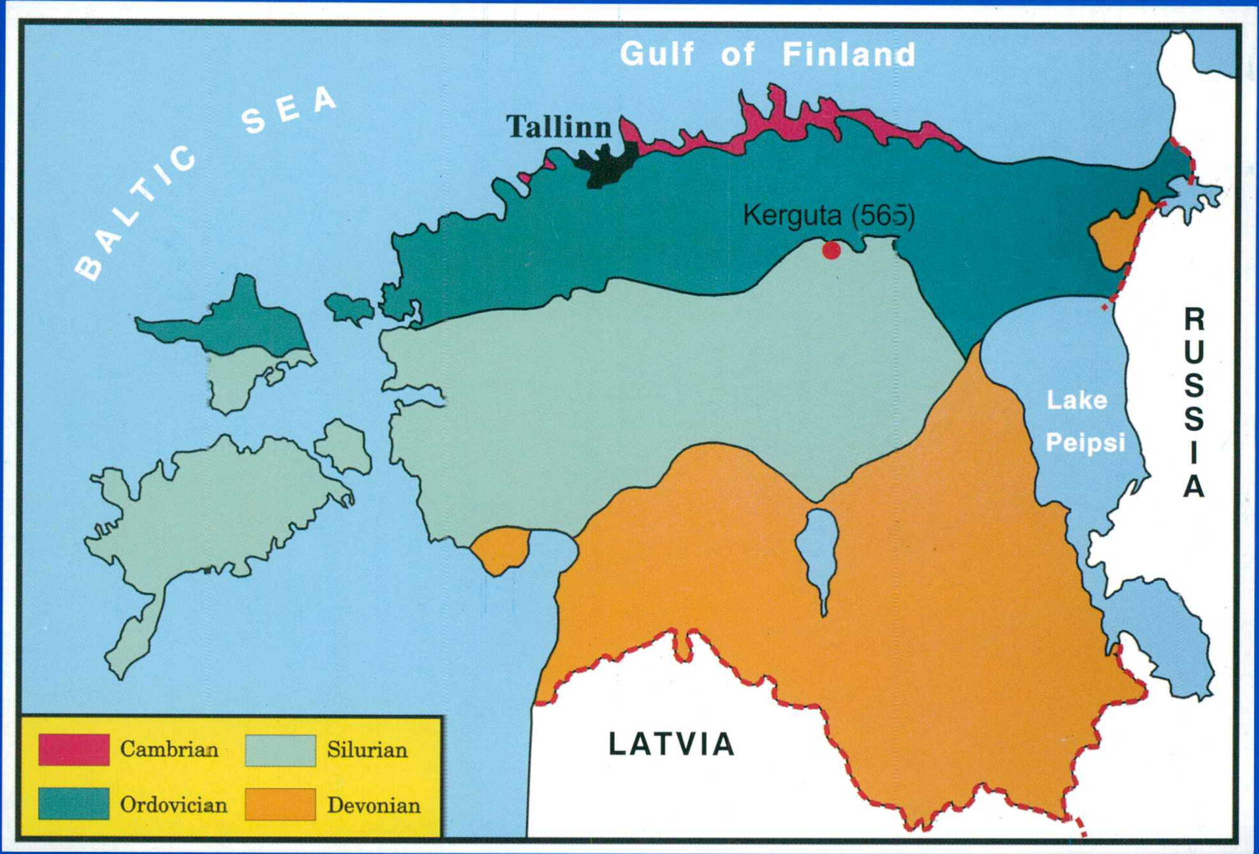
EESTI GEOLOOGIAKESKUS
GEOLOGICAL SURVEY OF ESTONIA

ESTONIAN GEOLOGICAL SECTIONS

BULLETIN 7

KERGUTA (565) DRILL CORE



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PREFACE

Detailed restudy of selected high-quality drill cores was started at the Geological Survey of Estonia in 1995. Six issues of the journal *Estonian Geological Sections* have been published until now, each dealing with one drill core. The bedrock succession studied ranges from the Proterozoic (Palaeoproterozoic–Neoproterozoic) to Palaeozoic (Cambrian–Devonian). The stratigraphic subdivision of the sections has been improved on the basis of new data on the distribution of chitinozoans, conodonts and ostracods in the Ordovician and Silurian, and acanthodians in the Devonian. Rock composition has been specified by thin sections, and different chemical and mineralogical analyses. Stable isotope data of Ordovician and Silurian rocks were first included in the 2003 issue.

More than 70 people have contributed to the publication of the journal, including 41 authors from eight geological institutions of the USA, Denmark, Lithuania and Estonia. A large set of data has been compiled as a result of long-term collaboration between the authors, and thus the journal can be considered as a kind of Estonian geological heritage from older generation to younger.

The present issue of *Estonian Geological Sections* concentrates on the Kerguta (565) core (also known by the name of Tamsalu). The Kerguta drill hole in northern Estonia was made in the course of complex geological-hydrogeological mapping (at a scale of 1:50 000) of the phosphorite-bearing sediments of Rakvere district (Saadre *et al.* 1984). The core is housed at Särghaua field station of the Institute of Geology at Tallinn University of Technology (IGTUT). The source material for the present study is available in unpublished reports (Saadre *et al.* 1984; Põldvere & Saadre) stored in the Depository of Manuscript Reports of the Geological Survey of Estonia (GSE), Kadaka tee 82, Tallinn. The results of earlier oil shale exploration (Kattai & Reinsalu 1991; Bauert & Kattai 1997; Kattai 2000) and micropalaeontological, mineralogical and chemical investigations (Männil 1986; Männil & Saadre 1987; Sturesson & Bauert 1994; Bauert & Bauert 1996) are used in this work together with recently obtained data.

INTRODUCTION

The Kerguta (565) drill hole (59° 07′ 40” N, 26° 00′ 45” E) is located in the NW part of the East European Platform, to the south of the town of Tapa, near the Kerguta village (Fig. 1). The 192.9 m deep drill hole penetrates the Ordovician (178.5 m) and Silurian (7.4 m) sedimentary rocks and 7.0 m thick loose Quaternary deposits (Fig. 2).

The macrolithological characterization of the lower part of the Ordovician (up to the Kukruse Stage) was compiled by Tõnis Saadre (GSE). Anne Põldvere (GSE) provided the lithology of the upper strata (from Haljala to Juuru stages), using as supplementary material the description by Tiina Haas. The description of the core was improved using the results of laboratory studies.

To specify the stratigraphic subdivision of the Kerguta (565) section, Ordovician sediments were additionally sampled for microfossils. Chitinozoans from the interval of 135.25–181.44 m were identified by Garmen Bauert and Heikki Bauert (both from IGTUT) in 1996. In 2005, Jaak Nõlvak (IGTUT) took 52 new samples from the interval of 89.0–136.2 m and examined both the old and new collections (193 sam-

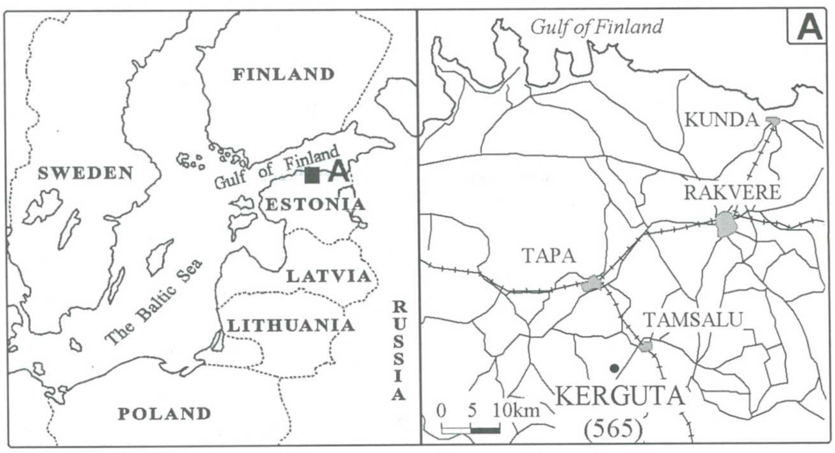

Fig. 1. Location of the Kerguta (565) drill hole

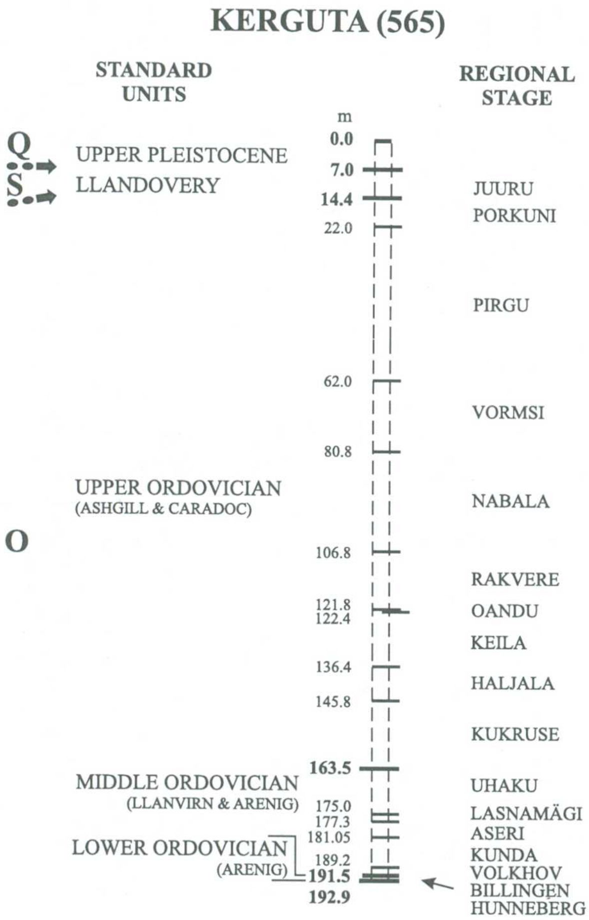

Fig. 2. Generalized stratigraphy of the Kerguta (565) core. O – Ordovician; S – Silurian; Q – Quaternary.

ples) for this work. Ordovician conodonts (75 samples) were identified by Viive Viira (IGTUT), Anita Löfgren and Lisa Sjöstrand (both from the Department of Geology, Lund University, Sweden).

Tõnu Martma (IGTUT) provided carbon isotope ($\delta^{13}C$) data of the Ordovician and lowermost Silurian rocks based on the analysis of 90 whole-rock samples.

Alla Shogenova (IGTUT) supplied results of wet silicate chemical (90 samples), X-ray fluorescence (XRF) spectrometry (90) analyses and measurements of physical properties (84; under the supervision of Fabio Donadini, University of Helsinki) of Ordovician and Silurian sediments. XRD and XRF analyses of 13 Ordovician volcanic ash beds were made by Toivo Kallaste (IGTUT) and Kiira Orlova (GSE). The contents of CaO, MgO and insoluble residue of 28 Ordovician samples, and the results of 82 semiquantitative arc emission spectral analyses of Ordovician and Silurian sediments obtained during complex geological-hydrogeological mapping of the phosphorite-bearing sediments of the Rakvere district were taken from Saadre *et al.* (1984).

Forty-five thin sections were made from the Ordovician and Silurian samples collected by Alla Shogenova. The thin sections were described by Jaanika Lääts (IGTUT) and Anne Põldvere (GSE) under the guidance of Asta Oraspõld (IGTUT).

Photos of the core and selected intervals were taken by Gennadi Baranov (IGTUT). Ranek Rohtla (GSE) and Elar Põldvere (Institute of Geography, University of Tartu) provided technical assistance.

Useful comments by Juho Kirs (Institute of Geology, University of Tartu), Jaak Nõlvak, Asta Oraspõld, Dimitri Kaljo (all from the IGTUT) and Jaan Kivisilla (GSE) were of great help in finalizing the report.

CORE DESCRIPTION AND TERMINOLOGY

The description of the Kerguta (565) core is presented in the form of a table (Appendix 1) including the main lithological features of the rock. The material studied comprises 131 chemical (103 XRF, and 28 CaO, MgO and insoluble residue analyses) and 13 XRD analyses, 82 semiquantitative emission spectral analyses, 84 physical properties analyses and 45 thin sections. Chitinozoans (193 samples) and conodonts (75 samples) were used for age specification in the Ordovician part of the section. Additionally, 90 Ordovician and lowermost Silurian carbon isotope ($\delta^{13}C$) samples were analysed.

The degree of dolomitization of carbonate rocks was determined during field work using 3% hydrochloric acid, whereas the content of clay was estimated visually. The rocks were referred to as slightly argillaceous (insoluble residue 10–15%), medium argillaceous (15–20%) and highly argillaceous (20–25%) (Oraspõld 1975). Different contents of calcite in marlstones are denoted by terms "calcareous" ($CaCO_3$ < 25%) or "calcitic" (> 25%). Dolomitic limestone contains 10–50% mineral dolomite.

The descriptions of the textures of carbonate rocks are based on the traditional Estonian classification by Vingisaar *et al.* (1965), Loog & Oraspõld (1982) and Nestor (1990), where the relative amounts of clastic and micritic components are crucial to identification of the textures. The content of carbonaceous clasts (including bioclasts) is given in most cases in per cent.

The particles with the diameter > 0.05 mm are described as grains. Skeletal remnants of organisms or their fragments (bioclasts) are mainly <1 mm in diameter. The size of chemogenic or biochemogenic ooliths is usually < 1 mm, while the size of carbonate intraclasts is > 1 mm. For the major part of the core, the amount of grains was determined with the magnifying glass on the slabbed surfaces of the core. The micritic component consists of particles < 0.05 mm in diameter. The terms used for textures are explained in Appendix 1. Depending upon the degree of recrystallization, several transitional textures can be observed (secondary textures occurring as patches or spots). 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.

The textures recorded are illustrated in photographs of thin sections of the Kerguta (565) core in Appendix 2 (on the CD-ROM).

Several sedimentary structures are described in the style used in the previous issues of the bulletin (see Põldvere 2001). The relationships between different parts of rock are given in Appendix 1. The variation of these structures in the Kerguta (565) core is illustrated in Appendixes 3 and 4 (on the CD-ROM). A selection of split core specimens collected by Heikki Bauert and stored at the Institute of Geology at Tallinn University of Technology is presented in Appendix 3 (with the prefix GIT). The numeration and levels of all specimens (GIT-1…72) are shown in Appendix 4.

GENERAL GEOLOGICAL SETTING AND STRATIGRAPHY

The bedrock succession of the Kerguta (565) core includes Ordovician (Lower, Middle, Upper) and Silurian (Llandovery) rocks (Fig. 2; Appendixes 1, 4–7), overlain by the Quaternary cover. The stratigraphy of the section is based on the correlation charts for the Ordovician of Estonia by Nõlvak (1997, p. 54, table 7) and for the Silurian by Nestor (1997, p. 90, table 8). Systematic data on Ordovician conodonts and chitinozoans are used for the biostratigraphical subdivision of the section (see Viira *et al.* and Nõlvak in this volume).

The **Lower Ordovician** (interval 191.5–192.9 m; Appendix 1, sheet 8) is represented by the Leetse (glauconitic quartz sandstone of the Joa Member and glauconitic limestone of the Mäeküla Member) and lowermost Toila formations (dolostones with scattered glauconite grains and glauconite layers of the Päite Member; Appendix 2, T-44 and T-45) corresponding to the Hunneberg and Billingen stages. The formations are widely distributed in northern Estonia. In southeastern and southern Estonia they are replaced by other lithostratigraphical bodies (Nõlvak 1997).

The Kerguta (565) drill core terminates in the lowermost part of the Hunneberg Stage (Joa Member of the Leetse Formation).

The **Middle Ordovician** (interval 163.5–191.5 m; Appendix 1, sheets 7, 8; Appendix 3, D-4…7; Appendix 4) is represented by the dolostones and limestones of the Toila, Sillaoru, Loobu, Napa, Aseri (Männil & Meidla 1994), Väo and Kõrgekallas formations corresponding to the Volkhov, Kunda, Aseri, Lasnamägi and Uhaku stages. The dolostones of the lower part (Saka Member) of the Middle Ordovician are violetish-red and yellow mottled. Some red- or yellow-coloured mottled interbeds are found in the Sillaoru, Loobu, Napa and Aseri formations. The rest of the Middle Ordovician comprises grey limestones and dolostones. The lower boundary of the Middle Ordovician at a depth of 191.5 m is marked by a widespread distinct smooth discontinuity surface with "amphora-like" borings (depth of borings up to 6 cm in Estonian sections).

The dolostones of the Toila Formation (in part of the Volkhov Stage) contain scattered glauconite grains, mainly 3–30% (Appendix 2, T-43). Rare glauconite grains are also found in the Nõmmeveski Member of the Loobu Formation.

