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

THE SEVENTH BALTIC STRATIGRAPHICAL CONFERENCE

ABSTRACTS & FIELD GUIDE

7th Baltic Stratigraphical Conference
17-18 May 2008
Tallinn, Estonia

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P. Männik and T. Meidla

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Abstracts and Field Guide

Edited by O. Hints, L. Ainsaar, P. Männik and T. Meidla

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Preface

Baltic co-operation in the field of regional stratigraphy started already in 1969 when the Baltic Regional Stratigraphical Commission (BRSC) was founded. In 1970–1980s, many meetings, workshops and field excursions were organized. BRSC played an important role in promoting stratigraphical research in the former Soviet Union and contributing to the development of stratigraphical schemes used for geologic mapping in the Baltic region and NW Russia.

In 16 October 1990, owing to increased independence of the Baltic States, the BRSC was reformed into a less formal organization — the Baltic Stratigraphical Association (BSA), which unites the national stratigraphical commissions. The regional stratigraphical commission of NW Russia also joined BSA in 2003.

One of the main activities of BSA has been organizing regular scientific conferences devoted to regional geology and stratigraphy. Up to now six meetings have been held in Tallinn (1991, 1996), Vilnius (1993, 2002), Riga (1999) and St. Petersburg (2005). The Seventh Baltic Stratigraphical Conference to be held on 18–19 May 2008 in Tallinn has attracted nearly 80 participants from 10 countries. The current volume includes 66 abstracts dealing with different aspects of palaeontology, regional geology, chemostratigraphy and biostratigraphy, stratigraphical methodology, correlation issues and so forth. A special session of IGCP Project 503 "Ordovician Palaeogeography and Palaeoclimate" will be arranged and the conference is an event of the UNESCO International Year of Planet Earth (2007–2009).

Starting already from the first "open" meeting in Vilnius in 1993, the scientific scope of the Baltic stratigraphical conferences has always been wider than just "Baltic stratigraphy". Thus one may wonder why we call it a "stratigraphical conference" at all? This is perhaps something to discuss in connection with the next meetings. Also, the future role of BSA itself should be discussed. In recent meetings no formal decisions or agreements that affect stratigraphy and corresponding nomenclature have been made. Yet there are many possibilities how closer co-operation between the geologists of the Baltic region could promote stratigraphy and Earth sciences in general. Organizing stratigraphical information, increasing its accessibility, compiling joint stratigraphical schemes and building connections with the International Commission on Stratigraphy and its subcommissions — these could be some of the future tasks for BSA.

We welcome you in Estonia and wish you a nice stay here.

Olle Hints and Tõnu Meidla
On behalf of the Organizing Committee
and the Estonian Commission on Stratigraphy

Contents

Middle and Upper Ordovician carbon isotope stratigraphy in Baltoscandia: towards a regional chemostratigraphic standard

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Fluctuations in the oceanic dissolved inorganic carbon (DIC) stable isotope composition ($\delta^{13}C$) are considered to be indicators of global or regional environmental changes. Unless the marine carbonates are diagenetically altered, their carbon isotope composition is expected to reflect original composition of DIC in seawater. Secular variations of $\delta^{13}C$ in marine carbonates have become an important tool in stratigraphy, especially in correlation of sections from facies formed in different biotic and sedimentary environments. Relatively good preservation of the Middle and Upper Ordovician carbonate rocks in Baltoscandia makes this region unique for chemostratigraphical and palaeoenvironmental isotopic studies of this period.

Previous stratigraphic studies suggested a relatively slow but constant carbonate deposition in the Baltoscandian epeiric sea from Middle Ordovician to Silurian. Detailed biostratigraphic investigation of the succession demonstrates relatively continuous deposition in the Livonian Basin but shows also numerous local and regional sedimentary gaps in the Estonian Shelf facies. Therefore, the core sections from the Livonian Basin (southern Estonia, Latvia) are keys for stratigraphic subdivision of the Ordovician strata in the region.

The main goal of previous studies on Early Palaeozoic carbon isotope stratigraphy in Baltoscandia has been the correlation of isotope excursions. Seven positive and one negative Ordovician isotope excursion are described in the Baltic sections. The studies have demonstrated that the isotopic events can be correlated across the different lithologies over the Baltoscandian palaeobasin and some of them (Hirnantian Excursion, Guttenberg Excursion) even between different continents.

The goal of present study is subdivision of the Middle and Upper Ordovician succession into chemostratigraphic zones. The analysis is based on $\delta^{13}C$ data from 10 key sections, published by different authors in 1999–2007. Jurmala, Valga, Ruhnu, Viljandi and Mehikoorma represent the Livonian Basin facies, Männamaa, Orjaku, Rapla, and Kerguta the Estonian Shelf facies, and Gullhögen Quarry the Scandinavian Basin. Additionally, stratigraphically limited intervals of 11 other sections (Kaugatuma, Taagepera, Kardla, Tartu, Ristiküla, Pärnu, Kõrgessaare, Tamme, Vistla, Kadriorg, Fjäcka) have been used. All chemical analyses have been made from whole-rock samples.

Carbon isotope zones described here are generally consistent with available biostratigraphic data. Some difficulties are met in correlation of thin units bounded by sedimentary gaps. As a result of the chemostratigraphic analysis of the studied sections, we present a composite carbon isotope succession for Baltoscandian region, which can be used as a regional standard and a base for comparing the region with other basins. The composite curve also reflects history of oceanographic changes in the region, serving as a good base for understanding the global environmental history during the Ordovician.

Sedimentary evidence about Middle Ludfordian climatic event on the north-eastern European Platform

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The study area on the Chernov (the Padimejtyvis River) and Chernyshev (the Shar'yu, Bolshaya Synya and Iz'yayu rivers) swells (the Pre-Urals Foredeep), and in Subpolar Urals (the Kozhym and Shchuger rivers) encompasses the uppermost Gerd''yu (brachiopod *Didymothyris didyma* Zone) and lowermost Greben' (*Collarothyris canaliculata* Subzone) superformations. The thickness of this interval amounts to approximately 6–9 m and includes a wide range of facies, spanning from lagoonal to supratidal dolostone laminites with mud cracks and brecciated grainstones to burrow-mottled bioclastic lime wackestones and argillites deposited in deep-water areas. The temporal arrangements of these facies along with pronounced erosional surfaces implies that sea-level changes took place simultaneously with the Late Ludfordian carbon isotope excursion recorded in the Urals and Pre-Ural areas. Of particular importance is the deposition of evaporites and formation of subaerial erosional surfaces during the latest Gerd''yu time in the Pechora Syneclise areas. These units mark an unusually profound sea-level fall within the Timan-northern Ural basin. Our sequence analysis has revealed a sequence boundary bearing evidence of forced regression. The regressive succession starts few metres below the appearance of the conodont *Polygnathoides siluricus* in the middle part of the Sizim Formation, the lower member of the Gerd''yu Superformation. The maximum lowstand (sequence boundary) is indicated by a widespread minor hiatus on top of the Gerd''yu Superformation. The lowermost Tselebej Formation (lower member of the Greben' Superformation) is represented by a widespread argillite microfacies. This resulted from an abrupt sea level rise producing environments of a deep subtidal or middle ramp. Based on detailed facies mapping, the shoreline migrated at least 60–150 km (different distance in different areas of the region) landward during this transgression. Such a sharp facies shift is a good sedimentological marker of environmental changes in the late Ludfordian basin. The association a pronounced positive shifts in $\delta^{18}O$ and $\delta^{13}C$ (Modzalevskaya, Wenzel, 1999) with a regressive facies development in our region and elsewhere (Gotland, Estonia, Austria, Australia, Prague region, Bohemia), and considering the known causes of short-term global sea-level changes, this shift is best explained by climatic cooling and glaciation (Kaljo et al., 2003; Lehnert et al., 2007). The absence of tillites from the succeeding Late Silurian like one from the Late Ordovician and Early Silurian (Caputo, 1998) has till now been important in preventing global climatic cooling hypothesis for stratigraphic anomalies within the Late Ludfordian although the global carbon anomalies and coeval abrupt sea-level shift persist in comparison.

Caputo, M.V. 1998. Ordovician-Silurian glaciation and global sea-level changes. In: Landing, E & Johnson, M.E. (eds.) Silurian cycles – Linkages of dynamic stratigraphy with atmospheric, oceanic, and tectonic changes. *New York State Museum Bull.* 491: 15–25.

Modzalevskaya, T.L., Wenzel, B. 1999. Biostratigraphy and geochemistry of Upper Silurian brachiopods from the Timan-Pechora region (Russia). *Acta Geologica Polonica* 40/2: 145–157.

Kaljo, D., Martma T., Männik, P. & Viira, V. 2003. Implications of Gondvana glaciations in the Baltic Late Ordovician and Silurian and a carbon isotopic test of enironmental cyclicity. *Bull. de la Societe Geologique de France* 174: 59–66.

Lehnert, O., Eriksson, M. J., Calner, M., Joachimski, M. & Buggisch, W. 2007. Concurrent sedimentary and isotopic indications for global climatic cooling in the Late Silurian. *Acta Palaeontologica Sinica* 46 (Suppl.): 249–255.

Main Turns and Factors of Timan – Northern Ural Biota Transformation during Early Paleozoic

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Analysis of diversity dynamics and evolutionary transformations in benthic faunas (stromatoporoids, tabulate corals, rugose corals, brachiopods, gastropods, crinoids, ostracodes) widespread in the Timan-northern Ural basin in Early Paleozoic showed the defining role of environmental changes in these processes. Variations in taxonomic diversity of biota correlate with the changes in the character of sedimenation defined by tectonic regime in the basin, and by global eustasy.

Significant regional reconstructions in the structure of benthic communities, and extinctions of taxa, resulted from rapid climitic and eustatic changes which often caused almost complete replacement of existing ealier biotopes with new ones (e.g. the faunal turnover at the Ordovician–Silurian boundary; faunal changes during Ireviken Event; etc.). Benthic fauna was the most diverse and abundant during stable periods with optimum environmental conditions, in the pre-Hirnantian, Rhuddanian, Early Přidoli, and Early Lochovian time. Relatively stable shallow-water conditions in the Timan-northern Ural basin in Wenlock, Late Silurian, and Early Devonian favoured appearance and existence of longliving taxa, such as brchiopods from the genera *Morhynorhynchus, Atrypoidea, Collarothyris, Prothathyris,* and *Howellella.*

Main environmental changes in the basin affected both, the faunas and character of sedimentation. As a result, events in faunal succession correlate quite well with levels of main sedimentary events.

Nature of the so-called 'reefs' in the Přidolian carbonate system of the Silurian Baltic Basin

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Nowadays oil becomes more and more important for energy supply in our world. There is a growing interest in different aspects of carbonate reservoirs, because of the importance of a number of large and giant carbonate oilfields in the Middle East and the Caspian Sea area. A number of these reservoirs are in Palaeozoic carbonates. The Silurian carbonates in the Silurian Baltic Basin form an excellent target for research because of the availability of numerous cores and outcrops and the limited impact of tectonic deformation in this marginal cratonic basin. This research is focused on Přidoli carbonates, including shallow to deep basin facies, in the Lithuanian subsurface. Here new opinion will be present about the sedimentological nature of the so-called reefs in this basin. The term reef appears often loosely applied to different types of deposits. Although the tectonic synsedimentary setting is undoubtedly important, it is however crucial to determine the exact nature of the reefal deposits since they tend to determine the nature of the carbonate system. In case of real reefs, i.e., bioconstructed deposits with significant relief, carbonate platforms develop while otherwise ramps develop. The research shows that Přidoli carbonates lack reefs since a framework constructing fauna is absent, and probably was absent during most of the Palaeozoic. Contrary to bioherms or reefs, biostromal deposits are formed on a ramp system and appear to be one of the main carbonate producing parts of the system. The exact importance of the different facies in carbonate production is difficult to assess. It is crucial to distinguish between ramp and platform systems because these two end members react differently to diagenesis that ultimately determines the petrophysical properties and thus the reservoir quality.

Late Ordovician (Turinian–Chatfieldiean) climate of Laurentia

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Upper Ordovician conodonts from Minnesota and Kentucky were studied for oxygen isotopes. The oxygen isotope composition of biogenic apatite is dependent on temperature during the precipitation of apatite and $\delta^{18}O$ of ambient seawater. Reversely, changes in seawater temperature or composition can be calculated from $\delta^{18}O$ values of conodont apatite.

Conodonts immediately below the Deicke K-benthonite exhibit $\delta^{18}O$ values between 18 and19.1‰. Mean values rise to >20‰ in the Carimona Member of the Decorah Formation of Minnesota giving evidence for an abrupt cooling during the Late Sandbian *P. undatus* conodont biozone. Temperatures kept low during deposition of the Carimona Member for about 100,000 years and rose fast at the base of the Decorah shale. The Galena Group is characterized by warm climate. A minor drop in temperature is observed in the lower Dubuque Formation.

The first cooling step predates the large positive $\delta^{13}C$ excursion of the GICE event. Therefore drawdown of CO_2 during the GICE event cannot be responsible for this climate change.

The abrupt drop of temperature coincides with the giant eruption of the Deicke K-benthonite posing the assumption that both events are linked.

Lowering of earth surface temperature was observed in consequence of recent Plinian eruptions (Krakatau, Tambora, Pinatubo). The giant prehistoric Toba eruption probably caused a cooling of several °C for some years.

The Deicke eruption outreached the Toba event by far regarding ejection of ashes and sulphur. The arising aerosols caused low surface temperatures on earth and cooling of oceans. A possible spread of sea ice probably caused a positive feedback and intensified the albedo. The eruption provided immense volumes of Ca-rich volcanic glass which weathered to clay minerals. The released Ca was able to fix atmospheric CO_2 and lower the level of this greenhouse gas considerably.

A first report on the Upper Ordovician stratigraphy of the Borenshult-1 core, Motala, Sweden

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We have launched an integrated research project in order to study environmental and faunal changes through the Upper Ordovician of Baltoscandia and their ties to the climatic changes of this time period. In addition to the perturbations in the global carbon cycle manifested by the early Katian Guttenberg excursion (GICE) and the Hirnantian excursion (HICE) a series of three or four additional Upper Ordovician carbon isotope anomalies have been shown to be of intercontinental importance (Kaljo et al., 2004; Bergström et al., 2007). These data have improved the potential for correlation of strata and, importantly, may throw new light on the climatic evolution of this time period in Earth history. We aim to study the timing of environmental perturbations and establish a detailed time series for changes in the carbon cycle, sea-level, and in benthic and planktonic biodiversity. In addition, we will study the skeletal grain composition of the rocks in order to record variations in the marine benthic ecosystem during the time interval. For the purpose of this project, the Borenshult-1 core (71.33 m long) was drilled in the city of Motala in south-central Sweden in July 2007. The core will function as a continuous reference section for detailed sampling through the interval and for comparison with other areas. The first and still preliminary studies of the core section have revealed a condensed succession that at this stage only provisionally can be tied to the existing stratigraphic framework for the Baltoscandian Ordovician (Bergström & Bergström, 1996; Ebbestad et al., 2007 and references therein) and that represents the late Darriwilian(?), Sandbian, Katian, Hirnantian, and a few metres of the basal Silurian. The Kinnekulle K-bentonite has been identified along with at least two additional thin bentonite beds. Initial stable carbon and oxygen isotope studies of the core have revealed the GICE (near above the Kinnekulle K-bentonite) and HICE excursions, as well as additional smaller scale variations between these two major anomalies (Lehnert et al., in this volume). At least four flooding surfaces appear to be significant and can potentially be used for sequence stratigraphical subdivision of the strata in five depositional cycles. Of particular interest is the basal flooding surface of the Fjäcka Shale, which superimposes palaeokarst in the Slandrom Formation, suggesting profound and most likely climatically induced sea-level changes across this boundary.

Bergström, S.M. & Bergström, J. 1996. The Ordovician-Silurian boundary succession in Östergötland and Västergötland, S. Sweden. *GFF* 118: 25–42.

Bergström, S.M., Young, S., Schmitz, B. & Saltzman, M.R. 2007. Upper Ordovivian (Katian) δ^{13}C chemostratigraphy: a trans-Atlantic comparison. *Acta Palaeontologica Sinica* 46 (Suppl.): 37–39.

Ebbestad, J.O.R., Wickström, L.M. & Högström, A.E.S. 2007. WOGOGOB 2007. *9th meeting of the Working Group on Ordovician Geology of Baltoscandia, Field Guide and Abstracts. Sveriges geologiska undersökning, Rapporter och meddelanden* 128: 1–110.

Kaljo, D., Hints, L., Martma, T. & Nõlvak, J. 2004. Late Ordovician carbon isotope trend in Estonia, its significance in stratigraphy and environmental analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology* 210: 165–185.

Biostratigraphic (graptolites, chitinozoans, acritarchs, brachiopods) and chemostratigraphic ($\delta^{13}C$) correlations between latest Ordovician strata in Laurentia and Baltica

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From low to mid latitude palaeocontinents, numerous Upper Ordovician and Lower Silurian outcrops and boreholes are now biostratigraphically and chemostratigraphically well constrained. At Anticosti Island (eastern margin of Laurentia), chitinozoan, brachiopod, graptolite, carbon isotopic, and now acritarch data, are available for the whole Ellis Bay Formation, which is long known to be (at least partly) Hirnantian in age. In the Baltoscandian Basin (Baltica), numerous outcrops and boreholes have been intensively studied and can be correlated with high precision.

At Anticosti, the Hirnantian Isotopic Curve Excursion (HICE) is located in the upper part of the Ellis Bay Fm (upper Lousy Cove and La Framboise members), where graptolites of the *N. persculptus* Zone occur. The lower members of the Ellis Bay Fm (Grindstone, Velleda, Prinsta, and lower part of Lousy Cove) do not yield graptolites; however, they correlate with the *B. gamachiana* chitinozoan Zone. A further chitinozoan biozone (*S. taugourdeaui*) has been identified in the upper Lousy Cove Mb., in correspondence of the beginning of the HICE; thus being at least partly correlated to the *N. persculptus* graptolite Zone. In Baltica, the *B. gamachiana* Zone occur in the upper part of the Pirgu Stage (pre-Hirnantian), while the *S. taugourdeaui* Zone occur within the lowermost Porkuni Stage (Hirnantian), and is correlated to the very beginning of the rising limb of the HICE curve.

Brachiopod and chitinozoan biostratigraphy shows inconsistent correlation in the two areas. At Anticosti, the *Hirnantia* fauna occur throughout the Ellis Bay Fm., meaning that the entire *B. gamachiana* chitinozoan Zone is correlated with the *Hirnantia* fauna. In the Baltic sections however, it occurs just above the *S. taugourdeaui* Zone and disappears while carbon isotope values are still high. This inconsistency can be easily solved by assuming a diachronous character of the *Hirnantia* fauna.

Acritarch assemblages where recovered from the entire Ellis Bay to the very base of the Becsie formation (basal Silurian), at Anticosti, and comapred with coeval acritarch assemblages of the Estonian Rapla borehole. In this section, however, the acritarch record is not complete because of a hiatus embracing the *B. gamachiana* chitinozoan Zone and because of impoverished dolomitized strata of the Porkuni Stage. The acritarch assemblages from the pre-HICE sediments in Anticosti and from the Pirgu Stage in the Rapla section show similarities, sharing 19 interesting acritarch species, as follows: *Baltisphaeridium aliquigranulum*, *B. bystrentos*, *B. pseudocalicispinum*, *Cheleutochroa elegans*, *C. gymnobrachiata*, *C. venesa*, *Diexallophasis denticulata*, *Estiastra* sp., *Goniosphaeridium oligospinosum*, *G. polygonale* s.l., *Hoegklintia digitata*, *Leiofusa granulicatis quincux*, *Multiplicisphaeridium* aff. *borracherosum*, *Ordovicidium elegantulum*, *O. groetlingboensis*, *Orthosphaeridium chondrodora*, *O. rectangulare*, *Sacculidium tricolumneare* nov. comb., and *Stellechinatum helosum*.

In conclusion, the integration of the various data show that:

1) The HICE interval in the Ellis Bay Formation (from the upper half part of the Lousy Cove Member to the topmost La Framboise Member, possibly even the lowermost Becsie Formation) correlates exactly with the Porkuni Stage of the Baltic sections.
2) The pre-HICE sediments from the Ellis Bay Fm (from the Grindstone to mid-Lousy Cove Members) correlate with at least the top of the Pirgu Stage; *B. gamachiana* Zone (pre-Hirnantian).

It follows that, at Anticosti, the Hirnantian is confined to the top of the Ellis Bay Fm. This is not in contradiction with the brachiopod data, because the diachronous character of the *Hirnantia* fauna has been demonstrated in previous studies. A substantial part of the Ellis Bay Fm. (e.i., the Grindstone, Velleda, Prinsta Members, plus the lower half of the Lousy Cove Member) belongs to the *B. gamachiana* chitinozoan Zone, which is also found in the topmost Pirgu Stage in Baltic sections, and is demonstrably pre-Hirnantian in age.

Trilobite taxonomy of the Middle and Upper Ordovician of western Leningrad district (Russia) and northern Estonia

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Trilobites comprise an important component of fossil assemblages in the Darriwilian, Sandbian and Katian (Ordovician) of Baltoscandia. A summary on the taxonomic composition of trilobites in Estonia and NW Russia is presented according to the new and published data, and trilobite collections from Estonia, Leningrad region and Sweden. Regional variation of the trilobite distribution (comparison to Sweden and Norway) is considered.

The new trilobite material was collected from several Middle and Upper Ordovician outcrops in Estonia (Kohtla, Viivikonna, Narva, Aluvere and Keila quarries, Pääsküla Hillock, Uhaku and Oandu River and Osmussaar Island) and Leningrad region (Dyatlicy, Alekseevka, Klyasino, Zimiticy, Kas`kovo, Slobodka, Gorki, Il`eshi, Elisavetino and Pechurki quarries and a section on the banks of the Volhov, Hrevica Dolgaya and Plyussa rivers and other localities). This material contains some taxa, previously not recorded in this area.

The trilobite fauna of the East Baltic (Estonia and Leningrad region) comprises 157 species attributed to 56 genera, 17 families and 5 orders, Asaphida, Corynexochida, Phacopida, Lichida, Proetida and Ptychopariida. All the same orders are present also in Scandinavia. Ptychopariida have not been formerly studied in the Leningrad region and are represented only by one genus and species.

The Order Asaphida comprises three families, Asaphidae, Remopleurididae and Raphiophoridae (29 species in total: 21 belonging to Asaphidae, 5 to Remopleurididae and 3 to Raphiophoridae). On the generic level, Asaphidae are dominating (8 genera and two subgenera, mostly from the Uhaku–Kukruse interval). Two other families are each represented by one genus (*Remopleurides* and *Lonchodomas*). Highest diversity of Asaphida (24 species) occurs in North Estonia, it is slightly lower (21 species) in Leningrad region. In both regions the diversity of Asaphida generally decreases in the Uhaku–Rakvere interval.

The Order Corynexochida is represented by two families: Illaenidae, Stygenidae (Scutelluidae). In total 15 species were recorded (13 species of Illaenidae and 2 species of Stygenidae). The Family Illaenidae is represented by five genera, all are widely common in the Leningrad region and North Estonia, except for *Illaenus intermedius* which occurs only in the Uhaku Stage in North Estonia. The family Srygenidae (Scutellidae) is recorded from North Estonia (Uhaku–Kukruse interval) but not from the Leningrad Region.

The Order Phacopida comprises the suborders Calymenina, Phacopina and Cheirurina, in total 72 species were recorded (3 of Calymenina, 31 of Phacopina and 38 of Cheirurina species). The Suborder Calymenina is represented by one genus only whereas Phacopina and Cheirurina are widely common. The phacopines are represented by the family Pterygometopidae (9 genera), cheirurines with two families, Cheiruridae and Encrinuridae. Diversity is the highest in Cheiruridae but Pterygometopidae are prevailing numerically. Of all recorded Phacopida about 90% occur in North Estonia but less than 57% in the Leningrad region. Through the Uhaku–Rakvere interval, both diversity and number of collected specimens of Phacopida is decreasing.

The order Lichida comprises the families Lichidae (25 species) and Odontopleuridae (6 species). Both families are present in North Estonia and in the Leningrad region, but they are less diverse in the Leningrad Region (less than 50% of recorded taxa are found here). The maximum diversity of this group is related to the interval from Kukruse to upper Oandu.

The order Proetida comprising the families Proetidae, Schariidae, Aulacopleuridae, Brachimetopidae and Dimeropigidae is less diverse than other orders (9 species in total). All families are represented in North Estonia but only Proetidae, Aulacopleuridae and Dimeropygidae are met in the Leningrad Region. Maximum diversity of this group is related to the Kukruse–Oandu interval.

Mishina Gora section and its position on the Ordovician facies profile

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The Ordovician succession exposed in the old quarry near the former village of Mishina Gora (20 km to SE from Gdov, on the eastern shore of the Peipsi Lake) is unique in its characteristics. The succession combines features typical for both North Estonian and Central Baltoscandian Confacies belts and belongs to a narrow transitional area between these two belts. Studies of core sections from Central and SW Estonia demonstrate closest similarity of the Mishina Gora section to the borehole sections from the vicinity of Pärnu. Position of the Mishina Gora section on the idealized lithofacies profile across the confacies belts lies somewhere between Are and Pärnu. In eastern Estonia, the Mishina Gora-type Ordovician successions can be expected in a territory between Põltsamaa and Laeva. The Tjälsten Grey interval between Lanna and Holen Formations of Sweden (Central Baltoscandian Confacies belt) seems to correlates to the member N9 (“Glauconite enriched interval”) of the Mishina Gora section. The Lower Oolite bed (member N7 of the Mishina Gora section) is separated from this interval by marine red bed facies (member N8) that indicates a short time transgression between the regressive events.

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New data on the Ordovician of the Irkutsk Basin

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The field studies in the key Ordovician sections in the Irkutsk Amphitheater in 2007 provided some new data about palaeogeography, facies distribution, depositional environments and sea level changes in the Ordovician epicontinental basin of Southern Siberia. The main conclusions based on these studies are as follows.

1. The Ordovician deposits of the Irkutsk Amphitheater formed in a separated epicontinental basin. During most of the Ordovician time, it had only limited connections with the other basins on the platform. This is evidenced, both, by independent evolution of sedimentation and by specific and endemic character of faunal associations.
2. Numerous measurements of bed dipping directions in the cross-bedded deposits of the Badaran Formation and Mamyr Series indicate that the bottom currents were directed from northwest to southeast. As suggested by changes in thickness and granulometric composition of the sediments, depth of the basin increased in the same direction. Thus, a siliciclastic material was transported into the basin from the north and northwest, from the Enisei Ridge and Katanga Land, but not from the south, from the Altaj-Sayan and Baikal-Vitim folded zones, as it was supposed earlier.
3. A sequence of greenish-grey shales of the Krivaya Luka Formation in the Upper Lena facies zone (the eastern Irkutsk Amphitheater) is a product of erosion of an island-arc association. Formation of such sequence in the southeastern (according to the recent position) margin of the Siberian platform, and the basin deepening, suggest subsidence of the passive margin of the Siberian palaeocontinent in the Middle Ordovician and appearance of a source area of terrigenuous material outside the platform, in the Baikal-Vitim folded area.
4. Depositional sequences corresponding to the Pakerort, Latorp, Volkhov, Kunda and Tallinn sequences of the Ordovician basin of Baltoscandia can be recognized in the Ordovician epicontinental basin of the Irkutsk Amphitheater. This may indicate eustatic character of sea level fluctuations related to these sequences.

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Group of Quaternary meteoritic craters in the east of Moscow area (Russia)

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A group of lakes, Smerdyacheye, Lemeshenskoe and Karpovskoe, is located in the East of the Moscow district, in Shatura region nearby the town Roshal' (140 km from Moscow). They are visible in satellite images and aero-photographs of the territory. All lakes are of the regular rounded shape and of great depth. It is surprising that all of them are located along one line (azimuth 36º NE). Carst is not developed in the area and the lakes are located in Mesozoic sandy-clay sediments. At present, we may surely state meteoritic (impact) origin of these lakes.

The Smerdyacheye Lake is the best investigated one: it is 31.4 meters deep and about 270 meters in diameter. The lake is surrounded by ringed hill. The height of the hill is around 4–5 m above the water level and 1–2 m above the surrounding land. The hill is composed of strongly dislocated sandy-clay deposits, which cover mellow glacial sands. Deposits of the hill contain fragments of flint, developed at the depth of 40–50 m. We found deposit containing melted impact glass in the pits drilled in the hill. In impact glass were found crystals moissanite (SiC). This rare mineral is formed in conditions of high pressures. This mineral was found in Meteor Crater (Arizona, USA) and in several meteorites.

The Lemeshenskoe Lake is located in 4,4 km from the lake Smerdyacheye. It is of the round shape. Diameter of the lake is 290 meters, the depth is around 15 meters. Ringed hill may also be observed here and the hill is composed of sandy deposits. Blister impact glasses were found on a coast of lake.

The Karpovskoe lake is located to the south from the lake Lemeshenskoe at the distance of 4,8 km. Diameter of the lake is around 280 meters, its depth is 17,5 meters. Low ringed hill is observed around this lake. The bottom relief is made of ringed terraces and benches. We found fragments of black blistered impact glass on the shore of the lake.

We implemented the Comparison analysis of morphological parameters of these lakes with the morphology of the known meteor craters, the analysis revealed the significant similarity. Evidently, basins of the lakes were formed after glacier drifted from the territory and their age is less than 10 thousand years. It is not excluded that some other lakes of the Eastern Moscow region are also of meteor nature.

Falling of a cosmic body and formation of craters had catastrophic consequences for the whole region. Thus, according to the estimates, the explosion, which resulted in the formation of only one crater Smerdyacheye was equivalent to the explosion of ten atomic bombs dropped on Hiroshima. Traces of this event (catastrophic layer) are to be found in Quaternary sediments of the region. This layer may be used for the local correlation of the Quaternary post-glacial sediments. The exact age of the craters may be determined based on the analysis of the Quaternary post-glacial sediments, containing the catastrophic layer. Such works have been implemented for a group of craters "Kaali" in Estonia.

It is difficult to overestimate the importance of the founding for the Midland Russia. To preserve the craters it is expedient to apply the successful experience of meteor craters protection of the USA, Germany and Estonia.

Diagnostic microlithotypes for the main facies complexes of the Ordovician in Northwest Siberia

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The type section of the Ordovician (the Kulumbe River section) located in the Igaro-Norilsk Region in northwestern part of the Siberian Platform has been analyzed for microlitotypes in order to distinguish typical facies complexes characterizing environmental conditions and evolution of the sedimentary basin.

Following microlithotypes and complexes were distinguished:

1) Bioclastic packstone with bioclasts represented by broken skeletons of trilobites, brachiopods, gastropods and ostracods. The whole complex displays a flyshoid intercalation of bioclastic packstones and siltstones (Zagorninskaya Formation, Upper Ordovician, Sandbian). The rocks relate to slope facies.
2) Bioclastic wackestone with re-deposited quartz grains and diagenetic dolomite crystals. *Thalassinoides* ichnotextures are very common. Black shales can also occur (Angir Formation, Middle Ordovician, Upper Darriwilian). The rock relates to middle shelf facies.
3) Mudstone to saturated wackestone. This facies complex is located between open-shelf and lagoon. (upper Il'tyk Formation, Floian to Dapingian).
4) Floatstone. Non-carbonate pebbles and glypthomorphoses after halite crystals occur there as well as caverns from gypsum nodules. This litho-type relates to tidal hollows and hypersaline lagoons. (Guragir and Amarkan formations, Darriwilian-Sandbian).
5) Oolite grainstone-packstone. Pure carbonates with ripple marks, flat-pebbled conglomerates, with abundant marine fauna. Extremely shallow-water facies, oolite barrier complex (lower and middle Il'tyk Formation, Tremadoc-Floian).

These microlithotypes are diagnostic for five facies complexes, which reflect four sea-level fluctuations (two transgressions and two regressions).

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Correlation of the Middle and Upper Ordovician rocks of Baltoscandia using CONOP9: preliminary results

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The Middle and Upper Ordovician rocks of Baltoscandia have been spatially divided into distinct, composite litho- and biofacies units called confacies belts. A regional correlation of outcrops (in North Estonia and Central Sweden) and boreholes in different confacies belts has always been problematic due to the pronounced biogeographical and lithofacies differentiation. Chronologically, the traditional Baltoscandian Stages were also defined by combined litho- and biofacies assemblages, primarily mainly by benthic macrofossil faunas, and the base of most of the Baltoscandian chronostratigraphic units have not been defined by diagnostic fossils. The stage boundaries do not closely coincide with commonly used microfossil biozone boundaries (North Atlantic conodont, Baltoscandian chitinozoan, or graptolite zones). We used the quantitative correlation method constrained optimization (CONOP9) to analyze the stratigraphic range information of 404 chitinozoan, conodont, ostracod, and graptolite species and construct a best fit correlation model among 14 boreholes and one outcrop in Baltoscandia (Poland, Latvia, Estonia, and Sweden).

These sections span three confacies belts, the Scanian (slope, black shale), Central Baltoscandian (outer shelf, argillaceous limestones), and North Estonian (carbonate platform) belts. Generally, the Central Baltoscandian are more continuous and contain substantially more events (taxon FAD's and LAD's) than the North Estonian platform sections. This is especially true in the Upper Ordovician where the North Estonian strata contain more numerous and larger gaps. In order to examine the synchronicity of the Baltoscandian Stage boundaries we coded each one as a unique event in the individual sections and examined their placement within the CONOP composite. The Lasnamägi, Uhaku, Pirgu and Porkuni Stage bases were not well constrained with respect to the microfossil range data. However, these subdivisions are also as lower- and uppermost subdivisions in our investigated sections, where taxon FAD's and LAD's data need an additional revision. Conversely, the Kukruse through Nabala stages (lower Upper Ordovician) have boundaries that better approximate synchronous surfaces. Conodonts had the lowest *per* taxon, *per* occurrence penalty assessment indicating that for the available data (four sections), conodont ranges were the most consistent across the study area. Penalty assessments for chitinozoans (all sections) and ostracods (four sections) were not significantly different.

Facies and sequences of the Vormsi Stage of the East Baltic

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The regional facies relations of the Vormsi Stage are wellknown but sequence stratigraphic interpretations have varied. For this study the thickness and facies relations are examined from about 100 cores. Stratigraphic relations are based mainly on chitinozoan biostratigraphy.

In the North Estonian Shelf, the contact between the Vormsi strata and the underlying Nabala ramp deposits (Saunja Formation) is sharp and marked by erosional channels (up to 15 m deep by data from cores). In shelf sections the lower chitinozoan subzones (*Fungochitina spinifera* and b1-2) occur in transgressive deposits, the upper subzones (b2-1 and *Acanthochitina barbata*) are characterized by shallowing-upward, prograding shallow shelf carbonate successions that are capped by higher-energy, grain-supported facies. Vormsi shelf sections are 10–20 m thick.

The transition from outer shelf facies to basinal is marked by a relatively abrupt decrease in thickness less than 6 meters. This corresponds to a change from mixed grain and mud-supported carbonates to exclusively mud-supported lithologies. The transgressive carbonate thins and pinches out toward the southern side of the transition zone where the unit is unusually thin (Ruhnu, Ohesaare, Ikla) and is represented mainly by beds with *A. barbata*. The top of the Vormsi appears truncated locally where the uppermost chitinozoan subzone is not found in cores studied biostratigraphically (Viljandi, Kaugatuma). The distribution of truncated sections indicates that the transition from shelf to basin settings was locally the site of erosion along the sequence boundary that shifted or steepened the original shelf profile.

South of the transition zone, Vormsi strata are less than 5 m and grade from mud-supported argillaceous carbonates into the black Fjäcka Shale. In the central Livonian Basin, a thin (0.2–1.2 m) argillaceous carbonate occurs below the Fjäcka Shale.

In contrast to the patterns along the north flank of the Livonian Basin, the Vormsi sections in the Lithuanian Shelf sections are generally 10–15 m thick, and lack clear evidence of regional progradation. The lithologies are muddy and grain-supported.

The transect across the North Estonian Shelf to the Livonian Basin indicates that the Vormsi Stage is a single sequence. The thin basinal limestone is the lowstand deposit that corresponds to the erosion and channeling of the post-Nabala surface in shelf areas. The transgressive deposits include a lower carbonate unit and overlying argillaceous unit in shelf and transition areas. The overlying shallowing-upward successions are markedly progradational in the late highstand interval as shoal deposits infilled the shelf. At the top of the sequence, erosion of the outer shelf margin resulted in a sharp shelf break that was retained into overlying shelf successions. The basin center was starved during transgressive and highstand deposition as evident by the Fjäcka Shale.

The lack of progradation in Lithuanian Shelf sections indicates that vertical accumulation did not completely fill the available accommodation space, and that higher subsidence rates characterized this part of the basin. The coincidence of the differential subsidence rates, the shift from ramp to shelf systems (North Estonian Shelf), and the timing of the contemporaneous initial interaction of Baltica and Avalonia suggests that regional tilting was responsible for these stratigraphic changes across the East Baltic.

Lake ecosystem responses to Holocene environmental changes: two diatom-based high-resolution case studies from southern Estonia

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Diatom analyses of two lake sediment cores from southern Estonia have provided important insights into understanding the Holocene environmental history of these lakes. The study is mainly based on diatom analysis, these aquatic sub-fossils preserved in sediments give precise data for reconstructing past trophic changes in lakes. Additional information is extracted from pollen evidence, which allows tracking of climate change, vegetation history as well as prehistoric human impact on the lake catchment. Chronology of the core from Lake Rõuge Tõugjärv (57º44´30´´N; 26º54´20´´E; surface area 4.2 ha; max. depth 17 m) was established on the basis of counting annually laminated lake sediment varves and the varvochronology of the sequence was validated by ^{14}C dates and paleomagnetic measurements. Chronology for Lake Tollari sediment sequence (57º45´08´´N; 26º20´27´´E; surface area 5.7 ha; max depth 10 m) was developed by 10 radiocarbon dates. Lake environment changes during the Holocene in the light of succession of diatom assemblages and diatom inferred lake water total phosphorus concentration are described and impact of climate and long-term agricultural land-use practises on the lake ecosystem are discussed.

Biogeography of early Paleozoic scolecodont-bearing polychaetes: new data from South China and Tarim

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Scolecodonts, the jaws of eunicidan polychaetes, constitute one of the most common groups of acid-resistant microfossils in Ordovician and Silurian deposits, reflecting the prominent role of polychaetes in early Paleozoic communities. Despite more than 100 research papers and monographs devoted to early Paleozoic scolecodonts and increasing publication activity starting from the 1990s, the global knowledge on this group is still meagre. Almost half of the publications deal with the Baltic material and more than a third are based on North American collections; thus less than 20% of publications describe faunas of other regions. Moreover, none of these papers is based on comparably large collections and/or apparatus-based classification concept. Therefore, the global picture of the palaeobiogeography of this fossil group is strongly biased and every new account from the hitherto poorly known continents and regions deserves full attention.

The palaeocontinents that make up what is now China are generally well characterized palaeontologically. Scolecodont records from China are nevertheless practically absent apart from a few notes on their occurrence. In 2007 efforts were made to find scolecodonts from the acritarch and chitinozoan collections deposited at the Nanjing Institute of Geology and Palaeontology, and several large samples were collected during the Yangtze Conference field trips to South China, with particular emphasis on the limestones of the Yangtze Platform.

Study of acritarch and chitinozoan slides revealed common occurrence and relatively good preservation of scolecodonts in the Tarim Basin (Xinjiang province). On average one-third of the samples contained scolecodonts, the richest slide nearly 100 teeth and jaw fragments. Several genera well known from Baltica were identified from the Hetian-1 well and Dawangou section (Caradoc): *Oenonites*, *Tetraprion*, *Lunoprionella*, *Mochtyella* and possibly *Ramphoprion*, *Xanioprion*, *Pteropelta*, *Kalloprion* and *Pistoprion*. In addition, a peculiar left MI with a prolonged posterior margin and postero-medially directed appendage of a new labidognath genus and possibly a new family was recovered.

Out of the 15 new samples processed so far, only three contained scolecodonts. The low yield of organic-walled microfossils is partly due to the thermal overprinting (CAI values 4–5 in many samples) and strong effect of weathering. A specimen of fused elongated placognath maxillae, possessing one row of denticles and resembling slightly the jaws of *Lunoprionella*, was recovered from the Dawan Fm (Floian) of the Chenjiahe section (Hubei province). It confirms the earlier opinions that most of the Early Ordovician scolecodonts were primitive forms with placognath/ctenognath apparatuses. The Meitan Fm (Dapingian) of the Honghuayuan section (Guizhou province) contained a richer fauna with species of *Oenonites* and *Mochtyella*-like placognaths. Possibly the assemblage contains also *Pistoprion*, which would be the earliest record of this genus common in younger strata in Baltica. The same sample was also rich in chitinozoans. The Shihniulan Fm (Llandovery) of the Daijiagou section (Guizhou) yielded a rather abundant but poorly preserved assemblage of *Oenonites*, *Mochtyella* and a possible prionognath.

These new finds of scolecodonts from China allow extending the biogeographical distribution of several early Paleozoic polychaete genera. They confirm that many Ordovician and Silurian genera had intercontinental distribution and that the polychaete faunas of South China and the Tarim Basin were rather similar to those of Baltica.

Multiphase Silurian bentonites from western Estonia: possible diagenetic pathways

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Succession of Silurian carbonate deposits of western Estonia, once formed in shallow-water peripheral part of the Baltic Palaeobasin, contains more than 50 distinct altered volcanic ash beds. These beds differ from typical lower Paleozoic bentonites of the region by the occurrence of heterogeneous authigenic mineral assemblage, composed of illite-smectite (I-S), kaolinite (Kaol) and K-feldspar (Kfs). In order to determine the variables responsible for the development of multiphase mineral assemblage the whole-rock and clay mineral composition were studied in the Ruhnu and Ohessaare drill cores. These cores represent some of the most complete Silurian sections in Estonia.

Quantitative whole rock mineral composition of the beds was measured by XRD using Siroquant-2.5 software, and the clay minerals were identified by XRD coupled with NEWMODE and MLM2/MLM3C modeling.

The typical Silurian bentonites from Scandinavia are characterized by considerably homogenous illite-smectite composition. The corresponding beds studied in Estonia have mineral composition ranging from illite-smectite dominated assemblages to varieties composed almost entirely of potassium-feldspar or kaolinite.

The total observed I-S–Kaol–Kfs assemblage is thermodynamically unstable under low-temperature conditions. However, the lower Palaeozoic complex of the region has never been deeply buried and the maximum burial temperatures apparently stayed below 60°C, thus excluding the possibility of potential late diagenetic high-temperature alteration of the bentonites.

The ratio of the authigenic minerals varies greatly between individual layers as well as laterally within a single bed. In some cases distinct bentonites with contrasting composition occur in distance of some tens of centimeters. Interestingly, I-S in all studied beds falls into narrow composition range having R1 ordered structure with 58–70% illitic layers. We propose, that observed variations probably reflect the bentonite development and diversification during initial stages of volcanic ash transformation and diagenesis. Comparison with mineral stability and transformation in recent marine pyroclastic diagenetic systems suggest that the early evolution of the bentonites comprised at least two metastable phases, early smectite and zeolite, which during progressive diagenesis were replaced by I-S and Kfs, correspondingly.

The transformation of ash to either primary zeolite or smectite was controlled by aluminium and silica activity in pore water. The low pH needed for kaolinite stabilization was probably locally induced by the decomposition of organic matter as the occurrence of Kaol coincide with higher content of organic matter in the succession.

Several internal factors, like the composition host rocks (incl. organic material content) and interstial water, and also permeability of the ash beds, have probably played a key role in defining compositional variability of the studied Silurian bentonites.

The key section of the Shundorovo Formation (the Idavere Regional Stage) in the western part of St. Petersburg Region: lithostratigraphy and sedimentology

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The upper part of the Idavere Regional Stage is represented by the Shundorovo Formation that corresponds approximately to the Vasavere Formation in North Estonia. Stratigraphy of this unit is still poorly known because of the absence of complete sections and general scarcity of stratigraphically important faunal remains. At present, the Kas`kovo Quarry is the only representative section in the type area. In the drill cores of the type area a thickness of the Shundorovo Fm. is about 13–15 m, whereas in the Kas'kovo Quarry only 10 m is exposed. In this locality the formation consists of an alteration of two contrasting carbonate lithofacies: unstratified mudstones and bedded storm-derived bioclastic limestones (secondary dolostones). This alteration reflects the cyclicity of flooding and shallowing.

Blocky unstratified mudstones are composed of bioturbated marl and/or argillaceous limestone beds (1.2–1.6 m thick) without inner stratification. Mudstones consist of dolomitized fine-grained carbonate matrix with rare bioclasts and scarce quartz silt. There are few but diverse remains of crinoids, brachiopods, and very sporadic gastropods. The specific features of these lithofacies is the occurrence of relatively abundant organic-walled tests of *Tasmanites* and graptolites.

Mudstones are thought to be formed below the basis of storm-waves, under conditions of low sedimentation rate and continuous (argillaceous-) lime mud supplement. These layers are strongly compacted. This is evident from the deformed *Thalassinoides* traces, organic-walled tests of *Tasmanites*, and calcareous shells. The traces of selective dissolution of aragonite constituents are common. Calcitic bioclasts and fossils have undergone dissolution and nonmimical replacement by dolomite in late stage of burial diagenesis.

Bedded bioclastic limestones with "marly" interbeds (0.3–1.0 m thick) represent a relatively shallow-water member in the succession. We interpret them as storm-derived beds (5–10 cm thick) that were originally composed by skeletal wacke- to packstone (locally floatstone) enriched by large fragments of macrofauna, mostly brachiopods and gastropods. Organic-walled tests of *Tasmanites* and graptolites are rare. In some layers cross stratification, intraclasts and vertically oriented shells occur. In limestones, tunnels of *Thalassinoides, Tasmanites* and delicate calcareous shells are undeformed or only slightly deformed, indicating early lithification of the sediment. These beds are now completely changed to fine-grained yellowish dolostones with abundant moldic porosity and "ghosts" of bioclasts, although primary skeletal structure can be recognized often. "Marly" interbeds (1–3 cm thick) consist of argillaceous limestones or marls with the structure of bioclastic mudstone and traces of compaction.

Wide occurrence of **sponges and related flinty nodules** in all lithofacies is the unique feature of the Shundorovo Fm. The stratigraphic distribution of sponges is clearly controlled by facies, and the amount of nodules in rocks directly depends on sponge abundances. In mudstones rare and partly dissolved rounded sponges of genus *Hindia* are most common. In contrast, bedded bioclastic limestones contain more abundant and diverse sponge assemblage (genera *Hindia, Carpospongia, Caryospongia, Astylospongia, Aulocopella*) as well as numerous flinty nodules. Sponges and their spicules dissolved during early diagenesis were the source of silica for different nodules, including those that were formed by passive infilling of *Thalassinoides* traces.

Viséan vertebrate assemblage of Moscow Syneclise

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A taxonomically diverse vertebrate assemblage was found in the Upper Viséan deposits of the Novgorod Region (north-eastern slope of Moscow Syneclise, Russia). The assemblage includes abundant chondrichthyan teeth and scales, rare acanthodid and elonichthyoid scales (Savitskiy *et al*. 2000). The chondrichthyan teeth belong to the phoebodontiform *Thrinacodus ferox* (Turner), symmoriiform *Stethacanthus* and *Denaea* sp. nov., two ctenacanthiforms resembling the teeth of *Glikmanius* and *Saivodus*, anachronistid *Cooleyella* cf. *C. fordi* (Duffin & Ward) and a new genus, hybodontoid *Sphenacanthus*, polyacrodontid "*Lissodus*", petalodontiforms, helodontiforms, and psephodontiforms. The chondrichthyan scales are represented by ctenacanthid, protacrodontid, orodontid, hybodontoid and neoselachian types.

Similar Late Viséan assemblages occurs in the Kuznetsk Basin, Siberia, Polar and South Urals, Russia (Rodina & Ivanov 2002), Holy Cross Mountains, Poland (Ginter 1995), Dinant Synclinorium, Belgium (Derycke *et al.* 2005), and Derbyshire, England (Duffin 1993, and author's data).

Analoquous assemblages are known also from Belgium (Royseux locality) and England (Steeplehouse quarry). Additional to several taxa mentioned above the assemblage from Royseux contains teeth of xenacanthiform *Bransonella nebraskensis* (Johnson), teeth of symmoriiform *Denaea wangi* Wang, Jin & Wang, teeth of protacrodontid *Protacrodus aequalis* Ivanov and the scales of various actinopterygians. However, the polyacrodontids are missing in that assemblage. The assemblage from Derbyshire includes additionally teeth of two polyacrodontids, "*Lissodus*" *zideki* (Johnson) and "*L.*" *wirksworthensis* Duffin.

Such assemblages of Late Viséan marine fishes are wide distributed and comprise many common taxa. Therefore they can be used in correlations of the Upper Viséan deposits in different palaeogeographic provinces.

