propose a new marker for the boundary.

This paper aims to discuss the possibilities of locating this important stratigraphic boundary in the regional succession, supplementary boundary criteria and correlation of the rock units in the Ordovician–Silurian boundary interval in Estonia, Latvia and northernmost Lithuania.

Materials and methods

This paper summarises the most recent palaeontological and stable isotopic evidence from the Ordovician–Silurian transition interval of the study area, published and in press. The new paired carbonate and organic matter carbon isotopic curve of the Reinu section is complemented with data from the Tartu (Bauert et al. 2014), Jurmala (Meidla et al. 2011) and Likėnai (Hints et al. in press) core sections. The biostratigraphically dated global key sections referred to in this paper are the Dob's Linn (GSSP of the Silurian System; Jones et al. 2011) and the Monitor Range sections (after Finney et al. 1999 and LaPorte et al. 2009).

Results and discussion

Recent $\delta^{13}C$ studies in the Ordovician–Silurian transition interval have revealed a number of sections where, in biostratigraphic sense, the 'basal Silurian strata' correspond to the falling limb of the HICE. This is true for the lower part of the Stačiūnai Formation in the Jurmala core (Meidla et al. 2011), the lower part of the Õhne Formation in the Tartu core section (Bauert et al. 2014) and the lowermost part of the Varbola Formation in Estonia – the Koigi Member and some overlying strata in the Karinu, Viki and Kamariku core sections (Hints et al. 2014; Ainsaar et al. 2015). The same applies to the newly studied section in the Reinu quarry, northern Estonia (see Fig. 1). Some of the sections also reveal a slow appearance of post-extinction 'Silurian' species of various shelly fossil groups and chitinozoans. Several of these species were traditionally used for locating the system boundary in the non-graptolitiferous Ordovician–Silurian boundary successions all over the eastern Baltic area. This is true for several chitinozoan species (*Spinachitina fragilis* – see Põldvere et al. 1998, *Ancyrochitina laevaensis* – see Hints et al. 2014; Nõlvak et al. 2023), conodonts (*Ozarkodina* ex gr. *oldhamensis* – see Kaljo et al. 2008) and ostracods (*Longiscula smithii*, *Rectella procera*, *Microcheilinella mobile*, *M. rozhdestvenskaja*, *Bipunctoprimitia bipunctata* – see Meidla et al. 2011). The macrofossil record in the sections with distinctive stable carbon isotopic signatures is very limited, but the ranges of all taxa previously recorded in the lower Varbola, Õhne and Stačiūnai formations need to be validated.

The organic carbon isotopic ($\delta^{13}C_{org}$) curves add a new aspect to the ongoing discussion. The shape of this curve in the Tartu and particularly in the Likėnai (e.g. Hints et al. in press) sections is remarkably different from the corresponding $\delta^{13}C_{carb}$ curves. The $\delta^{13}C_{org}$ values are high only in a short

