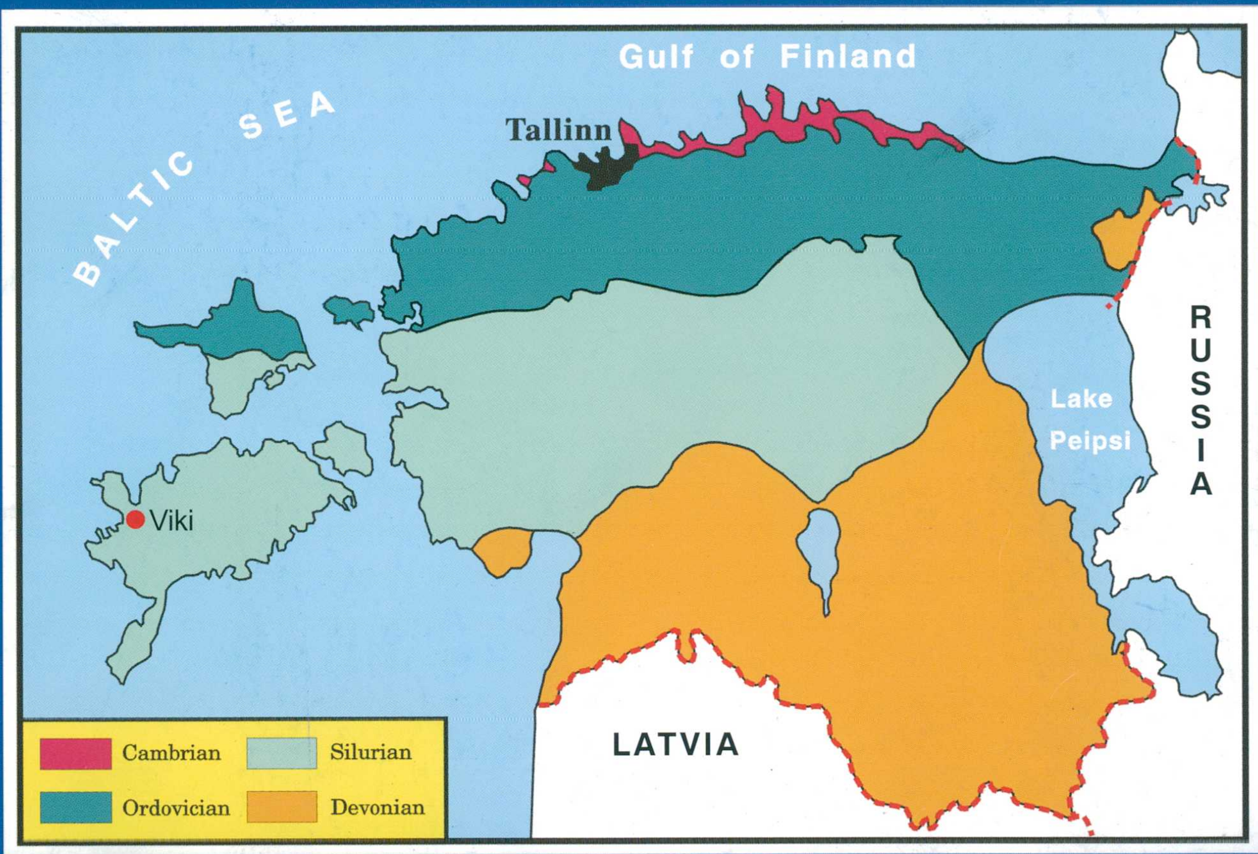
EESTI GEOLOOGIAKESKUS
GEOLOGICAL SURVEY OF ESTONIA

ESTONIAN GEOLOGICAL SECTIONS

BULLETIN 10

VIKI DRILL CORE



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INTRODUCTION

The 363.0 m deep Viki borehole (58° 21′ 03″ N, 22° 04′ 47″ E) is located near Kihelkonna settlement on Saaremaa Island (western Estonia), in the NW part of the East European Platform (Fig. 1). It was drilled for scientific purposes in the middle of the 1970s, after deep geological mapping of Saaremaa (at a scale of 1:200 000) in 1967–1973. The results of long-term investigations of the Viki core are summarized in this issue and serve as a substantial contribution to the study of Estonian geological sections.

The Viki borehole penetrates the Ordovician (120.2 m) and Silurian (229.3 m) sedimentary rocks, and 13.5 m thick loose Quaternary deposits (Fig. 2). The core is housed at Särghaua field station of the Institute of Geology at Tallinn University of Technology (IGTUT). The materials concerning the Silurian part are available in unpublished reports (Tiirmaa & Jürgenson 1979) stored in the Depository of Manuscript Reports of the Geological Survey of Estonia (GSE), Kadaka tee 82, Tallinn. The results of earlier lithological, palaeontological and stable isotope investigations (Jürgenson 1987; Nestor, H. 1990a, 1997; Nestor, V. 1994, 1998, 2005, 2009; Bergström *et al.* 1995; Kiipli & Kallaste 1996, 2002, 2006; Kiipli *et al.* 2001, 2006, 2007, 2008, 2010; Kaljo *et al.* 2003; Kallaste & Kiipli 2006; Munnecke & Männik 2009; Cramer *et al.* 2010; Lehnert *et al.* 2010) are used in this work together with recently obtained data.

Many old field notes and unpublished laboratory data were taken into account in improving the lithology of the Viki core. Of great help were the macrolithological descriptions of Silurian rocks by Erika Jürgenson (worked in the Institute of Geology in 1950–1997) made in 1976. In the years 1976–1983 she measured also the contents of CaO, MgO, CO_2 and insoluble residue (IR), and investigated the mineralogical composition of IR. Heldur Nestor (IGTUT) described the Silurian intervals 169.8–288.6 m and 13.5–90.0 m, respectively, in the years 1982 and 1988. Lembit Põlma's (worked in the Institute of Geology in 1964–1988) field descriptions of the interval 242.8–288.6 m (of the year 1976) were used as supplementary material for the Ordovician part. Anne Põldvere (GSE) re-described the entire Ordovician section in 2008 in collaboration with Peep Männik (IGTUT), using also the schematic drawing of the core section (scale 1:200)

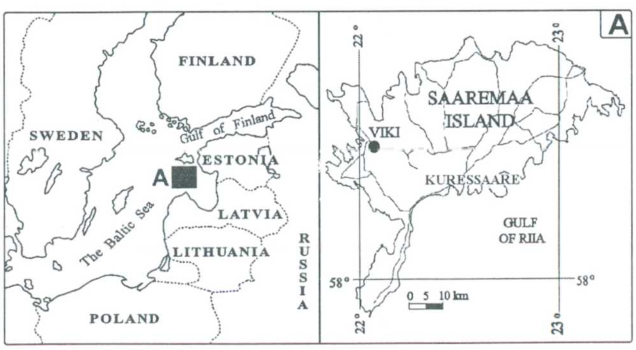


Fig. 1. Location of the Viki drill site.

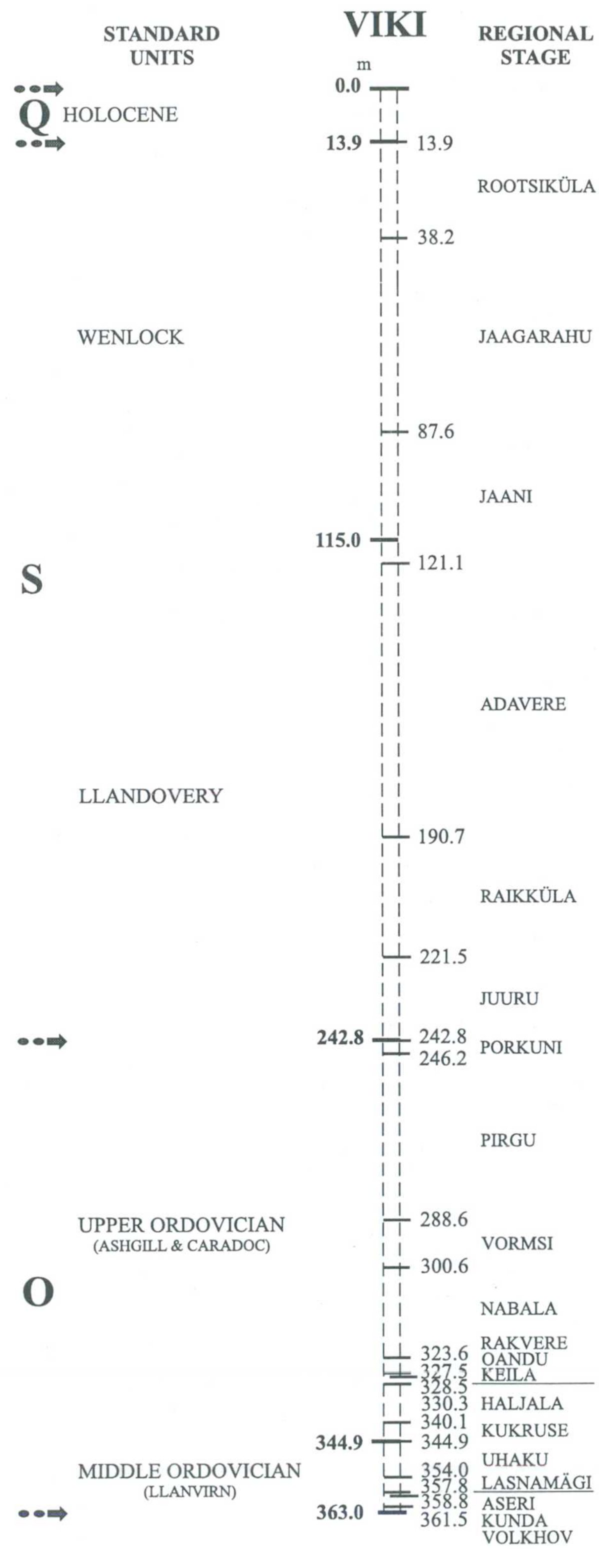


Fig. 2. Generalized stratigraphy of the Viki core. O – Ordovician; S – Silurian; Q – Quaternary.

provided by Rein Einasto (University of Applied Sciences, Tallinn) in the 1980s. Complementary investigations of the Silurian part were conducted in the years 2008–2010, initiated by Peep Männik. For the present issue Anne Põldvere compiled a renewed core description considering besides new field data, also all laboratory data and earlier descriptions. Additionally, she described 45 thin sections collected by Alla Shogenova and Kazbulat Shogenov.

Systematic long-term study of chitinozoans and conodonts enables the most precise stratification and regional and global correlation of Estonian sections (Nestor 1994, 2009; Nõlvak 2002; Nõlvak *et al.* 2006). The stratigraphic subdivision of the Viki section is based on the distribution of chitinozoans and conodonts. Jaak Nõlvak (IGTUT) examined Ordovician (130 samples) and Viiu Nestor (IGTUT) Silurian chitinozoans (232 samples). Ordovician and Silurian conodonts (504 samples) were identified by Peep Männik (IGTUT). The distribution of species was mostly compared with the earlier investigated Ruhnu (500) and Mehikoorma (421) cores (Männik 2003; Männik & Viira 2005; Nestor 2003; Nõlvak 2003, 2005) to identify key assemblages for Estonian regional stages.

Tõnu Meidla and Oive Tinn (both from the Institute of Ecology and Earth Sciences at the University of Tartu, IEESUT) studied Silurian ostracods in 17 samples from the Adavere Stage.

The composition of 26 Ordovician and Silurian volcanic ash beds was investigated by Tarmo Kiipli, Toivo Kallaste and Margus Voolma (all from the IGTUT) on the basis of X-ray fluorescence (XRF) and X-ray diffractometry (XRD) analyses.

Magnetic susceptibility analysis of the Ordovician part of the core in the interval 296.7–363.0 m was made by Jüri Plado and Anna-Liisa Kalberg (876 measurements; both from the IEESUT).

Alla Shogenova, Kazbulat Shogenov, Toivo Kallaste (all from the IGTUT) and Norbert Schleifer (University of Leoben, Austria) provided results of 154 chemical analyses and 106 measurements of physical properties from the Ordovician and Silurian sediments.

Photos of the core were taken by Gennadi Baranov (IGTUT) and Anne Põldvere (selected Silurian intervals). Gennadi Baranov, Heikki Bauert (GEOGuide Baltoscandia) and Elar Põldvere (Alkranel) provided various technical assistance.

Useful comments by Juho Kirs, Jüri Plado (both from the IEESUT), Jaak Nõlvak, Dimitri Kaljo (both from the IGTUT), Kalle Suuroja, Mati Niin and Jaan Kivisilla (all from the GSE) were of great help in finalizing the report.

CORE DESCRIPTION AND TERMINOLOGY

The description of the Viki core is presented in the form of a table (Appendix 1) including the stratigraphical division, review of illustrations and sampling, and main lithological features of the rock. In places comments on core yield and supplementary data are added. The material provided is a summary of macrolithological characteristics and laboratory analyses described in the introduction to the bulletin. The depths and positions of the studied samples are also indicated in drill core photos in the database of the IGTUT (accessible online at http://sarv.gi.ee/search.php?currentTable=drillcore).

The global chronostratigraphic division is based on the International Stratigraphic Chart available on the website of the International Commission on Stratigraphy. For the regional chrono- and lithostratigraphy of the Viki section the Estonian charts were employed, referred to in Põldvere & Nestor in this volume. The Ordovician and Silurian regional stages are tightly tied to Baltoscandian chronostratigraphy as well as to British series (Grahn *et al.* 1996; Kaljo *et al.* 1998; Nestor 2009).

The descriptions of the textures of carbonate rocks are based on the traditional Estonian classification by Vingisaar *et al.* (1965), Loog & Oraspõld (1982) and H. Nestor (1990b). The terms used for textures are explained in Appendix 1. The content of carbonate clasts (including bioclasts) is given in most cases in per cent. For the major part of the core the amount of grains was determined with the magnifying glass on the slabbed surfaces of the core. Thin section data were used only in selected intervals. In case of mixed texture, the word marking the dominant component is given last, while those marking less important components are placed before the basic word. The same principles were followed in descriptive terms for other characteristics of the rock as well. Estonian lime- and dolostones are additionally referred to as slightly argillaceous (insoluble residue 10–15%), medium argillaceous (15–20%) and highly argillaceous (20–25%) (Oraspõld 1975).

The sedimentary structures are presented in the style used in the previous nine issues of the bulletin. The classification of structures is given in Appendix 1 and their variation in the Viki core is illustrated with photos of selected intervals (Appendix 2). Photos of all core boxes are included in the database mentioned above.

GENERAL GEOLOGICAL SETTING AND STRATIGRAPHY

The bedrock succession of the Viki core includes the Ordovician (Middle, Upper) and Silurian (Llandovery, Wenlock) carbonate strata (Fig. 2), overlain by the Quaternary cover. The stratigraphy of the section is based on the correlation charts for the Ordovician by Nõlvak (1997, p. 54, table 7) and for the Silurian by Nestor (1997, p. 90, table 8), and on the generalized log of the Viki section (Nestor, H. 1990a). Systematic data on Ordovician and Silurian conodonts and chitinozoans are used for the biostratigraphical subdivision of the section (see Männik, Nestor and Nõlvak in this volume).

The Viki drill core ends at the level of the lowermost light multicoloured limestones (Fig. 3) corresponding to the Toila Formation (interval 361.5–363.0 m; Appendix 1, sheet 14). The limestones comprise 20–50% bioclasts and up to 30% glauconite grains. Coarse and fine skeletal fragments of crinoids, brachiopods, trilobites, rare ostracods, sponges and molluscs are rounded, deformed, in places oriented in one direction and selectively silicified (Appendix 3, T-44, T-45). Scattered glauconite grains (diameter 0.1–1.0 mm; 10–30% of the rock) are angular, round, elongated and have distinct edges. Numerous discontinuity surfaces occurring in the section are burrowed and mineralized by iron compounds (limonite, goethite).

The content of glauconite increases above the rugged limonitized discontinuity surface at 362.25 m, where limestones comprise darker glauconite grains and are less bioturbated and mineralized. The proportion of crinoids and brachiopods among skeletal grains also rises noticeably above that level (Appendix 3, T-44, T-45). Such lithological differences may indicate the boundary of the Päite and Saka members, corresponding to the boundaries of the Billingen and Volkhov stages, and the Lower and Middle Ordovician series (Appendix 1, sheet 14) in Estonian sections (Nõlvak 1997; Nõlvak *et al.* 2006). Yet, without reliable palaentological data these chronostratigraphical boundaries are only tentative in the Viki core.

The **Middle Ordovician** (interval 344.9–363.0 m or 344.90–362.25? m; Appendix 1, sheets 13, 14; Appendix 2, D-71; Appendix 3, T-40…44) is represented by limestones of the Toila (supposedly only the upper part), Loobu, Kandle, Väo and Kõrgekallas formations, corresponding to the Volkhov, Kunda, Aseri, Lasnamägi and Uhaku stages.

Light grey glauconite-containing limestones of the Toila Formation are overlain by limestones of the Loobu Formation (interval 358.8–361.5 m; Appendix 1, sheet 14). They contain marlstone films and numerous weak phosphatized discontinuity surfaces. Skeletal fragments of mainly trilobites, crinoids, brachiopods and cephalopods form 10–50% of the rock. Rounded and crushed fragments are in places densely packed, surrounded by sparry calcite, pyritized and rarely silicified. Elongated fragments are in some layers of similar orientation. Crinoids have goethite-limonite coatings (mostly without visible texture) or are just strongly impregnated by iron compounds. These iron oolith-like grains 0.08–0.7 mm across, making 5–10% of the rock, are usually rounded (Appendix 3, T-42). Bioturbation and solution features are observed. Open vugs (0.1–4.0 mm across) with clay mineral-rich edges form locally 10% of the rock.

The lowermost 20 cm of the Loobu Formation (361.3–361.5 m) differ from the rest of the section. Limestone with violet spots in that part shows markedly higher contents of MgO and insoluble residue (respectively 1.19% and 14.36%; see Shogenova *et al.* in this volume). Mainly coarse, rounded and rarely micritized skeletal fragments of brachiopods, molluscs and crinoids form only 1–2% of the rock (Appendix 3, T-43). About 20% (in patches 40%) of the rock consists of iron ooliths with concentric lamination, 0.1–0.5 mm in diameter. Ooliths are ellipsoidal and spheroidal, rarely crushed and lie irregularly (affected by bioturbation?) side by side on the flat and sharp-pointed side. They may be broken and overgrown, but also composite, with several nuclei. Rounded or angular, often fractured about 0.2 mm nuclei consist of glauconite and micrite. Open, often irregular vugs 0.03–0.3 mm across are found particularly near ooliths and within coarser crystals, in patches forming up to 10% of the rock. Branching 0.06–1.15 mm wide clay mineral-rich seams are in places displaced by 0.4 mm and pass into 0.5 mm wide veins, which are unevenly filled with erosional carbonate crystal silt. Burrows about 1.0–2.0 mm across have different directions and are filled with very finely crystalline to microcrystalline calcite. The limestone contains scattered oval and round, often fractured 0.08–2.3 mm glauconite grains and rare feldspar grains which are about 1.0 mm across, rounded and with fractured surface. This stained 20 cm thick layer between rugged and inclined iron mineralized hardgrounds on the boundary of the Toila and Loobu formations corresponds probably to the Sillaoru Formation and points to major breaks in sedimentation.

The lower and upper boundaries of the Kandle Formation of the Aseri Stage (interval 357.8–358.8 m; Appendix 1, sheet 14) are marked in the Viki core respectively as the appearance and disapperance lev-

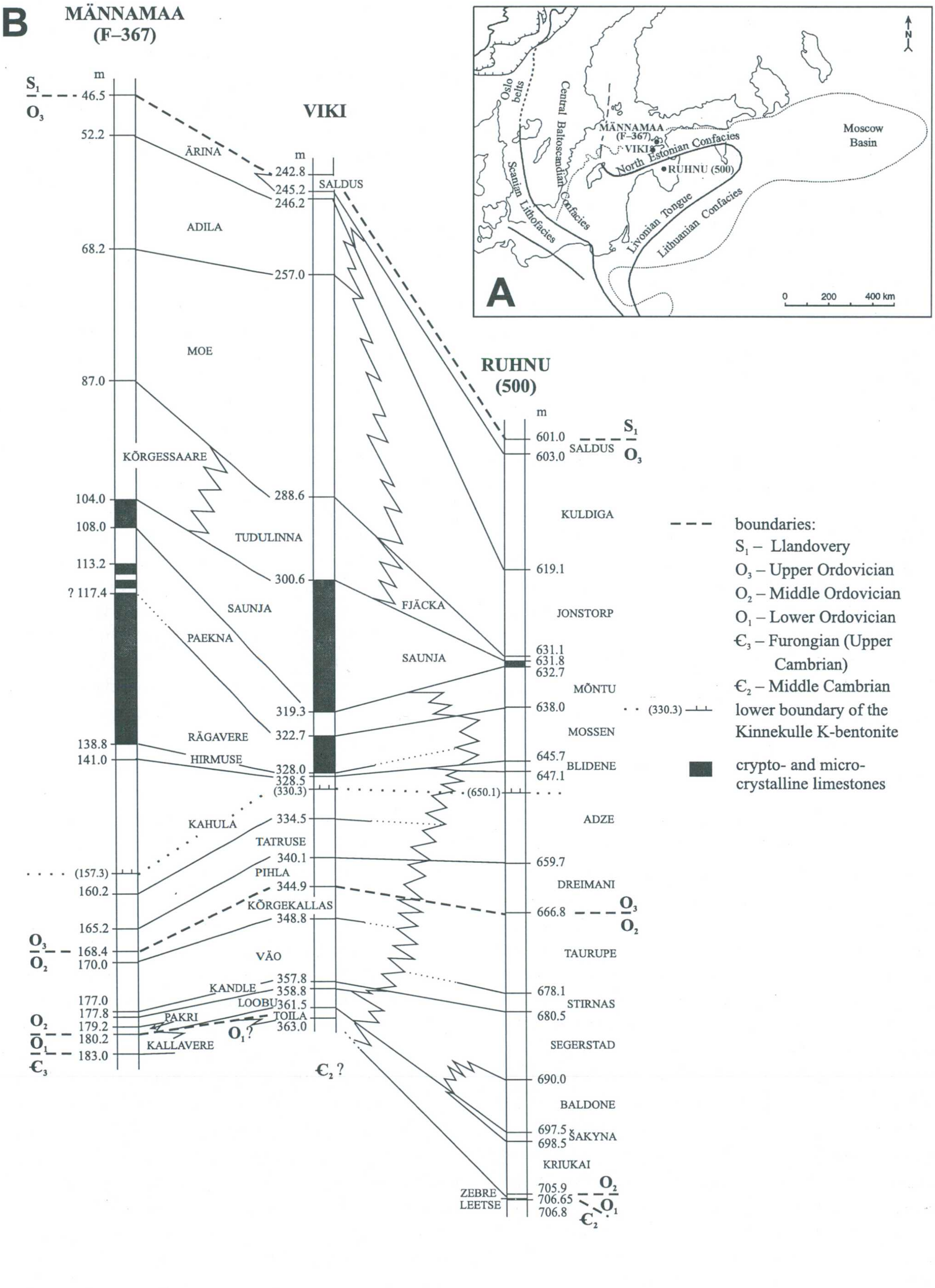


Fig. 3. (A) Baltic Ordovician confacies belts (after Jaanusson 1995, modified from Nõlvak 1997). (B) Correlation of Ordovician formations in the Männamaa (F–367) (Suuroja et al. 2008), Viki and Ruhnu (500) (Põldvere et al. 2003) core sections.

els of iron ooliths. Light grey limestone in that level contains 10–50% unevenly distributed bioclasts and about 5–25% oolith-like grains. Coarse and fine skeletal fragments of crinoids, brachiopods, rarely trilobites, ostracods and bryozoans are rounded, crushed, not oriented and selectively silicified (Appendix 3, T-41). Circular swirls and up to 1.7 mm wide twisted structures of fine fragments point to bioturbation. Indistinct burrows 0.5–1.0 mm across comprise coarser crystals in their central parts. Pure skeletal fragments are mixed with 0.1–1.0 mm rounded and angular iron-pigmented crinoid fragments which are surrounded by goethite-limonite coatings, mainly without visible texture. Diagenetic red and yellow, patchy impregnation of iron compounds and disjointed solution seams with accumulations of insoluble residue are observed (Appendix 2, D-71).

Light grey limestones of the Väo Formation (interval 348.8–357.8 m; Appendix 1, sheet 13) contain numerous weak phosphatized discontinuity surfaces and rare calcareous ooliths in the uppermost part. Stylolite seams are concentrated in irregular layers. Usually rounded, not oriented skeletal fragments of cephalopods (about 4 cm) and bryozoans form mainly 10–25% of the rock and are often recrystallized and rarely replaced by pyrite.

The boundary of the Lasnamägi and Uhaku stages within the Väo Formation in the Viki core (see Appendix 1, sheet 13) is confirmed by chitinozoan data (see Nõlvak in this volume) and is also marked by a fall in apparent magnetic susceptibility values (see Plado & Kalberg in this volume). In contrast to the Uhaku Stage, the underlying limestones of the Lasnamägi Stage are very rich in cephalopod fragments.

A complex of phosphatized discontinuity surfaces on the upper boundary of the Väo Formation is overlain by light grey limestones of the Kõrgekallas Formation (interval 344.9–348.8 m; Appendix 1, sheet 13), intercalated by dark grey marlstone films and stylolite seams. Rounded skeletal fragments of crinoids, brachiopods, rare ostracods, trilobites and bryozoans form 10–50% of the rock (Appendix 3, T-40). They are in places oriented subparallel to bedding, pyritized, silicified and micritized.

The Kõrgekallas Formation is separated from the rather monotonous Viki core section by erosional lower and upper boundaries. The formation is hard to recognize in western Estonian sections because of uniform low clay content in limestones and low percentage of marlstone interbeds (see Hints 1997), but also due to changes in its thickness (Fig. 3).

The Viki core represents the northwestern marginal area of the North Estonian Confacies Belt (Fig. 3). The Lower? and Middle Ordovician carbonate section shows many breaks in sedimentation. Carbonates have accumulated in separate parts, which have developed through erosion on a loose or lithified substrate during the regional transgressive-regressive events of shallow sea. The morphology and mineralization of discontinuity surfaces and fossil fragments (mainly crinoids, trilobites and brachiopods) indicate sedimentation on the shallow shelf to deeper open-marine environment where the input of clay and quartz grains was very low. The glauconite-containing part of the section points to a slow sedimentation rate in the Volkhov Age. Intervals with iron ooliths and iron impregnated grains were probably formed in shallow warm-water setting with high salinity and low water energy (Flügel 2010). Significant changes in water energy are expressed mainly by different positions of skeletal fragments and clasts because the roundness of grains in limestones is very similar. Reliable clear orientation of grains is more characteristic of sediments of the Volkhov and Kunda ages. The usual bioturbation in limestones also complicates the study of sedimentation conditions. Features of diagenetic bedding (solution and stylolite seams) are very frequent. Diagenetic processes, such as staining iron mineralization at 361.3–361.5 m, displaced seams and findings of erosional carbonate crystal silt (Appendix 3, T-43) may indicate nearshore-marine or terrestrial environments at the beginning of the Kunda Age.

The **Upper Ordovician** (interval 242.8–344.9 m; Appendix 1, sheets 9–13) limestone belongs to the Pihla, Tatruse, Kahula, Hirmuse, Rägavere, Paekna, Saunja, Tudulinna, Moe, Adila, Ärina and Saldus formations, corresponding to the Kukruse, Haljala, Keila, Oandu, Rakvere, Nabala, Vormsi, Pirgu and Porkuni stages.

The lower part of the Pihla Formation (interval 340.1–344.9 m; Appendix 1, sheet 13) is cut by a complex of weak phosphatized discontinuity surfaces. Bioturbated and pyrite-mottled limestones of the formation contain pyritized skeletal fragments on average 10–30% of the rock, often oriented parallel to bedding. Some layers are rich in marlstone films (solution seams) and stylolite surfaces.

The pyritized and phosphatized smooth hardground on the upper boundary of the Pihla Formation at 340.1 m is known as a hiatus marker in northeastern sections of Estonia (Suuroja *et al.* 1991, 1993). In places distinct borings within the hardground have been filled repeatedly (Appendix 2, D-70) and contain also kerogen particles. The upper part of the Pihla Formation is missing in the Viki core (see also Nõlvak in this volume). The Pihla Formation is overlain by limestones of the Tatruse Formation rich in marlstone seams.

Light grey limestones of the Tatruse Formation (interval 334.5–340.1 m; Appendix 1, sheet 13) contain microbedded intervals with marlstone films. Coarse and fine skeletal fragments (10–50% of the rock) of crinoids, trilobites, brachiopods, bryozoans and ostracods are usually crushed, rounded and pyritized. In places silicified and strongly recrystallized fragments are found.

The limestones of the Kahula Formation (Appendix 1, sheet 13) are intercalated by eleven 2–50 cm thick K-bentonite beds. K-bentonite, which is widespread in Estonian sections at the lower boundary of the Keila Stage, lies at 329.8–330.3 m in the Viki core (see Kiipli *et al.* in this volume).