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Devonian vertebrates from the Andoma Hill and correlation of sequences in western and eastern parts of the Main Devonian Field

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Givetian-Frasnian deposits of the western part of the Main Devonian Field (MDF) including Baltic States and north-western Russia are rich in vertebrate remains suitable for correlation purposes, and typical assemblages of placoderm and heterostracan zones established for this interval are widely distributed in the East European Platform. Still, some intervals corresponding to the Frasnian carbonate facies demonstrate scarce remains of vertebrates with low value for correlation. Recently, in result of extensive lithological, sedimentological and palaeontological studies over several fieldwork seasons at the Andoma Hill (Onega Lake, Russia), three new formations have been established (Ivanov *et al*, 2006). All three formations (Pavlikovskaya, Andoma and Klimovskaya) consist of siliciclastic deposits well characterised by plant, animal and trace fossils.

The fossil fish remains from the Andoma Hill, though often fragmentary but rather diverse, provide clear succession of vertebrate assemblages within the siliciclastic sequence. Based on the comparison of vertebrate assemblages tentative correlation of the Pavlikovskaya, Andoma and Klimovskaya formations with the Givetian-Frasnian sequence in the western part of MDF is provided. Vertebrate assemblage typical for the *Asterolepis ornata* zone has been found in the upper part of the Pavlikovskaya Formation. It allows to correlate this part of the section with the Gauja Regional Stage. Fish and agnathan assemblage from the lowermost Andoma Formation corresponds to the *Bothriolepis prima–B. obrutschewi* zone, which lies within the Amata RS. The *Bothriolepis cellulosa* zone reliably belonging to the Frasnian and corresponding to the lower and middle part of the Pļaviņas RS, can be traced in the middle and upper parts of the Andoma Formation, as well as at the base of the Klimovskaya Formation. The middle part of the Klimovskaya Formation contains scarce remains of non-indicative vertebrates and at present correlation to the zonal succession is impossible. The vertebrate assemblage from the uppermost Klimovskaya Formation is not well established due to a rather poor preservation of fossils. Still, it yields the remains of *Psammosteus falcatus* characteristic for the middle or upper part of the Frasnian sequence. Preliminary results of processing of the fossil material demonstrate the upper Givetian–middle Frasnian age of the succession thus modifying previous conclusions regarding the age of the rocks exposed at the Andoma Hill.

The completeness of the Devonian section on the MDF decreases from southwest to northeast and interval of sedimentary break increases. However, this study shows that the Devonian sequence of the Andoma Hill could be more complete than sections from the surrounding area in the eastern part of MDF.

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Ordovician–Silurian boundary beds at Neitla, North Estonia: sedimentological and carbon isotopic signatures of events, some consequences

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Geo- and bio-events connected with the Hirnantian are highlights of the Ordovician history. However, dating of some events is far from being exact, vice versa we have doubts even about timing of the well-known mass extinction etc. In Baltic carbon isotopes have been helpful for time correlation, but gaps below, within and above the Porkuni Stage complicate construction of a standard curve considerably. Therefore any new outcrop of these beds deserves close attention.

Neitla outcrop is a new locality of the Ordovician–Silurian boundary beds recently discovered by R. Einasto in a gravel-pit ca 5 km east of Järva-Madise, Järvamaa County. A section of rocks was measured and sampled as follows (from top): 1. The Varbola Formation (Juuru Stage, Silurian) — 1.2 m marl- and argillaceous limestones (mainly wackestones) with thin skeletal limestone intercalations, dominating in the top. The lowermost 0.3 m represented by nodular micritic limestone with a few packstone interbeds belongs to the Koigi Member (Mb). In the bottom of the latter a clear discontinuity surface occurs. 2. The Ärina Formation (Porkuni Stage, Ordovician): the Kamariku Mb — 1.3–1.4 m silty dolostones with green dolomitic marl- and red claystone interbeds in the lower 0.5 m and several discontinuity surfaces, in the uppermost 20 cm in particular. Direct contact with the underlying Tõrevere Mb is not observed, but a typical for the latter coral-bearing biohermal mound (diameter ca 10 m, height 0.5+ m) rises from the quarry bottom close to the measured wall. Micritic limestone is highly variable, skeletal particles are scattered in the matrix.

Carbon isotopes were analysed from 18 samples. Results are as follows: Tõrevere Mb shows the $\delta^{13}C$ value of 4.5‰, in the the lowermost Kamariku Mb 3 values are between 2.9–3.5‰, in the uppermost 20 cm of the Kamariku Mb values from 9 samples vary between 0.7–1.3‰ with clear cyclic changes by beds. Silurian shows falling limb of the $\delta^{13}C$ curve: 3 samples from the Koigi Mb 1.4–1.3‰ and values from 2 samples higher in the Varbola Fm fall below the zero -0.9 and -1.2‰. In summary we conclude that at Neitla the Hirnantian carbon isotope excursion is represented by a peak value in the Tõrevere Mb followed by slightly lower values in the Kamariku Mb. The general pattern is very similar to that observed in the Porkuni stratotype and nearby sections (Hints et al., 2000), but not only, e.g. the Ruhnu a.o. curves.

Sedimentological change above the Tõrevere mounds is substantial (silt influx etc.), but the $\delta^{13}C$ curve don't suggest any notable gap. A series of discontinuity surfaces and linked to them cyclic decrease of the $\delta^{13}C$ values is more characteristic to the uppermost Hirnantian than to the middle Porkuni as a current correlation shows (Hints et al., 2000). A microlaminated dolostone bed at the top of the Kamariku Mb points to a specific facies story towards the end.

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Unusual quartz forms in Ordovician bentonites

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Pyroclastic material in Lower Palaeozoic bentonites of Estonia and Latvia is commonly in a size below 0.1 mm and rarely larger. Remarkable exceptions are ash layers from Keila Stage (Caradoc), where pyroclastic material is often of larger grain size and reaching 0.5 mm. Common pyroclastic minerals are quartz, sanidine and biotite with minor addition of zircon, apatite and some other minerals. Broken phenocrysts with sharp angles are typical for bentonites.

In bentonite from Aizpute-41 drill core (depth 1049.35–1049.50 m, upper part of Adze Formation) curious elongated quartz crystals with dissolution surfaces were found. By shape these crystals resemble icicles growing at eaves of roofs. Some have preserved (fully or partly) faces and angles of prismatic crystals, others are subjected by step-like dissolution of surface destroying original prismatic external shape of quartz. Usually crystals are not straight, but a little bit curved. The crystals are elongated (diameter 0.07–0.1 mm and length up to 0.8 mm), transparent and containing extremely rare inclusions. We found similar quartz forms also from Vasagård section on Bornholm in the *Dicellograptus* Shale (*D. clingani* Zone). These two finds are the only ones among hundreds of bentonite samples we have looked during last ten years.

Byström (1956) published photograph of similar forms from Mossen. Stratigraphic level of her sample No 15 was not exactly defined, but undoubtedly it was within Caradoc.

Bipyramidal β-quartz is common for high temperature crystallization from magma. Prismatic quartz crystals are not characteristic for magmatic phenocrystals and occur preferably in hydrothermal veins as druses. Prismatic water-clear quartz cannot grow and dissolve in sediments during diagenesis. Therefore we propose following hypothesis for origin of these rare quartz forms:

1) Formation of fissures in volcanic cone under pressure from magma chamber.
2) Penetration of silica rich hydrothermal fluids into fissures in volcanic cone and precipitation of quartz druses.
3) Rise of temperature in fluids before eruption and start of dissolution of quartz crystals.
4) Volcanic eruption destroying the volcanic cone and distributing ash and quartz crystals to wide areas.

Considering above hypothesis for origin, and rare occurrence, these quartz forms can be used as correlation criterion for this eruption layer in Caradoc.

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Mire stratigraphy in Latvia

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Approximately 10% of Latvia is covered by peatlands and mires, which include more than 6000 raised bogs, fens and transitional bogs. They have been formed under different geological and paleoecological conditions and at different time.

Latvian mires date from as long ago as the very Late Glacial time and beginning of the Holocene. At the beginning of the Preboreal, around 10 300 years ago, the territory of Latvia was completely free of the glaciers' ice, the climate became milder. In the depressions around lakes became favourite conditions for gyttja and fen type peat accumulation. The largest part of the oldest mires, which started to develop during the Preboreal, originated filling in of smaller or larger lake depressions, including glaciocarst depressions at the uplands.

Around 9 000 years ago, when the Boreal climate became warmer and less humid, the groundwater level decreased. The mire vegetation gradually started to be fed mainly by rain waters. The eutrophic plant species were gradually replaced by mesotrophic ones. *Hypnum* moss was replaced by sphagnum moss and cotton-grass (*Eriophorum vaginatum*). During the Boreal Time a number of the largest mires were formed. Some of them gradually turn from fens to transitional mires, and the first layers of raised bog peat started to form.

About 7 400 years ago the climate became warm and humid. In the central areas of the many mires vegetation subsisted only on precipitation. In these parts ombrohophic raised bog vegetation developed. When it decayed, raised bog peat was formed with transitional peat at the edges of the bog.

During the Atlantic Time low coastal areas of the Littorina Sea were overflowed and large shallow lagoons were formed. Nowadays just the deepest ones are preserved as lakes (Kanieris, Engure, Babite), but the shallowest are overgrown and have became bogs.

About 4 800 years ago the Subboreal Time set in with dryer and little bit cooler climate. In this period the bog phytocenoses were basically formed by sphagnum and cotton grass which produced magellanicum-sphagnum peat at the decaying. Thick layers of sphagnum peat have been formed in large number of bogs.

At the second half of the Subboreal, before 3500–3000 years, the inter-dune mires started to form in the northwestern coastal area of Latvia, predominantly in the region of novaday Slitere National Park.

About 2 800 years ago, during the Subatlantic Time, climate became cooler and more humid. For this period was characteristic very intensive formation of low decomposed sphagnum peat in the largest mires.

During last hundred years mire development has been significantly influenced or stopped by drainage and peat cutting. Mire stratigraphy has been used for estimation of peat age, calculation of accumulation rate, and understanding mire formation and development dynamics. It helps also to find differences of accumulation rate and resource values between raised bogs and fens. Knowledge of mire stratigraphy and development is very important for their management and protection.

Late Silurian tessellated heterostracans from the East Baltic and North Timan

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Tesserae and scales of *Strosipherus* (= *Oniscolepis*) from Lõo and Ohesaare cliffs, Saaremaa Island, Estonia, were described for the first time by Pander (1856). Later on scattered exoskeleton elements of this genus, found in the boulders of the North German Lowland and Saaremaa Island, were re-studied by Gross (1961). Tesserae and scales of *S. indentatus* from North Timan and *Strosipherus* sp. from the uppermost part of the Jūra Formation in Lithuania were described by Karatajūtė-Talimaa (1970). Tesserae of *S. indentatus* with lateral line system pores were presented for the first time in Märss (1986), along with the description of the material from the type locality and the stratigraphical range of the taxon. The morphological variability of tesserae and scales of *Strosipherus* is high (see Pander, 1856; Karatajūtė-Talimaa, 1970). Histologically the superficial layer of *Strosipherus* consists of the orthodentine of ridges and tubercles. The middle layer is of well expressed spongious tissue. The middle layer of the scales is very dense in old scales and is penetrated by vascular canals. The basal layer is not very distinct; it is pierced by relatively sparse vertical ascending vascular canals.

Reddish-brown spotted uppermost Silurian siltstones cropping out on the banks of the Velikaya River, North Timan, Komi, contain abundant microremains of vertebrates such as thelodonts, osteostracans, acanthodians and heterostracans (Valiukevičius et al., 1983). The heterostracans are represented by fragments of the shield and scales of *Tolypelepis* Pander, and by numerous tesserae and scales of *Strosipherus indentatus* Pander. In the report and following paper the species content of the genus *Strosipherus* will be discussed.

Besides typical *Strosipherus*, the material comprises tesserae with sculpture elements similar to *Kallostrakon* Lankester and *Corvaspis* Woodward. The carapace of *Kallostrakon* was composed of cyclomorial tesserae, and discrete plates formed by fusion of tesserae. The specimens described by Halstead Tarlo (1964, 1965) represent large plate fragments superficially subdivided into tesserae, and smaller pieces of large plates. On either side of a tessera, a central longitudinal ridge or primordium has successive ridges, which were added until the growth of the tessera was complete. It is difficult to ascertain to which extent *Kallostrakon* was covered with plate(s) and tesserae. Its lateral line system is not known.

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Reconstruction of currents in the Ordovician–Silurian Baltic Basin

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The central Baltic Basin got terrigenous material from two main denudation areas, from the Baltic Shield and from the Ukrainian Shield. Temporally the Rügen Caledonides contributed material to the Basin as well. The main pathways of sediment income changed from time to time. The Ukrainian-side sediment influx was active in the Arenig–Llanvirn (Ordovician), and in the Llandovery (Silurian). Material from the Rügen side reached the central Baltic in the Caradoc–Ashgill (Ordovician). The change in sediment influx is recorded by mineralogy, geochemistry and grain size in a deep shelf Aizpute-41 core. Kaolinite and Cr were the indexes of the sediment income direction. Kaolinite is recorded in the Byelorussian sections through the Ordovician and Silurian (Ropot & Pushkin, 1987; Ropot, 1981), whereas in the Estonian geological sections the kaolinite is not identified (Põlma, 1982; Jürgenson, 1988), except in metabentonites. In the Aizpute-41 core the kaolinite is identified in the Arenig–lower Caradoc and Llandovery strata. Two times elevated Cr content in the Caradoc–Ashgill interval in the Aizpute-41 core, about 200 ppm in the terrigenous component, is supposedly derived from the chromite grains of which are recorded in the ophiolites of the Rügen 5/66 borehole (Giese et al., 1994).

The sediment was transported by water flow, which turned into more rapid currents at times. In the Arenig–early Llanvirn, Mid-Ashgill, and Late Llandovery the oxygenated currents came from the ocean surface waters facilitating red facies formation in the central Baltic Basin. Currents on the shelf were linked to the adjacent oceanic ones. In accord with the Baltica drift equator-ward the waters reached the Baltic shelf from different parts of the ocean. In the Arenig–Llanvirn the current came from the Ukrainian side and ran northward. It was probably a continuation of the West Wind Drift. In the early Caradoc and mid-Ashgill the current came from the west, and was a continuation of the southern branch of the Subtropical Gyre. In the Late Llandovery the current reached again from the Ukrainian side, made a crescent in the central part of the Baltic Basin and quitted to the west. Now it was a continuation of the northern branch of the Subtropical Gyre. Distinguishing of currents makes it easier to understand climatic changes, faunal distribution, and sediment accumulation in regional as well as in the global scale.

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A new correlation tool: chemostratigraphy based on the sanidine composition of bentonites – recent achievements and future perspectives

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Altered volcanic ashes (bentonites, K-bentonites, metabentonites) in sedimentary sections serve as uniquely precise correlation levels. Their importance in correlation of the Lower Palaeozoic of Scandinavia was recognized more than half a century ago (Thorslund, 1945). Nevertheless, only a few eruption layers with remarkable thickness and definitive biostratigraphic position were successfully correlated over large areas (Bergström et al., 1998; Vingisaar, 1972). Noteworthy advancement was achieved using chemical fingerprinting of bulk altered ash and of magmatic phenocrysts (Batchelor & Jeppsson, 1999; Bergström et al., 1995). Recently, composition of magmatic sanidine, $(K,Na)AlSi_3O_8$, was used for identification of Llandovery bentonites in Estonia and Latvia (Kiipli & Kallaste, 2002). XRD measurements of sanidine reflection give quantitative characteristic for many ash layers enabling to recognize these layers in distant sections and different facies zones. Sanidine composition varies between 20–59 mol % of sodium component being stable within a single eruption bed. Precise correlation of conodont and graptolite zonation using bentonites as time markers helped to refine position of Llandovery/Wenlock boundary in graptolite zonation scheme (Kiipli et al., 2008). At the present state of knowledge sanidine can be used in wide area including Baltic States, Gotland and South-Central Sweden. In sections heated more than $100^{o}C$ (Oslo region, Bornholm, Podolia) sanidine was recrystallized and other correlation criteria must be used. In Ordovician and Silurian of Estonia and Latvia 140 eruption layers were found.

Future aims are to correlate all these volcanic ash layers over wide areas, refine correlations of sections using bentonite stratigraphy together with biostratigraphy and via mapping of distribution of layers establish connections with source volcanoes.

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Microfossil dynamics and biostratigraphy in the Väo Formation (Darriwilian) of NW Estonia

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The Middle Ordovician Darriwilian Global Stage, embracing the topmost Volkhov Stage and Kunda, Aseri, Lasnamägi and Uhaku regional stages in the Baltic area, represents a crucial interval of geological time characterized by rapid diversification of several groups of organisms. The Väo Formation, most of which corresponds to the so-called Building Limestone, is distributed in northern and central Estonia and comprises the Lasnamägi and lower Uhaku stages. The formation is rich in shelly faunas and different groups of microfossils. Some of the highest diversities of acritarchs and chitinozoans in the Baltic Ordovician, and also the major diversification of jaw-bearing polychaetes are found in this interval.

The aim of this ongoing study was to analyse the dynamics and mutual distribution of different microfossil groups and to contribute to biomicrostratigraphy of the Building Limestone. The study concentrates on the Uuga cliff on the Pakri Peninsula, NW Estonia, which is one of the key sections of Lower and Middle Ordovician strata in Estonia. The interval from Aseri to Uhaku stages was sampled bed-by-bed. Microfossils were extracted from 62 samples by acid digestion. In order to characterize the sedimentary succession and palaeoenvironments, the same samples were analysed also for chemical composition and stable carbon isotope record. Additional microfossil data come from the cliff on the nearby Väike-Pakri Island.

The studied succession at Uuga cliff is composed of limestone and dolostone with variable content of siliciclastic material (SiO_2 values reaching 13% in the basal part of the section). The $\delta^{13}C_{carb}$ curve shows only slight variations with most values in the -1.0 to 0.0‰ range. Chitinozoans, scolecodonts, conodonts and acritarchs turned out to be the most common acid-resistant microfossils in the samples. The microfossils are excellently preserved, except in the dolostone bed, and the conodont colour alteration index (CAI) is 1.0.

The chitinozoan abundance varies greatly, ranging from 5 to 130 specimens per gram of rock. The entire collection contains more than 40 species, among which *Euconochitina*, *Belonechitina*, *Cyathochitina* and *Desmochitina* commonly predominate. Usually, the dominant species make up 40–60%, occasionally nearly 90% of the assemblage. Below the Pae Member (“dolomite bank”), chitinozoan abundance decreases gradually, showing subsequently a gradual increase within the member. This might denote an increased deposit input or impoverished assemblages, indicating also that the formation of the dolomite bed is likely related to the environment rather than being merely a post-depositional feature. Chitinozoan biostratigraphy fits rather well with earlier data from the Lasnamägi quarry and the interval contains several well traceable levels (e.g., appearance of *Conochitina clavaherculi*). The recurrent patterns of *Cyathochitina* species have also been recorded in the Uuga section, possibly implying a gap in the basal part of the Väo Formation.

Other groups are still being studied, but the preliminary observations confirm high abundance and diversity of acritarchs, conodonts and scolecodonts. Biostratigraphically, the lineage of the conodont genus *Eoplacognathus*, common in the samples studied, provides another possibility for subdividing the Väo Formation.

The graptolite *Gymnograptus linnarssoni*, which occurs in the upper part of the Väo Formation in the Tallinn area and is used for drawing the base of the Uhaku Stage, was not recovered from the Uuga section. Further efforts are needed to ascertain if this indicates a gap in the section or results from unfavourable facies.

Fossil ostracod fauna from the sediment intrusions at the Osmussaar Island

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Osmussaar Island, situated near the North-West coast of Estonia, is a relict island of the Baltic Klint, where the exposed carbonate section at the northern part of the island ranges from the Hunneberg to the Uhaku Stage. The most intriguing part of the Osmussaar section is related to the Volkhov and Kunda stages, where the limestone is split into blocks and penetrated by veins and bodies of breccia-like sandstone, the so-called sediment-intrusions. The sediment intrusions consist of yellow to grey-coloured (and the mixture of these both) calcareous quartz sandstone.

For the pilot study, ten samples from different intrusion rock types were disintegrated with hyposulphite. Yellow-coloured rock provided the greatest number of ostracods, grey-coloured rock contains much lesser ostracods. Grey rock is rich in pyrite, it can be presumed, that most fossils were destroyed in the course of pyritization. The XRD analysis of the rock showed that the mineral composition of it is: 75% Mg-calcite, 22% quarz, 2% illite and 1% pyrite.

Apart from some new, undescribed species, most ostracods have previously been described from the Kunda Stage. While some of the species, like *Glossomorphites grandispinosus*, *Ogmoopsis bocki* and *Aulacopsis simplex* have been documented from a wide range of facies from the Baltoscandian Palaeobasin, certain species, like *O. alata*, *O. variabilis* and *Aahithis varia* (Sarv, 1959) have been described from a certain rock type only. Sarv (1959) described specific ostracod fauna from the erratics of Pakri sandstone from Estonia, and Schallreuter (1989, 1993) described ostracod fauna from the erratics of the so-called Rogö-Sandstein. Both rocks probably represent the Pakri Formation of the Kunda Stage.

About half of the ostracod fossils showed excellent preservation with complete carapaces, quarter of the ostracods are valves and quarter are fragments.

Both, the unusual rock type for the area and the composition of the ostracod fauna refer to the Kunda age of the Osmussaar sediment intrusions.

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Some lithological signatures of basin evolution in Baltic Devonian sequences

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The Devonian sequence in the East Baltic is mainly represented by terrigenous rocks with carbonate complexes and interlayers. Weakly clay-cemented siliciclastic rocks contain abundant hard interlayers, cemented mainly by dolomite. Interbeds (usually 5–20 cm) of siliciclastic rocks cemented by carbonate material form commonly 5–10% of the sequence of the Rēzekne, Pärnu and Aruküla stages, are rare in the Burtnieki and Gauja stages, and make up 20–60% of the Leivu and Kernavė formations. Hard-cemented interlayers include thin laminae of peculiar globular structures, where rounded hard-cemented nodules (5–10 mm in diameter) occur in medium-cemented sandstone. Such structures are typical of the Kernavė Formation in the East Baltic, but are found also at some levels in the Aruküla Stage and Leivu Formation. Globular, patchy cementation is interpreted as formed through the influence of groundwater in increasingly episodic depositional conditions with frequent shoreline shifts accompanied by repeated alternation of subaerial and shallow-marine conditions (Seilacher, 2001; Sinha et al., 2006). In the Kernavė Formation and in the lower part of the Aruküla Formation, shallow-marine siliciclastic sediments interfinger with offshore deposits. Probably, at the time of deposition marine conditions were repeatedly interrupted by short subaerial periods. Levels with globular structures possibly mark the positions of subaerial unconformities.

Together with the data on mineralogy, grain size distribution and sorting, the quantitative data on the roundness of the clastic material revealed some clear trends in the studied sections. The degree of rounding is comparatively high in the lower part of the Leivu Formation, which is also characterized by an increased content of clastic material in carbonate rock. In northern regions the lower part of the Leivu Formation is thin (0.1–0.5 m; Tartu, Mehikoorma, Värska and Tõlla cores) and falls partly in a local sedimentation break with a strongly eroded surface (Kleesment & Kurik, 1997). In southern areas (Rieshutine, Remte, Liepaja and Palanga cores) it is 20–30 m thick. The increased roundness of clastic material is connected with repeated erosion, redeposition and transport, which took place during the sedimentation break in the northern region, marking here a subaerial unconformity. The material was transported to the south where the sedimentation was continuous. In the south this level marks a correlative conformity, while erosion-type unconformity occurs in the northern part. In the Rezekne and Pärnu formations the roundness values vary largely, indicating the shifting of the shoreline due to alternation of intensive erosion and influx-dominated periods. The highest degrees of rounding are recorded in some interlayers of the Gauja Formation, marking the periods of intensive erosion and repeated redeposition. The obtained data help to clarify events in basin evolution.

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The paleoecological dimension of the nautiloid diversification during the Ordovician in the context of the marine trophic web

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Here, we present for the first time a comprehensive database of all Ordovician nautiloid occurrences compiled from the literature mainly by Theo Engeser (Berlin) and BK. More than 4600 occurrences mainly from Laurentia, Baltoscandia and the European terranes allow the calculation of a genus based diversity curve, normalised by rarefaction and the Chao 2 diversity estimator with a resolution at the level of the Timeslices of Webby et al. (2004). Together with a new mean standard diversity curve this allows a new evaluation of the Ordovician nautiloid diversity trend.

The mean standing diversity shows an early Katian nautiloid diversity maximum for the Ordovician, a second subordinate maximum is recorded in the Floian and a third minor peak in the middle Tremadocian. The rarified data confirm this three-peak trend but show instead an overall Ordovician diversity maximum in the Tremadocian with a slight tendency of decreasing during the Ordovician. In Baltoscandia nautiloids are rare and of low diversity during the Early Ordovician, the diversity strongly increases during the Darriwilian reaching a total maximum in the early Sandbian. The rarified data confirm this trend but differ in showing a nearly constant diversity during the Late Ordovician.

Therefore, the increasing genus diversity, which was published in earlier estimations (e.g. Frey et al. 2004), may be an artefact. Nevertheless, a clear increase of higher-level diversity (families, orders) is evident, starting in the early Floian and reaching its maximum increase during the Middle Ordovician.

Because the different nautiloid orders can be related to different predominant lifestyles (e.g. nektobenthonic, demersal, planktonic) the relative diversity of higher taxonomic groups can be interpreted paleoecologically. The curves show a clear trend toward a successive appearance and diversification of deeper water forms and planktic forms, while shallow water forms retained a nearly constant diversity throughout the Ordovician. The large straight and coiled forms that are typical for deeper sublittoral settings show a pronounced early Floian and a steady Middle Ordovician diversity increase. The Orthocerida, a group interpreted as predominantly planktic, diversified strongly during the Darriwillian. The diversity curves of these latter nautiloid groups are parallel with comparable diversity curves of the microplankton in particular with the new acritarch diversity curve of Baltoscandia (Servais et al., this volume).

In summary the new nautiloid data support the hypothesis of Servais et al., 2008, in press) that the Great Ordovician Biodiversification Event is intimately linked with a net increase of primary production and a diversification of the microplankton.

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Systematic position, distribution and shell structure of the Devonian brachiopod *Bicarinatina bicarinata* (Kutorga)

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Bicarinatina bicarinata (Kutorga) is the type species of the linguloid brachiopod genus *Bicarinatina* Batrukova. It was first described by Kutorga in 1837 as *Lingula bicarinata* from the Kütimägi (Jägerberg) section in Tartu, Estonia. The type material originates from the Aruküla Stage; the layers yielding brachiopods at the type section has been covered with soil and is not accessible today. Orviku (1948) documented the occurrence of *Bicarinatina bicarinata* in the Narva Stage in several Estonian sections.

Gravitis (1981) reported the occurrence of the genus *Bicarinatina* in several sections of the Aruküla and Narva Stages in Estonia and Latvia. Based on variable size and shape, he assigned the specimens in his collection to the type species and eight new species of the genus *Bicarinatina*. The study of the original collection of Gravitis at the Latvian Museum of Natural History revealed that four of the new species names should be considered as subjective junior synonyms of the type species, while the type specimens of the other four new species are juvenile or poorly preserved specimens, not sufficient for distinguishing separate species or for verification if they are conspecific with *Bicarinatina bicarinata* (Lang, 2007). We conclude that all known identifiable specimens of *Bicarinata* in Estonia and Latvia belong to *Bicarinatina bicarinata*. This species occurs in the Narva and Aruküla stages in Estonia and Latvia, and has been found from the Petseri core in the Pskov Region, NE Russia (Popov et al., 1994).

The environmental SEM (ESEM) study of new material of *Bicarinatina* collected from the outcrops on the banks of Poruni River and Gorodenka Stream revealed that the shell of *Bicarinatina* is almost three times thinner than the *Obolus* shell. *Bicarinatina bicarinata* has the baculate symmetrical secondary shell structure composed of rhythmically alternating compact and baculate laminae. This cross-section view for the genus *Bicarinatina* has not been previously documented, although Cusack et al. (1999, Text-fig. 3: G) have illustrated an oblique view of *B. wilsoni* from the Carboniferous of Scotland showing a baculate structure.

In the light of our systematic revision of the northern East Baltic specimens, only four species assigned to the genus *Bicarinatina* can be considered as valid: the type species *Bicarinatina bicarinata* (Kutorga), *Bicarinatina kongakutensis* Popov, Blodgett & Anderson (1994) from the Eifelian, Devonian of Alaska, and two species from the Missisippian, Carboniferous of Scotland: *Liralingua indicis* Graham and *Liralingua wilsoni* Graham.

Cusack, M., Williams, A. & Buckman, J.O. 1999. Chemico-structural evolution of linguloid brachiopod shells. *Palaeontology* 42: 799–840.

Gravitis, V. 1981. Rod *Bicarinatina* Batrukova, 1969. In: Sorokin et al. (eds). *Devon i karbon pribaltiki*. 455–462.

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$\delta^{13}C$ record of the Upper Ordovician succession of the Borenshult-1 core (Motala, Sweden) and its intracontinental correlation

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Based on lithostratigraphy and carbon isotopes, the strata recovered from the Borenshult-1 core span late Darriwilian through early Llandovery (corresponding to the Uhaku through Juuru or Raikküla stages). The recognition of some of the typical rock units of this time interval along with identification of positive carbon isotope excursions forms a sufficient base for initial intracontinental correlation of the core.

Lithologies in the lowermost part of the core (equivalents to the Furudal Formation), below strata typical for the Dalby Limestone with its "crystal apples", are at this stage not assigned to any named unit. The overlaying succession, however, is visibly attributable to, in ascending order; the Dalby Limestone, the Kinnkulle K-bentonite, the Freberga Formation, the Slandrom Limestone, the Fjäcka Shale, the Jonstorp Formation, and the Nittsjö Bed, the latter overlain by a thin shaly unit coeval with the Glisstjärn Formation. Dark and red coloured mudrocks of the Motala Formation represent the youngest interval in the core.

The core was studied in detail for carbon isotopes and above the Kinnkulle K-bentonite even every decimetre was sampled. The detected carbon isotope excursions are less pronounced than in the coeval shallow-water facies of the East Baltic area (cf. Kaljo et al., 2007), likely reflecting that a deeper-water environment prevailed in the Motala area [examples of a basinward decline in the magnitude of carbon isotope excursions have been compiled by Loydell (2007)]. Instead, our carbon data are well comparable with the $\delta^{13}C$ record presented from the Estonian Valga-10 and Mehikoorma-421 cores (Kaljo et al., 2007). The early Katian Guttenberg excursion (GICE) is observed in the lower to middle Freberga Formation. A new shift to higher values starts in the topmost part of the Freberga Formation and continues across a discontinuity surface (range of gap unknown) into the overlying Slandrom Limestone. This excursion may correspond to the 2nd late Caradoc excursion in the Rakvere Stage. The 1st Ashgill excursion is observed in the overlaying lower Jonstorp Formation, corresponding to the lowermost Pirgu Stage. The HICE (Porkuni Stage) starts in the uppermost metre of the Jonstorp Formation, and has peak values around 3.7‰ in the laminated, sandy limestone of the overlaying Nittsjö Bed, a unit that is well comparable to the sandy channel-like deposits of the Saldus Formation in southern Estonia and Latvia. This shallow-water unit represents the Hirnantian glacial interval and is followed by a thin shaly unit formed during the post-glacial flooding (including the "falling limb" of the HICE). $\delta^{13}C$ values remain stable in the basal Silurian Motala Formation, presumably evidencing that these youngest core strata are older than late Aeronian (early Raikküla Age) since this time interval is known for significant carbon isotope excursions in many locations.

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A first δ^{18}O record from conodont apatite across the Lower Silurian Ireviken Event in Estonia

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We present a study on oxygen isotopes of late Telychian (Adavere) to early Sheinwoodian (Jaani through Jaagarahu) conodonts from the East Baltic region. The well-preserved conodonts from northern Saaremaa (western Estonia) exhibits a CAI of 1, indicating only very minor thermal alteration and presenting an excellent base for geochemical analyses. Our data cover pre- through post-event strata, from the upper Subzone of the *P. amorphognathoides amorphognathoides* Zone through the *O. sagitta rhenana* Superzone (Männik, 2007). The bulk of the samples originate from the Viki core (a future global reference for a detailed Telychian δ^{18}O record) and only a few samples from the Liiva Cliff section. The strata recovered from the Viki core can be correlated with high precision to the Ireviken Event strata on Gotland (Jeppsson & Männik, 1993).

We observe variations in the oxygen isotope ratios of conodont apatite across the Ireviken (biotic) Event. Latest Telychian δ^{18}O values are relatively high indicating cool sea-water temperatures before datum point 1 of the Ireviken Event. Just before (topmost *P. a. amorphognathoides* Zone) and also after datum point 1 sea-water temperatures increase. This first step of extinction affected predominantly hemipelagic groups like graptolites, conodonts and trilobites. Before datum point 2 (strongest extinction event with respect to conodonts and trilobites) and between datum points 2 and 3, higher δ^{18}O values indicate again cooler temperatures (a short glacial?). Above datum point 4 through a level above datum 6, there is a slight decrease in δ^{18}O reflecting warmer sea-water temperatures (interglacial?). Extinctions in shallow-shelf groups like corals, brachiopods, ostracods took place at datum 4 (base of *Phaulactis* layer in the Visby Fm. on Gotland). Below datum point 7 (below the extinction level of *D. staurognathoides*), δ^{18}O values start to increase (by ~0.9‰) indicating that the cooling of the early Sheinwoodian isotope event (glacial) started in the upper part of the Ireviken biotic event (drop of about 4°C), thus post-dating most of the extinctions. The conodonts show only minor extinctions in this interval and benthic assemblages start to flourish. After datum 7, δ^{18}O values remain relatively high with only slight variations in the range of 0.5‰ indicating colder sea water temperatures environments for post-Ireviken strata (interval of the early Sheinwoodian isotope excursion sensu Loydell, 2007) than before the biotic events. Our present oxygen isotope data range into *O. s. rhenana* Zone which represents the peak interval of the early Sheinwoodian oxygen isotope excursion on Gotland (δ^{18}O$_{brach}$; Calner et al., 2004).

Calner, M., Jeppsson, L. & Munnecke, A. 2004. The Silurian on Gotland – Part I: Review of the stratigraphic framework, event stratigraphy, and stable carbon and oxygen developement. *Erlanger Geologische Abhandlungen, Sonderband* 5: 113–131.

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Succession of the stratigraphical units of the Upper Pleistocene in Estonia

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Autochthonous marine deposits on Prangli and Põhja-Uhtju islands in the Gulf of Finland, alluvial gas-bearing layers in the Purtse buried valley in NE Estonia, and the alluvial deposits at the Peedu site in SE Estonia serve as guide units of the Eemian Stage (c. 115–128 ka, isotope stage (i. st.) 5e) and mark the beginning of the Upper Pleistocene in Estonia. The destructed and glaciotectonically dislocated bog-lacustrine deposits of the Rõngu, Küti and Kitse sites, located on the Otepää Heights in SE Estonia, provide information about the Eemian forest vegetation valuable for biostratigraphical correlation.

In Estonia, the Weichselian (Järva) Stage is subdivided into the following five substages: Harimäe-Kelnase, Mägiste, Tõravere, Valgjärv and Võrtsjärv.

The Lower Weichselian Harimäe-Kelnase Substage is represented by continental waterlain deposits comprising pollen and spores of cryophilous and hygrophilous periglacial vegetation. These deposits in S Estonia have yielded five TL ages within the range of about 90–108 ka. The Brørup (i. st. 5c) interstadial warming is represented in the form of forest tundra at the Otepää site, but also at the Savala site in NE Estonia. The pollen spectra of the Harimäe-Kelnase deposits indicate possible, but not clear interstadial warming at the Prangli site but a continuous climate cooling at the Põhja-Uhtju and Juminda sites.

The first Middle Weichselian till of the Mägiste Substage (i. st. 4) separates the Lower and Middle Weichselian periglacial deposits at several sites in Estonia.

The Middle Weichselian Tõravere Substage (i. st. 3) is characterized by pollen spectra of periglacial vegetation, which is more xerophilous than that of the Lower Weichselian. TL ages within the range 62.4–66.5 ka have been obtained in S Estonia. Foraminiferal assemblages suggest the water temperature below +3°C in the shallow basin at the Vääna-Jõesuu site in NW Estonia.

The till of the Upper Weichselian main stadial (i. st. 2), extending as far as the northern part of Belarus, is widespread and termed as the Valgjärv Substage in Estonia.

During the lateglacial a complicated sedimentary complex, known as the Võrtsjärv Substage, was accumulated in Estonia. The Kammeri interstadial deposits, containing plant remains and pollen, were formed, like the bushy tundra, during the first essential glacier retreat in SE Estonia. Soon the advancing glacier deposited the Haanja (DR1) till, upon which the varved clay of the Bølling age accumulated in the proglacial Lake Peipsi basin. During the Allerød, the advances of the Palivere and Tahkuna glaciers stopped the vegetation development, which started during the Vigala and Küdema warmings, respectively, in NW Estonia. At the end of the Allerød, the Estonian area was freed from the ice cover.

This stratigraphical record is suggested for a new stratigraphical chart in Estonia.

Devonian trace fossils from the Andoma Hill (Onega Lake, Russia)

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The Andoma Hill fossil site located at the eastern coast of the Lake Onega, in Vytegra district of the Vologda government, Russia, represents an approximately 3 km long series of outcrops along the lake coast where glaciotectonically disturbed Devonian rocks crop out. Studies of the sections by members of joint expeditions of St. Petersburg University and University of Latvia in 2002–2007 provided remarkable fossil material (Ivanov et al., 2006). In the Andoma Hill section (represented by three formations: Pavlikovskaya, Andoma and Klimovskaya) vertebrates, bivalves, lingulid brachiopods, ostracods, phyllocarids, and plant remains, as well as numerous trace fossils have been collected from several sites along the coast. Previously only vermiculating trackways, U-shaped burrows (determined as *Corophioides* ichnogen.indet.), and unspecified bioturbation have been reported from the Andoma Hill (Yengalichev, 2003). The trace fossils listed below are much more abundant and diverse, and come from different stratigraphic levels within the Andoma Formation.

The richest assemblage of the trace fossils occurs in the middle part of the Andoma Fm. Here, ichnogenera *Bergaueria*(?)*, Cochlichnus*, *Cruziana*, *Diplocraterion, Glockerichnus, Lockeia*, *Monomorphichnus* isp. nov.(?), *Paleophycus, Planolites, Rusophycus*, *Skolithos*, *Teichichnus, Trepichnus,* and *Undichna* occur as epi- and hiporeliefs on the surface of very fine grained thin bedded sandstone. The overall composition of the assemblage shows similarities with that characteristic of the Cruziana ichnofacies indicative for the middle and distal ramp environment. Another distinct assemblage of trace fossils comes from the upper part of the Andoma Fm. It occurs in fine to medium grained sandstones, is much less diverse and contains only *Diplocraterion* and *Skolithos*. This assemblage possibly indicates the presence of the Skolithos ichnofacies typical for the shallow water environment. *Skolithos*-like burrows are rather widely distributed in the section, usually associated with layers of silty and clayey deposits. The distribution of the trace fossils shows that various trace makers inhabited the sea bottom almost permanently during the Andoma time. However, the intensity of bioturbation is seldom high, therefore the colonization intervals were usually short, presumably due to the rapid sedimentation.

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Sea-level and biotic changes, events and stratigraphy of the Upper Devonian of Latvia

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A number of events representing combination of palaeotectonic, palaeogeographic, climatic, and biotic changes have been reported for the Devonian. The sequence of these events is well established in the marine record and traced in many different areas (e.g, Sandberg et al., 2002). However, the well-established lithostratigraphic succession of the Upper Devonian of Baltic was rarely examined to correlate it with the sequence of the Late Devonian events.

Previous analyses of sedimentary record of the Upper Devonian of Latvia were chiefly based on paradigm of fixed or expanding Earth (e.g. Sorokin, 1978) thus largely ignoring influence of tectonic plate movement and global climate changes on the sequence of the rocks. Re-evaluation of signatures of the world-wide events using sedimentological and palaeontological data enables better understanding of the development of the Late Devonian basins of the Baltics. Indications of some events such as eustatic fall of the sea-level close to the Givetian-Frasnian and Frasnian-Famennian boundaries or several small-scale transgressions during Famennian interglacials are rather clearly traceable within the sequence. The most significant event levels that could be identified within the section are as follows:

- Amönau event coinciding with the Givetian-Frasnian boundary, at the base of the Pļaviņas Formation, indicated by dolocretes in the top of the Amata Formation; it gives additional evidence that the Amata Formation corresponds to the Givetian Stage;
- Fast eustatic rise (event No. 5 in nomenclature of Sandberg et al., 2002) at the base of the Stipinai Formation;
- Continued eustatic rise (event No. 6) at the base of the Bauska Member of the Stipinai Fm;
- Eustatic fall (event No. 7) at the base of the Amula Formation;
- Storm deposits and possible tsunami breccias (events No. 10 and 11) represented by coarse grained conglomerates within the Upper Amula Member; event No.11 coincides elsewhere with the Frasnian-Famennian boundary;
- Eustatic rise (event No. 12), clearly reflected within the sequence of the Eleja Formation, demonstrate dramatic changes of miospore, vertebrate and invertebrate assemblages;
- Eustatic rise at start of the first interglacial episode (event No. 13) could be traced at the base of the Joniškis Formation;
- Eustatic rise at start of the second, third and fourth interglacial episodes (events No. 14, 15 and 16) most probably coincide with the base of the Kursa, Akmene and Žagare formations respectively;
- The Šķervelis Formation shows signatures of the long-lasting subaerial exposition of the rocks, therefore this interval could correspond to the start of the major eustatic fall at the maximum of Southern Hemisphere glaciation, or even coincide with the Latest Famennian mass extinction.

However, some events are traceable with difficulties, mainly due to peculiarities of facies distribution, lack of conodonts in the vast majority of units composing the sequence and restricted connection of the Baltic Devonian basin with the world ocean.

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Forming of the cardinal process in the ontogeny of some Middle Ordovician strophomenids from the Leningrad Region

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At present time, based on the structure of the cardinal process, the order Strophomenida Öpik is divided into two superfamilies: Strophomenoidea and Plectambonitoidea (Rong & Cocks). The strophomenoids have bilobed cardinal process and plectambonitoids have simple or trilobed cardinal process. The assumed history of the group development supposes that the initial cardinal process of the first plectambonitoids was simple and plate-shaped, then it splitted and the bilobed strophomenoid process formed. Later, in plectambonitoids the cardinal process complicated by forming of two additional lateral plates. Then median highest and strongest lobe became project anteriorly and thus "undercut" plectambonitoid cardinal process formed. So, at first a simple plate must have been appeared in the ontogeny of the plectambonitoid cardinal process and then two lateral lobes must have been grown near it. We studied early development stages of strophomenids on the collection of about fifty ventral and dorsal valves obtained by washing of clays from the Volkhov, Kunda, and Rakvere stages (Middle to Upper Ordovician) from the Leningrad and Pskov Regions. Most of the valves are about 1.5 to 4–5 mm wide. The valves of the juvenile strophomenids are very thin and it is very hard to prepare them. That is why many valves were partly or completely broken during washing. Although the studied material is scanty, the main trends in the forming of the complicated cardinal process can be observed. The trilobed process forms by growing of the small lobe on the massive basement or on two accreted lobes. Thus part of the plectambonitoids evolved from the strophomenoids with bilobed cardinal process. The undercut cardinal process was not formed by the projecting anteriorly third lobe but, instead, it consists of four parts. Two lower lobes serve as the basement for two upper lobes, which grow from their inner upper regions, accrete in the ontogeny and then become curved posteriorly. The lower lobes may be fused with the socket ridges. At the early developmental stages the upper lobes were absent and thus it is questionable if the whole structure could serve as the basement for the adductors attachment. There may be two possible variants: 1) the diductors were absent at the early evolutionary stages and the shell was permanently open; 2) the diductors were attached not to the cardinal process but to the cavity between two lower lobes and the structure served for the closing of the pedicle opening. The cardinalia of *Ujukella* that lacks cardinal process and has only accreted socket ridges at the adult stage testifies to such possibility.

However, the studied material is not good enough for definitive conclusions about the ontogeny of both superfamilies and more specimens have to be studied for understanding the phylogeny of the order Strophomenida.

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A Middle Devonian holonematid arthrodire with unusual ornament from Estonia

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The Middle Devonian (Eifelian) Narva Formation in Estonia has yielded two new species of the arthrodire *Holonema*: *Holonema* sp. A and *B* (Mark-Kurik, 2000). The former comes from the lower, Vadja Member and was discovered in the Narva oil shale quarry. The locality of *Holonema* sp. B is Gorodenka, an outcrop of the upper, Kernavė Mb. of the formation. Two more holonematids are known from the Givetian (Aruküla and Burtnieki Fms). These are *Holonema obrutshevi* Mark, 1953 and *Tropinema haermae* (Mark) (Nessov & Mark-Kurik, 1999).

Holonema sp. A is undoubtedly a characteristic representative of the genus *Holonema*. It has typical for the genus AL, ADL and PDL plates, long and slender Sp plates. Skull plates are scarce but the Nu plate resembles that of *H. westolli* (Miles, 1971), and there is a characteristic PSG plate. Exceptional is the ornament in the exoskeletal plates, consisting of isolated tubercles. The other holonematids from Estonia, including *Holonema* sp. B, have a characteristic 'striped' ornament in which the tubercles form ridges, consisting of one to five rows of tubercles.

The tuberculated ornament may occur in several holonematids. In *Holonema* it is not very uncommon, e.g. there are almost tuberculated PL and PVL plates in *H. westolli.* Miles (1971) noticed that 'The ornament in small individuals is overly tubercular'. It is also the case with *Holonema* from Iran (Blieck et al., 1980) as a juvenile ADL plate shows. The non-ridged ornament is partly found in *H. farrowi* at the ossification centers of the plates.

However, a totally non-ridged ornament is also known in *Holonema bruehni* from the Eifelian of Germany (Otto, 1998). Otto pointed out the resemblance of *H. bruehni* and *Holonema* sp. A not only in ornament but in other aspects as well. Probably *H. bruehni* and *Holonema* sp. A, retaining a juvenile character in their ornament, represent a special group among holonematids. They show that the fish faunas of the Baltic area and Rhineland had similar elements. *H. bruehni* and *Holonema* sp. A are close in their geological age. The former comes from the Brandenberg Group, corresponding largely to the *australis–kockelianus* conodont Zones. *Holonema* sp. A from the Vadja Mb., a probable equivalent of the *costatus* Zone, is somewhat older (Valiukevicius, 2000).

The ornament of *Holonema* sp. A appears to be confusing from a regional aspect. Namely, the *Holonema* species occurs together with a coccosteid *Protitanichtys*? sp., which possesses an extremely similar tuberculated ornament. It is impossible to identify fragments of these arthrodires, otherwise quite different in their structure. But the SEM photos show that the tubercles of both arthrodire differ markedly in their finest ornament.

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Recognising the Givetian Taghanic Event in the Devonian Baltic Basin and its importance as a high-resolution international correlation datum

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The Orcadian Basin in Scotland is a terrestrial basin that contains an excellent record of Middle Devonian palaeoclimate and lies on the same palaeolatitude as the Devonian Baltic Basin. A high resolution correlation has already been made (Marshall et al., 2007) between the late Eifelian Achanarras fish bed (Orcadian Basin) and the Kernavė Member (Baltic). A second late Givetian 'Taghanic' correlation tie has now been achieved between the basins.

The Taghanic Event and Onlap in the Orcadian Basin (Marshall et al., submitted) was a distinctive group of climatic events within, and immediately overlying, the Eday Marl Formation in Orkney. The Eday Marl is an arid sabkha system that contains a high resolution archive of climatic change controlled by the relative strength of the seasonal insolation. This includes episodes of basin flooding as shown by the presence of lacustrine laminites, bedded evaporites, marginal sheet flood sands and marine influenced bioturbated sheet sands. These flooding events are intercalated with intense and sustained episodes of aridity at times of relatively low seasonal insolation. Cycle analysis demonstrates their climatic origin and shows that the event had a duration of some four 400 ky long eccentricity cycles. Spores from the base of the Eday Marl are from the ex 3 spore zone. In contrast, the spore assemblage from the upper part of the Eday Marl reveals a marked collapse to a vegetation dominated by archaeopteridalean progymnosperms (*Contagisporites optivus* and *Geminospora lemurata*, i.e. the IM spore sub-zone). The same spore assemblage was found in the Küllatova Quarry, Estonia, coeval with the Lode Quarry, Latvia, yielding rich fish assemblage and fossil flora; both localities are in the Lode Formation, Gauja Regional Stage (Mark-Kurik et al., 1999).