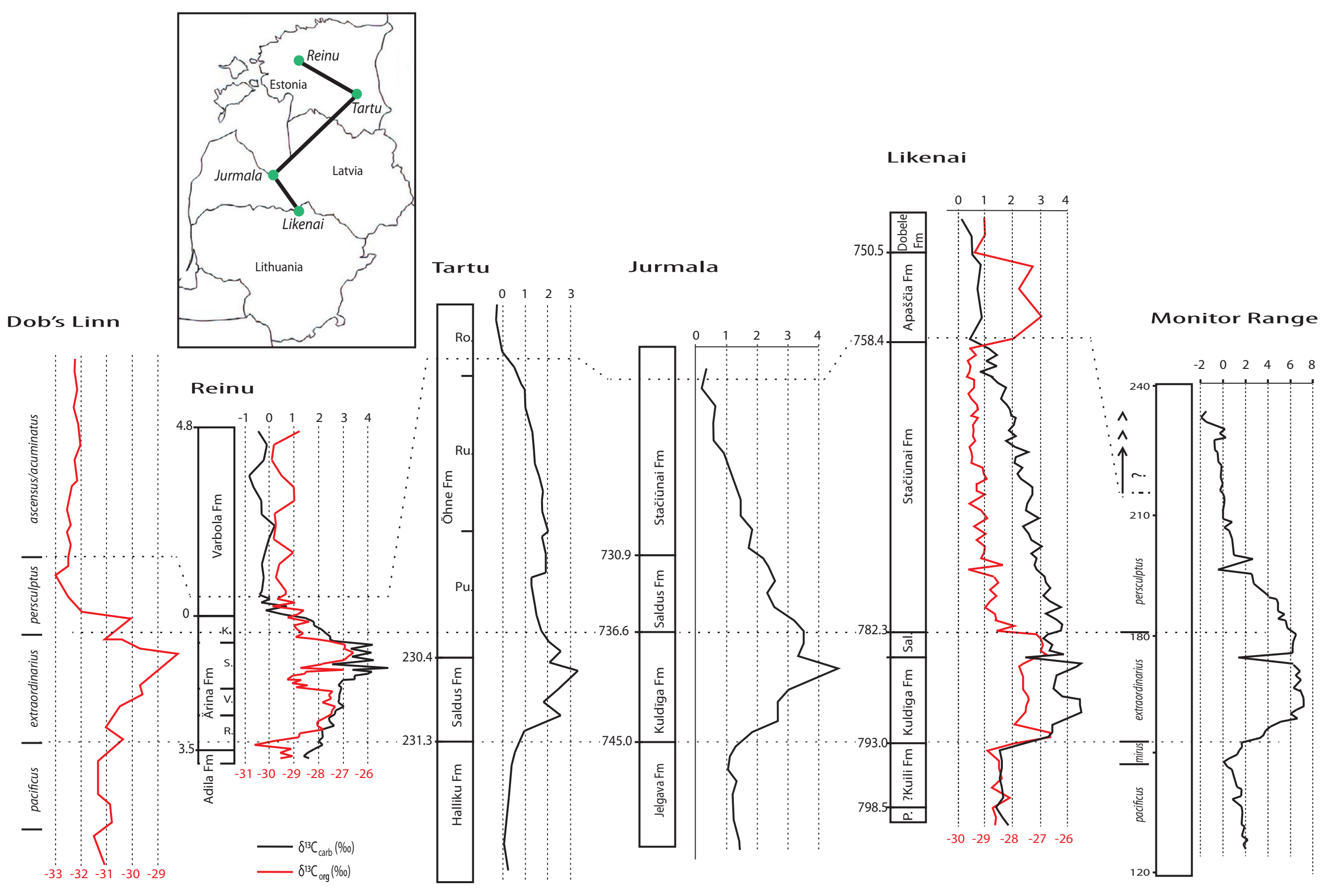

Fig. 1. Stable carbon isotopic correlation of the sections along the Reinu-Tartu-Jurmala-Likėnai profile and with the biostratigraphically dated global reference sections at Dob's Linn, UK (after Jones et al. 2011) and the Monitor Range, US (after Finney et al. 1999 and Laporte et al. 2009). Abbreviations: Fm – formation, K. – Kamariku Member (Mb), P. – Parovėja Fm, Pu. – Puikule Mb, R. – Röa Mb, Ro. – Rozeni Mb, Ru. – Rūja Mb, S. – Siuge Mb, Sal. – Saldus Fm, V. – Vohilaid Mb.

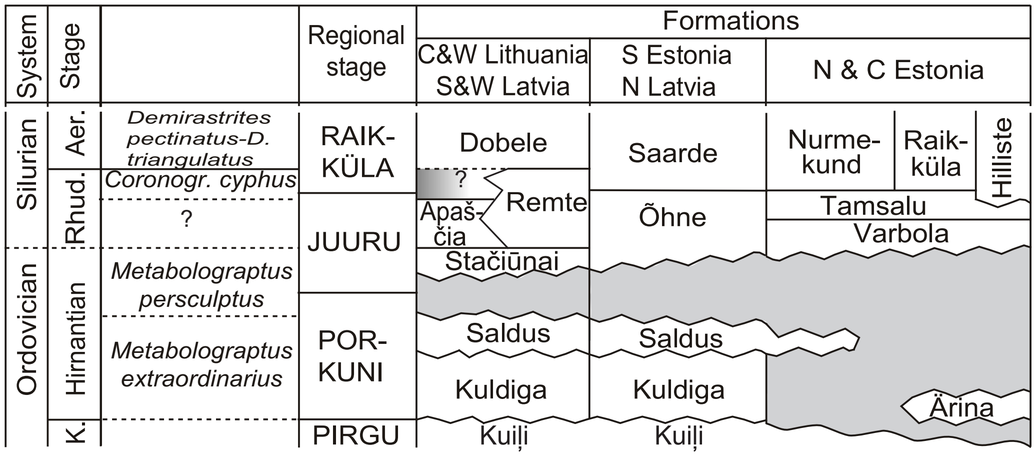

Fig. 2. Correlation of the Ordovician–Silurian boundary strata in Estonia and Latvia with the graptolite zones and the global standard. The compilation is based on Gailite et al. 1987, Nestor 2012, Männik 2014, Meidla et al. 2020 and the authors' new data. Abbreviations: C – Central, N – North, W – West, S – South, K. – Katian, Rhud. – Rhuddanian, Aer. – Aeronian, *Coronogr.* – *Coronograptus*.

