The Ordovician System in Estonia

Tõnu Meidla
University of Tartu

The Ordovician System in Estonia

Tõnu Meidla[1], Leho Ainsaar[1] and Olle Hints[2]

[1]*Department of Geology, University of Tartu, Estonia*
[2]*Institute of Geology at Tallinn University of Technology, Estonia*

Ordovician rocks are widespread in the Baltoscandian region. The main distribution area of Ordovician strata in the East European Platform extends from the Baltic Sea islands in the west to the vicinity of Moscow in the east and from the Gulf of Finland in the north to Belarus and Poland in the south. In the northern part of this area, in the eastern coastal region of the Baltic Sea, beds are exposed in the magnificent sections of the Baltic–Ladoga Klint, in other coastal and river bank sections, old and new limestone quarries and open-cast pits of northern Estonia and northwestern Russia. Good accessibility of geological exposures and excellent preservation of fossils and sedimentary structures attracted the attention of investigators already in the early 19th century when the strata were described and figured by O. M. L. v. Engelhardt (1820), W. Strangways (1821), E. Eichwald (1825) and others. The researchers have been interested in the characteristic Cambrian to Middle Ordovician succession, represented by several distinctive rock units (the Cambrian Blue Clay, phosphatic brachiopod coquina, *Dictyonema* argillite, dark green glauconite sandstone and a wide variety of limestone units above).

The main features of the Ordovician stratigraphy were first outlined by F. Schmidt in his thorough monographic paper of 1858. The general pattern of his geological map, presented in the same volume, is well recognized in the modern geological maps of the bedrock of Estonia. The generally simple geological structure of the area, with almost horizontal strata, only 2–5 m/km dipping to the south, results in nearly latitudinal orientation of the outcrop belts of the Ordovician stages in northern Estonia (see the geological map of Estonia on the back cover of the present volume).

The main part of the Ordovician succession in northern Estonia is composed of limestones, with some intercalations of kukersite oil shale concentrated mainly in the Kukruse Stage. Only the basal Ordovician strata comprise a relatively thin succession of clastic sediments – sandstones, argillites and clays of the Pakerort and Varangu stages, overlain by the glauconitic sand- and siltstones of the Hunneberg and Billingen stages. The transition from the terrigenous to carbonate rocks in the Billingen Stage is marked by the appearance of calcareous interbeds in the siltstones, which grade into the first limestone/dolomite unit, the Toila Formation. The appearance of the first representatives of the numerous characteristic Middle Ordovician fossil groups is recorded in the same transition interval or in the overlying Volkhov Stage.

The Ordovician limestone succession in Estonia and adjacent areas begins with cold-water carbonates deposited in a sediment-starving shallow marine basin. The sedimentation rates have increased upwards. Changes in sedimentation rates in the calcareous main part of the Ordovician succession are in obvious correlation with the carbonate production rates. The corals make their first appearance in the Upper Ordovician, and the first carbonate buildups can be recorded in about the same interval, emphasizing a striking change in the overall character of the palaeobasin.

Generally the change in the type of sedimentation and the character of biofacies is ascribed to a gradual climatic change resulting from the northward drift of the Baltica Palaeocontinent from the temperate climatic zone to the (sub)tropical realm (Nestor & Einasto 1997). During the Middle and Upper Ordovician the climatic change resulted in an increase in the carbonate production and sedimentation rate on the carbonate shelf, whereas the deposition pattern was controlled by the accommodation space available there.