The Eday Marl is a time of sustained cool aridity and coincident with a series of marine regressions forced by thermally(?) driven expansion and contraction of the water column. The pattern of events within the Eday Marl can be correlated with the Taghanic levels in New York State, USA. In NE Latvia and SE Estonia the top of the Sietiņi Fm. represents maximum regression of the Eifelian to Givetian deltaic system, and is marked by a quartz-pebble conglomerate (Pontén & Plink-Björklund, 2007). The overlying Lode Fm. reflects a relative sea-level rise, and a turn-around into an aggradational phase of the delta succession (Pontén & Plink-Björklund, 2007). Hence the main Taghanic Event level can be recognised as this sub-Lode regression and hiatus with the Taghanic Onlap as the overlying Lode transgression and can be used to identify the base of the new latest Givetian sub-stage.

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Taphonomic experiments in ostracod research

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Ostracod fossil record has been commonly used as an excellent textbook example; ostracods are ranked as one of the most complete fossil records of marine faunas in terms of living groups with a fossil record, after brachiopods, bryozoans and echinoids. Actualistic methods, used in the present research, focus on the study of present-day patterns and processes in ostracod taphonomy. It is assumed, that quantitative data on the post-mortem behavior of organic remains can provide new insights into fossil assemblages as sources of sedimentological information.

The present pilot project focuses on actualistic taphonomy of ostracodes that can be regarded as a model group for carbonate microfossils. The goal of the study is finding ways for unravelling and explaining past sedimentary environment by complex anayses of ostracod taphonomy. In order to fully understand the fossil record of Ostracoda, presence/absence of carapaces, preservation, distributional dynamics, diversity etc., we need information about the way how ostracod carapaces behave in sedimentary environment. The pilot study focuses on the analysis of major taphonomic processes that are critical to fossilization of ostracods: decay time and sediment chracteristics.

The material for the experiments was collected in the Varangu lime quarry near Rakke. Ostracodes in the lime are mostly well-preserved; both juvenile and adult specimens occur. The lime was washed through under tapwater and left to dry in a porcelain bowl. The complete shells and valves of ostracodes were picked out from the dry material under microscope. Microscopic observation revealed the presence of following ostracode species: *Cyria ophtalmica, Cypridopsis vidua, Fabaeformiscandona protzi, Metacypris cordata*e, *Metacypris cordata* and *Pseudocandona rostrata.*

The experiments were made with female specimens of *Metacypris cordata*. For the experiments, 1 liter cubage electrical tumbling barrel, rotating at a steady speed, is used. The barrel was filled with 100 ostracode shells/valves, about 5 g of sediment and 50 ml of water. After each experiment, the state of ostracod carapaces was estimated and the fragments with different sizes will be counted. The experiments are repeated, changing the rotation time, type (grain size) of the sediment, or ostracode species. Microscopic observations showed that the ostracod valves were separated and many of them had been broken. For more precise observation SEM photos were made. The latter show different types of damages on ostracode shells and valves which were not visible in microscopic observation. The pilot study has proved that ostracode complete carapaces, as well as valves are rather resistant to mechanical treatment.

Reflection of the Mulde Event in the chitinozoan succession of the East Baltic

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Based on the conodont succession on Gotland, Jeppsson (1990) worked out a model of oceanic and climatic cyclicity, and linked it to the sedimentological and biotic changes. He distinguished more or less stable periods in faunal evolution as episodes and periods of rapid faunal extinctions as events. This conodont based model fits well with diversity cycles of chitinozoans in the Wenlock of Estonia (Nestor, 1997).

Recent study of the late Wenlock chitinozoan successions in the East Baltic cores (Nestor, 2007) displays severe extinction of these microfossils at the topmost part of the Jaagarahu Stage. Jeppsson and Calner (2003), correlating in more detail the Ohesaare core with the upper Wenlock sequence of Gotland, determined the Mulde Event between the depth interval of 150 m to 161.5 m. This embraces the boundary beds of the Jaagarahu and Rootsiküla regional stages.

Within the Mulde Event three main extinction levels (datums 1, 1.5 and 2) have been distinguished in the succession of conodonts on Gotland. Chitinozoans show the same pattern of extinction: *Conochitina argillophila* Laufeld, *Linochitina odiosa* Laufeld and *Calpichitina acollaris* (Eisenack) disappeared at the beginning and *Cingulochitina cingulata* (Eisenack) in the middle of the event on Gotland (Laufeld, 1974) and at the same levels in the Ohesaare core (Nestor, 2007). In total, twelve chitinozoan taxa disappeared in Ohesaare during the Mulde Event, most of them at datums 1 and 1.5, within the uppermost Jaagarahu Stage. No chitinozoan species disappear at the Datum 2, on the boundary of the Jaagarahu and Rootsiküla stages. The Mulde Event is distinguished also in deeper-water sections: nine chitinozoan species disappeared in the Ventspils D-3 core and eight species in the Pavilosta core.

According to Jeppsson and Calner (2003) Datum 1 had strong impact on all major taxa, including graptolites and conodonts. Datum 2 caused almost total extinction of graptoloids, but had less effect on conodonts. In the Ohesaare core the depth interval 153.5 m to 154.55 m, devoid of chitinozoans, is corresponding to graptolite-free interval above Datum 2 in the Gotland sequence. In the Ohesaare core the barren strata were followed by a recovery interval, where four species of chitinozoans appeared, including *Sphaerochitina lycoperdoides* Laufeld, the zonal species of the uppermost Wenlock. This level corresponds also to the lower boundary of the *G. nassa* graptolite Biozone.

Besides faunal changes the Mulde Event is characterized by some excellent stratigraphic markers: Grötlingbo Bentonite (154.25–154.50 m in Ohesaare), hardground at the sequence boundary (155.1 m in Ohesaare) and a strong positive shift in the $\delta^{13}C$ curve, peaked at 154 m in the Ohesaare core (Kaljo et al., 1997). This makes the Mulde Event one of the best correlative levels in the Silurian of East Baltic.

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Lower Cambrian sequence stratigraphy and palaeogeography in Baltoscandia

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A detailed sequence stratigraphical framework comprising more than twenty third order transgressive-regressive sequences forming three supersequences has been developed for the Lower and lower Middle Cambrian of Scandinavia. Comparison has also been made with successions in NE Poland and the East Baltic countries.

The sequence stratigraphical correlation is crudely constrained by acritarch and trilobite biozones. Revision of the existing trilobite zonation is proposed by merging the *Holmia kjerulfi* and the lower part of the *'Ornamentaspis' linnarssoni* zone into one informal zone. The upper part of the traditional *'O.' linnarssoni* Zone is separated as a new informal *Comluella*?-*Ellipsocephalus lunatus* zone. The *Holmia inusitata* Zone is abandoned as it overlaps with the upper part of the *H. kjerulfi-'O.' linnarssoni* zone. The *Triplagnostus gibbus* Zone is subdivided into two subzones, the lower containing *Paradoxides jemtlandicus*.

The stages defined for the Lower Cambrian of Eastern Europe are adopted also for Scandinavia, viz. the Rovno, Lontova, Dominopol, Ljuboml, Vergale, Rausve and Kibartai stages. The latter contains *Volborthella* and rare olenellid trilobites and is considered of Early Cambrian age. The Scandinavian Lower/Middle Cambrian boundary corresponds to the Kibartai/Deimena transition in the East Baltic area. The acritarch assemblage characteristic of the East Baltic Paneriai Stage (which is not adopted for Scandinavia) appears within the *Acadoparadoxides pinus-Pentagnostus praecurrens* Zone in south central Sweden.

Scandinavia was stepwise flooded associated with a series of major sea level rises during the Early Cambrian and concomitantly the clastic supply to the epicontinental sea declined significantly. However, the axis of mainland Sweden north of Västergötland-Närke as well as southern Norway remained a land area throughout the Early Cambrian. The terminal Early Cambrian Hawke Bay Event was associated with widespread regression and uplift of Scandinavia. The uplifted area progressively and differentially subsided during the early Mid Cambrian and for this reason the Hawke Bay unconformity spans a longer stratigraphic interval in some areas than in others. The smallest hiatus is recorded in the Gotland area and NE Poland. When the Hawke Bay uplift eventually disappeared in the mid Middle Cambrian (*Acidusus atavus* Zone) a new Baltoscandian basin outline emerged which broadly speaking lasted throughout the late Cambrian and Ordovician.

A series of new palaeogeographic maps has been constructed for the Lower and lower Middle Cambrian with at least one map for each stage.

If time permits a modelled, scaled sea level curve for the Early and early Middle Cambrian will be demonstrated. Based on this modelling a map of the Sub-Cambrian peneplain has been constructed showing the palaeotopography at the time of initial transgression. The average slope of the extremely flat peneplain was in most areas 0.5–1 m per kilometre. The modelling also revealed sub-regional uplifts/subsidence events overprinting the eustatic sea level pattern.

Ludlowian (Silurian) graptolites from the Milaičiai-103 well (West Lithuania)

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The Milaičiai-103 well is located in the western part of Lithuania. The Ludlowian part of the section is composed of limestone, clayey, organogenous and nodular limestone, and clayey dolomite and dolomite. The Ludlow is represented by the Dubysa Formation (Šešupė and Nova beds) of the Dubysa Regional Stage and the Mituva and Ventspils formations of the Pagėgiai Regional Stage. The lower boundary of the Ludlow is unclear as no core was derived from the part below 1301.0 m. The upper boundary is marked by clayey marl and argillite with limestone layers of the Minija Formation. The Minija Formation unconformably overlies the Ventspils Formation.

In the Ludlow section the *progenitor–scanicus*, *incipiens*, *praecornutus*, *cornutus*, *bohemicus tenuis*, *balticus* and *valleculosus* graptolite biozones have been identified.

The *progenitor–scanicus* and *incipiens* biozones have been distinguished in the Gorstian. The lower boundary of the *progenitor–scanicus* Biozone is unclear (because of the lack of core from 1301 m downwards). The graptolite assemblage of the *progenitor–scanicus* Biozone includes *Saetograptus chimaera chimaera* (Barrande), *Pristiograptus dubius ludlowensis* (Bouček), *Bohemograptus bohemicus bohemicus* (Barrande), *Lobograptus* ex. gr. *scanicus* (Tullberg) and *Neodiversograptus becklemishevi* Urbanek. The interval from 1284 to 1269 m is without graptolites. The *incipiens* Biozone ranges in the 1269–1263 m interval and is represented by *Saetograptus incipiens* (Wood), *Pseudomonoclimacis tauragensis* (Paškevičius) and *B. b. bohemicus*.

The *praecornutus*, *cornutus*, *bohemicus tenuis*, *balticus* and *valleculosus* biozones have been identified in the Ludfordian. The *praecornutus* Biozone (1263–1259 m) is represented by *Bohemograptus praecornutus* Urbanek. The lower boundary of the *cornutus* Biozone (1259–1255 m interval) is defined by the appearance of *Bohemograptus cornutus* Urbanek. The graptolite assemblage of the *cornutus* Biozone consists of *Pristiograptus tumescens* (Wood) and *Pseudomonoclimacis haupti* (Kühne). The lower boundary of the *bohemicus tenuis* Biozone is marked by the extinction of *B. cornutus*. The graptolite assemblage of that biozone includes *P. tauragensis* and *B. b. tenuis*. The interval from 1237.5 to 1182.2 m is without graptolites. Just one *Monograptus balticus* Teller has been found at 1210 m depth. So, this interval is tentatively attributed to the *balticus* Biozone. *Monograptus valleculosus* Tsegelniuk has been identified in the 1182.2–1181.0 m interval. *M. valleculosus* marks the upper Ludfordian *valleculosus* Biozone. No graptolites are found higher than the last occurrence of *M. valleculosus*.

Distribution of proetid trilobites in Baltoscandia

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The order Proetida was introduced by Fortey and Owens (1975) to include superfamilies Proetacea, Bathyuracea, Dimeropygacea, and Holotrachelacea, which were combined into the superfamilies Proetoidea, Aulacopleuroidea and Bathyuroidea in the last edition of *Treatise on invertebrate paleontology* (Fortey, 1997). At least 470 Late Cambrian to Permian genera are attributed to this order. About 30 genera are known from the Ordovician succession of Baltoscandia, including the glacial erratic boulders (*geschiebes*) of Northern Europe.

The earliest to appear in Baltoscandia were the Bathyuroidea. The Bathyuridae are well known as near-shore trilobites showing the provinciality in Laurentia during the Early Ordovician, while other families are more widely distributed, even globally. For example the Telephinidae, with their specific morphology, are recognized as an epipelagic community. Of those, *Carolinites* spread worldwide during the Early Ordovician, being also represented in the Floian Mäeküla Member sandstone in Popovka, Ingria. The other globally dispersed genus, *Telephina*, occurs mostly in shales and (calcareous) mudstones west of or within the Central Confacies Belt, appearing first in the Darriwilian Elnes Formation in Oslo Region and afterwards (late Katian) in the Lower Allochthon in Jämtland, in Västergötland and Öland, Sweden, and in western Latvia (Blidene Marls). In general, proetids are very small, but one dimeropygid – *Celmus* – is relatively large. It is one of the few trilobite genera crossing over the Kunda/Aseri boundary, and is found in limestones in Östergötland, Öland, Ingria, and in *geschiebes* in Germany. The minute *Dimeropyge* appears together with a rich trilobite association in Sandbian Oil Shale of Estonia and in the equivalent horizon of the lower *Chasmops* Limestone in Jämtland. Interestingly, this genus might be originated from Laurentia. The Toernquistidae, earlier assigned to the Dimeropygidae, are represented by two genera in Baltoscandia, *Mesotaphraspis* and *Toernquistia*. Both are known from the Upper Ordovician, the former from Norway, the latter from Sweden (Jämtland). The latter is mainly found in reefal limestone, and was first identified in the Keisley Limestone in Scotland.

Similarly to the bathyuroids, the aulacopleuroids and proetoids are relatively rare in Baltoscandia during the Ordovician. The first, but rather diverse appearance occurred at the beginning of the Sandbian in all confacies belts. Only one genus, *Stenophlebarum*, appeared earlier, and has been collected from *geschiebes* of the Red *Orthoceratite* Limestone. Infrequent findings of these genera show their sparse distribution over the basin until the development of the Boda reefs. During the Late Ordovician at least 16 different species belonging to 10 genera evolved in reefal environment. Of those, *Decoroproetus* and *Cyamella* occur very abundantly in so-called pockets. Of all 30 genera of proetids about 10 survived the major extinction event during the Hirnantian and ranged into the Silurian.

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Ordovician calcareous sandstone and gravellite erratic boulders from Hiiumaa: composition and origin

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Numerous bedrock-derived erratic boulders found in northern Hiiumaa represent previously unknown Ordovician high water-energy mixed siliciclastic-carbonate facies. The boulders consist of two types of sedimentary rocks: fossil-rich calcareous quartzose sandstone and fossil-free quartzose gravellite, both of which are distributed in a narrow area at the only about 10 km long western coastline of the Tahkuna Peninsula. Sedimentological, mineralogical and faunal analyses were conducted in order to determine the age and origin of the material.

Sandstone boulders vary in size from small pebbles to blocky boulders of 1.5 m in diameter, whereas the largest gravellite boulders are about 20 cm in diameter. Rare findings of boulders containing both types of sediments indicate original intercalation of sandstone and gravellite in the bedrock. The yellow, yellowish-grey or grey sandstone consists mainly of spherical, well-rounded and well-sorted medium-sized sand grains in dolomitized carbonate matrix. No substantial variation in lithology or macrofauna was observed in samples. Gravellite varied more largely in colour (from yellow to grey or brown) and grain-size (from medium sand to coarse pebbles), was poorly sorted and with variable grain shape in different specimens. Mineral composition was almost identical in both rock types, consisting mainly of quartz (grain material) and dolomite (matrix and skeletal material) in equal quantities. The Ordovician shallow-water shelly faunal community consists of abundant extensively re-crystallized thick-walled macrofossils in sandstone, brachiopods, gastropods, bivalves, echinoderm columnals, cephalopods and trilobites. Unfortunately, the macrofauna is poorly preserved and not identifiable to family or species level because of secondary dolomitization. Some chitinozoan findings (*Cyathochitina calix, C. primitiva, Desmochitina* sp; identified by J. Nõlvak) allow dating the calcareous sandstone to the interval from Kunda to Haljala stages.

The Middle to Upper Ordovician sedimentary succession in NW Estonia is characterized by carbonates, with only two exceptions: calcareous quartzose sandstone of the Pakri Formation, Kunda Stage, and the Kärdla impact ejecta, Haljala Stage. Tahkuna calcareous sandstone resembles that of the Pakri Formation by siliciclastic mineral composition, but differs in coarser grain-size. Tahkuna gravellite has no analogues in the Ordovician bedrock of NW Estonia. The very limited distribution area of the erratic boulders and their blocky shape indicate a short transportation distance. Considering the direction of ice-sheet movements in Estonia, the original outcrop area of the Tahkuna sandstone and gravellite may lie northward from Hiiumaa, possibly on the submarine Baltic Klint terrace. Grain-size characteristics and structure of the Tahkuna sandstone and gravellite indicate near-shore high water-energy sedimentary environment. Deposition of the Pakri facies in Kunda time, spreading from NW Estonia under the Baltic Sea area until Gotska Sändö Island near the Swedish coast, took place in a similar environment. Tahkuna sandstone and gravellite may hypothetically form an intermediate facies between the Pakri fine sand sediments and previously described *Jentzshi*-conglomerates of Kunda age, exclusively found in the southern Baltic area as erratic material.

Examples of taphonomic alteration of shell structure and composition in lingulate brachiopods

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The shells of brachiopods, alongside with some other invertebrates have attracted interest as geochemical archives. It is assumed that more or less "pristine" material would allow to use these signals as proxies of past palaeoclimatic and palaeoenvironmental parameters. When high-resolution analytical techniques became available, geochemical heterogeneity of the composition of fossil shells, both calcitic and phosphatic, became common knowledge. Still, as often it is difficult to be selective about the fossil samples, many geochemical and isotope studies tend to use bulk samples of any available skeletal material. In these cases, the knowledge of the taphonomic factors, potentially causing biased results, is relevant.

Our study of the taphonomic alteration of phosphatic lingulates was based on the ESEM observations in Trondheim and was supported by XRD studies at the Institute of Geology at the Tallinn University of Technology. The ESEM studies revealed a wide spectrum of taphonomic scenarios in fossilization of the shell microstructure. The presence of different apatite varieties in fossil lingulate shells was corroborated by the XRD studies: in some cases, two groups of apatite varieties in a single shell differed significantly by lattice parameters. This taphonomic bias explains the results of our previous studies on average lattice parameters of certain lingulates.

As a result of a wide range of ESEM observations and XRD studies of fossil lingulates, we concluded that the taphonomic scenarios may depend on many factors. Some of them can be outlined as follows. (1) The initial shell structure, especially the thickness of organic layers that after their destruction make available pore space for precipitation of new mineral phases. (2) The early diagenetic environment controls what minerals are precipitated in the vacant pore space. Except for precipitated apatite, pyrite and hematite were most common diagenetic minerals observed in the shells from different facies. (3) Recrystallization of original apatitic needle-like rods (*baculi*) forming trellised baculate structures was observed. As a result, the original baculi get thicker and become better observable in lower-resolution SEM studies. However, the baculi that have not thickened by recrystallization may be visible only in higher resolution. (4) ESEM studies revealed "fibre-like" structures, presumable phosphatized organic compounds that occur in cases of exclusive preservation. (5) In some cases, different taphonomic scenarios and even the transitions of the resulting structures can be observed in a single shell.

Depending on the diagenetic scenarios, the resulting shell structures look very different and the knowledge of the whole spectrum of taphonomic alteration is helpful for their interpretation. The significance of taphonomical studies of fossils has been best captured by Bengtson & Budd (2004) in their paraphrase of Dobzhansky: "Nothing in palaeontology makes sense except in the light of taphonomy and diagenesis." We believe that this applies also to most geochemical interpretations of the composition of fossils or traces of ancient life.

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The crystalline basement of Estonia: rock complexes of the Paleoproterozoic Orosirian and Statherian and Mesoproterozoic Calymmian Periods, and regional correlations

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Through the various international research programs such as Europrobe and Babel Project a lot of new geological, geochemical and geophysical data have been gathered in recent years on Precambrian rocks of the Baltic Sea region (Gee and Stephenson, 2006). The ideas about the distribution of Paleoproterozoic rock complexes from Archean Karelian protocontinent to Ukrainian Archean protocontinent through crystalline basement of Finnish, Swedish, Baltic Republics, Polish and Belorussian territories as an area of Svecofennian Domain were fixed. The tectonic model of Svecofennian Domain as a mosaic of predominantly accretionary orogenic belts evolving towards south and west from Karelian active margin has been accepted (Korja et al., 2006, Bogdanova et al., 2008).

On the basis of this new understanding of the Svecofennian Domain framewark and taking into account the existing U-Pb and Sm-Nd zircon data from Estonian basement rocks (Soesoo et al., 2004) the following statements concerning their age relationships can be formulated.

The volcanic-supracrustal and metaigneous rocks from Tallinn, Tapa and Alutaguse zones started to form during the Orosirian period in the marginal basins of the Svecofennian ocean. The rocks were regionally metamorphosed in the processes of Fennian orogeny arc accretions between 1.89–1.84 Ga and correlate with the complexes of Southern Svecofennian terraine from northern central Sweden, southern Finland and north-western Russia.

The volcanic-supracrustal and metaigneous rocks from West- and South-Estonian zones started also to form during the Orosirian Period in the environment of the Svecofennian ocean basin, but were regionally metamorphosed (and thrusted to NE?) in the processes of Svecobaltic orogeny arc accretions between 1.80–1.78 Ga. Their age counterparts inside the Svecobaltic terrain can be found from Sörmland basin SE Sweden and Central and South-Baltic areas.

During Statherian and Calymmian periods uplift, fault and block tectonics inside the Svecofennian Domain was the background for post- and anorogenic shoshonitic (1.83–1.63 Ga) and rapakivi (AMCG; 1.67–1.62 Ga Wiborg subprovince, 1.59–1.54 Ga Riga-Aland subprovince) magmatism occurring in this area.

New geochronological studies across the whole Estonian basement structural units are needed for more detailed and grounded interpretations of their geologic history.

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Wenlock bentonites in Lithuania in the frame of graptolite stratigraphy

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Wenlock bentonites were sampled in four wells in Lithuania: Šiupyliai-69, Lygumai-47, Kunkojai-12, and Viduklė-61 (total 7 bentonite samples). Bentonites in Lithuanian sections are very thin, mostly less than 1–2 cm, only those in Kunkojai-12 at 1289.8 m and at 1296.0 m, and in Viduklė-61 at 1308.0 m are about 5–6 cm thick.

In Lithuania, the lower boundary of Wenlock has been drawn at the level of appearance of *C. centrifugus* and the upper boundary of the series was drawn at the level of disappearance of *P. ludensis*. In total, thirteen graptolite biozones have been identified in Wenlock in lithuania: *centrifugus, murchisoni, riccartonensis, antennularius, flexilis, perneri, radians, lundgreni, parvus, nassa, praedeubeli, deubeli*, *ludensis*.

Near the *antennularius/flexilis* boundary, two bentonites were found. In Lygumai-47 these occur directly above the level of first appearance of *M. flexilis* (at 1343.4 m); in Viduklė-61 one bentonite lies directly below this zonal boundary (at 1385.6 m). These bentonites revealed very similar sanidine spectra (by XRD) characterized by strong, wide reflection indicating approximately 26 mol% of Na-component in sanidine. XRF analyses showed similarly high Zr, Y, Th and low Nb and P_2O_5 concentrations in these beds. These two bentonite records can be correlated with confidence. The bentonite at about 0.4 m higher in the Lygumai-47 core reveals very similar Zr, Nb and Th concentrations, but differs significantly by very low content of sanidine in the coarse fraction.

Studies of another bentonite from the Kunkojai-12 core (at 1296.0 m, in *flexilis* biozone) showed wide sanidine reflection indicating in average 35 mol % Na. Similar sanidine spectra was previously measured from a thin (0.5 cm) bentonite at 423.5 min the Ruhnu core, SW Estonia.

The bentonite at 1289.74 m (*perneri* biozone) in the Kunkojai-12 core was characterized by a sharp sanidine reflection (in two different measurements) indicating, respectively, 30.3 and 30.8 mol % of $NaAlSi_3O_8$ in the sanidine. According to these data, two alternative correlations are possible. The most likely is correlation with the bentonite at 288.44 m in the Ohesaare core section. This conclusion is based on the low biotite content in in this bentonite in both, in Ohesaare and Kunkojai-12 sections. The bentonite in the Ruhnu core at 374.0 m reveals similar characteristics and was previously correlated with that at 288.44 m in the Ohesaare core. The bentonite at 307.61 m in the Ohesaare core is characterized by similar sanidine but contains abundant biotite and is therefore a less probable candidate for correlation.

A bentonite in the Šiupyliai-69 core at 1032.3 m, in the middle of the *lundgreni* biozone, reveals very wide and strong sanidine reflection indicating an average content of Na in the $(Na,K)AlSi_3O_8$ of 40 mol %. Correlation of this bentonite with that in the Ohesaare section is provisional and must be checked by further studies.

The bentonite in the Viduklė-61 core at 1308.0 m (in *parvus* biozone) revealed a weak sanidine reflection. The bentonite at 1308.0 m in the Vidukle core can be correlated with the lower part of the Grötlingbo Bentonite in the Hörsne 3 outcrop section (Gotland).

On the Quaternary time scale and physical age of Estonian Pleistocene deposits

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A joint working-group of the International Union for Quaternary Research (INQUA) and the International Commission on Stratigraphy (ICS) has recently recommended to shift the lower boundary of the Quaternary to the base of the upper Pliocene Gelasian Stage (about 2.6 Ma), which coincides with the start of global cooling and Gauss-Matuyama geomagnetic boundary. Also, during the past 2.6 million years, hominids evolved and began to exert an increasing influence on the geomorphological processes, flora and fauna. On the other hand, Pliocene will be deformed and Quaternary will loose a lot of its specific features. Revision of the stratigraphic scale without extreme necessity and careful investigation of stratotypes is a delicate matter. Therefore it is preferable to retain, at least for some time, the former lower boundary of the Quaternary (at 1.8 Ma) and keep the Quaternary in the rank of a system or period, as it was decided at the XXXII International Geological Congress in Florence in 2004.

According to the decision of the INQUA Congress in Paris in 1969, the base of the Holocene Series as broadly accepted corresponds to the level with an age of 10 000 radiocarbon years (some 11 500 calibrated years). In a global scale this is a very convenient level. Some time ago the ICS Subcommission on Quaternary Stratigraphy recommended to define the boundary as the 1492.3 m level in the GRIP ice core from Greenland, reflecting the first signs of climatic warming at the end of the Younger Dryas. Based on multiparameter annual layer countings, the age of the boundary is 11 734 cal radiocarbon years. However, this dating is difficult to use in practice and also rather disputable. It means that the old boundary is preferable for the Baltic States.

The Quaternary cover in Estonia is at its thickest in the Haanja and Otepää Heights (often more than 100 m) and in the buried valleys in southern Estonia (e.g. 207 m in the Abja valley). About 95% of the Quaternary cover is formed of glacial and aqueoglacial deposits. Five till formations, often of great thickness, can be traced. Only in few cases they are separated from each other by spore- and pollen-containing deposits of interglacial or interstadial origin. This considerably aggravates the correlation and dating of glacial strata. Continental stratotype layers of Eemian (Rõngu) and Holsteinian (Karuküla) interglacials are redeposited, which also complicates the problem. Nowadays we know that tills have accumulated prevailingly below the moving ice and therefore we cannot use physical methods for dating of tills. In last decades TL and OSL methods have been used widely for the dating of aqueoglacial deposits, but at least for Estonia the obtained data are extremely heterogeneous and mostly entirely unreliable. Controversial results depend on geological factors, because the deposits have accumulated in extremely different sedimentological conditions and are often redeposited, but with no doubt also physical grounds of study methods need significant improvement. Aqueoglacial sediments are accumulated in various depositional settings: on the ice, in the ice and below the ice, and show great variation in the granulometric composition and structure. Often these sediments were under the sunlight only for a very limited time or not at all. They can contain a considerable admixture of unbleached mineral grains from older Quaternary sediments or from Palaeozoic rocks. The extent of bleaching of the luminescence signal in the environments studied varies and is difficult to reconstruct in laboratory, thus causing the variability of dates. If the mechanism of the formation of the deposits is unknown, as in intermorainic layers, even the most accurate measurements of their TL properties will be meaningless. To our mind, the potential of the TL and OSL methods is clearly overestimated and up to now no reliable methods for direct dating of Quaternary clastic sediments are available.

Mitrates (Echinodermata: Stylophora) from the Silurian of Gotland, Sweden

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Cornutes and mitrates (Stylophora) were vagile benthic echinoderms, ranging from the Middle Cambrian to the Late Carboniferous, closely related to asterozoan and crinoid echinoderms. They were one of the most diverse groups of Early Palaeozoic echinoderms. Stylophoran echinoderms are non-radiate, calcite-plated forms, consisting of two well-defined regions: a delicate flexible, tripartite appendage (aulacophore), and a massive, asymmetrical, flattened body (theca). Comparable to the situation in other echinoderm groups, the stylophoran skeleton disarticulated more or less rapidly after the death of the organism. Fully articulated specimens are consequently known mostly from fossil Lagerstätten deposits, but however, stylophoran isolated skeletal elements can be locally abundant. Only few Silurian Stylophora have been described so far, and all of them were reported from shallow, high-energy deposits in low-palaeolatitude regions. Recently, new collections of well-preserved isolated echinoderm material have been made from nearly all Silurian strata of the Isle of Gotland. Several hundred marl and rock samples were investigated using micropalaeontological techniques. More than 50,000 echinoderm ossicles were isolated in the last 10 years. The main focus of preceding research on this material was on echinozoan echinoderms. However, microscopical isolated remains as well as small articulated specimens (proximal appendage and theca) of mitrate stylophorans are once in a while common in some localities. Based on SEM analysis, most of these specimens can be unambiguously assigned to the suborder Peltocystida. This identification relies on their reduced number of marginals, the very large expansion of their two adorals, and their thecal ornamentation. These mitrates from Gotland are the first peltocystids ever documented in Silurian strata. Consequently, they "fill the gap" between the abundant and diverse peltocystid taxa described from Ordovician strata (Kirkocystidae, Peltocystidae), and the few ones documented in the Late Palaeozoic (Jaekelocarpidae). The new mitrates from Gotland are remarkably intermediate in morphology between Kirkocystidae and Jaekelocarpidae. They show interesting similarities with poorly known peltocystids from the Lower Devonian of Germany (Hunsrück Slate). The palaeoecology of the new peltocystids from Gotland was possibly comparable to that of jaekelocarpids (epifaunal stylophorans living in shallow, tropical environments).

Ordovician fluvial erratics from Baltica in The Netherlands and northern Germany

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Fluvial deposits in the Netherlands and northern Germany from unknown provenance in the Baltic area have yielded numerous blocks of silicified limestone and isolated fossils of Late Ordovician age. The material has been transported by the Eridanos River System, which drained the Baltic shield from Miocene to Early Pleistocene times. Deposits of the Eridanos delta occur in Poland, northern and eastern Germany, Denmark, Netherlands, on Gotland and in the present North Sea. The erratics may contribute to knowledge about the extension of the Eridanos, especially to its tributary, the Pra-Neva River, which probably extended to the White Sea area, and possibly farther to the northeast.

Two preliminary remarks: 1. Silurian clastics are absent. 2. The clastics discussed here exclude geschiebes (glacial erratics) in deposits from Late Pleistocene glaciers, being distinct both in composition and provenance.

Four groups of Ordovician erratics can be distinguished.

1. The Haljala group, comprising yellowish-gray, porous, weathered, brick-like limestones. Its association of fossils is similar to that from coeval Estonian strata. This group is relatively common in Lower Pleistocene deposits in the Netherlands, but is rare or absent in the other areas mentioned before.

2. The Pirgu-group comprising boulders of chert, obviously fragments of nodules; silicified mudstones; argillaceous, stratified limestones (rare); silicified coarse limestone, rarely comprising sponges. This group is relatively common in the Netherlands and on Gotland, but is rare in the other areas.

3. 'Lavender-blue' silicifications, comprising a range of types, varying from bluish-grey to black, from porous to chert-like, often with small agates. Surfaces often give evidence of transport in two or more stages. They are Jõhvi to Keila Stage and Nabala to Pirgu Stage in age. They predominate in Miocene to Pliocene deposits, and represent the oldest deposits of the Eridanos, mainly in Poland, eastern and northern Germany, are less common in southern Denmark, rare in the Netherlands and probably absent on Gotland. They obviously represent distinct associations, originating presumably from areas in the upper reaches of the Pra-Neva.

4. Isolated sponges, tabulates and stromatoporoids. The sponges represent two distinct assemblages: a - the bluish sponge assemblage which is dominated by anthaspidellids (which preferably inhabited outer shelf areas and continental slopes), showing strong affinities with the bluish silicifications; b - the brownish sponge assemblage which is dominated by astylospongiids (which preferably inhabited continental basins), predominating on Gotland and in the Netherlands, and obviously related to the brick-like and chert association.

Silicification, decalcifying and weathering of clastics resulted in uncommon preservation of fossils, revealing details that may be unknown in those from original bedrock.

Detailed study of fossils in deposits of the Eridanos delta may contribute to the stratigraphy of the East Baltic.

The clastics discussed in 1, 2 and 4b are considered to represent eroded strata in the Pra-Neva area, and, probably, do not originate from areas west of Estonia or from the Bothnian Gulf. Detailed comparison of associations of fossils in Ordovician erratics from the Pra-Neva area, if present, and those in deposits of the Eridanos delta, is recommended.

Areas of the White Sea, and perhaps farther to the northeast, might be source areas of the bluish silicifications and sponges, discussed in 3 and 4a, considering the preferable environment of the latter on outer shelf areas of Baltica.

Stratigraphic correlation of the Baltic Silurian sections by implementing CONOP software

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Biostratigraphy is based on Smith's law of faunal sucession: distinctive assembleges of fossils occur in the same stratigraphic order in different areas. Computers and appropriate software are essential tools for processing distributional data of fossils. Several programs like CONOP, BioGraph, DISTR, RASC etc. have been created to accomplish automated correlation.

DISTR is a deterministic correlation method developed by Rubel and Pak (1984).

CONOP (constrained optimization) is a graphic correlation method introduced by Kemple et al. (1995) and Sadler (1998).

Two Silurian faunistic groups were analysed: (i) 160 chitinozoan ranges (Llandovery– Wenlock) from 46 sections and (ii) 114 ostracode ranges (Ludlow–Přidoli) from 14 sections. CONOP and DISTR both use maximum range intervals for creating the sequence of species. While DISTR eliminates all controversial species (40% chitinozoan taxa and 60% ostracod taxa) from the output time-scale, CONOP ranks all First Appearance Datums (FADs) and Last Appearance Datums (LADs) into the best-fit sequence. Resolution of the time-scale is considerably high.

There are 17 citinozoan biozones known in Estonian Llandovery–Wenlock and 5 ostracode biozones in Ludlow–Přidoli. Estonian regional stages are traced in Latvian and Lithuanian sections by calibrating CONOP's ordinal time-scale with index species.

Stage boundaries and relative rates of sedimentation (including gaps) in studied sections are expressed in fence-diagrams.

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Litorina Sea transgression based on the study of the sediment sequence of the ancient Vääna lagoon

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The ancient Vääna lagoon (59º22´29´´N, 24º25´46´´E) is located at the 22 m Litorina Sea isobase, in Vääna klint bay 25 km west of Tallinn. Lagoonal deposits were re-investigated and new results of pollen, diatom, loss-on-ignition and magnetic susceptibility analysis and radiocarbon ^{14}C dating were used for the re-interpretation of previous studies. Based on the location of beach ridges at two different levels, Kents (1939) suggested that two-wave Litorina Sea transgression occurred at Vääna. Biostratigraphical studies carried out by Thomson (1939) and Kessel (1963) confirmed the presence of marine gyttja rich in brackish-water diatoms. These studies became a benchmark and provided grounds for speaking about two- or threefold Litorina Sea transgression in Estonia.

A 2.25 m long sediment sequence (at the altitude of 16.85–19.10 m above sea level) from present-day Vääna bog, which comprises Litorina Sea and partly Ancylus Lake deposits, was selected for detailed laboratory analyses. This core opened up sediments that have deposited in different environments belonging into five lithostratigraphical units: sand (16.85–17.31 m a.s.l.), calcareous silt (17.31–17.52 m a.s.l.), calcareous silty gyttja (17.52–17.75 m a.s.l.), coarse detritus silty gyttja (17.75–18.20 m a.s.l.) and peat (18.20–19.10 m a.s.l.). Basal sand is characterized by the pollen assemblage typical of the Early Holocene. It contains very few diatoms, the species, which are generally found in large freshwater lakes and are also common in Ancylus Lake sediments. The next unit – calcareous silt – also deposited in the conditions of the regressive Ancylus Lake. Pollen assemblages show that the area of broad-leaved coppices widened at the expense of pine. The diatom assemblage is similar to that of the former one with a high proportion of littoral diatoms.

At the end of the Early Holocene the Vääna lagoon entirely isolated from the Ancylus Lake, forming a coastal lake in which calcareous silty gyttja started to deposit. High abundance of *Alnus* pollen could result from the alder rim around the isolated lake. Large-lake planktonic diatoms declined and the importance of diatom species living in small shallow hard-water lakes, such as *Cymbella ehrenbergii*, *Gomphonema angustatum*, *Mastogloia smithii* var. *lacustris* and *Navicula oblonga*, as well as the abundance of chrysophyte cysts, increased. At about 8400 cal BP the Litorina Sea transgressional water surpassed the Vääna lagoon threshold (18.2 m a.s.l.) and filled the basin with brackish water. The deposited coarse detritus silty gyttja contained mollusc shells of *Litorina littorea*, *L. saxatilis, Ceratoderma glauccum*, etc., typical of the Litorina Sea, and brackish-water periphytic diatoms, such as *Campylodiscus clypeus*, *Mastogloia baltica* and *M. braunii*. Moreover, resting spores of *Chaetoceros* spp., commonly recovered from the sediments of the Litorina Sea stage of the Baltic basin, are present. The diatom composition indicates re-opening of the connection to the sea and the Litorina Sea transgression. On the Litorina Sea isolation contact (about 7000 cal BP) tree pollen sharply declined and herb pollen increased. This could point to a hiatus between coarse detritus silty gyttja and peat, which is confirmed also by new radiocarbon dates. Our results refer to one main Litorina Sea transgression in the surroundings of Vääna and contradict the possibility of a twofold wave, as suggested earlier.

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Composition of the terrigenous admixture in the Volkhov–Kunda clayey carbonate deposits in the eastern part of the Ladoga Klint

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Terrigenous admixture in the studied interval of the section is composed of silt-sized quartz and feldspar. Its content is low (< 8%) in the lowermost Volkhov Formation ("Dikari" and "Zheltyaki" members) although this interval is mostly condensed, but increases up to 27% in the terminal part of the formation ("Frizy" Member). The lowermost part of the Kunda Regional Stage is also rich in terrigenous admixture (18–21%).

The pelitic constituent of the studied deposits is represented by the chlorite–kaolinite–hydromica association with a smaller content of mixed-layered minerals. Hydromica is the main component and forms up to 85% of the Middle Kunda Substage. The ratio of second-order to first-order reflections is low in hydromica, ranging from 0.10 to 0.38, and being usually 0.16–0.23 in glauconite. The extent of hydration is high; the reflection d_{001} in saturated samples varies from 9.95 to 9.85 Å, which corresponds to the presence of a large quantity (up to 15%) of smectite packets in the structure of hydromica. The hydromical phase consists of hydromica ($b < 9.05$) and glauconite ($b > 9.05$).

The content of kaolinite in the section varies from 9 to 23%. It is higher in the interval from the upper part of the "Frizy" Member to the middle of the Lynna Formation, while chlorite is absent. The content of kaolinite and chlorite is minimum in the base of the Volkhov Formation and in the Middle Kunda Substage. Thus the inverse relationship between the distribution of kaolinite and chlorite is observed in the intervals with low terrigenous admixture. As the content of chlorite is small, its terrigenous genesis may be supposed.

Judging from the presence of feldspar, the relatively close-lying Fennoscandian Land could be suggested as the provenance area of terrigenous sediments. The ratio of feldspar to quartz in the studied deposits is > 2. In recent deposits such ratio characterizes material derived from the weathering crust (Serova et al., 1979). In our case the source of kaolinite and chlorite was probably the middle part of the weathering crust (Strakhov, 1979). The Sarmatian Land was located in lower latitudes and was another possible source of kaolinite. The enrichment of coeval intervals of the South Baltic Region with kaolinite testifies to this possibility (Põlma, 1982).

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The Great Ordovician Biodiversification Event: Linked to phytoplankton evolution or to asteroid impacts?

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The 'Great Ordovician Biodiversification Event' is considered the biggest and most rapid radiations of life on Earth, succeeding the 'Cambrian Explosion', when most modern phyla appeared for the first time.

After an International Geoscience Programme (IGCP) focused on this *Great Ordovician Biodiversification Event* (IGCP 410: 1997–2002), another International Geoscience Programme (IGCP 503), based on the results of IGCP 410, was proposed to understand the causes and conditions of the Ordovician Biodiversification. This programme, entitled *Ordovician Palaeogeography and Palaeoclimate* (2004–2008), analyses in particular the impact of the changing palaeogeography and the evolution of the palaeoclimate on the marine biotas, in the context of the rapid radiation during the Ordovician and the important extinction at the end of this period, considered to be related to the Hirnantian glaciation.

Recently, Schmitz et al. (2008) advanced the hypothesis that the impact of numerous meteorites on the palaeocontinent of Baltica, resulting from an asteroid breakup, is related to the Ordovician biodiversification. This hypothesis, certainly very spectacular, is possibly not the most suitable answer to explain the rapid evolution of the marine organisms during the Ordovician.

As it has been proposed previously, the radiation of the marine microphytoplankton during the Ordovician can possibly be linked to the biodiversification of many marine invertebrates (Vecoli et al., 2005; Servais et al., in press).

Here, we present new data on the biodiversification of the marine microphytoplankton (acritarchs), several groups of micro(zoo)plankton (chitinozoans, scolecodonts, etc.), as well as different marine invertebrates, including the cephalopods, from the palaeocontinent Baltica.

These data provide arguments that the evolution of different fossil groups seems to be strongly linked to the evolution of the marine microphytoplankton (that can be related to the sea-level changes) but not necessarily to the increased frequency of meteorite impacts.

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Correlation of Ordovician rocks by gamma ray logs and petrophysical data: case study from South Estonia

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Natural gamma ray logs, geochemical, petrophysical and lithological data of 199 samples from four South Estonian drill cores (Valga (10), Võru, Värska (6) and Mehikoorma (421)) were used for stratigraphic correlation of Ordovician formations. The missing core interval of 60 m in the Värska-6 borehole was correlated using logging data. Gamma ray (GR) logs reflect mainly clay content in all sedimentary rocks and potassium feldspar content in siliciclastic rocks. Anomalous accumulation of radioactive isotopes (U, Th and K^{40}) is usually registered in thin metabentonite layers (altered volcanic ash) and highly argillaceous carbonate and siliciclastic rocks. Iron-bearing minerals and organic matter can adsorb radioactive elements from fluids and cause increase in GR readings. Thin metabentonite layers (0.5–30 cm) and other highly argillaceous rocks serve as reference layers for correlation of Ordovician carbonate sequences in Estonia. The lowest GR readings give the most pure limestone of Rakvere Stage in Valga (10) borehole and dolomitized rocks of O_3nbSn in Võru and Värska (6) boreholes. The highest GR readings give black shales and claystones of O_3vrFj (Td) in all boreholes, thin glauconite sandstone layer of O_1hnLt in Värska (6) borehole, and argillaceous rocks of O_3onMsn in Valga (10) borehole. Discrimination of carbonate lithologies is difficult only by gamma-ray logs, because GR readings of dolomitized and primary carbonate rocks could be equal.

The limestones and dolostones of early diagenetic origin from the upper part of the Ordovician (O_3rk–prg) are characterized by the lowest GR readings, low porosity, high density and the lowest magnetic susceptibility. These dolostones have higher density and magnetic susceptibility than limestones. South Estonian black shales of O_3vrFj, changing into the dark grey strongly argillaceous marlstones and claystones of O_3vrTd in Mehikoorma (421) borehole, have anomalous radioactivity. GR logs permit easily to correlate black shales, which have usually low core yield. The O_3vrFj–Td Formation is a reference layer in the upper part of the Ordovician section. These rocks have high porosity, low density and increased magnetic susceptibility. The rocks of O_2as–O_3on are usually represented by primary rocks, beginning from limestones up to the highly argillaceous marlstones in O_3on. The relatively low porosity of the pure limestones increases with growing clay content and in kerogen-bearing rocks of O_3kk Stage. Late diagenetic dolomitization of O_2as–O_3on rocks in Mehikoorma borehole causes increase in their porosity, grain density, total iron content and magnetic susceptibility. Similar, but more significant changes in properties are caused by dolomitization of the lowermost part of the Ordovician (O_1bl–O_2kn), in some intervals containing glauconite and/or iron-hydroxides admixture. Application of magnetic susceptibility, porosity (neutron log) and density logs together with gamma ray spectrometry can be applied for correlation of the studied carbonate rocks and discrimination of limestones from dolostones.

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New data about Llandovery conodonts of the Subpolar Urals

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In the Kozhym sections (Subpolar Urals) the strata of Llandovery age are divided into four stages (horizons): the Yarenej, Lolashor, Philipp``el` and Marshrut. Also the lower part of the Ust`-Durnayu stage corresponds to the Llandovery. The upper part of this stage is dated as Wenlock.

Distribution of lower Silurian conodonts from the sections on the Kozhym River was studied by S. V. Melnikov. He described some conodont species as index taxa for the regional stages: *Pterospathodus tenuis* (Aldridge), *Pt. siluricus* (Pollock, Rexroad et Nicoll) and *Aulacognathus calavator* Melnikov for the Lolashor Stage; *Galerodus magalius* Melnikov for the Philipp``el` Stage; *Pt. amorphognathoides* Walliser and *Apsidognathus tuberculatus* Walliser for the Marshrut Stage and for the lower part of the Ust`-Durnayu Stage

After additional studies of the Upper Ordovician–Lower Silurian strata, *Oulodus*? aff. *nathani* McCracken et Barns, *Walliserodus* cf. *curvatus* (Branson et Branson) and *Panderodus* sp. were identified by P. Männik in the lower part of the Yarenej Stage in the Kozhym-108 section.

According to P. Männik, the strata in the upper part of the Yarenej Stage and the lower part of the Lolashor Stage contain conodonts *Aspelundia expansa* Armstrong, *Oul.*? *panuarensis* (Bischoff) and *Pranognathus tenuis* (Aldridge). *Gamachignathus*? *macroexcavatus* (Zhou et al.) occurs in an interval from the upper part of the Lolashor Stage to the lower part of the Marshrut Stage. In the lower part of the Marshrut Stage appear *Oul.*? ex gr. *australis* Bischoff*, Pterospathodus* spp. and *Apsidognathus* sp. n.

Studies of conodonts from the sections Kozhym-109, Kozhym-229, Kozhym-236 and Schugor-10 located on the western slope of Subpolar Urals revealed a quite distict succession of conodont associations**.** In the strata of the **Lolashor Stage** *Oul.*? cf. *panuarensis, W.* cf. *curvatus, Distomodus* sp., *Pranognathus*? sp., *Aul.* cf. *clavator, Panderodus* ex gr. *greenlandensis, Ozarkodina* sp. and *Oulodus*? sp. waere recognized. Together with these conodonts brachiopod *Pentamerus*? sp. occurs.

The **Phillip``el` Stage** is characterized by *Oz. waugoolaensis* Bischoff, *Coryssognathus*? sp., *Pand.* ex gr. *greenlandensis, Ctenognathodus*? sp, *Oulodus*? sp.*, Oulodus?* sp. 2, and *Pand.* ex gr. *recurvatus.*

Conodonts in the **Marshrut Stage** are represented by *Oul.*? ex. gr. *australis*, *Oulodus*? sp. 1, *Oulodus*? sp. 4, *Oz. waugoolaensis, Oz.* ex gr. *waugoolaensis*, *Oz.* aff. *kozhimica*, *Oz.* ex gr. *paraconfluens*, *Panderodus* spp, *Pterospathodus*? sp. and *Asp.* sp. (aff. *Aspelundia fluegeli* Walliser).

The strata of the **Ust`-Durnayu Stage** contain *Oulodus*? sp. 1 Melnikov, *Oulodus*? sp., *Oz. excavata* (Branson et Mehl), *Oz. confluens* (Branson et Mehl), *Coryssognathus*? sp. and *Ctenognathodus* sp. Together with these conodonts occur brachiopod *Spirinella nordensis*, an index taxon of the *S. nordensis* Zone.

The succession of conodonts from the Llandovery strata in Subpolar Urals described above differs from that reported by S. V. Melnikov from the section Kozhym-217. It is evident that there is much more to be find out about lower Silurian conodonts in the region and it is essential to continue detailed studies in Subpolar Urals.

Dolocretes in the Devonian deposits of Latvia

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Calcretes are near-surface secondary carbonate accumulations (Wright, 1990). They usually form as hard crusts in arid and semi-arid climate environment in vadose and phreatic zones. Dolocretes are analogues of calcretes composed of early dolomite.