interval that is biostratigraphically confined to the Porkuni Regional Stage (RS). The $\delta^{13}C_{carb}$ curves of stratigraphically more complete sections reveal a long decline in the values in the Juuru RS. In the Jurmala and Likėnai core sections (Fig. 1), the falling limb of the HICE extends throughout the entire Stačiūnai Formation. This discrepancy may look controversial, but comparison with the stratotype section in Dob's Linn, Scotland, and the Laframboise Point section in Anticosti, Canada, suggests that the interval of high $\delta^{13}C_{org}$ values may correspond to the *Metabolograptus extraordinarius* Graptolite Zone (Jones et al. 2011), whilst the HICE does most probably range up into the *M. persculptus* Zone in the eastern Baltic area (Meidla et al. 2020).

However, the question about the position of the system boundary is still open. The correlation with the global standard remains complicated because of the poor graptolite record of the Ordovician–Silurian transition in a large area reaching from northwestern Estonia (Nestor and Einasto 1997) across Latvia (Gailite et al. 1987) and Lithuania (Paškevičius 1997) to marginal northeastern Poland (Podhalańska 1977). The only known section with graptolites in the boundary interval (Ulst 1992) has not been studied for other fossil groups and stable isotopes. In other sections all over the region, the graptolite record seems to begin in the *Coronograptus cyphus* Graptolite Zone, i.e., in the upper Rhuddanian.

In the hope of covering this 'information gap' in the biostratigraphic succession, we tried to use the upper limits of the stable carbon isotopic excursions (both $\delta^{13}C_{org}$ and $\delta^{13}C_{carb}$) as correlation markers. Figure 1 displays the stable carbon isotopic correlation of the sections along the Reinu-Tartu-Jurmala-Likėnai profile and with the biostratigraphically dated global reference sections. Based on the Dob's Linn section, the *Metabolograptus extraordinarius* Zone is taken as nearly equivalent to the prominent Hirnantian $\delta^{13}C_{org}$ excursion. The *M. persculptus* Zone is correlated with the falling limb of the HICE, as in the Monitor Range section. These results suggest an improved correlation with the Ordovician–Silurian boundary strata in Estonia and Latvia.

The correlation of the Ordovician–Silurian boundary strata in Fig. 2 is a compilation based on Gailite et al. 1987, Nestor 2012, Männik 2014, Meidla et al. 2020 and the correlation in Fig. 1. The basal part of the Varbola Fm corresponding to the limit of the falling limb of the HICE has been attributed to the Ordovician in several papers already. The same is true for the lower part of the Õhne Fm (Meidla 2020 and references therein) and for the Stačiūnai Fm (see Fig. 1). The topmost part of the Õhne Fm in the Ikla core reveals graptolites indicative of the *Coronograptus cyphus* Zone (Kaljo and Vingisaar 1969). According to Gailite et al. (1987), the same is true for the topmost Remte Fm, but not for the Apaščia Fm, which still remains poorly dated. The Dobele Fm is characterised by graptolites from the *Demirastrites pectinatus–D. triangulatus* Zone up to the *Stimulograptus sedgwickii* Zone, whilst a tentative gap between the Apaščia and Dobele formations is drawn as equivalent to the *C. cyphus* Zone, which may be missing in the Apaščia–Dobele transition interval, judging from the published data (mainly Gailite et al. 1987).

Conclusions

Regional Ordovician and Silurian correlation charts of the eastern Baltic area have mainly been based on biostratigraphic evidence, but the data on the Ordovician–Silurian transition interval are poor and controversial. Integration of the stable isotopic evidence with the limited data on the distribution of graptolites allows the correlation of the Varbola, Õhne and Stačiūnai formations to be justified. As the lower boundary of the Silurian System still does not have a proper biostratigraphic marker in the regional succesion, the ranges of all zonal microfossil taxa previously recorded in the lower Varbola, Õhne and Stačiunai formations need to be validated for its definition.