Discontinuity surfaces are numerous in the whole of the Middle Ordovician, except oolith-bearing and vuggy dolostone intervals. In the Saka Member the surfaces are limonitized and uneven. Usually distinct limonitized and pyritized discontinuity surfaces alternate in the upper part of the Napa Formation. Indistinct phosphatized discontinuity surfaces, between which limestone is often burrowed (borings filled with clayey material), occur in the Väo and Kõrgekallas formations. In the uppermost part of the Middle Ordovician the surfaces (hardgrounds) are not impregnated.

Iron ooliths are found in the Sillaoru, Napa and Aseri formations. The limestone lenses and interbeds (1–5 cm thick) of the Sillaoru Formation contain up to 50% ooliths. Scattered ooliths in the limestones of the Napa Formation are present; the richest interval is at 181.9–182.45 m. The dolomitized limestones of the Aseri Formation include less than 10%, in some lenses up to 30% ooliths and oolitic coatings on carbonate skeletal fragments or quartz grains (oval, quadrangular, rounded, elongated, etc.; 0.03–0.7 mm in diameter; Appendix 2, T-39). Rare carbonate ooliths are found on the lower boundary of the Väo Formation (177.3 m).

Kerogenous interbeds occur in the uppermost Middle Ordovician limestones. These are described by A. Põldvere and T. Saadre in a separate chapter of this volume.

The Kerguta (565) section represents the northern marginal area of the North Estonian Confacies Belt (Fig. 3). Lower and Middle Ordovician sediments have formed in shoal and open shelf environment, where the deposition was very slow and with many breaks (Nestor & Einasto 1997).

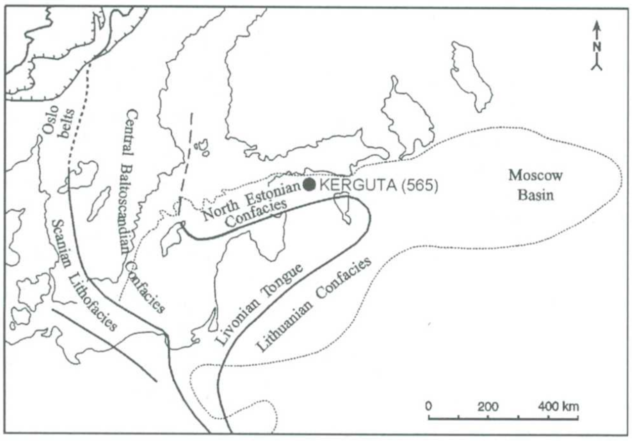

Fig. 3. Baltic Ordovician confacies belts (after Jaanusson 1995, modified from Nõlvak 1997).

Upper Ordovician (interval 14.4–163.5 m; Appendix 1, sheets 1–7; Appendix 4) is represented by the limestones and rare marlstones of the Viivikonna, Tatruse, Kahula, Hirmuse, Rägavere, Paekna, Saunja, Kõrgessaare, Moe, Adila and Ärina formations corresponding to the Kukruse, Haljala, Keila, Oandu, Rakvere, Nabala, Vormsi, Pirgu and Porkuni stages.

An altered K-bentonite bed is present in the uppermost part of the Viivikonna Formation (146.50–146.55 m; Appendix 1, sheet 6; see Kiipli *et al.* in this volume). The limestones of the lowermost part of the Kahula Formation intercalate with three 3–6 cm thick beds with minor volcanic component (see also Appendix 4). K-bentonite, widespread in Estonian sections at the lower boundary of the Keila Stage, lies at 136.2–136.4 m in the Kerguta (565) core. This clayey interbed includes biotite flakes and silt grains. A K-bentonite bed has been identified also 3.2 m higher (at 133.0 m) in the Kahula Formation of the Keila Stage and in the Moe Formation at a depth of 46.6 m (contains some biotite flakes) in the middle of the Pirgu Stage (Appendix 1, sheet 3).

The limestones of the Viivikonna Formation have been divided into the Kiviõli, Maidla and Peetri members. They contain 0.05–2.30 m thick kukersite oil shale beds (indexed from A to VII; Appendix 1, sheets 6, 7; see Põldvere & Saadre in this volume), with different contents of organic matter, carbonate and terrigenous material (Appendix 3, D-1...3). These beds alternate with slightly to highly argillaceous, in places kerogenous limestone intervals (thickness 0.1–0.8 m), which are often burrowed, pyrite mottled and contain marlstone interbeds. The rocks of the Viivikonna Formation are rich in fine and coarse bioclasts (on average 10–30%, locally up to 50% of the rock). In the kukersite beds pyritized bioclasts (echinoderms, trilobites, brachiopods, bryozoans, ostracods, gastropods, etc.) are often oriented subparallel to bedding (Appendix 2, T-32...35). Many discontinuity surfaces (mainly pyritized and distinct) of the Viivikonna Formation can be followed throughout the Baltic Oil Shale Basin and can be used as boundary markers in the section (Bauert & Kattai 1997).

In northern Estonia the argillaceous bioclast-rich (10–40%; Appendix 2, T-26...31) limestones of the Kahula Formation are overlain by marlstones of the Hirmuse Formation of the Oandu Stage (Appendix 1, sheet 5). The lower boundary of the Hirmuse Formation is marked by an uneven distinct pyritized discontinuity surface (depth of impregnation 25 cm) with borings infilled with the overlying marlstone. This specific surface is present in sections over a wide area and is used as a boundary marker in northern Estonia.

In the Kerguta (565) core, the limestones of the Rägavere Formation (interval 106.8–122.2 m; Appendix 1, sheet 5) have been divided into the Tõrremägi, Piilse and Tudu members. The Tõrremägi Member belongs to the Oandu Stage and Piilse and Tudu members form the Rakvere Stage. The boundary of these stages is marked by a distinct pyritized discontinuity surface.

In general, the Rägavere Formation is represented by finely crystalline and very finely crystalline limestones containing crypto- and microcrystalline interbeds (Appendix 2, T-24 and T-25). The average bioclast content is less than 10%. Calcite-filled primary and secondary veins are found. The members of the formation differ in several aspects (Põlma & Haas 1987; Nõlvak 1987). The rocks of the lower Tõrremägi Member are slightly to medium argillaceous and contain usually pyrite grains and pyritized bioclasts (up to 20% of rock). Small black pyrite mottles are observed throughout the Piilse Member and discontinuity surfaces are rare. The limestones of the Tudu Member are characterized by wavy and smooth pyritized discontinuity surfaces (Appendix 4). Rock impregnation of varying intensity reaches 1–5 cm, rarely 10 cm below the surfaces. The lower part of the Tudu Member includes interlayers of calcareous algae *Vermiporella* (20–30% of rock; interval 114.6–117.4 m). In the middle and upper parts of the member thin kerogen-bearing interbeds are present, particularly in the uppermost part close to the lithostratigraphical boundary of the Rägavere and Paekna formations in northeastern Estonia. Usually the argillaceous rocks of the Paekna Formation appear 0.1–0.7 m higher (Nõlvak 1987). The biostratigraphical boundary of the Rakvere and Nabala stages in the lowermost part of the Paekna Formation (depth 105.0 m) is determined by chitinozoans (see Nõlvak in this volume).

The lithostratigraphy of the overlying sediments in the interval of 22.0–106.8 m (Appendix 1, sheets 2–5) is based on the intercalation of variously argillaceous limestones and the frequency of marlstone interbeds. The Paekna, Kõrgessaare and Adila formations are represented by slightly to medium, rarely highly argillaceous, very finely crystalline limestones (bioclasts in places up to 35%; Appendix 2, T-4…6, T-15…18, T-22 and T-23). In all formations marlstone beds (0.2–3 cm, rarely 7–10 cm thick) account for 5–20%, rarely 40% and nodular intervals are present. Contacts between marlstone and argillaceous limestone are usually indistinct. Most of the pyritized discontinuity surfaces are found in the Adila Formation (Appendix 4). Rock impregnation is of various intensity, reaching 1–5 cm below the surfaces; depth of borings is up to 1–2 cm.

The Saunja and Moe formations lie between the above mentioned argillaceous limestone units (Appendix 1, sheets 2–4). Pure micro- and cryptocrystalline, in places very finely crystalline limestones of the Saunja Formation (Appendix 2, T-20 and T-21) contain calcitic marlstone films, rare interbeds (thickness 0.2–2 cm) and pockets less than 2% of the section. Contacts between marl- and limestone are distinct. Thick- to thin-bedded rocks are pyrite mottled or impregnated, in places burrowed and dolomitized.

The limestones of the Moe Formation (Appendix 1, sheets 2, 3) are mainly finely crystalline and very finely crystalline (Appendix 2, T-7…14). Marlstone films, interbeds (thickness 0.2–3, rarely 4–5 cm) and nodules make up 5% of the section. Pyritized discontinuity surfaces (depth of impregnation 1 cm) are found. Fragments of calcareous algae *Palaeoporella* and *Vermiporella* are abundant especially in the lower part of the formation. Calcite-filled primary and secondary veins are characteristic of both the Saunja and Moe formations.

The Upper Ordovician section of Estonia ends in the Kerguta (565) core with the Ärina Formation (interval 14.4–22.0 m) of the Porkuni Stage (Hints & Meidla 1997). The thickness and succession of different lithostratigraphic units of the Porkuni Stage are variable (Nestor 1987; Hints *et al.* 2004). In the Kerguta (565) section (Appendix 1, sheets 1, 2) five successive members are distinguished in the Ärina Formation (from below): Röa (argillaceous limestones; thickness 1.5 m), Vohilaid (bituminous, bioclast-rich limestones; 1.5 m), Siuge (bituminous, argillaceous limestones and calcitic marlstones; 3.6 m), Tõrevere (limestones, biohermal limestones and calcitic marlstones; 0.9 m) and Kamariku (limestones with sandy interbeds; 0.1 m). Except for the uppermost part of the section, limestones are dolomitized. Due to lithological differences the upper boundary of the Ordovician is distinct. The quartz sand-rich limestones of the Kamariku Member (uppermost Ordovician) are overlain by micro- and very finely crystalline limestones of the Koigi Member (lowermost Silurian).

The Upper Ordovician sediments in the Kerguta area have formed in the conditions of gradually deepening or shallowing open shelf while the Baltica palaeocontinent drifted northwards closer to the equator (Nestor & Einasto 1997). Lithofacies characteristics and carbon cycling studies (see also Martma in this volume) show the influence of humid and arid climate on sedimentation (Kaljo 2004). Lithological changes and local hiatuses are considerable at the end of Kunda, Kukruse, Keila, Oandu, Nabala, Vormsi, Pirgu and Porkuni times in the Kerguta (565) section. A hiatus on the Ordovician–Silurian boundary resulting from the pre-Silurian shallowing is connected with the Gondwana glaciation (Brenchley *et al.* 2003). The non-deposition period was followed by Early Llandovery glacio-eustatic rise of the sea level and deposition of pure lime mud (Nestor & Einasto 1997).

Llandovery (Silurian; interval 7.0–14.4 m; Appendix 1, sheet 1; Appendix 4) limestones with marlstone interbeds are represented by the Varbola Formation corresponding to the Juuru Stage. The lowermost limestones belong to the Koigi Member (interval 14.0–14.4 m) at the base of the Varbola Formation. This whitish-grey, usually very finely crystalline to cryptocrystalline limestone bed poor in bioclasts (< 3%; Appendix 2, T-2) on the Ordovician rocks is widespread in northern Estonia (Nestor 1997).

The overlying nodular, very finely crystalline to finely crystalline limestones (bioclasts 5–25%; Appendix 2, T-1) with calcitic marlstone interbeds (Varbola Formation) are covered by Quaternary sediments.

The **Quaternary** cover in the Kerguta (565) core is 7.0 m thick (Appendix 1, sheet 1). Tills of the last glaciation of Estonia (Raukas & Kajak 1997) formed in the Upper Pleistocene (Järva Formation, Võrtsjärve Subformation).

DISTRIBUTION OF ORDOVICIAN CHITINOZOANS

As many as of 193 samples from the Middle and Upper Ordovician of the Kerguta (565) core (interval of 89.0–181.4 m) were processed and studied for chitinozoans (Appendixes 8, 9; Plates 1–4). The work was carried out at the Institute of Geology at Tallinn University of Technology (IGTUT), and financially supported by the Estonian Science Foundation (grant No. 5922).

Chitinozoans (stored at IGTUT) were collected in two sets. The samples provided by Heikki Bauert in the 1980s varied in size from 0.2 to 0.5 kg, and those collected by Jaak Nõlvak in 2004, from 0.3 to 0.6 kg. The vertical range of the samples was, respectively, 10–20 and 5–10 cm. All productive samples yielded a relatively rich assemblage of acid-resistant microfossils including poorly to excellently (mainly from the Keila to Nabala stages) preserved chitinozoans. In total, 80 chitinozoan taxa were distinguished. Their distribution is given in Appendix 9, where the taxa under open nomenclature (designated with members) are identical with those found from the Tartu (453) (Bauert & Bauert 1998), Taga-Roostoja (25A), Valga (10), Ruhnu (500) and Mehikoorma (421) sections (see Nõlvak 1999a, app. 6; Nõlvak 2001, app. 8; Nõlvak 2003, app. 23; Nõlvak 2005, app. 27). Almost all biostratigraphically important chitinozoan zones introduced by Nõlvak & Grahn (1993) and revised by Nõlvak (1999b, 2002a) were established in the Kerguta (565) section. Due to secondary dolomitization organic-walled microfossils in the beds below 165.0 m are poorly preserved: dolomite crystals have partly destroyed walls of chitinozoans, sometimes growing out of vesicles. It is interesting to note that black, a few microns thick organic walls of vesicles are destroyed irregularly, without any visible direction or order.

The lowermost part of the section is represented by the uppermost *Cyathochitina regnelli* Zone corresponding to the latest Kunda time.

The zonal species *C. regnelli* was not found above the base of the Aseri Stage at a depth of 181.05 m. At that level *Cyathochitina campanulaeformis* (ranges up to the Silurian) appears for the first time together with *Belonechitina crinita, Lagenochitina tumida* and *Belonechitina* sp. 1 among others, exactly as in the Rapla (North Estonia, 60 km south of Tallinn; unpublished data by J. Nõlvak) and Taga-Roostoja (25A) (Nõlvak 1999a, app. 6) sections. The zonal form *Laufeldochitina striata* appears about 1 m above the base of the Aseri Stage, and the base of the *Cyathochitina sebyensis* Subzone lies in the middle part of the Aseri beds at a depth of 178.5 m.

The boundary between the Aseri and Lasnamägi stages can be followed easily by lithological features (see Appendix 1, sheet 7). This level is not fixed in chitinozoan zonation, however, the short range (see Bauert & Bauert 1996) of *Tanuchitina tallinnensis* characterizes well these boundary beds as in the Rapla section (unpublished data by J. Nõlvak). A very interesting association was found in the interval of 175.5–176.0 m where among others there occurs *Baltochitina nolvaki* (earlier *Sagenachitina* sp.). This interval can be correlated with the Pae Member (dolomitized part of the Väo Formation) in North Estonian sections. These beds contain interesting forms of *Linochitina* sp. aff. *pissotensis* with a specific thick brownish secondary(?) cover, similar to those recorded in the Taga-Roostoja (25A) section at a depth of 104.4 m (Nõlvak 1999a, app. 6). Paris (1981) described this species approximately at the same stratigraphical level in Portugal, where it was a zonal form together with the graptolite *Gymnograptus linnarssoni* (Moberg).

The stratigraphically important graptolite *Gymnograptus linnarssoni* was not found in the interval of 172.5–175.0 m (lowermost Uhaku Stage; Appendix 9). However, it is present in many sections (Männil 1976; Nõlvak 2001) and its appearance level can be used as the main criterion for the base of the Uhaku Stage.

The next *Conochitina tuberculata* Subzone is represented by very abundant specimens, which appear at a depth of 172.0 m. The number of type specimens is larger in the northern sections closer to the stratotype area (e.g. Taga-Roostoja (25A) core, Nõlvak 1999a; see also Männil 1986, fig. 2.2.1) than in South Estonian sections (e.g. Valga (10) and Ruhnu (500); see Nõlvak 2001, 2003).

The boundary between *Laufeldochitina striata* and *L. stentor* lies within the uppermost part of the Uhaku Stage in most of the investigated sections. This level coincides roughly with the lower boundary of the Erra Member (argillaceous limestones with kukersite oil shale interbeds in the uppermost Kõrgekallas Formation of the Uhaku Stage, North Estonia; Männil 1966, 1986).

The succeeding *Eisenackitina rhenana* Subzone can be clearly followed. The index species appears about 1.5 m higher than the base of the kukersite oil shale layer A, together with *Conochitina* sp. 1 (Appendix 9). The latter species occurs only in early Kukruse time, when the main kukersite-bearing beds were formed in northeastern Estonia. Such an order of changes in chitinozoan assemblages can be used to define the lower boundary of the Kukruse Stage in Estonian (e.g. Ruhnu (500) and Mehikoorma (421) cores; see Nõlvak 2003, p. 23; Nõlvak 2005, app. 27) and Swedish (Vandenbroucke 2004) sections.