The details, but also the problems of the Ordovician geology in the subsurface area in central and southern Estonia were first revealed only in the 1950s. A large number of drill cores, obtained in the course of an extensive drilling programme in the 1950s–1980s, revealed a marked difference between the stratigraphic successions in the outcrop area and southern Estonia. As a result of the comparison of the eastern Baltic and Scandinavian successions, the concepts of the structural-facies zones (by Männil

1966) or confacies belts (by Jaanusson 1976) were introduced for the Ordovician of Baltoscandia. As the term "confacies" is unique (being exclusively used for the Ordovician of Baltoscandia), a different terminology that is widely applied in newer publications has been introduced by Harris *et al.* (2004; Fig. 1). The micropalaeontological and macrofaunal studies of the core sections have also revealed the distinctive biogeographic differentiation pattern, characteristic of the Ordovician rocks (e.g. Männil 1966; Männil *et al.* 1968; Männil & Meidla 1994; Meidla 1996). Although the biofacies pattern is described for the eastern Baltic area, the facies zonation of the entire Baltoscandian area is still imperfectly known. The seismic investigations of the Baltic Sea area performed in the last decades (Tuuling 1998; Tuuling & Floden 2013 and references therein), but also new detailed (micro-)palaeontological investigations (*e.g.* Tinn & Meidla 2001) might produce valuable new information in this field.

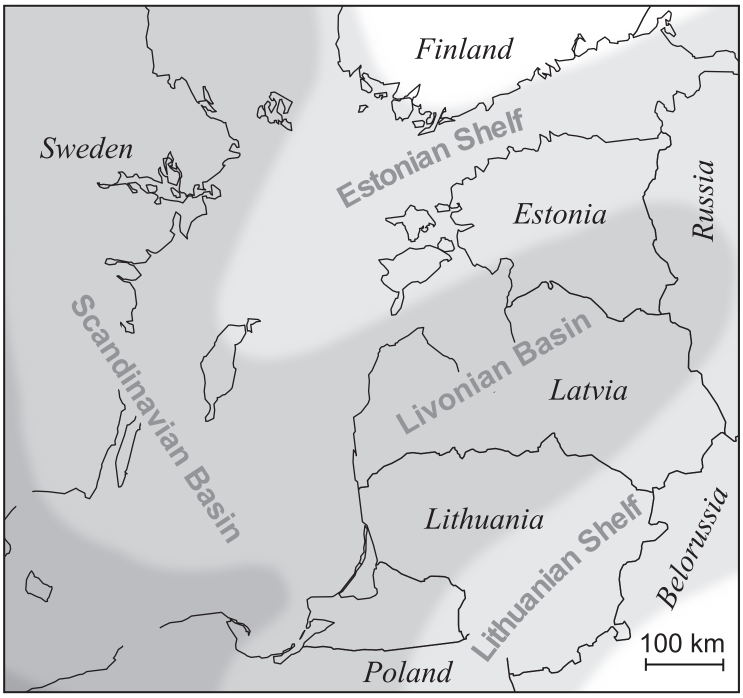

Fig. 1. Post-Tremadocian Ordovician facies zonation.

The total thickness of the Ordovician in Estonia varies from 70 to 180 m, being greatest in central and eastern Estonia and considerably less in the outcrop area, as well as in the southwestern mainland of Estonia.

Several correlation problems still persist in the Ordovician of Estonia, due to marked biofacies differences between northern and southern Estonia. In part, they are discussed also in a recent monographic overview of Estonian geology (see Heinsalu & Viira 1997, Meidla 1997, Hints 1997, Hints & Meidla 1997 in Raukas & Teedumäe 1997). During the last years the application of the stable carbon isotopic zonation (Ainsaar *et al.* 2010) has opened new opportunities to solve still persisting problems in regional stratigraphy.

The term "Stage", first employed by Bekker (1921), has become the principal category in the chronostratigraphic classification of the Ordovician System in Estonia. The development of the stratigraphic classification of the Ordovician strata in Estonia, from the "beds" (Schichten) by Schmidt (1858) to the stages in modern meaning is documented in detail in Männil (1966), Rõõmusoks (1983) and Rõõmusoks *et al.* (1997). The term "Ordovician" was introduced for Estonia by Bassler (1911). A number of regional series and subseries for the Ordovician System in Estonia and neighbouring Russia were brought into use by Schmidt (1881) and several subsequent authors. Raymond (1916) applied the traditional American three-fold subdivision of the Ordovician System to this particular area, but this classification was subjected to repeated changes until 1987. Also the terms "Oeland Series", "Viru Series" and "Harju Series" have been widely used as a basic classification for the Ordovician System of the area since the 1950s (introduced by Kaljo *et al.* 1958 and Jaanusson 1960 in a nearly recent meaning). The subseries have been introduced as well (see Männil & Meidla 1994 and Nõlvak *et al.* 2006 for a summary), but they are very rarely used today and the well-established framework of the Ordovician System has in fact replaced the regional suprastadial units in publications. The modern three-fold classification of the Ordovician System (IUGS 2013) was first used for the Estonian succession by Webby (1998) and is presented here in detail (Fig. 2).