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References

Ainsaar, L., Truumees, J. and Meidla, T. 2015. The position of the Ordovician–Silurian boundary in Estonia tested by high-resolution $\delta^{13}C$ chemostratigraphic correlation. In *Chemostratigraphy. Concepts, Techniques, and Applications* (Ramkumar, M., ed.). Elsevier, 395–412.

Bauert, H., Ainsaar, L., Põldsaar, K. and Sepp, S. 2014. $\delta^{13}C$ chemostratigraphy of the Middle and Upper Ordovician succession in the Tartu-453 drillcore, southern Estonia, and the significance of the HICE. *Estonian Journal of Earth Sciences*, **63**(4), 195–200.

Brenchley, P. J., Marshall, J. D., Carden, G. A. F., Robertson, D. B. R., Long, D. G. F., Meidla, T. et al. 1994. Bathymetric and isotopic evidence for a short-lived Late Ordovician glaciation in a greenhouse period. *Geology*, **22**(4), 295–298.

Brenchley, P. J., Carden, G. A., Hints, L., Kaljo, D., Marshall, J. D., Martma, T. et al. 2003. High-resolution stable isotope stratigraphy of Upper Ordovician sequences: Constraints on the timing of bioevents and environmental changes associated with mass extinction and glaciation. *Geological Society of America Bulletin*, **115**(1), 89–104.

Finney, S. C., Berry, W. B. N., Cooper, J. D., Ripperdan, R. L., Sweet, W. C., Jacobson, S. R. et al. 1999. Late Ordovician mass extinction: A new perspective from stratigraphic sections in central Nevada. *Geology*, **27**(3), 215–218.

Gailite, L. K., Ulst, R. Zh. and Yakovleva, V. I. 1987. *Стратотипические и типовые разрезы силура Латвии* (*Silurian Stratotype and Reference Sections of Latvia*). Zinatne, Riga.

Hammarlund, E. U., Dahl, T. W., Harper, D. A. T., Bond, D. P. G., Nielsen, A. T., Bjerrum, C. J. et al. 2012. A sulfidic driver for the end-Ordovician mass extinction. *Earth and Planetary Science Letters*, **331–332**, 128–139.

Hints, O., Martma, T., Männik, P., Nõlvak, J., Põldvere, A., Shen, Y. et al. 2014. New data on Ordovician stable isotope record and conodont biostratigraphy from the Viki reference drill core, Saaremaa Island, western Estonia. *GFF*, **136**(1), 100–104.

Hints, O., Ainsaar, L., Lepland, A., Liiv, M., Männik, P., Meidla, T. et al. 2023 (in press). Paired carbon isotope chemostratigraphy across the Ordovician–Silurian boundary in central East Baltic: regional and global signatures. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **624**, 111640.

Jaanusson, V. 1979. Ordovician. In *Treatise on Invertebrate Paleontology, Part A* (Robison, R. A. and Teichert, C., eds). Geological Society of America, Boulder, University of Kansas Press, Lawrence, 136–166.

Jones, D. S., Fike, D. A., Finnegan, S., Fischer, W. W., Schrag, D. P. and McCay, D. 2011. Terminal Ordovician carbon isotope stratigraphy and glacioeustatic sea-level change across Anticosti Island (Quebec, Canada). *Geological Society of America Bulletin*, **123**(7–8), 1645–1664.

Kaljo, D. and Vingisaar, P. 1969. О разрезе райккюлаского горизонта на южной окраине Эстонии (On the sequence of the Raikküla stage in southernmost Estonia). *Eesti NSV Teaduste Akadeemia Toimetised. Keemia. Geoloogia*, **18**(3), 270–277.

Kaljo, D., Nestor, H. and Põlma, L. 1988. East Baltic Region. *Bulletin of British Museum* (*Natural History*), *Geology*, **43**, 85–91.

Kaljo, D., Hints, L., Männik, P. and Nõlvak, J. 2008. The succession of Hirnantian events based on data from Baltica: brachiopods, chitinozoans, conodonts, and carbon isotopes. *Estonian Journal of Earth Sciences*, **57**(4), 197–218.

Kiipli, E. and Kiipli, T. 2020. Hirnantian sea-level changes in the Baltoscandian Basin, a review. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **540**, 109524. https://doi.org/10.1016/j.palaeo.2019.109524

LaPorte, D. F., Holmden, C., Patterson, W. P., Loxton, J. D., Melchin, M. J., Mitchell, C. E. et al. 2009. Local and global perspectives on carbon and nitrogen cycling during the Hirnantian glaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **276**(1–4), 182–195.