The most remarkable find among graptolites in the Kerguta (565) section is that of *Nemagraptus* cf. *gracilis* (Hall) at a depth of 147.75–147.92 m, in the uppermost beds of the Kukruse Stage. The appearance level of this species marks the global lower boundary of the Upper Ordovician Series (Bergström *et al.* 2000), which coincides with the lower boundary of time slice 5a by Webby *et al.* (2004, fig. 2.1), and the upper boundary of the global Darriwilian Stage. According to our latest finds and identifications of *N. gracilis* in the East Baltic sections (Nõlvak & Goldman 2004), its appearance level can be drawn within the upper part of the Kukruse Stage, below kukersite beds III (Peetri Member; Appendix 1, sheet 6). This level shows also substantial similarities in changes of chitinozoan assemblages in the East Baltic and Scania (Sweden; see Vandenbroucke 2004) and provides a clear signature for correlations with the Fågelsång stratotype section, recently selected as the GSSP for the base of the Upper Ordovician (Bergström *et al.* 2000).

In the Kerguta (565) section the base of the Haljala Stage (Idavere Substage) cannot be determined precisely by chitinozoans but is well defined lithologically. Both *Laufeldochitina stentor* and *Eisenackitina rhenana* disappear already below the lithological boundary at a depth of 145.8 m. Additional data (samples) are needed from the topmost layers of the lithologically clear Kukruse Stage to determine the exact age of these condensed beds. However, the sampling of the topmost beds in drill cores is often complicated due to specific well-developed discontinuity surfaces with wide conspicuous borings and pockets, sometimes more than 0.3 m deep, and mixing of fauna.

All species of the well-known *Armoricochitina granulifera, Angochitina curvata* and *Lagenochitina dalbyensis* zones were not found, although the lower Haljala layers were sampled almost completely (Appendix 9). This indicates a gap in the lowermost Haljala beds that belong mainly to the lower Idavere Substage. The *Belonechitina hirsuta* Zone occurs as a very condensed part of the Idavere Substage, in the interval of 144.64–144.83 m (two samples), just below the appearance of the *Spinachitina cervicornis* Zone. However, the subdivision of the Haljala Stage into substages in terms of chitinozoan zonation is still complicated in most of the studied North Estonian sections, because no clear changes or differences are observed in the distribution of acid-resistant microfossils.

The base of the Keila Stage in Estonian sections is marked by the widely distributed Kinnekulle K-bentonite bed (Hints & Nõlvak 1999). In the present study the Kinnekulle bed was determined at 136.2–136.4 m (Appendix 1, sheet 6; see also Kiipli *et al.* in this volume) and the well-known but very brief *Angochitina multiplex* Subzone was identified above this level (together with *Hercochitina lindstroemi*). So, the correlation in terms of chitinozoans is precise, although both species are often relatively poorly represented.

The problems concerning the systematics of the key species of the *Fungochitina fungiformis* Zone complicate the use of this zone, as noticed already in the Valga (10) and Mehikoorma (421) sections (Nõlvak 2001, 2005). Nõlvak & Grahn (1993) defined this zone as the total range of *F. fungiformis* but later the name of the zone was changed to *F. spinifera* (see Nõlvak *et al.* 2006). Moreover, according to the new data from the Mehikoorma (421) and Viljandi (Kaljo *et al.* 2004, fig. 4) sections, *Saharochitina fungiformis* appears earlier than typical spiny *F. spinifera*, which was proved also in the Kerguta (565) section (Appendix 9).

For the top of the Keila Stage detailed data are available from many sections of the North Estonian Confacies Belt. These show a clear change in lithology, microfossil distribution, and the well-known gap in the boundary beds of the Keila and Oandu stages interpreted as an extinction event (Kaljo *et al.* 1996). However, the gap known from North Estonian sections is filled with new layers in the south. Chitinozoan assemblages change more gradually in the Mehikoorma (421) section (Nõlvak 2005) than in the Rapla (Kaljo *et al.* 1996) and Kerguta (565) sections, where a very distinct level of change can be defined (see Appendix 9).

A distinct new and extremely well-preserved chitinozoan fauna appears in very finely to cryptocrystalline limestones of the Rägavere Formation above the very condensed (thickness 0.2 m) marlstones of the Hirmuse Formation, where the beds of the *Ancyrochitina* sp. n. 1 chitinozoan Subzone are absent (for comparison see Nõlvak 2005). This fauna represents the *F. spinifera* Zone and is relatively stable.

The appearance of *Armoricochitina reticulifera*, together with specific variable forms of the *Cyathochitina* group, marks the most important biostratigraphical level between 104.2 m and 105.3 m. This level correlates with the lower boundary of the Nabala Stage in the East Baltic sections over a wide area, not depending on the lithology of the layers above. It shows again that the lithological change could be gradual in the interval of 104.5–106.8 m in the Kerguta (565) section (Appendix 9; see also Põldvere *et al.* in this volume).

To sum up, it could be stressed that very dense sampling of every interval is not necessary, at least of beds where acid-resistant microfossils are poorly preserved (e.g. in the middle of the Uhaku Stage; see Appendix 9).

In the future repeated sampling seems prospective. However, the chitinozoan zonation in the Kerguta (565) core serves as a good tool for subdivision of that section and for further correlations.

It was proved once again that significant gaps occurred at the lower boundaries of some stages (e.g. Aseri, Haljala, Oandu) in the sections of the North Estonian Confacies Belt.

DISTRIBUTION OF ORDOVICIAN CONODONTS

From the Kerguta (565) core (also known as the Tamsalu core) 75 samples (plus two from unknown depth) were studied for conodonts (Appendixes 10, 11). Of these, 17 samples were processed at Lund University, Sweden, 60 samples from the beds between 144.83 and 181.34 m were provided by Garmen Bauert. The conodonts of the first set of samples, from the interval of 183.20–191.70 m, were studied by Lisa Sjöstrand for her graduation work at Lund University, under supervision of Anita Löfgren. Seven samples representing the *Eoplacognathus pseudoplanus* Zone were used for general comparison by Löfgren (2004).

The preservation of conodonts is good and all conodont elements have a CAI (colour alteration index) value less than 1.5. The number of taxa and specimens in samples decreases rapidly from great abundance in the lower part (up to 6052 specimens counted at a depth of 190.7 m) to few elements in the upper part of the section. The studied collection is housed at the Institute of Geology at Tallinn University of Technology.

The conodont distribution from the *Oepikodus evae* to *Eoplacognathus pseudoplanus* zones is given according to Sjöstrand (2003).

The *Oepikodus evae* Zone (samples from 191.70 and 191.30 m, 1210 and 1950 specimens, respectively) is represented by 15 species (Appendix 11), including redeposited *Prioniodus elegans* and *Tripodus* sp. The index species *O. evae* is represented by 50 specimens in the lower sample (4.1%). *Drepanoistodus forceps* is the most abundant species (55.1 and 59.6%, respectively, in the lower and upper samples), *Oistodus lanceolatus* (7.4 and 5.2%), *Scolopodus striatus* (8.1 and 8.5%), *Drepanodus arcuatus* (5.6 and 1.8%) and *Protopanderodus rectus* (4.6 and 2.2%) are common. *Periodon flabellum* (4.1 and 12.8%) is typical of the upper part of the *O. evae* Zone in Estonia (Viira *et al.* 2001; Männik & Viira 2005). Two new species, *Parapaltodus* n. sp. A and *Texania* n. sp. A, were found (Sjöstrand 2003, fig. 7B–D, fig. 8A–C). On the lithostratigraphical column the second sample (191.3 m) is assigned to the Saka Member of the Toila Formation, which is in contradiction with the generally accepted Billingen age for the *O. evae* Zone. It might have been caused by invalid depth identification.

The *O. evae* Zone has been identified in two of the six drill core sections published in the series of *Estonian Geological Sections* during 1998–2005. In the Taga-Roostoja (25A) core this zone is represented by two samples from the upper part of the Leetse Formation and in the Mehikoorma (421) section by one sample from the Zebre Formation of Billingen age (Viira & Männik 1999; Männik & Viira 2005).

The *Baltoniodus navis* Zone (sample from 190.7 m, 6052 specimens) is represented by the most abundant species *Microzarkodina flabellum* (34.5%) and *D. forceps* (31.9%). *Baltoniodus navis* (14.2%), *Protopanderodus rectus* (4.5%) and *Trapezognathus quadrangulum* (4.5%) are also rather numerous. The sample with conodonts of this zone comes from the Saka Member of the Toila Formation. In the Mehikoorma (421) and Tartu (453) sections single samples from the lowermost part of the Kriukai Formation of Volkhov age yielded the index species *B. navis* (Männik & Viira 2005; Põldvere *et al.* 1998)

The *Paroistodus originalis* Zone (sample from 190.2 m) was first defined by Lindström (1971) by abundant occurrence of the index species, and discussed in detail by Löfgren (1995). The 1093 elements in this sample represent 10 different species. *Paroistodus originalis*, which was found in an earlier sample, reappears here in fair abundance (13%). Two other important conodonts for this zone are *Triangulodus brevibasis* (12.8%) and *Drepanoistodus basiovalis* (41.6%). *Baltoniodus navis* (21.5%) is quite numerous. The sample with conodonts of this zone comes from the level of the Telinõmme Member of the Toila Formation. Two samples with *P. originalis* from the Taga-Roostoja (25A) section come also from the level of the Toila Formation (Volkhov age). In the Tartu (453) and Mehikoorma (421) sections the *P. originalis* Zone is equivalent to the middle part of the Kriukai Formation of Volkhov age (Põldvere *et al.* 1998; Männik & Viira 2005).

The *Baltoniodus norrlandicus* Zone (sample from 189.7 m, 2769 specimens) is represented by the zonal species (43.2%) and *D. basiovalis* (39.9%), *Microzarkodina parva* (5.0%) and *Scalpellodus latus* (2.8%). *Semiacontiodus cornuformis* (2.6%) makes its first appearance in this sample. The presence of *Trapezognathus* *quadrangulum* (0.1%) denotes the lower subzone of this zone. This species, together with *P. originalis* (0.7%), *T. brevibasis* (0.04%), and some others disappear at this level. In the Kerguta (565) section the lower part of the zone is of Volkhov age and forms an interval in the Kalvi Member of the Toila Formation. The upper part of the zone, the *Lenodus antivariabilis* Subzone, is not found in the Kerguta (565) drill core, but has been identified as *L.* cf. *antivariabilis* in the Sillaoru Formation of Volkhov age in the Taga-Roostoja (25A) section (Viira & Männik 1999). In the Tartu (453) and Mehikoorma (421) core sections the *B. norrlandicus* Zone is equivalent to the upper part of the Kriukai Formation of Volkhov age (Põldvere *et al.* 1998; Männik & Viira 2005).

The *Lenodus variabilis* Zone is represented by a sample from 188.2 m (383 specimens), where *Baltoniodus medius* (49.9%) is the most abundant species and *S. cornuformis* is also quite numerous (25.8%). Apart from the zonal species *L. variabilis* (9.7%), *Scalpellodus gracilis* (2.9%) and *Drepanoistodus venustus* (2.6%) first appear in this sample. This zone comprises an interval in the Nõmmeveski Member of the Loobu Formation. Besides the Kerguta (565) core, the *L. variabilis* Zone has been identified only in the Taga-Roostoja (25A) section, in the Loobu Formation of Kunda age (Viira & Männik 1999).

The *Yangtzeplacognathus crassus* Zone was defined by Zhang (1998) for south-central China, and has also been recognized in Öland (Löfgren 2000), Västergötland and Dalarna (Löfgren 2003) in Sweden. In Estonia this zone was first established in the Kerguta (565) core (Appendix 11), in samples from 187.7 m (710 specimens) and 187.2 m (620 specimens). The index species *Y. crassus* is relatively abundant in these two samples (3.1% and 6.3%, respectively). *Baltoniodus medius* (49.9 and 55.4%) is still dominating together with *S. cornuformis* (16.3 and 10.8%). *Dapsilodus viruensis* (0.3%) first appears and *M. parva* (3.2%) disappears in the upper sample. The two samples of this zone come from the Nõmmeveski Member of the Loobu Formation (Kunda age).

The *Eoplacognathus pseudoplanus* Zone is subdivided into two subzones, the lower one characterized by *Microzarkodina hagetiana* and the upper one by *M. ozarkodella* (Zhang 1998; Löfgren 2004). Zhang (1998) introduced the *E. pseudoplanus* Zone in its present scope, although earlier Viira (1974) proposed the zonal species as an index for the upper part of the Kunda Stage. In the Kerguta (565) core the proportion of *E. pseudoplanus* is above 1%, with a maximum in the sample from 186.4 m (8.1%). According to the absence of *Polonodus* and only sparse occurrence of *Protopanderodus*, the *E. pseudoplanus* interval in the Kerguta (565) core represents a shallower depositional environment in comparison with Swedish sections (Löfgren 2003, 2004).

The *Microzarkodina hagetiana* Subzone is represented by samples from 186.8 m (950 specimens), 186.4 m (1831) and 185.7 m (1471). The dominating species is *B. medius* (52.8–71.7%), followed by *S. cornuformis* (7.7–14.9%) and *D. basiovalis* (8.6–13.1%). The relative abundance of the index species *M. hagetiana* is 1.1, 0.8 and 1.6% per sample. *Semiacontiodus davidi* (0.2–10.1%) first appears in the middle part of this subzone and continues into the basal part of the upper subzone.

The *Microzarkodina ozarkodella* Subzone is represented by samples from 184.7 m (573 specimens), 184.3 m (999), 183.7 m (638) and 183.2 m (1094). The relative abundance of the subzonal species, *M. ozarkodella*, is respectively 0.9, 4.55, 0.55 and 3.2%. The dominant species is still *B. medius* (69.4–84.5%); quite numerous are also *S. cornuformis* (4.1–12.1%) and *D. basiovalis* (2.0–5.2%). *Drepanodus arcuatus* occurs sporadically in both subzones.

Kerguta (565) is the only core section where both subzones of the *E. pseudoplanus* Zone are represented. The lower, *M. hagetiana* Subzone, corresponds to the upper part of the Nõmmeveski Member and the upper, *M. ozarkodella* Subzone, to the Valgejõgi Member of the Loobu Formation. The upper subzone is also found in the Taga-Roostoja (25A) core, where it is equivalent to the lower part of the Kandle Formation (Kunda and Aseri age), and in the Mehikoorma (421) section, where it comprises a short interval in the Baldone and Segerstad formations of Kunda age (Viira & Männik 1999; Männik & Viira 2005).

Sjöstrand (2003) mentions two more samples without depth identification in a 3.6 m thick interval above the last sample from the *M. ozarkodella* Subzone (183.2 m), where *M. ozarkodella* (5.6 and 1.8%) is represented together with *Eoplacognathus suecicus* (respectively 1.1 and 3.2%). But three samples from the upper part of this interval with depths identified (180.11–180.19 m, 180.85–180.90 m and 181.27–181.34 m) contain the specimens of *E. pseudoplanus*, which may represent transitional forms to *E. suecicus* (Appendix 11).

The *Eoplacognathus suecicus* Zone was identified by typical specimens in the sample from 179.78–179.87 m. In this zone *B. medius* is replaced by *B. prevariabilis*

(Appendix 11). Few specimens of *Protopanderodus* cf. *P. graeai* and *P.* cf. *P. varicostatus* occur in this zone. The first specimens of *Panderodus* sp. were found at a depth of 179.52–179.59 m. In four samples of this zone *Amorphognathus* cf. *A. kielcensis* was identified. This species is known in the Mójcza section of Poland, in the interval from the *M. ozarkodella* Subzone to *Pygodus anserinus* Zone (Dzik 1994). In Estonia this species has been found in the Taga-Roostoja (25A) core together with *E. suecicus* (Aseri age), and in the Mehikoorma (421), Valga (10) and Ruhnu (500) cores (all Uhaku age) together with *E. lindstroemi* and *Pygodus anserinus* (Viira & Männik 1999; Männik & Viira 2005; Männik 2001, 2003). Following Dzik (1994), in all mentioned core sections *A. kielcensis* has been identified as belonging to the genus *Sagittodontina*. We prefer the original description of the species as of the genus *Amorphognathodus* (Dzik 1976).

The zonal species *E. suecicus* is also found in the Taga-Roostoja (25A) (upper part of the Kandle Formation, Aseri age) and Mehikoorma (421) (boundary beds of the Segerstad and Stirnas formations, Aseri age) core sections (Viira & Männik 1999; Männik & Viira 2005).

The *Pygodus serra* Zone is represented by the index species only in the sample from 172.86–172.96 m. Nevertheless, the interval between 170.68 and 177.89 m may be subdivided into five subzones, where the lower *Yangtzeplacognathus foliaceus* Subzone of the *P. serra* Zone is missing (Appendix 11).