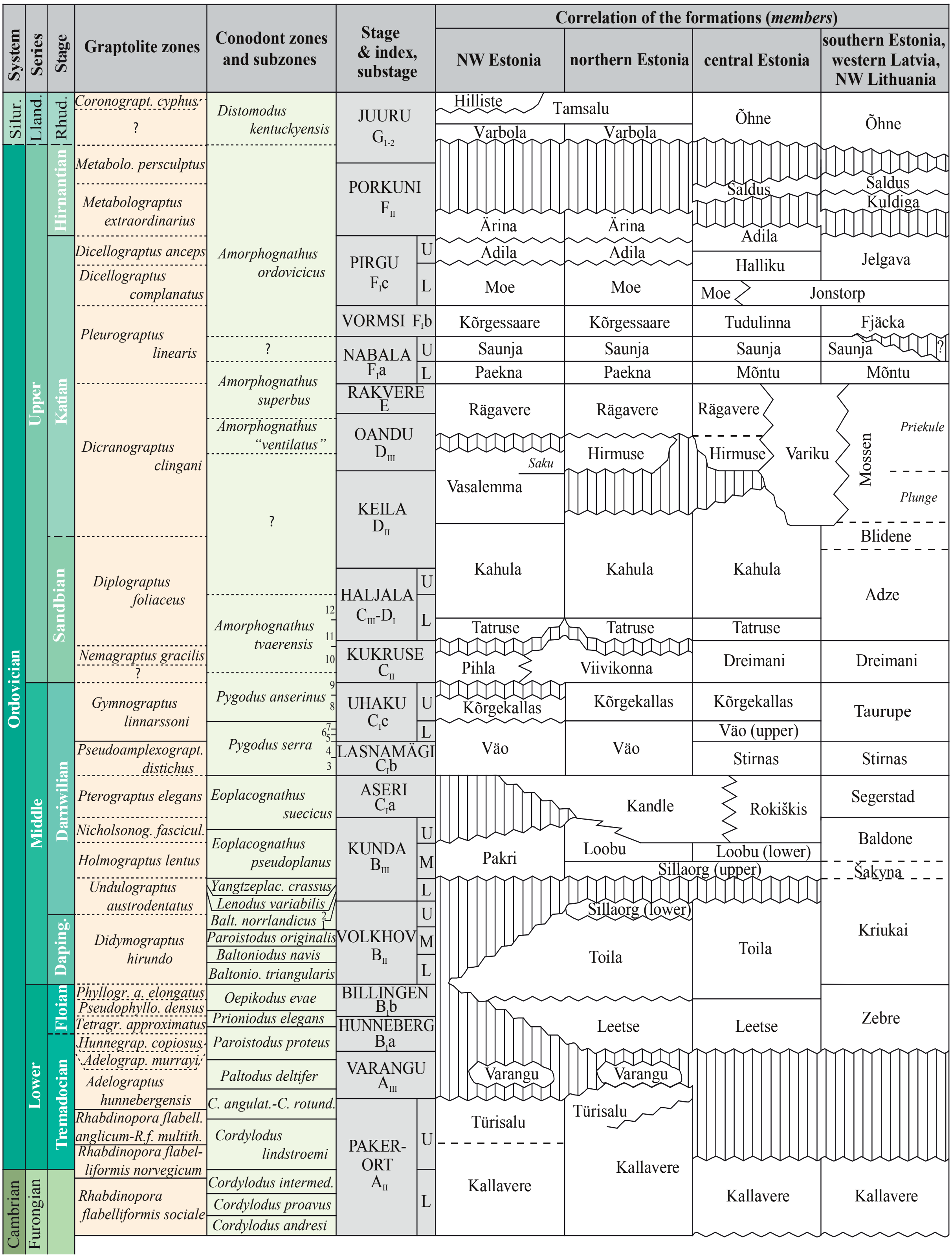

Figure 2. Ordovician stratigraphy of Estonia. Graptolite zonation according to Kaljo & Vingissaar, 1969, Kaljo *et al.*, 1986, Männil, 1976, Resheniya..., 1987, Männil & Meidla, 1994, Nõlvak *et al.*, 2006, conodont zones according to Kaljo *et al.*, 1986, Meidla, 1997 and Männik in Nõlvak *et al.*, 2006. Numbers in the column of the conodont zonation correspond to the conodont subzones as follows: subzones of the *Baltoniodus norrlandicus* Zone: 1 – *Trapezognathus quadrangulum* Subzone, 2 – *Lenodus antivariabilis* Subzone; subzones of the *Pygodus serra* Zone: 3 – *Eoplacognathus foliaceous* Subzone, 4 – *Eoplacognathus reclinatus* Subzone, 5 - *Eoplacognathus robustus* Subzone, 6 – *Eoplacognathus protoamosus* Subzone, 7 – *Eoplacognathus lindstroemi* Subzone; subzones of the *Pygodus anserinus* Zone: 8 – *Sagittodontia kielcensis* Subzone, 9 – *Amorphognathus inaequalis* Subzone; subzones of the *Amorphognathus tvaerensis* Zone: 10 – *Baltoniodus variabilis* Subzone, 11 – *Baltoniodus gerdae* Subzone, 12 – *Baltoniodus alobatus* Subzone.

In relation to the definition of the GSSP for the base of the Ordovician System in the Green Point section, Newfoundland (Remane 2003), a revision of the traditional position of the Cambrian–Ordovician boundary at the base of the Pakerort Stage in Estonia turned out to be necessary. According to conodont data, the systemic boundary in the northern Estonian sections lies a few metres higher than previously suggested, i.e. in the middle