Carbonate and clayey carbonate deposits such as dolostone and dolomitic marl are abundant in the Devonian sequence of Latvia, and also the Devonian siliciclastic deposits contain many carbonate inclusions – various kinds of concretions, veins and cement. These inclusions are composed of two carbonate minerals: dolomite and calcite, first of which is supposed to be early diagenetic (penecontemporaneous), but the second most possibly crystallised from groundwater in meteoric phreatic environment (Stinkulis, 1997).

The Devonian siliciclastics are rich in dolomite inclusions in several stratigraphic intervals, especially in the Gargždai Beds (lowermost Devonian) at south-eastern Latvia, in the Burtnieki Formation (Givetian) at western Latvia, and in the Amata Formation (Frasnian) in whole area of its distribution in Latvia.

Studies of deposits of the Burtnieki and Amata formations show that the dolomite inclusions occur in different intervals within these units. In the Amata Formation content of dolomite inclusions sharply increases upwards, and near its upper boundary crusts, tens of centimetres thick, with abundant dolomite cementation are present. In the Burtnieki Formation the carbonate crusts are found in intervals not related to boundaries of stratigraphic units. Branched and cellular fabric of dolomite veins and slabs, presence of pure dolomite aggregates without admixture of sand grains, horizontal layer-like distribution of dolomite inclusions, infilling of desiccation cracks with dolomite and other features indicate that in many cases these are dolocretes.

The Nīkrāce Member, Šķervelis Formation (uppermost Famennian), present only in south-western Latvia, is composed of dolostone rich in features typical for calcretes and dolocretes. These features are as follows: irregular bedding of dolostone; cellular structure (cell-shaped vugs in dolostone are filled with clay); clayey materials within the vugs contain paligorskite; admixture of chert and high content of magnesium; dolostone contains pisoids, which have pendant shape and are sorted in reverse grading; aggregates of several pisoids are attached to each other by bridge-like cement; cell-shaped vugs often have pendant shape; fine wavy-laminated crusts, lower part of which is more irregular than the upper one. Such signatures are ubiquitous in these youngest Devonian deposits and indicate that almost the complete dolostone sequence of the Nīkrāce Member, 5 m thick, is dolocrete. The above data show that it corresponds to the dolomitised alpha calcrete (after Wright, 1990), which is dominated by micrite, contains large dolomitised calcite rhombohedra, and there is almost no influence of organisms.

Carbonate crusts in the Devonian siliciclastic deposits have formed during episodes of subaerial exposure and could be used as indicator of breaks in deposition.

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Advances in graptolite biostratigraphy of the St.Petersburg area, Russia

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The Ordovician shallow water shelf deposits are exposed along the Russian part of the Baltic-Ladoga Klint. Compared to abundant benthic fauna and conodonts, graptolites occur only at some stratigraphic levels being numerous in marl and clay and very rare in carbonate layers.

The first graptolites in the St. Petersburg area were discovered as early as in 19th century. Later on, during the 20th century graptolite collections were made from exposures and in drill cores by M. E. Janishevskii, A. F. Lesnikova, V. D. Prinada, T. N. Alikhova, V. Yu. Gorjanskii and Yu. E. Dmitrovskaya. Though graptolites were not systematically studied and not always reliably tied to the sections, the following zones were recognized (with different degree of certainty): *Rhabdinopora flabelliforme, Phyllograptus densus, Ph. angustifolius tenuis* and *Diplograptus multidens*. Based on additional collections made by L. E. Popov and N. M. Borovko from the Pakerort Regional Stage the *Rhabdinopora flabelliforme* Zone was divided into several subzones. Recently the lower part of the Ordovician succession, spanning the Hunneberg, Billingen and Volkhov Regional stages, was studied more thoroughly. Number of graptolites was collected by P. V. Fedorov, A. Yu. Ivantzov, L. E. Popov, A. V. Dronov and T. N. Koren' from well-measured sections. Based on systematic description and biostratigraphic analysis the *Tetragraptus phyllograptoides* and *Expansograptus hirundo* zones of Baltoscandia were established.

Current field work at the Ordovician sections of the St.Petersburg area aimed at collecting of graptolites from the Aseri to Idavere Regional stages, where only sporadic occurrences of rare specimens were known. New graptolite finds in the upper Aseri allowed to establish the *Pterograptus elegans* Zone. In the upper Uhaku *Hustedograptus teretiusculus* (Hisinger) was found. An occurrence of *Amplexograptus bekkeri* (Öpik) in the lower Kukruse enabled a correlation of this part of the section with well known *Nemagraptus gracilis* Zone of the lower Sandbian. Detailed sampling of the Shundorovo Fm (the upper Idavere) resulted in finding of numerous and well preserved *Climacograptus antiquus lineatus* Elles et Wood in association with various dendroids at five stratigraphic levels. This occurrence supports an assignment of the Shunderovo Fm. to the *Diplograptus foliaceus* Zone of Baltoscandia. However, there are several intervals within the Darriwilian to Katian stages in the study area, which still require further more meticulous sampling. Up to now, all attempts of etching graptolites by use of chemical treatment gave no positive results.

In general, the Ordovician carbonate successions of the Baltic-Ladoga Klint (North Estonian Confacies Belt) contain taxonomically impoverished graptolite associations, which are typical for shallow water environment, unfavorable for habitation and preservation of graptolites.

Exceptionally preserved algal flora from the Silurian of Estonia

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Algae are the most diverse and numerous eukaryotic autotrophs in recent marine ecosystems. Although known for their long evolutionary history, confirmed by modern molecular studies, their fossil record is sparse and has preserved remains of taxa with heavily calcified thalli mainly. However, the preservation of noncalcified plantlike macroalgae or seaweeds, also termed thallophytic algae is rare. Our present knowledge of noncalcareous algal flora, its place and importance in the early Paleozoic ecosystems is extremely poor and spurious.

A new and highly diverse flora of noncalcareous thallophytic algae was recovered in the Kalana Quarry, Central Estonia. The material comes from a succession of shallowing upward shelf limestones of the early Aeronian (Llandovery, Silurian, ca 440 m.y.) age. The calcareous mudstones contain abundant noncalcified thallophytic algal remains. Most of the material is related to the light to dark brown organic-rich, microlaminated, partly dolomitized limestones, which form 1–20 mm thick laminae in the micritic calcareous succession. Algal fossils occur as pale brown to dark brown kerogenous and black-coloured carbonized compressions on bedding planes. The carbonaceous three-dimensional material is represented by slightly compacted “stems” and sporangia but occasionally also by laterals or entire thalli.

In the material from Kalana we could preliminarily distinguish eight to ten morphological groups (species), tentatively assigned to Rhodophyta and Chlorophyta. This marks remarkably higher diversity than it has been up to now documented from the Cambro-Silurian strata. Altogether 14 species of noncalcified dasycalacean algae have been reported from the entire Silurian system in the whole world. In this context, material from the Kalana Quarry apparently represents the richest Silurian Lagerstätte of thallophytes recorded so far.

Ordovician ostracods from the Mishina Gora section, Russia

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Mishina Gora impact structure is situated in NW Russia, some 15 km east of Lake Peipsi. Blocks of disturbed and uplifted bedrock have presented a unique opportunity to study Ordovician rocks in the area otherwise covered by Devonian sediments. A succession in thickness more than 37 m of southward tilted (at about 70°) Ordovician strata have been cleaned out in the old limestone quarry during the last decade. The micropalaeontological samples were collected during two field seasons: the lowermost 25.2 meters of the main section were sampled in 2001, the uppermost part (19.5m) of the main section, and two adjacent smaller sections (5.1 and 2.4 m), were sampled in 2004.

Stratigraphically, the section ranges from the Middle Cambrian Sablinka Formation up to the Middle Ordovician Uhaku Stage. However, field observations, as well as microfaunal studies have revealed that due to dislocations, part of the strata are "repeated", i.e. they recur in the section several times. Lithologically, the section shows characteristics transitional between the shallow-water North Estonian facies and the deeper Central Baltoscandian facies.

The micropalaeontological samples, treated with sodium hyposulphite, yielded a rich fauna, with ostracods as the most numerous and taxonomically diverse fossil group. Samples from certain levels also yielded microscopic gastropods, brachiopods, sponge spicules, bryozoans and echinoid fragments. Ostracod carapaces are well preserved in most part of the section. However, similarly to most of the eastern Baltic area, dolomitization has destroyed most of the carbonate fauna in the lower part of the Volkhov Stage.

The earliest ostracod assemblage in the upper part of the Leetse Formation (Lower Billingen?) is reprented by poorly preserved low-diversity *Conchoprimitia* sp. fauna that has been described in most sections of that age. A well-preserved and diverse ostracod assemblage appears in the upper part of the Volkhov Stage. The specific ostracod assemblage with *Incisua ventroincisurata* as the prevailing species has been observed in all North-Estonian sections as well as in the Lava section in NW Russia and in the Kaugatuma core section in the Saaremaa Island, all representing a transitional zone between the shallow and deep-water facies.

Most species in the ostracod assemblage from the Kunda Stage have been observed in the strata of the same age also in the North Estonian as well in the Swedish sections. However, the middle part of the Kunda Stage comprises a diverse interval with *Aahithis varia*, a species that has been recorded only from the Pakri sandstone so far. Ostracod assemblages of the Lasnamägi and Uhaku stages are rich and diverse, revealing a large number of palaeocopes, as well as leiocopes and metacopes.

Conodonts in kimberlite xenoliths from the Arkhangelsk region: key to stratigraphy of the lost Ordovician in northern Baltica

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Sedimentary sequence of the northern part of the Russian Platform consists of late Vendian–early Cambrian clastic rocks that are overlain unconformably by the carbonate-terrigenous Lower and Upper Carboniferous or Quaternary deposits. The gap between the Vendian–early Cambrian and Carboniferous rocks led to suggestions that in the early Paleozoic time the area was exposed as land and so subjected to extensive erosion. The discovery of late Cambrian and Ordovician sedimentary xenoliths in several kimberlite pipes in the region to the north of Arkhangel'sk gave the first evidence that Ordovician seas inundated the northern part of Baltica. The first data on conodonts from the limestone xenoliths allow the determination of depositional environments and precise ages of Ordovician sedimentary succession in the inferred but now eroded Lower Paleozoic part of the sedimentary cover.

Ordovician conodonts were recovered from limestone xenoliths from the cores of five drilled kimberlite pipes. A total of one hundred twenty xenolith samples were processed. Half of the samples were found to be barren and only forty samples yielded well preserved conodont elements. The faunas are represented by more than 1500 identifiable conodont specimens assigned to 25 taxa. Conodonts were only slightly altered (CAI 1,2) suggesting a weak thermal effect in Ordovician rocks of the region.

Conodonts recovered from xenoliths ranged in age from Early (but not the earliest) to Late Ordovician. In general, the conodont faunas are of low-diversity and, except for several stratigraphically oldest assemblages, indicate deposition in shallow and warm water environments. The conodont faunas have a strong similarity to those in the Timan-Pechora region.

The oldest conodont fauna occurs in a single glauconitic limestone xenolith. The elements of *Scolopodus striatus*, *Drepanoistodus forceps* and *Protopanderodus* sp. indicate a Floian age of this sample. Two glauconite-bearing limestone xenoliths include elements of Dapingian conodonts *Baltoniodus* sp., *Scalpellodus* sp. and *Drepanoistodus* cf. *D. basiovalis.* The upper Dapingian age of several dolomite xenoliths is suggested from the occurrence of *Tripodus* sp. A., *Pectinognathus* cf. *P. nibelicus* and of *Scandodus* cf. *S. furnishi*. The former species dominates in that assemblage. The conodont fauna from eight clayey limestone xenoliths contains numerous *Pectinognathus* cf. *P. nibelicus, Trigonodus* sp., *Tripodus* sp. B, *Erraticodon* cf. *E. balticus* and *Dr. suberectus*. This assemblage can probably be placed in the Lower Darriwilian. The most diverse conodont fauna include *Phragmodus* cf. P. *flexuosus*, *Pectinognathus khoreyvericus*, *Ansella* cf. *A. nevadensis*, *E.* cf. *E. balticus, Plectodina* cf. *P. aculeata*, *Coleodus* sp., *Stauffarella* sp. and *Dr. suberectus.* This fauna indicates uppermost Darriwilian and was recovered from ten dolomite xenoliths. The early Sandbian xenoliths include identical conodont species plus unidentified elements of *Aphelognathus* sp. The Katian age of several xenoliths is suggested from the assemblage with *P. khoreyvericus*, *P.* cf. *P. aculeata*, *Icriodella* cf. *I.suberba, Aphelognathus* sp., *Staufferella carinata, D. suberectus* and *Panderodus* sp. A single xenolith contained a specimen of *Ozarkodina*? *oldhamensis* (Rexroad) indicating the existence of sedimentary basin in the region during early Silurian time.

Conodonts characteristic of middle Darriwilian, upper Katian and Hirnantian ages have not been found in the xenoliths, suggesting probable depositional hiatuses of these ages within the now eroded early Paleozoic sequence.

Implications of fluvial, tidal and wave processes to the deposition of siliciclastic succession of Devonian, Andoma Hill, NW Russia

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The Andoma Hill is located on the southeastern coast of the Onega Lake, about 2 km south-west from mouth of the Andoma River, NW Russia. The sequence of Devonian deposits is exposed there in a 55 m high cliff. Detailed sedimentological study was carried out and several parallel sections, reaching in total 355 m, were described. In the studied area, the Devonian strata are locally strongly influenced by glacial deformations. Detailed lateral correlations of the facies are possible only for restricted areas.

Recently (Ivanov et al., 2006), the Devonian succession of Andoma Hill was devided into three lithostratigraphic units. The lowermost unit, Pavlikovskaya Formation, contains poorly sorted very fine to fine-grained sandstone with siltstone interlaminae. The Pavlikovskaya Formation is separated from the overlying Andoma Formation by an erosional surface. The last formation is represented by high variety of deposits: from mudstone to clay conglomerates. The alternation of siltstone and fine-grained sandstone laminae is common. The uppermost unit of the sequence, the Klimovskaya Formation, consists mainly of fine- and medium-grained sandstone, includes intrabasinal conglomerate facies, fish and plant fossils, and clay clasts.

Our study indicated that the Devonian successions described have formed in a fluvial to shallow marine settings under the dominance and combination of fluvial, tidal and wave processes. Fluvial processes influenced significantly the deposition of the Pavlikovskaya Formation. However, signatures of wave and tidal influence for this part of the section are very scarce. Various wave-induced sedimentary structures, in combination with tidal signatures, are typical for the deposits of the Andoma Formation. Current and wave ripple laminated sandstones formed in a low energy settings by migration of ripples. Tidal influence to the strata of the Andoma Formation is rather evident, although not dominant. Most characteristic are irregular mud drapes, as well as flaser to lenticular lamination. In some intervals the flaser and lenticular laminations replace each other cyclically suggesting waning currents during the deposition of each lamina, thus indicating unsteady current regime. Lack of storm-induced structures, such as swaley and hummocky cross-stratification, suggests deposition in shallow settings, above the wave base.

The Klimovskaya Formation has been deposited mainly from traction currents by migration of 3-D dunes in tidal channels and bars. A number of significant tidal signatures are observed. Mud and mica drapes on cross laminae deposited from suspension during slack water periods between flood and ebb currents. The abundance of double mud drapes is typical, suggesting deposition in sub-tidal environemnt. The bundles of alternating mud and sand, as well as lateral changes in the bundle thicknesses, associated with reactivation surfaces, are also the indicators of tidal influence. Such systematic changes in bundle thickness suggest deposition in alternating neap and spring tides.

Distinguishing the detailed facies association assemblage, based on vertical and lateral facies transition, and identifying temporal and spatial relationships in sedimentary environments of the Devonian deposits in Andoma Hill is currently under way.

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New data on Estonian Late-Glacial chronology and environment: evidence from lake Nakri, Southern Estonia.

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The aim of the study is to reconstruct the environmental conditions in Southern Estonia during the Late-Glacial time (ca 14 000–11 550 cal BP) by applying several biostratigraphical methods (including pollen, diatom, ostracode, Cladocera and plant macrofossil analyses) to construct a reliably dated postglacial succession of taxa.

The new investigated Late-Glacial site, Lake Nakri (0.9 ha, 48.5 m a.s.l. 57º 53,703 N, 26º 16,389 E) is situated in South Estonia. It is a small shallow (3.2 m deep) hardwater waterbody surrounded by mixed conifer forest. The lake basin lies within the Otepää ice marginal zone, which formed approximately 14 700–14 500 cal y BP and rises more than 20 m above the present lake surface. Palaeoecological modelling (Rosentau, 2006) suggests that Lake Nakri was located at the edge of a larger ice-dammed-lake (the so-called Laatre basin) which was drained into the River Gauja valley during the Otepää ice retreat stage.

Evidence from 9 AMS dates of terrestrial macrofossils suggests that sedimentation of silt started 14 000 cal years BP in Nakri. Macrofossil analysis shows a *Betula nana–Dryas octopetala* dominated community with *Juncus* on wet ground at 14 000–13 300 cal BP. Pollen concentration is very low and pollen is corroded. At 13 300 to 12 800 the organic content of the sediment rises from 2% to up to 7.5%. Also pollen concentration, especially tree pollen, increases considerably and accompanies tree birch finds (based on macrofossil evidence). Clear signs of a 500 year long warming end at 12 800 cal BP. The Younger Dryas is again dominated by herbs and dwarf shrubs. Organic sedimentation started rapidly at about 11 600 cal BP, at the late-glacial Holocene boundary.

Lower and Middle Ordovician conodonts from south-eastern Estonia and adjacent Pskov region of Russia

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In Estonia, Lower–Middle Ordovician conodonts have mostly been studied in the northern part of the country (North Estonian confacies belt). However, the conodonts discussed here come from the Ordovician deposits of the Livonian Tongue (Central Baltoscandian confacies belt) and southern Estonia (Männil, 1966). Collections from five boreholes, drilled during the geological mapping of Estonia in the 1960s–1970s, were restudied. The Laanemetsa and Hino boreholes are situated on the northern slope of the Lokno-Mõniste uplift and the Karula, Petseri and Dekshino boreholes in the northern neighbouring area. Lower–Middle Ordovician sediments of these boreholes are red-coloured, as as in all cores of the Central Baltoscandian confacies belt in North Latvia and South Estonia (Kajak, 1962; Ulst et al., 1982). The conodont fauna of this zone differs greatly from the rich and diverse fauna of northern Estonia, particularly of the Volkhov and Kunda stages. The lowermost Ordovician deposits of the Zebre Formation are assigned to the *Paroistodus proteus* and *Oepikodus evae* zones, and contain a rather rich fauna. The Kriukai Formation represents a lithostratigraphic unit of reddish-brown calcareous sediments, the Volkhovian age of which is only weakly proved biostratigraphically. The Volkhov Stage is generally defined by the conodont *Microzarkodina flabellum* in the Petseri and Karula boreholes, but more precisely by *Paroistodus originalis* found in the middle part of the stage in the Petseri borehole. The Volkhov and Kunda stages are characterized by different large representatives of the genera *Protopanderodus* and *Drepanodus* and by rare and fragmentary specimens of *Baltoniodus* and *Lenodus*. The *Eoplacognathus pseudoplanus* Zone is defined in the Baldone Formation (upper part of the Kunda Stage) in the Hino, Petseri and Karula sections. *Microzarkodina ozarkodella* is found in the Dekshino and Karula boreholes and *Histiodella* sp. in the Hino borehole. The Aseri Stage is represented by reddish-brown limestones of the Segerstad Formation and belongs to the *Eoplacognathus suecicus* Zone. In the Aseri Stage and higher specimens of *Baltoniodus* become more numerous, and dominating on some levels. The Lasnamägi (Stirna Formation) and Uhaku (Taurupe Formation) stages are fully represented in the Karula borehole; in other boreholes the rest of the Ordovician rocks are denuded to a variable degree. The *Eoplacognathus foliceus* Subzone is still established in the Petseri and Dekshino sections, but the *E. reclinatus, E. robustus, E. lindstroemi* subzones and the *Pygodus anserinus* Zone are only represented in the Karula section. Some specimens of *Complexodus* sp. were found in the Dekshino and Karula boreholes.

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The acritarch diversity changes and their significance in South China

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The oldest acritarch assemblage in South China appears in the early Floian *T. approximatus* graptolite biozone, and is represented by 29 species assigned to 19 genera. The assemblages recorded in the *A. filiformis* graptolite biozone display a diversity of 18 species assigned to 10 genera. The acritarch diversity increases quickly to 70 species (assigned to 32 genera) in the *D. eobifidus* graptolite biozone. The number of genera recorded in the *C. deflexus* graptolite biozone reaches its peak at 43, while the number of species increases to 97. The number of species recorded in the *A. suecicus* graptolite biozone reaches its peak at 105, but the number of genera decreases slightly, to 41. In the overlying *E. hirundo* graptolite biozone, the diversity is reduced, with 80 species assigned to 39 genera. The *E. clavus* graptolite biozone continues the diminishing trend of diversity and includes 59 species assigned to 26 genera. In the *U. austrodentatus* graptolite biozone, the diversity increases again, with 85 species assigned to 36 genera. Diversity decreases sharply in the *U. intersitus* graptolite biozone, with 27 species assigned to 16 genera. After a gap (no acritarch genera recorded), specimens of phytoplankton are again found in the latest Darriwilian-earliest Sandbian. In the *G. linnarssoni* graptolite biozone, 20 species assigned to 12 genera have been recorded, and 27 species assigned to 15 genera occur in the *N. gracilis* graptolite biozone.

The diversity changes are different in various areas in South China, perhaps indicating different environment changes, especially sea level changes. The three peaks of acritarch diversity of South China appear in the *C. deflexus–A. suecicus*, *U. austrodentatus* and *G. linnarssoni–N. gracilis* graptolite biozones that correspond to transgressions in the early Floian, early Darriwilian and early Sandbian respectively.

With rising sea levels, spreading of continental masses and increasing habitat space, the disparity of acritarchs increased rapidly during the Early-Middle Ordovician.

Remarkably, the rapid increase of acritarch assemblages in the Floian interval corresponds to the increase of new acritarch forms. We can assume that the Ordovician phytoplankton radiation paralleled a long-term rise in sea level with an accompanying expansion of flooded continental shelf areas that can be observed in South China during the Ordovician. With the radiation of acritarchs, seawater oxygen and nutrient content and went up. The availability of increased quantities of phytoplankton in the Early Ordovician oceans allowed the radiation of zooplanktonic groups, and at the same time accelerated the rise of suspension feeders.

THE SEVENTH BALTIC STRATIGRAPHICAL CONFERENCE

FIELD GUIDE

Excursion A: Ordovician and Silurian bentonites of Estonia
15–16 May 2008
lead by Tarmo Kiipli

Excursion B: Ordovician of northeastern Estonia
19 May 2008
lead by Tõnu Meidla and Oive Tinn

Excursion C: Silurian of Saaremaa Island
20–22 May 2008
lead by Peep Männik and Olle Hints

Excursion D: Devonian of South Estonia
(19)20–21 May 2008
lead by Leho Ainsaar and Kati Tänavsuu

Notes on the geology of Estonia

by Ivar Puura

Estonia is situated in the northwestern margin of the East European Platform. The boundary between the sedimentary rocks of the East European Platform and the Precambrian rocks of the Fennoscandian Shield runs along the seabed of the Baltic Sea. The geological structures of the mainland of Estonia continue along the seabed, reaching the opposite seashores in Finland and Sweden. This brief account is mostly based on the comprehensive book on Estonian geology edited by Raukas & Teedumäe (1997), with some new remarks on the geological history, mineral resources and geological features.

The geological history of Estonia is best understood in the context of prehistory and formation of the Baltica plate. Estonia is situated in the central part of a 50–65 km thick block of the Earth's crust, as large as 1 million square kilometres. The structures of this block formed during an orogeny about 2.0–1.8 Ga ago, and during rapakivi magmatism about 1.65–1.5 Ga ago. For some time, since about 1–1.3 Ga ago, this block was part of the supercontinent Rodinia that began to rift apart about 800 Ma ago. The Baltica plate rifted off about 600–550 Ma ago, during Ediacaran time, and started its journey from the southern hemisphere towards the north. It passed the equator about 440–360 Ma ago, in Silurian and Devonian time and continued drifting to its current position.

The Proterozoic crystalline basement is composed of Paleoproterozoic rocks, mainly of 1.8–1.9 Ga old gneisses and migmatites of the Svecofennian orogenic complex, intersected by 1.54–1.67 Ga old rapakivi intrusions. The upper surface of the basement has been reached at the depth of about 100 m in northern Estonia and about 800 m in southern Estonia. From northern Estonia towards Finland, the basement lies closer to the surface, being exposed in the central part of the Gulf of Finland, about 100 m below the water level.

The Ediacaran and Paleozoic (630 to 540 Ma and 540 to 360 Ma, respectively) sedimentary rocks of Estonia have been formed in a shallow sea basin. The Ediacaran rocks of Estonia are usually referred

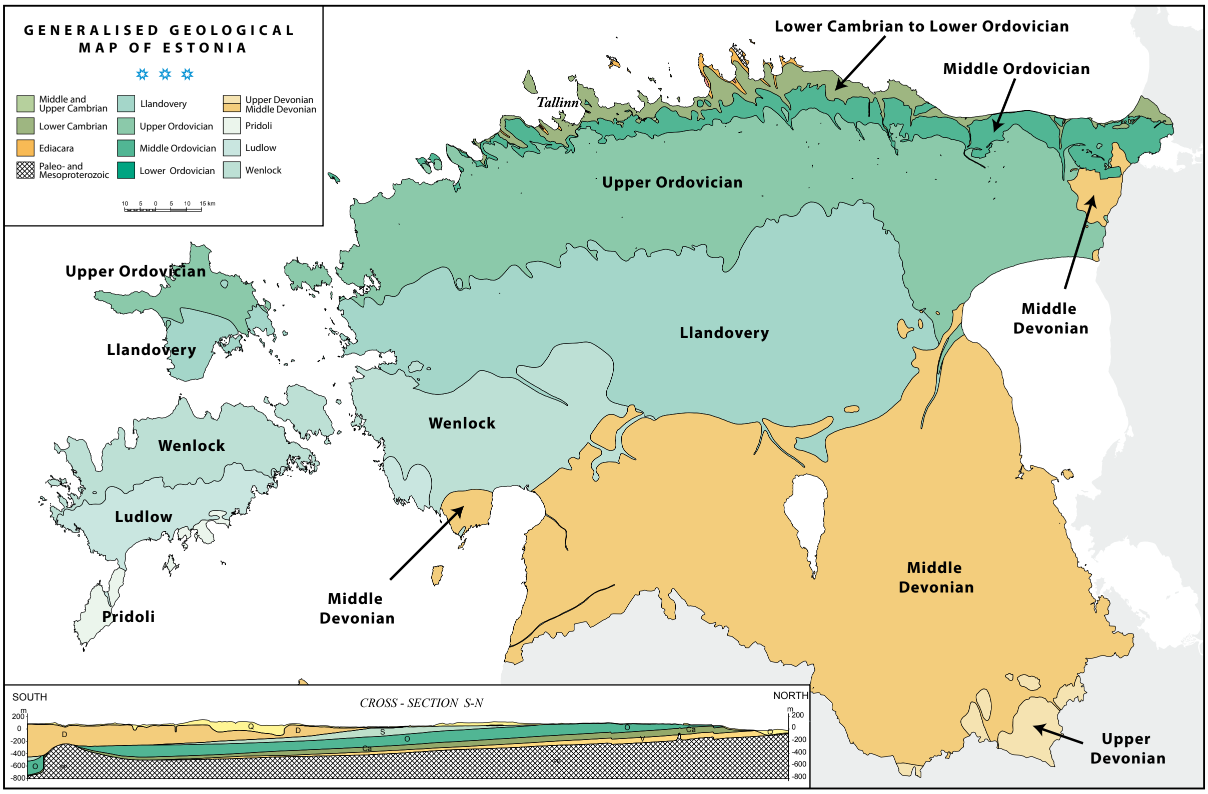


Fig. 1. Generalised geological map of Estonia showing outcrop areas of lower and middle Paleozoic rocks and southward dip of Proterozoic crystalline basement. Map compiled by the Estonian Geological Survey (http://www.egk.ee).

to as the Vendian complex. The Paleozoic rocks are represented by Cambrian, Ordovician, Silurian and Devonian rocks. In the large scale, Ordovician and Silurian carbonates are sandwiched between the Vendian-Cambrian and Devonian terrigenous rocks.

The smooth surface of the crystalline basement is covered by the upper Vendian sedimentary rocks, represented by sandstones and clays, exposed at the bottom of the Gulf of Finland. The Paleozoic sedimentary rocks usually overlie the Vendian rocks. An exception is northwestern Estonia, where the Vendian rocks thin out and the Paleozoic rocks overlie the weathered surface of the crystalline basement.

Because of a slight dip to the south, about 0.1–0.3 degrees (2 to 5 metres per kilometre), the Paleozoic rocks are exposed as sublatitudinal belts, successively younger in the southward direction (Fig. 1).

Cambrian sandstones and clays are exposed in the coastal plain of northern Estonia. Ordovician limestones crop out in northern Estonia as a wide belt from the Narva River in the east to Hiiumaa Island in the west. Silurian carbonate rocks are exposed as a belt in the middle and western Estonia and on the Saaremaa Island. Devonian siliciclastic rocks, mostly sandstones, are exposed south of the Pärnu-Mustvee line, extending from eastern and southern Estonia to the Kihnu and Ruhnu islands in the west. Middle Devonian carbonate rocks crop outcrop near Narva in northeastern Estonia and Upper Devonian carbonates in southeastern Estonia.

As the sediments between the Devonian and the Quaternary have been eroded, the rocks corresponding to about 300 million years of geological history are missing in Estonia. At the same time, the accessibility and extraordinary preservation of the Cambrian to Devonian rocks makes Estonia unique field museum for Paleozoic geology.

The Quaternary cover of Estonia consists mostly of glacial, glaciolacustrine, and glaciofluvial deposits of the Pleistocene Series. The sediments of the Holocene Series are thin and have patchy distribution. Quaternary sediments are usually less than 5 m thick in northern Estonia, and more than 10 m thick in southern Estonia. Exceptionally, they exceed tens of metres and often 100 metres in the Haanja and Otepää heights and in the buried valleys (207 m in the buried valley of Abja). Five till beds corresponding to different glaciations have been distinguished. The sediments overlying the till began to accumulate in southern Estonia in the Late Pleistocene. During the Late Glacial and Holocene, Estonia was influenced by glacioisostatic rebound (neotectonic uplift), most intensively northwestern Estonia. Because of the uplift, the width of Estonia's coastal region exceeds 130 km and ancient coastal formations occur at various elevations.

Estonia is a flat land whose uplands and plateau-like areas alternate with lowlands, depressions, and valleys. These land forms, along with the coastal cliffs in northern and western Estonia, are larger features of Estonian topography. The bases of the uplands of Estonia are usually 75 to 100 m above the sea level. The highest point in Estonia and the Baltic States, the Suur Munamägi Hill (318 m), is located in the middle part of the Haanja Heights.

The erosional uplands are mostly flat, with relatively thin Quaternary cover, and the relief is dominated by moraine plains: the Pandivere Upland (Emumägi Hill, 166 m) and the Sakala Upland (Rutu Hill, 146 m). The accumulative uplands have the relief dominated by hills and valleys, built up of Quaternary sediments: the Haanja Upland (Suur Munamägi Hill, 318 m); the Otepää Upland (Kuutsemägi Hill, 217 m); and the Karula Upland (Rebasejärve Tornimägi Hill, 137 m). Other elevations include the Saadjärv Drumlin Field, reaching 144 m, the West-Saaremaa elevation, reaching 54 m and the Ahtme or the Jõhvi elevation, at 81 m above sea level.

Among the higher areas are the plateaus. The Harju and Viru plateaus are located in northern Estonia and are bordered from the north by the steep escarpment of the Baltic Klint. Both plateaus are about 30 to 70 m above sea level. The flat surface of the plateaus is occasionally cut by river valleys and karst features. The erosion of the Harju Plateau has left some separate flat plateau-like hills: the Toompea Hill and the Viimsi Lubjamägi Hill in Tallinn, and the Pakri islands. The relief of the Viru plateau is formed by artificial features (oil shale pits and waste rock and ash hills). The Ugandi Plateau (40 to 100 m above sea level) in southern Estonia is a sandstone plateau, cut by ancient valleys and bordered by high escarpments: Tamme outcrop near Lake Võrtsjärv in the west and Kallaste outcrop on the beach of Lake Peipsi. Other relatively high areas are the Central-Estonian Plain (60 to 80 m above sea level) and Kõrvemaa (50 to 90 m above sea level).

Lowlands are plains reaching less than 50 m above the sea level that have been flooded by the Baltic Sea, ancient Lake Peipsi, and ancient Lake Võrtsjärv. The lowlands cover nearly half of the Estonian territory. The largest lowlands are located in western Estonia.

Mineral resources. Most of the larger deposits of the most important mineral resources — oil shale, phosphorite, and carbonate rocks — are located in the northern and northeastern part of Estonia. Peat, sand, and gravel resources are distributed almost evenly over the country. During the past hundred years, two economically important and geologically unique mineral resources have been Upper Ordovician oil shale and Cambrian-Ordovician shelly phosphorite. Unfortunately, both have been mined and industrially used for more than half a century in environmentally hazardous ways, devastating large regions in northern and north-eastern Estonia. Environmental impact is one of the reasons why phosphorite mining was discontinued and phosphorite was excluded from the list of active mineral reserves in late 1990s.

Oil shale is currently the main energy source in Estonia, covering more than 95% of the country's energy needs. Its peak consumption in 1981 exceeded 30 million tons, continuously decreasing to about 10 million tons in 1999. Cold winters and development of shale oil industry increased the yearly consumption to 14 million tons early this century, with the growing demand. For the coming years, the yearly consumption limit of oil shale has been set to 20 million tons.

Other relevant mineral resources include Ordovician and Silurian and, in small amount, Devonian carbonate rocks, and gravel, sand, peat and sea and lake muds from the Quaternary deposits. Also, mineral water originating from Vendian and Paleozoic sediments is in use in many parts of Estonia. At present, Estonia is relatively well equipped with ground water resources, but mining of bedrock resources, e.g. oil shale and limestone, involves local and regional risks of destruction of water reserves. Thus, Estonia faces the need of preserving the water resources, that may require setting local and regional restrictions to the extensive use of mineral resources.

Most remarkable geological features of Estonia include the North Estonian Klint, West Estonian Klint and several meteorite craters, including the Paleozoic Neugrund and Kärdla craters.

The North Estonian Klint is part of the Baltic Klint that begins on the western coast of Öland island in Sweden, extends under the sea to the western coast of Estonia, and then runs through Estonia to northwestern Russia, ending at the southern shore of Lake Ladoga. The rocks of the klint wall (Cambrian and Lower Ordovician siltstones and shales overlain by Lower and Middle Ordovician limestones) are about 470 to 540 million years old.

The West Estonian Klint runs from the mainland through the island of Muhu and the northern coast of the Saaremaa island. It is part of the Silurian (Gotland–Saaremaa) Klint, 500 km long, that continues westward on the sea floor and appears from the sea on the northern and western coasts of the Gotland island. The Silurian limestones and dolomites in the klint outcrops are about 420 million years old.

The Neugrund crater in the shallow sea near the northern coast of Estonia, NE of Osmussaar, with the outer rim diametre of 20 km, was discovered in 1990s. According to the current considerations, it is of Cambrian age, possibly about 535 Ma.

The Kärdla crater in Hiiumaa near Kärdla, has the diametre of 4 km and depth of 540 m. According to the biostratigraphic estimations, its age is Ordovician, about 455 Ma.

Excursion A:
Ordovician and Silurian bentonites of Estonia

Ordovician and Silurian bentonites of Estonia

by Tarmo Kiipli

Volcanism marks important geological events and sites, accompanying lithosphere subduction, dissecting of continents along deep faults and hot spots where magma rises from the depth of hundreds of kilometres. One of the greatest mountain formation processes in the Earth's history was Caledonian Orogeny which occurred when the Baltica, Avalonia and Laurentia palaeocontinents collided. Many problems related to these ancient processes are difficult to solve because the mountain ridges uplifted at that time have been deeply eroded (Norway) and buried under younger sediments (Poland, Germany).

The East Baltic region is located at a distance of 700–1400 km from potential source volcanoes, therefore each ash bed found in this area represents very large eruption comparable and exceeding the largest known eruptions from the historical period. In search of the volcanic sources the correlated ash layers have been mapped. Most isopach maps indicate that the source areas were in West or North-West of Estonia, and some in South-West direction. XRF analyses of Ti, Zr, Nb, Th from bulk bentonite indicate source magma types from andesite and trachyandesite to dacite and rhyolite (Table A1). EDXRF analyses of biotite phenocrysts showed Mg-rich and Fe-rich varieties.

Table A1. XRF analyses of altered volcanic ash layers from Estonian outcrops

Locality		Peetri tunnel	Peetri quarry	Pääsküla lower	Pääsküla upper	Orgita	Päri	Valgu lower	Valgu upper
Thickness, cm		5	5	27	5	7	6	7	2
Regional Stage		Haljala	Haljala	Keila	Keila	Raikküla	Adavere	Adavere	Adavere
SiO_2	%	60.57	59.67	63.06	60.31	60.88	44.99	60.71	
TiO_2	%	0.53	0.25	0.20	0.40	0.57	0.33	0.62	0.36
Al_2O_3	%	19.02	18.31	18.05	18.20	17.91	12.71	17.03	
Fe_2O_3 T	%	3.92	4.12	0.89	2.03	3.02	1.50	1.32	2.27
MgO	%	2.31	1.22	0.77	1.04	3.14	1.65	0.64	
CaO	%	1.17	0.17	0.31	0.18	1.68	13.46	1.10	6.37
K_2O	%	10.30	13.15	14.90	14.12	10.47	10.42	14.86	12.70
P_2O_5	%	0.05	0.01	0.076	0.05	0.21	0.19	0.03	
S	%	0.01	0.51	0.06	0.04	0.01	0.57	0.33	
LOI	%	3.97	2.00	1.37	1.25	4.55	11.76	1.38	
As	ppm	20	46	3	16	<8	11	9	
Ba	ppm	219	139	123	228	211	222	254	100
Br	ppm	4	<3	2	3	4	<3	3	
Ce	ppm	<60	<60	22	<60	<60	<60	<60	
Cr	ppm	39	13	9	18	55	11	17	
Ga	ppm	18	13	15	11	17	7	10	
La	ppm	<40	<40	9	<40	<40	<40	<40	
Mn	ppm	112	24	17	36	187	121	28	146
Mo	ppm	<3	3.0	1	<3	<3	4.2	<3	
Nb	ppm	33	18	11	15	18	7	28	6
Ni	ppm	15	3	7	12	23	7	9	25
Pb	ppm	23	13	10	30	15	24	6	10
Rb	ppm	114	59	63	68	117	46	45	54
Sr	ppm	27	10	10	15	27	49	25	33
Th	ppm	21	23	10	18	20	17	32	9
U	ppm	<8	<8	2	<8	<8	<8	<8	
V	ppm	70	<20	13	41	59	27	21	
Y	ppm	23	17	16	8	34	9	58	11
Zn	ppm	20	<4	42	209	31	11	4	30
Zr	ppm	323	268	111	147	339	120	616	130

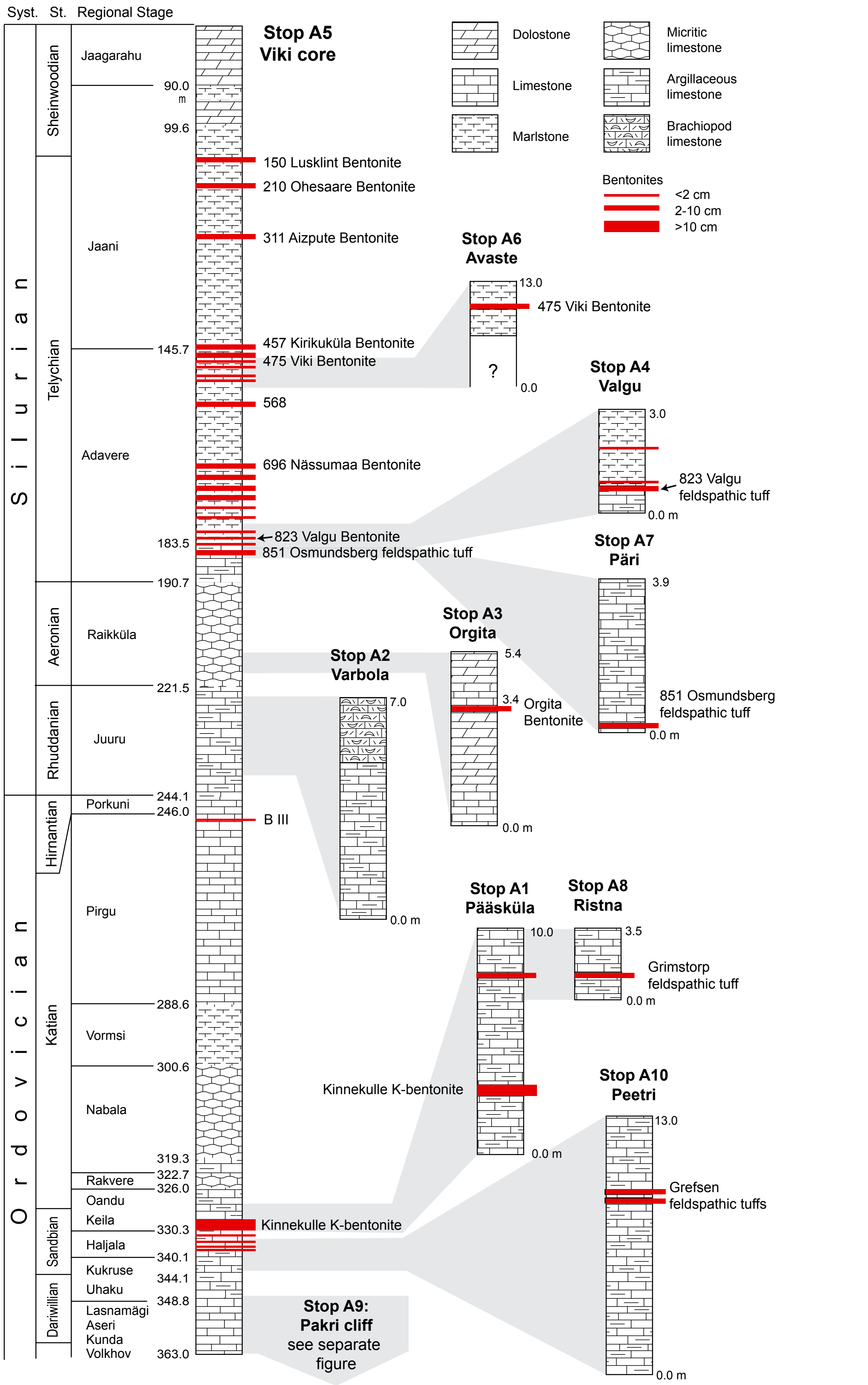


Fig. A1. Ordovician-Silurian succession of the Viki core with numerous bentonites and corelation with excursion stops to be visited.

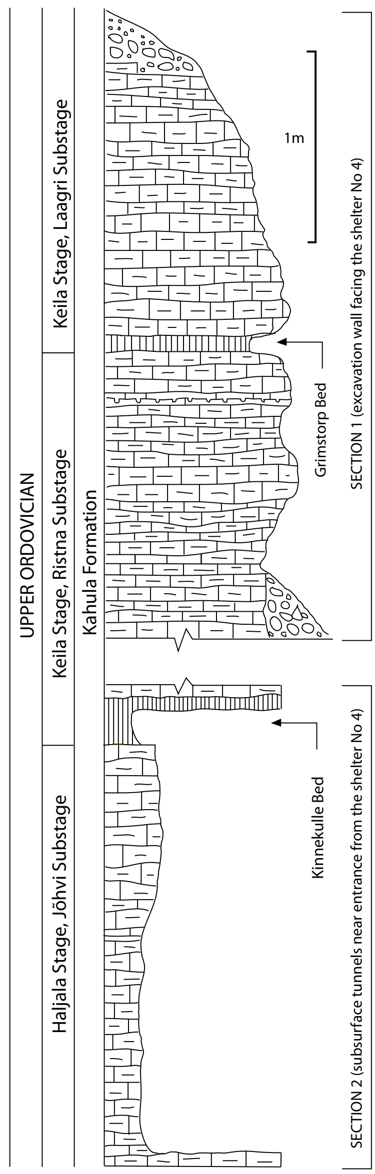
Sedimentary sections from the East Baltic contain accurate records of volcanic eruptions (ash layers altered to bentonites) from the neighbouring tectonically active areas offering unique possibility for restoring detailed magmatic history. Magmatic sanidine composition analysed by XRD from coarse (0.04–0.1 mm) fraction of clay rich altered volcanic ash samples gives primary quantitative characteristic to each eruption layer. Concentration of $NaAlSi_3O_8$ in sanidine is stable within one eruption bed and varies from 20 to 59 mol % (precision ± 1–2 mol %) in different ash beds. Sanidine composition was used for correlation of volcanic layers between Estonia, Latvia, Lithuania and Sweden. Presently, volcanic ash beds from about 140 eruptions are known from the Ordovician and Silurian of East Baltic.

Intensity of volcanism varies in time. Numerous bentonites occur in Sandbian (27 ash beds) whilst only few beds are known from the Katian and Hirnantian (5 layers) and from the Rhuddanian and Aeronian (3 layers). Late Llandovery and Wenlock, on the other hand, are characterized by most intensive volcanism represented more than 100 layers in Estonia and Latvia (Fig. A1). In the lower part of Ludlow a few ash beds occur and higher in Silurian evidences of volcanism are not known in the studied area. Many of these volcanic interbeds can be used as valuable marker horizons in detailed stratigraphy (Kiipli et al., 2008a).

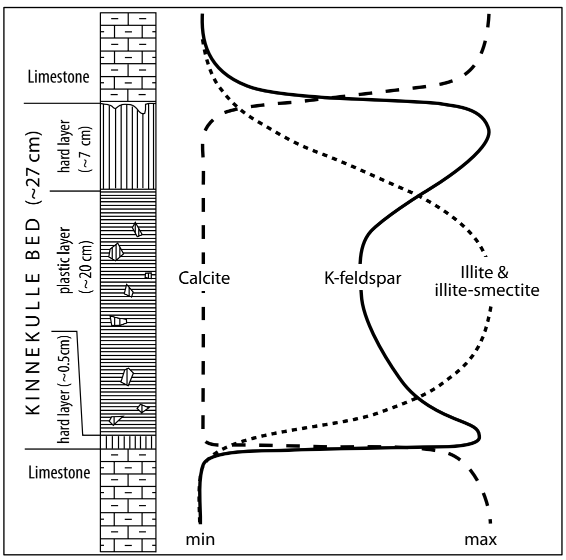
Stop A1: Pääsküla Hillock

by Tarmo Kiipli

Pääsküla Hillock is located at the southern margin of Tallinn. In 1913–1918 Russian army constructed six subsurface shelters and over 2.5 km of tunnels connecting them into the bedrock. Altogether the outcrops in Pääsküla Hillock expose more than 10 m of Upper Ordovician argillaceous limestones (Fig. A2; Hints et al., 1997). The Kinnekulle K-bentonite (Bergström et al., 1995) is exposed in almost full extent of the underground tunnels in thickness of about 30 cm (Figs A3 and A5). In southern Sweden this volcanic bed reaches thickness of 2 m and the corresponding eruption has been considered as one of the largest in the Earth's history (Fig. A4). Geochemically the Kinnekulle bed is characterized by very low content of all trace elements (Table A1). The source magma was extremely silica-rich. Studying glass inclusions in quartz Huff et al. (1996) estimated SiO_2 content greater than 78%. The Kinnekulle



→ Fig. A2. Upper-Ordovician succession exposed in Pääsküla Hillock (from Hints, 2004).



← Fig. A3. Mineralogical composition of the Kinnekulle bentonite in Pääsküla section (after Hints et al., 1997).