The *Baltoplacognathus reclinatus* Subzone was identified by findings of the index species in five samples from 177.05–177.12 to 175.11–175.19 m. Typical complete specimens occur in the sample from 176.12–176.18 m. *Oslodus semisymmetricus* makes its first appearance close to the lower boundary of this subzone (Appendix 11). *Baltoniodus prevariabilis* and *S. cornuformis* are rather numerous.

The *B. reclinatus* Subzone comprises a certain interval in the lower part of the Väo Formation (Lasnamägi age) in the Kerguta (565) and Tartu (453) sections (Põldvere *et al.* 1998). In the Ruhnu (500) section this subzone includes the Stirnas and lowermost part of the Taurupe formations (Lasnamägi age; Männik 2003).

The *Baltoplacognathus robustus* Subzone is well enough represented by the index species in the interval of 173.49–174.86 m. *Protopanderodus* cf. P. varicostatus appears for the second time in the Kerguta (565) core, and disappears finally in this subzone. From the lower boundary of this subzone upwards, *Panderodus* sp. is identified in almost all samples.

The *B. robustus* Subzone is found besides the Kerguta (565) core (Väo Formation, Uhaku age) also in the Tartu (453) (Väo Formation, late Lasnamägi and Uhaku age) and Ruhnu (500) (Taurupe Formation, Uhaku age) sections (Põldvere *et al.* 1998; Männik 2003).

The *Yangtzeplacognathus protoramosus* Subzone was determined by finds of the index species in the sample from 173.18–173.27 m of the Väo Formation. The zonal species was determined also in the Taga-Roostoja (25A) (Väo Formation), Mehikoorma (421) (Väo Formation) and Valga (10) (Taurupe Formation) core sections (all Uhaku age; Viira & Männik 1999; Männik & Viira 2005; Männik 2001).

The *Eoplacognathus lindstroemi* Subzone comprises the interval of 170.68–172.96 m *Semiacontiodus cornuformis* is replaced by *S. carinatus* in this subzone (Appendix 11). The zonal species has been identified besides the Kerguta (565) core (upper part of the Väo Formation) also in the Mehikoorma (421) (upper part of the Väo and lowermost Kõrgekallas formations), Tartu (453) and Taga-Roostoja (25A) (lower part of the Kõrgekallas Formation), and Valga (10) and Ruhnu (500) (middle part of the Taurupe Formation) cores (all Uhaku age; Männik & Viira 2005; Põldvere *et al.* 1998; Viira & Männik 1999; Männik 2001, 2003).

Upwards in the Kerguta (565) core section, only long-ranging conodont species of the genera *Semiacontiodus*, *Baltioniodus*, *Panderodus* and *Drepanoistodus* occur (Appendix 11). In a few samples they may be even rather numerous. The appearance of *Baltoniodus variabilis* is rather difficult to follow because of the absence of complete Pa elements, and many fragile specimens are hardly distinguishable from the same element of *B. prevariabilis*. The gradual boundary between these two species is drawn on the level of about 164.0 m.

ORDOVICIAN AND LOWERMOST SILURIAN CARBON ISOTOPES

A total of 90 samples from the Lower to Upper Ordovician and the lowermost Silurian rocks of the Kerguta (565) core (Appendix 1, sheets 1–8) were analysed for stable isotopes. The entire Ordovician sequence was sampled, but the interval from 15.20 to 106.80 m is not yet analysed (Appendix 12). Samples for whole rock analyses were taken at more or less regular intervals of 1 m, not depending on the possibility of finding any bioclasts (Martma 2003). For isotope analysis about 1 g of rock material was collected.

Our research is based on the whole-rock sampling method, with consideration of the stratigraphic context (lithology, unit thickness, positions of unit boundaries). The quality of the carbon isotope data obtained from whole-rock analyses has been discussed in several papers (Brenchley *et al.* 1994, 2003; Kaljo *et al.* 1997, 1998; Martma 2003). Detailed study of isotope signals in the Upper Ordovician rocks of Estonia has shown that major changes in isotope values reflect the primary composition of sediments.

The methodology of carbon isotope analysis used in the isotope palaeoclimatology laboratory of the Institute of Geology at Tallinn University of Technology is

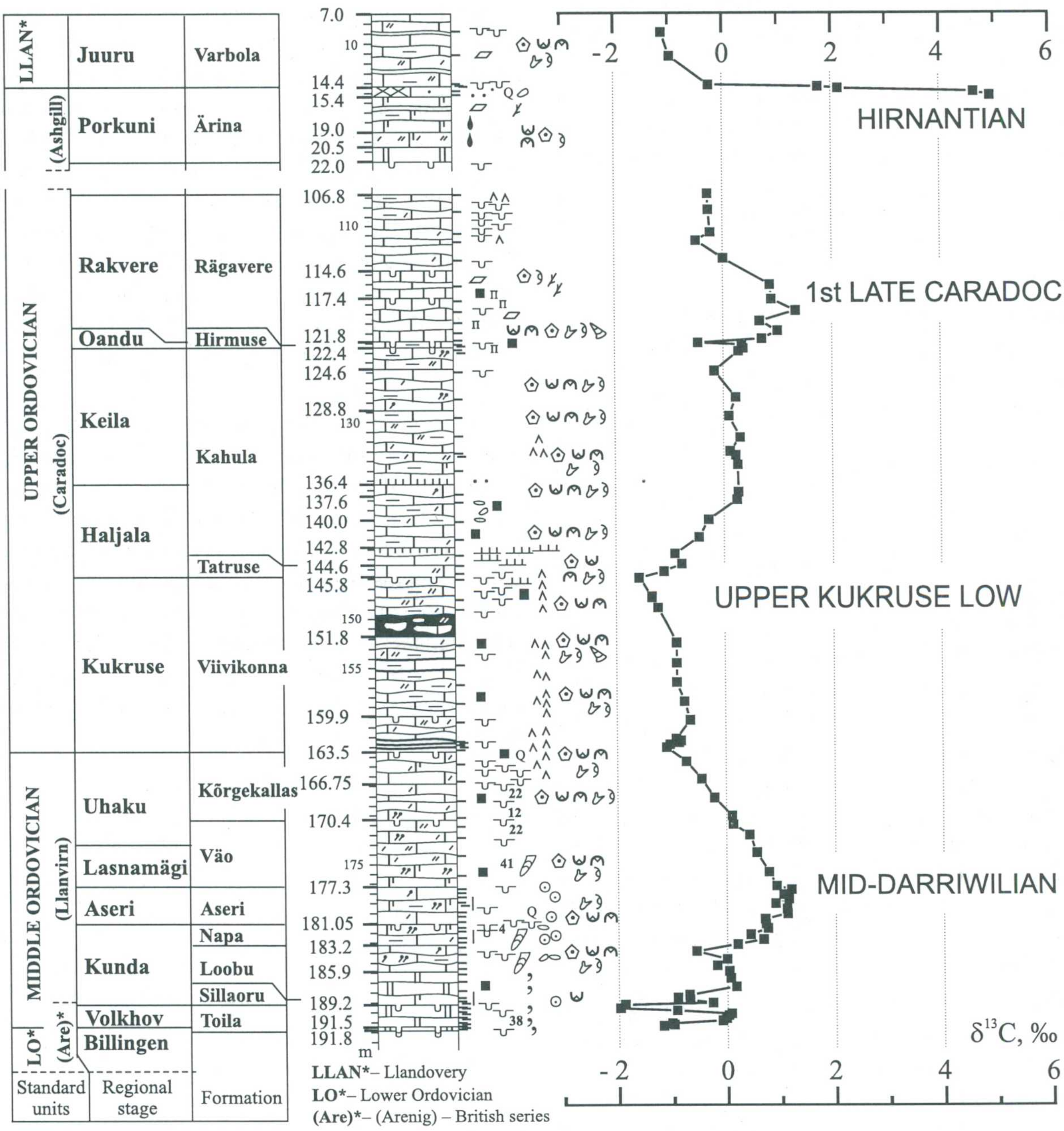

Fig. 4. The Ordovician and lowermost Silurian bulk carbonate carbon stable isotope profile of the Kerguta (565) core. Refer to Appendix 1 for lithology and Appendix 12 for sample depths. Sampling points are marked on the right side of the column.

explained in detail in Kaljo *et al.* (1997, 1998). Here only some comments are made on essential details of the study. The whole-rock samples were powdered to a <10 μm grain size, 30 mg of powder was reacted with 100% phosphoric acid at 100 °C for 15 min and analysed with a Finnigan MAT "Delta E" mass spectrometer. The results are presented in the usual δ notation, as per mil deviation from the VPDB standard. The reproducibility of the results is better than 0.1‰.

A full set of analytical data on the carbon isotopes obtained from bulk rock samples of the Kerguta (565) drill core will be published in a forthcoming paper (Kaljo *et al.* submitted).

The application of carbon isotopes as a tool in stratigraphic correlation and dating of rock sequences is in principle a simple method. The reliability of the results depends on how detailed and complete is the database available for comparison. A more or less complete carbon isotope trend for the Middle and Late Ordovician of Baltica and Laurentia has been ascertained on the basis of studies by Ainsaar *et al.* (1999, 2004a, 2004b), Kaljo *et al.* (1999, 2001, 2004) and Meidla *et al.* (2004). Considering the earlier data and analyses included in Fig. 4, the following main carbon isotopic events and specific intervals of the $\delta^{13}C$ temporal variation through the Ordovician of the Kerguta (565) core could be listed:

(1) The Mid-Darriwilian isotopic event or positive excursion was described by Ainsaar *et al.* (2004b) from the Segerstad Formation in the Jurmala and Ruhnu (500) cores ($\delta^{13}C$ values reach close to 2‰). Our data from the Kerguta (565) and Mehikoorma (421) cores (Martma 2005) show a relatively rapid rise in $\delta^{13}C$ values from 0.5‰ in the Baldone Formation (Kunda Stage) through the Segerstad Formation to a peak value of 1.7‰ in the Stirnas Formation of the Aseri Stage. The falling limb of the excursion is located in the Väo Formation of the Lasnamägi and Uhaku stages. New data from the Mehikoorma (421) and Kerguta (565) cores show that the excursion is considerably wider than thought earlier – it begins in late Kunda time and ends in Lasnamägi time.

(2) The mid-Caradoc excursion is missing in the Kerguta (565) core due to a gap in the Central Belt of Estonia (Ainsaar *et al.* 2004a).

(3) The 1st late Caradoc isotopic event (peak value reaching 1.5‰) is confined to the Rägavere Formation (Rakvere Stage) and is much better represented than in the Mehikoorma (421) core, where this formation is very thin and also confined to a discontinuity surface.

(4) A wide negative excursion at the Darriwilian/Caradoc transition (maximum negative $\delta^{13}C$ values – 1.6‰), which seems to have a wider distribution than only the Kerguta (565) and Mehikoorma (421) cores.

(5) The Hirnantian event, the study of which is still in progress. The falling limb is located in the very top of the Ordovician Porkuni rocks just below the Juuru Stage (Silurian). The limb is rather steep and points to a possibility that a part of the uppermost Porkuni section is missing here.

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UPPER ORDOVICIAN VOLCANIC ASH BEDS

Thirteen argillaceous beds of suspected volcanogenic origin were sampled from the Kukruse, Haljala, Keila and Pirgu stages of the Kerguta (565) core (Appendix 1, sheets 3 and 6). The methods applied in the study are described in detail in Kiipli & Kallaste (2005). The bulk sediment chemical composition and trace elements were analysed by XRF (Appendix 13). The Na content of sanidine was established by XRD (Table 1). Bulk sediment diffractograms showing the presence of illite-smectite, and high authigenic feldspar and low quartz contents were considered to be

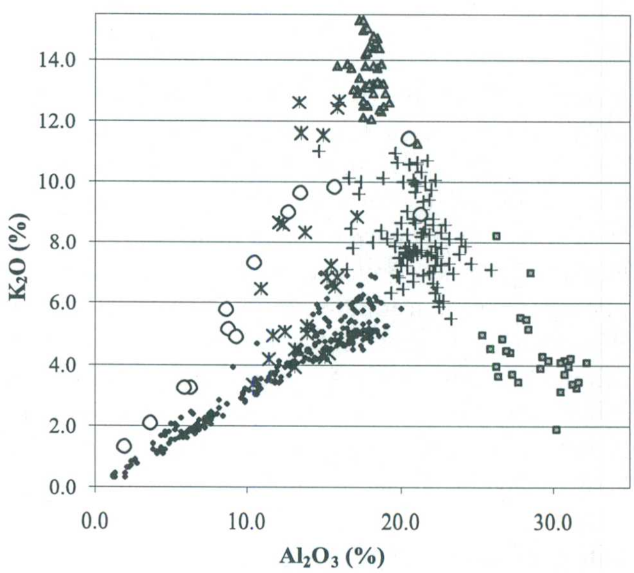


Fig. 5. Comparison of K_2O and Al_2O_3 contents of K-bentonites and common sedimentary rocks of the Kerguta (565) and other Estonian and Latvian sections. Black dots – limestones, marlstones and shales, crosses – volcanogenic K-bentonites (illite-smectite dominated), triangles – volcanogenic feldspathites (potassium feldspar dominated), grey quadrangles – volcanogenic tonsteins (kaolinite dominated), stars – mixed volcanogenic-terrigenous-calcareous samples, circles – Kerguta (565) samples.

Table 1: XRD data of the sedimentary rocks and volcanic ash beds of the Kerguta (565) core

Sample depth (m)	Regional stage	Bed thickness (cm)	Main and *trace* minerals	$NaAlSi_3O_8$ in sanidine*(mol%), shape of the 20ī reflection	Origin of sampled rock
23.00	Pirgu	0.5	Illite, quartz, dolomite, *K-feldspar, chlorite, calcite*	–	Terrigenous-calcareous
26.10	Pirgu	0.5	Illite, quartz, calcite, dolomite, *K-feldspar, chlorite*	–	Calcareous-terrigenous
46.60	Pirgu	0.5	Illite, quartz, K-feldspar, dolomite, *calcite, chlorite*	Weak reflection	Mixed volcanogenic-terrigenous-calcareous
57.00	Pirgu	0.5	Illite, quartz, K-feldspar, calcite, dolomite, *chlorite*	–	Terrigenous-calcareous
133.00	Keila	0.5	Calcite, *illite, chlorite, quartz, K-feldspar*	–	Calcareous-terrigenous
136.30	Keila	20.0	Illite/smectite, K-feldspar, *biotite*	24.3 Sharp reflection	Volcanogenic K-bentonite
142.80	Haljala	6.0	Illite/smectite, K-feldspar	Weak reflection	Volcanogenic K-bentonite
143.10	Haljala	0.5	Illite, quartz, K-feldspar, calcite, *chlorite, dolomite, pyrite, biotite*	Weak reflection	Mixed volcanogenic-terrigenous-calcareous
143.30	Haljala	6.0	Illite/smectite, K-feldspar, *gypsum*	Weak reflection	Volcanogenic K-bentonite
143.35	Haljala	0.5	Illite, quartz, K-feldspar, calcite, dolomite, *chlorite*	Weak reflection	Mixed volcanogenic-terrigenous-calcareous
144.10	Haljala	1.5	Illite, quartz, K-feldspar, *calcite, chlorite, pyrite*	Weak reflection	Mixed volcanogenic-terrigenous-calcareous
144.60	Haljala	3.0	Illite, quartz, K-feldspar, *calcite, chlorite, pyrite*	Weak reflection	Mixed volcanogenic-terrigenous-calcareous
146.50	Kukruse	5.0	Illite, quartz, K-feldspar, calcite, *dolomite, pyrite*	40.0 Wide reflection	Mixed volcanogenic-terrigenous-calcareous

*K–Na sanidine 20ī reflection was studied using the two-component model, only the main component is included in the table.

indicative of volcanogenic material. On the basis of the low content of CaO and relatively high contents of K_2O and Al_2O_3, three pure volcanogenic K-bentonites and six mixed volcanogenic-terrigenous-calcareous interbeds were recognized (Fig. 5; Table 1). Four samples revealed only common sedimentary terrigenous-calcareous signs. In addition to XRD data, conclusions about sample genesis (Table 1) were made through comparison with K_2O, Al_2O_3 and CaO contents in about 250 sedimentary clay-, marl- and limestones and 200 volcanogenic samples from the authors' database of XRF analyses (Fig. 5).

Volcanic ash bed of the Kukruse Stage

A bluish-grey bioturbated interbed (thickness 5 cm) with carbonate-filled borings was found at a depth of 146.5 m. The high content of authigenic potassium K-feldspar and a relatively high K_2O content in the Kerguta (565) sample confirm mixed volcanogenic-terrigenous-calcareous origin of the bed (Table 1; Appendix 13). XRD measurement of the coarse fraction (0.04–0.1 mm) revealed a wide sanidine 20ī reflection, yielding the calculated average $NaAlSi_3O_8$ content in the sanidine main component around 40 mol%. The wide reflection indicates variable composition of sanidine. The bluish-grey interbed in the upper part of the Kukruse Stage has already been interpreted by Nõlvak (2002b) as volcanogenic in many drill cores from the southern part of the North Estonian Confacies Belt (Jaanusson 1995; Nõlvak 1997).