The main part of the Kahula Formation (interval 328.5–334.5 m; Appendix 1, sheets 12, 13) is represented by intercalation of variously argillaceous limestones with rare calcitic marlstone films and interbeds. Skeletal fragments of crinoids, trilobites, brachiopods, bryozoans and ostracods form 10–40% of the rock. They are rounded and pyritized, less often silicified and recrystallized. Bright orange to red skeletal fragments impregnated probably by titanium- or/and iron compounds are found near the K-bentonite beds (Appendix 2, D-68, D-69). Unevenly distributed burrows are mainly horizontal and rare rugged discontinuity surfaces are impregnated with pyrite (Appendix 2, D-67). In comparison with the Männamaa (F-367) section in Hiiumaa Island, the thickness of the Kahula Formation decreases significantly in the Viki core (Fig. 3).

A specific surface, known over a wide area in northern Estonia, is observed on the lower boundary of the Hirmuse Formation in the Viki core. It is represented by an uneven pyritized discontinuity surface at 328.5 m (depth of impregnation 15 cm) cut by erosional gullies (visible depth up to 2 cm), filled with variously argillaceous limestone (Appendix 2, D-66). The overlying Hirmuse Formation (interval 328.0–328.5 m; Appendix 1, sheet 12) is represented by indistinctly bedded variously argillaceous limestone with indistinct interlayers of calcitic marlstone. The fossil fragments (locally up to 30%) are rounded and burrows are usually horizontal.

The discontinuity surface on the lower boundary of the Rägavere Formation (depth 328.0 m; Appendix 2, D-65) has specific pyrite mineralization with sharp outlines, disjointed pyrite crust (thickness about 1 mm) and eroded gullies, characteristic of northwestern sections (Suuroja *et al.* 2008).

The lower part of the Rägavere Formation (interval 322.7–328.0 m; Appendix 1, sheet 12) belongs to the Oandu Stage. Light greenish-grey limestones (bioclasts in places < 30%; crinoids, bryozoans, trilobites) of the Tõrremägi Member (interval 327.5–328.0 m; Appendix 1, sheet 12) are bioturbated, intercalated by rare marlstone interbeds and cut by pyritized discontinuity surfaces within the member (Appendix 2, D-64) and on the upper boundary.

The main part of the Rägavere Formation, separated by pyritized discontinuity surfaces (Appendix 2, D-63), belongs to the Rakvere Stage (interval 322.7–327.5 m; Appendix 1, sheet 12). It is represented by light beigish-grey, very finely crystalline to cryptocrystalline limestones (bioclasts 10–40%) with argillaceous limestone and marlstone films containing calcite-filled veins. Coarse and fine skeletal fragments (Appendix 3, T-38) of algae, brachiopods, trilobites, crinoids, bryozoans and ostracods are rounded, not oriented, in places silicified and strongly recrystallized (particularly algae). The thickness and lithology of the Rägavere Formation in the Viki core point to periods of non-deposition above the upper boundaries of the Tõrremägi Member and Rägavere Formation. Supposedly the main part of the Rägavere Formation in the Viki core correlates to the lower part of the Tudu Member of the Rägavere Formation in the Männamaa (F-367) core (see Fig. 3 and Suuroja *et al.* 2008). The uppermost part of the Rägavere Formation in the Viki core is determined by the distribution of chitinozoans in the Nabala Stage (see Nõlvak in this volume).

The Paekna Formation (interval 319.3–322.7 m; Appendix 1, sheet 12) is represented by unusually pure light greenish-grey limestones (bioclasts in places 25%) comprising argillaceous limestone and dark greenish-grey marlstone films. Light beigish-grey micro- and cryptocrystalline interbeds with sharp borders occur in the lower part of the formation. Burrows within limestone and rare marlstone interbeds are mainly horizontal and surrounded by pyrite mineralization. The uppermost part of the formation contains fine glauconite grains, stylolite-like seams and uneven pyritized discontinuity surfaces (Appendix 2, D-61, D-62). According to lithological data, the Paekna Formation in the Viki core is believed to correlate with the lower part of the Paekna Formation in the Männamaa (F-367) core in Hiiumaa Island (see Fig. 3 and Suuroja *et al.* 2008). This implies that gaps in sedimentation occur on the lower and upper boundaries of the formation in the Viki core.

Two complexes are distinguished in the limestones of the overlying Saunja Formation (interval 300.6–319.3 m; Appendix 1, sheets 11, 12). The lower complex (interval 308.3–319.3 m) is represented by unusually coloured and bedded rock. Whitish-grey limestone (bioclasts 1–10%; in the middle part dolomitized) contain horizontal or inclined argillaceous limestone and rare marlstone films and interbeds. In places beds differ only in crystal size. Intercalation of thick- to microbedded and even conglomeratic intervals are common (Appendix 2, D-60). Coarse and fine skeletal fragments of crinoids (oriented subparallel to bedding), trilobites and shells are rounded, in places replaced by pyrite and recrystallized (Appendix 3, T-37). Burrows are mainly horizontal and in places slightly bituminous. Fractures (width up to 0.06 mm) are usually oriented across bedding. Branching clay mineral-rich seams (width up to 0.3 mm, rarely 0.6 mm) form in places up to 1 mm thick bunches.

The upper complex of the Saunja Formation (interval 300.6–308.3 m) is represented by light beigish-grey, pyrite mottled crypto- and microcrystalline limestones containing 1–2% bioclasts (crinoids, trilobites, ostracods) and rare argillaceous limestone and marlstone patches, films and interbeds (Appendix 3, T-35). The structure of limestone is often breccial (Appendix 2, D-58, D-59). The breccia-veins (Appendix 3, T-34, T-36) contain subangular and angular clasts (0.1–10.0 mm across) lined with uneven crystals (like drusy mosaic). The up to 10 mm wide interclast breccia-veins are filled with sparry calcite, angular clasts and erosional carbonate crystal silt. Sparry calcite in veins shows differently oriented twin lamellae and undulatory extinction. A sharp eroded hardground separating formations and stages lies on the upper boundary of the complex at 300.6 m (Appendix 2, D-57).

The Tudulinna Formation (interval 288.6–300.6 m; Appendix 1, sheet 11) is represented by marlstones with variously argillaceous limestone nodules and interbeds. Dark greenish-grey (locally with violet spots) marlstone forms 10–80% of the section. Highly argillaceous marlstone layers at 298.0–299.4 comprise silt-sized quartz, brachiopod shells and limonitized burrows. Burrows are mostly horizontal, in marlstone layers often with iron-containing edges. Contacts between marlstone and argillaceous limestone are usually indistinct. Bioclasts (crinoids, brachiopods, bryozoans) forming mainly 10–25% of the rock, are rounded, crushed and pyritized. Pure limestone prevails at 299.2–300.6 m.

A sharp lithological contact (hardground) at 288.6 m ends the section of the Tudulinna Formation (Appendix 2, D-56). The overlying light beigish-grey limestones of the Moe Formation (interval 257.0–288.6 m; Appendix 1, sheets 10, 11) are rich in calcareous algae *Palaeoporella* (= *Dasyporella*) and *Vermiporella* (Appendix 2, D-54…56). Other important rock builders are crinoids, ostracods and brachiopods (Appendix 3, T-32, T-33). The content of bioclasts reaches locally 50%. Biohermal limestones with irregular stylolite sets, solution surfaces, cavities (calcite druses) and bituminous areas occur at 270.8–276.4 m (Appendix 2, D-52…55; Appendix 3, T-29…31). The bioherm is overlain by indistinctly bedded limestones, where breccia intervals are very common (Appendix 2, D-50, D-51). In places limestone clasts are embedded within greenish-grey plastic clay layers (Appendix 2, D-51). Tightly packed angular, locally cracked limestone clasts have often bituminous edges and are surrounded by solution seams. Pyritized discontinuity surfaces in the Moe Formation point to changes in rock composition, particularly in bioclast content.

The overlying bioturbated limestones of the Adila Formation (interval 246.2–257.0 m; Appendix 1, sheets 9, 10) are in places very similar to limestones of the Moe Formation. The frequency of marlstone interbeds is often the same, but the colour of marlstone changes more green. Rounded and crushed skeletal fragments of algae, crinoids, brachiopods, rugosae, bivalve (10–50% of the rock) are often accumulated in patches and layers (Appendix 3, T-27, T-28). Uneven and disjointed discontinuity surfaces have weak pyrite impregnation and the rock is significantly bioturbated. The uppermost argillaceous limestones (Kabala Member at 246.2–249.3 m; Appendix 1, sheet 9) are bioturbated, locally dolomitized and bituminous (Appendix 2, D-49). Here marlstone and highly argillaceous limestone interbeds make up 45% of the section. This part of the section contains also pyritized surfaces, conglomeratic layers and one K-bentonite bed at 249.3 m.

The hardground at 246.2 m separates variously dolomitized limestones of the Pirgu and Porkuni stages (Appendix 2, D-48). Smooth pyritized, stylolitized and sharp-edged clasts of limestones occur along this hardground surface. Solution seams with accumulations of insoluble residue cross the limestone clasts. Trace fossils under the hardground were formed in a more consolidated substrate than in the overlying section between the limestone clasts.

The Upper Ordovician section ends with the Ärina and Saldus formations of the Porkuni Stage. The thickness and succession of five lithostratigraphic units of the Ärina Formation are variable in Estonia (Hints & Meidla 1997; Hints *et al.* 2000). In the Viki core (interval 245.2–246.2 m; Appendix 1, sheet 9) only the lower, Röa Member of the Ärina Formation is distinguished (see Fig. 3). The member is represented by light greenish-grey argillaceous limestones containing rounded skeletal fragments of crinoids, rugosae, bryozoans, trilobites, brachiopods and algae in places up to 20%. The lower part of the Ärina Formation above the hardground at 246.2 m is intensively bioturbated. The lithologically distinct upper boundary of the formation at 245.2 m is marked by rocks of different colour, structure and texture. A weak pyritized discontinuity surface, covered by subrounded carbonate clasts, crinoid fragments and pyrite aggregates, lies about 10 cm higher. Limestone between these discontinuity surfaces contains rare disjointed marlstone films.

The limestones of the Saldus Formation are represented by the Piltene and Broceni members in the Viki core (interval 242.8–245.2 m; Appendix 1, sheet 9). The stylolite seam at 244.1 m separates these members of different colour (Appendix 2, D-47).

The limestones of the Piltene Member consist of ooliths (10–70% of the rock) in combination with carbonate and bioclasts (both up to 50%). The content of calcareous ooliths increases upwards and they are often cemented by sparite. White, rounded ooliths 0.2–3.0 mm across, with radial crystal structure and concentric lamination, have well-preserved and diverse fabric (Appendix 3, T-26). The dominating shape is spheroidal, but crushed and composite ooliths are observed as well. Nuclei (about 0.5 mm across) are variously rounded and angular crinoid fragments, carbonate clasts (micrite) and rarely unbroken ostracod valves with micrite and pyrite. Often nuclei (darker in colour) form half of the ooliths. The ooliths are more densely packed in the upper part of the member containing also many horizontal stylolites. Inclined bedding occurs only in the lower part of the member. Fine and coarse skeletal fragments of crinoids (5–20% of the rock), bryozoans, gastropods, ostracods, rugosae, brachiopods and rare trilobites between ooliths are rounded, not oriented and locally pyritized. Carbonate clasts, usually 1 mm across, are of irregular shape. Single quartz grains are present.

The Broceni Member of the Saldus Formation is represented by variously dolomitized limestones. Subangular bioclasts (crinoids, brachiopods, rugosae, algae), and carbonate clasts form up to 30% of the rock. The silt- and sand-sized weathered feldspar and rounded quartz grains form in places 50% of the insoluble content (Appendix 4). The lower part of the member contains variously argillaceous calcitic dolostones, in places with strictly parallel thin laminae and convolute bedding (Appendix 2, D-45, D-46). Laminae may contain films of organic matter. Horizontally thin- and microbedded intervals occur in the lower and upper parts (thickness respectively 30 cm and 20 cm) of the Broceni Member, but the middle part is non-typically micro- and thin-bedded, with nodules or lens-shaped particles. Greenish-grey marlstone films are here concentrated in intervals and often form bunches.

The upper boundary of the Broceni Member at 242.8 m is marked by an uneven pyritized discontinuity surface (Appendix 2, D-44). The surface is underlain by a 20 cm thick interval with black (pyritized) up to 1 mm wide branching vertical cracks and vertical burrows, and overlain by a 12 cm thick limestone interval with wavy sandy marlstone films. This is the Ordovician–Silurian boundary in the Viki core.

In general, Late Ordovician light grey carbonate sediments in the Viki core accumulated in shallow marine conditions. The composition, shape and position of skeletal fragments in limestones are rather stable. The main part of fragments belongs to crinoids, trilobites, brachiopods, bryozoans and ostracods. They all are indicators of normal marine environment (see Flügel 2010). The crushed and rounded fragments, usually like free-"floating" grains in cement, refer to continuous moderate water circulation related to wave agitation and tidal currents. Bioturbation also affected significantly the position of bioclasts and primary structures. Different directions of burrows refer to subtidal conditions, while vertical burrows are more common in hardened intertidal areas. Discontinuity surfaces point to breaks in sedimentation: impregnated surfaces occur in shelf environments and sharp lithological contacts indicate extensive erosions at the shoreward position (see Flügel 2010). Lack of encrustations on lithological contacts often refers to long erosion periods.

Significant changes in biota took place at the beginning of Saunja and Moe times. Pure lime muds that deposited in Saunja time (Nabala Age) contain bioclasts, mainly crinoids and trilobites, only 1–2%. Obviously the sea level fell at the beginning of Saunja time and mainly erosional carbonates deposited in the surroundings of the Viki drill site (see Appendix 2, D-59). The following large temperature fluctuations and poor circulation led to decline in biota within the shoal water basin. The lowstand of sea level continued up to the end of Saunja time and marine environment was at least twice replaced by subaerial conditions (Appendix 3, T-34, T-36). The carbonate breccias with drusy mosaics, undulatory extinction of calcite crystals and twin lamellae found in the rock probably suggest palaeokarst horizons reflecting a middle Katian glaciation (Calner *et al.* 2010).

The development of reefs rich in calcareous algae, crinoids and brachiopods began in Moe time (Pirgu Age). Algal reefs probably formed isolated patches segmented by channels (James 1983). Colonies of corals occurred together with sediments rich in crushed and rounded skeletal fragments (30–50% of the rock). Periodic wave approach helped to create brecciated intervals rich in solution seams.

High-energy conditions in the Porkuni Age caused the accumulation of small carbonate sand bars in shallow sea in the surroundings of the Viki drill site. Assembly of encrusted skeletal fragments within ooliths, carbonate and bioclasts (crinoids, bryozoans, gastropods, brachiopods) indicates transition from warm-water to cool-water carbonates (see Flügel 2010). Well-sorted and densely packed oolitic sediments are replaced with fluvial tidal flow in a small isolated basin within intertidal to subtidal environment. The end-Ordovician hiatus resulting from the pre-Silurian drop of the sea level is connected with the Gondwana glaciation (Brenchley *et al.* 2003).

The **Llandovery** (interval 115.0–242.8 m; Appendix 1, sheets 5–9) is represented by limestones, marlstones and claystones of the Varbola, Nurmekund, Rumba and Velise formations corresponding to the Juuru, Raikküla and Adavere stages. The exact boundary of the Llandovery and Wenlock series is determined in the lowermost part of the Jaani Formation and Stage (see Männik in this volume and Nestor in this volume).

The uneven pyritized discontinuity surface on the lower boundary of the Varbola Formation is overlain by locally dolomitized micro- and cryptocrystalline limestones of the Koigi Member (interval 239.7–242.8 m; Appendix 1, sheet 9). Non-typically high content of brownish- to greenish-grey argillaceous limestone and marlstone beds in the Koigi Member points to a transition area between the Mid- and South Estonian confacies belts (Nestor 1997) in the surroundings of the Viki core (Fig. 4). Limestones comprise here silt- and sand-sized feldspar and quartz grains (Appendix 4), which are well rounded in the lower part and angular towards the upper boundary. Usually rocks poor in skeletal fragments (less than 10% of the rock) include rare thin layers where skeletal fragments account for up to 50%. Coarse fragments of rugosae, stromatoporoids and brachiopods are recognized. Some differences are observed also in the composition of chitinozoans and conodonts (see Männik in this volume and Nestor in this volume).

The main part of the Varbola Formation (interval 224.2–239.7 m; Appendix 1, sheet 9) is represented by brownish-grey dolomitized limestones (bioclasts 10–50% of the rock) with greenish-grey calcitic marlstone (20–30% of the section), argillaceous limestone and rare plastic clay interbeds. Coarse, rounded skeletal fragments of brachiopods, trilobites, rugosae and

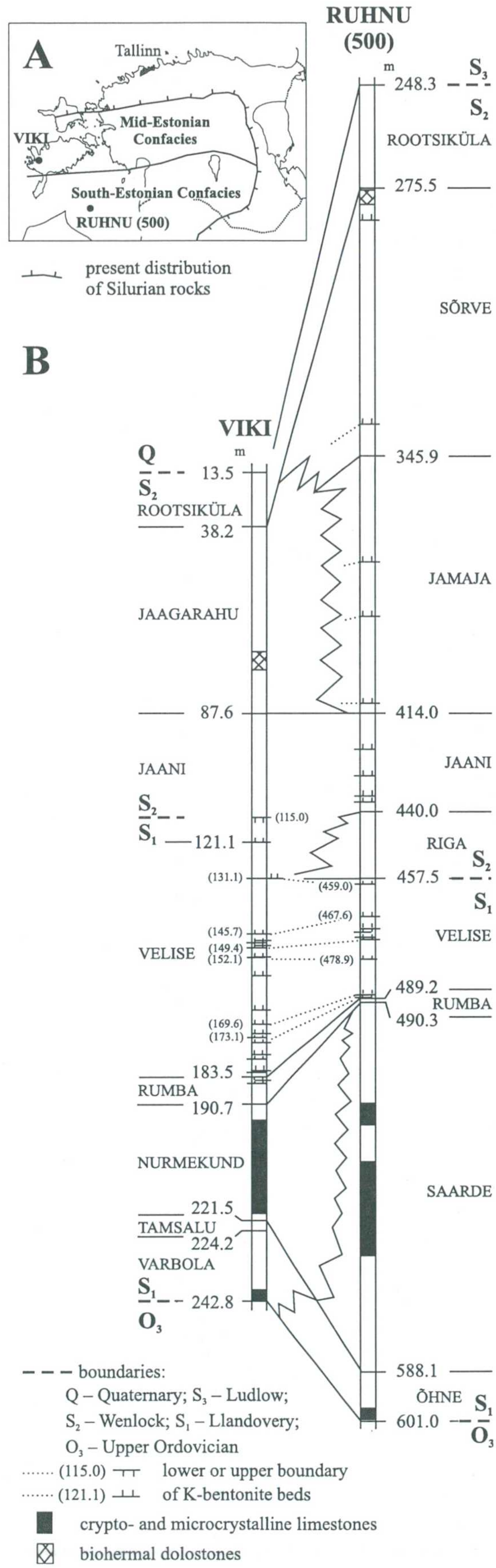


Fig. 4. (A) Baltic Silurian confacies belts on the Estonian territory (modified from Kaljo 1977). (B) Correlation of Silurian formations and K-bentonite beds in the Viki (Kallaste & Kiipli 2006) and Ruhnu (500) (Kiipli & Kallaste 2003) core sections.

corals are found. Intensely bioturbated interlayers rich in coarse to fine bioclasts are common. Admixture of angular to rounded silt- and sand-sized quartz and weathered feldspar grains decreases upwards. Rare glauconite grains occur in the upper part of the section. Pyritized discontinuity surfaces are weak and uneven.

The limestones of the Tamsalu Formation (interval 221.5–224.2 m; Appendix 1, sheet 9) in the uppermost part of the Juuru Stage contain many carbonate- and bioclast-rich (about 50% of the rock) interlayers and weak uneven pyritized discontinuity surfaces. Coarse, rounded fragments of brachiopods (*Stricklandia*), rugosae, tabulate corals and stromatoporoids are common. Fine bioclasts are often pyritized and concentrated in bioturbated intervals of limestone. Glauconite grains are accumulated in patches. A weak discontinuity surface on the upper boundary of the formation separates lithologically different limestones.

The Raikküla Stage is represented in the Viki core only by its lowermost part – the Järva-Jaani Beds of the Nurmekund Formation (interval 190.7–221.5 m; Appendix 1, sheets 7, 8), whereas a long hiatus corresponds to the higher strata of the stage. The Järva-Jaani Beds consist of dolomitized limestones which are brownish- to beigish-grey, often pyrite mottled, bioturbated and very finely crystalline to cryptocrystalline with rare marlstone interbeds (about 5%). Marlstone and argillaceous limestone interbeds are more numerous in the lower- and uppermost parts of the beds. Skeletal fragments of bryozoans, trilobites, brachiopods (*Borealis* and *Stricklandia*), crinoids, graptolites and ostracods form 10–50% of the section (see Appendix 1, sheets 8). Bioclast-rich layers are in places silicified, pyritized and poorly sorted. The content of silt- and sand-sized quartz or weathered feldspar grains is higher (about 5–10%) in the middle part of the Järva-Jaani Beds (Appendix 4) where well-sorted grains are mainly rounded to subrounded. Rare intervals with glauconite grains and bituminous patches are found. Pyritized discontinuity surfaces with weak to strong impregnation are more frequent in the upper part of the beds (Appendix 2, D-43). At the top of the Järva-Jaani Beds (depth 190.7–191.2 m) there occurs a thick monolith bed of dark grey, strongly bioturbated, pyritized and dolomitized limestone with numerous pyritized discontinuity surfaces. On the basis of certain lithological resemblances this bed was formerly (Nestor, H. 1990a, 1997) erroneously attributed to the Rumba Formation of the Adavere Stage, but is here included in the Raikküla Stage due to its microfossil content (see Nestor in this volume). A considerable subregional stratigraphical cap exists between the Raikküla and Adavere stages in the Viki core (Nestor 1997, table 8, fig. 65).

The Rumba Formation (interval 183.5–190.7 m; Appendix 1, sheet 7) of the Adavere Stage consists of variously argillaceous limestones (in the upper part dolomitized), calcitic marlstones (40–60% of the section) and claystones. The content of skeletal fragments (brachiopods and ostracods are recognized) is highly variable, reaching up to 50%. The silt- and sand-sized quartz and feldspar (eroded, in the lower part weathered) grains are more rounded in the lower and middle parts of the formation. Glauconite grains are found only in the upper part. The first Silurian volcanic ash beds in the Viki core are described from the upper part of the Rumba Formation (Appendix 1, sheets 5–7; for details on volcanic ash beds see Kiipli *et al.* in this volume).

The Velise Formation of the Adavere Stage (interval 121.1–183.5 m; Appendix 1, sheets 5–7) consists of greenish-grey marlstones (20–95% of the section), dolomitic claystones and variously argillaceous dolomitized limestones. The lower part of the section is intercalated by reddish-brown layers. The rock is mainly medium-bedded and nodular with rare microlaminated claystone intervals. Skeletal fragments of crinoids, trilobites, brachiopods, bryozoans and ostracods are mostly rounded and form 5–25% of the rock (Appendix 3, T-22, T-23). On bedding planes also fragments of graptolites are found. Burrows are often horizontal, in the upper part more vertical (Appendix 2, D-40...42). The silt- and sand-sized quartz and feldspar grains make about 5% in marl- and claystones (Appendix 4). Subrounded quartz grains are common in the middle and uppermost parts of the formation. Weathered feldspar grains occur mainly in the lower part within a reddish-brown interval. Glauconite grains and pyritized coatings on bedding planes (Appendix 2, D-39) are found in different levels. Twenty volcanic ash beds have been recognized in the Velise Formation (see Kiipli *et al.* in this volume).

The upper boundary of the Velise Formation is lithologically transitional. The carbonate content increases gradually upwards and the formation boundary is therefore defined on the palaeontological boundary of the Adavere and Jaani stages at the level of 121.1 m. The position of the latter and that of the Llandovery and Wenlock series is discussed by Männik in this volume and Nestor in this volume.

The well-preserved Llandovery section of the Viki core was formed in the peripheral part of the Mid-Estonian Confacies Belt (Fig. 4; Kaljo 1977; Nestor 1997).

The carbonate and terrigenous sediments of the Viki area accumulated in the moderately deep-water open marine conditions.

After a considerably long glacio-eustatic sedimentation break at the Ordovician–Silurian boundary, the Silurian sedimentation started with a short episode of lime mud accumulation (micritic limestones of the Koigi Member of the Juuru Stage). It was followed by rapid deepening and intensive input of fine terrigenous material, evoking deposition of mixed terrigenous-carbonate sediments rich in organism remains (intercalating marlstones, argillaceous and biomicritic limestones of the Varbola Formation). Gradually the sedimentation basin shallowed and the proportion of the carbonate component increased, until in the second half of the Juuru Age almost pure bioclastic carbonates of the Tamsalu Formation were accumulated.

During the Raikküla Age cyclic sedimentation of almost pure, barren lime muds and Varbola-type terrigenous-carbonate sediments took place respectively during alternating arid and humid climate periods (Nestor *et al.* 2003). In the Viki core only the lowermost body of lime muds (micritic limestones of the Järva-Jaani Beds) is preserved from the end-Raikküla subregional erosion.

The stratigraphical break at the end of the Raikküla Age, having probably a glacio-eustatic nature (Nestor *et al.* 2003), was followed by a eustatic deepening of the basin followed. It proceeded in two steps (Nestor 1972). During the first, moderate deepening stage mixed terrigenous-carbonate sediments (intercalating marlstones, argillaceous and biomicritic limestones with *Pentamerus oblongus* of the Rumba Formation) were deposited. They contain tempestite interlayers with quartz grains, rounded carbonate- and bioclasts and winnowed accumulations of *Pentamerus oblongus*, which proves the deposition of the Rumba Formation near the storm wave base.

The second, rapid deepening followed at the beginning of Velise time when the influx of clay increased significantly and deposition of marls and clays with a few calcareous nodules and interbeds began. Discontinuity surfaces, typical of shallow-marine environments, are not recognized in Velise sediments. The presence of numerous K-bentonite interlayers in the Velise Formation indicates intensive volcanic activity in neighbouring areas and stable calm water environment to preserve ash beds. The erosional stratigraphic gap, established in several South Estonian sections at the Adavere–Jaani boundary (Nestor & Nestor 2002) is not recognized in the Viki section.

The **Wenlock** (interval 13.5–115.0 m; Appendix 1, sheets 1–5) is represented by limestones, dolostones and marlstones of the Jaani, Jaagarahu and Rootsiküla formations corresponding to the stages of the same names. In comparison with southern Estonian sections, the thickness of the Wenlock strata has decreased significantly (Fig. 4). The boundaries of the stages are discussed in Männik in this volume and Nestor in this volume.

Two members are distinguished in the Jaani Formation (interval 87.6–121.1 m; Appendix 1, sheets 4, 5). The lower, Mustjala Member (interval 99.6–121.1 m; Appendix 1, sheets 4, 5) is represented by greenish-grey marlstones (60–95% of the section) with nodules and interbeds of limestones and dolostones. Skeletal fragments of brachiopods, crinoids, trilobites, bryozoans, stromatoporoids and corals are rounded and not oriented (Appendix 2, D-35…38; Appendix 3, T-21). The general content of bioclasts increases upwards from 10% to 25%; in some interbeds bioclasts form 25–50%. Stromatoporoids "*Pseudolabechia*" *hesslandi* (= *Pachystroma*) and *Clathrodictyon simplex* (= *Petridiostroma*) were identified by Einar Klaamann in 1976 (unpublished data). Fragments of a coral colony underlain by bituminous burrows occur at 112.6–113.0 m. The rocks of the Mustjala Member are commonly intensively bioturbated. The content of insoluble residue decreases and that of silt- and sand-sized grains (mainly quartz and feldspar) increases upwards (Appendix 4). The sub- to well-rounded quartz grains are found in the middle and upper parts of the section. All feldspar grains are eroded. Glauconite grains are found only in the lower part of the member.

The upper, Ninase Member (interval 87.6–99.6 m; Appendix 1, sheet 4) of the Jaani Formation is represented by light grey dolostone with rare marlstone interbeds forming 1–2% of the section. Rounded, strongly recrystallized skeletal fragments (5–50% of the rock) of crinoids, bryozoans, brachiopods, algae and corals, oriented parallel to bedding planes, are found only in the lowermost part of the member (Appendix 2, D-31…34; Appendix 3, T-17…20). In the lower part of the section intensive bioturbation is visible, which is probably destroyed in vuggy dolostones of the upper part. Some layers are rich in calcareous oncoids (Appendix 2, D-31, D-32). The content of silt- and sand-sized grains (mainly quartz and feldspar) decreases upwards to a minimum (Appendix 4). Angular quartz grains are present in the upper part of the section. Feldspar grains are usually eroded and in the upper part weathered. Pyritized discontinuity surfaces are weak and uneven.

The Vilsandi, Maasi and Tagavere beds are distinguished in the light grey dolostones (less often limestones) and coral bioherm of the Jaagarahu Formation (interval 38.2–87.6 m; Appendix 1, sheets 2–4).

The lower, Vilsandi Beds (interval 70.5–87.6 m; Appendix 1, sheets 3, 4) consist of brownish-grey biohermal and bioclast-rich dolostones. Bioclast content, estimated in different layers, formed probably 5–50% of the original rock (Appendix 2, D-28…30). At present original depositional textures are lost and vugs make 10–40% of the dolostones (Appendix 3, T-10…16). However, branching corals obviously built the frame of the bioherm. In the rock the bryozoa-like fossils and intensive bioturbation are recognized. A smooth, pyrite mineralized hardground with a sharp upper contact and cavity occurs on the upper boundary of the Vilsandi Beds (depth 70.50 m; Appendix 2, D-27).