of the Pakerort Stage, within the Kallavere Formation (Puura & Viira 1999). The lower boundary of the Silurian System has traditionally been drawn at the base of the Juuru Stage. The most recent results on the stable carbon isotopic chemostratigraphy disagree with this viewpoint and emphasize that the evidence behind this traditional solution is not convincing, arguing for a higher position of this boundary in the regional succession, within the Juuru Stage.

Main features of the chronostratigraphic (stage) classification of the Ordovician System were outlined already by Männil (1966). Only minor changes in stage nomenclature have been made in the later decades: the Ceratopyge Stage has been renamed the Varangu Stage (Männil 1990), the Latorp Stage replaced by the Hunneberg and Billingen stages (Hints *et al.* 1993) and a new unit, the Haljala Stage, has merged the former Idavere and Jõhvi Stages (following Jaanusson 1995 and Nõlvak 1997) that were difficult to distinguish outside northwestern Estonia. Hints & Nõlvak (1999) brought the concept of boundary stratotypes ("golden spike") into the Estonian stratigraphy, proposing a stratotype – the Pääsküla outcrop – for the lower boundary of the Keila Stage that also marks a faunal change in the succession. However, as stratigraphic hiatuses on the stage boundaries are very common in northern Estonia (and all remarkable faunal changes are usually related to hiatuses), wide usage of this concept for the stage boundaries in this area still seems rather complicated.