Volcanic ash bed of the Haljala Stage

The Idavere Substage of the Haljala Stage contains two yellow-coloured pure bentonite beds (sample depths 142.8 and 143.3 m) and four mixed volcanogenic-terrigenous-calcareous beds (sample depths 143.1, 143.35, 144.1 and 144.6 m; see Table 1). Mixed beds are grey, contain little biotite and cannot be visually distinguished from common sedimentary marlstone interbeds. However, laboratory analyses revealed a clear volcanogenic component in these interbeds. Measurements of coarse fractions (0.04–0.1 mm) of

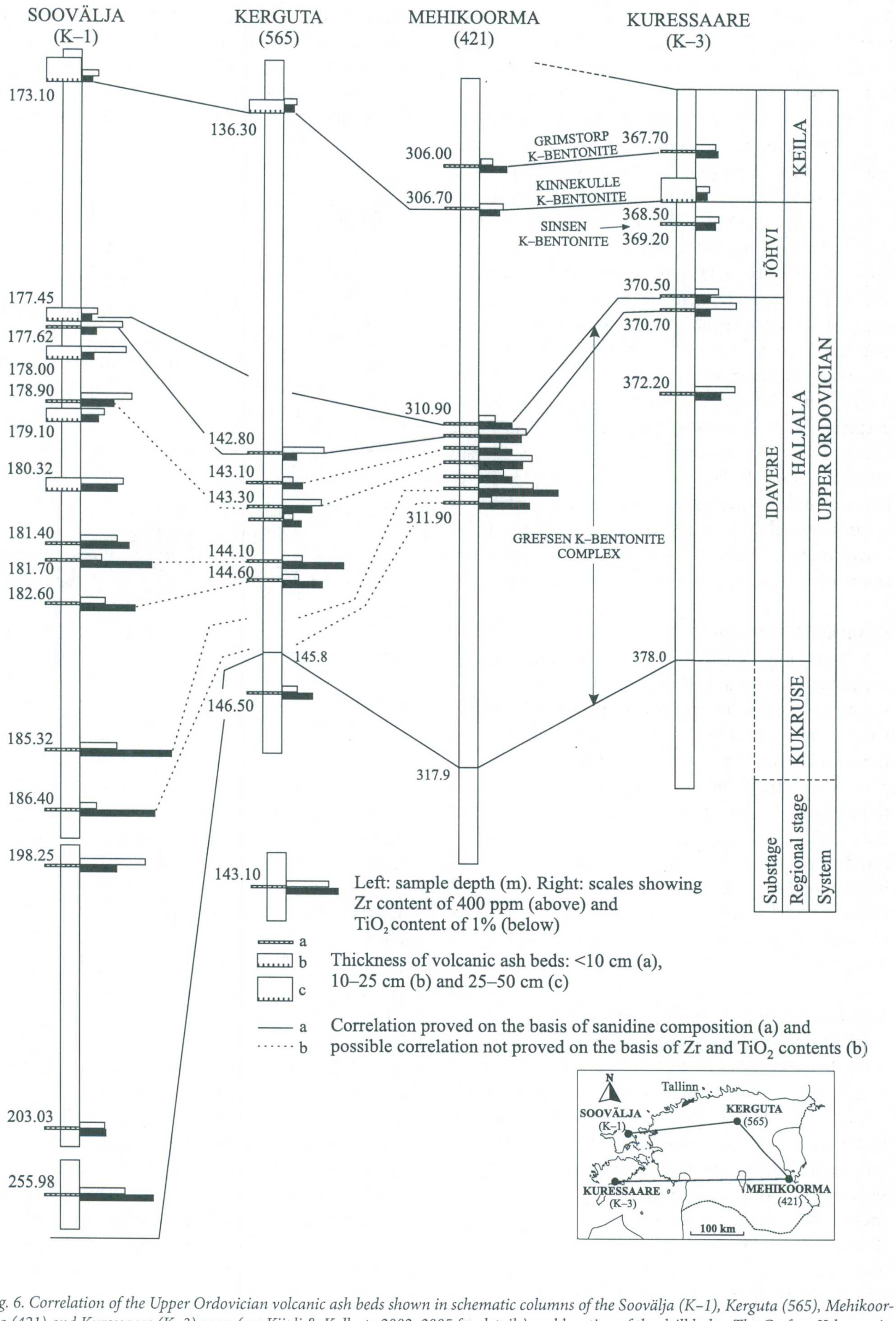


Fig. 6. Correlation of the Upper Ordovician volcanic ash beds shown in schematic columns of the Soovälja (K–1), Kerguta (565), Mehikoorma (421) and Kuressaare (K–3) cores (see Kiipli & Kallaste 2002, 2005 for details) and location of the drill holes. The Grefsen K-bentonite complex and the Sinsen, Kinnekulle and Grimstorp K-bentonite beds are indicated after Bergström et al. (1995).

these interbeds showed only weak sanidine reflections not allowing reliable correlations. Anyway, these measurements proved that the K-bentonite at a depth of 142.8 m is not the uppermost Grefsen K-bentonite (Fig. 6), which revealed a well measurable distinct sanidine reflection in the Soovälja (K–1), Mehikoorma (421) and Kuressaare (K–3) sections (Kiipli & Kallaste 2005, table 1). Most probably this bentonite correlates with those at 177.62 m in the Soovälja (K–1), 311.0 m in the Mehikoorma (421) and 370.7 m in the Kuressaare (K–3) sections (Fig. 6). Relatively high Zr and low TiO_2 contents characterize this bed in all sections, except for Mehikoorma (421), where large amounts of terrigenous admixture cause rise in TiO_2. Generally, many volcanic ash beds from the upper part of the Idavere Substage have a similar geochemical fingerprint - high Zr and low TiO_2 contents, while lower bentonites of the substage, on the contrary, contain little Zr and much TiO_2. Using Zr and TiO_2 for correlations, we must take into account the effect of terrigenous material on their concentration. Highly reliable correlations can be achieved by the study of more representative sections and support from other methods.

Kinnekulle K-bentonite

A light grey K-bentonite bed containing greenish-yellow pockets and biotite flakes lies on the lower boundary of the Keila Stage at a depth of 136.2–136.4 m (Appendix 1, sheet 6; Appendix 4). Bulk analysis of the sample from 136.3 m showed pure bentonite composition and the measured sanidine 20$\bar{1}$ reflection gave the calculated value of 24.3 mol% $NaAlSi_3O_8$ in sanidine (Table 1). This composition corresponds to the sanidine compositions measured from the Kinnekulle bentonite in other localities and confirms the correlation (Fig. 6). The other sample taken at 133.0 m from the Keila Stage revealed no signs of the volcanogenic component.

Volcanic ash bed of the Pirgu Stage

Four samples of argillaceous interbeds were studied from the Pirgu Stage (Table 1). Three of these showed no signs of the volcanogenic component (Fig. 5). The volcanic ash bed at 46.6 m was recorded by Tiina Lang (Geological Survey of Estonia) in 1983. The high content of authigenic potassium feldspar indicates the presence of some volcanogenic material. Measurement of the coarse fraction revealed only a weak sanidine 20$\bar{1}$ reflection not allowing reliable correlations. Most probably this bentonite cannot be correlated with sanidine-containing volcanic ash beds identified at 251.8 m in the Pirgu Stage of the Mehikoorma (421) core (Kiipli & Kallaste 2005). Possibly this bed correlates with the volcanogenic bed at 628.05 m in the lower part of the Jonstorp Formation in the Ruhnu (500) section (Kiipli & Kallaste 2003). The bentonite in the Ruhnu (500) core reveals a wide sanidine reflection with an average $NaAlSi_3O_8$ content of 25.3 mol%.

KUKERSITE OIL SHALE BEDS

The Kerguta (565) borehole is located in the central part of the Tapa oil shale deposit (area 1150 km^2). The deposit was discovered south of the town of Tapa in 1967–1968 (Fig. 7) and the exploration of oil shale was conducted in 1978–1981. The estimated resources of the prospective Tapa deposit are 2.6 x 109 tonnes (Bauert & Kattai 1997).

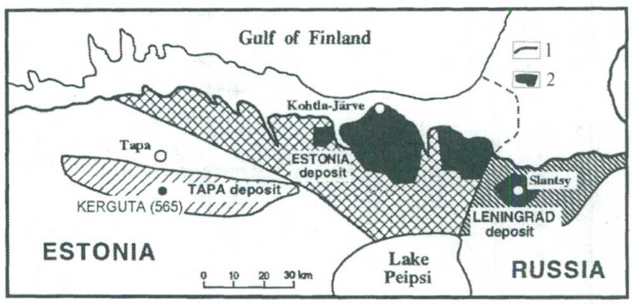


Fig. 7. Location of oil shale deposits in the Baltic Oil Shale Basin (after Bauert & Kattai 1997). 1 – recent erosional boundary of kukersite oil shale; 2 – mined-out areas and fields of active mines.

The Tapa deposit is based on kukersite seam III in the upper part of the Viivikonna Formation, while in the easterly Estonia oil shale deposit the commercial kukersite seams are A–F_1 (Bauert & Kattai 1997). Kukersite layer III in the Kerguta (565) core is 2.3 m thick (in the deposit area ranging from 1.6 to 2.3 m; Table 2) and lies at a depth of 149.5–151.8 m (in the deposit area at 50–160 m).

The kukersite oil shale beds in the Kerguta (565) core are lithostratigraphically confined to the Kõrgekallas (thickness 6.9 m) and Viivikonna formations (thickness 17.7 m) (Table 2; Appendix 1, sheets 6, 7; Appendix 3, D-1…3; Appendix 4). A uniform stratigraphic nomenclature of kukersite beds has been accepted for the Viivikonna Formation (Bauert & Kattai 1997; see also Taga-Roostoja (25A) section in Põldvere 1999), where capital letters and Roman numerals are used to designate separate beds (Table 2). The succession of kukersite beds (usually indexed with lowercase letters; Kattai 2000, table 4.3) in the Kõrgekallas Formation, gradually thinning westwards, is not clear. In Table 2 only nine 5–18 cm thick unindexed kerogenous limestone beds and rare argillaceous kukersite-containing marlstone intervals are presented (see Appendix 4). Correlation of these layers with the 20 indexed beds, widespread in the eastern sections, is not known with certainty.

The indexed oil-shale-bearing beds of the Viivikonna Formation in the Kerguta (565) core consist of kerogenous limestone and kukersite, intercalating with argillaceous limestone and calcitic marlstone. Fine and coarse bioclasts account locally up to 50%. The rock structure varies from nodular to wavy bedding. Discontinuity surfaces and burrows are present (Appendix 4).

In the lower, Kiviõli Member of the Viivikonna Formation the kukersite oil shale bed is composed of individual 0.05–0.45 m thick kukersite seams A–K (Table 2). Seams B+C and E+F_1+F_2 are the richest in yellowish-brown kukersite (content 50–70%), while the other seams contain lenses and nodules of limestone. The kukersite seams alternate with light grey or beigish-grey limestone intervals of variable thickness (0.1–0.5 m), which may be pyrite mottled, burrowed, argillaceous, nodular or wavy bedded with thin marlstone interbeds (Appendix 4).

Table 2. Kukersite oil shale beds of the Kõrgekallas and Viivikonna formations in the Kerguta (565) core

Formation	Member	Kukersite beds		
		Index	Interval (m)	Thickness (m)
Viivikonna	Peetri	VII	145.80–146.47	0.67
		VI	146.70–146.87	0.17
		V	147.50–147.95	0.45
		IV	148.10–148.70	0.60
		III	149.50–151.80	2.30
	Maidla	IIb	151.95–152.55	0.60
		IIa	152.90–153.60	0.70
		II	153.80–154.35	0.55
		I	155.15–155.75	0.60
		P	156.00–156.40	0.40
		N+O	156.90–158.25	1.35
		M	158.40–158.80	0.40
		L	159.25–159.85	0.60
	Kiviõli	K	159.95–160.35	0.40
		J	160.85–161.30	0.45
		H	161.40–161.60	0.20
		G	161.75–161.85	0.10
		F_4	162.10–162.20	0.10
		F_3	162.35–162.40	0.05
		E+F_1+F_2	162.50–162.90	0.40
		B+C	163.10–163.30	0.20
		A	163.45–163.50	0.05
Kõrgekallas		–	163.60–163.78	0.18
		–	164.27–164.30	0.03
		–	164.37–164.50	0.13
		–	164.70–164.80	0.10
		–	164.85–164.90	0.05
		–	165.40–165.50	0.10
		–	165.60–165.70	0.10
		–	166.10–166.20	0.10
		–	166.70–166.75	0.05

Kukersite seams L–IIb with a thickness of 0.40–1.35 m are distinguished in the middle, Maidla Member of the Viivikonna Formation (Table 2). The content of kukersite is here 20–60%, being the highest in seam II. Limestone intervals (thickness 0.15–0.80 m) of the member are in places argillaceous, nodular and wavy bedded with thin calcitic marlstone interbeds (Appendix 4).

The Peetri Member in the upper part of the Viivikonna Formation shows an increase in kukersite. Here 0.17–2.30 m thick seams III–VII are distinguished, with kukersite content ranging from 10 to 75%. The thickest is the potential commercial oil shale bed III (Table 2; Appendix 3, D-1; Appendix 4), where the content of kukersite is up to 70–75%. Thick- to medium-bedded and thick- to medium-nodular yellowish-brown and brown, in places splitting kukersite contains small lenses of limestone, beigish-grey kerogenous limestone nodules and abundant skeletal fragments.

Limestone nodules make up 25–60% of the total volume of commercial bed III in the Tapa deposit area. The main mineral composition of the bed is as follows: OM content 10–25%, carbonates 60–70%, clay minerals 14–20%. The calorific value of oil shale in kukersite seam III is 6–8 MJ/kg and oil yield 9–13% (Bauert & Kattai 1997), both decreasing considerably towards the lower- and uppermost parts of the bed and the periphery of the deposit area (Kattai 2000).

Mining activities in the Tapa deposit are not regarded feasible at present because of several inhibiting factors, such as rather low-grade oil shale, thick overburden (50–160 m) and environmental restrictions (Kattai & Reinsalu 1991).

CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF THE ROCK

A total of 90 rock samples from the Ordovician (Lower, Middle, Upper) and Silurian (only 3 samples from the Llandovery) from the Kerguta (565) drill core were studied by geochemical methods (Appendix 7). Of those, 84 samples were additionally studied by petrophysical methods (Appendix 14). Thin sections were made from 45 samples to determine relationships between minerals, skeletal and nonskeletal rock-forming grains, cements, fabric, porosity and diagenetic alteration of rocks (Appendix 2). The investigated core section (Appendix 1) is represented mainly by primary carbonate (limestones, argillaceous limestones, calcitic marlstones) and dolomitized rocks (dolomitic limestones, dolomitic argillaceous limestones, dolostones, dolomitic marlstones).

Methods

The bulk chemical composition of the rocks was determined by XRF spectrometry in the laboratories of the All-Russian Geological Institute (VSEGEI), St. Petersburg. The insoluble residue (IR), MgO and CaO contents were additionally measured by wet chemical analysis in the Institute of Geology at Tallinn University of Technology (IG TUT).

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 Solid Earth Geophysics Laboratory of the University of Helsinki. Chemical and physical parameters were interpreted together using correlation analysis. The examined thin sections were prepared in the IG TUT.

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 water in vacuum for 24 hours and after that weighed in air (P_w). From the obtained measurements the following parameters were calculated: dry density $\delta_d = P_d/V$, where V represents sample volume calculated from sample size; wet density $\delta_w = P_w/V$; effective porosity $\varphi = (P_w - P_d)/V$ and effective density $\delta_e = P_d/(V \times (100 - \varphi)/100)$, which is close to grain density $\delta_g = P_d/V_g$, where V_g represents grain volume.

The P-wave velocity was calculated from the transit time (dt) of electrical pulses through the sample. The travel time is determined using two identical P-wave transducers as transmitter and as receiver. The transmitter generates a continuous train of electric pulses, which will travel through the sample and will be picked up by the receiver depending on how fast the P-wave can travel trough the sample. Hence, the P-wave velocity (V_p) was determined using the formula $V_p = 1000 \times ((L_1 + L_2)/2)/dt$, where L_1 and L_2 represent two independent measurements of the sample length.

To compare transit time dt in the samples of different size, it was calculated as $dt = 1/V_p$.

The magnetic susceptibility of rock samples was determined with an AGICO KLY-3A kappabridge.