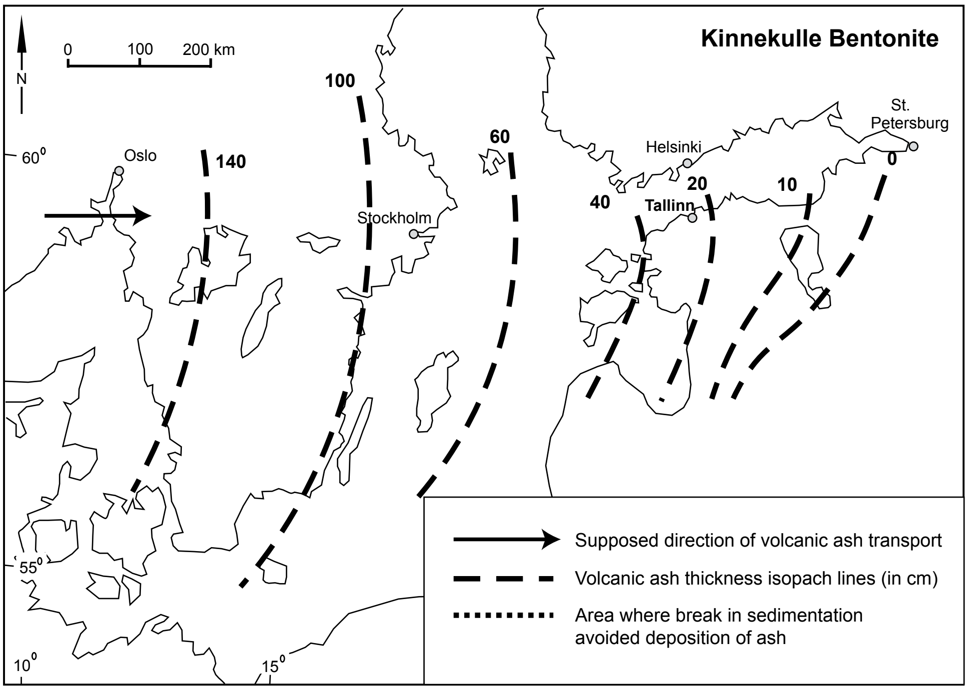


Fig. A4. Thickness map of the Kinnekulle bentonite (after Bergström et al., 1995).

Fig. A5. The Kinnekulle bentonite is exposed in the roof of the subsurface tunnels constructed in 1912–1918. Photo by O. Hints.

bed can be easily traced by it's sanidine composition containing ca 25 mol % of Na-component (Kiipli et al., 2007). The Kinnekulle eruption has been dated as 455 Ma.

In the upper part of the Pääsküla section the Grimstorp K-bentonite (Bergström et al., 1995) in thickness of about 5 cm occurs. Both volcanic ash layers as well as other exposed altered ashes in Estonia are characterized by very high content of authigenic K-feldspar formed after volcanic glass in shallow Palaeozoic sea (Kiipli et al., 2007).

Apart from the bentonites, the outcrops in Pääsküla Hillock are well known for being rich in various shelly faunas. In the stratigraphical nomenclature the area has given names for the Pääsküla Member and Laagri Substage.

Stop A2: Varbola

by Tarmo Kiipli

Varbola Stronghold was built and used for defence from the 11th to 13th Centuries. It was the largest fortress in Estonia in that time. It covers an area of 2 ha and is embraced by 7–8 m high ring wall. Various models of military equipment for attack and defence of fortifications of that time are exposed in Varbola Stronghold.

In the 7 m deep fortification well argillaceous limestones of the Varbola Formation are exposed in the lower part of the section overlain by brachiopodal limestones of the Tamsalu Formation (Rhuddanian, Juuru Stage). The braciopod coquina is composed dominantly by the shells of *Borealis borealis*. This is the type section of the Varbola Formation. Argillaceous limestones of the Varbola Formation formed during the initial Silurian transgression after major regression at the end of Ordovician.

In the lowermost Silurian (Rhuddanian and Aeronian), the volcanic ash beds are very rare in Estonia and do not occur in the Varbola section. Very intensive volcanism of that time is known from the American side of the Iapetus Ocean. For instance, Batchelor & Weir (1988) report 50 volcanic ash layers in Rhuddanian and Aeronian strata of Dob's Linn section, Scotland

Stop A3: Orgita quarry

by Tarmo Kiipli

In the Orgita quarry, about 5 km from Märjamaa, shallow-water (lagoonal?) microlaminated dolostones alternated with micritic and bioclastic limestones of Aeronian age (Raikküla Stage) are exposed in thickness of 5.4 m. They often exhibit desiccation cracks at bedding planes evidencing about very shallow water environment and frequent subaerial exposure. The lagoonal dolostones are used for production of decorative building stones.

About 2 m below the top of the section 5–10 cm thick bed of green clay occurs. Abundance of the authigenic K-feldspar in it, and angular quartz shards in 0.04–0.1 mm coarse fraction indicate volcanic origin of this layer. Since bentonites are rare in Estonia in this stratigraphical interval, the bed observed in the Orgita quarry cannot be correlated to other sections for the time being.

Stop A4: Valgu

by Tarmo Kiipli

In the banks of Velise River and in the nearby trench lower Telychian (lower part of the Adavere Stage) rocks are exposed in a total thickness more than 3 m. In the lower part of section (north of the road) light-grey variously dolomitized argillaceous limestones of the Rumba Formation containing abundant shells of *Pentamerus oblongus* occur. Above the Rumba Formation (south of the road) marlstones of the Velise Formation with limestone nodules and rare interbeds are exposed. These rocks contain deeper-water association of braciopods, ostracods and rich assemblage of conodonts.

Fig. A6. Cleaned outcrop in Valgu ditch exposing the Valgu Bentonite. Photo by T. Kiipli.

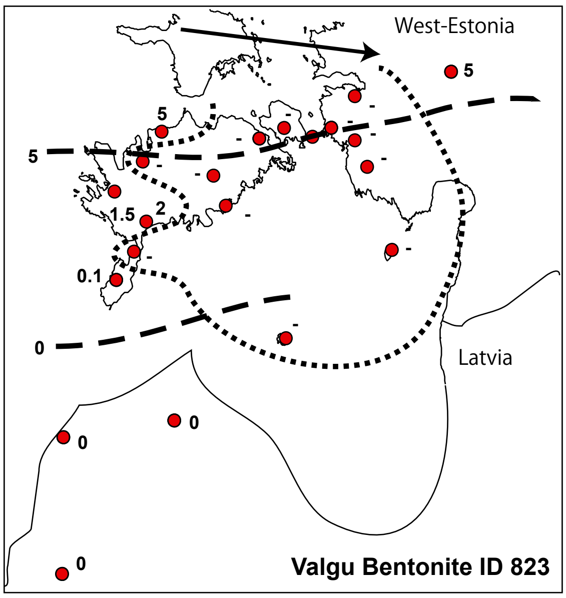


Fig. A7. Distribution of Valgu bentonite. For legend see Fig. A4.

Two closely located feldspathic volcanic tuff layers occur in the interval 0.45–0.55 m above the Rumba/Velise boundary (Fig. A6). The Lower one of these layers is about 6 cm thick and characterized by remarkably high concentrations of Zr, Y, Th, Nb (see Table A1). Pyroclastic sanidine XRD reflection measured from the 0.04–0.10 mm fraction indicates 45 mol % of Na-component in sanidine. These geochemical signatures and stratigraphic position within *Pterospathodus eopennatus* ssp. n. *1* conodont Zone (Männik pers. comm.) indicates correlation with 1.5 cm thick bentonite in the Viki core at the depth 182.3 m. From this depth identification number ID 823 was derived and the name "Valgu Bentonite" was assigned to this layer (Kallaste & Kiipli, 2006). Distribution of the Valgu Bentonite is shown in Fig. A7. Geochemically this ash layer belongs to the Zr rich type (Kiipli et al. 2008b). Just above this bed, separated from it by a thin marlstone layer, another, two centimetres thick feldspathic tuff occurs. Geochemically this layer is markedly different characterized by low concentration of the above listed elements evidencing different volcanic eruption from the other source.

Stratigraphically higher, in the middle part of the river bank section another 0.5 cm thick bentonite layer occurs. This latter layer is not analysed and correlated to the drill core sections so far.

Stop A5: Särghaua field station

by Tarmo Kiipli

The Särghaua field station, founded in 1973, is located in central Estonia, ca 110 km south of Tallinn. It was rebuilt from an old farm for drill core storage, geological work and field seminars by the Institute of Geology of Estonian Academy of Sciences (now Institute of Geology at TUT).

During this excursion an 89 m thick Telychian part of the Viki drill core section will be shown consisting of argillaceous limestones in the lower part and red and grey marlstones in the middle and upper part (Fig. A8). 21 bentonites each 0.5–10 cm thick, including the Lusklint and Osmundsberg bentonites known from Scandinavia, occur in this part of the section. In total 45 Telychian bentonites have been discovered in Estonia and Latvia (Kiipli et al. 2008b). Correlative layers for ash beds from stops 4, 6 and 7 are established in the Viki core.

Fig. A8. Viki drill core boxes No. 63, 62 and 33 showing Upper Ordovician Grefsen, Kinnekulle and Grimsorp bentonites (two first boxes) and Telychian Osmundsberg Bentonite (third box).

Stop A6: Avaste terrace

by Tarmo Kiipli

Thirteen metres high Avaste terrace is formed in Telychian (middle part of the Velise Formation, Adavere Stage) marlstones seven thousand years ago as coastal cliff of the Litorina Sea. Soft marlstones do not form permanent exposure, but can be easily excavated. In the upper part of terrace slope 5 cm thick yellowish soft sticky bentonite occurs (Fig. A9). This bentonite contains pyroclastic sanidine with 46.2 mol % of Na-component and, as the strata exposed in Avaste correspond to the *P. a. lithuanicus* conodont Zone (P. Männik pers. comm.) it can be confidently correlated with the Viki Bentonite (ID 475). The distribution of the Viki Bentonite is shown in Fig. A10.

Fig. A9. Avaste terrace exposing the Viki bentonite. Photo by T. Kiipli.

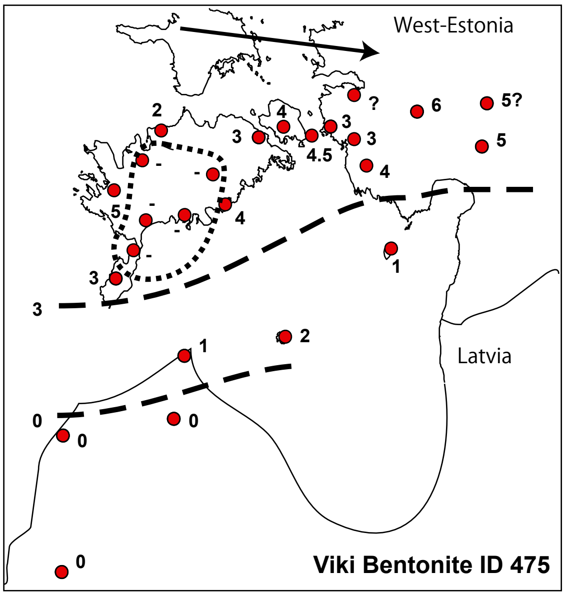


Fig. A10. Distribution of the Viki Bentonite. For legend see Fig. A4.

Stop A7: Päri quarry (see also stop C1)

by Tarmo Kiipli

Päri quarry is located ca five kilometres to the south-west from Kullamaa on a flat limestone hillock near the ruins of Päri manor house. In this quarry 3.9 m thick succession of dolomitized argillaceous limestones of the Rumba Formation (lower Telychian, lowermost part of the Adavere Stage) is exposed. Limestones contain abundant brachiopod *Pentamerus oblongus*.

In the lower part of the section ca 6 cm thick volcanogenic feldspathite tuff layer occurs. It was correlated with “O” bentonite using lithological and palaeontological criteria (Kaljo & Einasto, 1990). XRF analysis of the trace elements (see Table A1) confirms this correlation. Carbonate content in borrows in this tuff layer forms two rising cycles evidencing two stages of eruption. In drill cores this layer is 2–19 cm thick (Kiipli et al., 2006) and represented also by two cycles which are expressed by the varying content of biotite. Biotite is abundant in the lower part of the bed decreasing gradually upwards to almost none in the middle part of the bed. Then above a sharp boundary, which is sometimes bioturbated, 3–5 cm dark tuff with very high content of biotite follows . Sanidine composition in both subdivisions of this layer is identical containing ca 21 mol % of Na-component. Biotite is Mg-rich (Kiipli et al., 2008b). Bergström et al. (1998) correlated the “O” bentonite in Estonia with the Osmundsberg K-bentonite that is found in Scandinavia. In Osmundsberget, Central Sweden, this eruption layer is 1.1 m thick pointing to the source somewhere in Trondheim region of Norway (Fig. A11).

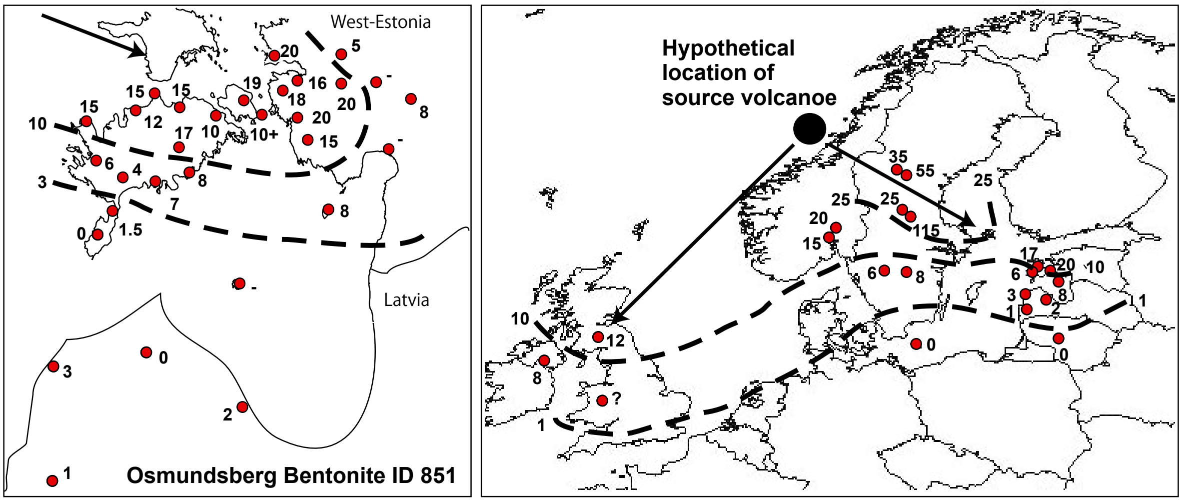


Fig. A11. Distribution and thickness (cm) of the Osmundsberg Bentonite. Left – in Estonia and Latvia, right – in northern Europe (modified from Bergström et al. 1998 and Kiipli et al. 2006). Fore legend see Fig. A4.

Stop A8: Ristna cliff

by Tarmo Kiipli

In North-West Estonia at Ristna Peninsula argillaceous limestones of the Keila Stage (latest Sandbian) are exposed in a thickness of 3.5 m. In the lower part of the cliff section 5 cm thick feldspathic tuff layer occurs (Fig. A12). It belongs to the Grimstorp series of K-bentonites of Bergström et al. (1995). Although this layer is not yet analysed, the stratigraphic position suggests correlation with the upper tuff layer in the Pääsküla outcrop seen in Stop A1.

Ristna cliff is rich in shelly fossils Among erratic boulders breccias from Neugrund impact crater, locating some kilometres in the north-west in the sea can be found.

Fig. A12. Ristna cliff exposing one of the Grimstorp bentonites of the Keila Stage (in the basal part of the cliff). Photo by R. Hints.

Stop A9: Pakri cliff (see also stop B3)

by Tarmo Kiipli and Olle Hints

The coastal cliffs on Pakri Peninsula provide some of the best exposures of Cambrian and Lower- and Middle Ordovician rocks in Estonia. They are part of the Baltic Klint (or North Estonian Klint) — a nearly 1200 km long escarpment that runs from Öland, Sweden, through the Baltic Sea and North Estonia to NW Russia. The scenery Pakerort cliff, to be visited during the excursion, is up to 24 m high and one of the most important geoturism sites in Estonia (Figs A13 and A14). The following succession from base to top can be observed (after Mens & Puura, 1996):

Tiskre Formation (Lower Cambrian) is represented by light gray silty sandstones of which up to 4 m is exposed.

Pakerort Stage (Furongian–Tremadocian) consists of sandstones of the Kallavere Formation (3.7 m) and dark brown graptolite argillite (Dictyonema Shale) of the Türisalu Formation (ca 4.5 m). The Cambrian-Ordovician boundary lies within the sandstones.

Varangu Stage (Lower Ordovician, Tremadocian) is represented by greenish-gray clay and silty sandstone (0.5 m, poorly exposed).

Hunneberg and Billingen stages (Lower Ordovician, Tremadocian-Floian) is represented by greenish-gray glauconitic sandstones of the Leetse Formation (ca 4 m) and calcareous silty sandstones and glauconitic packstone of the lowermost Toila Formation (0.3 m).

Volkhov Stage (Middle Ordovician, Dapingian) consists of highly condensed grey limestone with glauconite (ca 1 m).

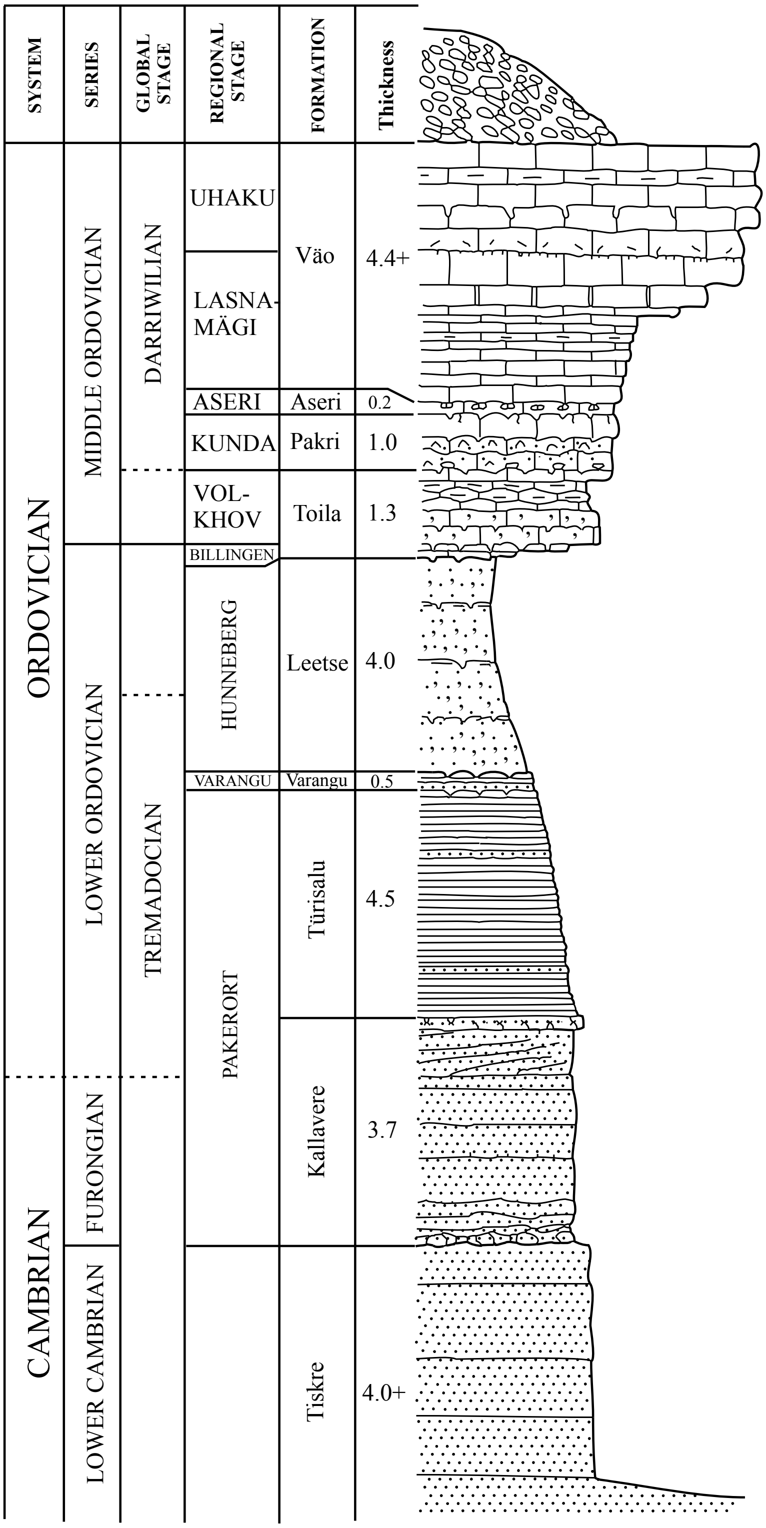


Fig. A13. Composite section of the Baltic Klint in Pakri Peninsula after Mens & Puura (1996)

Fig. A14. Uuga cliff on Pakri Peninsula where Early Ordovician glauconitic sandstones and Middle Ordovician limestones can be easily reached. Photo by O. Hints.

Kunda Stage (Middle Ordovician, Dariwillian) is represented by sandy limestones of the Pakri Formation (1 m). In this interval the oldest kukersite, which in Uhaku and Kukruse stages forms the commercial oil shale deposits in NE Estonia, has been found.

Aseri Stage (Middle Ordovician, Dariwillian) is represented by 0.2 m of oolithic limestone.

Lasnamägi and Uhaku stages (Middle Ordovician, Dariwillian) make up the main limestone part of the top of the cliff composed of argillaceous limestone and dolomite of the Väo (ca 5 m) and Kõrgekallas formations (up to 1.5 m in southern part of the cliff).

No bentonites have been recorded in the Pakri cliff. However, some authors (Petersell, 1997 and references therein) have suggested that the K-feldspar-rich Türisalu Formation (graptolite argillite or Dictyonema Shale) may be related to volcanic activity.

Stop A10: Peetri outcrop

by Tarmo Kiipli

The Peetri outcrop is located north of the Tallinn-Keila road near Hüüru. In a small quarry and entrance into subsurface tunnels altogether 13 metres of Upper Ordovician argillaceous limestones are exposed. The lower part of the section corresponds to the Kukruse Stage and includes also small intercalations of kukersite oil shale. The thickness of kukersite oil shale interbeds grows eastwards and in NE Estonia they are heavily mined for chemical industry and for power plants.

The upper part of section belongs to the Haljala Stage, the lower part of which (Idavere Substage) contains two 5 cm thick volcanic interbeds. They belong to the Grefsen series of K-bentonites of Bergström et al. (1995).

Excursion B:
Ordovician of NE Estonia

The Ordovician System in Estonia

by Tõnu Meidla, Leho Ainsaar and Olle Hints

The main distribution area of the Ordovician strata in the East European Platform extends from the Gulf of Finland in the north to Belarus and Poland in the south, and from the Baltic Sea islands in the west to the vicinity of Moscow in the east. Within this area, beds are exposed in the magnificent sections of the Baltic-Ladoga Klint, in several river bank sections, old and new limestone quarries and open cast pits of northern Estonia and north-western Russia. Good accessibility of strata, excellent preservation of fossils and sedimentary structures and perhaps also the characteristic succession of the Cambrian to Middle Ordovician, represented by several distinctive rock units (like phosphatic brachiopod coquina, *Dictyonema* argillite, dark green glauconite sandstone, etc.), attracted the attention of investigators already in the early 19th century (Engelhardt, 1820; Strangways, 1821; Eichwald, 1825).

The main features of the Ordovician stratigraphy were brought to attention already by F. Schmidt in his thorough monographic paper of 1858. The general pattern of his geologic map, presented in the same volume, is well recognised in the modern bedrock maps of Estonia. The generally simple geologic 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 in back cover of the present volume).

The main part of the Ordovician succession in northern Estonia is composed of various kinds of limestones, with some intercalations of kukersite oil shale concentrated mainly in the Kukruse Stage. Only the basal strata of the Ordovician comprise a relatively thin succession of clastics — 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. Upward the sedimentation rates have increased. Changes of sedimentation rates are in obvious correlation with the carbonate sedimentation rates and carbonate production, except for the terrigenous Lower Ordovician. The corals make their first appearance in the Upper Ordovician, and the first carbonate buildups can be recorded, emphasising a striking change in the overall character of the palaeobasin.

Generally the change in the type of sedimentation and in 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, climatic change resulted in increase of carbonate production and sedimentation rate on the carbonate shelf whereas the deposition pattern was controlled by 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 high number of drill cores, obtained in the course of an extensive drilling programme in the 1950s–1980s, revealed a marked difference between the stratigraphic sucessions 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 (see Fig. B1). As the term „confacies“ is unique (being exclusively used for the Ordovician of Baltoscandia only), a different terminology has been introduced by Harris et al., 2004 (see explanation to the Fig. B1). The micropalaeontological and macrofaunal studies of the core sections also revealed the distinctive biogeographic differentiation pattern, characteristic of the Ordovician rocks (Männil, 1966; Männil et al., 1968; Meidla, 1996, etc.). Although the biofacies pattern is generally described for the eastern

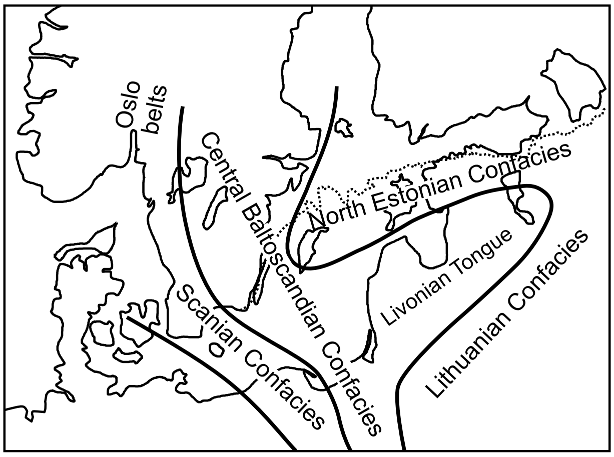


Fig. B1. Post-Tremadocian Ordovician facies zonation in Baltoscandia (Jaanusson, 1976). According to Harris et al. (2004), the North Estonian and Lithuanian confacies comprise the Estonian and Lithuanian shelf (respectively), the "Livonian Tongue" is termed "the Livonian Basin" and it is a part of the Scandinavian Basin (the Central Baltoscandian and Scanian confacies by Jaanusson).

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 and references therein), but also detailed (micro)palaeontological investigations (e.g. Tinn, 2002) might produce valuable new information in this field.

The total thickness of the Ordovician varies from 70 to 180 m, being maximal 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). New prospects in this field have already been opened by stable isotope studies, as the stable carbon isotope curves have demonstrated a good correlation potential (Kaljo et al., 2004, 2007, and references therein; Ainsaar et al., 2004, 2007).

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 introduced by Schmidt (1881) and several subsequent authors. Raymond (1916) introduced the traditional American three-fold subdivision of the Ordovician System for 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 rarely used today. The modern three-fold classification of the Ordovician System (IUGS 2004) was first used for the Estonian succession by Webby (1998) and is presented here in detail (Fig. B2).

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 system boundary in the northern Estonian sections lies some metres higher than previously suggested, i.e. in the middle of the Pakerort Stage, within the Kallavere Formation (Puura & Viira, 1999).

The term "Stage", first applied by Bekker (1921), has become the principal category in the chronostratigraphic classification of the Ordovician System in Estonia. Main features of the chronostratigraphic classification of the Ordovician System were established already by Männil (1966). Only minor changes were introduced in the later decades: the *Ceratopyge* Stage was renamed the Varangu Stage (Männil, 1990), the Latorp Stage was replaced by the Hunneberg and Billingen stages (Hints et al., 1993) and a new unit, the Haljala Stage, is used instead of the Idavere and Jõhvi Stages (following Jaanusson, 1995 and Nõlvak, 1997). 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. However, as stratigraphic hiatuses on the stage boundaries are very common in northern Estonia (remarkable faunal changes are usually related to

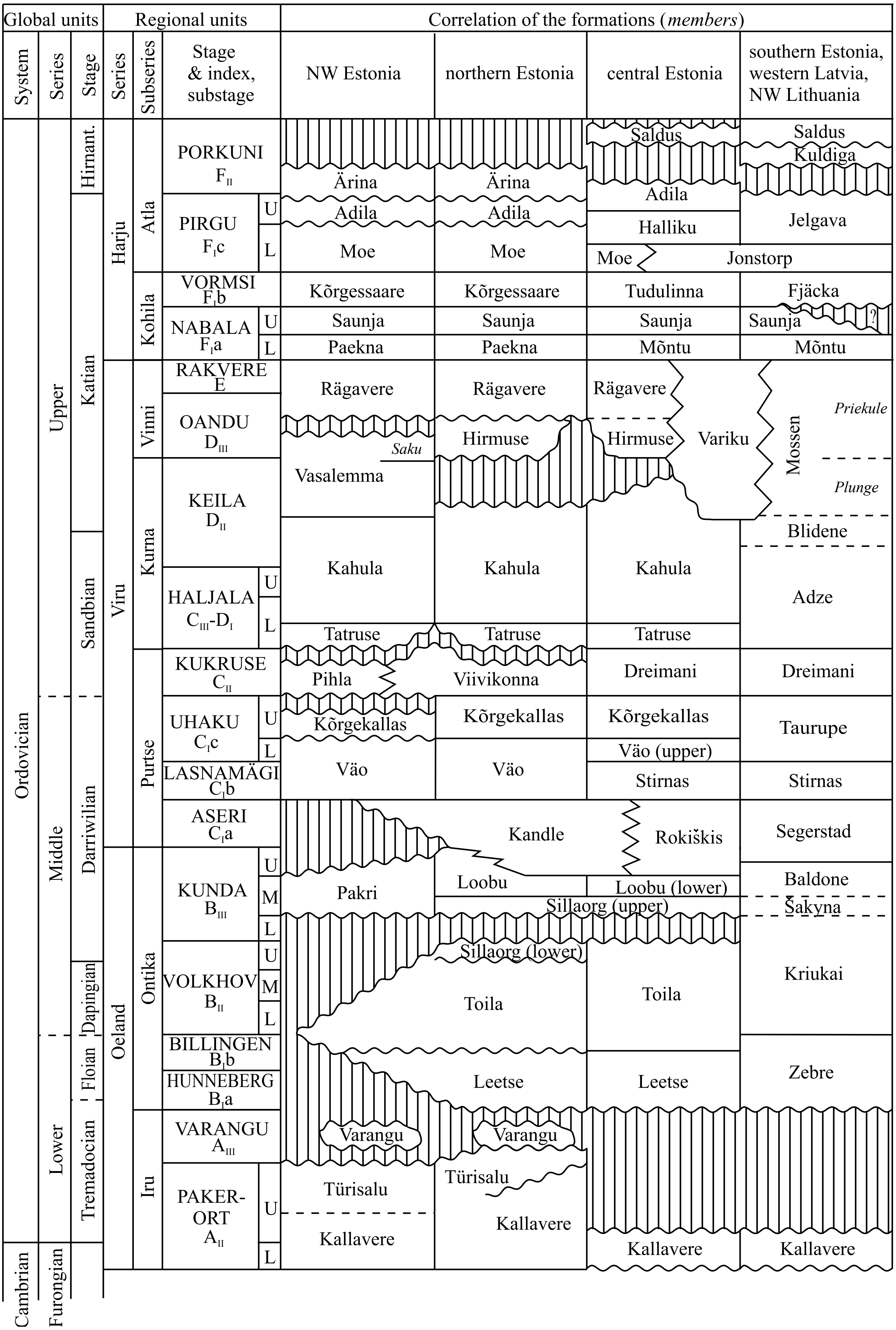


Fig. B2. The Ordovician stratigraphy of Estonia.

hiatuses), wide usage of this concept for the stage boundaries in this area looks rather complicated.

The lithostratigraphic classification of the Ordovician rocks was introduced by Orviku (1940) for the upper Middle Ordovician. This approach was widely accepted by subsequent authors and led to 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. B2 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 also been published by Hints et al. (1993) and Nõlvak (1997). The composition and textures of the Ordovician carbonate rocks and the principal differences between the confacies belts were summarised 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 were 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 recent monograph "Geology and mineral resources of Estonia" (Raukas & Teedumäe, 1997).

Stop B1: Jägala Waterfall section

by Tõnu Meidla

The Jägala Waterfall („Jägala juga" in Estonian) is the highest natural waterfall in Estonia being about 8 metres high (Figs B3 to B5). It is located about 25 km east of Tallinn, near the Jägala-Joa village. Water is falling from an escarpment in valley of the Jägala River.


Fig. B3. The Jägala Waterfall in spring of 2008. Photo by T. Meidla.

The Jägala Waterfall is one of the waterfalls near the northern coast of Estonia. Several rivers and streams have cut deep valleys into the Ordovician carbonate bedrock south of the North Estonian Klint. This is explained by the continuous neotectonic land rise related to glacioisostasy (Miidel & Vaher, 1997). All these waterfalls are geologically similar, due to the relationship to the Baltic-Ladoga Klint: the hard Ordovician limestones and dolomites lie over the softer beds (argillaceous limestones, sandstones or argillites) which are heavily eroded at the base of the escarpment. In case of the Jägala Waterfall, the escarpment is topped by hard dolomitized limestone of the Loobu Formation, which is exposed close to the right bank of the river in periods of low water level (see Fig. B4). This unit was formerly (Schmidt, 1897 and subsequent papers) called the *vaginatum* limestone, due to common occurrence of *Cyclendoceras vaginatum* (Schlotheim). Abundance of cephalopods can be considerd also in the bedding plane which is widely exposed on top of the escarpment. The hard limestone unit is hanging over a cave in the lower part of the escarpment. In the left bank of the river, downstream of the waterfall escarpment, the this unit is forming a potentially dangerous „roof".

Fig. B4. Jägala, section near the right bank of the waterfall escarpment. Photo by T. Meidla.

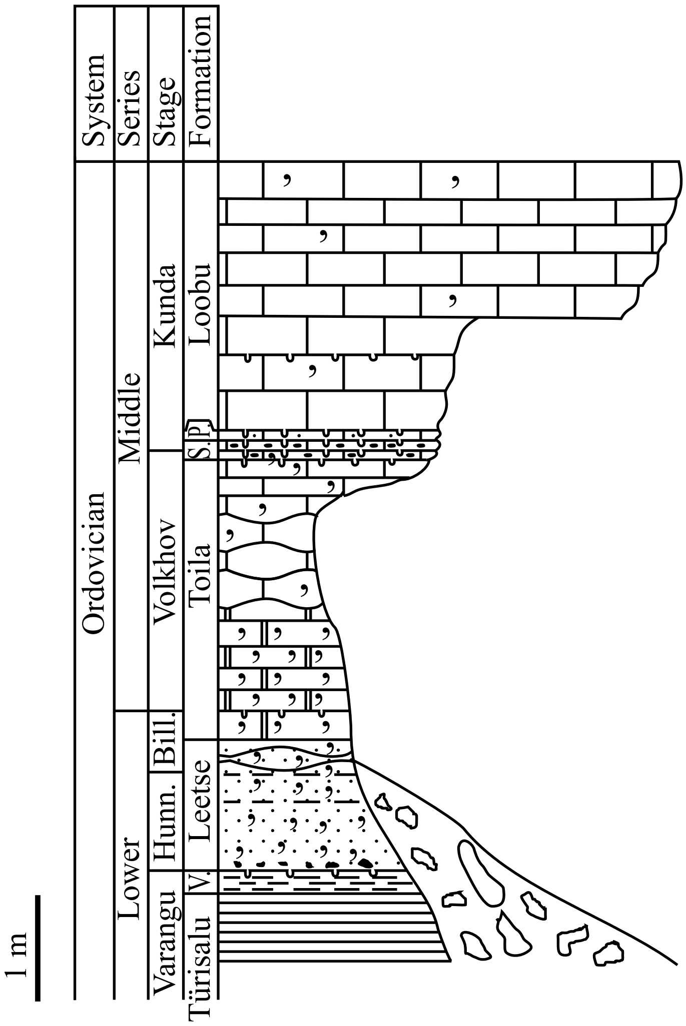


Fig. B5. Lower-Middle Ordovician sequence at the Jägala Waterfall (after Mägi, 1991). See also description in the text.

Like most other waterfalls along the Baltic-Ladoga Klint, the Jägala Waterfall is also receeding upstream. A deep steep-walled canyon has been formed downstream of the waterfall. The waterfall is today situated in a 3 km distance distance of the Klint escarpment and moving slowly but continuously southward. According to different estimates (see Miidel, 1997 for a summary), the average rate of retreat seems to be 16–17 cm per year.

The bedrock sequence exposed in the escarpment and the sections downstream represent outcrops well known already for a century. The sections have been studied by several generations of geologists (Schmidt, 1858; Mickwitz, 1896; Orviku, 1960; Mägi, 1991 and many references therein).

Above the waterfall escarpment, marly limestone of the Aseri Stage is locally exposed. Orviku (1940) describes 0.62 m of limestones: a hard limestone with cephalopod remains underlain by variously argillaceous limestones with ferriferrous and occasional phosphatic ooids and a with a few glauconite in the lower part.

On the right bank of the river (Fig. B5) the section is as follows (adopted from Mägi, 1991):

Kunda Stage
2.65 m – Loobu Formation: grey to yellowish-grey thick-bedded dolomitized limestone with glauconite, with abundant phosphatic discontinuity surfaces, brachiopods and cephalopods.
0.1 m – Pakri Formation: yellowish-grey dolomitized limestone with quartz grains; inarticulate brachiopods and graptolites occur.

Volkhov/Kunda boundary beds
0.2 m – Sillaoru Formation: brownish-grey argillaceous limestone with ferriferrous ooids.

Volkhov Stage
2.5 m – Toila Formation (main part): light grey limestone with glauconite. The rocks are dolomitized and with abundant glauconite grains within the upper 0.4 m (Kalvi Mbr), argillaceous, nodular and with only few glauconite within the underlying 1.2 m (Telinõmme Mbr). The lower 0.9 m of the unit is dolomitized limestone, with abundant glauconite grains (Saka Mbr).

Billingen Stage
0.3 m – Toila Formation (lowermost part): dolomitized glauconitiferous limestone.
0.3 m – upper part of the Leetse Formation (the Mäeküla Member): glauconitic carbonaceous quartz sandstone.

Hunneberg Stage
1.0 m – Leetse Formation: poorly cemented glauconite sand with occasional clay interbeds.

Varangu Stage
0.2 m – Varangu Formation: grey silty clay, with abundant burrows with some glauconite.
0.75+ m – Türisalu Formation: dark brown kerogenous argillite.

In dry season, the water flow in the river is narrowing towards the left bank where the coastal escarpment is covered by loose debris in its lower part. Further downstream, in the river valley, the exposures of sandstones of the Kallavere and the Ülgase formations have been reported.

Stop B2: Ordovician-Silurian boundary in Estonia: localities at Porkuni and Neitla

by Dimitri Kaljo, Rein Einasto and Linda Hints

The boundary between the Ordovician and Silurian systems was established at the level close to the lowest occurrences of *Akidograptus ascensus* in the Dob's Linn section and ratified in 1984 by IUGS (Holland, 1985). This boundary marks the termination of a complicated episode in the Ordovician history called the Hirnantian, the time of the great End-Ordovician glaciation. The glaciation caused mass extinction, several sea-level changes (falls and rises), formation of gaps and characteristic lithologies in the sections, etc. Certainly, for better understanding these interrelated events, a reliable stratigraphical framework is of great help. Estonian and Latvian sections can provide useful hints, although true graptoloids do not occur in this interval.

During the Late Ordovician, the Baltica palaeocontinent was drifting towards the equator and, correspondingly, the local climate became warmer and gave rise to flourishing coral faunas and "reef" structures. Due to the narrowing of the Iapetus Ocean, the cosmopolitan faunal elements became more common and the local faunas suffered from several extinction events. At the same time the formation of large ice caps in Gondwana and remarkable sea-level fall caused a step by step retreat of the sea from peripheral areas of the Baltic Gulf. By the end of the Ordovician a marine environment was preserved only in the former deeper sea areas. As a result, the Ordovician-Silurian boundary interval is discontinuous in this area. The succession is more complete in the South Estonian and Latvian sections, being represented by deeper open shelf sediments of the Central Baltoscandian Confacies Belt (the

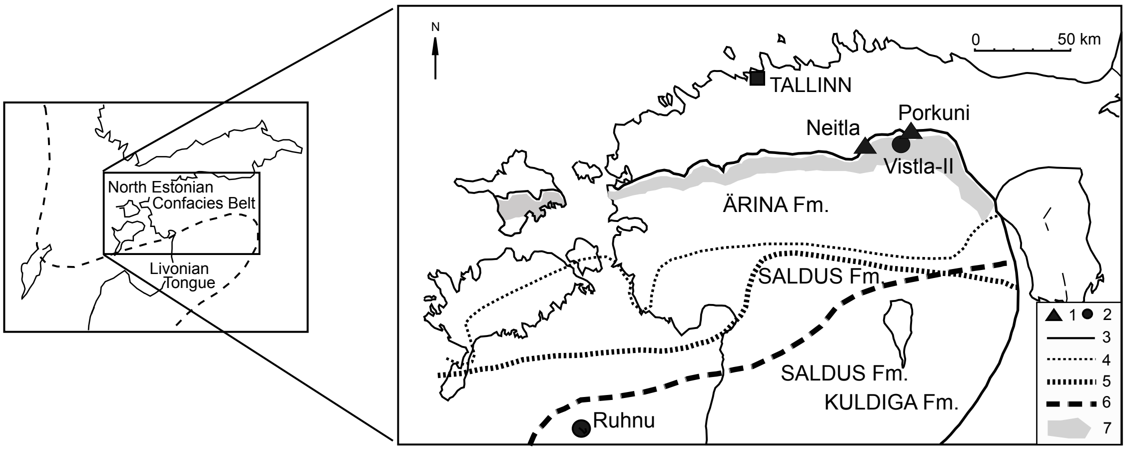


Fig. B6. Location of sections and distribution of formation of the Porkuni Stage. 1, outcrop; 2, drill core; 3, limit of the distribution area of the Porkuni Stage; 4 – southern limit of the distribution area of the Ärina Formation; 5, northern limit of the distribution area of the Saldus Formation; 6, northern limit of the distribution area of the Kuldiga Formation; 7, outcrop area of the Silurian Juuru Stage.

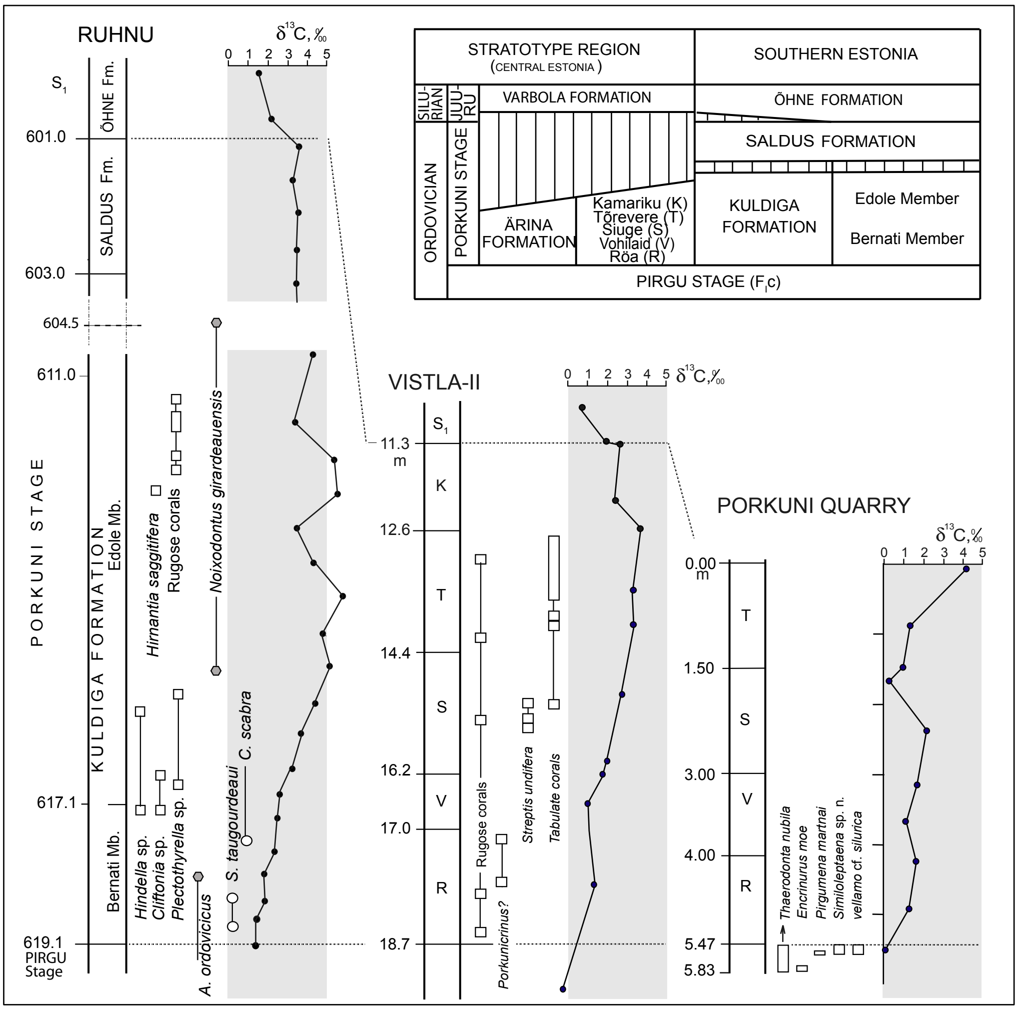


Fig. B7. The carbon isotope curves and data on selected fossils in the Ruhnu and Vistla-II drill cores and Porkuni quarry sections (Kaljo et al., 1998, 2000; Hints et al., 2000). In the top right corner are the stratigraphical units in Ordovician-Silurian boundary interval.

Livonian Tongue area in sense of Jaanusson, 1995). The North Estonian Confacies Belt (Fig. B6) is characterized by shallow shelf and shoal sediments and shows sharp faunal and lithological differences along the deepening gradient during Porkuni age. In the sections to be visited during this excursion, some gaps are obvious and will also be discussed at the conference (see the abstract by Kaljo et al. in the present volume).

According to East Baltic stratigraphical classification, the Porkuni Stage (Fig. B7) is nearly equivalent to the Hirnantian Global Stage. The base of the latter unit was defined in the Wangjiawan North section in China (in the global stratotype) as a level marked by the lowest occurrences of *Normalograptus extraordinarius* (Chen et al., 2006). This level is believed to coincide with the base of a major positive $\delta^{13}C$ excursion and beginning of a pronounced sea level fall associated with onset of a major glaciation (Chen et al., 2006). Most of these criteria are rather well applicable also in case of the Porkuni Stage (Brenchley et al., 2003; Kaljo et al., 2001, 2003, 2004), but we are not sure that all the listed events are really synchronous. As mentioned above and shown in Fig. B7, some gaps occur also in the top of the section and several "question marks" are persisting. The sea level was fluctuating, as seen from the fact that the Saldus Formation has wider distribution than the Kuldiga Formation.