Graptolites are rare in the carbonate succession of Estonia. The Scandinavian graptolite zones are usually adopted for the correlation charts, although their correlation to the local succession is mainly based on indirect evidence as the local graptolite record is well resolved in some intervals only (the intervals of the Pakerort–Varangu and Uhaku–Kukruse stages (Kaljo & Kivimägi 1970, 1976; Kaljo *et al.* 1986; Männil 1966, 1976, 1987; Nõlvak *et al.* 2006; Fig. 2). Conodont zonation, however, has been elaborated in detail and is of very high resolution for the Lower and Middle Ordovician (see Fig. 2).

The elaboration of lithostratigraphic classification of the Ordovician rocks was initiated by Orviku (1940), who proposed the lithostratigraphic subdivision for the upper Middle Ordovician. This approach was widely accepted by subsequent authors and led to description of a very substantial number of formations and members and compilation of a series of detailed correlation charts approved by the Interdepartmental Stratigraphic Committee of the former USSR (Resheniya... 1965, 1978, 1987 and a related paper by Männil & Rõõmusoks 1984). The last version of such a formal correlation chart (the edition of 1987) was, in a slightly emended form, published also in English, in the series of the IUGS publications (Männil & Meidla 1994). The correlation chart in Fig. 2 contains some recent improvements compared to this publication, the most recent ones being introduced by Ainsaar & Meidla (2001) and Nõlvak *et al.* (2006). Some more modifications of the Ordovician correlation charts for Estonia have been published by Hints *et al.* (1993) and Nõlvak (1997). The composition and textures of the Ordovician carbonate rocks and main differences between the confacies belts were summarized by Põlma (1982 and references therein).

The monographic studies on the Ordovician palaeontology started already in the 19th century. After the comprehensive review on the Ordovician and Silurian strata (in modern meaning) by Schmidt (1858 and several subsequent monographic papers), a number of important monographic papers were published by F. B. Rosen, W. Dybowski, A. Pahlen, G. Holm, A. Mickwitz, O. Jaeckel, J. H. Bonnema and R. F. Bassler. The tradition of palaeontological investigations on the Ordovician material of Estonia was continued by A. Öpik (1930, 1934 and others) and, later on, by the recent generation of palaeontologists. Monographs and extensive monographic papers have been published on the Ordovician brachiopods, corals, stromatoporoids, chitinozoans, scolecodonts, ostracods, conodonts, etc. Summaries on the palaeontological investigations on virtually all fossil groups recorded from the Ordovician of Estonia are published in the monograph *Geology and mineral resources of Estonia* (Raukas & Teedumäe 1997; http://sarv.gi.ee/geology/).

References

Ainsaar, L. & Meidla, T., 2001. Facies and stratigraphy of the middle Caradoc mixed siliciclastic-carbonate sediments in eastern Baltoscandia. *Proceedings of the Estonian Academy of Sciences. Geology*, 50, 5–23.

Ainsaar, L., Meidla, T. & Martma, T., 2004. The Middle Caradoc facies and faunal turnover in the Late Ordovician Baltoscandian palaeobasin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 210, 119–133.

Ainsaar, L., Kaljo, D., Martma, T., Meidla, T., Männik, P., Nõlvak, J. & Tinn, O., 2010. Middle and Upper Ordovician carbon isotope chemostratigraphy in Baltoscandia: A correlation standard and clues to environmental history. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 294, 3–4, 189–201.

Bassler, R. F., 1911. *The Early Palaeozoic Bryozoa of the Baltic Provinces*. Smithsonian Institute. US National Museum Bulletin, 77, 1–382.

Bekker, H., 1921. The Kuckers Stage of the Ordovician Rocks of NE Estonia. *Acta et Commentationes Universitatis Tartuensis*, A2, 81–84.

Eichwald, E., 1825. *Geognostico-zoologicae per Ingriam marisque Baltici provincias nec non de trilobitis observationes*. Casani, 58 pp.

Engelhardt, M., 1820. *Darstellung aus dem Felsgebäude Russlands. Erste Lieferung. Geognostischer Umriss von Finland*. Berlin, 44 pp.