The middle, Maasi Beds (interval 56.4–70.5 m; Appendix 1, sheet 3) consist of light grey dolostone (Appendix 2, D-21…26). The original bioclast content was probably 25–50% of the rock. Skeletal fragments of crinoids, branching bryozoans, tabulate and branching corals, and stromatoporoids are rounded and partly dissolved. Einar Klaamann (unpublished data) identified tabulate corals *Riphaeolites*, *Thecia confluens* Eichwald, *Parastriatopora priva* Klaamann and *Striatopora coenitoides* Klaamann and Heldur Nestor identified stromatoporoids *Ecclimadictyon astrolaxum* Nestor and *Yabeodictyon* sp. nov. from the interval 57.3–60.8 m (Appendix 2, D-21, D-22). The lower part of the Maasi Beds contains also calcareous oncoids and bituminous patches. Dolostones of the beds contain vugs (in places up to 20%), bioturbation and disjointed stylolite-like surfaces of different directions (Appendix 3, T-8, T-9). Discontinuity surfaces, mainly hardgrounds, are concentrated in the lower (phosphatized, pyritized) and middle (pyritized) parts of the Maasi Beds (Appendix 2, D-23…26). They are smooth to uneven, with borings and grooves. The upper boundary of the beds is a pyritized, smooth surface with wide grooves.

The upper, Tagavere Beds of the Jaagarahu Formation (interval 38.2–56.4 m; Appendix 1, sheets 2, 3) consist of light grey pyrite mottled dolostones and variously dolomitized limestones. Crushed, rounded, often recrystallized skeletal fragments form 5–50% of the rock and include crinoids, trilobites, brachiopods, bryozoans, gastropods, corals, stromatoporoids and algae (Appendix 3, T-7). Dolostones are penetrated by vugs (about 10%), fractures and disjointed stylolite-like surfaces (Appendix 3, T-6). Vertical calcite-filled fractures occur in limestones at 48.5 m and 48.7 m. Dolomitic marlstone interbeds are locally bituminous. Pyritized hardgrounds (Appendix 2, D-12…20) in the beds are smooth to uneven, often with grooves and intensely bored. The upper boundary of the Tagavere Beds is represented by two pyrite mineralized hardgrounds.

The limestones and dolostones of the Jaagarahu Formation contain insoluble residue generally less than 10%. The content of silt- and sand-sized grains (mainly quartz and feldspar) in insoluble residue changes from 0.4% to 32.6%, whereas the minimum values are measured mainly in the middle parts of all three beds (Appendix 4). The percentage of quartz grains in the formation decreases upwards, but angular to subrounded grains are more common at the boundaries of the beds. Feldspar grains in the section are usually eroded and weathered.

A long stratigraphical break exists between the Jaagarahu and Rootsiküla stages in carbonate sections (Nestor & Nestor 1991), including the Viki core. Light grey dolostones (less often limestones) and striped argillaceous eurypterid-dolostones of the Rootsiküla Stage are distinguished in the Rootsiküla Formation (interval 13.5–38.2 m; Appendix 1, sheets 1, 2), divided into four subunits: the Viita, Kuusnõmme, Vesiku and Soeginina beds.

The lowermost, Viita Beds (interval 26.0–38.2 m; Appendix 1, sheet 2) consist of light grey, often pyrite mottled dolostones with fine-laminated eurypterid-dolostone interbed (interval 29.0–30.5 m; Appendix 2, D-9…11; Appendix 3, T-3…5). In places horizontal to inclined microlaminated and intensely bioturbated layers occur and bioclasts are mixed with carbonate clasts. Skeletal fragments are recrystallized and dissolved. Supposedly they formed originally 5–50% of the rock. At present original depositional textures and structures are destroyed, and vugs make up to 20% of the dolostones (Appendix 3, T-4, T-5). Sparse surfaces are intensely bored and enriched mainly with pyrite (Appendix 2, D-9, D-11).

The next, Kuusnõmme Beds (interval 22.3–26.0 m; Appendix 1, sheet 1) are represented by light grey variously dolomitized limestones, dolostones and dolomitic marlstones. The marlstones form up to 20% in the uppermost part of the section. Skeletal fragments originally probably amounted to 25% of the rock (Appendix 2, D-8). Microlaminated and intensely bioturbated intervals are common. The upper part of the beds contains some indistinct uneven pyrite impregnated discontinuity surfaces with grooves.

The Vesiku Beds (interval 14.5–22.3 m; Appendix 1, sheet 1) are represented by light grey, bioturbated and micro- to thin-bedded dolostones. Skeletal fragments of gastropods, pelecypods, ostracods and stromatoporoids make in some layers up to 25% of the rock (Appendix 3, T-2). The lower part of the beds includes inclined to horizontally microlaminated dolomitic marlstone interlayers (up to 20% of the section) with dolostone clasts and interbeds (Appendix 2, D-7), which are overlain by dolomitic limestone, rich in irregular oncoids (Appendix 2, D-5, D-6). Nuclei of centimetre-sized oncoids consist of pelecypod fragments. The upper boundary of the Vesiku Beds is marked by a sharp and smooth surface (Appendix 2, D-4).

Only the lowermost part of the Soeginina Beds (interval 13.5–14.5 m; Appendix 1, sheet 1) is represented in the Viki core. Light grey, bioturbated and variously argillaceous dolostones contain carbonate and bioclasts in places up to 40% (Appendix 2, D-1…4). Fragments of gastropods are recognized. Skeletal fragments are often recrystallized or leached out and irregular vugs form in places 25% of the rock (Appendix 3, T-1). Discontinuity surfaces are uneven and weakly pyrite impregnated.

The dolostones of the Rootsiküla Formation contain about 5% silt- and sand-sized grains (mainly quartz and feldspar; Appendix 4). The content of sub- to well-rounded quartz grains decreases upwards. Feldspar grains are weathered and eroded.

The transition from Llandovery to Wenlock in the surroundings of the Viki drilling site took place in a comparatively deep-water environment. Limited bioturbation and bituminous patches in sediments refer to the oxygen minimum zone in bottom waters of the epicontinental sea (Einsele 2000). Only storm waves enriched monotonous deposition in quiet water at the beginning of the Ireviken Event (see Männik in this volume).

The Jaani Age came to an end in the conditions of the shallowing of the basin and higher carbonate production (Ninase time). The diversity of biota increased and tidal currents created conditions for the formation of oncoids. The proportion of silt- to sand-sized quartz and feldspar grains decreased upwards to a minimum.

During the Jaagarahu Age the gradual shallowing of the basin continued, interrupted by short deepening episodes (Nestor & Einasto 1997). This resulted in a cyclic alternation of normal-marine bioclastic or biohermal carbonates (often overprinted with secondary dolomitization), common in the lower part of the sedimentary cycles, with primary dolomitic sediments (barren massive, laminated or bioturbated dolostones) formed in littoral-lagoonal conditions and prevailing in the upper part of the cycles. Three of such shallowing-up sedimentary cycles have been recognized in the Jaagarahu Formation, treated in ascending order as the Vilsandi, Maasi and Tagavere beds. As the Viki section is situated at the peripheral, more deeper-water margin of the Jaagarahu Formation, the upper, littoral-lagoonal part of the cycles is relatively weakly expressed, or even completely missing in the Maasi Beds. Vilsandi time was conspicuous for intensive reef building. Different reef and inter-reef sediments formed also in the Viki area. Primary dolostones deposited only at the very end of Vilsandi time (interval 70.5–71.2 m). Sedimentation of the Maasi Beds proceeded in normal-marine, shallow-water conditions near the wave base, where bioclastic carbonates, rich in organism remains (corals, stromatoporoids, pelmatozoans, brachiopods) and with numerous discontinuity surfaces, were deposited. Lagoonal primary dolostones are missing at the end of Maasi time and deposition of bioclastic carbonates was replaced by deposition of primary dolomitic sediments only at the end of Tagavere time (interval 38.2–43.6 m).

During late Jaagarahu time a long sedimentation break occurred all over the carbonate platform of the basin margin and a considerable stratigraphical hiatus exists between the Jaagarahu and Rootsiküla formations (Nestor & Nestor 1991), including also in the Viki section, and even subaerial exposure of the area is suggested (Calner 2008).

Cyclic sedimentation of bioclastic carbonates and primary dolostones continued in Rootsiküla time in somewhat shallower-water conditions. Therefore the upper, lagoonal part of the sedimentary cycles is generally better developed than in the Jaagarahu cycles.

The **Quaternary** cover in the Viki core is 13.5 m thick (Appendix 1, sheet 1), but only about 7.3 m of the core is available. The Holocene silty and clayey sands with pebbles deposited during the Ancylus Lake stage.

DISTRIBUTION OF ORDOVICIAN CHITINOZOANS

As many as of 130 samples from the Middle and Upper Ordovician of the Viki core (interval 242.8–363.0 m) were processed and studied for chitinozoans (Appendix 5; Appendix 6, sheets 1, 2). The work was carried out at the Institute of Geology at Tallinn University of Technology (IG TUT) and financially partially supported by the Estonian Science Foundation (grants 7640 and 7674). Fossils are stored at the IGTUT.

The samples were provided by Peep Männik (processed for conodonts, C 08 series partly) and Olle Hints (processed for scolecodonts, OM series). The size of the samples was 0.5–0.8 kg and thickness was usually 15 cm or more. In addition, 16 smaller samples from the uppermost Ordovician (and 28 from the Silurian; for data see Nestor in this volume), 0.3–0.4 kg in size and with the thickness not over 5 cm, were collected by the author. The thickness of samples is important when calculating the fluctuations in chitinozoan diversity in very condensed beds like in the lower part of the Viki core. There the rate of sedimentation was much lower and density of fossils was higher than in the beds of e.g. the Pirgu Stage where the thickness of samples is less important.

All productive samples yielded a rich assemblage of acid-resistant microfossils, including well- to excellently preserved chitinozoans from limestones and poorly preserved chitinozoans from more argillaceous beds of the Oandu and Vormsi stages. Only 8 samples were barren (see Appendix 6, sheets 1, 2): in the Volkhov (possible Billingen), Pirgu (bioherm complex) and Porkuni stages.

In total, 111 chitinozoan taxa were distinguished. Their distribution is given in Appendix 6, where the same taxa as in Nõlvak & Bauert (2006, app. 9) and Nõlvak (2008, app. 6) are shown under open nomenclature and designated with numbers. Those marked with letters are new and will be described elsewhere. Secondary dolomitization, which is an important factor in preservation of organic-walled microfossils and widespread in the sections of North Estonia (see discussion in Nõlvak 2008), was rarely observed in the Viki samples, except in the middle part of the Saunja Formation (interval 309.4–313.4 m). This proves again that in general secondary dolomitization, which occurs in different levels in Estonian sections, and the clay content of the Ordovician carbonate rocks are decreasing westwards. Chitinozoans are poorly preserved only in more argillaceous rocks. Almost all biostratigraphically important chitinozoan zones introduced by Nõlvak & Grahn (1993) and Nõlvak *et al.* (2007) were established in the Viki core (Appendix 6, sheets 1, 2).

The lowermost productive part of the Viki core is represented by the *Conochitina cucumis* Zone (Nõlvak *et al.* 2007, text-fig. 1) and contains stratigraphically important *Desmochitina papilla* (Grahn 1984). The former species is also known from the uppermost part of the Langevoja Substage of the Volkhov Stage (also in the Taga-Roostoja (25A) core; see Nõlvak 1999 and Fig. 5). On this basis these very condensed Volkhov Stage beds can be identified as corresponding to the oldest part of the global Darriwilian Stage. If the identification is correct, this level coincides also with the lower boundary of the Middle Ordovician in the Viki core.

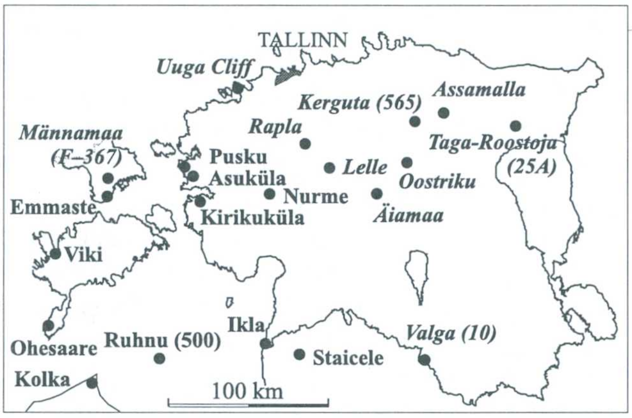


Fig. 5. Sketch map of the area with location of the drill holes and Uuga Cliff mentioned in the texts on Ordovician (in italics) and Silurian chitinozoans.

The next biostratigraphically important zone, the *Cyathochitina regnelli* Zone, could be distinguished in the Viki section only tentatively as no typical specimens (such as *Cyathochitina* aff. *regnelli*) were found in the studies samples. This species needs a revision also in the earlier published Taga-Roostoja (25A) and Kerguta (565) sections (Nõlvak 1999; Nõlvak & Bauert 2006; see Fig. 5), however, typical forms are found in samples not illustrated here. Consequently, the upper boundary of this zone is not conspicuous and additional more detailed sampling is needed. Several new species were found below the well-defined *Cyathochitina sebyensis* Zone from the beds of the Kunda, Aseri and lowermost Lasnamägi stages (interval 356.6–361.1 m). However, as these very condensed beds between lithologically very distinct gaps contain a rich and well-preserved assemblage of chitinozoans, in future a much denser series of samples of smaller thickness should be studied from this part of the Viki core.

Some biostratigraphically important levels can be distinguished higher in the section. First of all, considering the species content and disappearance levels of *Lagenochitina tumida* and *Belonechitina crinita*, the beds between the depths of 354.0 and 357.8 m should be treated as belonging to the older part of the Lasnamägi Stage, i.e. below dolostones of the Pae Member (Väo Formation; Hints 1997) in the North Estonian stratotype area. Secondly, in the Viki core the lithologically poorly recognized and indistinct lower boundary of the Uhaku Stage is formally defined (Männil 1987) by the appearance of *Gymnograptus linnars-soni* (Moberg), although this graptolite was not found here. However, the level of the last abundant occurrence of *Belonechitina pellifera*, determined during in the bed-by-bed study of the Uuga Cliff section by Tammekänd *et al.* (2010, fig. 5), is followed also here at a depth of 354.0 m within the *Conochitina clavaherculi* Zone and reliably defines the base of this stage biostratigraphically. It should be noted that some rare specimens found in the Ruhnu (500) core at depths of 668.7 and 670.7 m (Nõlvak 2003, app. 23) and in the Mehikoorma (421) core at a depth of 334.7 m (Nõlvak 2005, app. 27) are younger, as in the Uuga Cliff section (see also Fig. 5). Thirdly, specimens in the upper part of the *Laufeldochitina striata* range have a brownish cover on the vesicle wall (marked as cf. in Appendix 6, sheet 2) like those from the Männamaa (F-367) section (Nõlvak 2008, p. 14). This would enable distinction of these forms on the basis of this probably secondary feature for biostratigraphical purposes.

The succeeding chitinozoan zones and subzones are relatively distinct, especially the always very short-ranging *Armoricochitina granulifera* and *Lagenochitina dalbyensis* zones, also the *Angochitina multiplex* Subzone just above the Kinnekulle K-bentonite layer (Appendix 6, sheet 2). These are all excellent biostratigraphical markers. The stage boundaries are precisely fixed biostratigraphically and are in accordance with earlier data. In some samples below the Haljala Stage the average content of chitinozoan taxa is higher in the Viki core (e.g. 18 species at 354.1 m, see Appendix 6, sheet 2) than, e.g,. in the Valga (10) (Nõlvak 2001, app. 8) and Männamaa (F-367) (Nõlvak 2008, app. 6) sections due to greater thickness of samples in the Viki core (over 15 cm per sample). As in many North Estonian sections, macroscopically easily recognized, widely distributed good index microfossils, such as phytoplanktic prasinophycean algae *Leiosphaeridia baltica*, were found in all samples from the Haljala and Keila stages.

The base of the Nabala Stage, biostratigraphically fixed by the appearance of *Armoricochitina reticulifera* higher in the Viki core, is about 0.8 m lower than the lithological change at a depth of 322.7 m. This is analogous to the case in the Männamaa section (Nõlvak 2008, p. 17) and special analysis is needed in future.

In general, the chitinozoan distribution is different in the upper Nabala, Vormsi and Pirgu stages (see Appendix 6, sheet 1). The beds contain relatively thick limestones in which chitinozoans are markedly scantier and their diversity is much lower than in the Middle and lower Upper Ordovician.

The low-diversity period with only short innovations during the late Vormsi and late Pirgu ages reveals a step-by-step decreasing diversity trend. Short innovations were probably caused by two transgressive periods. The widely distributed *Acanthochitina barbata* Subzone at the top of the Tudulinna argillaceous limestones and the base of the *Tanuchitina bergstroemi* Zone in the Viki core (see Appendix 6, sheet 1) show that the uppermost part of the Vormsi Stage is probably absent, according to the correlations with Lelle (D-102; Hints *et al.* 2007, fig. 2) and Assamalla (Calner *et al.* 2010, fig. 4) sections. The faunal change is clear near the upper boundary of the Moe Formation, below which many long-ranging species disappear like in the Männamaa (F-367) (Nõlvak 2008, app. 6, sheet 1) and other sections where the Pirgu Stage has been studied (Rapla and Oostriku in central Estonia, unpublished data by the author; see also Fig. 5). However, the subdivision problem arises with beds below the *Conochitina rugata* Zone (see Appendix 6, sheet 1). There is an interval without any zonal taxa like in the Valga (10; Nõlvak 2001, app. 8) and Äiamaa (Hints *et al.* 2005, fig. 4) sections, which was not known earlier (see Nõlvak & Grahn 1993).

The *Tanuchitina anticostiensis* Zone was recorded above the *Conochitina rugata* Zone. Higher in the Viki section, all samples above the level of 246.2 m were totally barren, which means that chitinozoans do not prove biostratigraphically the Porkuni age of sedimentary rocks.

In general, the changes in the chitinozoan succession conform relatively well to most boundaries of regional stratigraphical units, which are often marked by hiatuses, and zonation serves as a good basis for correlations.

DISTRIBUTION OF SILURIAN CHITINOZOANS

Altogether 232 samples from the Llandovery and Wenlock sequence of the Viki core were studied for chitinozoans (Appendix 7; Appendix 8, sheets 1–3). Part of this material has already been published (Nestor 1994, 2005), but many new samples have been collected and investigated by the author and Peep Männik. In addition, Jaak Nõlvak kindly provided for study his chitinozoan samples from the Juuru Stage of the Viki core. The samples were processed and the collection is stored at the Institute of Geology at Tallinn University of Technology.

The East Baltic Lower Silurian chitinozoan biozonation has earlier been discussed by V. Nestor (1990, 1994). These papers give descriptions of 22 biozones, based on the study of chitinozoans from 31 core sections. In order to avoid gaps in the zonal succession, interzones were distinguished, i.e. the intervals, containing only scarce chitinozoans without specific forms.

Later 23 biozones were distinguished in the Ruhnu (500) core (Nestor 2003) and 19 biozones in the Kolka core (Loydell *et al.* 2010; see also Fig. 5). However, only 17 chitinozoan biozones have been established in the Viki core (Appendix 8), because there exist some stratigraphic gaps, e.g. upper parts of the Raikküla and Jaagarahu stages are evidently missing.

The samples contain numerous chitinozoans, except for a few samples from the lower part of the Varbola and Velise formations and most samples from the lower- and uppermost Jaagarahu and Rootsiküla formations. Thirty-five samples were barren of chitinozoans, mostly those from the redbed, biohermal and dolostone intervals.

A total of 79 species were identified, with the most diverse assemblages in clay- and marlstones of the Velise Formation. Owing to the location of the Viki drill core in westernmost Estonia (Fig. 5), the species composition has some specific features in comparison with southern sections (Ohesaare, Ruhnu; see Nestor 1998), more precisely, the absence of *Spinachitina* species in the lowermost Juuru and Raikküla stages and the occurrence of *Cyathochitina kuckersiana* (Eisenack) instead of *Cyathochitina calix* (Eisenack) in the Raikküla Stage.

The lower part of the Varbola Formation in the Viki core is rather well represented by chitinozoans, whereas in some other West Estonian sections (Kirikuküla, Nurme, Emmaste, Pusku; see Fig. 5) this interval is barren or contains only a few specimens of *Ancyrochitina ancyrea* (Eisenack). The Viki core includes *Ancyrochitina laevaensis* Nestor, *Plectochitina nodifera* Nestor and *Belonechitina aspera* Nestor, characteristic of the Puikule and Ruja members in the Õhne Formation of the South Estonian core sections (Ohesaare, Häädemeeste, Ikla, Laeva; see Nestor 1994).

The appearance of *Cyathochitina calix* and *Belonechitina postrobusta* Nestor at 228.20–228.40 m indicates the base of the *postrobusta* Biozone, whereas the disappearance of these species and appearance of abundant *Euconochitina electa* (Nestor) at 223.15–223.30 m indicate the base of the next, *electa* Biozone in the upper part of the Tamsalu Formation. *Ancyrochitina bifurcaspina* Nestor occurs in the Viki core within the long interval of 200.0–220.3 m, which is exceptional for the Raikküla Stage, as in other sections this species is only sparsely represented (Nestor 1994). *Conochitina iklaensis* Nestor and *Cyathochitina campanulaeformis* (Eisenack) are more numerous.

The co-appearance of *Ancyrochitina convexa* Nestor and *Conochitina elongata* Taugourdeau at a depth of 196.4–196.5 m gives evidence of the succeeding *convexa* Biozone. *Conochitina edjelensis* Taugourdeau and *Ancyrochitina ramosaspina* Nestor also occur in this zone. The *Conochitina alargada* Biozone is very thin in the Viki core and is proved only by one sample from 191.3–191.4 m, 10 cm below the boundary of the Raikküla and Adavere stages. The next sample from 190.4–190.5 m belongs already to the *Conochitina malleus* Biozone, containing also a few specimens of *Rhabdochitina* sp. and *Belonechitina* cf. *oeselensis* Nestor. This assemblage may occur in the middle of the Raikküla Stage, but also at the base of the Adavere Stage, as in some sections (Ikla, Staicele) the lower part of the Rumba Formation lacks species characteristic of the Adavere Stage (see Nestor & Nestor 2002; Nestor *et al.* 2003). The extensive gap in the upper part of the Raikküla Stage in the Viki core coincides with the statement by H. Nestor (1997) that the upper beds of the Nurmekund Formation are eroded out and only the lower part of the formation is present on Saaremaa Island.

The appearance of *Ancyrochitina rumbaensis* Nestor, *Conochitina emmastensis* Nestor, *Conochitina praeproboscifera* Nestor and *Eisenackitina dolioliformis* Umnova marks the base of the *dolioliformis* Biozone. This zone coincides with the Rumba Formation and the lower part of the Velise Formation in the interval from 190.4–190.5 m to 169.35–169.45 m. Nineteen species appear in the *dolioliformis* Biozone, but *Eisenackitina causiata* Verniers and *Ancyrochitina porrectaspina* Nestor are stratigraphically more important (besides the named species).

Besides the zonal and transitional species, very few new species are added to the *Angochitina longicollis* Biozone. More abundantly there occur *Angochitina longicollis* Eisenack, *Eisenackitina causiata* and *E. dolioliformis.*

The *proboscifera* Biozone has been distinguished between the depths of 156.5–156.7 and 141.3–141.5 m. Thirteen new species appear within this zone, many of them in large numbers. *Conochitina proboscifera* Eisenack is dominating in almost the entire upper part of the interval, but is missing in some samples from the lower part, and the sample from 155.2–155.4 m is barren. Among others there appear stratigraphically important species *Calpichitina densa* (Eisenack), *Ancyrochitina vikiensis* Nestor, *A. ansarviensis* Laufeld, *Ramochitina ruhnuensis* (Nestor) and *Conochitina visbyensis* Laufeld. In the Viki core *Margachitina banwyensis* Mullins was found already in the *proboscifera* Zone, at 144.4–144.5 m, but it usually appears in the next, *acuminata* Zone. In the Ohesaare core the range of this species forms a separate biozone above the *acuminata* Zone (Nestor 2005) as it was first differentiated in the Banwy River section (Mullins & Loydell 2001).

Apart from the zonal species *Conochitina acuminata* Eisenack (141.2–141.3 m), the first untypical *Conochitina flamma* Laufeld appear in the succeeding biozone. The last specimens of *Conochitina leviscapulae* Mullins & Loydell come from this zone, as well as findings of a very rare species *Anthochitina primula* Nestor (140.10–140.25 m), which was recently identified also in the Kolka core (Loydell *et al.* 2010; see also Fig. 5).

The first *Margachitina* cf. *margaritana* (Eisenack) appear at a depth of 136.05–136.20 m, indicating the *margaritana* Biozone. This zone ranges up to 110.75 m, with the disappearance of *Angochitina longicollis* marking its upper boundary. The occurrence of *Ancyrochitina mullinsi* Nestor, *Calpichitina opaca* Laufeld, *Belonechitina* sp. 1 (sensu Mullins and Loydell), *Ramochitina nestorae* Grahn (134.8–134.9 m), *Ancyrochitina digitata* Nestor (115.10–115.25 m) as well as *Belonechitina* sp. 2 and *Eisenackitina* sp. 1 (sensu Mullins and Loydell) is restricted to this zone. The uppermost part of the *margaritana* Biozone in the Viki core corresponds to the Ireviken Event, where 11 chitinozoan species disappear within the interval 110.75–115.10 m (see Nestor *et al.* 2002).

Considering the occurrence of chitinozoans (appearances and disappearances of species) in the Llandovery–Wenlock boundary stratotype section of Hughley Brook (Mullins & Aldridge 2004), the best level for this boundary in the Viki core is at a depth 115 m. A more detailed analysis of the distribution of chitinozoan species with regard to the Llandovery–Wenlock boundary is available in Nestor (2005).

An interval of about 12 m, conventionally named as Interzone, occurs between the disappearance of *Angochitina longicollis* and appearance of *Conochitina mamilla* Laufeld. It contains abundant *Conochitina proboscifera* and few *Conochitina claviformis* Eisenack. Usually the latter species appears above the Interzone or in its uppermost part, close to the first records of *C. mamilla* (Nestor 1994). The most remarkable event for this Interzone is the disappearance of *C. proboscifera* at 101.35–101.50 m, which dominates in all samples from a depth of 151.50 m (from the middle of the Velise Formation).

The *mamilla* Biozone was established in the Viki core in the interval 90.0–98.0 m, corresponding to the main part of the Ninase Member. It contains a rather poor assemblage of chitinozoans with two barren samples in the dolostone (see Appendix 1, sheet 4).

The boundary with the next, *Conochitina tuba* Biozone is not quite clear as only a few poorly identifiable specimens of this species were found in the Viki core. It should be noted that all chitinozoans are poorly preserved in this part of the section and sparse in dolostones; only *C. claviformis* is more numerous. The upper part of the Vilsandi Beds is represented by biohermal dolostone at 71.2–76.0 m, which is completely barren of chitinozoans. Thus, the position of the upper boundary of the *tuba* Zone in the Viki core remains questionable.

Mainly argillaceous dolostones of the Maasi Beds, except for six totally barren samples, yielded more chitinozoans than the lower beds. At 70.0–70.10 m there appears *Clathrochitina clathrata* Eisenack, a stratigraphically important species of the *Cingulochitina cingulata* Biozone (Nestor 1994). As representatives of *Cingulochitina* were quite sensitive to facies, and did not occur in shallow-water environment (Nestor 1994), they are missing also in the Jaagarahu Formation of the Viki core. At 69.30 m there appears *Conochitina* aff. *pachycephala* (sensu Nestor 1994), co-occurring with the above-named species in the Jaagarahu Stage in some other sections (Ohesaare, Ruhnu; Nestor 1994, 2003).

The middle part of the Tagavere Beds, represented mostly by dolomitized limestones (see Appendix 1, sheet 2), is characterized by the index species of the next biozone, *Eisenackitina spongiosa* Swire, and *Conochitina argillophila* Laufeld.

The dolostones of the upper part of the Tagavere Beds of the Jaagarahu Formation, as well as the most part of the Viita Beds of the Rootsiküla Formation, were barren of chitinozoans. Only one sample at 30.05–30.07 m contained a few species, including *Sphaerochitina lycoperdoides* Laufeld, the index species of the last chitinozoan biozone of the Wenlock sequence (Nestor 2007). Dolostones of the upper part of the Viita Beds, but also of the Kuusnõmme, Vesiku and Soeginina beds of the Rootsiküla Formation, are totally barren of chitinozoans.

DISTRIBUTION OF ORDOVICIAN AND SILURIAN CONODONTS

In total, 504 samples from the interval from the lowermost Haljala (lower Sandbian) to Rootsiküla (Homerian) stages were processed for conodonts (Appendixes 9–11). The size of the samples varied between 170 and 1180 grams, whereas the majority of them weighed about 400–600 grams. Most of the samples yielded conodonts. The number of specimens per sample is highly variable: from a single to few specimens (e.g. in most samples from the Juuru Stage) up to several thousands in the Adavere and lowermost Jaani stages. In the last intervals also the taxonomic diversity of conodont faunas is the highest in the Viki core as well as in the earlier studied sections (e.g. in the Ruhnu (500) core section: Männik 2003).