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. 8, Appendix 7). Rock types were distinguished based on the classification of carbonate rocks used in Estonia (Vingisaar *et al.* 1965; Nestor 1990; Kleesment & Shogenova 2005) and on international classifications (Mount 1985; Jackson 1997; Miall 2000; Selley 2000). The rocks were subdivided into nine lithological types based on the following limits of the calculated and measured chemical components (Fig. 8): (1) "pure" limestone (IR < 10%, $CaMg(CO_3)_2$ < 10%), (2) dolomitic limestone (IR < 10%, 10 < $CaMg(CO_3)_2$ < 50%), (3) argillaceous limestone (10 < IR < 25%, $CaMg(CO_3)_2$ < 10%), (4) argillaceous dolomitic limestone (10 < IR < 25%, 10 < $CaMg(CO_3)_2$ < 45%), (5) calcitic marlstone (25 < IR < 50%, $CaCO_3$ > $CaMg(CO_3)_2$), (6) dolostone, argillaceous dolostone (IR < 25%, $CaMg(CO_3)_2$ > 65%), (7) dolomitic marlstone (25 < IR < 50%, $CaCO_3$ < $CaMg(CO_3)_2$), (8) mixed carbonate-siliciclastic rock (50 < IR < 70%), (9) siliciclastic rock (IR > 70%). The first four rock types are represented by 76 samples from pure to variously

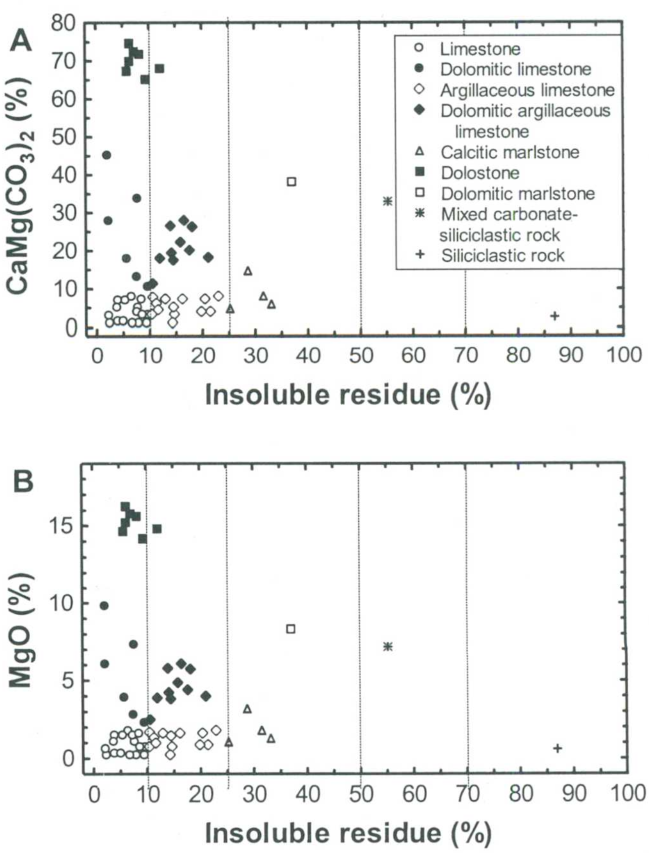


Fig. 8. (A) $CaMg(CO_3)_2$ calculated from MgO versus insoluble residue, both measured by wet chemical analysis.
(B) MgO content versus insoluble residue measured by wet chemical analysis.

argillaceous and dolomitized limestones. "Pure" limestones are represented by 33 (see Appendix 7), dolomitic limestones by 6, argillaceous limestones by 25 and argillaceous dolomitic limestones by 12 samples. All samples are from the Ordovician, except for one. Calcitic marlstones are represented by only one Silurian (Appendix 2, T-1) and three Ordovician samples (Kahula Formation), two of which were destroyed during cutting and petrophysical measurements. Dolostones are represented by seven Ordovician samples (Toila, Loobu and Ärina formations; Appendix 2, T-41, T-42, T-43). Dolomitic marlstones are represented by only one sample from the Silurian (Varbola Formation), which was destroyed during cutting and thus physical properties were not measured. The mixed carbonate-siliciclastic rock type is represented by sand- and silt-containing glauconitic dolomitic marlstone of the Lower Ordovician Billingen Stage (Toila Formation; Appendix 2, T-45), and the siliciclastic rock type is represented by one glauconitic sandstone sample from the Lower Ordovician Hunneberg Stage (Leetse Formation).

The total iron (Fe_2O_3 total) content of most of the studied pure and argillaceous limestones correlates with the clay content, and their Fe_2O_3 total/Al_2O_3 ratio is in the range of 0.4–1 (Fig. 9; Appendix 7). Three dolomitic limestone samples from the Väo and Saunja, two limestones from the Rägavere and Saunja, one argillaceous limestone from the Viivikonna and dolostones from the Toila and Loobu formations have the Fe_2O_3 total/Al_2O_3 ratio higher than one. The dolostones of the Toila (Volkhov Stage) and Loobu formations (Kunda Stage) including glauconite grain impurities showed the highest iron content (6.50–8.43%) among all carbonate rocks (Figs 9, 10; Appendix 2, T-42…44). This is higher than the iron content of the dolostones of the Kriukai Formation (Volkhov Stage) in the Mehikoorma (421) core, but close to that of the dolostones of the Kriukai Formation (Volkhov Stage) in the Ruhnu (500) core (Shogenova *et al.* 2003, 2005).

The correlation coefficient (R) of Fe_2O_3 total with Al_2O_3 as an indicator of clay is 0.77 for all rocks except for dolostones (Fig. 9A). This value is similar to the correlation coefficient in the Ruhnu (500) core (0.78; Shogenova *et al.* 2003), but lower than that for limestones and calcitic marlstones of the Mehikoorma (421) core (0.92; Shogenova *et al.* 2005). In general, pure, dolomitic and argillaceous dolomitic limestones have the lowest total iron content (0.18–1.35%); it is higher in argillaceous limestones (0.50–2.79%) and marlstones (1.6–2.4%) and the highest in dolostones (0.67–8.43%) (Figs 9, 10; Appendix 7).

The MnO content in general correlates with total iron content (R = 0.85) and increases with depth in

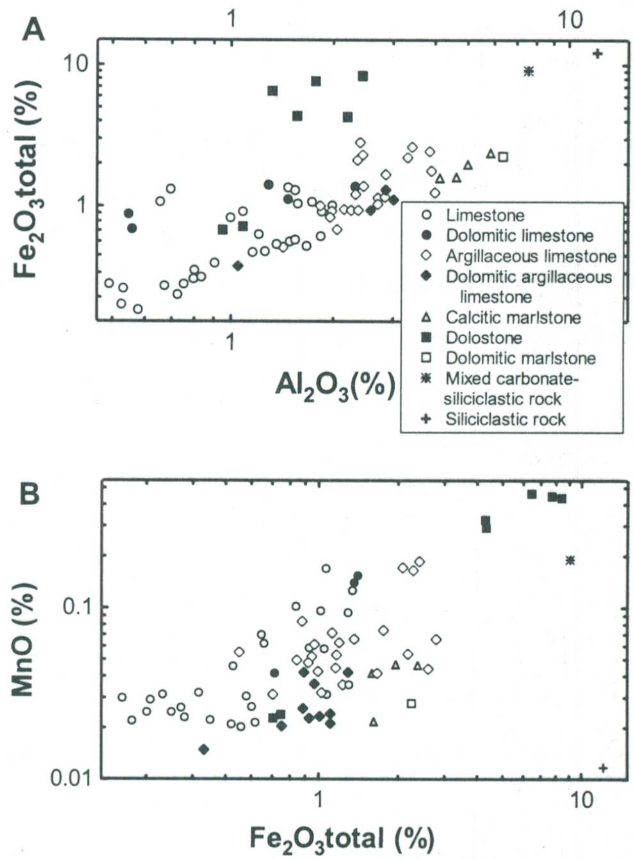


Fig. 9. (A) Total iron content versus Al_2O_3 content measured by XRF analysis. Correlation coefficient R = 0.77 for all samples except for the dolostones.
(B) MnO content versus total iron content measured by XRF analysis. Correlation coefficient R = 0.85 for all samples, R = 0.48 for primary rocks (limestones, argillaceous limestones and calcitic marlstones), R = 0.87 for dolomitized rocks (dolostones, dolomitic limestones, argillaceous dolomitic limestones and dolomitic marlstones).

carbonate rocks (Figs 9B, 10). The MnO content was lowest in the dolomitic argillaceous limestone and dolostone of the Moe, Adila and Ärina formations. It is higher in the rocks of the Kõrgessaare Formation and the highest in the lower Ordovician Toila to Aseri formations, with the peak in the dolostones of the Toila Formation. The MnO content of the sand- and silt-containing glauconitic dolomitic marlstone of the same formation is lower than that of dolostones. The lowest MnO content was recorded in the glauconite sandstone of the Leetse Formation (Figs 9B, 10; Appendix 7).

Porosity and density

Lithological discrimination of the primary and dolomitized carbonate rocks is usually revealed on the porosity–wet density plot. The density of dolostones is the highest for the given porosity and forms its own correlation line (Shogenova & Puura 1998; Shogenova *et al.* 2003, 2005). The same relation was observed in

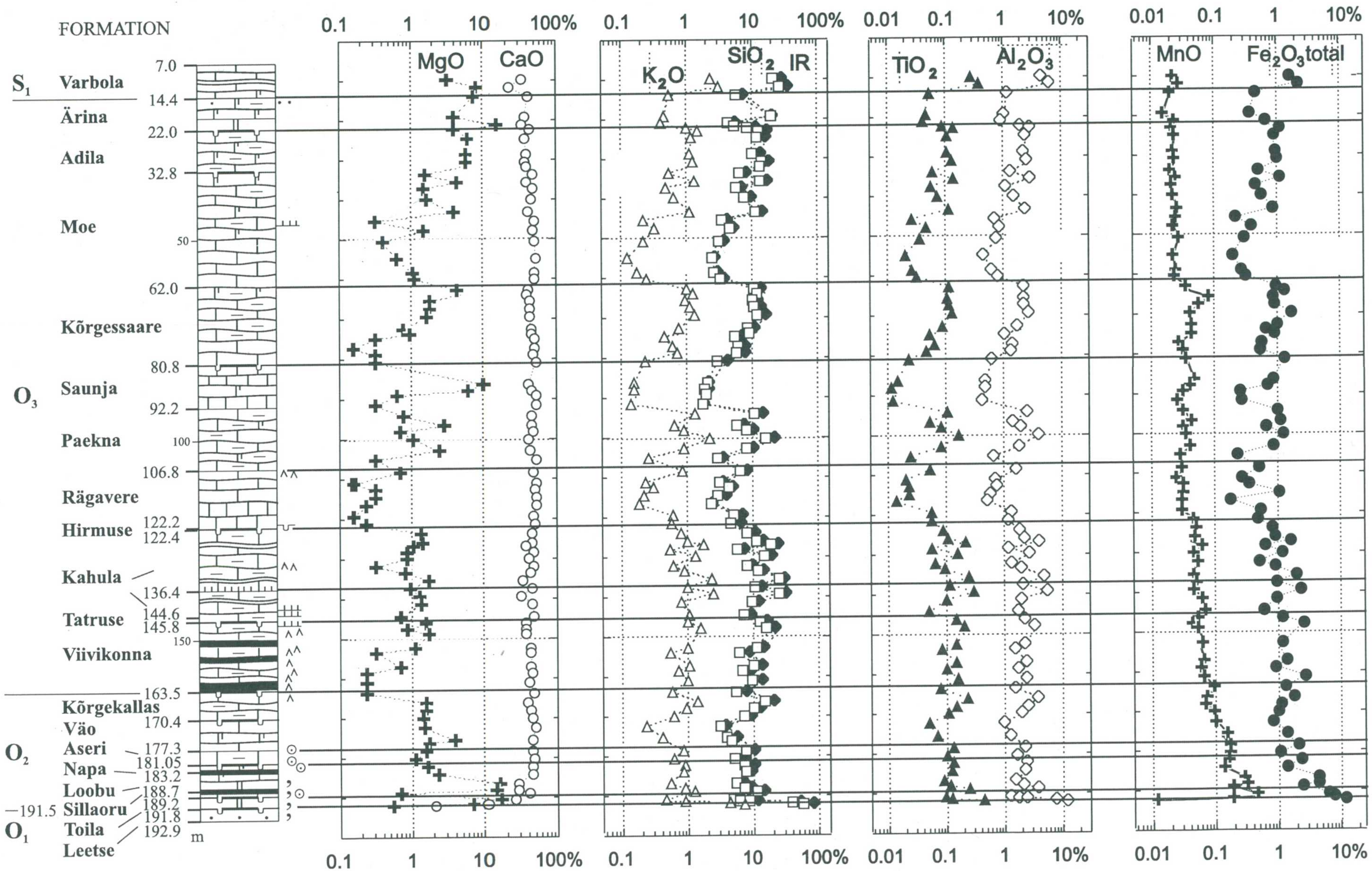


Fig. 10. Chemical composition of the Kerguta (565) core. CaO, MgO and insoluble residue (IR) measured by wet chemical analyses, other oxides measured by XRF analysis. O_1 – Lower Ordovician; O_2 – Middle Ordovician; O_3 – Upper Ordovician; S_1 – Llandovery. Refer to Appendix 1 for lithology and distribution of regional stages.

Selected Middle and Upper Ordovician chitinozoans from the Kerguta (565) section

PLATE I

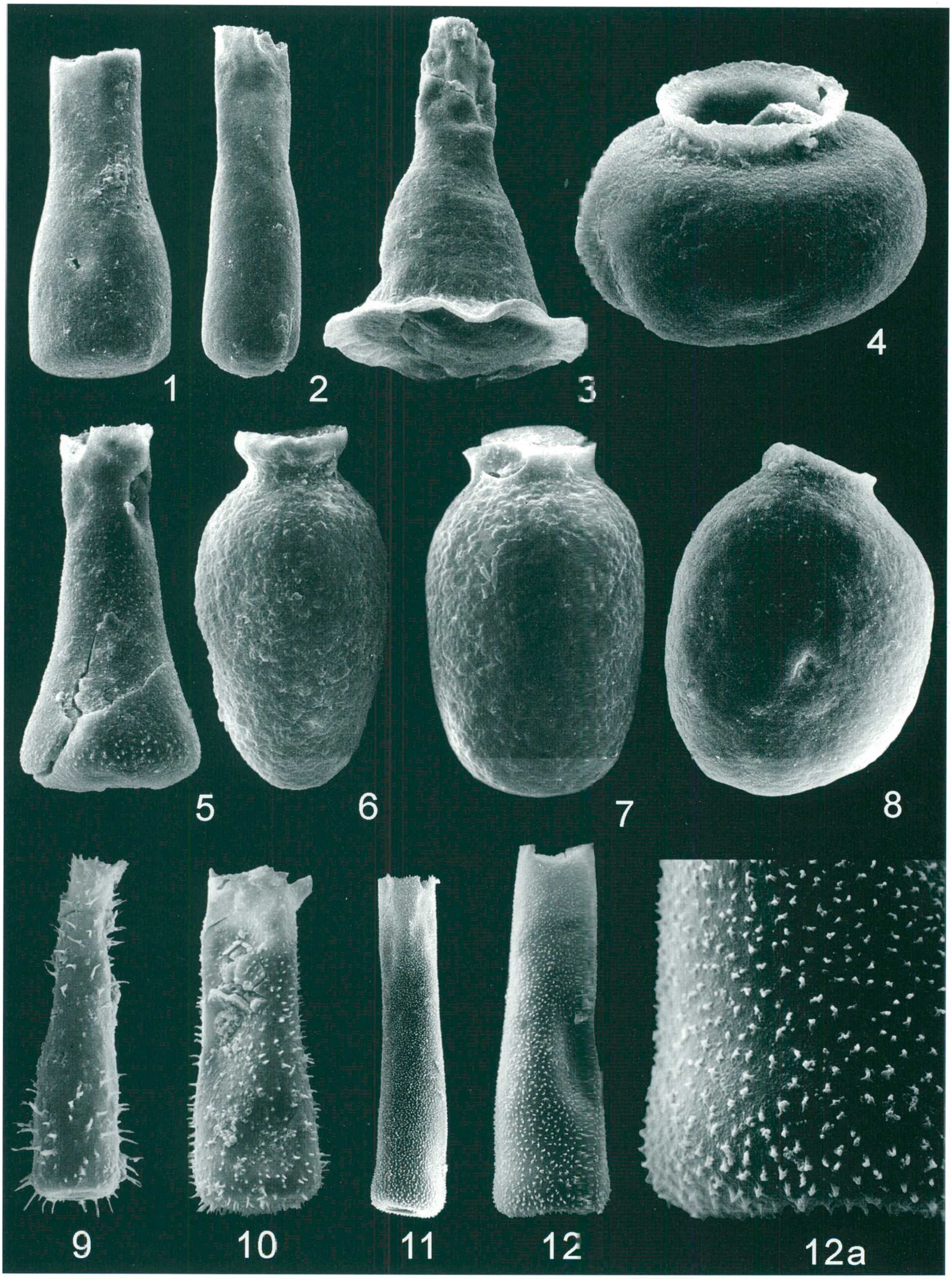


Fig. 1. *Conochitina* sp. 1, 160.07–160.12 m, × 930. **Fig. 2**. *Conochitina* sp. 2, 152.75–152.84 m, × 750. **Fig. 3**. *Cyathochitina kuckersiana* (Eis.), 147.43–147.50 m, × 750. **Fig. 4**. *Calpichitina complanata* (Eis.), 146.94–147.00 m, × 1860. **Fig. 5**. *Euconochitina primitiva* (Eis.), 161.60–161.73 m, × 1300. **Fig. 6**. *Desmochitina elongata* Eis., 169.08–169.21 m, × 1300. **Fig. 7**. *Desmochitina ovulum* Eis., 156.55–156.75 m, × 1700. **Fig. 8**. *Desmochitina amphorea* Eis., 145.94–146.00 m, × 1860. **Fig. 9**. *Belonechitina crinita* (Grahn), 180.97–181.03 m, × 560. **Fig. 10**. *Belonechitina pellifera* (Eis.), 175.43–175.54 m, × 930. **Fig. 11**. *Belonechitina* sp. A, 178.90–178.99 m, × 560. **Fig. 12**. *Belonechitina* sp. A, 178.49–178.61 m, × 930; **12a**, detail, × 3200.