Heinsalu, H. & Viira V., 1997. Pakerort Stage. Varangu Stage. *In:* Raukas, A. & Teedumäe, A. (eds). *Geology and Mineral Resources of Estonia.* Estonian Academy Publishers, Tallinn, 52–58.

Hints, L., 1997. Aseri Stage. Lasnamägi Stage. Uhaku Stage. Haljala Stage. *In:* Raukas, A. & Teedumäe, A. (eds). *Geology and Mineral Resources of Estonia*. Estonian Academy Publishers, Tallinn, 66–74.

Hints, L. & Meidla, T., 1997. Keila Stage. Oandu Stage. Rakvere Stage. Nabala Stage. Vormsi Stage. Pirgu Stage. Porkuni Stage. *In:* Raukas, A. & Teedumäe, A.(eds). *Geology and Mineral Resources of Estonia.* Estonian Academy Publishers, Tallinn, 74–88.

Hints, L., Meidla, T., Gailite, L.-I. & Sarv, L. (comp.), 1993: *Catalogue of Ordovician Stratigraphical Units and Stratotypes of Estonia and Latvia*. Institute of Geology, Estonian Academy of Sciences, Tallinn, 62 pp.

Hints, O. & Nõlvak, J., 1999. Proposal for the lower boundary-stratotype of the Keila Regional Stage (Upper Ordovician). *Proceedings of the Estonian Academy of Sciences. Geology*, 48, 158–169.

IUGS 2013. *International stratigraphic chart*. IUGS International Commision of Stratigraphy, http://www.stratigraphy.org/index.php/ics-chart-timescale.

Jaanusson, V., 1960. Graptoloids from the Ontikan and Viruan (Ordovician) limestones of Estonia and Sweden. *The Bulletin of the Geological Institutions of the University of Uppsala*, 38, 289–366.

Jaanusson, V., 1976. Faunal dynamics in the Middle Ordovician (Viruan) of Baltoscandia. *In:* Bassett, M. G. (ed.). *The Ordovician System*. Proceedings of a Palaeontological Association Symposium, Birmingham, September 1974. University of Wales Press, Cardiff, 301–326.

Jaanusson, V., 1995. Confacies differenciation and upper Middle Ordovician correlation in the Baltoscandian basin. *Proceedings of the Estonian Academy of Sciences. Geology*, 44, 73–86.

Kaljo, D., Borovko, N., Heinsalu, H., Khazanovich, K., Mens, K., Popov, L., Sergeyeva, S., Sobolevskaya, R. & Viira, V., 1986. The Cambrian–Ordovician boundary in the Baltic–Ladoga clint area (North Estonia and Leningrad Region, USSR). *Proceedings of the Academy of Sciences of Estonian SSR. Geology*, 35, 3, 97–108.

Kaljo, D., Hints, L., Hints, O. Martma, T. & Nõlvak, J., 1999. Carbon isotope excursions and coeval environmental and biotic changes in the late Caradoc and Ashgill of Estonia. *Acta Universitatis Carolinae Geologica*, 43, 507–510.

Kaljo, D., Hints, L., Martma, T. & Nõlvak, J., 2001. Carbon isotope stratigraphy in the latest Ordovician of Estonia. *Chemical Geology*, 175, 49–59.

Kaljo, D. & Kivimägi, E., 1970. On the distribution of graptolites in the *Dictyonema* shale of Estonia and on the uncontemporaneity of its different facies. *Eesti NSV Teaduste Akadeemia Toimetised. Keemia, Geoloogia*, 19, 4, 334–341. [in Russian, with English summary]

Kaljo, D. & Kivimägi, E., 1976. Zonal stratigraphy of the Estonian Tremadocian. *In:* Kaljo, D. L. & Koren T. N. (eds). *Graptolites and stratigraphy*. Academy of Sciences of Estonian SSR, Institute of Geology, Tallinn, 56–63. [in Russian with English summary].

Kaljo, D., Rõõmusoks, A. & Männil, R., 1958. On the series of the Baltic Ordovician and their significance. *Eesti NSV Teaduste Akadeemia Toimetised. Tehniliste ja Füüsikalis-Matemaatiliste Teaduste Seeria*, 7, 71–74. [in Russian with English summary].