The samples were collected by different persons during several years, hence the different sets of sample numbers. The Ordovician–Silurian boundary interval and the Telychian part of the section (particularly some intervals of it) were sampled repeatedly by me and/or other persons. For various reasons this necessitated corrections of measured levels/intervals of several samples, therefore the intervals of some samples published earlier (e.g. in Lehnert *et al.* 2010) may differ from those used in this paper. In such cases the sample number is crucial as it allows recognition of the same sample in successions published at different times. All sampled intervals are marked on the core boxes, which enables every investigator to make his/her own measurements. The positions of the studied samples are also indicated in drill core photos (available online at http://sarv.gi.ee/search.php?currentTable=drillcore).

The study of conodonts was supported by the Estonian Science Foundation (grants Nos 7138 and 7640). The collection is stored in the IGTUT.

Upper Ordovician

The lowermost sample studied comes from a level just above the lower boundary of the Haljala Stage, from the *Amorphognathus tvaerensis* Zone (Appendix 10). Due to lack of identifiable specimens of *Baltoniodus* in this sample, its precise age, i.e. subzone, remains problematic. However, the next sample from an interval less than 10 cm higher than the lowermost sample yielded well-preserved specimens of *B. gerdae*, indicating the *B. gerdae* Subzone, the middle of the *A. tvaerensis* Zone for this level. *Baltoniodus gerdae* ranges up to the middle of the Tatruse Formation (lower Haljala Stage) where it is replaced by *B. alobatus*, showing that the *B. gerdae–B. alobatus* Subzone boundary lies in the middle of the Tatruse Formation. This agrees with earlier data from the Mehikoorma (421) core section (Männik & Viira 2005). The upper boundary of the *A. tvaerensis* Zone is marked by the disappearance of *A. tvaerensis*. As in the studied section, also in the Mehikoorma (421) section the boundary lies in the middle of the Haljala Stage, in the lowermost Kahula Formation (Appendix 10; Männik & Viira 2005).

The main part of the Kahula Formation, up to the lower boundary of the overlying Oandu Stage (lower Katian), did not yield any specimens of *Amorphognathus*, indicating that this interval corresponds to the Mid-Caradoc Event sensu Männik (2004). The conodont succession in this interval in the Viki section is identical to that known from elsewhere in Estonia (Viira & Männik 1999; Männik 2003; Männik & Viira 2005). *Baltoniodus alobatus* ranges up into the lower Kahula Formation (upper Haljala Stage) and defines this interval as the "Uppermost *B. alobatus* range" sensu Männik (2007a, and references therein; Appendix 10). Higher in the section, up to the topmost Keila Stage, *Baltoniodus* is represented by rare unidentifiable specimens only. *Amorphognathus* has not been found in the interval corresponding to the "Uppermost *Baltoniodus* range".

Amorphognathus reappears in the lowermost Oandu Stage (Appendix 10). This is the only sample from the Viki section where *A. ventilatus* has been identified. Also in the Ruhnu (500) and Mehikoorma (421) sections *A. ventilatus* appears in the lowermost Oandu Stage, indicating that the lower boundary of the *A. ventilatus* Zone lies close to the lower boundary of the stage in Estonia (Männik 2003; Männik & Viira 2005). In the Ruhnu (500) and Mehikoorma (421) sections, in the upper part of the Oandu Stage, *A. ventilatus* is replaced by *A. superbus*, the nominal taxon of the next conodont zone. In the Viki section the next sample from the Oandu Stage (sample C 08-152: 328.08–328.24 m), and those from the following interval up to the basal Paekna Formation (basal Nabala Stage), did not yield any identifiable specimens of

Amorphognathus (Appendix 10). In this section the next identifiable *Amorphognathus*, *A. superbus*, appears in the lowermost Nabala Stage (in sample C 08-146; 322.30–322.46 m). Considering the data from the Ruhnu (500) and Mehikoorma (421) sections, suggesting that *A. superbus* appears already in the upper Oandu Stage (Männik 2003; Männik & Viira 2005), this level should be well in the *A. superbus* Zone and the poorly preserved unidentifiable specimens of *Amorphognathus* from the Rakvere Stage in the Viki section most probably also belong to *A. superbus*.

Amorphognathus superbus is almost continuously present in the Paekna Formation and disappears in the upper part of the formation (Appendix 10). In the Ruhnu (500) and Mehikoorma (421) core sections *A. superbus* occurs also in the lower part of the stage, in the Mõntu Formation, confirming earlier correlations between the Paekna and Mõntu formations (e.g. Nõlvak 1997, table 7).

The lower Saunja Formation yields specific *Amorphognathus* whose M element is morphologically almost identical to those described by Dzik (1999) from the Mójcza section (Holy Cross Mountains, Poland) and identified as *Amorphognathus* sp. n. Identifications of *Amorphognathus* from the upper Saunja Formation are somewhat problematic but they seem to be closest to *A. ordovicicus* (identified as *A.* cf. *ordovicicus*). Well-preserved *A. ordovicicus* appears in the lowermost Vormsi Stage in the Viki core (Appendix 10). In this paper the lower boundary of the *A. ordovicicus* Zone is tentatively drawn in the middle of the Saunja Formation, below the level of appearance of *A.* cf. *ordovicicus* (Appendix 10). The possible appearance of *A. ordovicicus* already in late Nabala time is indicated also by data from the Mehikoorma (421) core (Männik & Viira 2005).

The interval from the upper Nabala Stage (middle Saunja Formation) to the lower Porkuni Stage (Röa Member, lower Ärina Formation) is considered to correspond to the *A. ordovicicus* Zone, although the uppermost identifiable *A. ordovicicus* in the Viki core comes from the middle part of the Pirgu Stage (from the upper Moe Formation; Appendix 10). Data from the earlier studied sections (Ruhnu (500), Stirnas-18) show that *A. ordovicicus* is almost continuously present up to the lower Porkuni Stage where the diversity of conodont faunas decreases rapidly (Männik 2003; Hints *et al.* 2010). Higher in the conodont succession, an interval characterized by *Noixodontus girardeauensis* has been recognized. In the Viki core *N. girardeauensis* has been found in two samples, in the upper part of the oolithic interval and in the middle part of the overlying argillaceous limestones (Appendix 10). The distribution of intact *N. girardeauensis* in the northern Baltic is limited to the Kuldiga Formation (Männik 2001, 2003; Hints *et al.* 2010). This means that, most probably, also in the Viki core the strata containing *N. girardeauensis* are not younger than the Kuldiga Formation in southern Estonia–western Latvia, and that the upper Porkuni Stage corresponds to a gap in this section. The uppermost Ordovician strata from the level of appearance of *N. girardeauensis* to the Ordovician–Silurian boundary correspond to an informal unit called "*Noixodontus*-fauna" (Nõlvak *et al.* 2006; Appendix 10).

The Ordovician–Silurian boundary in the Viki core section is marked by a distinct discontinuity surface and lithological change (see Põldvere & Nestor in this volume). Conodonts are very rare in the boundary interval. The uppermost sample with surely Ordovician conodonts (several specimens of *Drepanoistodus* cf. *suberectus*) comes from a sample 0.4 m below the boundary (Appendix 10). The oldest representatives of *Ozarkodina*, a genus more characteristic of the Silurian, also appear in that sample. Only long-ranging taxa with simple-cone elements, mainly *Panderodus*, occur just below and above the boundary.

Llandovery and Wenlock

Conodonts are poorly represented in the Juuru and Raikküla stages (Rhuddanian and Aeronian) in the Viki section (Appendix 11, sheet 3). The fauna is dominated by *Panderodus*, mainly by *Panderodus* ex gr. *equicostatus*. Other taxa with simple-cone elements (e.g. *Walliserodus*) are also common in some intervals and/or samples. A few new taxa appear in the Raikküla Stage. *Ozarkodina excavata puskuensis* and Gen. et sp. n. 1 appearing in the lowermost Raikküla Stage are characteristic of this stage, although *O. e. puskuensis* is also known from the upper Juuru Stage (Männik 1992, 1994). The appearance of *Aspelundia*? *expansa* in the upper Raikküla Stage in the Viki section indicates that only the uppermost part of the stage exposed here corresponds to the *A.*? *expansa* Zone. However, earlier data (Männik 2007a, and references therein; Loydell *et al.* 2010) show that, in reality, only the lower Raikküla Stage (or part of it) corresponds to the *A.*? *expansa* Zone in the northern Baltic. The upper part of the stage correlates with the *A.*? *fluegeli* and lower *Distomodus staurognathoides* zones. In the Ruhnu (500) section *A.*? *expansa* also appears in the lower Raikküla Stage, in the Slitere Member (Männik 2003). In this section the lowermost idetifiable specimens of *D. staurognathoides* come from the upper Raikküla Staicele Member. The *A.*? *fluegeli* Zone was not recognized in the Ruhnu (500) core, probably due to too rare and poorly preserved faunas. Both the *A.? fluegeli* and *D. staurognathoides* zones are unidentifiable in the Viki section, evidently due to lack of the corresponding strata (in case of the Raikküla Stage: Nestor, H. 1997; Nestor, V. in this volume) or due to too poorly represented faunas (in the Rumba Formation).

Main part of the Adavere Stage (starting from the uppermost Rumba Formation) and the lower Jaani Stage yield the richest and most abundant conodont faunas known from the Silurian in Estonia as well as elsewhere in the world. Detailed conodont zonation has been worked out for this interval (Jeppsson 1997; Männik 2007b). The Telychian and pre-Ireviken Event Sheinwoodian conodont zonation is mainly based on data from the Viki core, and for many zonal units this section is the reference one (Männik 2007b). Two superzones, six zones and six subzones have been recognized in this interval (Appendix 11, sheets 2, 3).

Analysis of conodont data from the Viki but also from several other core sections and application of geochemical correlations (1) allowed dating the Llandovery–Wenlock boundary (as defined in its type section) in the sense of graptolite zonation and (2) revealed that the boundary between the Adavere and Jaani stages in Estonia does not coincide with the Llandovery–Wenlock boundary (Männik 2007c). The Llandovery–Wenlock boundary, which according to Aldridge *et al.* (1993) corresponds or lies very close to Datum 2 of the Ireviken Event, occurs between samples M-996 (113.50–113.70 m) and M-997 (113.30–113.50 m) and the Adavere–Jaani boundary close to (coincides with?) the bentonite at 121.10 m (Appendix 11, sheet 2). In the sense of conodont biostratigraphy, the stage boundary correlates with a level in the middle of the Upper *Pterospathodus amorphognathoides amorphognathoides* Subzone.

Both the Lower and Upper *Kockelella ranuliformis* zones of the *K. ranuliformis* Superzone are well represented in the Viki section. The *K. ranuliformis* Superzone corresponds to the upper Mustjala and lower Ninase members of the Jaani Stage and is followed by the *Ozarkodina sagitta rhenana* Zone (Appendix 11, sheet 2). *Ozarkodina s. rhenana* appears in sample C 01-92 (96.40–96.50 m), in the lower Ninase Member (upper Jaani Stage) and is continuously present up to a bioherm in the upper part of the Vilsandi Beds (interval 71.20–76.00 m, lower Jaagarahu Stage). From 76.00 m up to its uppermost occurrence in sample 62.65–62.80 m from the middle of the Maasi Beds (Jaagarahu Stage), *O. s. rhenana* has been found in some samples only. The total range of *O. s. rhenana* defines the *O. s. rhenana* Superzone (Jeppsson 1997). In the Viki section, and in Estonia in general, this superzone corresponds to the uppermost Jaani and lower Jaagarahu stages (Appendix 11, sheets 1, 2; Jeppsson *et al.* 1994). The lower part of the *O. s. rhenana* range, up to the level of appearance of *K. walliseri* in the lower Maasi Beds in sample 68.30–68.40 m, corresponds to the *O. s. rhenana* Zone and its upper part to the interval of co-occurrence of *K. walliseri* and *O. s. rhenana*, to the Lower *K. walliseri* Zone sensu Jeppsson (1997).

Conodont biostratigraphy in the upper Jaagarahu Stage is problematic in the Viki section. A single occurrence of *K. walliseri* in sample 54.40–54.60 m in the Tagavere Member (upper Jaagarahu Stage), about 8 m above the uppermost *O. s. rhenana*, indicates that the interval between these two levels (i.e. the upper Maasi Beds and lower Tagavere Member) most probably corresponds to the Upper *K. walliseri* Superzone. The uppermost *K. walliseri* comes from a sample just below a discontinuity surface at 50.9 m, evidently marking a gap. The number of discontinuity surfaces and rapid lithological changes in the upper Jaagarahu Stage indicate that sedimentation was episodic at that time and quite long intervals are probably not represented by sediments. No diagnostic conodonts were found in the interval from the level of occurrence of the uppermost *K. walliseri* in the upper Jaagarahu Stage up to the level of appearance of *O. confluens densidentata* and *O. bohemica longa* about 22 m higher, in the middle of the Viita Beds of the Rootsiküla Stage (Appendix 11, sheet 1). Still, considering that samples from the interval between the sample with the uppermost *K. walliseri* and the discontinuity surface at 43.6 m higher in the section yielded rich conodont faunas but not a single specimen of *Kockelella*, it is quite probable that this interval correlates with the lower *K. ortus ortus* Superzone, with the so-called "post *K. walliseri* interregnum" sensu Jeppsson (1997).

Conodonts are too rare in the samples from the interval between the discontinuity surface at 43.6 m below and the level of appearance of *O. c. densidentata* and *O. b. longa* above to allow the dating of these strata. As the Viki drill hole is located close to the outcrop area of the Jaagarahu Stage, it is possible that great part of the lower Homerian strata, probably those corresponding to the *O. s. sagitta*, *O. b. longa* and *K. o. absidata* zones, are missing in that section (e.g. Jeppsson *et al.* 1994). This seems to fit with conodont data from the Viki core. The problematic interval with poor conodont faunas is followed by rich faunas, characterized by *O. c. densidentata* and *O. b. longa* appearing in sample 30.50–30.70 m in the middle of the Viita Beds (Appendix 11, sheet 1). These two faunas are evidently separated by a gap, marked by a discontinuity surface and sharp lithological change at 31.1 m (see also

Appendix 2, D-11). Co-occurrence of *O. b. longa*, *O. c. densidentata* and *Ctenognathodus murchisoni* is characteristic of the upper Homerian *C. murchisoni* Zone. In the Viki core section, *Ctenognathodus murchisoni* itself appears somewhat higher in the section than *O. c. densidentata*, probably due to ecological reasons.

DISTRIBUTION OF SILURIAN OSTRACODS

A series of 17 ostracod samples was processed from the Viki core. The samples were taken over the interval 122.5–188.6 m, comprising the Adavere Stage, in the upper part of the Llandovery (Fig. 6).

Altogether 44 ostracod species, partly of open nomenclature, were identified in the collection. This new evidence nearly doubles the number of ostracod taxa previously recorded from the Adavere Stage by Sarv (1968, 1970). Silurian ostracods have been studied already for more than a century. About 300 Silurian species have been recorded from Estonia, Latvia, Lithuania, northwestern Russia, Sweden and Norway (for a thorough summary see Sarv 1970; Sarv & Meidla 1997). In spite of the large number of identified species, the documentation of this fauna is still incomplete. Most of the studies have been dealing with the Order Beyrichiocopa. The Order Podocopa, which comprises more than 95% of all specimens in the present collection, has received less attention and is still poorly documented.

The distribution of ostracods in the Adavere Stage of the Viki section is rather uneven (Fig. 6). In fossil-rich intervals the species diversity is comparable to ostracod diversity in the Upper Ordovician (eight to ten species in a sample). Samples from the intervals 135–136 m and 167–178 m, and from a depth of 184.3 m (likely including a part of the bentonite bed?) are barren or nearly barren. Ostracod shells are only moderately preserved; large valves are very often fragmented, especially those of large beyrichiids. Many podocope specimens, both single valves and bivalved carapaces, are strongly deformed, allowing only tentative identification of the species.

The new data are compared below with the distribution pattern of beyrichiaceans and some other key species summarized by Meidla & Sarv (1990, p. 70 and table 11).

The Rumba Formation (four samples from the interval 183.6–188.6 m) is characterized by the occurrence of *Apatobolbina simplicidorsata*, *Pullvillites triangulata*, *Daleiella semibulbosa*?, *Silenis mavii*? and *Microcheilinella tumefacta*. None of these taxa range into the overlying Velise Formation.

The Velise Formation is characterized by several successive ostracod assemblages, separated in the section by low-diversity intervals (Fig. 6). The lowermost part of the formation contains a podocope-rich assemblage, which also includes rare *Leptobolbina hypnodes*. The high-diversity intervals above two nearly barren samples yield very abundant *Daleiella variolaris*, *Tetradella extenuata*, *Longiscella caudalis*, *Nyhamnella musculimonstrans* and *Microcheilinella rozhdestvenskaja*, together with *Leptobolbina hypnodes*. The low-diversity interval (135–136 m, represented by two samples) in the upper part of the formation is characterized by abundant *Longiscella caudalis*, *Nyhamnella musculimonstrans*, *Microcheilinella rozhdestvenskaja* and *Thlipsuroides walensis*, together with *Leptobolbina hypnodes* and *Craspedobolbina* (*Mitrobeyrichia*) *paernuensis*.

The lowermost assemblage recorded in the Viki core represents the uppermost part of the so-called Llandovery ostracod complex (about 40 species according to Meidla & Sarv 1990). However, none of the species recognized in the Viki core belong to the typical "Llandoverian" taxa *sensu* Meidla & Sarv (1990, table 11). The only beyrichioidean species identified in this interval is *Apatobolbina simplicidorsata*, which was earlier thought to appear only in the Velise Formation (Sarv 1970; Meidla & Sarv 1990).

The late Llandovery–Wenlock ostracod complex comprises altogether about 70 species (Meidla & Sarv 1990). Compared to this formerly documented pattern, ostracod distribution in the Viki core is rather uneven. The zonal taxa for this interval (*Longiscella caudalis*, *Thlipsuroides walensis*) are recorded in the Viki section, but *L. caudalis* makes its first appearance only in the middle part of the Velise Formation (at a depth of 154.0 m) and *T. walensis* even higher in the section (at 138.2 m). *Apatochilina simplicidorsata*, which is considered to be characteristic of the upper part of the Adavere Stage only (Sarv 1970), was not recorded in the Velise Formation. The ostracod-based tri-partite subdivision of the Velise Formation, established in the Viki core, has not been mentioned in earlier publications.

The boundary of the Velise and Jaani formations has a transitional character in the Viki section (see Põldvere & Nestor in this volume), but the samples that were available for the present study obviously do not range into the Jaani Stage. It is still noteworthy that the uppermost sample (122.5 m) revealed *Daleiella ianica*, which formerly was found in the Jaani and Jaagarahu stages only (Meidla & Sarv 1990).

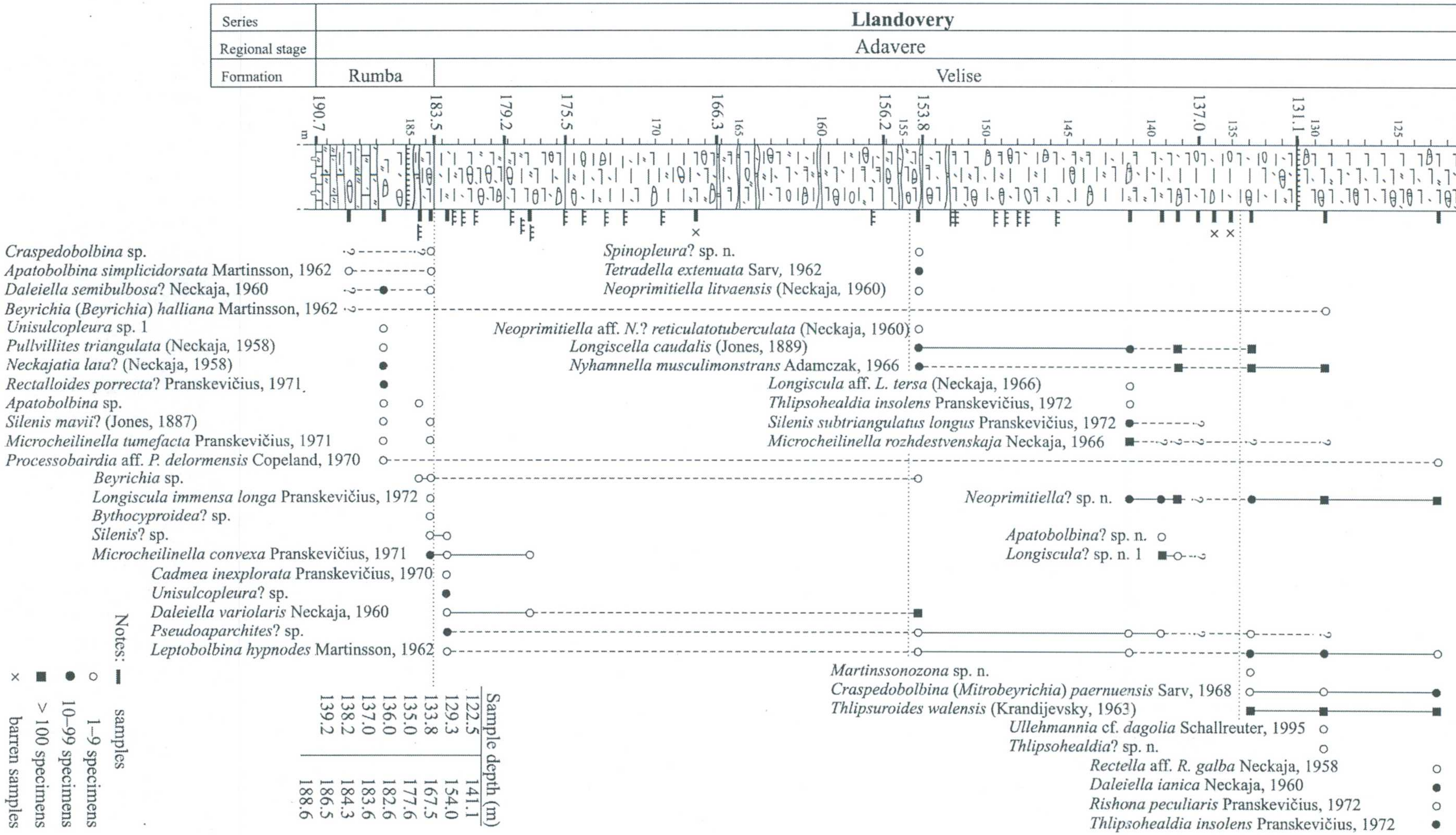


Fig. 6. Ostracods of the Adavere Stage in the Viki core. Refer to Appendix 1 for lithology.

Table 1. Lithology and sanidine properties of the K-bentonite beds in the Viki core, their names, identification numbers (ID) and correlation with biostratigraphy

Sample depth (m)	Bed thickness (cm)	Description	Biotite abundance	Width of the sanidine modal reflection (degrees) and other notes	Content of $(Na,Ca)AlSi_3O_8$ in sanidine (mol%)	"Bentonite name assigned to the bed"	Bentonite ID	Number of sections with the established bed	Chitinozoan biozones	Graptolite biozones	Conodont biozones	Regional stage
115.00	10.0	Grey clayey K-bentonite	+	0.28	35.2	Lusklint	150	10	*M. margaritana*	*"Cyrtograptus murchisoni"*	*P. amorphognathoides*	Jaani
121.05	8.0	Grey K-bentonite	+	0.28	38.5	Ohesaare	210	11				
131.10	2.0	Grey clayey K-bentonite	+	0.12	37.5	Aizpute	311	9				Adavere
145.75	5.0	Yellow, hard, K-feldspar-rich	+	Very wide reflection	–	Kirikuküla	457	15	*C. proboscifera*	*"Cyrtograptus lapworthi or Octavites spiralis"*		
147.50	5.0	Grey clayey K-bentonite	+	0.20	45.6	Viki	475	19			*P. a. lithuanicus*	
148.00	1.5	Grey clayey K-bentonite	++	0.25	42.3	Kaugatuma	480	9				
148.80	0.5	Yellow, hard, K-feldspar-rich	+	Very wide reflection	–	Kuressaare	488	12		*Octavites spiralis*		
149.40	3.0	White K-bentonite	+		–	Ruhnu	494	20				
151.80	?	Yellow, hard, K-feldspar-rich	+	Very wide reflection	–	Viirelaid	518	16?				
152.10	0.5	Yellow, hard, K-feldspar-rich	+	Very wide reflection	–	–	521	11?				
156.80	2.5	Yellow, hard, K-feldspar-rich	+	Very wide reflection	–	–	568	14?	*A. longicollis*		*P. a. angulatus*	
169.60	10.0	Grey K-bentonite	+++	0.04	23.1	Nässumaa	696	16	*E. dolioliformis*	*"Monoclimacis crenulata"*		
171.95	3.0	Red K-bentonite	+++	Quartz, little sanidine	–	Virtsu	719	14			*P. eopennatus ssp. n. 2*	
173.10	10.0	Red K-bentonite	+	0.11	39.8	Nurme	731	18				
174.40	3.0	Violet K-bentonite	++	0.1	25.8	Tehumardi	744	15				
175.55	2.0	Red K-bentonite	+	0.25	26.1	Paatsalu	755	14		**Mcl. griestoniensis*		
177.70	6.0	Grey clay with bentonite	+++	Very wide reflection	–	–	777	6		*Streptograptus sartorius*		
178.20	5.0	Grey clay with bentonite	++	0.22	26.6	–	782	1				
178.80	1.5	Violet K-bentonite	+++	0.17	40.6	–	788	3				
181.00	–	Grey clay with bentonite	+++	0.12-0.14	25.2–25.9	–	810	1		*Streptograptus crispus*		
181.80	0.5	Bluish-grey K-bentonite	+	Very wide reflection	–	–	818	3			*P. eopennatus ssp. n. 1*	
182.30	1.5	Violet K-bentonite	+	0.12	46.6	Valgu	823	6				
184.35	0.5	Grey K-bentonite	+	Very wide reflection	–	–	843	5				
185.10	6.0	Yellow, hard, K-feldspar-rich	+++	0.06	21.2	Osmundsberg	851	22		**Sp. turriculatus*	*D. staurognathoides*	
249.30	–	Grey clay with bentonite	+	0.1–0.2	35.3–36.2	–	bIII*	7				Pirgu
330.30	50.0	Light grey K-bentonite	++	0.065	24.9	Kinnekulle	XXII*	many				Keila

*Note: – not determined; biotite is abundant (+++), more than 10 flakes (++), only a few flakes (+). *Mcl. – Monoclimacis, *Sp. – Spirograptus.*
bIII – bentonite ID number for the uppermost Pirgu bentonite (Hints et al. 2005); XXII* – bentonite ID number, described as "bed XXII" in the Oslo region, Norway, the Big Bentonite in Sweden and "bed d" in the East Baltic (Hagemann & Spjeldnæs 1955; Jürgenson 1958; Männil 1966; Huff et al. 1992; Bergström et al. 1995).*
For biozones see Kiipli et al. (2010).

The stratigraphic range of this species seems to be similar also in Lithuania, where *Microcheilinella ianica* (= *D. ianica*) is known from the Paprieniai Formation (lower Wenlock) according to Pranskevičius (1972, 1975). The only former record of *Thlipsohealdia insolens* comes from the same unit in Lithuania (*ibid.*), whilst the occurrence of this species in the Viki core seems to be its first documentation outside Lithuania.

VOLCANIC ASH BEDS

Silurian volcanic ash beds of the Viki core (Appendix 1, sheets 5–7) have been correlated on the basis of their geochemical composition with Estonian, Latvian, Swedish and Norwegian sections (Kiipli & Kallaste 1996, 2002, 2006; Kiipli *et al.* 2001, 2006, 2007, 2008, 2010; Kallaste & Kiipli 2006). Detailed biostratigraphy in combination with geochemical data gave precise results in many investigated sections. Kallaste and Kiipli (2006) used the Viki section as a reference for establishing the identification numbers (ID) and stratigraphic names of the Silurian volcanic ashes. Restudy of the Viki section revealed three previously unknown clayey interbeds with biotite at depths of 177.7, 178.2 and 181.0 m. Laboratory XRD investigations indicate that all these layers consist mostly of terrigenous minerals quartz, illite and chlorite, but separation of the coarse fraction (40–100 μm) revealed high contents of pyroclastic minerals biotite, sanidine and fragmental quartz. The sample from a depth of 181.0 m contains considerably thick blocky biotite and several quartz crystals having bipyramidal high-temperature beta quartz shape (Fig. 7). Beta quartz forms are the most reliable indicators of volcanic origin. Therefore these newly studied samples represent terrigenous interbeds with significant volcanic admixture. The sample from a depth of 177.7 m exhibits a weak and wide sanidine reflection indicating correlation with the bed (ID 777) previously known from the Paatsalu and Viirelaid cores. The sample from 178.2 m is a new previously unknown eruption layer and we propose ID 782 for that. The sample from 181.0 m largely resembles the Mustjala K-bentonite (Kallaste & Kiipli 2006) containing similar sanidine (25.2 mol% of Na+Ca component) and abundant biotite. We still consider it as a separate eruption bed as it lies 1.5 m deeper than could be expected from graphic correlation with previously known finds of the Mustjala K-bentonite (ID 795) and as it contains beta quartz forms and blocky biotite not known from the Mustjala K-bentonite. We propose ID 810 as a stratigraphic index for this eruption bed. All characterizations of previously known and new volcanic ash layers are given in Table 1 and Appendix 12.