Selected Middle and Upper Ordovician chitinozoans from the Kerguta (565) section

PLATE II

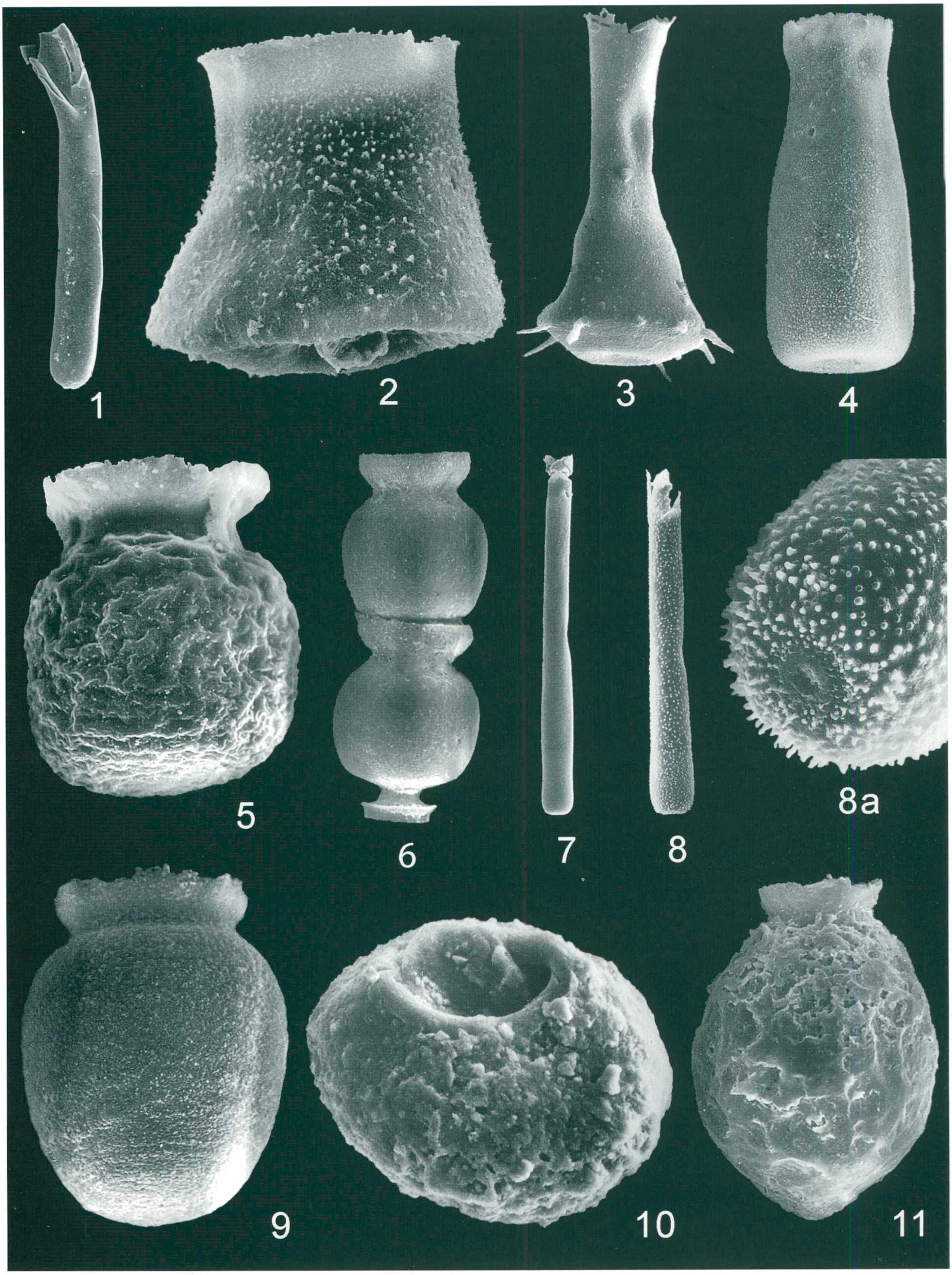


Fig. 1. *Conochitina minnesotensis* Stauffer, 144.15–144.27 m, × 220. **Fig. 2**. *Eisenackitina rhenana* (Eis.), 150.16–150.22 m, × 2200. **Fig. 3**. *Spinachitina multiradiata* (Eis.), 144.50–144.64 m, × 1400. **Fig. 4**. *Lagenochitina tumida* Umnova, 178.22–178.32 m, × 750. **Fig. 5**. *Desmochitina grandicolla* Eis., 178.10–178.22 m, × 1700. **Fig. 6**. *Desmochitina nodosa* Eis., 142.45–142.57 m, × 1100. **Fig. 7**. *Rhabdochitina gracilis* Eis., 174.48–174.58 m, × 220. **Fig. 8**. *Conochitina tuberculata* Eis., 168.71–168.78 m, × 390; **8a**, detail, × 2800. **Fig. 9**. *Desmochitina minor* Eis., 144.64–144.75 m, × 1700. **Fig. 10**. *Calpichitina lata* (Schallreuter), 139.19–139.33 m, × 1500. **Fig. 11**. *Desmochitina rugosa* Eis., 151.05–151.10 m, × 1200.

Selected Middle and Upper Ordovician chitinozoans from the Kerguta (565) section

PLATE III

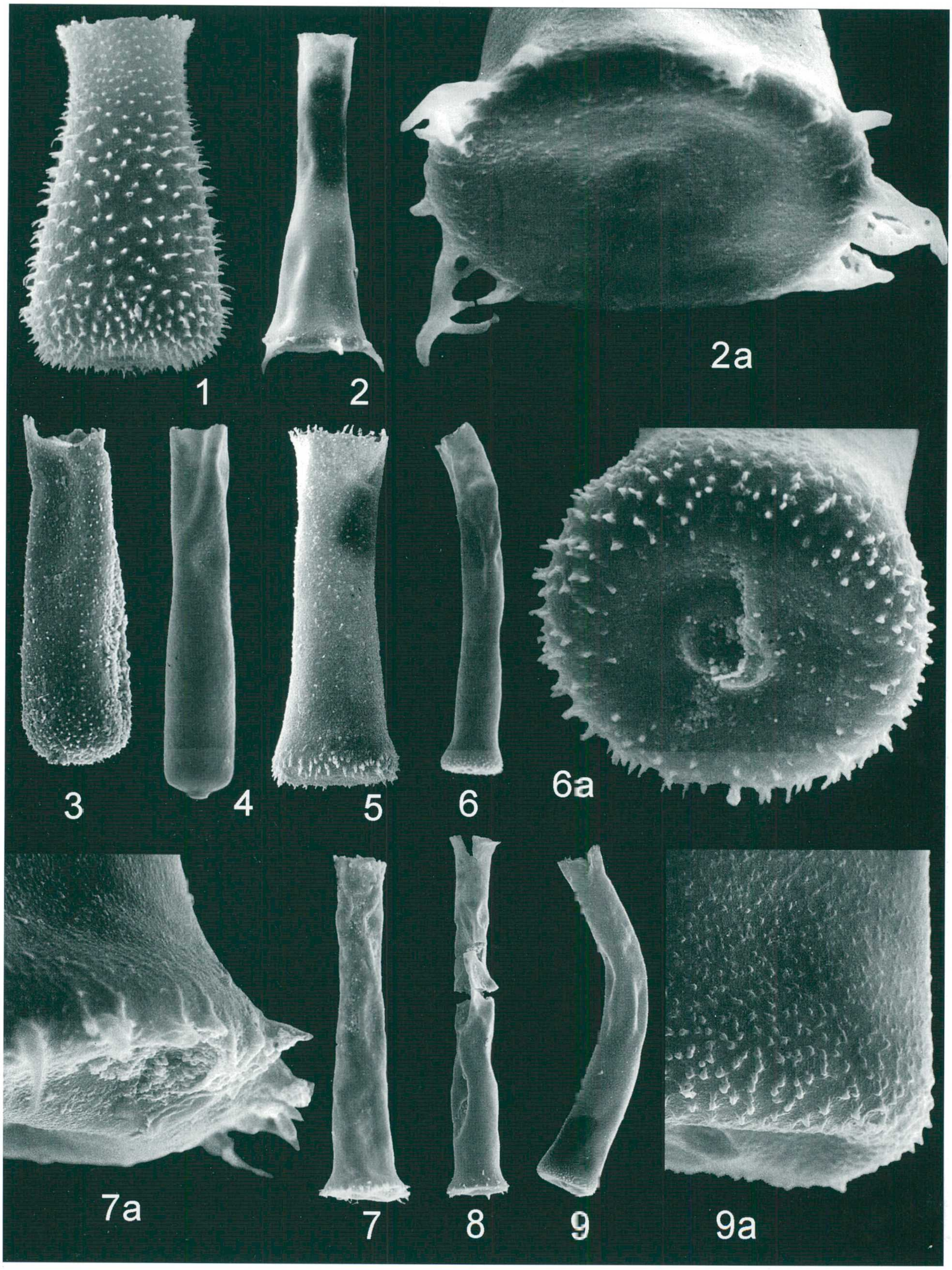


Fig. 1. *Belonechitina cactacea* (Eis.), 168.71–168.78 m, × 1300. **Fig. 2**. *Spinachitina cervicornis* (Eis.), 136.90–137.06 m, × 840; **2a**, detail, × 2050. **Fig. 3**. *Belonechitina* cf. *repsinata* Schallreuter, 143.87–144.02 m, × 930. **Fig. 4**. *Conochitina dolosa* Laufeld, 144.39–144.50 m, × 400. **Fig. 5**. *Belonechitina micracantha* (Eis.), 175.11–175.19 m, × 1100. **Fig. 6**. *Belonechitina capitata* (Eis.), 143.87–144.02 m, × 370; **6a**, detail, × 2050. **Fig. 7**. *Spinachitina suecica* (Laufeld), 143.22–143.36 m, × 600; **7a**, detail, × 5000. **Fig. 8**. *Belonechitina* cf. *capitata* (Eis.), 172.65–172.76 m, × 370. **Fig. 9**. *Belonechitina comma* (Eis.), 144.75–144.83 m, × 600; **9a**, detail, × 4300.

PLATE IV

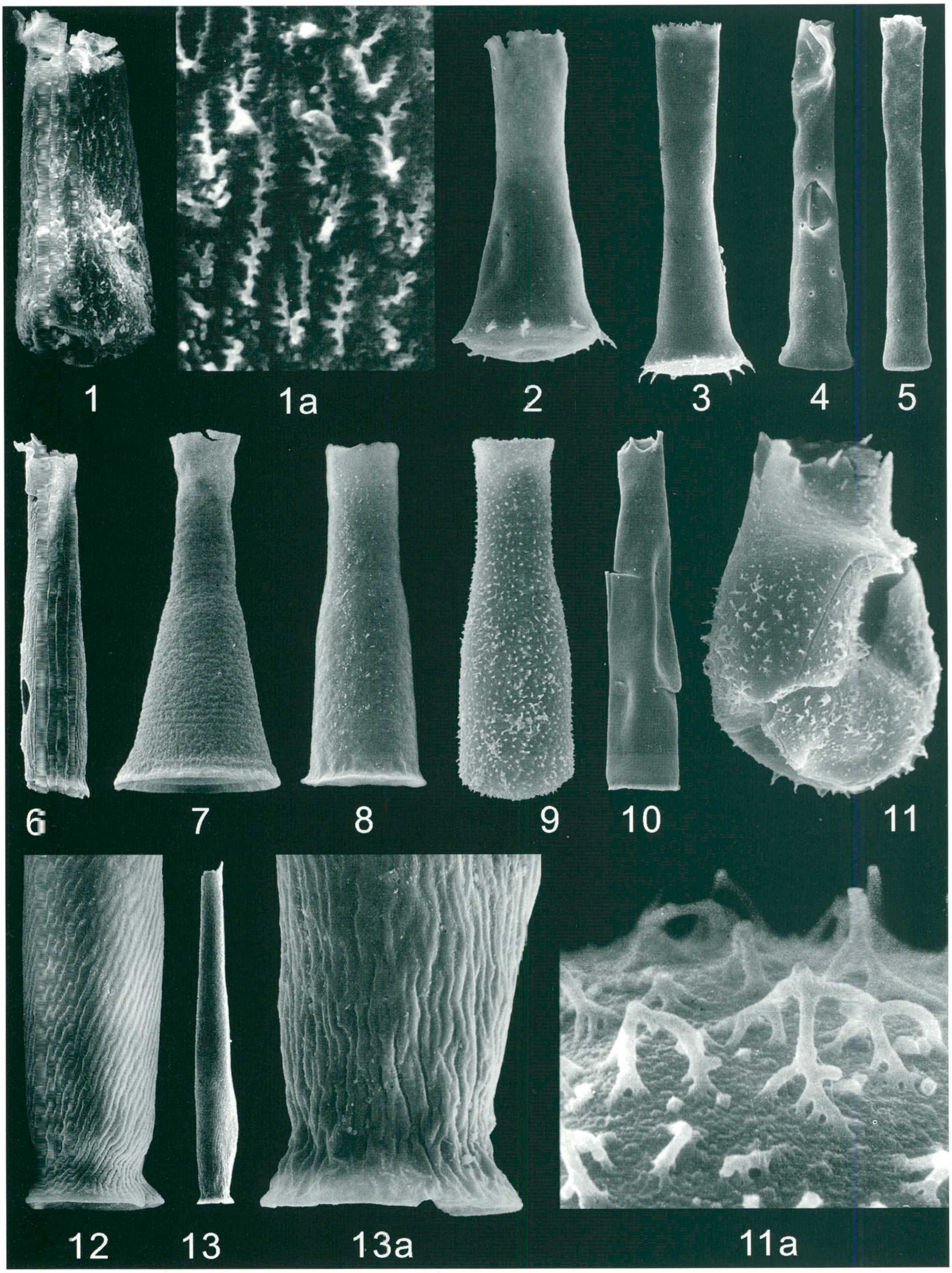


Fig. 1. *Hercochitina lindstroemi* Grahn *et* Nõlvak, 135.90–136.03 m, × 930; **1a**, detail, × 5600. **Fig. 2**. *Spinachitina multiradiata* (Eis.), 143.76–143.83 m, × 930. **Fig. 3**. *Spinachitina multiradiata* (Eis.), 142.45–142.57 m, × 750. **Fig. 4**. *Pistillachitina pistilliformis* (Eis.), 178.49–178.61 m, × 450. **Fig. 5**. *Pistillachitina elegans* (Eis.), 148.05–148.11 m, × 320. **Fig. 6**. *Laufeldochitina stentor* (Eis.), 162.83–162.88 m, × 270. **Fig. 7**. *Cyathochitina campanulaeformis* (Eis.), 157.10–157.19 m, × 450. **Fig. 8**. *Cyathochitina calix* (Eis.), 169.08–169.21 m, × 560. **Fig. 9**. *Belonechitina wesenbergensis* s.l. (Eis.) 157.10–157.19 m, × 930. **Fig. 10**. *Tanuchitina tallinnensis* Grahn, 179.52–179.59 m, × 370. **Fig. 11**. *Belonechitina hirsuta* (Laufeld), 144.75–144.83 m, × 1700; **11a**, detail, × 7500. **Fig. 12**. *Laufeldochitina striata* (Eis.), 175.11–175.19 m, detail, × 750. **Fig. 13**. *Laufeldochitina striata* (Eis.), 175.11–175.19 m, × 180; **13a**, detail, × 1400.