Männik, P. 2014. The Silurian System in Estonia. In *4th Annual Meeting of IGCP 591, Estonia, 10–19 June 2014, Abstracts and Field Guide* (Bauert, H., Hints, O., Meidla, T. and Männik, P., eds). University of Tartu, Tartu, 123–128.

Marshall, J. D., Brenchley, P. J., Mason, P., Wolff, G. A., Astini, R. A., Hints, L. et al. 1997. Global carbon isotopic events associated with mass extinction and glaciation in the late Ordovician. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **132**(1–4), 195–210.

Meidla, T., Ainsaar, L. and Truuver, K. 2011. Ostracods in Baltoscandia through the Hirnantian crises. In *Ordovician of the World.* Cuadernos Del Museo Geominero, **14** (Gutiérrez-Marco, J. C. Rábano, I. and García-Bellido, D., eds). Instituto Geológico y Minero de España, Madrid, 353–357.

Meidla, T., Ainsaar, L. and Tinn, O. 2016. Looking for the boundary of the Silurian System in the Baltic Region. In *International Geoscience Programme Project 591 Closing Meeting 'The Early to Mid Palaeozoic Revolution' Ghent University, Ghent, Belgium, 6–9 July 2016* (Gurdebeke, P., De Weirdt, J., Vandenbroucke, T. and Cramer, B., eds). Universiteit Gent, Gent, 59.

Meidla, T., Truuver, K., Tinn, O. and Ainsaar, L. 2020. Ostracods of the Ordovician–Silurian boundary beds: Jūrmala core (Latvia) and its implications for Baltic stratigraphy. *Estonian Journal of Earth Sciences*, **69**(4), 233–247.

Nestor, H. and Einasto, R. 1997. Ordovician and Silurian carbonate sedimentation basin. In *Geology and Mineral Resources of Estonia (*Raukas, A. and Teedumäe, A., eds). Estonian Academy Publishers, Tallinn, 192–204.

Nestor, H., Klaamann, E., Meidla, T., Männik, P., Männil, R., Nestor, V. et al. 1991. Динамика фауны в Балтийском бассейне на границе ордовка и силура (Faunal dynamics in the Baltic Basin at the Ordovician–Silurian boundary). In *Важнейшие биотические события в истории Земли* (*Major Biological Events in Earth History*) (Kaljo, D., Modzalevskaya, T. and Bogdanova, T., eds). Academy of Sciences of the USSR, All-Union Paleontological Society, Academy of Sciences of Estonia, Institute of Geology, Tallinn, 79–86.

Nestor, V. 2012. A summary and revision of the East Baltic Silurian chitinozoan biozonation. *Estonian Journal of Earth Sciences*, **61**(4), 242–260. https://doi.org/10.3176/earth.2012.4.05

Nõlvak, J., Liang, Y. and Hints, O. 2023. Latest Ordovician age of the *Spinachitina fragilis* Chitinozoan Biozone in Baltoscandia. *Estonian Journal of Earth Sciences*, **72**(1), 82–85.

Paškevičius, J. 1997. *The Geology of the Baltic Republics*. Vilnius University, Lithuanian Geological Survey, Vilnius.

Podhalańska, T. 1977. Problem granicy ordowik/sylur w świetle badań biostratygraficznych (Biostratigraphic problem of the Ordovician/Silurian boundary). *Acta Geologica Polonica*, **27**(4), 455–470.

Põldvere, A., Meidla, T., Bauert, H., Bauert, G. and Stouge, S. 1998. Ordovician. In *Tartu* (*453*) *Drillcore.* Estonian Geological Sections Bulletin, **1** (Männik, P., ed.). Geological Survey of Estonia, Tallinn, 11–16.

Ulst, R. 1992. Ордовик и силур в разрезах глубоких скважин на шельфе Балтийского моря (Ordovician and Silurian in the deep boring sections on the Baltic Sea). In *Палеонтология и стратиграфия фанерозоя Латвии и Балтийского моря* (*Phanerozoic Paleontology and Stratigraphy of Latvia and the Baltic Sea*) (Veinbergs, I. G., Danilans, I. Ya., Sorokin, V. S. and Ulst, R. Zh., eds). Zinatne, Riga, 120–138.