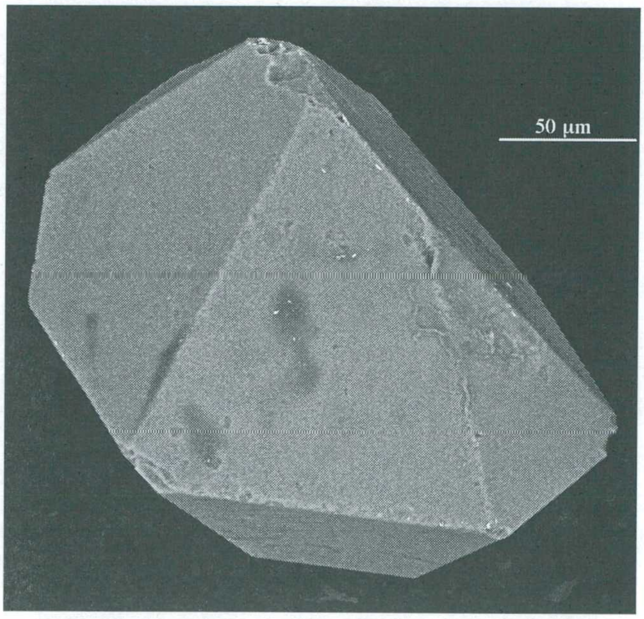


Fig. 7. Quartz phenocryst having bipyramidal high-temperature beta quartz crystal form. Quartz pseudomorphs of high-temperature beta form are the most reliable evidence of volcanic origin. Viki core, terrigenous interbed at 181.0 m with significant volcanic admixture.

A clayey interbed of suspected volcanic origin was studied at a depth of 249.3 m in the Pirgu Stage (Ordovician) of the Viki core (Appendix 1, sheet 9). XRD showed terrigenous minerals quartz, illite and chlorite as its main components, but the coarse fraction contains sufficient pyroclastic minerals enabling determination of sanidine composition. Sanidine composition (see Table 1) indicates correlation with the ash bed at the top of the Pirgu Stage (Pirgu bentonite bIII in Hints *et al.* 2005) in the Põltsamaa H-39 core (located in Central Estonia) at a depth of 116.5 m (Kiipli *et al.* 2004).

Several ash beds occur in the Haljala and Keila stages. Sanidine has been studied only in the Kinnekulle K-bentonite (Table 1). The Kinnekulle K-bentonite bed in the Viki section has great thickness of 0.5 m (interval 329.8–330.3 m; Appendix 1, sheet 12). The limestone bed (3–4 cm thick) below the Kinnekulle K-bentonite is replaced by chert. The occurrence of chert below and its absence above the bentonite indicate a major loss of silica from volcanic ash before the burial of ash under later sediments (Kiipli *et al.* 2007).

MAGNETIC SUSCEPTIBILITY OF ORDOVICIAN ROCKS

Magnetic susceptibility (MS) measurements have become widely used in the correlation of sedimentary rocks that are considered as a proxy for impurities delivered to sedimentary environments. Although the main constituents of sediments are dia- and paramagnetic with near-zero MS, many weathering products coming from the erosion of the mainland are ferromagnetic with higher MS values. As climatic and eustatic sea level variations affect the detrital input (a sea level fall increases the proportion of the exposed continent and possible ferromagnetic supply), higher MS values are attributed to marine regression. However, ferromagnetic minerals in sedimentary rocks can be destroyed or newly created in the course of diagenesis and even later during the post-sedimentation history. Thus, the MS value alone cannot be directly used for correlative purposes but as an additional source of information.

The MS values were measured from the interval 296.7–363.0 m of the Viki core with a portative MS meter SM-30. The instrument contains an oscillator with a 50 mm pickup coil that is enclosed in a box with flat sides. To reduce the oscillator's thermal drift, the interpolation mode of the meter was used by two measurements away (> 50 cm) from the core and one measurement from a side or top of the core. Magnetic susceptibility measurements from the rounded side of the core were correlated against the shape by multiplying the obtained value with the coefficient 1.95 (based on earlier experiments by A.-L. Kalberg). Altogether 876 measurements were made, which gave a mean frequency of 13.4 readings per 1 m of the core (Appendix 13). Susceptibilities were not corrected against mass or volume, therefore, the values should be treated as apparent. As all measurements of the core were conducted in identical conditions, we assume that the values are comparable with each other and reflect general trends.

As is typical of the Ordovician rocks in Estonia (e.g. Plado *et al.* 2010) and of sedimentary rocks in general (Dunlop & Özdemir 1997), the measured MS values are low (generally $< 100 \times 10^{-6}$ SI). Both negative and positive susceptibilities were recorded, hinting at a mixture of diamagnetic rock-forming minerals with para- and/or ferromagnetic constituents (Fig. 8). Nega-tive values prevail within the Saunja, Rägavere and Pihla formations (means are given in Table 2), suggesting an almost pure mixture of diamagnetic minerals, e.g. calcite with minimal detrital input. Stronger positive magnetic susceptibilities characterize rocks of the Tudulinna, Hirmuse, Kahula, Tatruse, Kandle and Toila formations. Higher values reflect a higher content of ferromagnetic and/or paramagnetic clay minerals.

Figure 8 illustrates the results of MS measurements and general trends along the core. The interval from Billingen to Volkhov stages (Toila Formation) has variable but the strongest (compared here to all other measured lithologies) positive magnetic susceptibilities ranging from 33×10^{-6} to 257×10^{-6} SI. By analogy to Plado *et al.* (2010), high values are likely due to early diamagnetic magnetite that accompanies glauconite. Susceptibilities of the Kunda Stage (Loobu Formation) limestone are low but positive. Higher values are recorded within the limestones of the Aseri Stage (Kandle Formation). Within the Lasnamägi Stage (lower part of the Väo Formation) the values decrease (until zero) upwards. Limestones of the overlying Uhaku and Kukruse stages are almost "non"-magnetic with susceptibilities close to zero. Somewhat higher and more variable values characterize the limestones of the Haljala, Keila and Oandu stages (Tatruse to the earliest Rägavere formations). Extensive pyritization of limestones of these formations may contribute to the higher positive values. All limestones of the Rakvere Stage are diamagnetic, with the lowest values within the depth limits from about 324 to 327 m. The Paekna Formation of the Nabala Stage includes an excursion towards positive values in its upper part. A similar excursion is registered in the middle of the Saunja Formation, whereas most of the values are negative. A sharp gradient exists at the boundary between

Table 2. Mean apparent magnetic susceptibilities (MS) and standard deviations (SD) in the Viki core

Formation	N	MS ($\times 10^{-6}$ SI)	SD
Tudulinna	18	47.4	40.3
Saunja	221	–14.5	14.1
Paekna	44	10.9	18.2
Rägavere	79	–15.7	14.2
Hirmuse	8	54.5	21.9
Kahula	72	22.8	25.9
Tatruse	76	23.0	13.1
Pihla	77	–3.1	8.8
Kõrgekallas	62	7.0	7.4
Väo	138	3.5	8.0
Kandle	13	59.1	20.5
Loobu	43	28.0	47.9
Toila	25	99.6	56.3

N, number of measurements

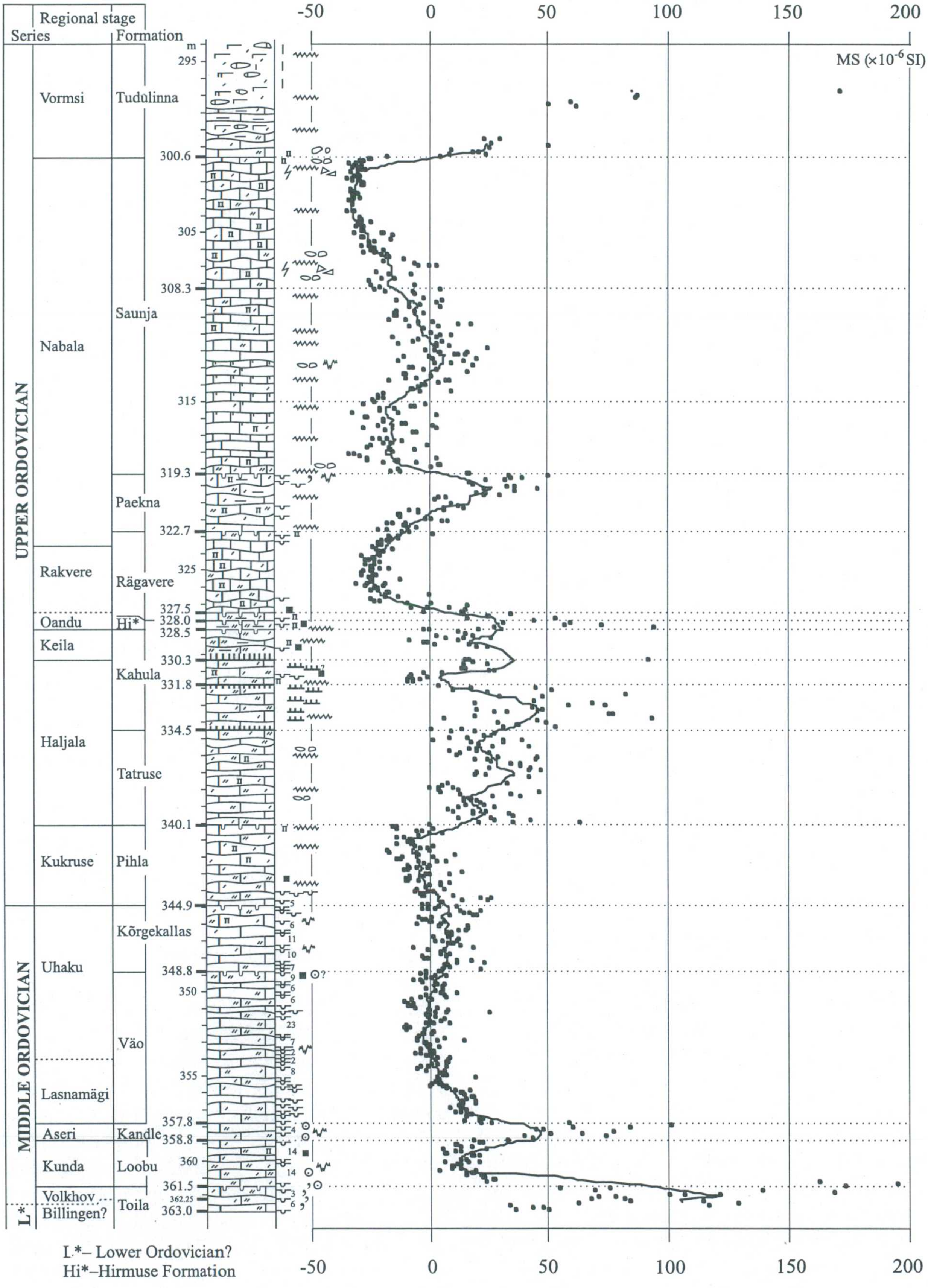


Fig. 8. Apparent magnetic susceptibility (MS) curve of the Viki core. Dots represent individual measurements, whereas the solid line is a mean calculated by applying a low-pass moving average filter with a width of 45 measurements. Refer to Appendix 1 for lithology and Appendix 13 for sample depths.

the Nabala (Saunja Formation) and Vormsi (Tudulinna Formation) stages. The higher positive susceptibility values of the Tudulinna Formation compared to the underlying Saunja Formation are likely due to compositional changes (Saunja "pure" limestone vs Tudulinna marlstone and variously argillaceous limestones) but also to iron mineralization (Appendix 1, sheets 11, 12).

CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF THE ROCK

The investigated Ordovician (Middle and Upper) and Silurian (Llandovery and Wenlock) section of the Viki core (Appendix 1) is represented by variously argillaceous primary and dolomitized carbonate rocks (limestones and dolostones, calcitic and dolomitic marlstones), mixed calcitic and dolomitic carbonate-siliciclastic rocks (silt- and sand-containing highly argillaceous marlstones) and siliciclastic rocks (silt- and sand-containing claystones). A total of 154 rock samples were studied with geochemical methods, whereas 105 samples were measured with petrophysical methods (Appendix 14). Thin sections were made in the Institute of Geology at Tallinn University of Technology (IGTUT) from 45 samples to determine relationships between minerals, skeletal and nonskeletal rock-forming grains, cements, fabric, porosity and diagenetic alteration of rocks (Appendix 3).

Methods

The bulk chemical composition of the rocks was determined in pressed powders by XRF spectrometry in the IGTUT. The insoluble residue (IR), MgO, CaO and FeO contents were additionally measured by wet chemical analysis in all samples, and Fe_2O_3 and Fe_2O_3total in 17 samples, using gravimetric and titration methods. Physical properties of the rock were analysed on cylinders, 25.4 mm in diameter and 27–28 mm high, at room temperature and pressure in the University of Leoben (Austria). The methods applied in the study are described in Shogenova *et al.* (2009).

Magnetic susceptibility was measured with a Bartington MS2D Kappameter. Measurement accuracy of the volume susceptibility is 10^{-5} SI. Volume susceptibilities of the samples were volume corrected using the measured bulk volumes.

Density and porosity were determined using the water saturation method. The brine composition was 0.01 mol NaCl (density of the brine $\rho_w = 0.999$ g/cm^3). For density measurements samples were dried at a temperature of 100 °C and the weight of dry samples (P_d) was determined. Then the samples were saturated with 0.01 mol NaCl brine under vacuum for 24 h and after that weighed in air (P_w). From the obtained measurements the following parameters were calculated: dry density $\delta_d = P_d/V/\rho_w$, where V represents sample volume; wet density $\delta_w = P_w/V/\rho_w$; effective porosity $\varphi = (P_w - P_d)/V$ and grain density $\delta_g = P_d/(V \times (100 - \varphi)/100)/\rho_w$.

Ultrasonic velocity of the compressional wave (V_p) was measured on dry and water saturated samples. Samples were saturated with the brine mentioned above. A delta-pulse was transmitted through the samples with a maximum resonance frequency of the measurement probes 0.1 MHz. On dry samples a good coupling of the transmitter and receiver was ensured by using a contact gel. An additional pressure of 0.5 MPa was applied to reduce wave attenuation between samples and probes.

Electrical resistivity of the samples was measured with a two-electrode setup. Brine conductivity was 2.39 mS/cm (0.01 mol NaCl) and the measurement frequency used was 108 Hz. In order to ensure good contact between electrical probes and samples, a pressure of 0.5 MPa was applied to the setup. The resistance reading (R) was taken after the value had stabilized. The electrical resistivity ρ was calculated using the measured resistance (R) multiplied by the geometrical factor $k = \frac{2 \times \pi \times r^2}{h}$, where h is the height of the sample and r is the sample surface radius.

Chemical and physical parameters were interpreted together, using regression and correlation analysis with the Statistica 7 software (StatSoft).

Composition of rock samples

The IR, MgO and CaO contents found by wet chemical analysis, and other chemical parameters measured by XRF analysis were used to determine the rock lithology (Fig. 9, Appendix 14). Rock types were distinguished, following the classification presented in Kleesment & Shogenova (2005) and other widely used classifications (Mount 1985; Jackson 1997; Miall 2000; Selley 2000). Seven lithological rock types were determined (Fig. 9, Appendix 14): (1) pure and variously argillaceous limestone (IR < 25%, $CaCO_3 > CaMg(CO_3)_2$; 74 samples), (2) calcitic marlstone (IR 25–50%, $CaCO_3 > CaMg(CO_3)_2$; 15 samples), (3) pure and variously argillaceous dolostone and dolomitic limestone (IR < 25%, $CaCO_3 < CaMg(CO_3)_2$; 29 samples), (4) dolomitic marlstone (IR 25–50%, $CaCO_3 < CaMg(CO_3)_2$; 1 sample), (5) mixed calcitic carbonate-

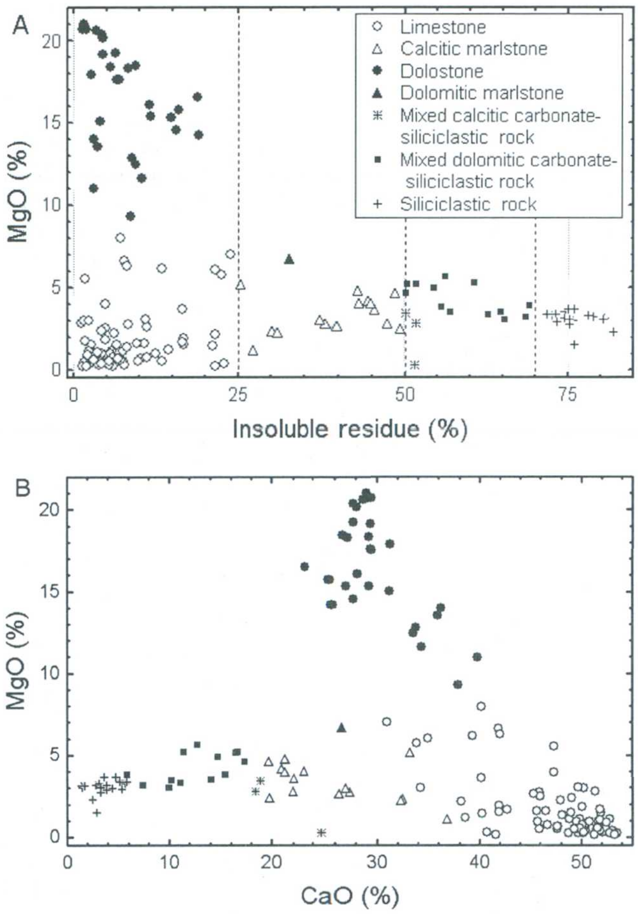


Fig. 9. (A) MgO content versus insoluble residue content, both measured by wet chemical analysis. (B) MgO content versus CaO content, both measured by wet chemical analysis.

siliciclastic rock (IR 50–70%, $CaCO_3 > CaMg(CO_3)_2$; 3 samples), (6) mixed dolomitic carbonate-siliciclastic rock (IR 50–70%, $CaCO_3 < CaMg(CO_3)_2$; 13 samples), (7) siliciclastic rock (IR > 70%; 19 samples). Dolostones and dolomitic rocks are mainly represented by Silurian samples, except for one dolostone of the Porkuni Stage and one mixed dolomitic carbonate-siliciclastic sample from the Vormsi Stage.

The total iron (Fe_2O_3 total) content of most of the studied rocks, measured by XRF, correlates with Al_2O_3 (indicator of clay content) with the common correlation coefficient of 0.9 (Figs 10, 11; Appendix 14). Correlation is higher for Silurian (0.88) than for Ordovician (0.83) rocks. The average total iron content is similar in limestones and dolostones (0.91% and 0.9%, respectively), higher in calcitic marlstones, mixed calcitic and dolomitic carbonate-siliciclastic rocks (mean 3.4%, 3.7% and 5.5%, respectively) and the highest in siliciclastic rocks (mean 6.4%) (Appendix 14). The highest iron content in carbonate rocks was recorded in Middle Ordovician limestone with iron ooliths and glauconite (Loobu Formation of the Kunda Stage, 361.4 m; Appendix 3, T-43). The highest iron content (7–10.5%) in mixed dolomitic carbonate-siliciclastic and siliciclastic rocks was measured in the Silurian claystones and marlstones of the Velise Formation (Adavere Stage). Iron minerals are represented mainly by three-valent iron oxides and hydroxides, more rarely by pyrite crystals (maximum FeO content is 1%).

Porosity and density

The porosity–wet density plot may be used for lithological discrimination of different rock types (Shogenova & Puura 1998; Shogenova *et al.* 2003, 2005, 2006, 2007). Usually dolostones have the highest density for the given porosity, but it is not the case in the Viki core (Fig. 12A), where Silurian dolostones have high secondary porosity, causing significant decrease in their wet density. Dolomitic limestones are not fully dolomitized and have lower grain and wet densities than fully dolomitized rocks.

Limestones have the lowest porosity (0.9–13.1%, mean value 4%), mainly correlated with Al_2O_3 (Figs 10, 12B, 13; Appendix 14) and high density (mean 2614 kg/m^3). Some limestones show secondary porosity (> 5%); their porosity for the given Al_2O_3 content is higher than in most of other limestones (Fig. 12B). Dolostones have higher porosity, varying from 3.3% to 20.6% (mean 10.9%), and relatively low density (mean 2460 kg/m^3). Most of the dolostones show secondary porosity, which is higher than the poro-sity of limestones with the same Al_2O_3 content. Primary porosity in the studied rocks increased with increasing clay content. Average porosity in calcitic marlstones was 12.9% and average wet density 2520 kg/m^3. Wenlock rocks, mainly represented by dolostones, had the highest porosity in the studied sequence. They show the greatest variability in wet density and lower grain density than other rocks. This is explained by open pores and caverns of 1–6 mm in the studied dolostone samples from the Jaani and Jaagarahu formations, which influenced water saturation measurements and reduced the values of calculated porosity and grain density. It was not possible to study the physical properties of the easily crumbling claystones of the Landovery Velise Formation.

P-wave velocity and electric resistivity

The relationship between P-wave velocity and porosity is different for various lithological types (Fabricius & Shogenova 1998; Shogenova & Puura 1998; Shogenova *et al.* 2003, 2005, 2007). The highest velocity and resistivity were measured in limestones, the lowest in calcitic marlstones and highly porous dolo-

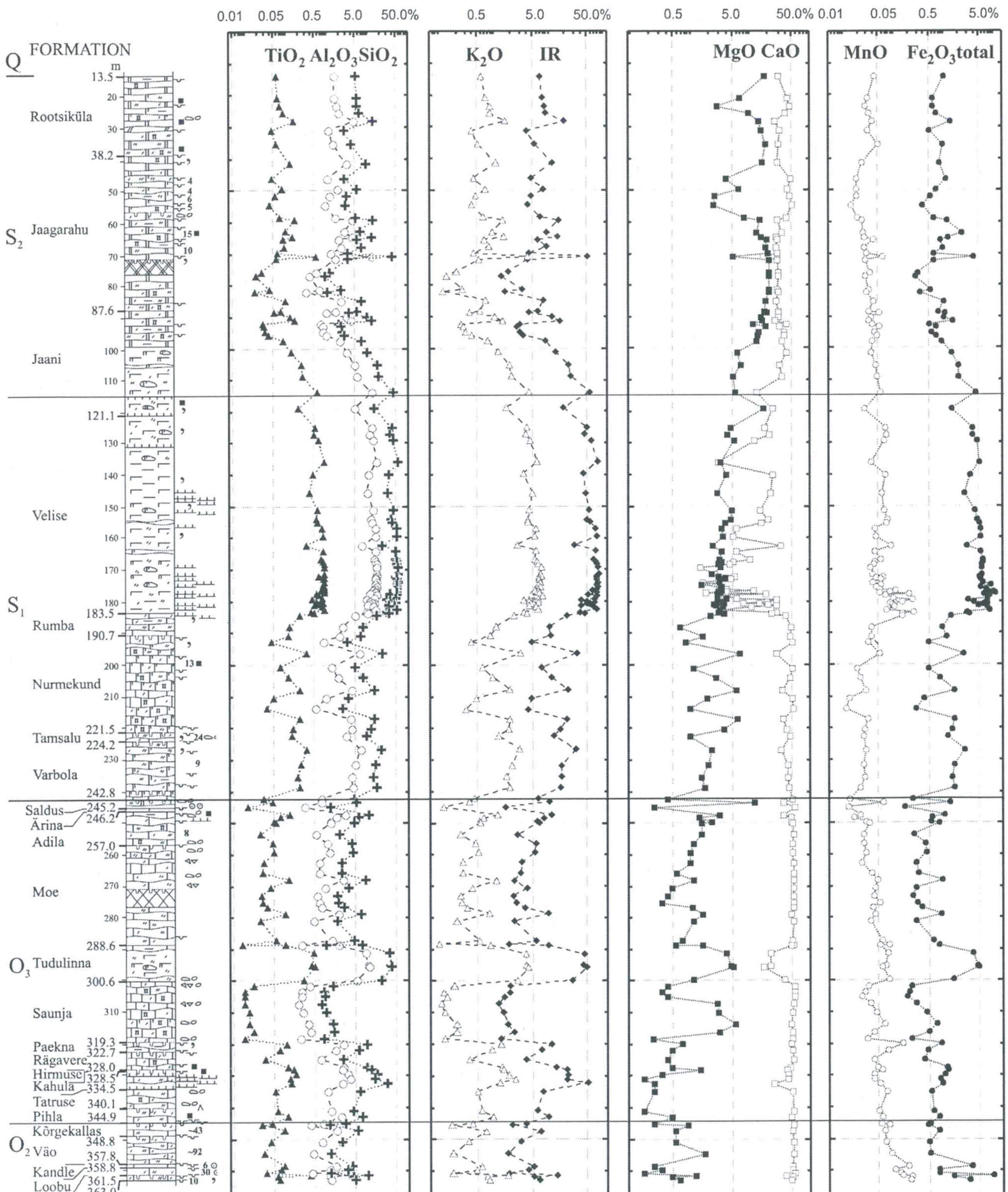


Fig. 10. Chemical composition of the Viki core. O_2 – Middle Ordovician, O_3 – Upper Ordovician, S_1 – Llandovery, S_2 – Wenlock, Q – Quaternary. Refer to Appendix 1 for lithology and distribution of the regional stages, and to Appendix 14 for sample depths.

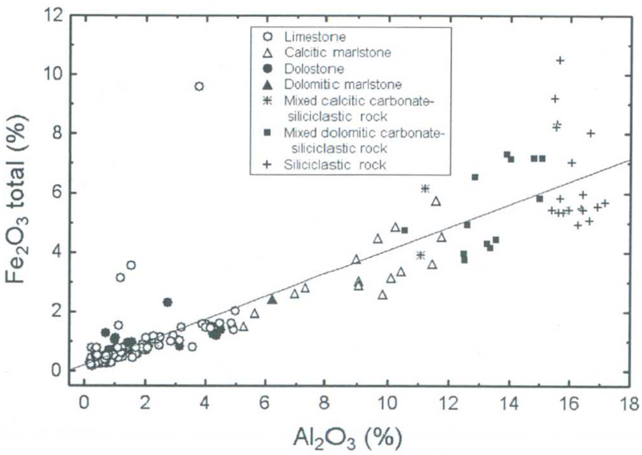


Fig. 11. Total iron content versus Al_2O_3 content, both measured by XRF analysis. Correlation coefficient R = 0.9 for all rocks (154 samples), R = 0.88 for Silurian rocks and R = 0.83 for Ordovician rocks.

stones (Figs 13–15). The resistivity was the lowest in the Wenlock argillaceous dolostone (at 28.3 m) with the highest porosity (Appendix 3, T-3; Appendix 14). P-wave velocity and resistivity of dolostones were higher than those of limestones with the same porosity (Figs 13–15). The P-wave velocity–porosity correlation for primary rocks (limestones and calcitic marlstones) is higher (−0.93) than for dolostones (−0.78). The common correlation coefficient is −0.83. The negative resistivity–porosity correlation was higher for Silurian rocks (−0.71) than for Ordovician rocks (−0.65), but lower than the correlation for all rocks together (−0.7).

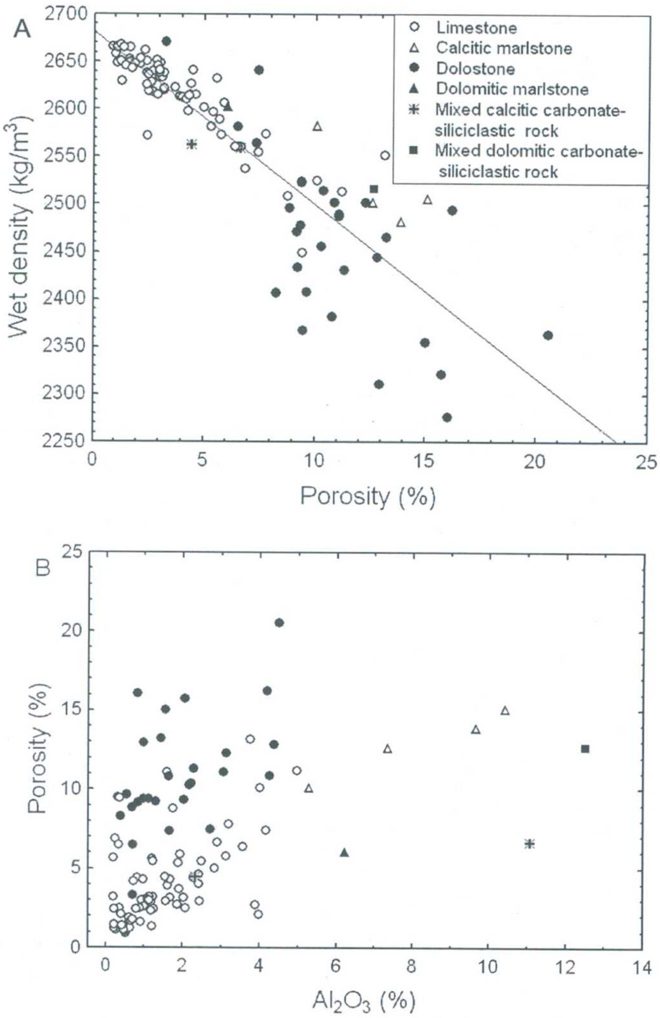


Fig. 12. (A) Wet density versus porosity. Correlation coefficient R = -0.86 for all rocks (105 samples), R = −0.8 for Silurian (53 samples) and R = -0.83 for Ordovician rocks (52 samples).
(B) Porosity versus Al_2O_3 content measured by XRF analysis. Correlation coefficient R = 0.47 for all rocks (105 samples) and R = 0.72 for Ordovician rocks. No significant correlation was recorded for Silurian rocks. R = 0.56 for all limestones (69 samples) and R = 0.53 for all dolostones (28 samples).