A reef complex packed between the dolomites beneath and the sandy limestones above is included in the Ärina Formation representing the Porkuni Stage in North-Central Estonia, the type area of the stage. These rocks are exposed in the Porkuni quarry (Fig. B8) and in the Neitla outcrop (Fig. B9), but the Ärina Formation comprises only the older part of the pre-Silurian Porkuni rocks. The youngest rocks of the Porkuni Stage are distributed in southern Estonia and in central East Baltic, where the Kuldiga and

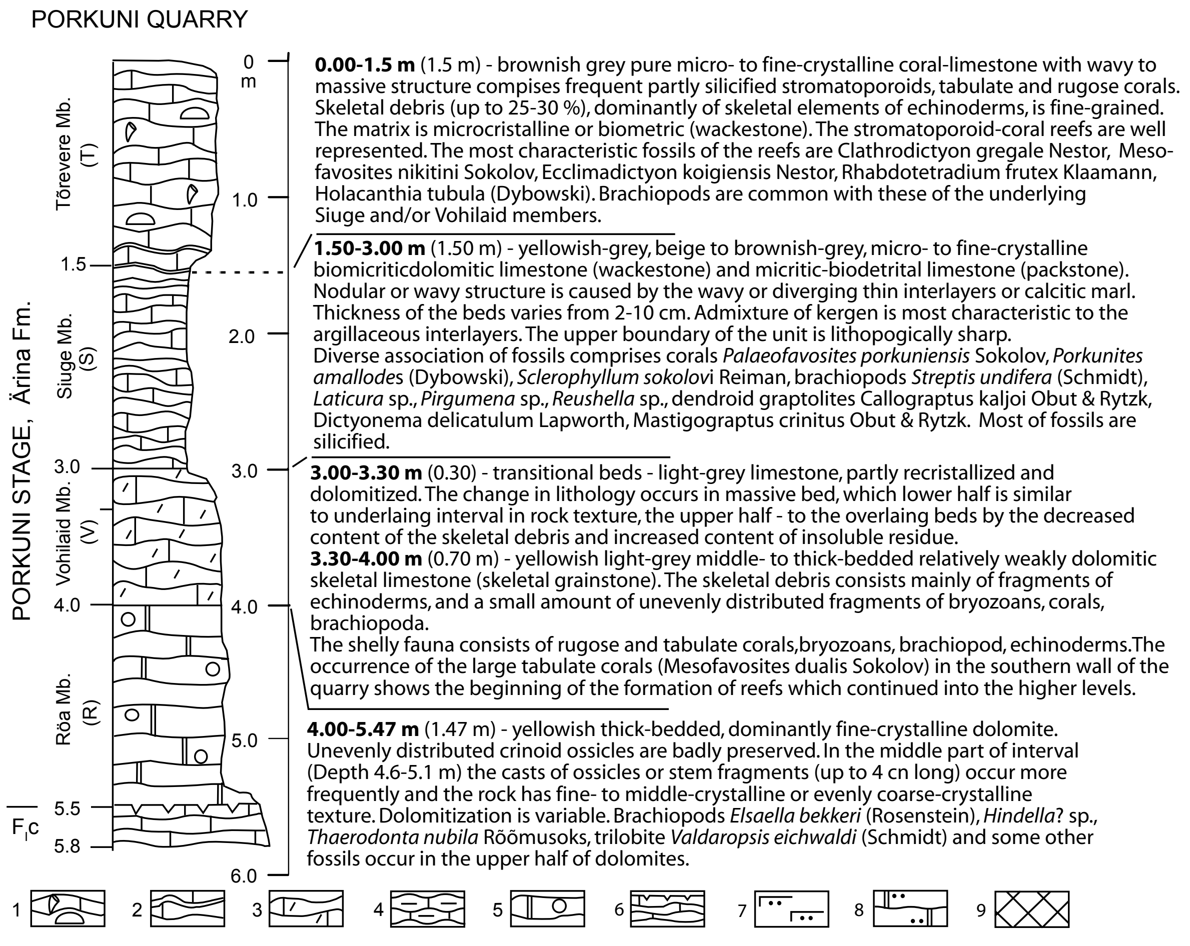


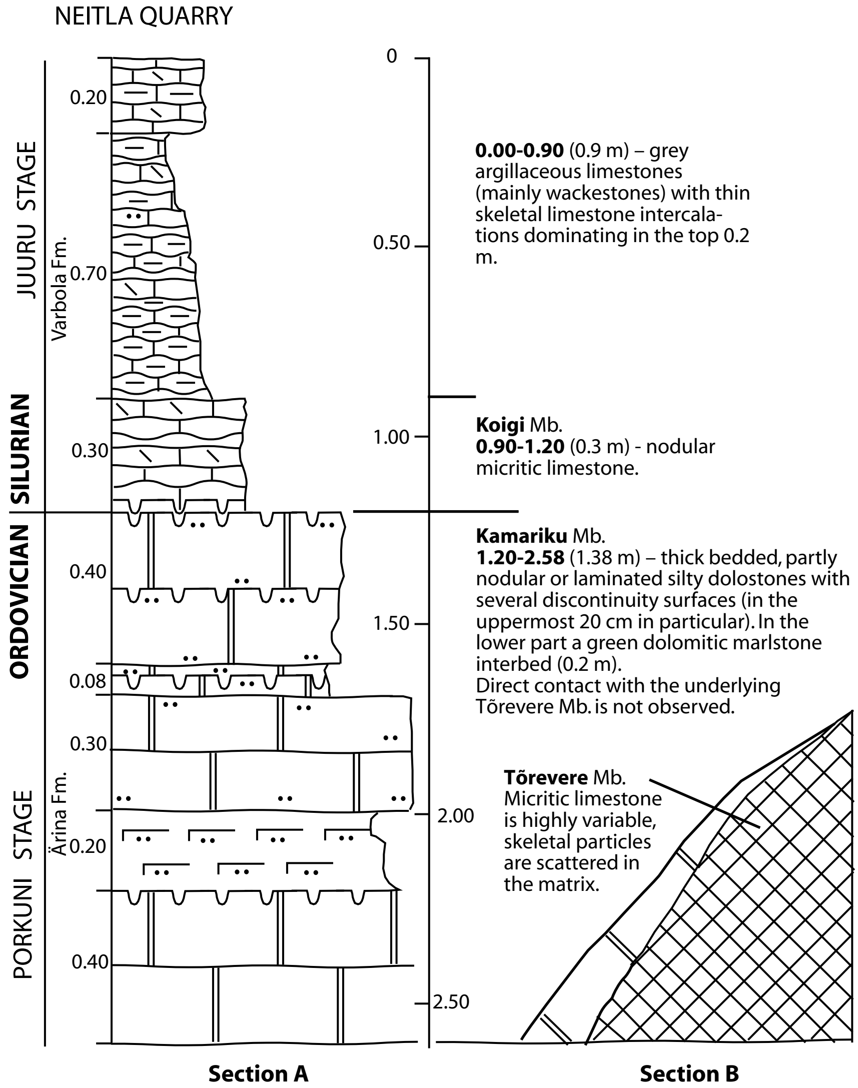
Fig. B8. Description of the Porkuni quarry section. Legend (simplified) for the log: 1, reef limestone with corals; 2, biomicritic dolomitic limestone with interlayers of calcitic marl; 3, dolomitic skeletal limestone; 4, nodular argillaceous limestone; 5, dolomite with crinoid ossicles; 6, argillaceous dolomite with discontinuity surface; 7, dolomitic marlstone; 8, silty dolostone; 9, reef limestone. FIc – Pirgu Stage.

Saldus formations, comprise the whole sequence of the stage, from the base up to the upper boundary. The occurrence of the cosmopolitan *Hirnantia* community in the middle of the Kuldiga Formation (Fig. B7) makes the Baltic latest Ordovician similar to that of many other regions, including the type section of the Hirnantian Stage (Rong et al., 2002; Chen et al., 2006). The lowermost Silurian Juuru Stage comprises the Varbola Formation in central Estonia and the Õhne Formation in the southern Estonia.

Porkuni quarry

The dolomites cropping out in the Porkuni quarry were first mentioned by Eichwald (1854). Schmidt (1858) established the "Borkholm´sche Schicht", the Porkuni Stage of current use. Describing this unit, he recorded a succession of four different rock types in the Porkuni quarry, beginning with the "Encrinitenlager", overlain by dolomitic limestones and brownish marls and topped by white limestones. A rich association of fossils was also described. About 60 years later Wahl (1923) added some data on fossil faunas of the Porkuni Stage and re-named the Schmidt´s units into "crinoidal dolomite" in the lower part of the stage, an ovelying "bryozoan-limestone", "*Conocardium*-limestone" and "coral limestone". New data on stratigraphy, lithology and distribution of fossils in the Porkuni Stage has been presented in the papers by Martna, Männil, Rõõmusoks, Oraspõld and others (see references in Hints et al., 2000).

The thickness of the section cropping out in the Porkuni quarry reaches 5.5 m whereas the lower boundary of the Porkuni Stage occurs presumably at a depth of about 0.4 m from the quarry floor. It is marked by an inconspicuous discontinuity surface. The short lithological description of the Porkuni quarry wall is presented in Fig B8. The uppermost Kamariku Member of the Ärina Formation is missing is the quarry but occurs in the Vistla-II core section (Fig. B7, designated by Hints et al., 2000 as the hypostratotype of the stage) and is exposed in the Neitla outcrop (Fig. B9). The succession of members of the reef complex (Tõrevere, Siuge and Vohilaid members) may be variable even in short distances.



Neitla outcrop

Neitla outcrop is a new locality of the Ordovician–Silurian boundary beds, recently reported by R. Einasto (2007) from a gravel-pit ca 5 km east of Järva-Madise, Järvamaa

Fig. B9. The Ordovician-Silurian boundary beds in the Neitla quarry. A and B show sections exposed in different walls of the quarry. For legend see Fig. B8.

County. The sandy rocks of the Kamariku Member (the uppermost part of the Ärina Formation) and the Ordovician-Silurian contact were previously known only from the core sections. The Neitla outcrop, located about 30 km SW of the stratotype area of the Porkuni Stage (Fig. B6) exposes the reefs of Tõrevere Member and the sandy Kamariku Member, overlain by the lowermost Silurian Varbola Formation. The measured and sampled section of the early Palaeozoic rocks is presented in Fig. B9.

On the local correlation of the Ordovician-Silurian boundary interval

The two sections described above, Porkuni and Neitla, characterize the O-S boundary interval in the shoal to open shelf environments of the North Estonian confacies belt (Fig. B6). The lithologically variable reef-bearing deposits of the Porkuni age in this area are separated from the latest Ordovician deposits in southern Estonia and central East Baltic (the Kuldiga and Saldus formations) by a transitional belt (Fig. B6; between the lines 4 and 5 – see legend). In this belt the Porkuni Stage is locally missing or represented by poorly fossiliferous dolomites in a restricted thickness (?Röa Member). Facies and faunal differences has long time hampered the correlation of the latest Ordovician sections in the Baltics. Progress in this field was obtained through the use of microfossils, mainly chitinozoans (Nõlvak & Grahn, 1993; Nõlvak, 1999), and carbon isotope data (Marshall et al., 1997; Kaljo et al., 1999, 2001, 2003).

The zonal chitinozoan *Spinachitina taugourdeaui* has been identified in the core sections in the interval from lower half of the Ärina Formation up to the Siuge Member (Nõlvak, 1986, Brenchley et al., 2003) as well in the Bernati Member of the Kuldiga Formation in the southernmost sections (Fig. B7). In the latter unit the *S. taugourdeaui* Biozone is replaced by the *Conochitina scabra* Biozone and the last occurrence of a zonal conodont *Amorphognathus ordovicicus* is supposedly related to the same interval. The younger *Hirnantia* brachiopod fauna associates with the *Noixodontus* conodont fauna (Fig. B7; Männik, 2001, 2003). In the type section of the Hirnantian Stage in China, *A. ordovicicus* zone conodonts occur also below the *Hirnantia* brachiopod association (Chen et al., 2006). Based on the distribution of zonal chitinozoans the Ärina Formation in the stratotype area, at least the strata with *S. taugourdeaui*, are correlated with the lowermost part of the Kuldiga Formation (Bernati Member) (Nõlvak & Grahn, 1993; Nõlvak et al., 2007).

The biostratigraphical correlation is well supported by the carbon isotope data. The more or less continuous rise of carbon isotope values begins in the Röa Member in North Estonia (Fig. B7; Kaljo et al., 1999, 2001; Brenchley et al., 2003). In the Porkuni quarry the $\delta^{13}C$ values reach over 4‰ in the top of the reef limestones of the Tõrevere Member. The shift back towards low values of $\delta^{13}C$ is observed in the topmost Porkuni or in the lowermost Silurian (Kaljo et al., 2001; Brenchley et al., 2003). This is well seen also in Neitla, where the Tõrevere Mb shows a peak ($\delta^{13}C$ value of 4.5‰) followed by a decreases in the lowermost Kamariku Member (2.9–3.5‰) continuing in the upper part of the Kamariku Member (0.7–1.3‰). The Silurian isotopic values in the Koigi Member are 1.4–1.3‰ but higher up in the Varbola Formation the values fall below zero (-0.9 and -1.2‰) like it is common to many sections.

The $\delta^{13}C$ curve from Neitla can be correlated with that of the Ruhnu section in South Estonia where the rise of values begins in the Bernati Member of the Kuldiga Formation and Saldus Formation shows some decline of the values. The highest isotopic values in South Estonia fall into the lower half of the Edole Member (Kuldiga Formation) where brachiopods of the *Hirnantia* fauna and chitinozoans of the *C. scabra* Biozone occur.

Stop B3: Baltic Klint at Saka and Valaste

by Oive Tinn

The Baltic Klint is one of the most extensive outcrops of the Lower Palaeozoic rocks in the world. The length of the Baltic Klint is 1100–1200 km, the height reaches 56 meters. The Klint emerges at the western coast of the Öland Island in Sweden, extends along the southern coast of the Gulf of Finland and reaches up to the Ladoga Lake in Northwest Russia. The nearly 300 km long North Estonian Klint is a part of

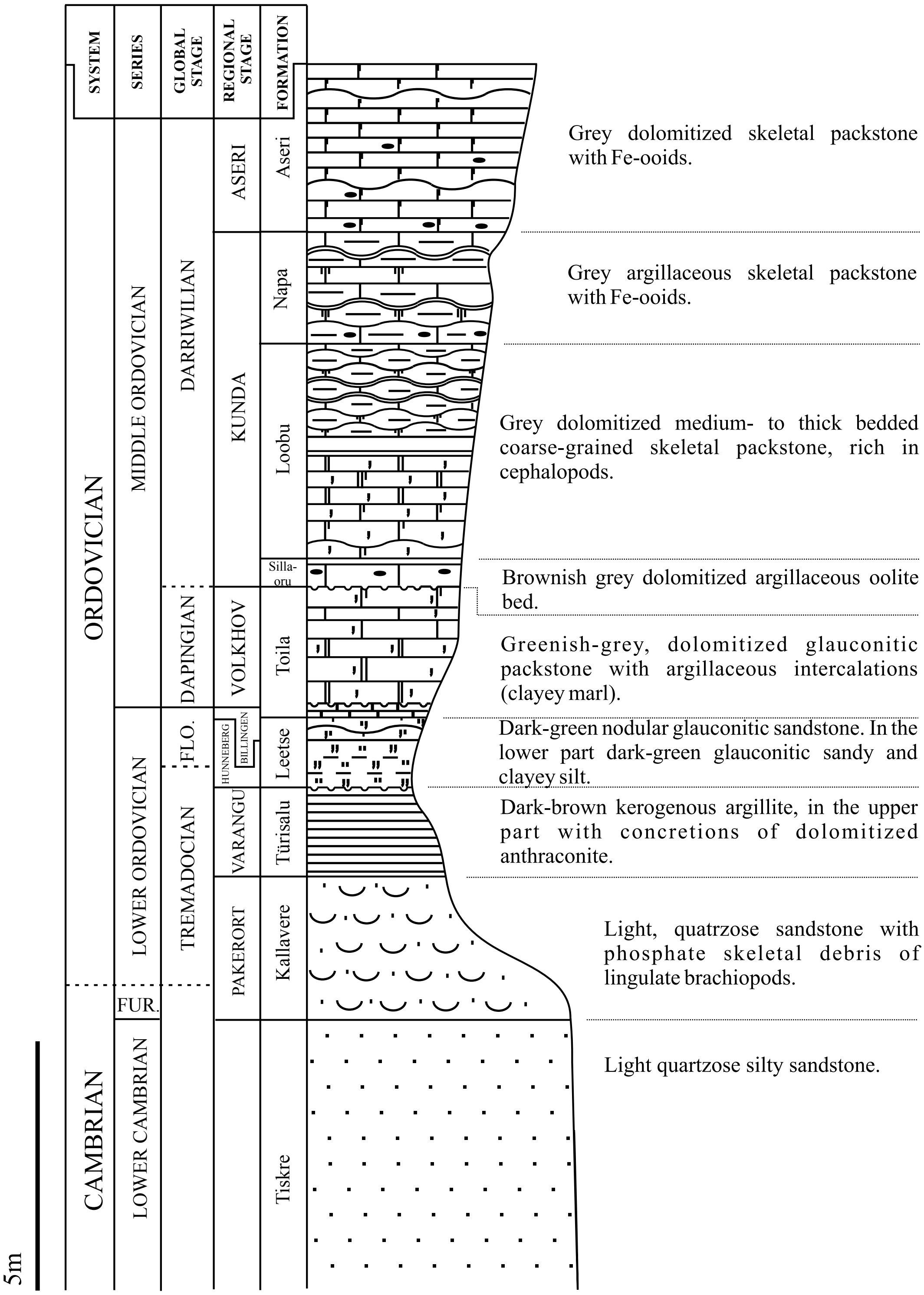


Fig. B10. The Valaste section.

Fig. B11. A View of the Saka trench section. Photo by T. Meidla.

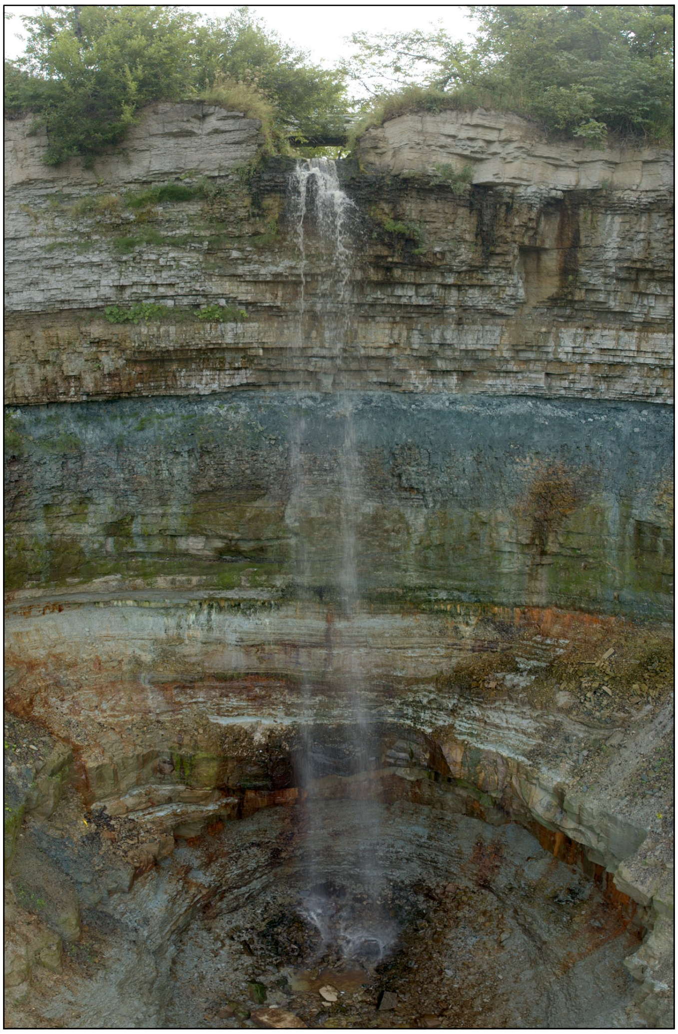


Fig. B12. Valaste waterfall. Photo by O. Hints.

this large structure. The Estonian National Committe of the UNESCO has accepted the Baltic Klint as a candidate for the world heritage site. Geologists value the Baltic Klint mostly because of the extraordinary preservation of the Lower Palaeozoic rocks that have not been subject to deep burial or folding.

The artificial Valaste waterfall (Figs B10 and B12), falling from the 54 m high North Estonian Klint is the highest waterfall in Estonia. Its height is usually between 26 and 28 m, but after exceptionally heavy rainfalls the strong flow may erode a deep pit into the sandstone on the foot of the Klint and the total height of the waterfall can reach up to 30 meters. Downwards, the waterfall continues as a rapid, flowing into the sea 10–15 m below.

Due to the slight southward dip of the limestone layers (3–4 m per 1 km) and the absence of water outlet, the fields in the Klint area have been suffering from excessive water during rainy seasons. At the beginning of the 19th century, a 7 km long and up to 2 m deep drain was made to aid water run off the manor's fields nearby. As a result, the water flow has cleaned and eroded the Klint wall, exposing the wonderful Lower Cambrian to Middle Ordovician sedimentary section.

The section (Fig. B10) is stratigraphically similar to that described in the Ontika Klint, 3 km west of Valaste (Mägi, 1990). It exposes the Lower Cambrian Ordovician sandstone (Tiskre Formation), Furongian to Lower Ordovician Sandstone (Kallavere Formation), black shale (Türisalu Formation), glauconitic sandstone (Leetse Formation) and Middle Ordovician limestone and dolomite (Volkhov, Kunda and Aseri stages). The banks of the stream below the Klint expose locally the "blue clay" of the Lower Cambrian Lükati formation. In 1999 a platform was constructed in front of the waterfall in order to make the observation of the site safer and more attractive.

The Saka section is situated 2 km west of the Saka village. The trench section — a 20–30 meter wide, as much deep and about 200 m long opening (Suuroja, 2006) — was cut into the Klint to lead the sewerage pipe from the nearby Kohtla-Järve city into the sea (Fig. B11) Basically, the seaward part of the trench shows the section from the Lower Cambrian Tiskre Formation up to the Middle Ordovician Aseri Formation (Fig. B10). However, a large part of the section is overgrown and so only the uppermost portion of the section (starting from the Volkhov Stage) is well observable.

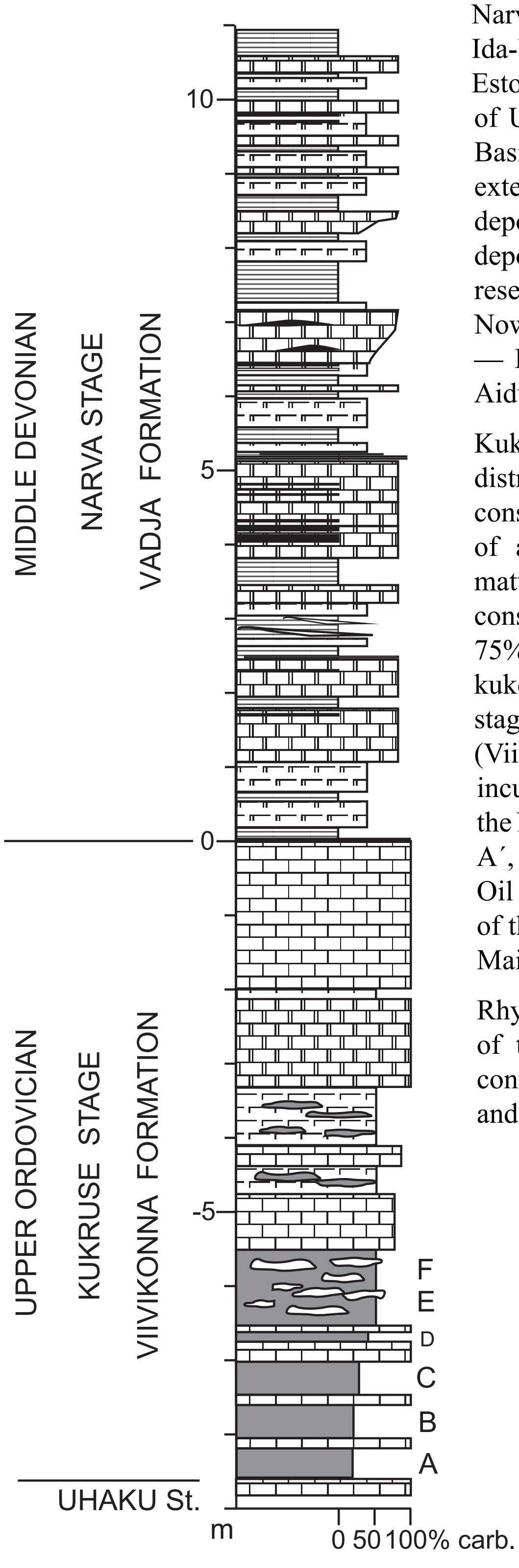
Stop B4/D1: Narva quarry

by Leho Ainsaar and Kati Tänavsuu

Narva oil shale quarry (opencast mine) is situated in the Ida-Virumaa county close to the Narva River. Kukersite, the Estonian oil shale, is mined here from the carbonate deposits of Upper Ordovician Kukruse Stage. The Baltic Oil Shale Basin is situated in north-eastern Estonia, with a part of it extending eastward into Russia. At present, the Estonian deposit is the largest commercially exploited oil shale deposit in the world. Its total area is nearly 3000 km^2. Total reserves of the deposit are approximately 5000 million tons. Nowadays oil shale is excavated in two underground mines — Estonia and Viru and in five open cast pits — Narva, Aidu, Sirgala, Põhja-Kiviõli and Ubja.

Kukersite is a unique mixed sedimentary rock, widely distributed in Ordovician carbonates in northern Estonia. It consists of the following main components: organic matter of algal and/or microbial origin (25–70%); siliciclastic matter, mainly clay (10–75%); calcareous component, consisting mainly of calcitic matrix and skeletal debris (10–75%; Bauert & Kattai, 1997). Up to 50 laterally continuous kukersite seams are described in the Uhaku and Kukruse stages (Darriwilian, Sandbian). Rocks of the Kiviõli Member (Viivikonna Formation, lower part of the Kukruse Stage) incuding the commercial oil shale seams can be studied in the Narva quarry (Figs B13, B14). Seven kukersite layers (A, A′, B, C, D, E, F1) form the commercial seam of Estonian Oil Shale Deposit, whereas kukersite layers in the upper part of the section do not have commercial value. The overlying Maidla Member has comparably low kukersite content.

Rhythmical alternation of different rock types is characteristic of the oil shale-bearing deposits: limestone of different content of argillaceous component and kerogene, kukersite, and marl. The rocks are frequently dolomitized within tectonic disturbances and karstification zones. The sediments have been bioturbated before lithification, numerous discontinuity surfaces are described in the sections. The rocks are extremely rich in fossils: over 300 species of benthic macrofossils are found in the Kukruse Stage which is the most fossiliferous stage in the Ordovician of Estonia (Rõõmusoks, 1970).



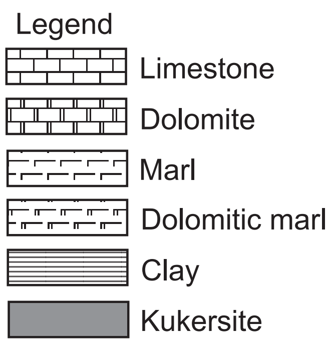


Fig. B13. Section from the southwestern part of the Narva quarry.

Fig. B14. Narva quarry, overview from the western part. Ordovician limestone (light) is covered by Devonian clays and dolomites (dark). Photo by L. Ainsaar, 1998.

The organic matter of kukersite is alganite A (telalganite) derived from *Gloeocapsomorpha prisca*. The deposition of kukersite took place in normal marine conditions in some distance from the coastline. This area was embraced by the nonsedimentation area in north where the rocky seabottom was covered by algal mats. The kerogene was probably derived from this hard-bottom area and deposited in some distance of the coastline (Männil et al., 1986; Bauert & Puura, 1990). The kukersite deposition facies gradually shifted southward (basinward), showing a clear progradational pattern (Männil et al., 1986; Bauert & Kattai, 1997).

Fig. B15. Contact between the Ordovician (grey limestone) and Devonian (intercalation of clay and dolomite) in the Narva quarry. Photo by K. Tänavsuu.

Another remarkable geological feature in the Narva quarry is the Caledonian stratigraphic unconformity, the Ordovician/Devonian contact. The Middle Devonian Eifelian argillaceous carbonates of the Narva Stage cover here the Upper Ordovician Sandbian carbonates of the Kukruse Stage (Fig. B15). The time equivalent of the sedimentary gap can be estimated as 65 million years. The contact represents an erosional smooth surface, with no change in bedding. It demonstrates relative tectonic stability of the area during the Caledonian Orogeny, which was mainly expressed here as a general uplift together with limited erosion.

The Narva Stage is represented here by an intercalation of clay, dolomitic marl and dolomite with a thickness of up to 11 m. These muddy deposits mark the major change in sedimentation during the Middle Devonian time. Siliciclastic sedimentation with dominantly sand accumulation in subaqueous delta plains in the Pärnu time turned into the deposition of the mixed carbonate-siliciclastic mud accumulated in shallow marine conditions (Kleesment, 1997; Plink-Björklund & Björklund, 1999).

There are very few outcrops where these Middle Devonian carbonates can be studied and the Narva quarry is the best among them. It serves also as a stratotype for the lower, Vadja Formation of the Narva Stage. The basal Devonian bed above the Ordovician limestone is a thin, black-coloured argillaceous mudstone with low organic material content. The Vadja Formation consists mostly of continuous massive, laminated carbonate (dolomite, dolomitic marl) and homogeneous, laminated siliciclastic mudstones beds. Occasional tempestite and syneresis cracks may occur. These carbonate and siliciclastic mudstones deposited during the major Middle Devonian transgression in the East European Platform and similar deposits are also found in neighbouring areas (Riding, 1984; Valiukevičius et al., 1986; Valiukevičius & Kruchek, 2000). These mixed muddy deposits are interpreted to have been accumulated in lagoonal environment (Paškevičius, 1997), in shallow marine tidally influenced environments (Kleesment, 1997; Plink-Björklund & Björklund, 1999).

Excursion C:
Silurian of Saaremaa Island

The Silurian System in Estonia

by O. Hints

During the Silurian Period the Baltica continent was located in equatorial latitudes drifting northwards (Melchin et al., 2004). The pericontinental Baltic paleobasin, embracing the territory of Estonia, was characterised by a wide range of tropical shelf environments and diverse biotas.

The Silurian rocks are distributed in western, central and southern parts of Estonia, south of the Haapsalu-Tamsalu-Mustvee line. Further to the south of the Pärnu-Mustvee line they are covered by Devonian strata (Fig. 1). Due to the southward inclination of Estonian basement and gradual infilling of the sedimentary basin from north to south during the early Palaeozoic, the oldest Silurian rocks are found in eastern and northern part of the outcrop area; to the south and south-west successivly youner strata become exposed. The best Silurian outcrops in Estonia are found on Saaremaa Island, especially on the coastal cliffs.

In the outcrop area the Silurian succession is represented by shallow-shelf limestones and dolostones rich in shelly faunas. In the subsurface of southwestern Estonia and Latvia more deeper-water facies were spread being represented predominantly by argillaceous rocks, from calcareous marlstones to graptolithic shales (see example in Fig. C1).

The Silurian successsion of Estonia has been studied since mid-19th century. The outlines of Silurian stratigraphy were worked out particularly by Schmidt (1881). Bekker (1925) and Luha (1933) established the present nomenclature of Silurian regional stages and subsequently various aspects of the Silurian System have been studied in Estonia, most of which are discussed in details by Kaljo (1970), Nestor (1997) and Nestor & Einasto (1997).

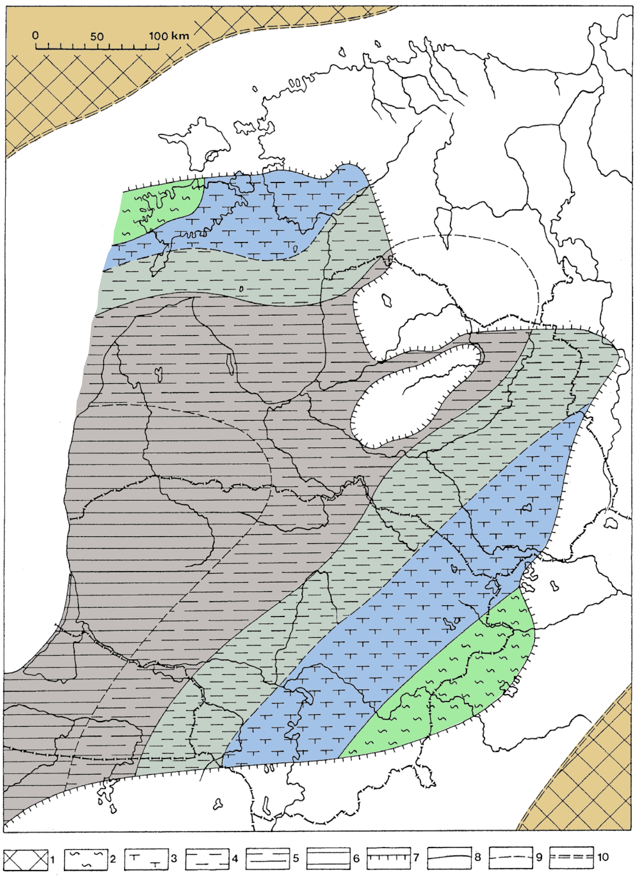


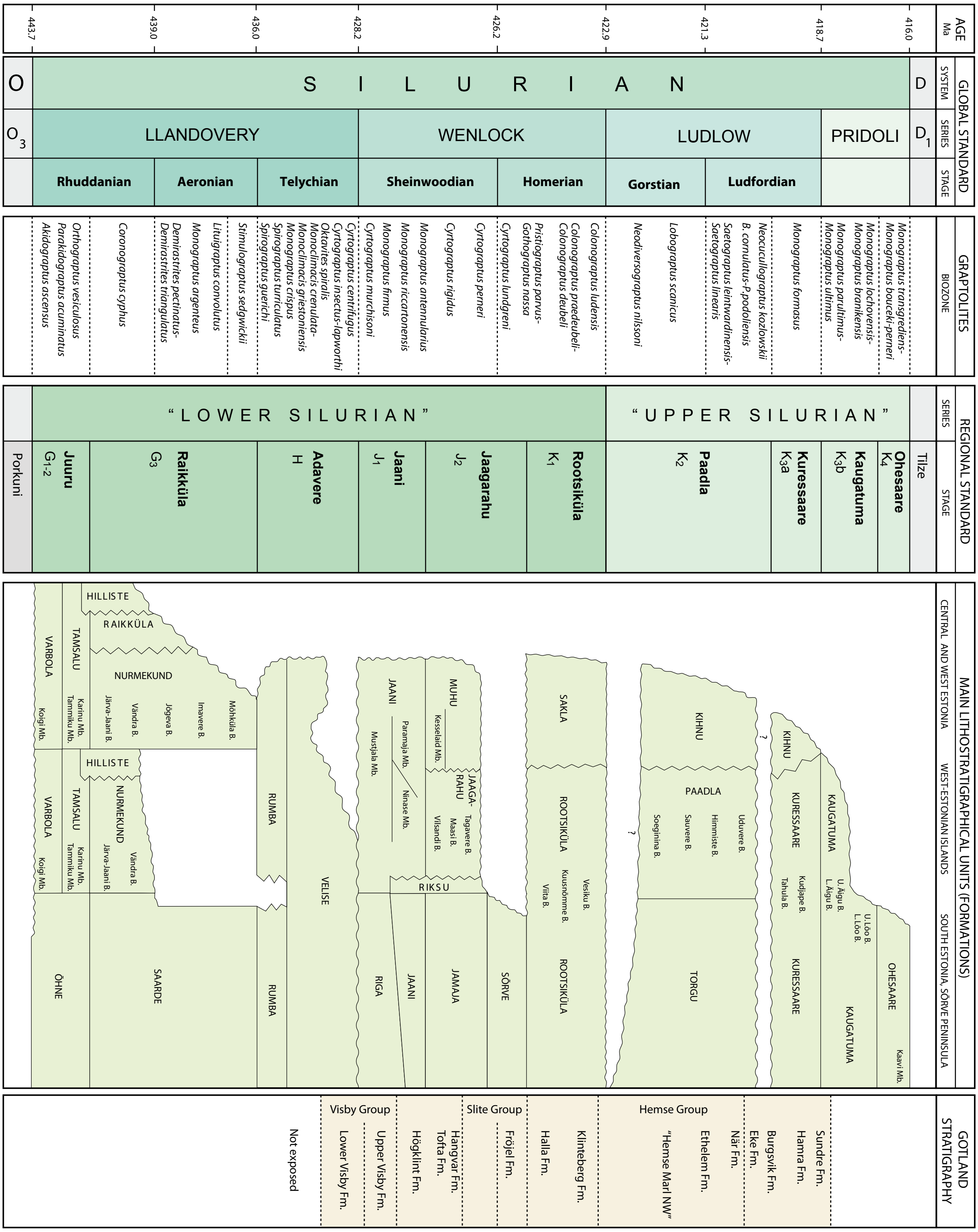
Fig. C1. Distribution of sediments and facies belts the during the mid-Jaani time (early Wenlock). 1 – land; 2 – bioclastic calcareous mud; 3 – argillaceous-calcareous mud; 4 – green terrigenous mud; 5 – grey terrigenous mud with graptolites; 6 – dark kerogenous graptolitic mud; 7 – boundary of the present extension of rocks; 8 – main facies boundaries; 9 – boundary of sediment types; 10 – shoreline. After Nestor & Einasto (1997).

The current stratigraphical scheme of the Silurian of Estonia is provided in Fig. C2. The Silurian sequence is subdivided into 10 regional stages, which group rather well into the global series. The Silurian succession is relatively complete in Estonia and hence the regional chronostratigraphical standard has been used as a proxy for the entire Baltic area (Melchin et al., 2004).

The correlation of regional stages is achieved mostly by the means of biostratigraphy, but in recent years chemostratigraphy has also played an important role in regional as well as global correlation of Estonian stratigraphical units (for review and references see Kaljo & Martma, 2006 and Kiipli & Kallaste, 2006). The most important fossil groups for regional stratigraphy are conodonts (e.g., Männik, 2007) and chitinozoans (e.g., Nestor, 2007). However, agnathans, ostracods and shelly faunas also provide useful correlation criteria. Graptolites are rare in the outcrop area but occur rather abundantly in the basinal facies of South Estonia and Latvia. Integrated biostratigraphical studies of graptolites, chitinozoans and conodonts (e.g., Loydell et al., 2003) have enabled corraletion of standard graptolite zones to biozonations of chitinozoans and conodonts.

The Silurian palaeontological record is rich and generally well-preserved in Estonia. The most common fossil groups are brachiopods, corals, stromatoporoids, echinoderms, trilobites, ostracods, molluscs, agnathans and fishes, eurypterids, bryozoans, conodonts, chitinozoans, scolecodonts, acritarchs, algae and stromatolites (see Kaljo, 1970; Kaljo & Nestor, 1990; and Raukas & Teedumäe, 1997).

Fig. C2. The Silurian stratigraphical chart of Estonia and its correlation with graptolite zones and the succession on Gotland, Sweden. Modified after Nestor (1997) and Nestor (pers. comm. 2007) and Männik (pers. comm. 2008). The Global Silurian time scale according to Melchin et al., 2004).



Stop C1: Päri quarry

after D. Kaljo and R. Einasto (1990)

A broad, shallow, disused quarry is located 5 km to southwest from Kullamaa village, on a flat limestone hillock (58°50′27″ N, 24°2′36″ E). In older German literature the outcrop was known by the name Kattentack and it serves as a type locality for several fossils, especially corals and stromatoporoids.

Argillaceous nodular limestones, containing brachiopods *Pentamerus oblongus*, are exposed in this outcrop (Figs C3–C5). They correspond to the upper part of the Rumba Formation of the Adavere Stage. The following section can be observed in the deepest part of the quarry (from the top):

1. 1.30 m – irregularly nodular, argillaceous limestone (skeletal packstone) with lense-like interlayers of *Pentamerus*-rudstone and skeletal grainstone. The basal 15 cm is highly argillaceous rock, in the uppermost 40 cm grainstone lenses are rare. Fig. 32B shows a detail through a ripple mark filled by a *Pentamerus*-rudstone.
2. 0.05 m – argillaceous marlstone lying on a double discontinuity surface.
3. 1.05 m – different grey argillaceous, mostly irregularly nodular limestones (packstones; containing pentamerid and stromatoporoid rudstone lenses, some beds of microcrystalline limestones and thin marl intercalations.
4. 0.10 m – grey argillaceous limestone with marl intercalations.
5. 1.15 m – greenish-grey, irregularly nodular, argillaceous skeletal limestone (packstone) with lenses of skeletal grainstone (*Pentamerus*-coquinas). Upper 15 cm contains purer limestone with a pyritic discontinuity surface at the top.
6. 0.06 m – bioturbated bentonite bed (Osmundsberg

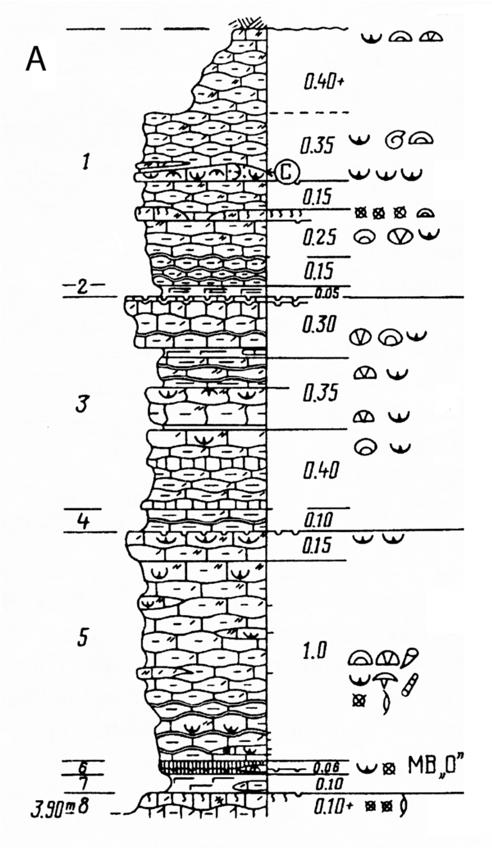


Fig. C3. Section of Päri quarry after Kaljo & Einasto (1990).

Fig. C4. Deepest accessible part of the Päri quarry. The 6-cm-thick Osmundsberg Bentonite is exposed where the hammer points. Photo by O. Hints.

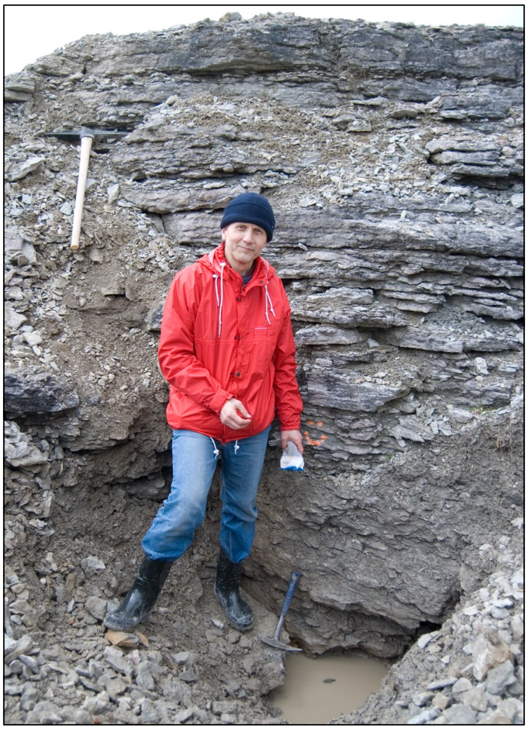


Fig. C5. Erosional surface with cut shells of *Pentamerus oblongus* in the Päri quarry. Photo by O. Hints.

Bentonite) with fragments of pentamerids.
7. 0.1 m – grey calcitic marl with grainstone nodules.
8. 0.1 m – brownish grey microcrystalline irregularly nodular limestone (packstone).

A detailed study of the section has revealed a rather distinct microcyclicity. Usually a cycle begins with a thin marlstone layer, upwards the clay content decreases and grainstone or coquinoid rudstone lenses appear. The cycle ends with a distinct discontinuity surface.

The section is rich in fossils although intense sampling has considerably reduced their abundance. More than 10 type specimens derive from this locality. Particularly common are typical members of the *Pentamerus oblongus* community, including numerous corals e.g., *Paleofavosites obliquus*, *Calostylis luhai* and stromatoporoids *Clathrodictyon variolare*. Rather common are the gastropods *Boiotremus* cf. *longitudinalis* and *Hormotoma* sp. and trilobites *Calymene frontosa* and *Encrinurus* (*Nucleurus*) *rumbaensis*. Practically no ostracodes and chitinozoans have been found and only scanty conodonts (*Panderodus* spp., *Ozarkodina* sp.) and thelodonts (*Thelodus* sp.) have been recorded.

Sightseeing stop: Koguva village

Koguva is a small, peaceful rural village on the Muhu Island. The village was first mentioned in 1532, in a document by Wolter von Plettenberg to grant freedom for a peasant called Hansken, his son and their descendants. There are many buildings in the village that are centuries old, dating back to feudal times under Swedish rule, and are still in use today. The entire village is under protection as cultural and architectural heritage. Estonian writer Juhan Smuul was born in Koguva and owned his fathers farm there until his death. Nowadays this farm works as a local museum displaying belongings of the writer and explaining the culture of the typical rural community of West Estonian islands in 19th and early 20th centuries (Fig. C6).

Fig. C6. Entrance to the Koguva village-museum. Photo by O. Hints.

EXCURSION C

Stop C2: Pulli cliff

after E. Jürgenson and H. Nestor (1990)

Pulli (=Oiu) cliff is located in the north-eastern corner of Saaremaa Island, about 10 km north-west of the Orissaare settlement (58°36′52″ N, 22°57′20″ E). The outcrop was first described by Fr. Schmidt (1858) as Ojo cliff. The boundary between the Jaani and Jaagarahu stages is exposed here (Figs C7 and C8). The Jaani Stage is represented by domerites (dolomitic marlstone) of the Paramaja Member, the Jaagarahu Stage by stratified cavernous and massive reef dolostones of the Kesselaid Member of the Vilsandi Beds. The Pulli section reveals a distinct strongly wavy contact between the Kesselaid dolostones and Paramaja domerites, caused by bending of strata under the weight of mud-mounds. Due to this, the thickness of beds is variable.

Jaagarahu Stage, Kesselaid member

1. In the upper part of the section (thickness up to 2 m) upwards expanding mud-mounds strike the eye,

consisting of grey fine- to microcrystalline fine cavernous dolostone with irregular structure and uneven fracture surface. They contain small irregular pockets or greenish argillaceous domerite and brownish-grey dolostone.

2. Mud-mounds are underlain and laterally replaced by bluish- to greenish-grey medium-bedded fine-crystalline cavernous dolostone (thickness about one meter) with relict texture of coarse-grained skeletal grainstone and thin discontinuous argillaceous partings. The caverns were formed by dissolution of calcitic skeletons of brachiopods, rugose corals, pelamatozoans and bryozoans. Chitinozoans *Conochitina claviformis*, *Ancyrochitina primitiva* and *A*. cf. *pachyderma* have been recorded from these dolostones. At the base of the Kesselaid dolostones there is an intensely impregnated limonitic discontinuity surface.

Jaani Stage, Paramaja Member

3. Lower part of the section (1.05+ m) is represented by bluish-grey, in weathered state yellowish, argillaceous dolostone and dolomitic domerite with rare pyritized fossil fragments (mostly brachiopods and trilobites), pyrite concretions and burrows. Conodonts *Kockelella ranuliformis* Walliser, *Ozarkodina* cf. *excavata*, *O*. *confluens*, *Pseudooneotodus bicornis* and *Panderodus* sp., chtinozoans *Conochitina claviformis*, *C*. cf. *mamilla*, *Margachitina margaritana*, *Desmochitina* cf. *acollaris* and trilobites *Encrinurus punctatus* and *Calymene blumenbachii* are identified from top of the bed.

In order to link the outcrop with the general stratigraphic sequence two boreholes were drilled – one on the top of the cliff (Pulli I), the other one (Pulli II) at its base near the sea. The assemblage of chitinozoans in the upper part of the Paramaja Member form these core sections indicates the *Conochitina tuba* Zone.

In general, the Pulli cliff section, but also several other outcrops located on the northern coast of Saaremaa and Muhu islands, are similar to those known from the north-western coast of Gotland where analoguous abrupt contact between marlstones (Upper Visby Beds) below and reefal limestones (Högklint Beds) above is exposed. However, the Paramaja-Kesselaid contact is stratigraphically younger than the the Visby-Högklint contact.

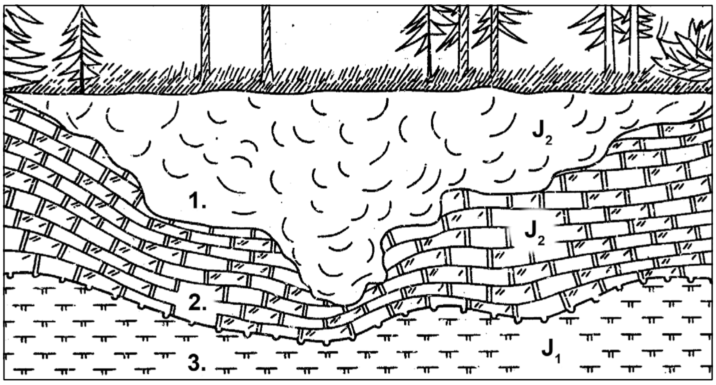


Fig. C7. Schematic cross-section of the Pulli cliff after Jürgenson & .Nestor (1990)

Fig. C8. Pulli cliff exposing contact beween Paramaja Member (Jaani Stage) and mud-mounds and dolostones of the Kesselaid Member (Jaagarahu Stage). Photo by G. Baranov.

Stop C3: Paramaja cliff and Jaani coast

after Reet Männil (1990)

Fig. C9. Paramaja cliff. Photo by G. Baranov.

Paramaja cliff is located at the eastern end of the northern coast of Saaremaa Island, about 1 km west of Jaani church (58°36′56″ N, 22°53′51″ E). Marlstones of the upper part of the Jaani Stage are exposed here (Fig. C9). The cliff serves as the stratotype of the Jaani Stage, Jaani Formation and Paramaja Member. The cliff and the pebbly coast lying immediately east of it (the so-called Jaani coast), is known as a rich fossil locality already since the middle of the 19th century. Trilobites were described from here by J. Nieszkowski (1857), from the fauna collected by A. Schrenk. Fr. Schmidt (1858) gave the first lithological description of the cliff (Paramägi-Pank) and list of fossils collected from the Jaani coast.

The exposed section is as follows (by E. Jürgenson): 0.7 m – Quaternary cover; 1.3 m – bluish-grey (in weathered state buff-grey) calcitic marlstone with argillaceous marlstone interlayer, with scarce argillaceous limestone nodules (10–20 cm in diameter).

Common fossils in marlstone are brachiopods, trilobites and corals. Skeletal fragments are often pyritized, also pyritized burrows occur. Lithologic composition of rocks and common articulated brachiopods and trilobite carapaces refer to a quiet-water environment at the boundary of the open shelf and transitional facies.