Kaljo, D. & Vingisaar, P., 1969. On the sequence of the Raikküla Stage in southernmost Estonia. *Eesti NSV Teaduste Akadeemia Toimetised. Keemia, Geoloogia*, 18, 3, 270–277. [in Russian with English summary].

Männil, R., 1966. *Evolution of the Baltic Basin during the Ordovician*. Valgus, Tallinn, 200 pp. [in Russian with English summary].

Männil, R., 1976. Distribution of graptoloids in the Ordovician carbonate rocks of the East Baltic area. *In:* Kaljo, D. L. & Koren T. N. (eds). *Graptolites and stratigraphy*. Academy of Sciences of Estonian SSR, Institute of Geology, Tallinn, 105–118. [in Russian with English summary].

Männil, R., 1990. The Ordovician of Estonia. *In:* Kaljo, D. & Nestor, H. (eds). *Field Meeting Estonia 1990. An Excursion Guidebook*. Estonian Academy of Sciences, Tallinn, 11–20.

Männil, R. & Meidla, T., 1994. The Ordovician System of the East European Platform (Estonia, Latvia, Lithuania, Byelorussia, parts of Russia, the Ukraine and Moldova). *In:* Webby, B.D.R., Ross, R.J. & Zhen, Yong Y. (eds). *The Ordovician System of the East European Platform and Tuva (Southeastern Russia): Correlation Charts and Explanatory Notes*. IUGS Publication, 28, A, 1–52.

Männil, R. & Rõõmusoks, A., 1984. The revision of the lithostratigraphic subdivision of the Ordovician of North Estonia. *In:* Männil, R. & Mens, K. (eds). *Stratigraphy of the Lower Palaeozoic rocks in the East Baltic*. Institute of Geology, Academy of Sciences of the Estonian SSR, Tallinn, 52–62. [in Russian with English summary].

Männil, R., Põlma, L. & Hints, L., 1968. Stratigraphy of the Viruan and Harjuan deposits (Ordovician) in the central East Baltic. *In:* Grigelis, A. (ed.). *Stratigraphy of the Lower Paleozoic and Correlation with Other Regions*. Mintis, Vilnius, 81–110. [in Russian with English summary].

Meidla, T., 1996. Late Ordovician Ostracodes of Estonia. *Fossilia Baltica*, 2, 222 pp.

Meidla, T., 1997. Hunneberg Stage. Billingen Stage. Volkhov Stage. Kunda Stage. *In:* Raukas, A. & Teedumäe, A. (eds). *Geology and Mineral Resources of Estonia*. Estonian Academy Publishers, Tallinn, 58–65.

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

Nõlvak, N., 1997. Ordovician. Introduction. *In:* Raukas, A. & Teedumäe, A. (eds). *Geology and Mineral Resources of Estonia*. Estonian Academy Publishers, Tallinn, 52–55.

Nõlvak, J., Hints, O. & Männik, P., 2006. Ordovician timescale in Estonia: recent developments. *Proceedings of the Estonian Academy of Sciences. Geology* 55, 95-108.

Öpik, A., 1930. *Brachiopoda Protremata der estländischen ordovizischen Kukruse-Stufe*. Tartu Ülikooli Geoloogia Instituudi Toimetised 20, 261 pp.

Öpik, A., 1934. *Über Klitamboniten*. *Acta et Commentationes Universitatis Tartuensis*, A 26, 5, 1–239.

Orviku, K., 1940. Lithologie der Tallinna-serie (Ordovizium, Estland). *Acta et Commentationes Universitatis Tartuensis*, A 36, 1–216.

Põlma, L., 1982. *Comparative Lithology of the Ordovician Carbonate Rocks in the Northern and Middle East Baltic*. Valgus, Tallinn, 164 pp. [in Russian with English summary].