Magnetic susceptibility

Low-field magnetic susceptibility in the studied rock sequence correlates with the total iron content (Figs 10, 13, 16; Appendix 14) and increases from diamagnetic and paramagnetic to ferromagnetic minerals as in all Estonian sedimentary rocks (Shogenova 1999; Shogenova *et al.* 2003, 2005, 2006, 2007, 2009). The correlation coefficient of magnetic susceptibility with total iron content is 0.87 for all rock samples from the Viki core. Correlation was high both for Ordovician and Silurian rocks (0.93 and 0.89). The highest magnetic susceptibility was measured at 361.4 m in the Middle Ordovician limestone with iron ooliths and glauconite (Loobu Formation of the Kunda Stage; 21.8×10^{-5} SI, total iron content 9.8%; Appendix 3, T-43; Appendix 14). Magnetic susceptibility, relatively high for limestones, was also measured in two other Ordovician samples: (1) 10.5×10^{-5} SI (total iron content 3.54%) at 358.55 m in limestone with iron ooliths (Kandle Formation of the Aseri Stage, Middle Ordovician); (2) 12.1×10^{-5} SI (total iron content 3.1%) at 362.7 m in limestone with glauconite grains from the Toila Formation of the Billingen? Stage (possibly Lower Ordovician).

The lowest magnetic susceptibility was determined in the purest limestones and dolostones in the entire studied sequence (-0.5×10^{-5} to 0.5×10^{-5} SI; Figs 13, 16; Appendix 14).

Conclusions

The lower half of the studied Viki drill core is represented mainly by primary carbonate rocks of the Middle and Upper Ordovician, and of the lower Llandovery. The upper half of the core consists of highly argillaceous siliciclastic rocks (the upper part of the Llandovery) and by prevailingly dolomitized carbonate rocks of the Wenlock. The purest limestones have

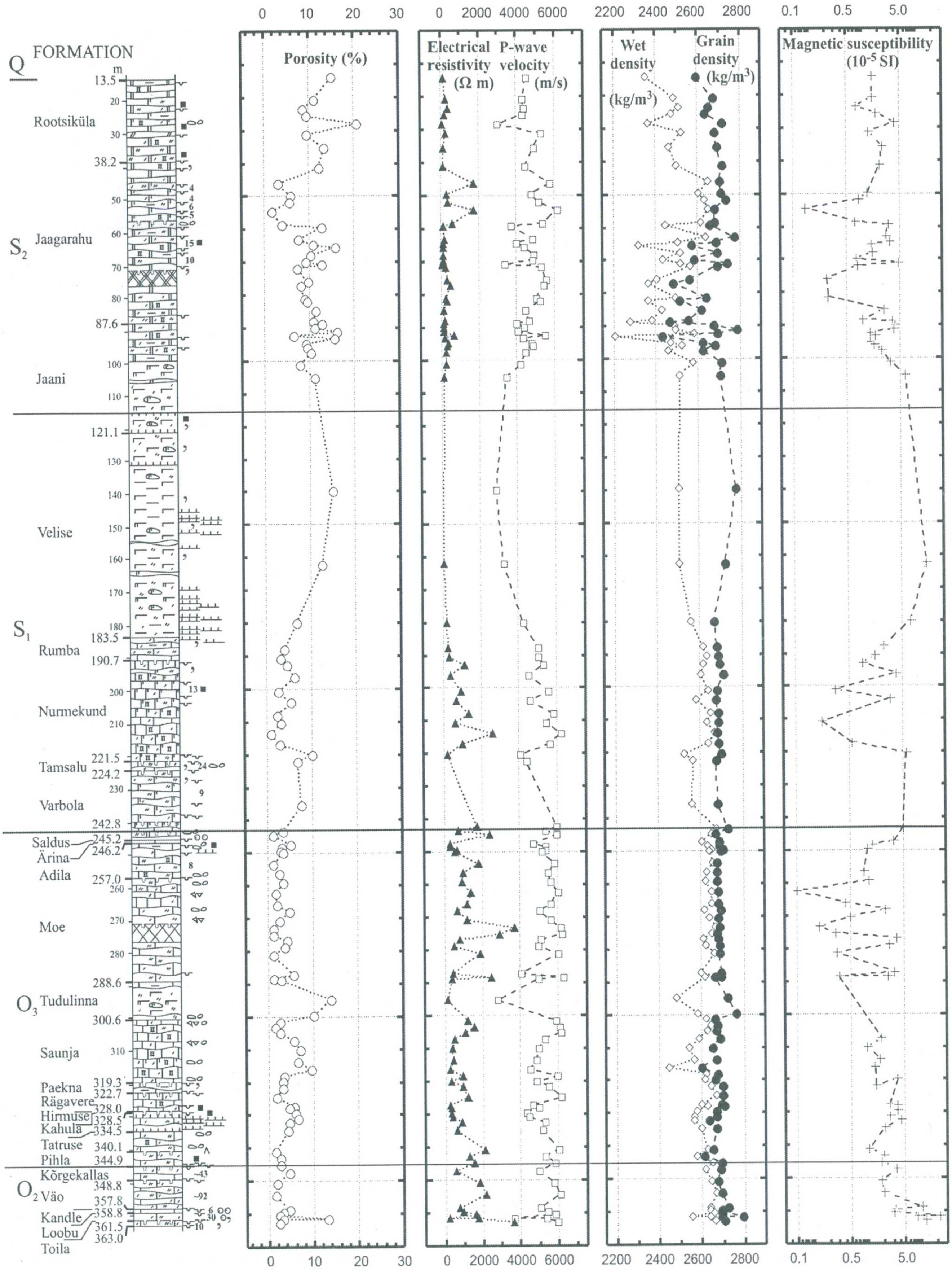


Fig. 13. Physical parameters of the Viki core. O_2 – Middle Ordovician, O_3 – Upper Ordovician, S_1 – Llandovery, S_2 – Wenlock, Q – Quaternary. Refer to Appendix 1 for lithology and distribution of the regional stages, and to Appendix 14 for sample depths.

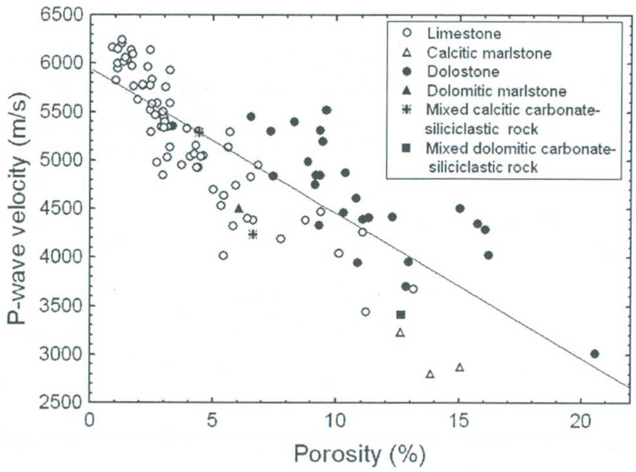


Fig. 14. P-wave velocity versus porosity. Correlation coefficient R = –0.83 for all rocks (52 samples), R = –0.93 for limestones and calcitic marlstones and R=. –0.78 for dolomitized rocks (30 samples).

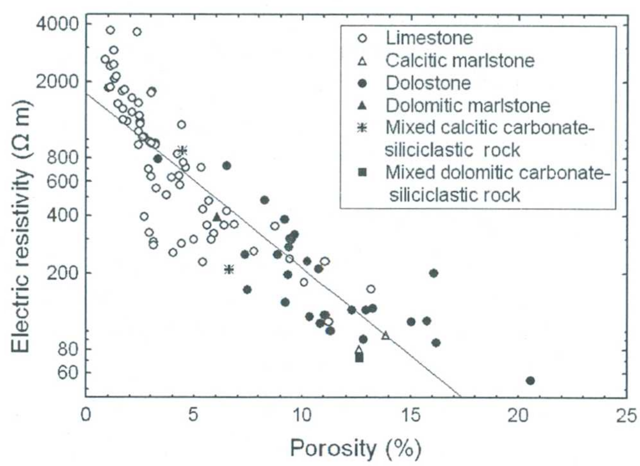


Fig. 15. Electric resistivity versus porosity. Correlation coefficient R = -0.7 for all rocks (105 samples), R = –0.71 for Silurian (53 samples) and R = -0.65 for Ordovician rocks (52 samples).

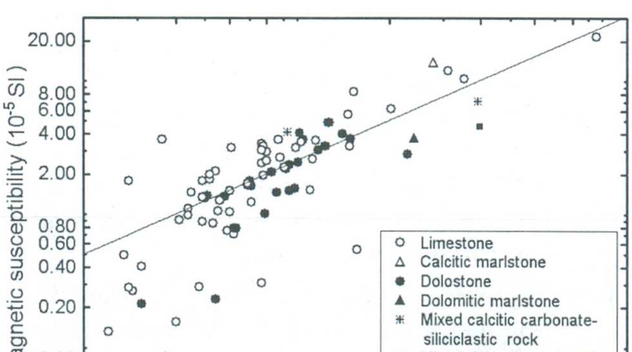


Fig. 16. Magnetic susceptibility versus total iron content measured by XRF analysis. Correlation coefficient R = 0.87 for all rocks (105 samples), R = 0.89 for Silurian (53 samples) and R = 0.93 for Ordovician rocks (52 samples).

the lowest porosity and magnetic susceptibility, and the highest density, P-wave velocity and electric resistivity. Porosity and magnetic susceptibility increase and density, velocity and resistivity decrease with the increasing clay content. The highest porosity was measured in Wenlock dolostones, which had the lowest density, electric resistivity and relatively low velocity. The best discrimination between limestones and dolostones could be seen on the velocity–porosity plot (Fig. 14).

REFERENCES

Aldridge, R. J., Jeppsson, L. & Dorning, K. J. 1993. Early Silurian oceanic episodes and events. *Journal of Geological Society of London*, **150**, 501–513.

Bergström, S. M., Huff, W. D., Kolata, D. R. & Bauert, H. 1995. Nomenclature, stratigraphy, chemical fingerprinting, and areal distribution of some Middle Ordovician K-bentonites in Baltoscandia. *Geologiska Föreningens i Stockholm Förhandlingar (GFF)*, **117**, 1–13.

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

Calner, M. 2008. Silurian global events – at the tipping point of climate change. In: *Mass Extinctions* (Ashraf, M. T. Elewa, ed.). Springer-Verlag, 21–58.

Calner, M., Lehnert, O. & Nõlvak, J. 2010. Palaeokarst evidence for widespread regression and subaerial exposure in the middle Katian (Upper Ordovician) of Baltoscandia: significance for global climate. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **296**, 235–247.

Cramer, B. D., Loydell, D. K., Samtleben, C., Munnecke, A., Kaljo, D., Männik, P., Martma, T., Jeppsson, L., Kleffner, M. A., Barrick, J. E., Johnson, C. A., Emsbo, P., Joachimski, M. M., Bickert, T. & Saltzman, M. R. 2010. Testing the limits of Paleozoic chronostratigrapic correlation via high-resolution (< 500 k.y.) integrated conodont, graptolite, and carbon isotope ($\delta^{13}C_{carb}$) biochemostratigraphy across the Llandovery–Wenlock (Silurian) boundary: is a unified Phanerozoic timescale achievable? *Geological Society of America Bulletin*, **122**, 1700–1716.

Dunlop, D. J. & Özdemir, Ö. 1997. *Rock magnetism: fundamentals and frontiers.* Cambridge University Press, Cambridge, 572 pp.

Dzik, J. 1999. Evolution of Late Ordovician high-latitude conodonts and dating of Gondwana glaciation. In: *Studies on conodonts – Proceedings of the Seventh European Conodont Symposium* (Serpagli, E., ed.), *Bollettino della Società Paleontologica Italiana*, **37**, 237–253.

Einsele, G. 2000. *Sedimentary basins: evolution, facies, and sediment budget.* 2nd ed. Springer-Verlag, 792 pp.

Fabricius, I. & Shogenova, A. 1998. Acoustic velocity data for clay bearing carbonate rocks from the Paleozoic deposits of Estonia and the Cenozoic and Mesozoic deposits of the Caribbean Sea. In: *Nordic Petroleum Technology Series IV: Research in petroleum technology* (Middleton, M., ed.). Nordisk Energi-Forskningsprogram, Ås, Norway, 111–123.

Flügel, E. 2010. *Microfacies of carbonate rocks. Analyses, interpretation and application.* 2nd ed. Springer-Verlag, 984 pp.

Grahn, Y. 1984. Ordovician Chitinozoa from Tallinn, Northern Estonia. *Review of Palaeobotany and Palynology*, **43**, 5–31.

Grahn, Y., Nõlvak, J. & Paris, F. 1996. Precise chitinozoan dating of Ordovician impact events in Baltoscandia. *Journal of Micropalaeontology*, London, **15**, 21–35.

Hagemann, F. & Spjeldnæs, N. 1955. The Middle Ordovician of the Oslo region, Norway. 6. Notes on bentonites (K-bentonites) from the Oslo–Asker district. *Norsk Geologisk Tidsskrift*, **35**, 29–52.

Hints, L. 1997. Lasnamägi Stage. Uhaku Stage. Kukruse Stage. In: *Geology and mineral resources of Estonia* (Raukas, A. & Teedumäe, A., eds). Estonian Academy Publishers, Tallinn, 67–72.

Hints, L. & Meidla, T. 1997. Porkuni Stage. In: *Geology and mineral resources of Estonia* (Raukas, A. & Teedumäe, A., eds). Estonian Academy Publishers, Tallinn, 81–82 and 85–88.

Hints, L., Oraspõld, A. & Kaljo, D. 2000. Stratotype of the Porkuni Stage with comments on the Röa Member (Uppermost Ordovician, Estonia). *Proceedings of the Estonian Academy of Sciences, Geology*, **49**, 177–199.

Hints, L., Oraspõld, A. & Nõlvak, J. 2005. The Pirgu Regional Stage (Upper Ordovician) in the East Baltic: lithostratigraphy, biozonation, and correlation. *Proceedings of the Estonian Academy of Sciences, Geology*, **54**, 225–259.

Hints, L., Hints, O., Nemliher, R. & Nõlvak, J. 2007. Hulterstad brachiopods and associated faunas in the Vormsi Stage (Upper Ordovician, Katian) of the Lelle core, Central Estonia. *Estonian Journal of Earth Sciences*, **56**, 131–142.

Hints, L., Hints, O., Kaljo, D., Kiipli, T., Männik, P., Nõlvak, J. & Pärnaste, H. 2010. Hirnantian (latest Ordovician) bio- and chemostratigraphy of the Stirnas-18 core, western Latvia. *Estonian Journal of Earth Sciences*, **59**, 1–24.

Huff, W. D., Bergström, S. M. & Kolata, D. R. 1992. Gigantic Ordovician volcanic ash fall in North America and Europe: biological, tectonomagnetic, and event stratigraphic significance. *Geology*, **20**, 875–878.

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

Jackson, J. A. (ed.). 1997. *Glossary of geology*. Fourth Edition, American Geological Institute, Alexandria, Virginia, USA, 769 pp.

James, N. P. 1983. Reef. In: *Carbonate depositional environments* (Scholle, P. A., Bebout, D. G. & Moore, C. H., eds), *The American Association of Petroleum Geologists, Memoir*, Oklahoma, 33, 345–462.

Jeppsson, L. 1997. A new latest Telychian, Sheinwoodian and Early Homerian (Early Silurian) Standard Conodont Zonation. *Transactions of Royal Society of Edinburgh: Earth Sciences*, **88**, 91–114.

Jeppsson, L., Viira, V. & Männik, P. 1994. Conodont-based correlations between Estonia and Gotland. *Geological Magazine*, **131**, 201–218.

Jürgenson, E. 1958. Metabentonites in Estonian S. S. R. *Eesti Teaduste Akadeemia Geoloogia Instituudi uurimused*, 2, 73–85. [In Russian with English summary].

Jürgenson, E. 1987. The change of mineralogical composition at the discontinuity surfaces in the Silurian beds of Estonia. *Proceedings of the Estonian Academy of Sciences, Geology*, **36**, 58–65.

Kaljo, D. 1977. Structural and facial subdivisions on the East Baltic Silurian basin. In: *Facies and fauna of the Baltic Silurian* (Kaljo, D., ed.). Institute of Geology, Academy of Sciences of the Estonian S. S. R., Tallinn, 6–13. [In Russian with English summary].

Kaljo, D., Kiipli, T. & Martma, T. 1998. Correlation of carbon isotope events and environmental cyclicity in the East Baltic Silurian. *Silurian cycles. Linkages of dynamic stratigraphy with atmospheric, oceanic, and tectonic changes* (Landing, E. & Johnson, M. E., eds), *New York State Museum Bulletin*, **491**, 297–312.

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

Kallaste, T. & Kiipli, T. 2006. New correlations of Telychian (Silurian) bentonites in Estonia. *Proceedings of the Estonian Academy of Sciences, Geology*, **55**, 241–251.

Kiipli, E. &. Kallaste, T. 1996. Geochemical characterization of some Estonian metabentonites. *Proceedings of the Estonian Academy of Sciences, Geology*, **45**, 68–77.

Kiipli, T. &. Kallaste, T. 2002. Correlation of Telychian sections from shallow to deep sea facies in Estonia and Latvia based on the sanidine composition of bentonites. *Proceedings of the Estonian Academy of Sciences, Geology*, **51**, 143–156.

Kiipli, T. & Kallaste, T. 2003. Altered volcanic ash beds. In: *Ruhnu (500) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 5, 31–33.

Kiipli, T. &. Kallaste, T. 2006. Wenlock and uppermost Llandovery bentonites as stratigraphic markers in Estonia, Latvia and Sweden. *Geologiska Föreningens i Stockholm Förhandlingar (GFF)*, **128**, 139–146.

Kiipli, T., Männik, P., Batchelor, R. A., Kiipli, E., Kallaste, T. & Perens, H. 2001. Correlation of Telychian (Silurian) altered volcanic ash beds in Estonia, Sweden and Norway. *Norwegian Journal of Geology*, **81**, 179–193.

Kiipli, E., Kallaste, T. & Kiipli, T. 2004. Metabentonites of the Pirgu Stage (Ashgill, Upper Ordovician) of the East Baltic. In: *WOGOGOB-2004 8th Meeting of the Working Group on the Ordovician Geology of Baltoscandia. Conference materials. Abstract and field guidebook* (Hints, O. & Ainsaar, L., eds). Tartu University Press, 53–54.

Kiipli, E., Kiipli, T. &. Kallaste, T. 2006. Identification of the O-bentonite in the deep shelf sections with implication on stratigraphy and lithofacies, East Baltic Silurian. *Geologiska Föreningens i Stockholm Förhandlingar (GFF)*, **128**, 255–260.

Kiipli, T., Kiipli, E., Kallaste, T., Hints, R., Somelar, P. & Kirsimäe, K. 2007. Altered volcanic ash as an indicator of marine environment, reflecting pH and sedimentation rate – example from the Ordovician Kinnekulle bed of Baltoscandia. *Clays and Clay Minerals*, **55**, 177–188.

Kiipli, T., Soesoo, A., Kallaste, T. &. Kiipli, E. 2008. Geochemistry of Telichian (Silurian) K-bentonites in Estonia and Latvia. *Journal of Volcanology and Geothermal Research*, **171**, 45–58.

Kiipli, T., Kallaste, T., Nestor, V. & Loydell, D. K. 2010. Integrated Telychian (Silurian) K-bentonite chemostratigraphy and biostratigraphy in Estonia and Latvia. *Lethaia*, **43**, 32–44.

Kleesment, A. & Shogenova, A. 2005. Lithology and evolution of Devonian carbonate and carbonate-cemented rocks in Estonia. *Proceedings of the Estonian Academy of Sciences, Geology*, **54**, 153–180.

Lehnert, O., Männik, P., Joachimski, M. M., Calner, M. & Frýda, J. 2010. Palaeoclimate perturbations before the Sheinwoodian glaciation: a trigger for extinctions during the "Ireviken Event". *Palaeogeography, Palaeoclimatology, Palaeoecology*, **296**, 320–331.

Loog, A. & Oraspõld, A. 1982. *Settekivimite ja setete (setendite) uurimismeetodid* [Methods of the study of sediments and sedimentary rocks]. TRÜ geoloogia kateeder, Tartu, 83 pp. [In Estonian].

Loydell, D. K., Nestor, V. & Männik, P. 2010. Integrated biostratigraphy of the lower Silurian of the Kolka-54 core, Latvia. *Geological Magazine*, **147**, 253–280.

Männik, P. 1992. *Upper Ordovician and Lower Silurian Conodonts in Estonia. Abstract*. Ph.D. thesis, Tartu University, Tartu, 50 pp.

Männik, P. 1994. Conodonts from the Pusku Quarry, lower Llandovery, Estonia. *Proceedings of the Estonian Academy of Sciences, Geology*, **43**, 183–191.

Männik, P. 2001. Distribution of conodonts. In: *Valga (10) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 3, 10–12.

Männik, P. 2003. Distribution of conodonts. In: *Ruhnu (500) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 5, 17–23.

Männik, P. 2004. Recognition of the Mid-Caradoc Event in the conodont sequence of Estonia. In: *WOGOGOB-2004 8th Meeting of the Working Group on the Ordovician Geology of Baltoscandia. Conference Materials. Abstract and field guidebook* (Hints, O. & Ainsaar, L., eds). Tartu University Press, 63–64.

Männik, P. 2007a. Upper Ordovician and lower Silurian conodont biostratigraphy in Estonia: general overview of recent developments. *Estonian Journal of Earth Sciences*, **56**, 35–46.

Männik, P. 2007b. An updated Telychian (Late Llandovery, Silurian) conodont zonation based on Baltic faunas. *Lethaia*, **40**, 45–60.

Männik, P. 2007c. Some comments on the Telychian–early Sheinwoodian conodont faunas, events and stratigraphy. *Acta Palaeontologica Sinica*, 46 (Suppl.), 305–310.

Männik, P. & Viira, V. 2005. Distribution of Ordovician conodonts. In: *Mehikoorma (421) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 6, 16–20.

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

Männil, R. 1987. Ob"jasnitel'naja zapiska k stratigrafičeskim shemam ordovikskih otloženij [Explanatory text to the stratigraphic chart of Ordovician deposits]. In: *Rešenija Mežvedomstvennogo stratigrafičeskogo soveščanija po ordoviku i siluru Vostočno-Evropejskoj platformy 1984 g. s regional'nymi stratigrafičeskimi shemami* [Resolutions of the Interdepartmental Stratigraphical Conference on the Ordovician and Silurian of the East European Platform, 1984, with regional stratigraphical charts] (Kaljo, D., ed.), Leningrad, 17–46. [In Russian].

Meidla, T. & Sarv, L. 1990. Ostracodes. In: *Field meeting, Estonia. An excursion guidebook* (Kaljo, D. & Nestor, H., eds). Institute of Geology, Estonian Academy of Sciences, Tallinn, pp. 68–71, pls. 7–10.

Miall, A. D. 2000. *Principles of sedimentary basin analysis*. Springer-Verlag, 616 pp.

Mount, J. 1985. Mixed siliciclastic and carbonate sediments: a proposed first-order textural and compositional classification. *Sedimentology*, **32**, 435–442.

Mullins, G. L. & Aldridge, R. J. 2004. Chitinozoan biostratigraphy of the basal Wenlock Series (Silurian) global stratotype section and point. *Palaeontology*, **47**, 745–773.

Mullins, G. L. & Loydell, D. K. 2001. Integrated lower Silurian chitinozoan and graptolite biostratigraphy of the Banwy River section, Wales. *Palaeontology*, **44**, 731–781.

Munnecke, A. & Männik, P. 2009. New biostratigraphic and chemostratigraphic data from the Chicotte Formation (Llandovery, Anticosti Island, Laurentia) compared with the Viki core (Estonia, Baltica). *Estonian Journal of Earth Sciences*, **58**, 159–169.

Nestor, H. 1972. On the stratigraphic range of the beds with *Pentamerus oblongus* and on the nature of the late Llandoverian transgression in North Europe. *Eesti NSV Teaduste Akadeemia Toimetised, Keemia, Geoloogia*, **21**, 344–350. [In Russian with English summary].

Nestor, H. 1990a. Silurian sequences at Särghaua field station. In: *Field meeting, Estonia. An excursion guidebook* (Kaljo, D. & Nestor, H., eds). Institute of Geology, Estonian Academy of Sciences, Tallinn, 184–186.

Nestor, H. 1990b. Some aspects of lithology of the Ordovician and Silurian rocks. In: *Field meeting, Estonia. An excursion guidebook* (Kaljo, D. & Nestor, H., eds). Institute of Geology, Estonian Academy of Sciences, Tallinn, 27–32.

Nestor, H. 1997. Silurian. In: *Geology and mineral resources of Estonia* (Raukas, A. & Teedumäe, A., eds). Estonian Academy Publishers, Tallinn, 89–106.

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

Nestor, H. & Nestor, V. 2002. Upper Llandovery to middle Wenlock (Silurian) lithostratigraphy and chitinozoan biostratigraphy in southwestern Estonia and northernmost Latvia. *Proceedings of the Estonian Academy of Sciences, Geology*, **51**, 67–87.

Nestor, H., Einasto, R., Männik, P. & Nestor, V. 2003. Correlation of lower-middle Llandovery sections in central and southern Estonia and sedimentation cycles of lime muds. *Proceedings of the Estonian Academy of Sciences, Geology*, **52**, 3–27.

Nestor, V. 1990. Silurian chitinozoans. In: *Field Meeting, Estonia. An excursion guidebook* (Kaljo, D. & Nestor, H., eds). Institute of Geology, Estonian Academy of Sciences, Tallinn, 80–83.

Nestor, V. 1994. Early Silurian chitinozoans of Estonia and North Latvia. *Academia*, Vol. 4, Estonian Academy Publishers, Tallinn, 163 pp.

Nestor, V. 1998. Chitinozoan biofacies of late early Llandovery (*Coronograptus cyphus*) age in the East Baltic. *Proceedings of the Estonian Academy of Sciences, Geology*, **47**, 219–228.

Nestor, V. 2003. Distribution of Silurian chitinozoans. In: *Ruhnu (500) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 5, 13–14.

Nestor, V. 2005. Chitinozoans of the *Margachitina margaritana* Biozone and the Llandovery–Wenlock boundary in West Estonian drill cores. *Proceedings of the Estonian Academy of Sciences, Geology*, **54**, 87–111.

Nestor, V. 2007. Chitinozoans in the Wenlock–Ludlow boundary beds of the East Baltic. *Estonian Journal of Earth Sciences*, **56**, 109–128.

Nestor, V. 2009. Chitinozoan diversity in the East Baltic Silurian. *Estonian Journal of Earth Sciences*, **58**, 311–316.

Nestor, V. & Nestor, H. 1991. Dating of the Wenlock carbonate sequences in Estonia and stratigraphic breaks. *Proceedings of the Estonian Academy of Sciences, Geology*, **40**, 50–60.

Nestor, V., Einasto, R. & Loydell, D. K. 2002. Chitinozoan biostratigraphy and lithological characteristics of the Lower and Upper Visby boundary beds in the Ireviken 3 section, Northwest Gotland. *Proceedings of the Estonian Academy of Sciences, Geology*, **51**, 215–226.

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

Nõlvak, J. 1999. Distribution of chitinozoans. Appendix 6. In: *Taga-Roostoja (25A) drill core* (Põldvere, A., ed.), *Estonian Geological sections*, 2, 10–12.

Nõlvak, J. 2001. Distribution of chitinozoans. Appendix 8. In: *Valga (10) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 3, 8–10.

Nõlvak, J. 2002. *Chitinozoan biostratigraphy in the Ordovician of Baltoscandia*. Ph.D. thesis, Institute of Geology at Tallinn Technical University, TTU Press, Tallinn, 200 pp.

Nõlvak, J. 2003. Distribution of Ordovician chitinozoans. Appendix 22. Appendix 23. In: *Ruhnu (500) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 5, 23–25.

Nõlvak, J. 2005. Distribution of Ordovician chitinozoans. Appendix 26. Appendix 27. In: *Mehikoorma (421) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 6, 20–22.

Nõlvak, J. 2008. Distribution of Ordovician chitinozoans. Appendix 6. In: *Estonian Geological Sections* (Põldvere, A., ed.), *Männamaa (F-367) drill core*, 9, 13–18.

Nõlvak, J. & Bauert, G. 2006. Distribution of Ordovician chitinozoans. Appendix 8. Appendix 9. In: *Kerguta (565) drill core* (Põlvere, A., ed.), *Estonian Geological sections*, 7, 9–11.

Nõlvak, J. & Grahn, Y. 1993. Ordovician chitinozoan zones from Baltoscandia. *Review of Palaeobotany and Palynology*, **79**, 245–269.