Marlstone contains a diverse and scattered fauna: brachiopods *Megastrophia* (*Protomegastrophia*) *semiglobosa*, *Atrypa reticularis*, *Dalejina hybrida*, *Estonirhynchia estonica*, *Strophonella euglypha*, *Dolerorthis rustica*; trilobites *Encrinurus punctatus*, *Calymene blumenbachii*, *Proetus concinnus osiliensis*, ostracodes *Craspedobolbina mucronulata*, *Beyrichia suurikuensis* and *Silenis subtriangulatus*; gastropods *Platyceras* (*Plaiyostoma*) *cornutum*, *Poleumita discors*, *P. sculptum* and *Praecordium striatum*; conodonts *Kockelella* cf. *ranuliformis*, *Ozarkodina excavata*, *Pseudooneotodus bicornis*, *P. beckmanni*; chitinozoans *Conochitina* cf. *claviformis*, *Conochitina* cf. *tuba* and *Desmochitina acollaris*. Rugose corals include the following species: *Rhegmaphyllum slitense*, *Neocystiphyllum keyserlingi*, *Phaulactis trochiformis*; tabulate corals and heliolitids are represented by *Thecia podolica*, *Favosites gothtandicus*, *F. desolatus*, *Heliolites interstinctus* (type locality of the *F. gothlandicus* tabulate community). V. Nestor (1994) has distinguished four chitinozoan zones in the Jaani Stage. The assemblage of chitinozoans in the Paramaja section shows that these beds belong to the upper, *Conochitina tuba* Zone and correlate with the Högklint "C" Beds on Gotland.

Stop C4: Panga cliff

after M. Rubel and R. Einasto (1990), with additional data by P. Männik

The Panga cliff is the highest (20 m) and the most prominent land-form on the northern coast of Saaremaa Island near Mustjala village ranging arch-shaped about 3 km from north-east to south along the seashore (Fig. 38; 58°34′15″ N, 22°17′22″ E). As a wonderful sight and an important object for scientific studies,

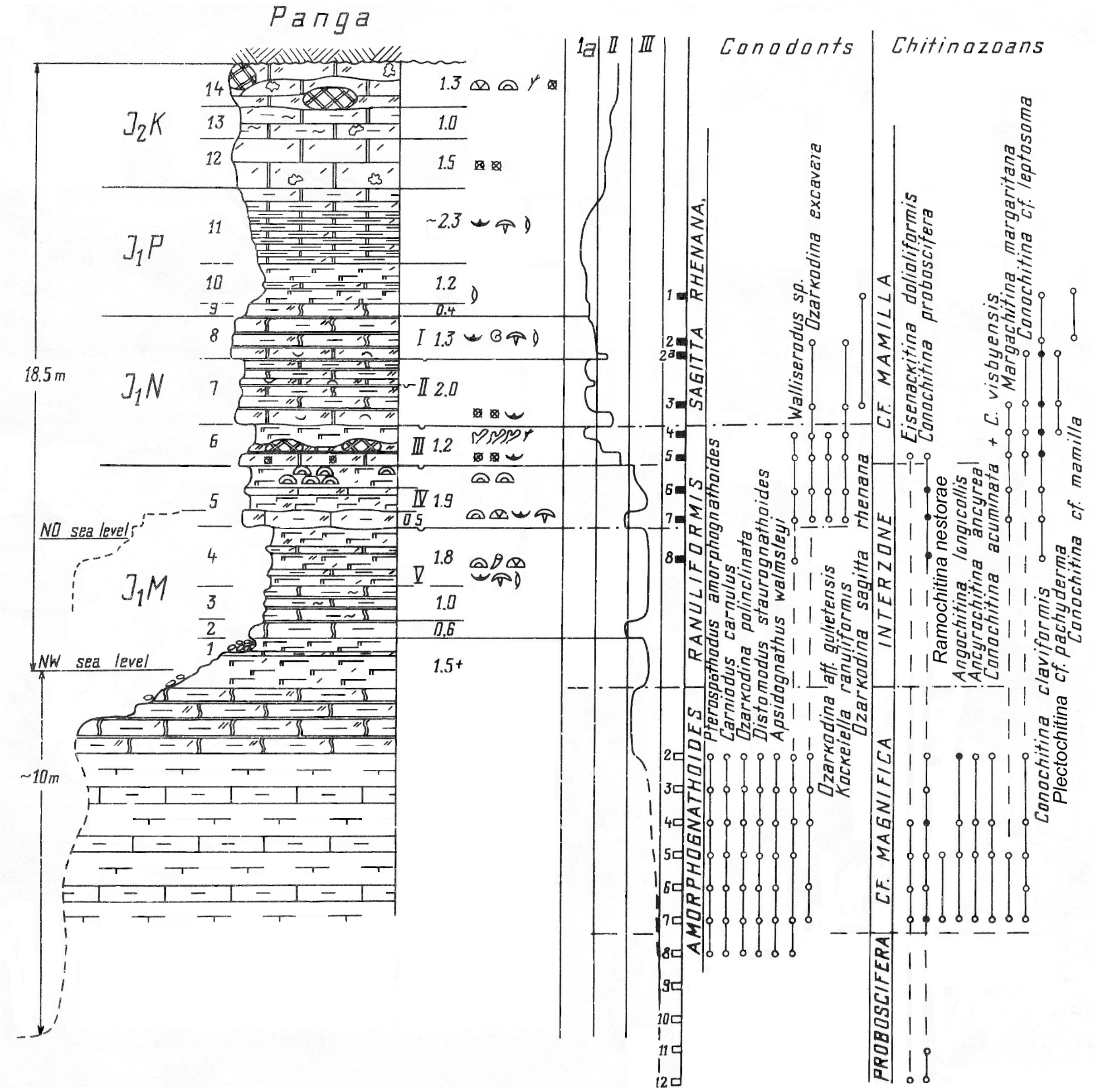


Fig. C10. Panga (Mustjala) cliff after Rubel & Einasto (1990).

the Panga cliff (also called the Mustjala cliff) has been taken under state protection. In the Panga cliff main part of the Jaani Stage and the lower Jaagarahu Stage (Sheinwoodian) are exposed (Figs C10, C11). The outcrop consists of two escarpments.

The lower escarpment on the seashore is composed of marlstones, variably argillaceous limestones and dolostones of the Jaani Stage. Porous dolostones of the Vilsandi Beds (Jaagarahu Stage) containing rare small bioherms crop out in a smaller upper escarpment, located inland of the main section. Additionally, an about 10 m high escarpment top of which is marked by a surf zone forms the underwater part of the section. This part of the section is mainly composed of highly argillaceous dolomitized limestones and dolomitic marlstones.

The section given in the figure represents the eastern part of the cliff (Fig. C10). From base to top:

Mustjala Member

1. 10 m – underwater part of the cliff; according to the samples taken after each meter it consists of grey bioturbated dolomitic marlstone containing argillaceous dolostone nodules, lenses and interbeds.
2. 0.6 m – grey argillaceous dolostone.

EXCURSION C

3. 1.0 m – bioturbated argillaceous dolostone with dolomitic marlstone interbeds.
4. 1.8 m – dolomitic marlstone with argillaceous dolostone interbeds and nodules, and erosional surface at the top.

Ninase Member

5. 1.9 m – similar to bed 3 but contains up to 35 cm high small "bioherms" formed by encrusting bryozoans and fine-grained dolostone (grainstone) at the base.
6. 1.2 m – analogous to bed 5. In the upper part of the bed bryozoan bioherms (size up to1.3x1.2 m) occur.
7. 2.0 m – cyclic intercalation of coquinoid biomorphic or skeletal secondary dolostones, argillaceous dolostones and dolomitic marlstones.
8. 1.3 m – similar to bed 7.

Paramaja Member

9. 0.4 m – bioturbated skeletal argillaceous dolostone.
10. 1.2 m – dolomitic marlstone with scarce skeletal debris and interbeds of skeletal argillaceous dolostone.
11. 2.3 m – grey thin-bedded highly argillaceous dolostone containing scarce and fine skeletal debris.

Fig. C11. Panga (Mustjala) cliff. Photo by O. Hints.

Jaagarahu Formation

12. 1.5 m – thick-bedded skeletal dolostone.
13. 1.0 m – slightly argillaceous dolostone with unevenly distributed skeletal debris.
14. 1.3 m – porous dolostone with small bioherms.

The Mustjala Member is the most fossiliferous. In several outcrops and core sections lens-like interbeds containing abundantly colonies of tabulate corals and stromatoporoids occur in the upper part of the Mustjala Member. The list of taxa is given below. Loose material at the coast has yielded *Clathrodictyon variolare*, *Clathrodictyon delicatulum* and *Oslodictyon suevicum*. These fossils are supposed to be an erratic material from the underlying Adavere Stage. The brachiopods identified from the Panga section are known from all members of the Jaani Stage (*Estonirhynchia estonica*, *Stegerhynchus borealis*, *Atrypa reticularis*, *Dolerothis rustica*, *Microsphaeridiorhunchus nucula*, *Dalejina hybrida*, *Whitfieldella* sp., *Resserella* sp., *Leptaena* sp. From the loose material of the Ninase Member also trilobites *Calymene blumenbachi* and *Proetus concinnus osiliensis* have been recorded.

Based on recent studies of conodonts, the sampled part in the underwater escarpment corresponds to the Upper Subzone of the *Pterospathodus amorphognathoides amorphognathoides* Zone. In the main, sea-side escarpment, the Upper *Kockelella ranuliformis* Zone and the lower part of the *Ozarkodina sagitta rhenana* Superzone are sampled. In the lower part of the underwater escarpment the *Conochitina proboscifera* Zone was recognized indicating that these beds correspond to the Adavere Stage.

Stop C5: Abula cliff

after R. Einasto (1990a)

The Abula cliff is situated on the eastern coast of Tagalaht Bay, 3 km north of Mustjala-Veere road (58°27′12″ N, 22°6′51″ E). The cliff exposes topmost lagoonal dolomitic marlstones of the Vilsandi Beds and the basal part of the Maasi Beds belonging to the Jaagarahu Stage (Figs C12, C13). Luha (1934) referred to these rocks as to Kurevere Limestone.

The section from top to base is as follows:

1. 0.4+ m – skeletal wackestone, rich in stromatoporoids, with 0.1 m thick lenses of skeletal marlstones in the lower part; at the base a distinct discontinuity surface occurs.
2. 0.7 m – light-grey wavy-bedded pelletal limestone with several discontinuity surfaces in the upper 15–20 cm, stromatoporoids are common, in the middle of the bed accumulations of brachiopod shells occur.
3. 0.6 m – light yellowish-grey fine-nodular pelletal limestone with stromatoporoids, tabulate corals (*Favosites mirandus* is the commonest), ostracods and calcareous algae; the lower 0.1 m contains marlstone; the upper 0.2 m comprises irregularly nodular skeletal wackestone with 0.15 m thick and 1.5 m long skeletal grainstone lenses; large Megalomus shells are found.
4. 0.10 – 0.15 - grey fine-grained pelletal limestone.
5. 0.5 – yellowish-grey fine-nodular pelletal and skeletal, slightly argillaceous limestone; brachiopods are common, while tabulate corals are rare; the basal 10-15 cm is more argillaceous; a discontinuity surface occurs at the base.
6. 0.2 – thin-bedded skeletal (ostracod) packstone with 1-2 cm thick interbeds of calcareous marlstone.
7. 0.5 – yellowish-grey wavy-bedded- pelletal limestone containing large ostracods and gastropods; at the base a 3 cm thick ostracode grainstone layer with small oncolites.
8. 0.2 (exposed on the sea bottom) – greenish-grey calcareous dolomitic marlstone with 1–2 cm lenses and laminations of fine-grained skeletal and pelletal packstone; large ostracods and fragments of eurypterids occur.

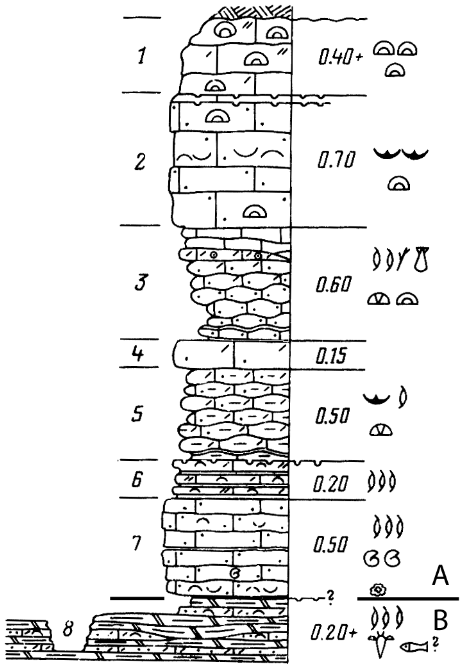


Fig. C12. Abula cliff after Einasto (1990a).

The last bed (= the top of the Vilsandi Beds) forming the first lagoonal complex in the Estonian Wenlock is presumably of the same age as the *Pterygotus* Marl on Gotland. Just below these lagoonal dolomitic marlstones a stromatoporoid limestone bed with *Vikingia tenuis* occur. This bed is exposed north of Abula cliff.

Fig. C13. Abula cliff. Photo by O. Hints.

Stop C6: Suuriku, Kuriku and Undva cliffs

after T. Märss and E. Jürgenson (1995, unpublished data)

Suuriku cliff is located in the northeastern coast of the Tagamõisa Peninsula in Saaremaa (58°30′26″ N, 22°0′6″ E). The outcrop is 1.6 km long and up to 8 m high (Fig. C14). In this locality the Mustjala and Ninase members of the Jaani Stage (Sheinwoodian, Wenlock) are exposed. Coarse-grained skeletal grainstones with interlayers of marlstones of the Ninase Member form the main, upper part of the section. The rock is mainly composed of pelmatozoans fragments. Brachiopods and gastropods are abundant, rugose corals are less frequent. Bioherms with abundant bryozoans (*Ceramopora*, *Lioclema*) occur in

Fig. C14. Suuriku cliff. Note the contact between Mustjala and Ninase members (Jaani Stage) in the lower part of the section. Photo by O. Hints.

the middle part of the Ninase Member. The lower part of the Suuriku section consists of marlstones of the Mustjala Member. Both, Ninase and Mustjala members contain tabulate (favositids) and rugose corals. Additionally, in the upper part of the Mustjala Member halystids are abundant. Many loose, eroded specimens of heliolitids, favositids and halysitids are spread along the coast.

Kuriku cliff is located very close to the Suuriku cliff, few hundred meters to the east from it (58°30′6″ N, 22°0′56″ E). The outcrop is smaller and lower (up to 2–3 meters high). In the Kuriku section, the Ninase Member of the Jaani Stage is exposed. Cavernous dolostones and dolomitic boundstones with marlstone interbeds are characteristic of the upper part of the section. Tabulate corals, rugose corals and bryozoans are common. Lower part of the section consists of dolomitized crinoidal limestones and coarse-grained skeletal grainstones. Small bioherms are found in the middle part of the section.

Undva cliff is situated in the northern end of the Tagamõisa Peninsula, few kilometers north from the Suuriku and Kuriku cliffs (Fig. 43; 58°31′1″ N, 21°55′7″ E). The cliff is about 350 m long and up to 2.5 m high. As in most of the cliffs on the northern coast of Saaremaa (Liiva, Panga, Suuriku and Kuriku cliffs) also here the Mustjala and Ninase members of the Jaani Stage (Sheinwoodian, Wenlock) are exposed. The 1.5 m thick Ninase member consists of coarse-grained skeletal grainstones with interlayers of marlstone. Bryozoans, brachiopods, crinoids and rare rugose corals occur. About 50 m to the east, a small bryozoan bioherm is exposed in the upper part of section.

If the sea level is low and limestone pebbles are not covering the beach, top of the Mustjala Member is exposed below the grainstones of the Ninase Member. Blue-green marlstones of the Mustjala Member contain nodules of biomicritic limestone (mainly in top of the section). Abundant brachiopods, crinoids, bryozoans, corals and stromatoporoids occur in the marlstone.

Stop C7: Jaagarahu quarry

after R. Einasto (1990b)

The old Jaagarahu quarry is situated on the western coast of Saaremaa, 6 km northwest from the Kihelkonna settlement (58°24´26″ N, 21°58´0″ E). In the 1930s limestone was quarried (about 300 tons per day) and exported mainly to Sweden, Finland, Poland and Germany. Lower part of the Jaagarahu Stage represented by bioherms and the surrounding limestone rich in algae, corals and stromatoporoids are exposed in the quarry (Figs C15, C16).

In the southern corner of the quarry, lagoonal dolomitic marlstones of the topmost Vilsandi Beds as well as the basal part of the overlying Maasi Beds are exposed (Fig. C15). In this point the following section is described (from base):

1. 1.6+ m (mostly under the water; except in the eastern part of the quarry) – light-grey massive boundstone of shoal reef facies. The commonest fossils of the reef are *Vikingia tenuis, Favosites mirandus, Solenepora filiformis, Wetheredella multiformis, Rothpletzella munthei*.

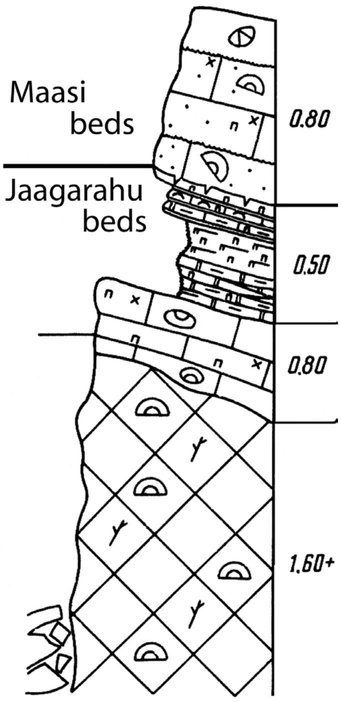


Fig. C15. Section of the Jaagarahu quarry after Einasto (1990b).

Fig. C16. Jaagarahu quarry. Photo by O. Hints.

2. 0.8 m (0.4 m above the water) – bluish-grey dolomitic skeletal argillaceous packstone of backreef origin. The rocks have fine pyritic pattern and contain calcite crystals. Stromatoporoid and tabulate coral colonies are not in the living position and bear erosion marks.
3. 0.5 m – greenish- or bluish-grey thin-bedded argillaceous dolostones with little skeletal debris are exposed. Numerous big ostracods *Leperditia* occur on some bedding planes. The upper surface of the bed shows mud cracks with abraded edges. It marks the boundary between the Vilsandi and Maasi beds.
4. 0.8+ m – bluish-grey thickbedded or massive microcrystalline pelletal limestone with slight pyritic patterns. The rock contains abundant abraded stromatoporoids and dolomitic pebbles from the underlying strata. The lower part of the bed is more argillaceous, contains ostracod debris and abundant *Cladopora perrara*.

Elsewhere in Saaremaa (except Sõrve Peninsula) this basal part of the Maasi Beds consists of floatstones and skeletal limestones with discontinuity surfaces and oncolites. It corresponds to the Tofta Limestone of Gotland. Accordingly, the topmost Vilsandi Beds are of the same age as the *Pterygotus*-Marl (Högklint d) of Gotland.

Stop C8: Elda cliff

after T. Märss (1995, unpublished data)

Elda cliff is located in NW part of the Atla Peninsula, western Saaremaa (58°18´16″ N, 21°49´46″ E). Kuusnõmme Beds of the Rootsiküla Stage are exposed on the cliff which is up to 1.8 m high and ca 200 m long. The cliff is important site for fossil agnathans and is under environmental protection.

Fig. C17. Elda cliff. Photo by G. Baranov.

The succession from top to bottom is as follows:

1. 0.00–0.40 m – light gray clayey dolostone, with scattered corals;
2. 0.40–0.55 m – light brown pyrite-rich dolostone;
3. 0.55–0.70 m – bluish mottled dolostone with numerous corals;
4. 0.70–0.80 m – rusty, slightly wavy-bedded dolostone;
5. 0.80–1.10 m – massive brownish or bluish grey dolostone, partly conglomerate-like;
6. 1.10–1.80 m – dolostone with numerous corals and calcareous algae. 0.25 m from the top a clayey interlayer occurs below which a bed rich in vertebrate fragments has been located.

Stop C9: Soeginina cliff

after V. Viira & R. Einasto (2003)

The **Soeginina** section located in the Atla Peninsula, western Saaremaa (58°17´13″ N, 21°50´30″ E) is the stratotype of the Soeginina Beds. The section from the base to top is as follows (Figs C18, C19):

1. 0.5 + m – microlaminated, silty, argillaceous eurypterid-dolostone with *Eurypterus* remains, nautiloids, and ostracods (*Herrmannina*). Large (over 1 m in diameter) *Stratifera*-type stromatolites occur. The upper boundary is a distinct pyritized discontinuity surface (DS).
2. 1.3 m – yellowish-brown, mottled, bioturbated, argillaceous dolostone. The upper boundary is a distinct pyritized DS, the boundary between the higher-rank mesocyclites. It is also considered to be the boundary between the Vesiku Beds of the Rootsiküla Stage below and the Soeginina Beds of the Paadla Stage above.

3a. 0.15 m – brownish-grey, bioturbated, argillaceous dolowackestone with varigrained biodetritus, rare oncolites, some DSs. This short interval corresponds to the strata exposed in the Anikaitse section in the eastern Saaremaa (tongue of the so-called Anikaitse Beds).

3b. 0.30 m – light brown, varigrained biodetrital dolopackstone to grainstone with oncolites and small stromatolites on the lower distinct smooth DS in the upper part. Nautiloids, bivalves, gastropods, dendroid corals, ostracods, calcareous algae (*Solenopora*), and bryozoans are present. A lens-like conglomerate interbed (0–7 cm), with flat pebbles of the underlying dolostone, occurs on the 3a and 3b boundary.

4. 0.15 m – light grey, microcrystalline, pure, unfossiliferous dolomudstone.
5. 0.70 m – light brownish-grey, fine-grained skeletal-pelletal dolograinstone with ostracods and gastropods. The upper boundary is a distinct eroded DS.
6. 1.2 m – dark brown varigrained pelletal-biodetrital dolofloatstone with oolites, small pebbles of light grey dolomudstone and rounded bivalves, gastropods, ostracods (*Herrmannina*), intercalated with light grey dolomudstone. The grain size varies considerably. On three levels 0.3–0.4 m high *Stratifera*-stromatolites are present. The upper boundary is a distinct erosional bedrock surface

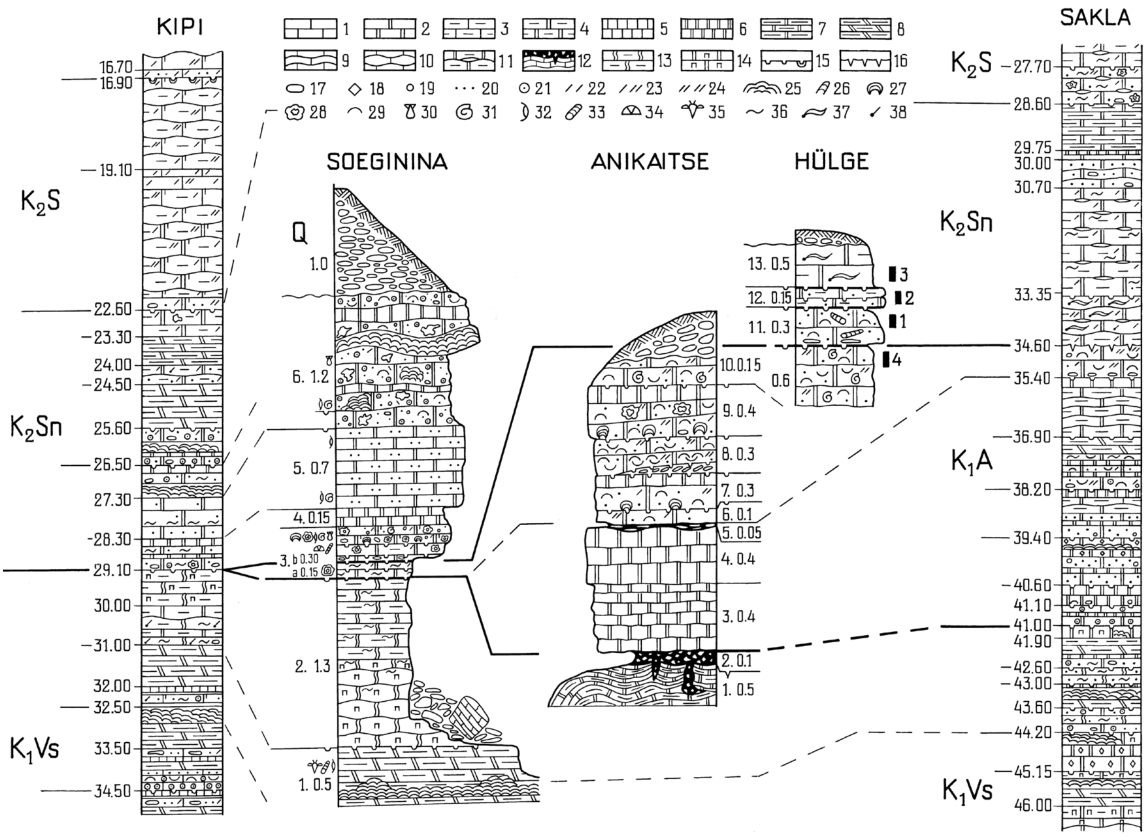


Fig. C18. Soeginina cliff and correlation of boundary beds between Rootsiküla and Paadla stages (from Viira & Einasto, 2003). Lithology and correlation of the Wenlock–Ludlow boundary beds in the West and East Saaremaa sections. K1, Rootsiküla Stage; K2, Paadla Stage; Vs, Vesiku Beds; A, Anikaitse Beds; Sn, Soeginina Beds; S, Sauvere Beds. Legend: 1, limestone; 2, dolostone; 3, argillaceous limestone; 4, argillaceous dolostone; 5, micritic limestone (calcareous mudstone); 6, micritic dolostone (dolomitic mudstone); 7, laminated argillaceous dolostone; 8, Eurypterus-dolostone; 9, wave-bedded lime- and dolostone; 10, nodular lime- and dolostone; 11, argillaceous dolostone with domerite (= dolomitic marl); 12, folded microlaminated argillaceous dolostone with mud-cracks and an intraclast interbed on the upper boundary; 13, bioturbated argillaceous dolostone; 14, mottled dolostone; 15, discontinuity surface (burrowed); 16, mud-cracks; 17, pebbles, conglomerate lenses; 18, intraclasts; 19, psammite; 20, pellets; 21, ooids; 22, fine-grained skeletal detritus; 23, unsorted skeletal detritus; 24, coarse skeletal detritus; 25, stromatolites (Stratifera); 26, columnar stromatolites; 27, encrusting stromatolites; 28, oncolites; 29, shells; 30, bivalves; 31, gastropods; 32, ostracods; 33, nautilods; 34, tabulate corals; 35, eurypterids; 36, burrows; 37, pyritized burrows; 38, pyritized skeletal detritus. Black rectangles denote conodont samples. Depth is in metres.

covered by coastal pebbles.

The section of this cliff can be correlated bed by bed with the interval of 22.6–33.0 m in the Kipi core section (Fig. C18). Conodont studies show that the lower part of the Soeginina cliff (beds 1, 2, and 3a) are of the Rootsiküla age, while the upper part of it (beds 3b and 4–6) correlate with the Paadla Stage (Fig. C18). The same biostratigraphic criteria allow correlation of the Soeginina section with the lower part of the Sauvere Beds (Paadla Stage) on middle and eastern Saaremaa (interval 28.6–34.6 m in the Sakla core section, traditionally assigned to the Sauvere Beds).

Fig. C19. Soeginina cliff. Photo by G. Baranov.

Stop C10: Katri cliff

after T. Märss (1995, unpublished data)

Katri cliff is located in the south-western coast of Saaremaa, 4 kilometers south from the Karala village (58°14′13″ N, 21°57′59″ E). The section has been up to 1 meter high but resulting from a strong storm in 2005, main part of the cliff is now covered by sand and debris (Fig. C20). The Uduvere Beds of the Paadla Stage (Ludlow) are exposed in the Katri cliff. The largest part of the section is represented by biostrome, which includes abundant stromatoporoids, tabulate and rugose corals, brachiopods (including rare specimens of *Didymothyris*) and algae. In some places the biostrome is rich in argillaceous material, and lenses and/or irregular lense-like interbeds of light-beige pelletal limestone occur. In the southern part of the section, large cephalopods are quite common.

Fig. C20. Katri cliff in 2007. After a storm of 2005 most part of it is covered by sand. Photo by O. Hints.

Stop C11: Kaugatuma and Lõo cliffs

after R. Einasto (1990d)

The 2.5 m high **Kaugatuma cliff** (or Kauatoma cliff) is situated on the western coast of the Sõrve Peninsula, some kilometers south from its neck and about 100 metres from the sea (58°7′22″ N, 22°11′36″ E). Rocks of two different facies types in the regressive succession can be seen representing the middle part of the Äigu Beds of the Kaugatuma Stage (Fig. C21, C22). From the base of the section:

1. 05+ m – greenish-grey nodular argillaceous wackestone of open shelf origin. Skeletal debris consists mostly of echinoderm and brachiopod fragments. Ostracods, trilobites, gastropods, bryozoans and fish fragments occur.
2. 1.5+ m – yellow-grey coarse-grained wavy-bedded crinoidal limestone of forereef origin. Grain size and sorting degree of skeletal debris is variable. Some bedding plains show erosion marks. Large colonies of *Syringopora blanda* (30 cm in diameter) occur.

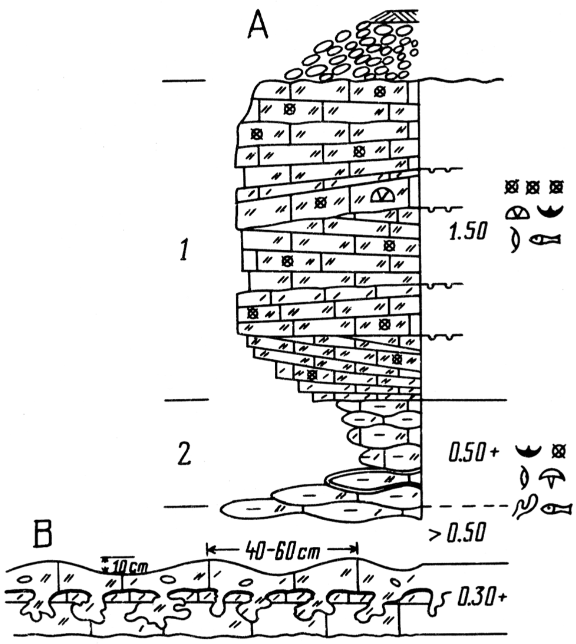


Fig. C21. Kaugatuma cliff after Einasto (1990d).

A great number of fossils has been recorded from

Fig. C22. Kaugatuma cliff. Photo by O. Hints.

the the Kaugatuma locality. These include trilobites *Proetus nieszkowskii*, *Calymene schmidti*, *C. kaugatumensis*, *C. dnestroviana*, *Acaste dayiana*, *Eophacops helmuti*; and tabulate corals and stromatoporoids. However, most of them are collected from the loose material at the beach and they obviously came from the older, underlying the Kaugatuma cliff strata. The following vertebrate remains have been found from the cliff: *Nostolepis striata*, *Gomphonchus sandelensis*, *Poracanthodes porosus*, *Thelodus parvidens* from the lower part of the section and *Nostolepis gracilis* from the upper part. Most of the chitinozoans identified from the section (*Angochitina echinata*, *Eisenackitina lagenomorpha*) represent long-ranging species, only *Eisenackitina filifera* is characteristic of the upper Äigu Beds.

Lõo cliff is situated about 2 km to south from the Kaugatuma cliff. A 1.5 m thick section of the Kaugatuma Stage (Přidoli) is exposed in an about 250 m long low cliff. It consists of coarse grained skeletal crinoidal grainstones with interlayers of marlstone. Brachiopods, ostracods, crinoids, stromatoporoids and tabulate corals occur. Abundant *Syringopora blanda* colonies are spread in the layer of marlstone.

Fig. C23. Ripple marks between Kaugatuma and Lõo cliffs. Photo by G. Baranov.

Between Kaugatuma and Lõo cliffs large east-west directed well-preserved Silurian ripple marks are exposed on a 200 m long seashore, observable only when the sea level is low (Fig. C23). Ripple marks are best preserved in a 30 cm thick interval of the section, immediately underlying the basal part of the cliff. Distance between the rounded crests is 40–60 cm (max up to 80 cm), height up to 10 cm. Under the uneven discontinuity surface that forms the base of this ripple mark bed, up to 10 cm of dark-grey unsorted skeletal packstone is exposed.

Stop C12: Ohesaare cliff

after H. Nestor (1990)

The Ohesaare (or Ohessaare) cliff is located on the western coast of the Sõrve Peninsula near Ohesaare village, 2.5 km southwest of Jämaja church (58°0´2″ N, 22°1´10″ E).

The lower beds of the Ohesaare Stage, the latest stage in the Silurian of Estonia are exposed here (Fig. C24). The outcrop serves as a stratotype of the Ohesaare Stage, being one of the best-known Silurian localities in Estonia. As a famous fish locality it is known a1ready since the pioneering work by C. Pander (1856). It also has attracted attention as the youngest Silurian outcrop in the whole Baltic area. It contains rich association of different fossils including fishes, molluscs, ostracods, conodonts, etc.

The Ohesaare cliff is over 600 m long and up to 4 m high, it is located immediately by the sea in the zone of storm abrasion (Fig. C25). The total thickness of the exposed bedrock is 3.5 m, whereas the thicknesses of separate layers are rather variable throughout the outcrop (Fig. C24). The section is almost completely observable in the northern part of the cliff in a small inlet (point 1 in Fig. C24).

The section is characterized by the intercalation of thin-bedded limestones and marlstones. The intervals containing relatively few or thin marlstone interlayers form three cornices in the cliff section: I – beds 2 and 3, II – beds 5–7, III – beds 10–13. In the niches the marlstone/limestone ratio changes from equal to predominance of marlstones. In the middle part of the section limestones are mostly with a biomicritic texture (skeletal packstones), but in its upper (bed 2) and especially in the lower parts (beds 10 and 13) they are biosparitic (skeletal grainstones). A few lens-shaped intercalations of cross-bedded fine-grained pelletal-skeletal grainstones are found also in the middle part of the section, in beds 7 and 9.

Marlstone interlayers are highly argillaceous, in places reaching the condition of the plastic carbonate

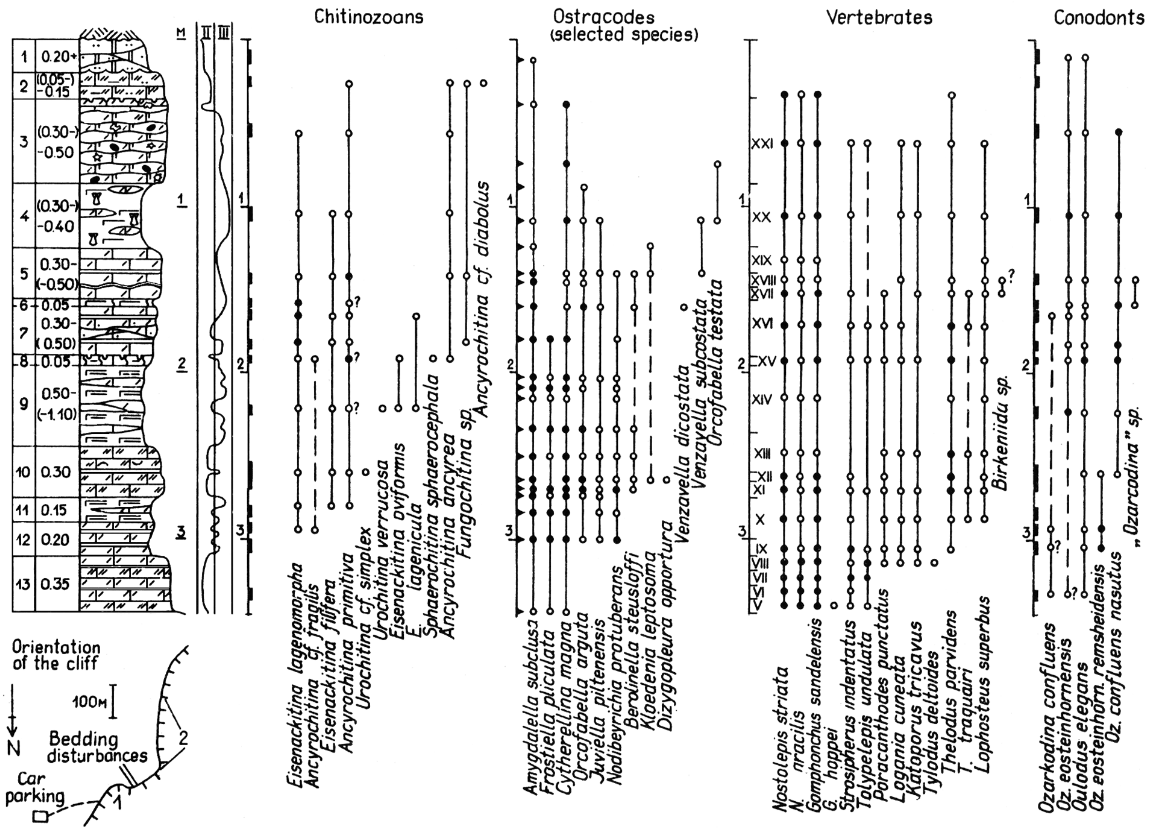


Fig. C24. Ohesaare cliff after Nestor (1990). Observation stops are shown on the small sketch map on the lower left corner.

Fig. C25. Ohesaare cliff in 2007. Lower part of the cliff is covered by debris brough by a strong storm in January 2005. Photo by O. Hints.

clays. In the upper beds of the outcrop (1–4) the rocks are somewhat dolomitized.

In this rather monotonous section there are some distinct interlayers. The lower part of the section reveals a layer of coarse-grained skeletal grainstone to coquinoid rudstone (10) with a 3–5 cm thick interbed of argillaceous marlstone in the middle. 0.5–1.0 m higher of it there is a 2–5 cm thick interlayer of fine-grained limestone (8) pierced by thin vertical burrows filled with light-green marl. Still higher (0.3–0.5 m) there is a thin (5 cm) interlayer (6) of light-green calcareous marlstone containing vertical cracks with brownish granular infilling.

In the upper half of the cliff a layer of greenish-grey marlstone forms a distinct niche containing abundantly shells of *Grammysia obliqua* buried in living position.

The section ends up with an up to 20 cm thick layer (1) of fissile wavy- to cross-bedded-laminated calcareous siltstone which has preserved only in the southern end of the observation point 2. It is underlain by a 5–15 cm thick interbed (2) of light-grey silty skeletal grainstone, the upper surface of which bears large ripple marks and the lower boundary displays a hardground.

The Ohesaare cliff is rich in diverse shelly fauna which has given the main part of the fauna recorded from the topmost Silurian Stage in the East Baltic. The most abundant macrofossils are brachiopods, represented by *Delthyris magna*, *D. elevata*, *Homoeospira baylei*, *Morinorhynchus orbignyi*, *Isorthis ovalis*, *Dalejina hybrida*, *Shaleria* (*Janiomya*) *ornatella*, *Collarothyris collaris*. Common in this section are also bryozoans *Fistulipora tenuilamellata*, *F. aculeata*, *Eridotrypa parvulipora*, *Trematopora porosa* and others, and bivalves *Grammysia obliqua*, *Cardiola interrupta*, *Palaeopecten danbyi*, *Modiolopsis complanata* and others. Trilobites are most often represented by *Calymene conspicua*, *C. soervensis* and *Acaste dayiana*. Stromatoporoids have not been recorded from the cliff section, corals occur at certain levels in the middle part and are represented by long-ranging species. The middle part of the section (beds 5–10) has yielded also tentaculites *Tentaculites scalaris* (Schlotheim) and *Lowchidium inaequale* Eichwald. Very diverse and rich is the association of microfossils (particularly ostracods) (Fig. 55). Characteristic of the section is the high content of terrigenous material, probably caused by intense influx of fine siliciclastic material into the basin at the final stage of its development.

Sightseeing stop: Kuressaare castle (museum)

from the homepage of Saaremaa Museum (www.saaremaamuseum.ee)

The convent building of Kuressaare castle (Fig. C26) is the only medieval fortification in the Baltic States that has not undergone considerable alterations and due to that is an internationally important architectural monument. The architectural style, modesty, strictness, grand and monumental beauty offers you not only an aesthetic experience but also many-sided historical information — contact the sense of the past and experience the Middle Ages.

The construction of the stronghold was closely connected with the Estonians' fight against the German feudals. In 1227 the last Estonian county — Saaremaa — surrendered to the German crusaders. A small feudal state was formed of Läänemaa and the West-Estonian islands in the years 1228–1234: it was Saare-Lääne (Oesel-Wiek) Bishopric with the territory of about 7600 sq. km. The centre of the bishopric was Haapsalu since 1265. The impact of the foreign rule on the island was not so strong and the islanders maintained some privileges. Despite the fact there were constant uprisings and rebellions, one most widely-spread in 1260. Soon after making the rebels surrender the other local feudal state, the Livonian Order, that possessed East-Saaremaa and island of Muhu, started building Pöide fortification. It is possible that the oldest stone fortification in Kuressaare — the castell type stronghold for the bishop was built at the same time — in the first half of 1260s. The first documented data about Kuressaare castle originate only from 1380s.

The convent type architecture of the castle is due to its function: it was the administrative centre of the district, it was possible to gather a group of people there (*conventus* means get together) and it offered shelter in case of an uprising or war. Convent type buildings are characteristically regular, strict, reclused; a well-defended entrance takes into the inner yard, surrounded by the four wings of the building.

Fig. C26. Front view of the Kuressaare castle. Photo by O. Hints.

Kuressaare castle remained the residence for the bishops of Saare-Lääne Bishopric until the beginning of the Livonian War. At the end of the XIV and the beginning of the XV century the castle was surrounded by a new mighty 625 m long and 7 m high belt of walls, erected around the old belt of walls dating from the XIII century. The necessity to improve the defence of the castle was due to the invention and usage of firearms. The old parts of the walls have been preserved in the new earthwork and bastions even today. In the middle of the XV century the wall was made higher and cannon towers were built. The most powerful was the Cannon Tower on the Northern Bastion from about 1470, restored in 1971–72.

In 1559 Bishop Johannes V Münchhausen sold his property in Saaremaa (Oesel) and Kurland to the **Danes.** At the beginning of the XVII century as the cannons became more powerful, the medieval stronghold built of stone had to be built into a new type of defence fortification. The Danes modernized the defence systems of the castle. The work began in about 1600 and lasted till 1640. Using the old belt of walls, they erected a mighty system of earthwork with bastions and encircled it with a 30 m wide moat, filled with seawater.

On the ground of Brömsebro peace treaty in 1645 **Sweden** took possession of Saaremaa. There is no information about the number of inhabitants in the castle during the reign of the bishops, but some figures date from the later period. During the fiscal year of 1618/1619 the castle employed 47 different clerks and servants, 50 mercenaries, 36 soldiers and 8 armourers among them. In 1623 there were 116 cannons in the castle. In 1645, in the state of war the garrison was considerably bigger: when the Swedes took over, there was an army of 850 mercenaries and 800 peasants.

In 1684 the Swedes once more modernized the fortification system of the castle. Already in 1676 the main gate was moved from the Cannon Tower to its present place and the first ravelin was founded at the place of the present hotel. Using the principles of the French fortification, engineers E. Dahlberg and P. Essen drew up a project, on the basis of which new mighty bastions and ravelins were erected, and they have preserved up to the present day. The construction work stopped in 1706 and the eastern seaside ravelin remained unbuilt.

On September 15, 1710 the Swedish garrison, ravished by the plague, surrendered to the Russian army with no resistance. The Russian garrison left in the spring of 1711. They blew up the wings of the bastions, the Cannon Tower, some of the vaults of the convent building and the interior of the Defence Tower. After that the convent building was left to its fate for about half a century.

In 1762 the south-western and north-western parts and in 1806 the north-eastern and south-eastern parts got a new roof, new vaults were erected in the cloister of the main floor. The demolished upper floors of the Defence Tower were taken down in 1791. Some of the rooms were used for storing grain in the XVIII and in the first half of the XIX century. In 1783 the convent building was excluded from the list of the fortifications. At the same time the earthwork, bastions and ravelins were actively being reconstructed.

After the third division of Poland and the conquest on Finnish territories by Russians (1809) Kuressaare castle lost its military importance. After Russia founded Bomarsund castle on just-occupied Åland islands and in the vicinity of the Swedish capital, Kuressaare was once and for all excluded from the list of the fortifications of the Tsarist Russia in 1836. A year before the castle had been sold to **the Knighthood of Saaremaa** for 3,000 roubles. In 1868–1878 there was a poorhouse in the building situated in the yard. During 1904–1912 the convent building was renovated by architects W. Neumann and H. Seuberlich. The two upper floors of the Defence Tower were constructed anew; the window frames in the cloister of the main floor were restored and the wall between the chapel and the festive refectory rebuilt; some of the doors were relocated and windows widened; new ovens and staircases were built; stone plates with the coats-of-arms of the local noblemen were mured into wall of the cloister. The main floor was re-designed to serve as the office and the festive rooms of the knighthood; a bank and an archive were installed in the basement, a museum was situated on the upper floor.

In 1968 extensive **restoration works** were started and carried out on the basis of the plan made by K. Aluve. First they restored a part of the north-eastern earthwork, a part of the walls of the eastern bastion and the Cannon Tower. The renovation of the convent building lasted for more than ten years, because the aim was to restore the medieval looks and give it the functionality of the present day. The most fundamental work was the restoration of the original roofs and the defence gallery, building the new intermediate ceilings, building a concrete staircase into the Defence Tower and re-shaping the widened windows.

The second phase of the restoration work was to renovate the fortress and expose it as an example of the development of the defence constructions during different periods in the XIV–XVIII centuries. By now the Northern Bastion with its entrance and a bridge, 1/3 of the exterior and 2/3 of the interior walls and all the XVIII century buildings of the garrison have been renovated and the moat cleaned.

Stop C13: Kaarma quarry

after R. Einasto (1990c)

The Kaarma quarry is located 12 km north of Kuressaare town, by Uduvere-Saia road (58°20´17″ N, 22°28´30″ E). In this quarry an interval of lagoonal microlaminated argillaceous dolostones is exposed in its total thickness (3.8 m; Fig. C27). Kaarma dolostone may be well processed and is weather-resistant, therefore being widely used as building and sculpture stone (Fig. C28).

Earlier the stratigraphical position of these lagoonal dolostones has been interpreted differently – being attributed to the upper part of the Rootsiküla Stage (Bekker, 1925; Luha, 1930) or to the Uduvere Beds of the Paadla Stage (Klaamann, 1970). According to the present views, Kaarma dolostone represents the upper part of a mesocyclite, tentatively attributed to the junction of the Sauvere and Himmiste Beds.

Kaarma section from top (Fig. C27):

1. 0.85-1.0 m - yellowish-grey cavernous massive secondary dolostone of variable texture, the basal layer of the mesocyclite mostly unsorted – skeletal to skeletal mickritic rock containing imprints of gastropods, pelecypods, large ostracods (*Hermannina*), bryozoans, calcareous algae (*Solenopora*), brachiopods, small tabulate corals and encrusted stromatoporoids. In the south-eastern part of the quarry this bed is partly not dolomitized containing up to 0.15 m thick lenses and interrupted interbeds of skeletal grainstone, and several wavy discontinuity surfaces occur.

2–7 – typical wavy microlaminated argillaceous ‘Kaarma dolostones’ with distinct irregular lamination and microcycles greatly resembling algal dolostone from Shark Bay.

5 – argillaceous dolomite interbed.

8 – brownish-grey medium-bedded dolostone, originally pelletal limestone.

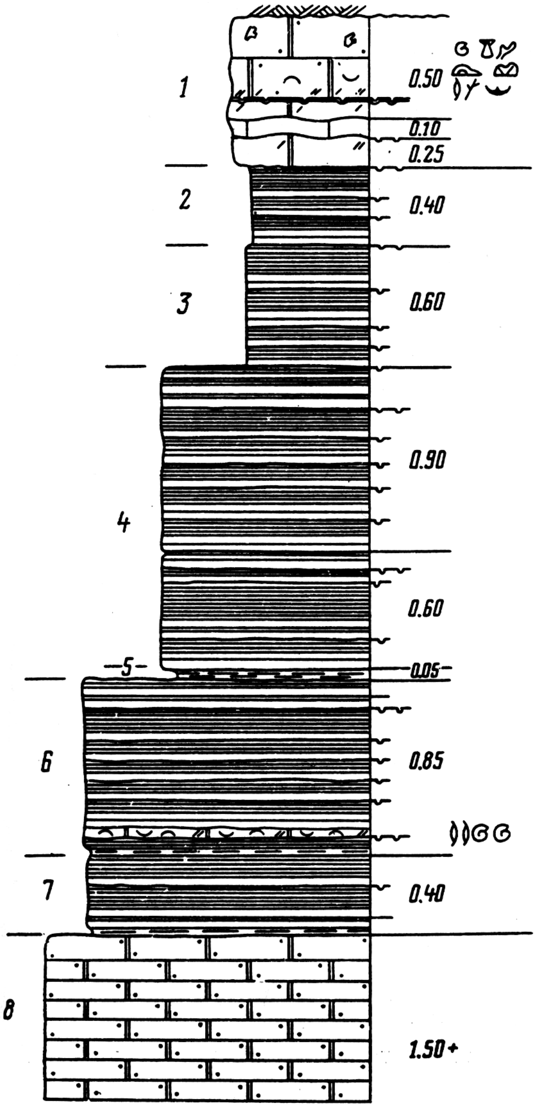


Fig. C27. Section of the Kaarma quarry after Einasto (1990c).