Puura, L & Viira, V., 1999. Chronostratigraphy of the Cambrian-Ordovician boundary beds in Baltoscandia. *Acta Universitatis Carolinae Geologica*, 43, 5–8.

Raukas, A. & Teedumäe, A. (eds), 1997. *Geology and Mineral Resources of Estonia*. Estonian Academy Publishers, Tallinn, 436 pp.

Raymond, P.E., 1916. The correlation of the Ordovician strata of the Baltic basin with those of North America. *In:* Raymond, P.E. & Twenhofel, W. (eds). *Expedition to the Baltic provinces of Russia and Scandinavia, 1914.* Bulletin of the Museum of Comparative Zoology at Harvard College, 56, 179–286.

Remane, J., 2003. Chronostratigraphic correlations: their importance for the definition of geochronologic units. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 196, 7–18.

Resheniya... 1965. *Resolution of the joint discussion on establishing an unitary Precambrian and Palaeozoic scheme for the Russian Platform, 1962*. VSEGEI, Leningrad, 79 pp. [in Russian].

Resheniya... 1978. *Resolution of inter-regional stratigraphic discussion on establishing an unitary stratigraphic scheme for the East Baltic region, 1976*. Lithuanian NIGRI, Leningrad, 86 pp. [in Russian].

Resheniya... 1987. *Resolution of the joint stratigraphic discussion on the Ordovician and Silurian of the East European Platform, 1984*. VSEGEI, Leningrad, 114 pp. [in Russian].

Rõõmusoks, A., 1983. *Eesti aluspõhja geoloogia*. Valgus, Tallinn, 224 pp. [in Estonian].

Rõõmusoks, A., Puura, V, Raukas, A. & Mark-Kurik, E., 1997. History of geological research. *In:* Raukas, A. & Teedumäe, A. (eds). *Geology and Mineral Resources of Estonia*. Estonian Academy Publishers, Tallinn.,15–26.

Schmidt, F., 1858. *Untersuchungen über die Silurische Formation von Ehstland, Nord-Livland und Oesel*. Archiv für die Naturkunde Liv- Ehst- and Kurlands, ser. 1, 2, Dorpat, 248 pp.

Schmidt, F., 1881. *Revision der ostbaltischen silurischen Trilobiten nebst geognostischer Übersicht des ostbaltischen Silurgebiets*. Abt. 1. Mémoires de l'Academie Impériale des Sciences de St. Petersburg, ser. 7, 30, 1, 238 pp.

Strangways, W. T. H. F., 1821. Geological sketch of the environs of Petersburg. *Transactions of the Geological Society of London*, 5, 392–458.

Tinn, O., 2002. Early ostracode evolution and palaeoenvironmental application in the Ordovician of Baltoscandia. *Dissertationes Geologicae Universitatis Tartuensis 13*, 145 pp.
Tinn, O. and Meidla, T., 2001. Middle Ordovician ostracods from the Lanna and Holen Limestones, south-central Sweden. *GFF*, 123, 129–136.
Tuuling, I., 1998. Shipborne geophysical study of an Ordovician–Silurian carbonate platform, Faro Hiiumaa area, northeastern Baltic Sea. *Meddelanden fran Stockholms Universitets Institution for Geologi och Geokemi*, 301, 21 pp.
Tuuling, I. and Flodén, T., 2013. Silurian reefs off Saaremaa and their extension towards Gotland, central Baltic Sea. *Geological Magazine*, 150, 5, 923-936.
Webby, B.D., 1998. Steps towards a global standard for Ordovician stratigraphy. *Newsletters on Stratigraphy*, 36, 1–33.

Institute of Ecology and Earth Sciences, University of Tartu
Institute of Geology at Tallinn University of Technology
Geological Survey of Estonia

4th Annual Meeting of IGCP 591

The Early to Middle Paleozoic Revolution

Estonia, 10-19 June 2014

Abstracts & Field Guide

Edited by

Heikki Bauert, Olle Hints, Tõnu Meidla & Peep Männik

Tartu, 2014