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

Nõlvak, J., Hints, O., Männik, P. & Pärnaste, H. 2007. Ordovician time scale in Estonia. *Acta Palaeontologica Sinica*, Beijing, China, **46**, Supplement, 351–356.

Oraspõld, A. 1975. Lithology of the Pirgu Stage in South Estonia. *Acta et Commentationes Universitatis Tartuensis*, 359, 14–32. [In Russian with English summary].

Plado, J., Preeden, U., Pesonen, L. J., Mertanen, S. & Puura, V. 2010. Magnetic history of Early and Middle Ordovician sedimentary sequence, northern Estonia. *Geophysical Journal International*, **180**, 147–157.

Põldvere, A., Kleesment, A., Mens, K. & Niin, M. 2003. Core description and terminology. In: *Ruhnu (500) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 5, 5–6.

Pranskevičius, A. A. 1972. South Baltic Silurian ostracoda. *Transactions of the Lithuanian Scientific-Research Geological Survey Institute*, Mintis, Vilnius, **15**, 1–280. [In Russian with English summary].

Pranskevičius, A. A. 1975. Silurian podocopida of the South Baltic area. In: *The fauna and stratigraphy of Palaeozoic and Mesozoic of Baltic and Byelorussia* (Grigelis, A. A., ed.). Mintis, Vilnius, 85–91. [In Russian with English summary].

Sarv, L. I. 1968. *Ostracode families Craspedobolbinidae, Beyrichiidae and Primitiopsidae in the Silurian of Estonia*. Valgus, Tallinn, 104 pp. [In Russian with English summary].

Sarv, L. 1970. Ostracodes. In: *Silur Estonii* [Silurian of Estonia] (Kaljo, D. L., ed.). Valgus, Tallinn, pp. 157–170. [In Russian with English summary].

Sarv, L. & Meidla, T. 1997. Ostracodes. In: *Geology and mineral resources of Estonia* (Raukas, A. & Teedumäe, A., eds). Estonian Academy Publishers, Tallinn, 233–234.

Selley, R. C. 2000. *Applied sedimentology*. Academic Press, USA, 523 pp.

Shogenova, A. 1999. The influence of dolomitization on the magnetic properties of Lower Palaeozoic carbonate rocks in Estonia. In: *Palaeomagnetism and diagenesis in sediments* (Tarling, D. H. & Turner, P., eds), *Geological Society, Special Publications, London*, **151**, 167–180.

Shogenova, A. & Puura, V. 1998. Composition and petrophysical properties of Estonian Early Palaeozoic carbonate rocks. In: *Nordic Petroleum Technology Series IV: Research in petroleum technology* (Middleton, M., ed.),. Nordisk Energi-Forskningsprogram, Ås, Norway, 183–202.

Shogenova, A., Jõeleht, A., Einasto, R., Kleesment, A., Mens, K. & Vaher, R. 2003. Chemical composition and physical properties of the rocks. In: *Ruhnu (500) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 5, 34–39.

Shogenova, A., Kleesment, A. & Shogenov, V. 2005. Chemical composition and physical properties of the rocks. In: *Mehikoorma (421) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 6, 31–38.

Shogenova, A., Shogenov, K. & Donadini, F. 2006. Chemical composition and physical properties of the rock. In: *Kerguta (565) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 7, 19–26.

Shogenova, A., Shogenov, K., Pesonen, L. J. & Donadini, F. 2007. Chemical composition and physical properties of the rock. Appendix 11. In: *Tsiistre (327) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 8, 21–29.

Shogenova, A., Kleesment, A., Hirt, A., Pirrus, E., Kallaste, T., Shogenov, K. & Vaher, R. 2009. Composition and properties of the iron hydroxides-cemented lenses in Estonian sandstone of Middle Devonian Age. *Studia Geophysica et Geodaetica*, **53**, 111–131.

Suuroja, K., Koppelmaa, H., Niin, M., Pukkonen, E., Gromov, O., Kivisilla, J. & Klein, V. 1991. Otčet o glubinnom geologičeskom kartirovanii o. Hiiumaa masštaba 1:200 000 za 1986–1991 gody [Report on deep geological mapping on Hiiumaa Island at a scale of 1:200 000 in 1986–1991]. Unpublished report of the Geological Survey of Estonia, Keila, 210 pp. [In Russian].

Suuroja, K., Mardim, T., Kadastik, E. & Eltermann, G. 1993. Hiiumaa kompleksse geoloogilise kaardistamise mõõtkavas 1:50 000 aruanne [Report on complex geological mapping on Hiiumaa Island at a scale of 1:50 000]. Unpublished report of the Geological Survey of Estonia, Keila, 206 pp. [In Estonian].

Suuroja, K., Põldvere, A., Mens, K., Niin, M. & Aaloe, A. 2008. Core description and terminology. In: *Männamaa (F-367) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 9, 5–6.

Tammekänd, M., Hints, O. & Nõlvak, J. 2010. Chitinozoan dynamics and biostratigraphy in the Väo Formation (Darriwilian) of the Uuga Cliff, Pakri Peninsula, NW Estonia. *Estonian Journal of Earth Sciences*, **59**, 25–36.

Tiirmaa, R. & Jürgenson, E. 1979. Opisanie razrezov Silurijskih porod v skvažinah Ventspils, Kaugatuma I, Kaugatuma II, Kingiseppa i Viki [Description of Silurian rocks in the Ventspils, Kaugatuma I, Kaugatuma II, Kingissepa and Viki cores]. Unpublished report of the Institute of Geology of the Estonian Academy of Sciences, Tallinn, 98–116. [In Russian].

Viira, V. & Männik, P. 1999. Distribution of conodonts. In: *Taga-Roostoja (25A) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, 2, 9–10.

Vingisaar, P., Oraspõld, A., Einasto, R. & Jürgenson, E. 1965. *Karbonaatkivimite ühtne klassifikatsioon ja legend* [Unified classification of carbonate rocks and legend]. Tallinn, 49 pp. [In Estonian and Russian].

APPENDIX 1

Description of the Viki core

The description is given in a standardized form. The table is divided into nine columns based on the type of information.

STANDARD UNITS — Chronostratigraphic and geological time units.

LOCAL STRATIGRAPHIC UNITS — Stages, substages, formations, members and beds.

CORE BOX NO./FIGURES — Numbers of boxes, and location of the detailed core photos marked as D-1…71 in Appendix 2). Note that the depths and positions of the studied samples are also indicated in drill core photos in the database of the IGTUT (available online at http://sarv.gi.ee/search.php?currentTable=drillcore).

DEPTH/SAMPLES — Depth of the boundaries and sample levels: C, conodonts, Ch, chitinozoans; K, chemical and physical properties; O, ostracods; T, thin sections (for photos see Appendix 3).

LITHOLOGY — For legend see the next page. The core section is given at a scale of 1:200.

SEDIMENTARY STRUCTURES — According to the thickness of beds: micro- (< 0.2 cm), thin- (0.2–2.0 cm), medium- (2–10 cm) and thick-bedded (10–50 cm); massive – visible bedding is missing.

MARLSTONE BEDS — The most frequent thicknesses of the marlstone beds; in parentheses infrequent thicknesses. Contacts between marlstone and other types of rock may be distinct (D) or indistinct (IND). Colours were identified on damp core.

MARLSTONE PERCENTAGE — The content of marlstone beds in the described interval was estimated visually.

SHORT DESCRIPTION — Main types of rocks are in bold. The colour of rocks was identified on damp core. The dominant size of limestone crystals (in italics) is as follows: cryptocrystalline (< 0.005 mm), microcrystalline (0.005–0.01 mm), very finely crystalline (0.01–0.05 mm), finely crystalline (0.05–0.1 mm) and medium-crystalline (0.1–1.0 mm). The percentage of allochems (mainly bioclasts and clastic material) is also indicated. The following clastic fractions are described: clay (< 0.005 mm), silt (0.005–0.05 mm), sand (0.05–2.0 mm), gravel (2–10 mm) and pebbles (10–100 mm).

Appendix 1 continued

LEGEND

- cultivated soil
- silty and sandy gravel with clay interbeds
- limestone (in general)
- argillaceous limestone
- dolomitized limestone
- dolostone
- argillaceous dolostone
- eurypterid-dolostone
- biohermal limestone
- calcitic marlstone
- dolomitic marlstone
- claystone
- a, b: K-bentonite bed, on (a) or under (b) the boundary
- breccia
- clastic material
- nodules

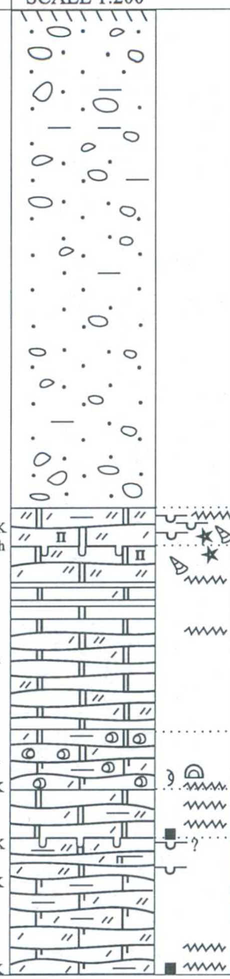
- a, b: skeletal limestones: grains 10–25% (a) and grains 25–50% (b)
- a, b: crypto- and micro-crystalline limestone (a) and dolostone (b)
- fine bioclasts
- coarse bioclasts
- a, b, c: horizontal bedding: thin (a), medium (b) and thick bedding (c)
- wavy bedding
- nodular
- thin intercalation
- discontinuity surface
- 4: number of discontinuity surfaces between the upper and the lower surface
- slickenside
- veins
- stylolites
- porous
- caverns (vugs)
- burrows
- pyritic mottles

- ooliths
- oncoids
- silicification
- glauconite grains
- kerogen
- pyrite
- calcite
- micas (in general)
- bitumen
- mottled, red-coloured and yellow streaks
- tabulate corals
- stromatoporoids
- rugosae
- brachiopods
- trilobites
- ostracods
- echinoderms (crinoids)
- bryozoans
- calcareous algae
- graptolites
- gastropods
- cephalopods

DESCRIPTION OF THE VIKI CORE

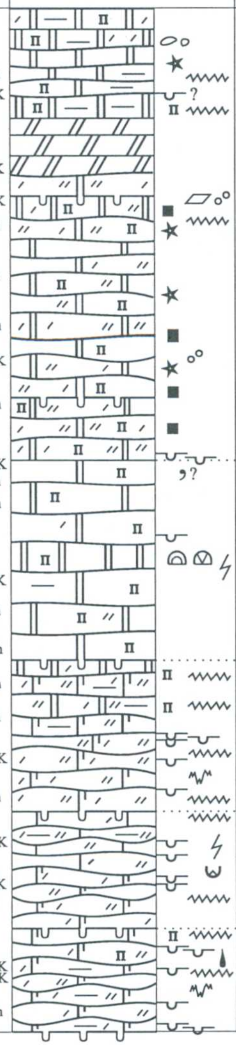
Location: 58° 21' 03" N, 22° 04' 47" E. Length of the core 363.0 m. Elevation of the top 22.0 m above sea level.

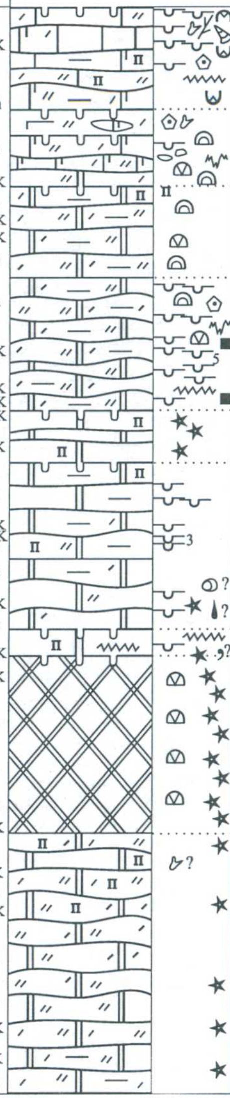
LITHOLOGY — SCALE 1:200

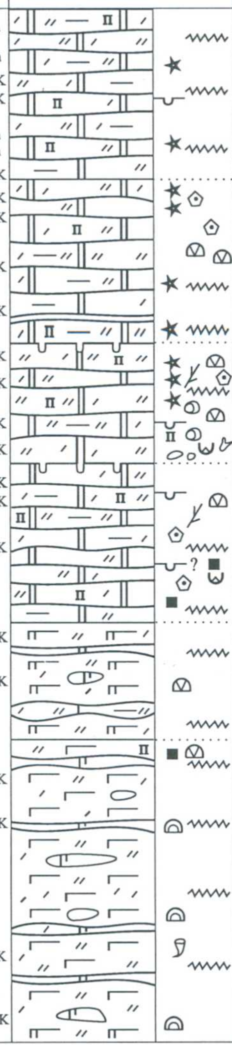


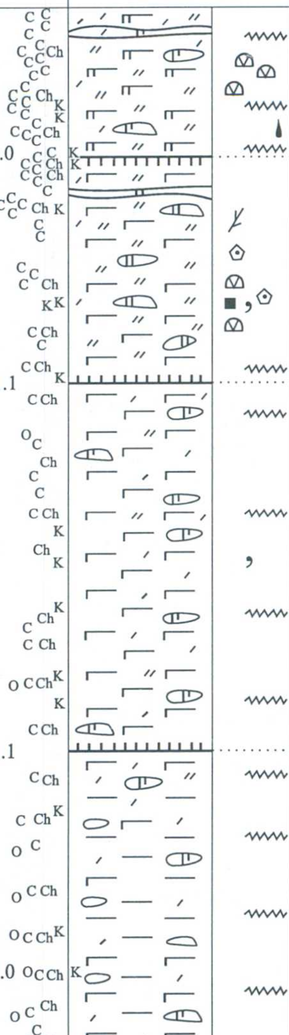
STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Holocene (Quaternary)		1, 2		0.0		(Core yield 50%)			Cultivated soil cover underlain by interbeds of silty sand and sandy gravel. Some clay interbeds are found, the uppermost 2 m is weathered. Carbonate pebbles (1–10 cm across) and cobbles make up about 80%, the rest is igneous rocks
Wenlock	Rootsikküla Stage, Rootsikküla Formation, S*	3	D-1, D-2, D-3	13.5	C T K Ch K, C	Indistinctly bedded	< 0.2, 0.2–1 cm; IND greenish-grey	1–2	Light brownish-grey, slightly argillaceous, *finely crystalline* **dolostone**
Wenlock	Rootsikküla Stage, Rootsikküla Formation, Vesiku Beds	3	D-4	14.5	Ch	Wavy and horizontal, indistinctly micro- and thin-bedded (Core yield 20%)	< 0.2, 0.2–1 cm; D and IND greenish- and brownish-grey	1–3	Light brownish- and greenish-grey, mainly *very finely crystalline* **dolostone** with rare dolomitic marlstone interbeds; the uppermost part is pyritized, with some gastropod-rich interbeds
Wenlock	Rootsikküla Stage, Rootsikküla Formation, Vesiku Beds	3	D-5, D-6	19.4	C Ch	Indistinctly nodular	< 1 cm; D and IND greenish-, brownish-grey	< 5	Light brownish- and greenish-grey patchy, slightly argillaceous, *very finely crystalline* **dolostone** and **dolomitic limestone rich in oncoids** (coated pelecypod fragments)
Wenlock	Rootsikküla Stage, Rootsikküla Formation, Vesiku Beds	3	D-7	21.0	C Ch T K, C	Horizontal and inclined, micro- and thin-bedded	< 1.5 cm; D greenish-, brownish-grey	2–20	Light brownish- and greenish-grey, in places argillaceous, *very finely crystalline* **dolostone** (grains < 10% and < 25%), bioturbated
Wenlock	Rootsikküla Stage, Rootsikküla Formation, Kuusnõmme*	3, 4	D-8, D-9	22.3–26.0	C Ch K, C Ch K, Ch, K	Indistinctly micro- to medium-bedded, in places nodular (Core yield 45%)	< 0.2, 1–2 cm; IND greenish- and brownish-grey	2–20	Light brownish- and greenish-grey (the uppermost part pyritized), in places argillaceous, *finely* and *very finely crystalline* **dolomitic limestone** and **dolostone** (in original rock carbonate grains formed locally < 10% and < 25%) with dolomitic marlstone and dolomitized limestone interbeds

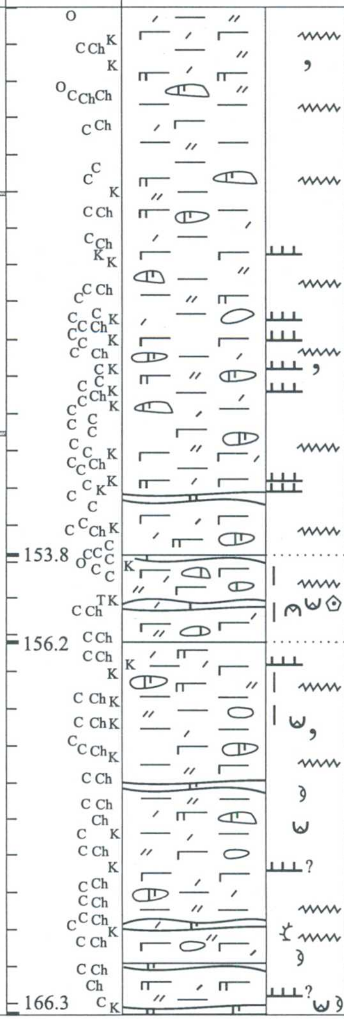
S*– Soeginina Beds; Kuusnõmme*– Kuusnõmme Beds

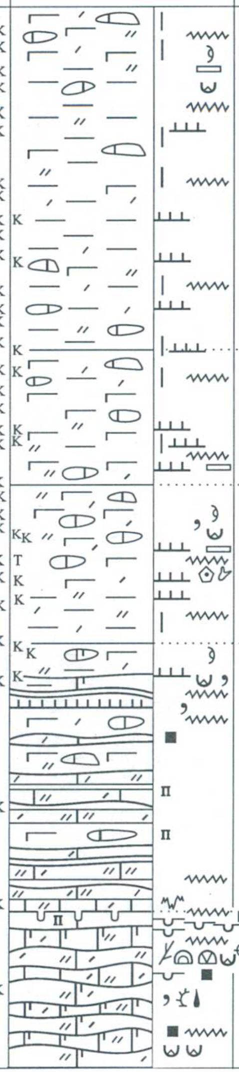
STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Wenlock	Rootsikiila Stage, Rootsikiila Formation, Viita Beds	4, 5	D-9, D-10, D-11	26.0–38.2	C; C Ch; C Ch TK; C Ch K; C TK; Ch; C Ch; Ch; C TK; C Ch		Wavy and horizontal, indistinctly medium- to thin-bedded, in places thick- to microbedded and indistinctly nodular (Core yield 50%)	< 0.2, 0.2–6 cm; D and IND grey and greenish-grey	1–2	Light grey and brownish-grey, often pyrite mottled, in places argillaceous, in the upper part mainly *crypto-* and *microcrystalline*, in the lower part *very finely* to *finely crystalline* **dolostone** (grains < 10%; in original rock 25–50%, in some layers > 50%) with rare dolomitic marlstone and claystone patches, films and interbeds. The interval 29.0–30.5 m is grey, indistinctly striped **eurypterid-dolostone**. Discontinuity surfaces are pyritized
	Jaagarahu Stage, Jaagarahu Formation, Tagavere Beds	5	D-12, D-13	38.2–43.6	K; C Ch; Ch; C; C TK; C Ch; C Ch		Indistinctly bedded and nodular, visually thick-bedded	< 0.2, 0.2–2 cm; IND and D light greenish-grey	1–2	Light grey to brownish-grey, pyrite mottled, *finely* to *very finely crystalline*, in places *cryptocrystalline* **dolostone** (grains mainly < 10%) with rare dolomitic marlstone films and interbeds. At 40.5–41.0 m rounded stromatoporoids and corals are found. Discontinuity surfaces are pyritized
		6	D-14, Ch, D-15	43.6–47.7	C Ch; C Ch; C K; C Ch		Wavy, indistinctly thin- to medium-bedded, in the lower part indistinctly nodular	< 0.2, 0.2–1 cm; IND greenish-grey	1–2	Light greenish-grey, in the upper part slightly pyrite mottled and *micro-crystalline*, in the lower part *very finely* to *finely crystalline* **dolostone** and dolomitized **limestone** (grains 25–50%, in places > 50%; often pyritized) with rare dolomitic marlstone patches, films and interbeds. Discontinuity surfaces are pyritized
			D-16, D-17	47.7–50.9	C Ch K; C Ch K; C Ch		Medium-nodular, in places indistinctly thin-nodular	< 0.2, 0.2–2 cm; D grey	< 5	Light grey and greenish-grey, *very finely crystalline* **limestone** (grains 25–50%, often pyritized) with marlstone patches and interbeds. The lower part is dolomitized, discontinuity surfaces are pyritized
		7	D-18, D-19	50.9–53.7	C; C Ch K; C Ch K; C Ch		Medium- to thin-nodular and indistinctly bedded	< 0.2, 0.2–2 cm; D grey and brownish-grey	< 5	Light brownish- and greenish-grey, dolomitized *very finely crystalline* **limestone** (some layers argillaceous; grains in places 10–25%, in original rock 25–50%), with dolomitic marlstone patches and interbeds. Discontinuity surfaces are pyritized

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Wenlock	Jaagarahu Stage; Tagavere B.	8	D-20	53.7	C Ch TK; C Ch; C C Ch		Wavy, indistinctly thin- and medium-bedded and nodular	< 0.2, 0.2–2 cm; IND brownish-grey	< 5	Light greenish-grey, in places pyrite mottled and argillaceous, *micro-* to *very finely crystalline* dolomitized **limestone** (grains in places 10–50%) with marlstone interbeds. Discontinuity surfaces are pyritized
	Maasi Beds		D-21	56.4	C Ch; C Ch; C K K		Wavy, indistinctly bedded and nodular	< 0.2, 0.2–2 cm; IND greenish-grey	< 5	Light greenish- and brownish-grey, in places argillaceous, *micro-* to *finely crystalline* **dolomitic limestone** (grains in places 25–50%, in original rock > 50%) with marlstone interbeds. Discontinuity surfaces are pyritized
		9	D-22	58.5	C Ch K; C Ch K; C Ch		Wavy, indistinctly medium-bedded	< 0.2, 0.2–1 cm; IND dark brownish-grey	1–2	Brownish-grey, argillaceous *finely crystalline* **dolostone** (grains in places 10–25% and > 50%) with rare dolomitic marlstone interbeds
			D-23, D-24	61.0	C Ch; C Ch K K; C Ch K		Wavy, indistinctly nodular and medium-bedded	< 0.2, 0.2–1 cm; IND dark brownish-grey		Light greenish- and brownish-grey, variously argillaceous, *medium-* to *very finely crystalline* **dolostone** (grains in places in original rock 25–50% and > 50%) with rare dolomitic marlstone and limestone interbeds. Discontinuity surfaces are pyritized
	Jaagarahu Formation	10	D-25	64.6	C Ch K; C Ch K; C Ch TK		Wavy, indistinctly bedded	< 0.2 cm; IND dark grey	< 2	Light brownish-grey, in places pyritized, *finely crystalline* **dolostone** with rare dolomitic marlstone films. The discontinuity surface is pyritized
			D-26	66.0	C Ch; C Ch; C Ch K K K; C C Ch; C C Ch Ch; TK		Wavy, indistinctly bedded and nodular	< 0.2, 0.2–1 cm; IND dark grey and brownish-grey	< 2	Light brownish-grey (the lower part darker), in places pyritized and variously argillaceous, *finely* to *very finely crystalline* **dolostone** (carbonate grains in places in original rock 25–50%) with rare dolomitic marlstone interbeds. Discontinuity surfaces are pyritized and rarely slightly phosphatized
			D-27, D-28	70.5	C C Ch Ch; T C K K K K		Massive	< 1 cm; IND		Light grey, with green and brown shade, pyrite mottled, *very finely crystalline* **dolostone** with argillaceous marlstone patches and horizontal burrows. Discontinuity surfaces are pyritized
	Vilsandi Beds	11	D-29	71.2	C Ch TK; C C Ch; C Ch; C Ch		Indistinctly bedded			Light brownish-grey *very finely crystalline* **biohermal dolostone** rich in vugs (often moulds of corals).
		12, 13	D-30	76.0–83.0	C Ch TK; C TK; C Ch; C Ch K; C C Ch Ch; C Ch; TK; C C Ch Ch TK; C Ch		Wavy, indistinctly thin- to medium-bedded	< 0.2, 0.2–2 cm; IND dark grey	< 10	Light brownish-grey (the lower part darker), in places pyritized, *finely* to *very finely crystalline* (locally *medium-* to *finely crystalline*) **dolostone** (carbonate grains in original rock > 50%) with rare dolomitic marlstone interbeds

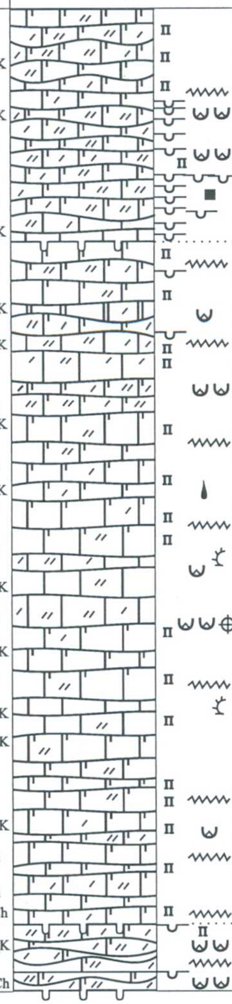
STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO. / FIGURES	DEPTH (m) / SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Wenlock	Jaagarahu Stage; Jaagarahu Fm. Vilsandi Beds	13	83.0; C Ch; C Ch Ch; TK K; C Ch C Ch K; C Ch; C Ch		Wavy, indistinctly medium-bedded, rarely thin-bedded	< 0.2, 0.2–2 cm; IND greenish-grey	< 2	Light brownish-grey, often pyrite mottled, in places argillaceous, *very finely* to *finely crystalline* **dolostone** (grains < 10% and 25–50%) with dolomitic marlstone patches and interbeds. Discontinuity surface is pyritized
	Jaani Stage; Jaani Formation; Ninase Member	14	87.6; C Ch K; C Ch TK; C Ch TK; C Ch; C K; C Ch; K; C Ch		Indistinctly wavy, thick- to medium-bedded	< 0.2, 0.2–2 cm; IND grey	1–5	Light grey, with brown shade, in places pyrite mottled and argillaceous, *finely* to *very finely crystalline* **dolostone** (grains in layers < 10%, < 20%, 25–50% and > 50%; often recrystallized, in the lowermost part accompanied by iron sulphides) with dolomitic marlstone films, patches and interbeds. Discontinuity surfaces are pyritized
		15; D-31; D-32	92.0; C Ch KK; C Ch TK; C Ch KK; TK		Indistinctly bedded	< 0.2, 0.2–2 cm; IND grey	1–2	Light greenish-grey, rarely pyritized, *finely* and *very finely crystalline* **dolostone** (grains locally 25–50% and > 50%; coarse bioclasts rounded and in places dissolved) with rare dolomitic marlstone films, patches and interbeds. The discontinuity surface is pyritized
		16; D-33; D-34	95.3; C Ch; C K; C Ch K; C Ch KK; C Ch; C C Ch		Wavy and horizontal, indistinctly thin- to medium-bedded, in places indistinctly nodular, below 97.7 m inclined	< 0.2, 0.2–2 cm; IND and D greenish-grey	1–5	Light brownish-grey, in places greenish-grey, pyritized and argillaceous, *very finely* to *finely crystalline* **dolostone** (grains 25–50%, in places > 50%) with rare dolomitic marlstone films, patches and interbeds. Bioclast (rounded, oriented parallel to bedding) content and size increase upwards. Discontinuity surfaces are pyritized
	Mustjala Member	17; D-35	99.6; C Ch K; C Ch; C C Ch TK; C		Indistinctly thick- to medium-bedded, in places nodular	0.5–15 cm; IND and D greenish-grey	70–80	Greenish-grey **dolomitic marlstone** (bioclasts < 25%) with light grey, *very finely crystalline* **dolostone** and rare dolomitic limestone (grains < 25%, locally 40–50%, in places pyritized) nodules and interbeds (thickness 1–5 cm; variously argillaceous)
		17; 18; D-36; D-37	102.8; C C Ch; K; C Ch; C K; C Ch; C C Ch; C Ch K; C C Ch; C K; C Ch		Indistinctly medium-bedded and nodular	0.2–10 cm; IND and D grey and dark grey	60–80	Grey to dark grey **calcitic marlstone** (bioclasts in places up to 30%) with light greenish-grey interbeds (thickness up to 5 cm) and nodules of variously argillaceous and dolomitized *finely crystalline* **limestone** (grains < 30%). Below 110.7 m contacts between **dolomitic marlstone** and dolomitized limestone are indistinct, limestone is *very finely crystalline* and the content of coarse bioclasts decreases. Horizontal burrows are pyritized, in the lowermost part bituminous. At 112.6–113.0 m fragments of a coral colony are found