Generally the section is poor in fossils, only at some levels the lower parts of microcycles show moulds of gastropods, pelecypods and ostracods.

Fig. C28. Kaarma quarry. Photo by U. Veske.

Stop C14: Kaali meteorite craters

after Tiirmaa (1997)

Kaali meteorite craters, nine in all, are located in the central part of Saaremaa, close to Kõljala (58°22´22″ N, 22°40´10″ E; Fig. C29). They are some of the best known craters in Europe and an important tourist stop in Saaremaa.

Until 1960s, the craters at Kaali on Saaremaa Island were the only known meteorite craters in Europe. They had attracted scientists since the first half of the 19th century. The first description of the Kaali main crater appeared in 1827 by J. W. von Luce (Luce, 1827).

Different hypotheses about the origin of the craters were advanced between 1827–1928, some of which suggested also their volcanic origin or the eruption of gas and steam (e.g., Hofman, 1837). Eichwald (1843) and Schmidt (1858) who were well acquainted with the geology of Estonia, considered the dislocation zones and karst phenomena most important. In 1854, Eichwald suggested that there had been an ancient stronghold, in which a natural karst lake with man-made walls served as a well.

In 1927, I. Reinwald carried out geological investigations in the craters. In 1937, he collected 30 fragments of meteoritic iron from craters 2 and 5. The chemical analysis showed, that in these pieces Fe and Ni made up 91.5 and 8.3%, respectively. Minerals, characteristic of iron meteorites, were also found (Spencer, 1938). According to more recent determinations, the Kaali meteorite belongs to the class of coarse octahedrite (Buchwald, 1975).

Fig. C29. Aerial photograph showing the main Kaali crater in the center. Photo from the Estonian Land Board (www.maaamet.ee)

Up to now, 3.5 kg of meteoritic material has been collected from the craters; the largest piece weighed 28.4 g. In the late 1970s and early 1980s, the types and distribution of the pulverized meteoritic matter were investigated and their preliminary classification compiled (e.g., Shymanovich et al., 1993).

In 1955, Ago Aaloe proceeded with the studies started by Reinwald. During the course of the succeeding 25 years he devoted to this work, the geological structure of the craters was studied in particular detail. In 1959, a geological protection area of craters was founded at Kaali and an exhibition pavilion was built near the main crater. In 1984, a memorial stone was opened to Ivan Reinwald and Ago Aaloe.

The Kaali metorite craters, 9 in all, are located within one square kilometer. On the bottom of the main crater there is a natural body of water known as Lake Kaali (Fig. C30). The diameter of the lake depends on the water level and ranges from 30 to 60 m. The depth of the lake is 1–6 m, the maximum thickness of lake sediments is 5.8 m. The smaller craters, locally known as dry lakes, are shallow hollows surrounded by fragmentary remains of a low walls. The craters have formed in the clayey basal till and underlying thick micro-bedded Upper Silurian dolostones. The main crater measures 105–110 m in diameter at the top of the mound, and is at least 22 m deep. The upper part of the mound consists of the material ejected from the crater during the explosion and of partly overhanging dolomite layers tilted at an angle of 25–90°. The uplifted bedrock complex, with an average thickness of 10 m, has been split into nine shifted blocks, each up to 50 m in diameter (Tiirmaa, 1997 and references therein).

The diameters of the secondary craters range from 12–40 m being 1–4 m deep. On the bottom of craters 4 and 5 meteorite impact traces have been discovered.

The energy at the formation of the Kaali craters has been estimated at 5–25 kilotons of TNT for the main crater (the atomic bomb dropped on Hiroshima in 1945 exploded with energy of about 15 kilotons of

Fig. C30. The main Kaali crater has diameter of 105–110 m. Photo by O. Hints.

TNT). Based on the main crater's energy of formation and the supposed angle of incidence of 45°, the following ranges of values were obtained: initial mass of meteorite 400 to 10,000 tonnes, mass at impact 20 to 80 tonnes, initial velocity upon entering the atmosphere 15 to 45 km/s, velocity at impact 10 to 20 km/s. The meteorite pieces causing the small secondary craters separated at an altitude of approximately 5–10 km, and their combined mass did not exceed 18 to 20% of the total mass.

Opinions differ as to the direction and angle of incidence of the Kaali meteorite. The sizes of the craters led the first investigators to believe that the direction of movement was from the southeast to the northwest (Tiirmaa, 1997 and references therein). Aaloe, basing primarily on the study of impact traces at the bottom of craters 4 and 5, maintained that the probable angle of incidence had been 35–40° relative to the horizon. The morphology of the wall of the main crater, the geophysical data available on the destruction zones of the main and secondary craters 1 and 6 and the distribution of dispersed material in the craters and outside the crater field suggest that the meteorite fell from the east-northeast (Tiirmaa, 1997 and references therein).

Various methods have been used to determine the age of the craters. As neither deformed remnants from the explosion nor more recent sediments of marine origin had been found in the crater, Linstow (1919) estimated the age of the crater at about 4000 to 8000 years. Since the craters or their embankments did not reveal any traces of marine erosion or accumulation, Reinwald (Tiirmaa, 1997 and references therein), basing on the data available on the history of the Baltic Sea at that time, considered the craters some 4000–5000 years in age. In his first papers, Aaloe expressed the same opinion, but some years later he maintained that the age of the craters could not be more than 3000 to 4000 years. ^{14}C dating of charcoal discovered in 1961, yielded an age of 2660±200 years; the later dates 2530±130 and 2920±40 years allowed Aaloe to place the age of the craters erroneously at about 2800±100 years.

As it was not excluded that the dated charcoal was much younger than the craters themselves, great hopes were placed on drilling and dating of lake sediments in the main crater. Palynological analysis by Kessel (Tiirmaa, 1997 and references therein) showed that the bottommost sediments are Sub-Boreal in age and the craters are more than 3500 years old. Simultaneous ^{14}C and palynological investigations initiated by L. Saarse, placed the craters' age at approximately 3500–4000 years (e.g., Saarse et al., 1992).

Recent investigations have shown that the Kaali area was freed from the waters of the Baltic Sea already some 8000 yr BP. In 1994, a high concentration of microimpactites was detected in the peat of the Piila Bog, about 10 km to the northwest from the Kaali craters. The age of the layer with microimpactites was established by means of palynological and radiocarbon methods. The studies suggest that the Kaali craters were formed probably close to 7500 BP (Raukas et al., 1995a).

The mid-1970s witnessed an ever growing interest of historians in the Kaali Crater. Impetus was given by Lennart Meri's books "Hõbevalge" (1976) and "Hõbevalgem" (1984) and by the first archaeological finds in the east wall of the main crater in 1976. In 1978, excavations were begun on the discovered fortification which is located on the outside slope of the northeastern wall of the main crater. From the side of the lake it is protected by a steep slope and from outside by a semi-circular wall. Archaeological finds in the fortress area are limited, few earthenware fragments are dated from the 7th century BC, most of the pottery dates from the Iron Age, the beginning of which is considered to be 600 years BC locally (Lõugas, 1978).

Stop C15: Tagavere quarry

after V. Nestor and R. Einasto (1990)

The Tagavere quarry is located in the eastern part of Saaremaa, about 10 km south of Jaani church (58°32´22″ N, 22°53´40″ E). Here dolostone plates are produced, widely used as facing material e.g. for the building of National Library and several other buildings in Tallinn (Fig. C32). The quarry serves as a stratotype of the Tagavere Beds which form the uppermost part of the Jaagarahu Stage.

The name "Tagavere" was originally suggested by A. Aaloe (1960) for the upper substage of the Jaagarahu Stage, containing Pangamäe and Maasi members. Later (Aaloe et al. 1976) the name "Tagavere Beds" was restricted to the uppermost (third) cycle of the Jaagarahu Formation, represented by nodular bioturbated and dolomitized skeletal limestones (bottom) and primary dolostones.

Description of the section (Fig. C31) is given in descending order, two upper beds are exposed only in the southern corner of the quarry.

1. 0.15 m – hard thick-bedded microcrystalline dolostone.
2. 0.15–0.35 m (0.2) – argillaceous dolostone containing two (at the top and bottom of the bed), 1–2 cm thick interlayers of argillaceous dolomitic marlstone. Numerous gastropods (*Murchinsonia*), pelecypodes and *Eurypterus* fragments occur on the hardground at the base of the bed.
3. 0.35–0.47 m (0.12) – bioturbated argillaceous dolostone with fine-grained skeletal debris, containing lenses of dolomitic marlstone and vertical burrows. Distinct pyritized hardground at the base is a good marker level.
4. 0.47–0.55 m (0.08) – bioturbated dolostone with skeletal debris, containing 3 distinct hardgrounds with underlying thin interlayers of dolomitized skeletal grainstones.

5–8. 0.55–1.35 m (0.80) – bioturbated argillaceous dolostone with fine-qrained skeletal debris, containing pyritized hardgrounds with underlying thin interlayers (1–3 cm) of dolomitized skeletal grainstones. Several flat or wavy interlayers and lenses of bioclastic dolomitic marlstone occur.

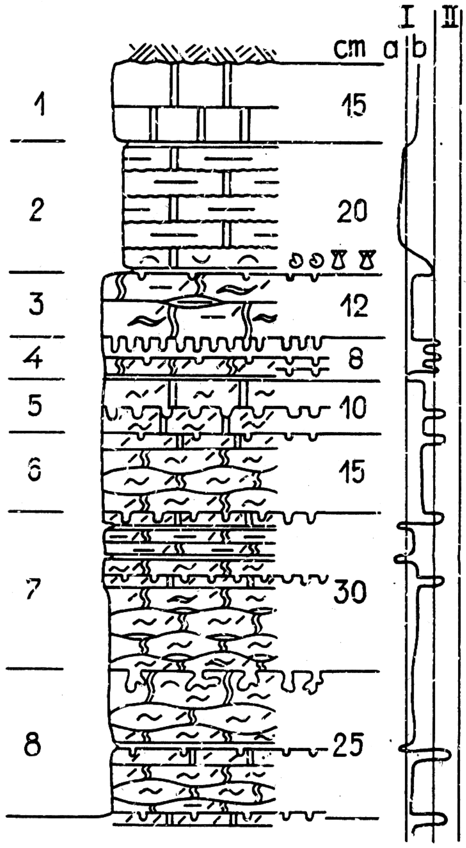


Fig. C31. Geological section of the Tagavere quarry after Nestor, V. & Einasto (1990).

Thus, in this quarry mostly formed in the restricted shelf environment secondary dolostones of the lower part of the

Tagavere Beds are exposed, but also primary lagoonal dolostones of the upper part of these beds are represented (layers 1–2). The outcrop is poor in micro- and macrofossils. From the lower beds of the section the gastropod *Murchisonia* cf. *M. cingulata* Hisinger, brachiopod *Howellella* sp. and nautiloids have been found.

Fig. C32. Tagavere quarry. Photo by O. Hints

Acid-resistant microfossils are represented by acritarchs and scolecodonts. Chitinozoans were recorded from the lower, 80 cm thick interval of the section and contain *Ancyrochitina primitiva* Eisenack and *A.* cf. *pachyderma* Laufeld. As the last species disappears already in the *C. lagena* Zone, which corresponds to the Jamaja Formation in the southernmost sections of Estonia (Ohesaare, Kihnu, Ruhnu core sections), the Tagavere Beds in the stratotype area seem to correspond stratigraphically (at least partly) also to the Jamaja Formation.

Stop C16: Kübassaare cliff

after T. Märss and E. Jürgenson (1995, unpublished data)

Kübassaare cliff is located on the eastern coast of the Kübassaare Peninsula in eastern corner of Saaremaa (58°26´12″ N, 23°18´42″ E). The cliff is about 360 m long and up to 1.5 m high. Soeginina Beds of the Paadla Stage, in total thickness of 2.7 m, are exposed here. Unique to this site are large, with diamater up to 2 m stromatolites.

The section in Kübassaare cliff from top to bottom is as follows:

1. 0.00–1.30 – Quaternary cover.
2. 1.30–1.75 – brownish-grey cavernous clayey bioclastic dolostone with wavy bedding planes and occasional fragments of eurypterids.
3. 1.75–2.40 – intercalation of bioclastic and argillaceous dolostones with numerous ostracods, gastropods and cephalopods. On bedding planes fragments of eurypterids occur. At some levels ripple marks and cavities left by dissolved salt crystals can be found. The above mentioned stromatolites also occur in this interval.

Fig. C33. Stromatolites in the Kübassaare cliff. Photo by G. Baranov.

4. 2.40–2.52 – interbed of bituminous marlstone below which a porous dolostone with stylolites occurs.
5. 2.52–2.80 – brownish grey thin-bedded dolostone.
6. 2.80–3.25 – brownish grey strongly bioturbated dolostone.
7. 3.25–3.60 – brownish grey dolostone rich in stylolites
8. 3.60–4.00 – brownish grey bioclastic dolostone with bebbles and oncolites.

Excursion D:
Devonian of South Estonia

The Devonian System in Estonia

by Anne Kleesment

The Devonian sequence of Estonia (Fig. D1) begins with incomplete succession of Lower Devonian rocks, represented by three siliciclastic units, separated from each other by major gaps. The oldest, Tilže Regional Stage (Lochkovian) is distributed in south-eastern Estonia as a narrow tongue and has been determined only by few drill cores here. Presumable distribution area of the Kemeri Regional Stage (Pragian) is also very limited in the south-western part of Estonia. The Rezekne Regional Stage (Emsian) is relatively widespread in southern Estonia.

The Middle Devonian is the most complete part of the Devonian succession in Estonia. The Eifelian Stage is represented by the Pärnu, Narva and Aruküla Regional Stages, and lower part of the Givetian Stage by the Burtnieki Regional Stage. These Middle Devonian siliciclastic or mixed siliciclastic-carbonate (Narva St.) beds have numerous outcrops in southern and eastern Estonia, among which many protected geological monuments occur. Distibution of siliciclastic sediments of the Gauja and Amata regional stages (upper Givetian) and carbonate rocks of the Pļaviņas Regional Stage, (basal Frasnian, Upper Devonian) is restricted to the south-easternmost part of Estonia.

Estonian Devonian succession is famous about its fossil fishes which have been studied since the first half of the 19th century (Mark-Kurik, 1997). Especially valuable are the fish localities of the Pärnu (Tori), Aruküla (Tartu, Kallaste, Tamme) and Burtnieki (Karksi) stages. Devonian microfossils are intensively examined during the last decades, serving for detailed subdivision and correlation of the sections (Valiukevicius, 1998; Mark-Kurik, 1999).

Fig. D1. Devonian stratigraphy of Estonia and position of stops.

Series	Stage	Regional Stage	Formation	Member, Beds	Thickness	Main lithology	Number of outcrops	Excursion stops
Upper Devonian	Frasnian	Pļaviņas	Pļaviņas	Chudovo	Up to 27m	Dolo- and limestone		
				Pskov			6	D7, D8, D9
				Snetnaya Gora				
Middle Devonian	Givetian	Amata	Amata		12-27m	Sandstone	5	
		Gauja	Gauja	Lode	48-58m		35	D5, D6
				Sietini	23-30m		6	
		Burtnieki	Burtnieki	Abava	15-32m	Sandstone	45	
				Koorküla	20-42m		13	
				Härma	13-28m		45	D3, D10
		Aruküla	Aruküla	Tarvastu	20-40m		38	
				Kureküla	20-44m	Sandstone	49	D2, D11
				Viljandi	15-23m	Sand-and siltstone	7	
	Eifelian	Narva	Kernave		17-49m		7	
			Leivu		12-57m	Dolomitic marl- and dolostone	2	
			Vadja		9-28m		6	D1
		Pärnu	Pärnu		15-47m	Sandstone	8	
Lower Devonian	Emsian	Rēzekne	Rēzekne		Up to 51m			
	Pragian	Ķemeri	Ķemeri		6-8m			
	Lochkovian	Tilžė	Tilžė		2-17m			

Stop B4/D1: Narva quarry

This is a joint stop with the Excursion B: Ordovician of NE Estonia. See description of the stop B4/D1 on pages 107–109.

Stop D2: Kallaste cliff

by Kati Tänavsuu

Kallaste cliff is situated in the Kallaste town in Tartu County, at the western coast of Lake Peipsi. The cliff is composed from 11 separate outcrops. The height of outcrops is mainly between 2–4 m but in the highest part it reaches 9 m. Wave-cut notches (caves) occur in the lower part of the cliff in many places. The exposed Devonian sandstone belongs to the Kureküla Member of the Aruküla Formation (and Regional Stage) and contains fish remains. The largest outcrop of the Kallaste cliff is situated near to the Kallaste cemetery and it is approximately 200 m in length.

The exposed beds consist of well sorted brownish-red cross-stratified and cross-laminated very fine- to fine-grained sandstone, with high concentration of mica drapes (Figs. D2, D3). The single and double mica drapes occur throughout the section. Mud drapes are rare or lacks in deposits. The deposits are built up from 0.2 to 3.5 m thick beds which form laterally continues bedsets. Characteristic features are bidirectional beds, sigmoidal bedding, and erosional structures (channels). Sedimentary successions infilling the erosional channels start with clay clast conglomerate (up to 30 cm in diameter) or large scale cross-stratified sandstone with clay clasts in bedding planes, and fine upward into the thin bedded cross stratified and cross-laminated sandstones. Measured palaeocurrent data from southeast and northwest suggest bidirectional water flow.

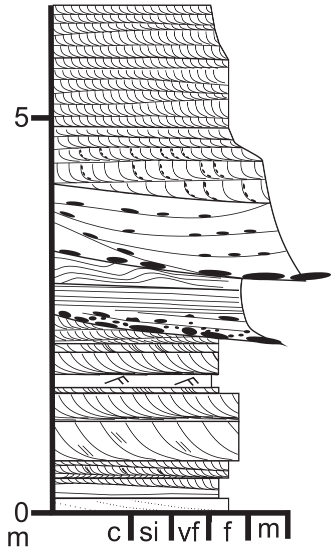


Fig. D2. Kallaste section after Zirk (2007, MSc thesis in manuscript).

Fig. D3. Kallaste cliff. Photo by E. Zirk.

The depositional environment of the sandstone in Kallaste is still somewhat unclear. Deposits of the Aruküla Stage have been interpreted to be formed in shallow marine settings (Kleesment, 1997), in fluvially dominated subaqueous delta plain (Plink-Björklund & Björklund, 1999), or in tide-influenced delta front settings (Zirk, 2007, MSc thesis in manuscript).

Stop D3: Taevaskoda cliffs

by Anne Kleesment

The Suur (Big) and Väike (Small) Taevaskoda cliffs are the main tourist attractions in the Põlva County. They are situated on the right bank of the Ahja River, near the Saesaare dam at a small hydroelectric power station. Härma Beds of the Burtnieki Regional Stage represented by complicatedly intercalated yellowish-white, pinkish-white, purplish-yellow, violet-brown and purplish-brown weakly to moderately cemented sandstone beds are outcropping. Sandstone is mostly fine-grained, in interlayers supplement of medium-grained particles is sufficient, in some cases also dominant. The sandstone is cross-bedded. The cross-stratified sets are usually 10–40 cm, in rare cases up to 1 m, thick. Often they thin laterally. The cosets are mainly dipping to the south. The boundaries of sets are sub-horizontal, in places uneven. Characteristic is occurrence of numerous goethite-rich surfaces and of 1–2 mm to 5–10 cm thick brownish, more rarely violet, relatively well-cemented interlayers. In boundaries of cross-stratified sets also thin mica-enriched laminas occur.

Fig. D4. Väike Taevaskoda cliff. Photo by G. Baranov.

The stretch of Väike Taevaskoda sandstone cliff is 140 m and the outcrop is up to 10 m high (Fig. D4). Many joints penetrated the sandstone wall, intersecting in several places. Two interesting caves are eroded by spring into sandstone scarp. The Neitsikoobas cave (Virgin's cave) at the middle part of the outcrop has been formed at the intersection point of the vertical and tilted joints. The opening is 5 m high and up to 4 m wide and is leading to the 14 m long tunnel-like passage with abounding spring stream. This cave is stayed unchangeable at least last 70 years. By legends the roar of spring water of cave is reminiscent of virgin's cray and loom clatter, because virgins had to weave cloth for the devil's family. At the very upstream part of the Väike Taevaskoda cliff is the Emaläte cave (Mother's or River Source cave). The opening of this cave is 3 m high and up to 8 m wide. Cave entrance leads to the 8 m long grotto, followed by the narrow tunnel (extent 5m). A spring stream abounding in water runs out of the back wall of the tunnel. The water of the spring brook is very pure and according to legends has rejuvenating effect.

Fig D5. Suur Taevaskoda cliff. Photo by G. Baranov.

The Suur Taevaskoda cliff is situated about 300 m upstream. The stretch of the sandstone cliff is 150 m and height up to 20 m (Fig. D5). The wall is penetrated by sets of fractures dipping in different directions. Often the intersection of joints is observable. In places beds are deformed. In lowermost part of sandstone scarp, on the water level of Ahja River some gullies are engraved by springs. According to legends, here was a big cave earlier in which the devil's family lived. Supposedly old Estonians performed religious ceremonies here. They named this majestic place Taevaskoda (Heaven's house). In Suur Taevaskoda there is a big stone, which was used as sacrifical place. It is also named as Spy's Stone.

Stop D4: Ilumetsa impact craters

by Jüri Plado

Ilumetsa meteorite impact crater field (57º57'N, 27º24'E) consists two relatively well-preserved simple structures, named Põrguhaud (Hell's Grave) and Sügavhaud (Deep Grave). The rim-to-rim diameter of the larger crater, Põrguhaud, is 75–80 m, its depth is 12.5 m. Sügavhaud is a 5.4 m deep conical depression with a diameter of ~50 m. The structures were first reported in summer 1938, during the regional geological mapping (Aaloe, 1961). The target of Ilumetsa projectile consisted of Middle Devonian brittle reddish or light-yellow silt- and sandstones of the Burtnieki Stage. One to two meters thick layer of brown basal till overlied this weakly cemented bedrock. In places, till was covered by peat and/or glaciofluvial sand (Tiirmaa, 1997). It is estimated (Aaloe, 1979) that the impact has been disturbed the Devonian sandstones through loose Quaternary sediments down to ~30 m in Põrguhaud and ~20 m in Sügavhaud. According to the excavations (Aaloe, 1979), the autogenic breccia is represented by fractured and bended silt- and sandstones, which interchange with loose sand. In a rim area, bedrock and Quaternary cover are uplifted, whereas the basal till has been intruded into the Devonian sandstone. Craters are filled with lenses of allogenic breccia, consisting sands, mixed with brown basal till, and peat.

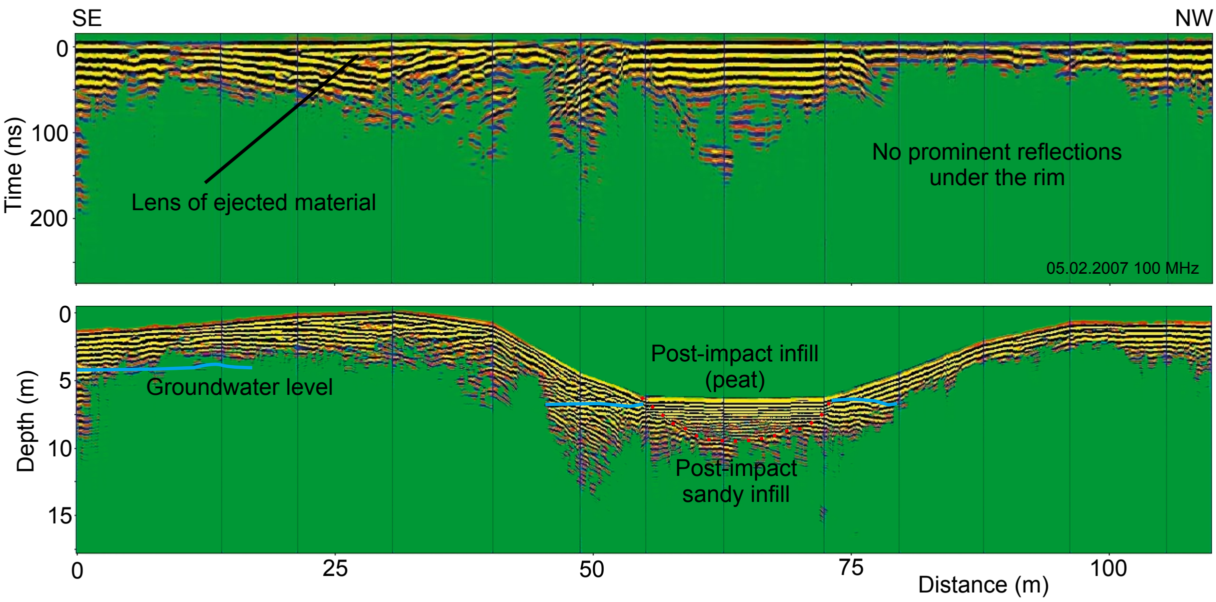


Fig. D6. Radargrams across the Põrguhaud, largest of Ilumetsa crater field, structure. The upper figure represents raw data measured at frequency of 100 MHz whereas the lower figure is a modification of the upper by including topography and converting time-scale into the depth (apparent permittivity value of 45 based on the drilling data was used for the peat body inside the structure and 16 for all the rest).

In 1970, the peat of Põrguhaud was sampled by hand-drilling. In total, 2.15 m of the organic material, composed of 2.00 m of peat and 0.15 m of gyttja in the lowermost part. The bottom-most organic layer radiocarbon ages of 6030±100 and 5970±100 years, which together with palynological analyses suggested ~6000 years for the age of the structure (Liiva et al., 1979). In summer 1996, glassy spherules at the depth of 5.7 m in the Meenikunno Bog, 6 km to SW from Ilumetsa, were found (Raukas et al., 2001). The radiocarbon age of the layer with spherules is 6542±50 (depth interval 5.6–5.7 m) and

6697±50 (depth interval 5.7–5.8 m) suggesting ~6600 years for the age of Ilumetsa.

In winter 2007 (Plado et al., 2008), ground-penetrating radar (GPR) was used to study the shallow subsurface of Põrguhaud (Fig. D6). It reveales several features / groups of features in GPR profiles as: (i) a bowl-shaped boundary between the sandy infill and peat, (ii) moderatly strong subhorizontal reflectors in crater-fill peat, (iii) an area of chaotic reflectors (lack of prominent reflectors) below the rim and peat, (iv) specific lens-like area outside the crater at the foot of the rim that includes ejected and eroded material, and (v) disappearance of the groundwater level, observable outside, while approaching the rim.

Stop D5: Tabina sand pit

by Kati Tänavsuu

Sandstone in the Tabina (or Imara-Tabina) sand pit belongs to the Lode Member of Gauja Formation. The height of walls in operating pit is up to 15 m varying according to the mining activities. The sediments show fining-upward and beds thinning-upward trend. A typical depositional unit starts with erosional surface, marked by conglomerate lag with clay-clasts (up to 20 cm in diameter) and gravel to pebble sized quarts grains (up to 5 cm in diameter), and cross-stratified sandstones (Figs D7, D8, D9). The unit pass upward into cross-stratified and cross-laminated sandstones. In places occur soft sediment deformations, mud and mica drapes in deposits. The bed thickness varies between 0.15 to 1.2 m. Measured paleocurrent data indicate southwest to south direction of water flow. Sandstones of the Gauja Formation have been interpretated to be deposited in delta (Kleesment, 1997), subaeral delta plain (Plink-Björklund & Björklund, 1999). Based on detailed descriptions of Tabina quarry Pontén and Plink-Björklund (2007) suggested that the coarser grained deposits with clay clasts and quartz pebbles formed in the braided fluvial channels within the major distributary channel belt. The fine-grained sands, with mud and mica drapes, formed in fluvially dominated channels with tidal influence.

In present day two sand pits are situated closely together where sand is mined mainly for building industry, however, it is suitable also for glass industry. Sandstone is quartzose (content of quarts 94–96%) with low content of iron. Some peculiar sandstone-filled clastic dikes occur in walls of the pit. One of them situated in eastern wall has been described in 2003 (Kleesment et al., 2003). In 2008 some dikes with width of 8–10 cm are still visible.

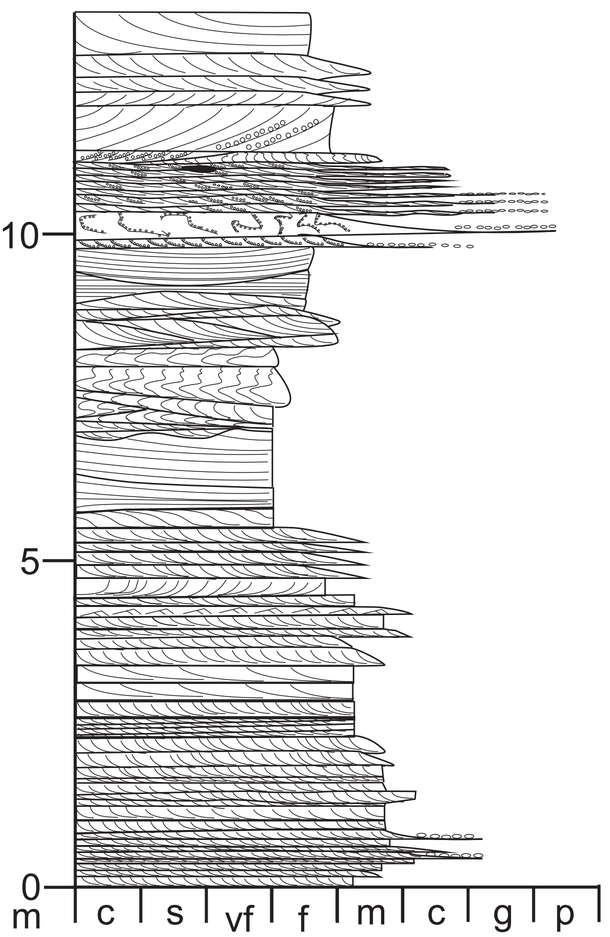


Fig. D7. Cross-section from the eastern wall of the Tabina sand pit after Pontén & Plink-Björklund (2007).

Fig. D8. Erosional surface with clay-clast conglomerate in the Tabina sand pit. Photo by L. Ainsaar.

Fig. D9. Erosional surface with quartz conglomerate in the Tabina sand pit. Photo by K. Kirsimäe.

Stop D6: Härma cliffs

by Anne Kleesment

Sandstone cliffs near the Härma village on the right bank of the Piusa valley are the highest and most picturesque Devonian outcrops of Estonia. Yellowish pink to light yellow well-sorted fine-grained cross-bedded sandstones of the Lode Member of Gauja Regional Stage are cropping out. Cross-set thickness varies usually from 5 up to 20 cm thinning often laterally. Sub-horizontal set boundaries are in many cases marked by iron-oxide pigmentation surfaces. In places set boundaries are uneven, in rare cases even wavy. Some erosion surfaces containing clay pebbles are penetrating the sandstone walls.

Downstream placed Kõlksniidu cliff is also known as Lower or Roikina wall. The outcrop is about 60 m wide and up to 20.5 m high. In downstream part in stretch of 30 m the sandstone scarp falls along an even fracture surface steep to the Piusa River. In upstream part a 19 m high, peculiar pyramidal sandstone tower occur, partly separated from the main outcrop. It has been formed by fracture systems oriented in directions 300–340º and 90–100º. The fractures are inclined causing the upward thinning of the tower. In lower part of this tower a synclinal deformation structure occur with lower surface penetrated by abundant gullies. Some dislocations of bedding surfaces are here observable. A spring runs out from the wall here. Some lenticular goethite-enriched conglomerate interbeds occur containing multi-coloured muddy clasts (up to 15 cm in diameter).

About 0.5 km upstream Suur-Härma or Celler or Hill-side wall is situated in 43 m high steep bank of the Piusa River (Fig. D10). This is the highest Devonian outcrop in Estonia where up to 30 m of sandstone profile is visible. The horizontal stretch of the outcrop is 150 m. In lower part on the wall a lenticular conglomeratic interbed (up to 20 cm) occur

Fig. D10. Suur-Härma cliff. Photo by M. Milkevičius.

with wavy lower boundary and containing abundant platy muddy clasts. Some smaller conglomerate lenticular bodies occur also higher. In upstream part of the outcrop a 10 m high sandstone tower occur determined by fracture systems 290–320º and 80–100º. Similar sandstone towers occur also in some other outcrops of the Gauja Stage, but have not found in other stratigraphic levels (Kleesment, 2002). They are weathering forms of the sandstone related to distribution of fracture systems characteristic to the Gauja Stage.

Stop D7: Tiirhanna quarry

by Leho Ainsaar

Small abandoned Tiirhanna limestone quarry is situated few hundred meters from the Estonia/Russia border. Limestone and dolomitic limestone has been quarried here until mid-twentieth century for local lime production and building stones. The section opens middle part of the Pĺavińas Stage (lower Frasnian), the Pskov Beds, and has been studied geologically long ago (Öpik, 1935; Bölau, 1944). In total, 3.9 meters of section was exposed here in September 1998 (Fig. D11). Lower and middle part of the section is represented by fossil rich limestone, containing abundant stromatoporoids and lime algae. A bed of fossil free dolomitic limestone with laminar bedding occurs in the upper part of the section, covered by dolomitized bed extremely rich in stromatoporoids.

Carbonate sedimentary basin replaced the siliciclastic Middle Devonian deposition in the Baltic Basin in early Frasnian. Lower part of the Pĺavińas Stage, the Snetnaya Gora Beds, are mostly represented by mixed carbonate-siliciclastic sediments, marls, clays and siltstones. This mixed sedimentation was followed by pure carbonates in the Pskov time. The sea was open to east, towards the Moscow Basin, which was dominated by carbonate normal marine sedimentation. The carbonate fauna was

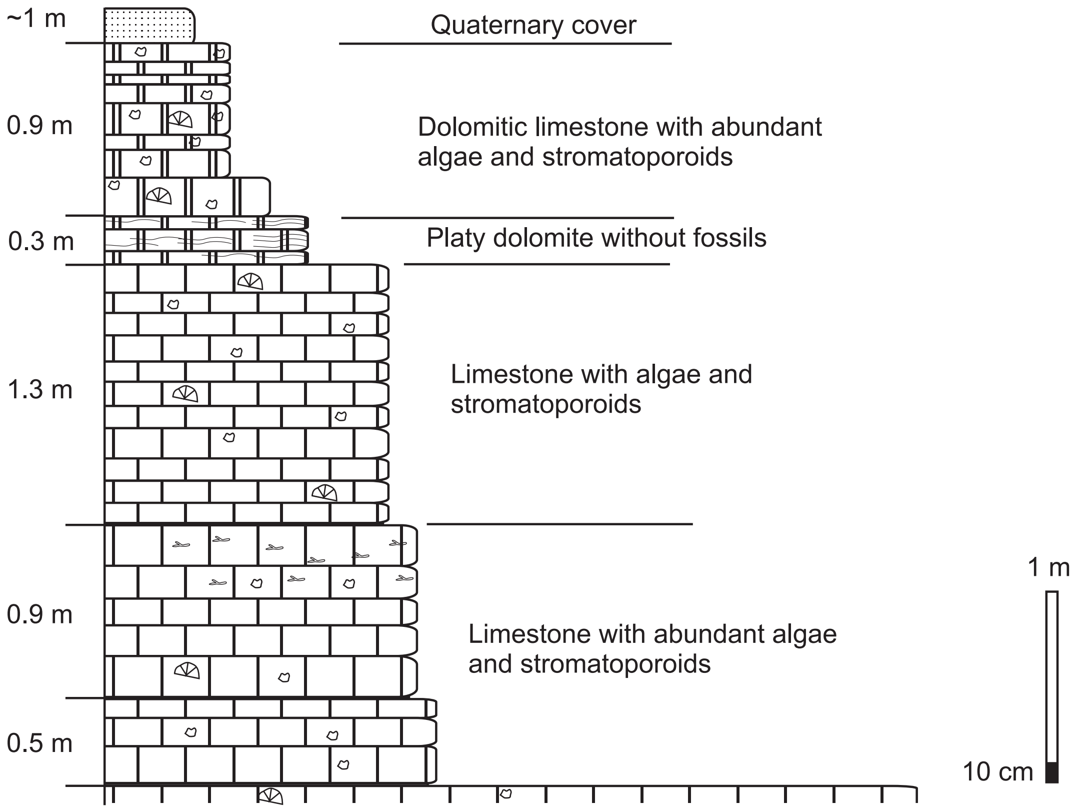


Figure D11. Tiirhanna quarry section.

EXCURSION D

represented by brachiopods, pelecypods, gastropods, stromatoporoids, corals, cephalopods and oncoids. The area of southeastern Estonia, together with Latvia, was characterized by shallow marine, partly lagoonal, environments. Carbonates of the Pĺavińas Stage have meter-scale cyclicity, caused by sea level changes. In dolomitized sections of Latvia two main types of rock intercalate cyclically: planar laminated, almost fossil-free dolomite, and fossiliferous, sometimes biostromal dolomite or dolomitized limestone. Laminated dolomite has been deposited during regressive episodes in restricted (lagoonal) environment, and fossliferous carbonate in the transgressive, shallow open shelf environment (Sorokin, 1974, 1978).

Carbonates in the Tiirhanna quarry represent the least dolomitized facies of the Pskov Beds, being similar to eastward situated sections in Izborsk and Pskov (Russia). Other sections in soutwestern Estonia and Latvia expose much more dolomitized carbonates, and even inclusions of gypsum occur in the same beds in western Latvia (Sorokin, 1978). It seems that a 30–40 cm thick bed of laminar dolomitic limestone in the upper part of the Tiirhanna section represents the lagoonal phase of sedimentary cycle, and fossiliferous limestones represent the open marine episodes.

Stop D8: Marinova quarry

by Leho Ainsaar

New Marinova dolomite quarry was opened in autumn 2007 by AS Põlva Teed for road material production. The operating quarry is situated about four kilometres south from Tiirhanna, 0.5 km west from Estonia/Russia border. In April 2008 it was possible to describe 2.7 meters of section in the northern wall of the quarry (Fig. D12).

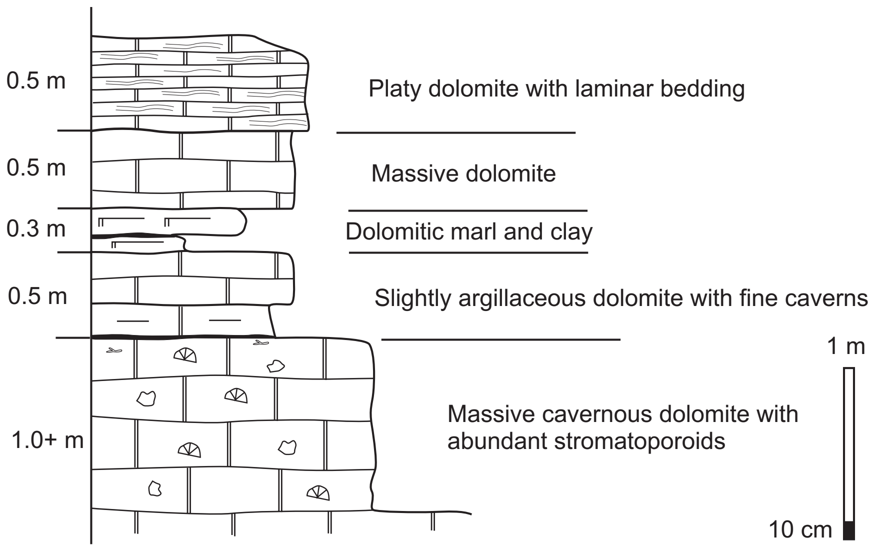


Fig. D12. Geological section from the northern wall of the Marinova quarry.

The section opens same Pskov Beds of the Pĺavińas Stage, as Tiirhanna quarry, but here the rocks are totally dolomitized. Upper part of the section is represented by laminar fossil-free dolomite and middle part by marl, clay and argillaceous dolomite. Lower part of the section exposes massive fossiliferous dolomite with abundant stromatoporoids. Dolomitization of originally fossiliferous limestone has caused formation of numerous caverns, infilled by dolomite crystals. All sections is probably representing one shallowing upward sedimentary cycle, with open marine or shoal sediments below and lagoonal dolomites above. According to the drilling data (Brutus, 1990, report in manuscript), total thickness of the Pskov Beds in Marinova deposit is 6.6–10.7 meters.

Stop D9: Ape quarry

by Leho Ainsaar

There are number of natural sections (Gaujena, Grube), operating (Dārzciems) and abandoned quarries (Ape) exposing the carbonates of the Pļaviņas Stage in northwestern Latvia, close to Estonian border. Ape quarry is situated in the southern limit of the Ape town, behind the Ape manor house. The Pskov Beds are exposed here almost in their full thickness. In October 1999, 7.2 meters of section was described here (Fig. D13; Vahtra, 2001, BSc thesis in manuscript), which is close to the total thickness of the Pskov Beds in the area (Sorokin, 1974).

The quarry section is represented by intercalation of fossiliferous, cavernous dolomite and fossil-free, sometimes argillaceous dolomite. Among the fossiliferous beds, the one in the upper part of the section, with thickness of 1.5 meters, is most remarkable, being extremely rich in stromatoporoids (Fig. D14). Carbonates on the top of the quarry contain shelly fauna (brachiopods).

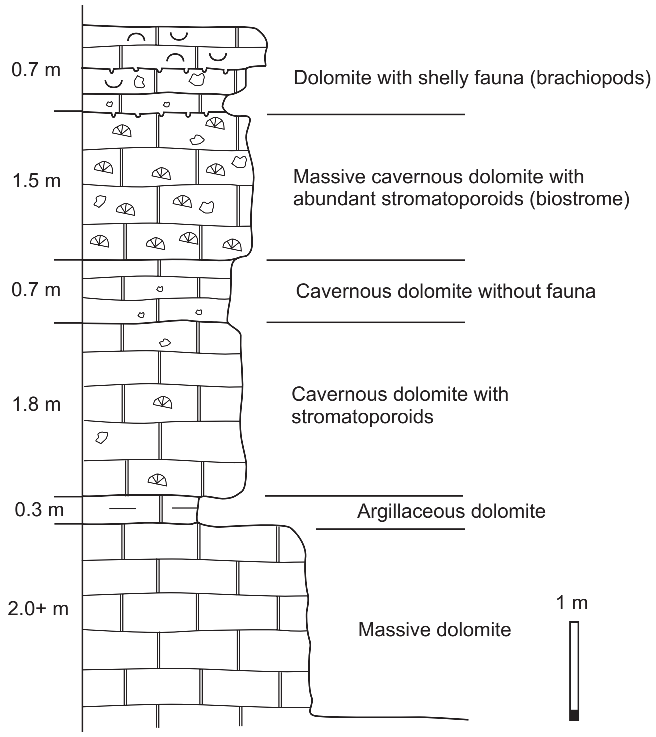


Fig. D13. Ape quarry section (modified from Vahtra, 2001, BSc thesis in manuscript).

V. Sorokin (1974) has divided the Pskov beds into 14 sedimentary cycles (rhythms) in Latvia, which can be grouped into five sets and these into two major cycles. However, according to his studies, small sedimentary cycles, often some tens of cm-s thick, may have been merged together, especially in the nearshore facies. At least three upward shallowing depositional cycles or cycle sets can be seen in the Ape quarry with thickness around 2 meters each (Fig. D14).

Another outcrop, Raganu cliff, exposes sandstone of the Gauja Stage in the eastern side of the Ape town, in the Vaidava river bank (Kurshs, 1975).

Fig. D14. Southern wall of the Ape quarry with fossiliferous (biostromal) cavernous dolomite in the upper part. Photo by L. Ainsaar.

Stop D10: Helme outcrops

by Anne Kleesment

Sandstone is outcropping in Helme settlement of the Valga County west of Tõrva town, close to the Pärnu-Valga road. Helme caves (Helme Hell) are situated near the ruins of a Helme Castle and a sacrifical well with curative water. The caves are in the main extent made by human activities, however, there must be occurred a natural cave system, created by spring streams along geological fractures which is widened by human. Caves are graved into white and yellowish white fine-grained cross-bedded sandstone of the Härma Beds of Burtnieki Regional Stage (Fig. D15). The cosets of the cross-bedding sets are mainly dipping to the south. Along the bedding planes mica concentrations are observed. In places bedding planes are marked by rusty pigmentation of iron hydroxides.

Fig. D15. Helme cave. Photo by G. Baranov.

The total length of the mostly dry cave system is in present day about 38 m. It comprises two 3 m high grottos with 3.5–6 m and 5.5 m in diameter, joined together with 1.2 m high passage. From grottos some narrow branches along fracture directions begin. In back wall of the second grotto a 1.3 m high and 1.2 m wide passage begins which turned to the north, become lower, but is passable in extent of 18 m. In its distant part bottom is covered with spring stream. The entrance to the cave system is situated in the eastern slope of the hill and is 2 m high and 1.5 m wide. Second entrance 20 m northward is passable only 5–6 m and ended with land collapse.

In folk-tales Helme caves are known from ancient times. In historical documents they are mentioned first in 18th century as a refuge caves used during wartimes. Later they were used as part of architecture of the estate park. At the beginning of the 19th century the cave system comprised 6–7 grottos connected with each other by passages, but most of them had collapsed before 1870. In present day there are four collapse hollows near the caves: one south from entrance, two on the hill opposite the entrance and the biggest, named Old Nick's Belly, north from the cave system, was probably the centre of the caves. Today it is a 40 m long, 12 m wide and 4 m depth hollow in which white sandstone is cropping out. In detailed observation entrances of four passages are guessed. According to folk legends 8 passages have been branched from the Old Nick's Belly into different directions. One passage had lead to Pokardi valley, the other to Helme Church and the third even to Viljandi and the forth to the Hell.

Arstle (Helme sandstone) outcrop is situated in the immediate vicinity of Helme caves, about 400 m from the Pärnu-Valga highway, at the Viljandi-Helme-Leebiku crossroad. It is the most representative outcrop of the Härma Beds of the Burtnieki Regional Stage in south-eastern Estonia. White cross-bedded fine-grained sandstone penetrated by some erosion surfaces is cropping out in 11 m high scarp. Cross-set thickness varies usually from 60–80 cm. Set boundaries are often marked by iron-oxide pigmentation surfaces. In places mica concentrations are observable. Cosets are dipping to the southern directions. At the 2 m level from the base a clear erosion surface occurs containing abundant clay pebbles (1–2 cm in diameter). At the base of the sandstone wall a dry small cave occur. It is only 2 m long and its opening is 2 m high and 2 wide. The outcrop is named after Arstle farm where in the 19th century and at the beginning of the 20th century curative water from Helme spring was sold.

Stop D11: Tamme outcrop

by Kati Tänavsuu

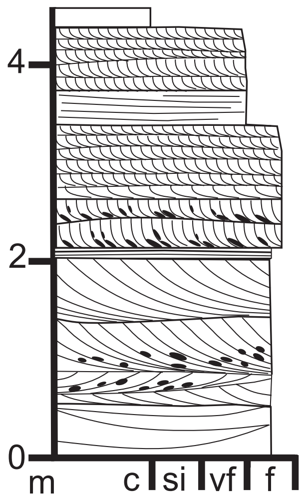


Fig. D16. Tamme section after Zirk (2007, MSc thesis in manuscript).

Tamme outcrop is situating at the eastern shore of Lake Võrtsjärv in Tartu County, between the Tamme and Neemisküla villages. Sandstone in the Tamme outcrop belongs to the Kureküla Member of Aruküla Formation. The best exposed outcrops occur in approximately 200 m long distance along the shoreline and are up to 5 meters high. The sediments consist of well sorted brownish-red very fine- to fine-grained sandstone, with bed thickness from 0.5 to 0.9 m (Fig. D16). Very fine- to fine-grained cross-stratified sandstone is exposed in the main part of the outcrop. Laminated siliciclastic mudstone, siltstone and dolomitic marl occur in the upper part of the section. Throughout the section the single and double mica and mud drapes occur in sandstones. Bidirectional beds and clay clasts in bedding planes can be found. Measured paleocurrent data indicate the south direction of water flow. These deposits were also known because of abundant fish remains found as concentrations in certain bedding planes. However, in present exposure only levels containing fish microremains have been found (Niit et al., 2005) and no beds with fish plates are exposed.

The depositional environment of these sandstones is still somewhat unclear. Deposits of the Aruküla Formation have been interpreted as shallow marine (Kleesment, 1997) or in fluvially dominated subaqueous delta plain sediments (Plink-Björklund & Björklund, 1999). Recent sedimentological investigations in Tamme outcrop suggest the forming of deposits in tidally influenced delta. The main, cross-stratified part of deposits is suggested to be formed in the tidally-influenced delta front and the thin-bedded upper part in delta plain environment (Zirk, 2007, MSc thesis in manuscript).

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