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES / LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Wenlock	Jaani Stage, Jaani Formation, Mustjala Member	18, 19	D-38	115.0					☞ follow up
Llandovery	Jaani Stage, Jaani Formation, Mustjala Member	19, 20		115.0–121.1		Indistinctly medium-bedded and nodular	1.0–10 cm; IND grey and dark grey	60–80	Grey to dark grey **marlstone** (bioclasts < 10%, rounded) with lighter interbeds (thickness up to 5 cm) and nodules of highly argillaceous *very finely crystalline* **dolostone** (grains < 25%). Burrows are pyritized. The level of 115.0–115.1 m is the **Lusklint K-bentonite** bed. The K-bentonite bed on the lower boundary (thickness 8 cm) is covered with burrowed rock
Llandovery	Adavere Stage, Velise Formation	21, 22		121.1–131.1		Wavy and horizontal, thick- to medium-bedded with rare nodules, in places thin- to microbedded	0.2–12 cm; IND and D greenish-grey	80–95	Greenish-grey **marlstone** (bioclasts < 10%) with calcitic marlstone and rare argillaceous, dolomitized *very finely crystalline* limestone nodules and interbeds (thickness up to 2 cm). Burrows are pyritized. A **K-bentonite** bed occurs on the lower boundary
Llandovery	Adavere Stage, Velise Formation	23, 24		131.1–137.0		Indistinctly medium-bedded and nodular	0.5–5 cm; IND and D dark greenish-grey	20–40	Dark greenish-grey **marlstone** (bioclasts < 5%, heaped in areas up to 1 cm across) and **dolomitic claystone** with nodules of argillaceous, dolomitized limestone. Abundant burrows (up to 0.5 cm across) are often pyritized. At 145.7, 147.5, 148.0, 148.8, 149.4, 151.8 and 152.1 m **K-bentonite** beds are found

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Llandovery	Adavere Stage Velise Formation	24 25 26	D-39 D-40					40–50 70–80	☞ follow up
		27		153.8		Wavy, indistinctly medium-bedded and nodular	1–10 cm; D dark violetish- and greenish-grey	70–80	Dark violetish- and greenish-grey **marlstone** (bioclasts < 10%, locally 10–20%) with greenish-grey *microcrystalline* limestone nodules and interbeds (thickness up to 5 cm). Some layers are limonitized
		28 29		156.2 166.3		Indistinctly medium-bedded and nodular	1–10 cm; IND and D dark greenish-grey	40–60	Intercalation of dark greenish-grey **marlstone** and **dolomitic claystone** interbeds (thickness up to 8 cm), with argillaceous dolomitized limestone nodules and interlayers (thickness up to 4 cm). Bioclasts (in places < 5%) are often pyritized. The upper part contains limonitized layers. At 156.8 m a **K-bentonite** bed is found

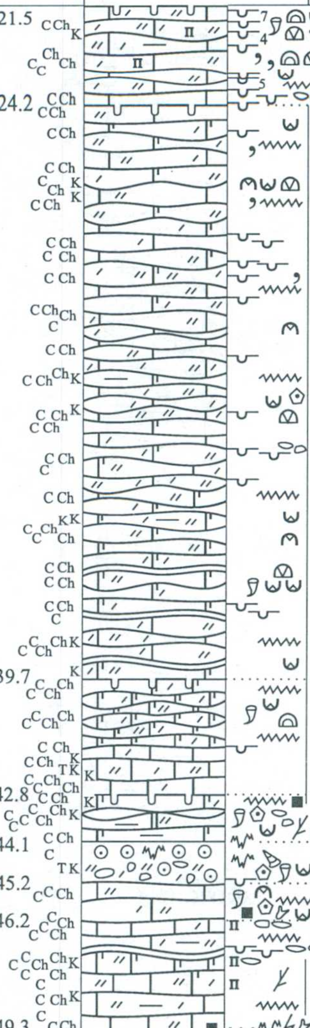
STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Llandovery	Adavere Stage; Velise Formation	29, 30	D-41, D-42	166.3			Wavy and horizontal, indistinctly medium-bedded and nodular, claystone, in places microbedded	1–5 cm; IND (D) dark greenish-grey and greenish-grey	20–60	Dark greenish-grey, in places dolomitic **claystone** with marlstone interbeds (thickness in the upper part up to 10 cm) and argillaceous limestone nodules and interlayers (thickness up to 4 cm). Bedding planes of microbedded claystone are covered by light silt-grade material and mica flakes. Bioclasts (in places < 10%) are often pyritized. In places violet, brownish-red and ochre-yellow patches and interbeds (thickness 1–20 cm) occur. At 169.6, 172.0, 173.1 and 174.4 m **K-bentonite** beds are found
		31		175.5			Wavy and horizontal, indistinctly thin- to medium-bedded and nodular	0.5–5 cm; IND (D) greenish-grey and reddish-brown	40–70	**Marlstone** with claystone interbeds and argillaceous limestone nodules and interlayers (thickness up to 3 cm). In the upper part rock is greenish-grey with reddish-brown interlayers, below 177.7 m mainly reddish-brown. Bioclasts form in places 5–10%. At 177.55, 177.7, 178.2 and 178.8 m **K-bentonite** beds are found
		32		179.2			Wavy and horizontal, indistinctly thin- to medium-bedded and nodular, claystone, in places microbedded	0.2–6 cm; D (IND) greenish-grey and reddish-brown	70–80	Greenish-grey and reddish-brown (rarely violet) mainly **calcitic marlstone** (grains locally < 25%) with light greenish-grey limestone nodules. Reddish-brown, in places greenish-grey **dolomitic claystone** with horizontal burrows occurs below 181.5 m. At 181.0, 181.8 and 182.3 m **K-bentonite** beds are found
	Rumba Formation	33		183.5			Wavy and horizontal, indistinctly medium-bedded and nodular, in places thick- and thin-bedded, marlstone and K-bentonite often microbedded	0.2–10 cm; D dark greenish-grey, brownish- and greenish-grey	50, 60, 50, 50, 40	Intercalation of **limestone** and **calcitic marlstone**. Claystone nodules and interbeds (thickness up to 6 cm) are observed. Light grey, greenish- and brownish-grey, in the upper part dolomitized, variously argillaceous **limestone** (grains 10–25%, 25–50%, in places < 10% or > 50%) is *very finely crystalline* to *cryptocrystalline*. Rare carbonate clasts are rounded and have pyritized edges. Burrows are mainly horizontal. At 184.35 and 185.1–185.2 m **K-bentonite** beds (the latter one Osmundsberg) are found. The discontinuity surface is pyritized
	Raikküla Stage; Nurmekund Fm.; Järva-Jaani Beds	34, 35	D-43	190.7–194.9			Wavy, indistinctly thin- and medium-bedded and nodular	< 0.2, 0.2–2 cm; D grey, brownish- and greenish-grey	< 5	Light-grey, locally pyritized, dolomitized, *crypto-* to *very finely crystalline* **limestone** (grains < 25%) with argillaceous limestone and marlstone interbeds and patches. Bioclast-rich (25–50% and > 50%) interbeds (up to 5 cm thick) at 191.6, 191.7, 192.0, 192.2 and 194.5 m are poorly sorted and selectively silicified. Discontinuity surfaces are pyritized

VIKI DRILL CORE

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO. / FIGURES	DEPTH (m) / SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Llandovery	Raikküla Stage Nurmekund Formation Järva-Jaani Beds	35 36	194.9 C; C ChK; C Ch K; C Ch C; C Ch; C K 201.2		Wavy, indistinctly nodular, in places medium- and thin-bedded	< 0.2, 0.2–2 (4) cm; D grey and greenish-grey	10 30 10 5	Light grey and beigish-grey, in places pyritized, dolomitized, *crypto-* and *microcrystalline* **limestone** (grains 10–25% and 25–50%) with calcitic marlstone and argillaceous limestone patches, films and interbeds. Bioclast-rich intervals (> 50%, thickness 3–35 cm) are often pyritized and contain carbonate clasts; brachiopods (*Stricklandia*?) occur at 197.75–197.90 and 198.77–198.8 m. Discontinuity surfaces are pyritized
		37 38 39	C Ch; C K; C C Ch T K; C; C Ch K; C Ch; K; C Ch C C Ch; C K; C Ch; C K; C Ch; C K; C Ch K; C; C Ch K; C Ch; C Ch Ch; C C Ch 219.7		Wavy and horizontal, thick- to medium-bedded, with indistictly thin-bedded intervals (thickness up to 12 cm); marlstone in places microbedded	< 0.2, 0.2–2 (3) cm; D grey and brownish-grey	2–5	Light brownish-grey, in places pyritized, variously dolomitized, *micro-* and *cryptocrystalline* **limestone** (grains mainly 10–30%) with argillaceous limestone and calcitic marlstone films, patches and interbeds. Marlstone is in places bituminous and contains dendroidea. Bioclast-rich layers (> 50%; thickness 3–5 cm) prevail in the interval 203.75–205.75 m. Burrows have often pyritized edges. Discontinuity surfaces are pyritized
		40	C ChK; C C Ch C Ch 221.5		Indistinctly nodular	< 0.2, 0.2–2 (3) cm; D greenish-grey	30	Light brownish-grey, dolomitized, *microcrystalline* (the uppermost 0.3 m) and *very finely crystalline* **limestone** (grains 10–25%, in places 25–50% and >50%) with calcitic marlstone and argillaceous limestone films, patches and interbeds. Layers rich in shells of the brachiopod *Borealis* occur at 220.45–220.60 m and fragments of the brachiopod *Stricklandia* at 221.35–221.42 m. Discontinuity surfaces are pyritized

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE
Llandovery	Juuru Stage; Tamsalu Fm.	40		221.5–224.2	Wavy, indistinctly thin- to medium-bedded and nodular	< 0.2, 0.2–1 (3) cm; D greenish-grey	10–20
Llandovery	Juuru Stage; Varbola Formation	41, 42, 43		224.2–239.7	Indistictly nodular, rarely medium- and thin-bedded	< 0.2, 0.2–1.5 (8) cm; D greenish-grey	20–30
Llandovery	Juuru Stage; Varbola Formation; Koigi Mb.	44	D-44	239.7–242.8	Indistinctly nodular, the lower part thin- and medium-bedded	< 0.2, 0.2–3 cm; D greenish- and brownish-grey	10–20; 5–10
Upper Ordovician (Ashgill)	Porkuni Stage; Saldus*; Br*		D-45, D-46	242.8–244.1	Thin- and microbedded with nodules	< 0.2, 0.2–1 cm; IND dark greenish-grey	1–2
Upper Ordovician (Ashgill)	Porkuni Stage; Saldus*; Pi*	45	D-47	244.1–245.2	Horizontal, the lower part inclined		
Upper Ordovician (Ashgill)	Porkuni Stage; Är*; Rö*			245.2–246.2	Medium-, thin-bedded	< 0.2, 0.2–1 cm; IND greenish-grey	1–2
Upper Ordovician (Ashgill)	Pirgu Stage; Adila Fm.; Kabala Mb.	46	D-48, D-49	246.2–249.3	Indistinctly nodular, thin- and medium-bedded	< 0.2, 0.2–3.0 cm; D grey and dark greenish-grey	< 40

LITHOLOGY



SHORT DESCRIPTION

Light brownish-grey, in places pyritized, *very finely crystalline* **limestone** (grains 10–25% and 25–50%, in places > 50%) with marlstone and greenish-grey argillaceous limestone patches, films and interbeds. Carbonate clasts have pyritized edges. Discontinuity surfaces are pyritized. (The interval 221.5–222.6 m probably belongs to the Hilliste Member)

Light brownish-grey, in places greenish-grey and pyritized, dolomitized *very finely crystalline* **limestone** (grains mainly < 25%) with calcitic marlstone and argillaceous limestone films, patches and interbeds. Interlayers of greenish-grey plastic clay are found. Bioclast-rich layers (25–50% and > 50%; thickness 1–5 cm) prevails in the lower part of the complex. Some burrowed interlayers (thickness up to 10 cm) in the upper part contain glauconite. Discontinuity surfaces are pyritized

Light grey, locally dolomitized *micro-* and *cryptocrystalline* **limestone** (grains < 10%, in places 25–50%) with marlstone and argillaceous limestone films, patches and interbeds. The lowermost 0.12 cm contains sandy marlstone layers. Discontinuity surfaces are pyritized

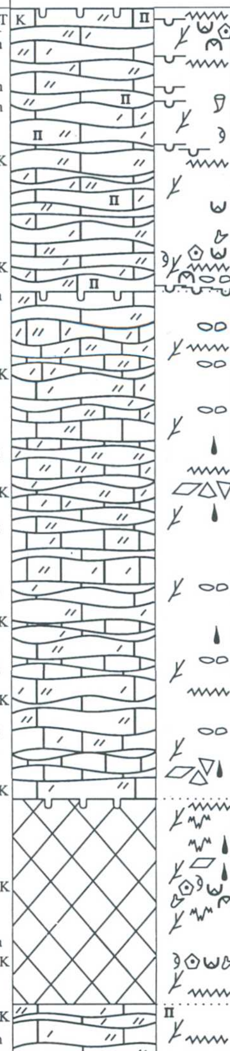
Light grey, variously dolomitized *very finely crystalline* **limestone** (grains in places < 30%) with marlstone and argillaceous limestone films, patches and interbeds. Quartz silt-sized grains and carbonate clasts are found. The uppermost 20 cm contains vertical cracks and burrows

Whitish-grey stylolite-rich **oolitic limestone** and **limestone** with carbonate and bioclasts (grains in places up to 50%; mainly up to 5 mm across). Content of well-rounded calcareous ooliths (up to 3 mm across) increases unevenly upwards from 10 to 70% of the rock

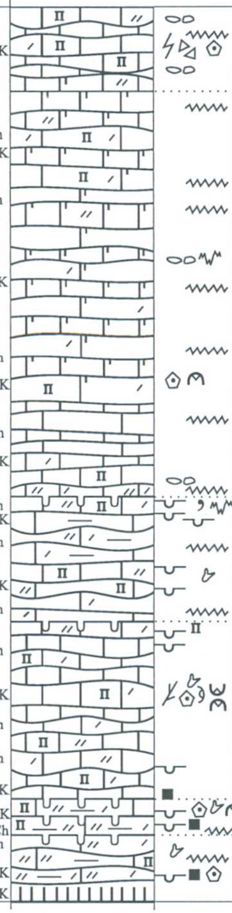
Light greenish-grey, *finely* and *very finely crystalline* **limestone** (grains in places < 20%) with marlstone films and interbeds. The lowermost 20 cm contains horizontal burrows

Light grey, in places pyritized and argillaceous, *very finely crystalline* and *microcrystalline* **limestone** (grains 10–25%, in places >30%) with argillaceous limestone and marlstone films, patches and interbeds. Carbonate pebbles are found. Discontinuity surfaces are pyritized

Är*– Ärina Formation; Saldus*– Saldus Formation; Rö*– Röa Member; Pi*– Piltene Member; Br*– Broceni Member

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Ashgill)	Adila Formation	46, 47		249.3–257.0	C Ch K T, C C Ch Ch, C Ch, C C Ch Ch C, C Ch K, C Ch, C Ch, C, C Ch, C TK		Wavy, medium-bedded with indistinctly thin-bedded and nodular intervals	< 0.2, 0.2–3 (5) cm; D dark greenish-grey and greenish-grey	< 10	Light grey, in the lower part beigish-grey, in places pyritized, *very finely crystalline*, locally *finely crystalline* and *microcrystalline* **limestone** (grains 10–25%, in places 25–50%) with marlstone (bio- and carbonate clasts < 20%) patches, films and interbeds. Fragments of calcareous algae *Palaeoporella*? (=*Dasyporella*) and *Vermiporella* are present, particularly at 251.8–257.0 m. Discontinuity surfaces are pyritized
	Pirgu Stage, Moe Formation	48, 49, 50	D-50, D-51	257.0–270.8	C Ch, C, C, C Ch K, C, C, C Ch, C K, C, C Ch, C, C, C Ch, C K, C, C Ch, C K, C, C Ch, C, C K		Wavy, thick- and medium-bedded, with indistinctly thin-bedded, nodular and breccial intervals	< 0.2, 0.2–1.0 (4) cm; D dark grey, the lowermost 1.0 m greenish-grey	5–10	Light beigish-grey, *microcrystalline* and *very finely crystalline* **limestone** (grains mainly < 30%) with marlstone (bioclasts 10–20%) and argillaceous limestone films, patches and interbeds. Fragments of *Vermiporella* are dominating. At 261.0–267.5 and 269.2–270.2 m limestone has often bituminous edges (width up to 1 cm) in contact with marlstone. Rare bituminous patches occur in limestone. The lowermost 1.0 m contains lens-shaped patches of greenish-grey claystone. The discontinuity surface is pyritized
		51	D-52, D-53, D-54, D-55	270.8–276.4	C, C, C Ch TK, C, C Ch TK, C		Wavy, indistinctly bedded, the lower part thin- to medium-bedded	< 0.2, 0.2–0.4 cm; D greenish-grey	1–2	Light grey with green shade, *very finely crystalline* to *microcrystalline* **biohermal limestone** (grains 10–30%, in places 30–50%). Fragments of *Palaeoporella*? (= *Dasyporella*) are dominating. At 270.8–274.7 m stylolites are common, the lower part contains marlstone films and interbeds. Bituminous patches and druses with calcite crystals are observed
		52		276.4	K, C Ch, C Ch, C				1–5	☞ follow down

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Ashgill)	Pirgu Stage Moe Formation	52 53	D-56	288.6	C, C Ch K, C, C, C Ch TK, C, C Ch, C, C, C Ch, C, C, C Ch, C TK, C, C CCh K K		Wavy, medium- and thick-bedded with indistinctly thin-bedded intervals	< 0.2, 0.2–0.5 (3) cm; D dark grey	2–5	Light grey with brown shade, in places pyritized, *very finely crystalline* to *microcrystalline*, in places *finely* and *cryptocrystalline* **limestone** (grains 30–40%, in places < 20% and 40%) with marlstone (bioclasts in places < 30%) patches, films and interbeds. Fragments of calcareous algae *Palaeoporella*? (=*Dasyporella*) are dominating in 20 cm thick interlayers with indistinct borders. The lowermost 40 cm contains stylolites, marlstone interbeds missing. The discontinuity surface is pyritized
	Vormsi Stage Tudulinna Formation	54 55 56		300.6	C Ch, C K, C Ch, C Ch, C, C Ch, C, C, C Ch K K, C, C, C Ch, C, C Ch, C, C C K, C Ch		Nodular, in places thick- and medium-bedded, rarely thin-bedded	< 0.2, 0.2–10 (12) cm; IND (D) dark greenish-grey, locally with violet spots	10 40–80 10–15	**Marlstone**, in the lower part locally dolomitized, with **argillaceous limestone** nodules and interbeds. The upper- and lowermost parts contain argillaceous **limestone** with marlstone films, patches and interbeds. Greenish-grey *finely* and *very finely crystalline* **limestone** (grains < 25%, mainly fine bioclasts) is mainly medium to highly argillaceous with horizontal burrows. Burrows in marlstone have iron-containing edges. At 298.0–299.4 m highly argillaceous marlstone layers comprise silt-sized quartz. The lowermost 0.2 m contains pyrite, pyritized bioclasts and horizontal films similar to stylolites
(Caradoc)	Nabala Stage Saunja Formation	57	D-57 D-58		C, C Ch TK, C, C Ch, C K, C, C Ch TK		Indistinctly thin- to medium-bedded, locally breccial	< 0.2, 0.2–0.5 cm (1–3 cm); D brownish-grey, the lowermost 2 m greyish-brown	1–2	Light beigish-grey, pyrite mottled *crypto-* to *microcrystalline* **limestone** (grains 1–2%) with rare argillaceous limestone and marlstone patches, films and interbeds. The beds at 301.9 and 307.0–307.6 m contain borings (about 3 cm across) formed in rigid rock. Indistinct layers comprise angular and variously rounded carbonate clasts (0.01–5 cm across)

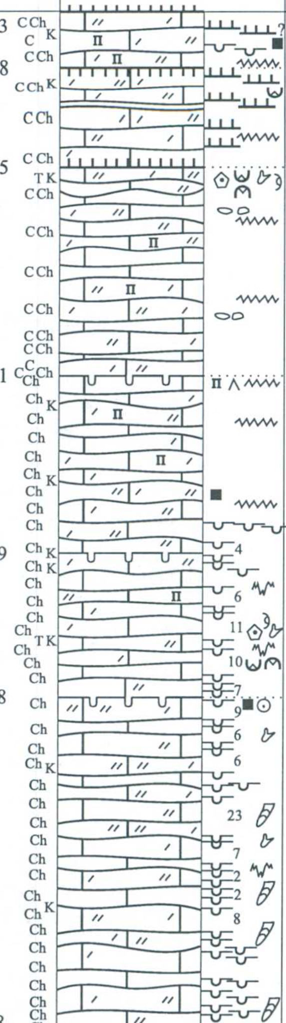


STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Caradoc)	Nabala Stage, Saunja Formation	57	D-59		C, C, TK, C				☞ follow up
	Nabala Stage, Saunja Formation	58, 59, 60	D-60, D-61	308.3	C, C, CCh, K, C, CCh, C, C, CCh K, C C, CCh, C TK, C, C CCh, CCh K, C	Wavy, locally inclined and horizontal, thick- and medium-bedded with indistinctly micro- and thin-bedded intervals (thickness 1–2 cm)	< 0.2, 0.2–2.0 cm; D brownish-grey	2–5	Whitish-grey, in places pyritized and dolomitized, *very finely crystalline* to *microcrystalline*, locally *cryprocrystalline* **limestone** (grains in places < 10%) with marlstone and argillaceous limestone films, interbeds and rare patches. Burrows are mainly horizontal and seem locally bituminous. At 312.9–313.0 m elongated carbonate fragments (length up to 3 cm) and stylolites are found. The discontinuity surface is pyritized
	Nabala Stage, Paekna Fm.	60	D-62	319.3	CCh K, CCh, C, CCh K, C CCh	Indistinctly thin- and medium-bedded	< 0.2, 0.2–0.5 cm; D dark greenish-grey and dark grey	5	Light greenish-grey, with greenish-grey and beigish-grey interbeds, pyrite mottled, *micro-* to *cryptocrystalline* and *very finely crystalline* **limestone** (grains in places < 25%) with argillaceous limestone and marlstone films, interbeds and rare patches. Discontinuity surfaces are pyritized
	Rakvere Stage, Rägavere Formation	61	D-63	322.7, (323.6)	CCh, CCh TK, CCh, CCh	Indistinctly thick- and medium-bedded	< 0.2, 0.2–2.0 cm; D dark grey	1–2	Light beigish-grey, in places pyrite mottled, *very finely crystalline* to *microcrystalline*, locally *cryptocrystalline* **limestone** (grains < 10, in places 10–40%) with argillaceous limestone and calcitic marlstone films, interbeds and rare patches. Calcite-filled veins are found. Discontinuity surfaces are pyritized
	Oa*, T*	61	D-64	327.5	CCh K, Ch	Indistinctly thin- and medium-bedded	0.2–3.0 cm; D and IND	< 5	Light greenish-grey (locally with brown shade) *very finely crystalline* **limestone** (grains in places < 30%) with argillaceous limestone and marlstone interbeds (= Tõrremägi Member). Greenish-grey, medium to highly argillaceous *very finely crystalline* **limestone** (grains 20–30%) with marlstone lenses and interbeds (= Hirmuse Formation). All discontinuity surfaces are pyritized
	Oa*, H*	62	D-65	328.0	CCh Ch K		dark greenish-grey	40	
	Keila Stage, Kahula Fm.	62	D-66	328.5–330.3	CCh, C Ch Ch K	Medium-bedded with micro- and thin-bedded intervals	< 0.2, 0.2–0.5 cm; D dark grey	10	Light grey, slightly to highly argillaceous, *finely* to *very finely crystalline* **limestone** (grains in places < 30%) with marlstone interbeds. A **K-bentonite** bed lies at 329.8–330.3 m. The discontinuity surface is pyritized

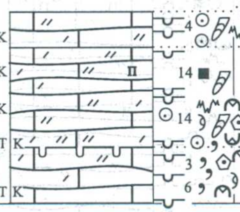
Oa*– Oandu Stage; H*– Hirmuse Formation; T*– Tõrremägi Member

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Caradoc)	Haljala Stage; Kahula Formation; Jõhvi*	62	D-67, D-68	330.3–331.8	Wavy, medium- and thick-bedded	< 0.2, 0.2–0.5 cm; D dark grey	< 5	Light grey, in places argillaceous, *very finely crystalline*, locally *finely crystalline* **limestone** (grains < 30%) with rare marlstone films and interbeds. Discontinuity surfaces are pyritized. **K-bentonites*** are found
Upper Ordovician (Caradoc)	Haljala Stage; Kahula Formation; Vasavere*	62, 63	D-69	331.8–334.5	Wavy, thick- and medium-bedded, with microbedded intervals	< 0.2, 0.2–3.0 cm; D dark greenish- and bluish-grey	5–10	Light grey, *very finely crystalline* **limestone** (grains in places 10–25% and 40%) with marlstone films and interbeds. Bioclasts are often impregnated with iron compounds. **K-bentonites*** consist mainly of two parts
Upper Ordovician (Caradoc)	Haljala Stage; Idavere*; Tatruse Formation	63, 64	D-70	334.5–340.1	Wavy, medium-bedded, with microbedded intervals (thickness up to 5 cm), rarely thick-bedded	< 0.2, 0.2–0.5 cm; D dark grey	5	Light grey, *crypto-* to *microcrystalline* and *very finely crystalline* **limestone** (grains 10–30%, in places 30–50%, often pyritized) with marlstone films and interbeds. The discontinuity surface is pyritized; the lowermost part is phosphatized and kerogenous
Upper Ordovician (Caradoc)	Kukruse Stage; Pihla Formation	64, 65		340.1–344.9	Wavy, thick- and medium-bedded	< 0.2, 0.2–0.5 cm; D dark grey	1–2	Light grey (light brownish-grey patches are *finely crystalline*) *very finely crystalline* **limestone** (grains 10–40%, often pyritized and oriented parallel to bedding) with rare marlstone films (in places stylolite-like) and interbeds. A phosphatized discontinuity surface lies on the lower boundary, the upper boundary is pyritized
Middle Ordovician (Llanvirn)	Uhaku Stage; Kõrgekallas Fm.	65, 66		344.9–348.8	Wavy, indistinctly thin- and medium-bedded	< 0.2, 0.2–0.5 cm; D dark grey	1–3	Light grey, *crypto-* to *microcrystalline* and *finely crystalline* to *very finely crystalline* **limestone** (grains 10–25%, in places 40–50%) with marlstone films and patches. Wavy discontinuity surfaces are phosphatized, rock impregnation is weak
Middle Ordovician (Llanvirn)	Uhaku Stage / Lasnamägi St. ?; Väo Formation	66, 67, 68		348.8–357.8	Wavy, indistinctly medium-bedded, locally thin- and thick-bedded	< 0.2, 0.2–0.5 cm; D dark grey	1–2	Light grey to grey, *very finely* and *finely crystalline* **limestone** (grains 10–25%, in places < 40%; often pyritized and recrystallized) with marlstone films and patches. Wavy and rugged discontinuity surfaces are phosphatized, rock impregnation is weak

SAMPLES / LITHOLOGY



Idavere*– Idavere Substage; Jõhvi*– Jõhvi Substage; Vasavere*– Vasavere Member. **K-bentonite*** beds of the Kahula Formation (Idavere and Jõhvi substages, Haljala Stage): 330.70–330.75 m; 330.88–330.90 m; 331.77–331.80 m; 331.97–332.00 m; 332.13–332.20 m; 332.67–332.70 m; 332.85–332.88 m; 333.35–333.40 m; 333.90–333.92 m; 334.48–334.50 m.

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Middle Ordovician (Llanvirn)	Aseri Stage, Kandle Fm.	68	D-71	357.8–358.8	Ch, T K, Ch		Wavy, thick- and medium-bedded	< 0.2, 0.2–0.3 cm; D dark grey	1–2	Light grey, with darker grey and violet patches, *finely* and *very finely crystalline* **limestone** (grains < 25%, in places 40–50%) with marlstone films and wavy yellow limonitized discontinuity surfaces. Lenses and interbeds contain 5–25% iron oolith-like grains
	Kunda St., Loobu Fm.			358.8–361.5	Ch K, Ch, T K, Ch, T K		Wavy, thin- and medium-bedded, rarely thick-bedded	< 0.2 cm; D dark grey	1–2	Light grey, with darker patches, *finely*, locally *very finely crystalline* **limestone** (grains 10–50%, often pyritized) with marlstone films and wavy phosphatized discontinuity surfaces. At 361.3–361.5 m violet spots and patches with iron ooliths and iron-impregnated grains (< 40% of the rock) are found; brownish-grey inclined surfaces occur on the upper boundary
Lower Ordovician ? (Arenig)	Billingen? Stage, V*; Toila Formation, Päite? Member, S*	69		361.5–363.0 (362.25)	Ch, Ch, Ch T K		Wavy, thick- and medium-bedded	< 0.2, 0.2–0.3 cm; D dark greenish-grey	1–2	Light grey, pinkish-, yellowish, greenish- and reddish-grey mottled, *very finely* and *finely crystalline* **limestone** (grains 20–50%) with rare marlstone films. Glauconite grains (mainly 10%, in patches < 30%) are often dark green, in places impregnated with iron compounds. Wavy and rugged discontinuity surfaces are limonitized. The interval 362.25–363.00 m probably belongs to the Lower Ordovician

V*– Volkhov Stage; S*– Saka Member

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