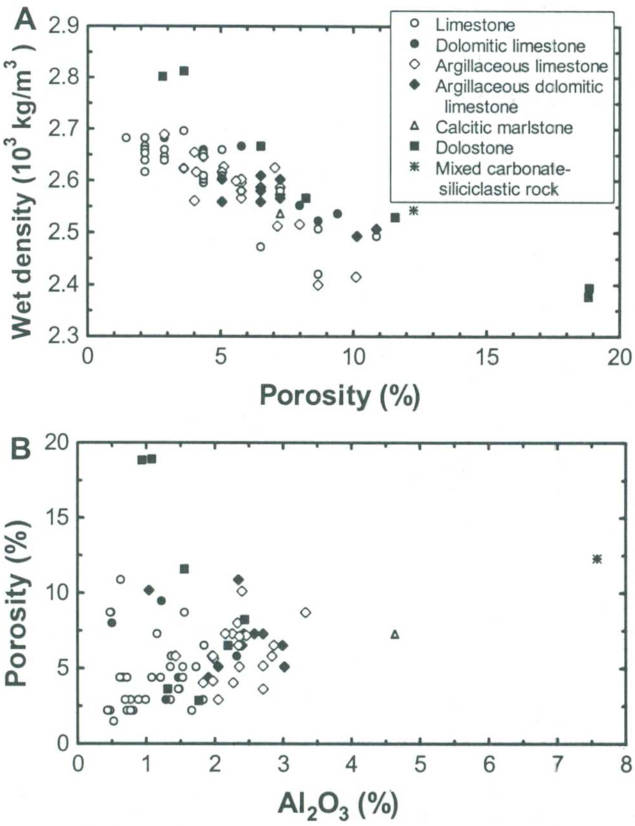


Fig. 11. (A) Wet density versus porosity. Correlation coefficient R = –0.80 for primary rocks (limestones, argillaceous limestones and calcitic marlstones), R = –0.87 for dolomitized rocks (dolostones, dolomitic limestones, argillaceous dolomitic limestones and dolomitic marlstones).
(B) Porosity versus Al_2O_3 content measured by XRF analysis.

the Kerguta (565) core (Fig. 11). The density of dolomitic limestone is generally higher than that of limestones with the same porosity. The limestones and argillaceous limestones of the Viivikonna Formation have the highest porosity and the lowest density among primary rocks, which can be explained by the lowest grain density of kerogen (Fig. 12; Appendix 14). Samples with kerogen impurities are in the lower part of the graph and form their own correlation line. The highest porosity (11.6%) among the samples of the Viivikonna Formation was measured in a sample with kerogen layers (depth 147.9 m; Appendix 14; Appendix 2, T-32). However, this sample was excluded from Figs 11–13, because it was partly destroyed before final weighing with full water saturation. It is the lightest sample studied from the Viivikonna Formation and its porosity was probably higher than 11.6%.

The limestones of the Rägavere, Saunja and Moe formations (Fig. 12; Appendix 14; Appendix 2, T-13, T-14, T-21, T-24) have the lowest porosity among the studied rocks. Two dolostones from the Toila Formation (part of the Volkhov Stage) have the highest density and low porosity (Appendix 2, T-43).

Similar to most of Estonian carbonate rocks (Shogenova & Puura 1998; Shogenova *et al.* 2003), carbonate rocks of the Kerguta (565) core show a significant positive correlation of porosity with the Al_2O_3 content, an indicator of the presence of clay (Fig. 11B). The samples with positive porosity–Al_2O_3 correlation are characterized by primary porosity associated with sedimentation processes. The porosity, which does not correlate with clay content, could be called secondary and is associated with diagenetic processes. Some Ordovician dolostones (Loobu and Ärina formations), two dolomitic limestones (Saunja Formation), some argillaceous dolomitic limestones (Adila and Ärina formations) and two limestones (Moe and Varbola formations) have secondary porosity up to 20% (Figs 11B, 12; Appendix 2, T-2, T-3, T-20). Open porosity was also underestimated (11.6%) in the dolostone of the Loobu Formation (Appendix 2, T-41). This rock sample contains open vugs and caverns (up to 5–10 mm), partly filled with dolomite crystals, and should have a higher porosity than could be measured by the water saturation method.

P-wave velocity

The relationship between P-wave velocity (or equivalently transit time) and porosity is different for limestones and dolostones of Estonia. The velocity of dolomitized rocks is higher and transit time usually lower for the given porosity (Fabricius & Shogenova 1998). The same relationships were observed in the Kerguta (565) core (Fig. 13A, B). The densest rocks of the Rägavere, Paekna and Saunja formations with the lowest porosity had the highest velocity (Fig. 12; Appendix 2, T-21, T-23, T-24). Low velocity and high transit time were measured in the rocks of the Viivikonna Formation with high porosity and low grain and bulk density (Figs 12, 13; Appendix 2, T-32...35). The lowest velocity (2400 m/s) is not shown in the figures because of the underestimated porosity of the kerogen-bearing sample that was partly destroyed during measurements (Appendix 2, T-32; Appendix 14). The lowest velocity shown in the figures was measured in the mixed rock (glauconitic dolomitic marlstone) of the Toila Formation (Figs 12, 13; Appendix 2, T-45).

Magnetic susceptibility

Low-field magnetic susceptibility in the studied rock sequence correlates with the total iron content (Fig. 14A) and increases from diamagnetic and paramagnetic to ferromagnetic minerals as in all Estonian sedimentary rocks (Shogenova 1999; Shogenova *et al.* 2003, 2005). The correlation coefficient is 0.96 for all rock samples from the Kerguta (565) core. Dolostones

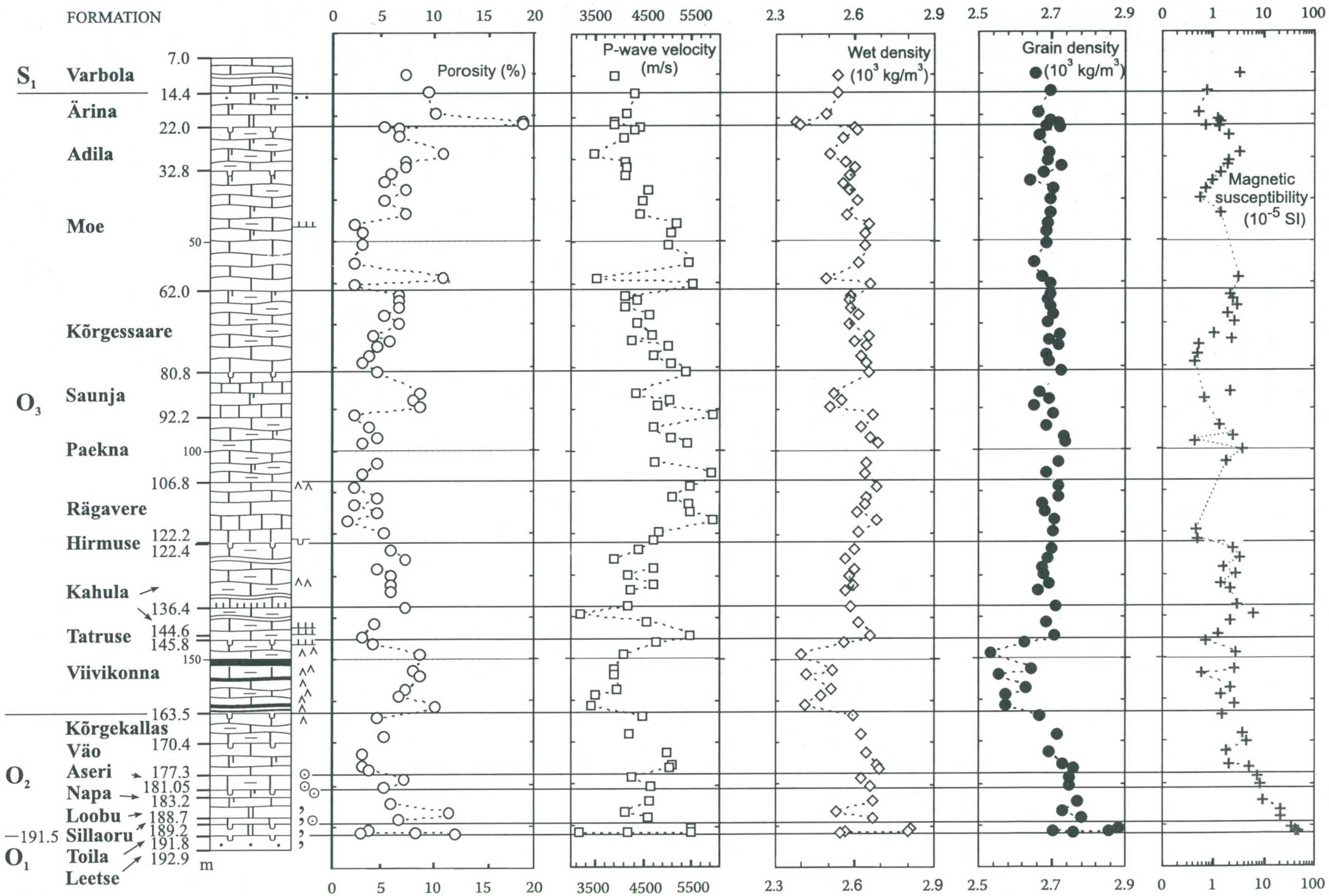


Fig. 12. Physical properties of the Kerguta (565) core. O_1 – Lower Ordovician; O_2 – Middle Ordovician; O_3 – Upper Ordovician; S_1 – Llandovery. Refer to Appendix 1 for lithology and distribution of the regional stages.

with glauconite impurities of the Loobu and Toila formations have relatively high magnetic susceptibility (21.5×10^{-5} to 42.6×10^{-5} SI) and a high total iron content (4.3–8.4%; Fig. 14A). The silt- and sand-containing glauconitic dolomitic marlstone of the Toila Formation had the highest magnetic susceptibility (Fig. 14; Appendix 2, T-45).

In general, magnetic susceptibility correlates with iron minerals occurring in the clay fraction of the rock. The dolostones of the Toila to Loobu formations have higher magnetic susceptibility for the given clay content (Fig. 14B), associated with glauconite impurities (see Appendix 1, sheet 8). Two dolostones from the Adila Formation have low iron content and magnetic susceptibility (Appendix 7; Figs 9, 10, 12, 14). The limestone of the Aseri Formation also has higher magnetic susceptibility for the given clay content owing to goethite-limonite oolitic coatings (Appendix 2, T-39). The dolomitic limestone of the Loobu Formation has higher magnetic susceptibility owing to pyrite aggregates and pyritization of microfossils (Appendix 2, T-40). Increase in magnetic susceptibility of some other samples is caused mainly by pyrite impurities found in the rock matrix (Fig. 12; Appendix 2).

Conclusions

The predominantly Middle and Upper Ordovician sequence studied in the Kerguta (565) core is represented mainly by argillaceous and variously dolomitized carbonate rocks. Some of them contain impurities of glauconite, kerogen and pyrite. The main factors influencing rock properties in the studied core section are primary and secondary porosity, dolomitization, impurities of iron-bearing minerals and kukersite oil shale layers.

Similar to the Ruhnu (500) core (Shogenova *et al.* 2003), the MnO content associates with iron minerals.

The density–porosity and velocity–porosity plots showed discrimination of primary carbonate and dolomitized carbonate rocks revealed in other cores (Fabricius & Shogenova 1998; Shogenova *et al.* 2003). Magnetic susceptibility correlates with total iron content in all rocks, and with clay content, except for the dolostones of the Toila and Loobu formations.

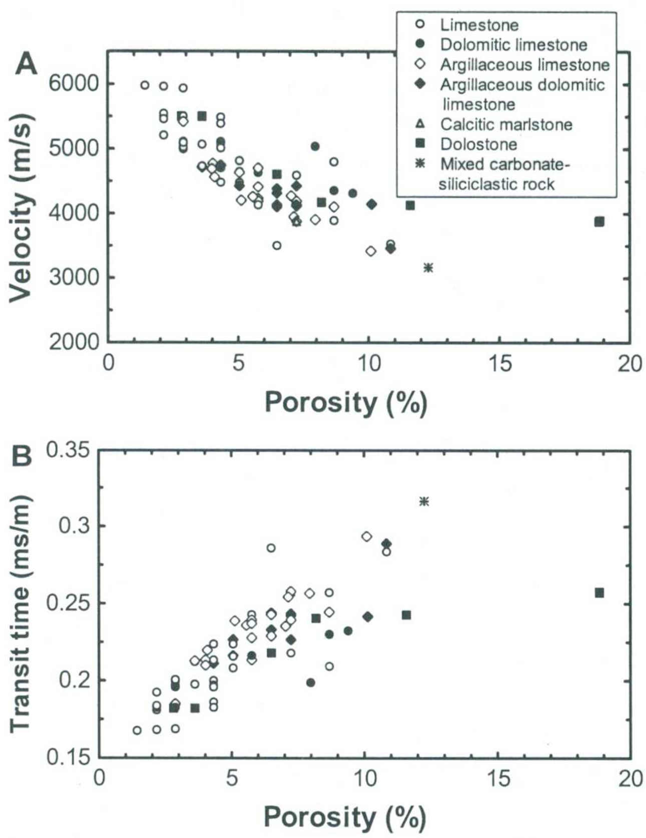


Fig. 13. (A) P-wave velocity versus porosity. Correlation coefficient R = −0.87 for primary rocks (limestones, argillaceous limestones and calcitic marlstones), R = −0.67 for dolomitized rocks (dolostones, dolomitic limestones, argillaceous dolomitic limestones and dolomitic marlstones).
(B) Transit time versus porosity. Correlation coefficient R = −0.85 for primary rocks (limestones, argillaceous limestones and calcitic marlstones), R = −0.66 for dolomitized rocks (dolostones, dolomitic limestones, dolomitic argillaceous limestones and dolomitic marlstones).

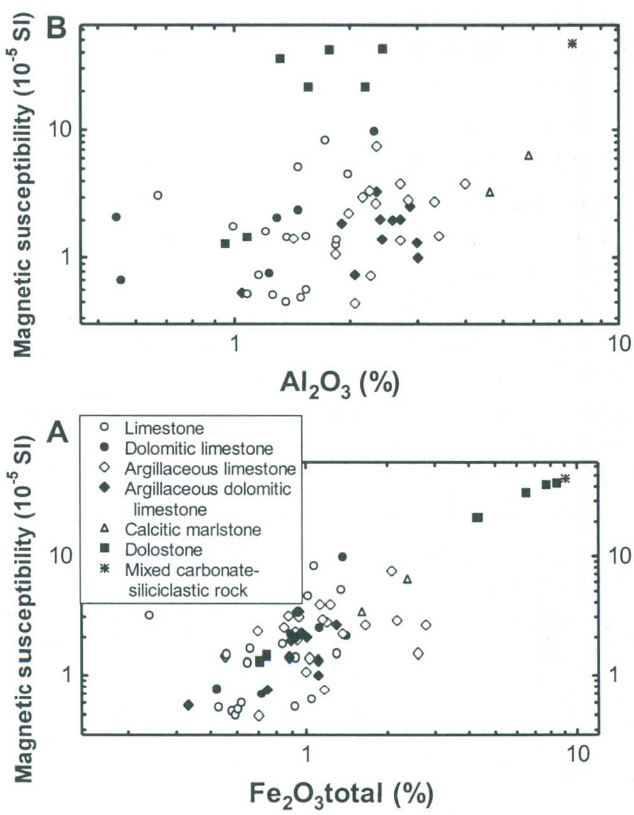


Fig. 14. (A) Magnetic susceptibility versus total iron content. Correlation coefficient R = 0.96 for all rock samples.
(B) Magnetic susceptibility versus Al_2O_3 content.

The highest porosity and the lowest density and P-wave velocity among primary rocks were recorded in the rocks of the Viivikonna Formation (Kukruse Stage) with kerogen impurities. The limestones of the Rägavere, Paekna and Saunja formations had the lowest porosity and the highest density and velocity.

The highest porosity and lowest density among dolomitized rocks were measured in the dolostones of the Ärina Formation (Porkuni Stage). These rocks had the lowest total iron content and magnetic susceptibility among studied dolostones. The dolostones of the Toila Formation had the lowest density but the highest total iron content and magnetic susceptibility.

Magnetic susceptibility correlates with total iron and clay content in all rocks except for the dolostones of the Toila and Loobu formations.

BED-BY-BED COMPARISON OF THE VÄO PAAS (1) BUILDING STONE WITH THE KERGUTA (565) SECTION

Ordovician carbonate rocks of Estonia lie under a thin Quaternary cover and are thus easy to access. These rocks, remarkable for unrivalled durability and great variety, have been widely used for building (strongholds, castles, churches, town houses, bridges, fireplaces, etc.), making sculptures, road-building and paving, lime and cement production, glass and paper industry, also for export, since the 13th century.

The quarries operated in northern Estonia, where the Ordovician building stone crops out as a continuous belt in average thickness of 8.0–8.6 m, thinning gradually from the surroundings of Tallinn towards Osmussaar Island and to the southwest (Fig. 15). Long traditions of stone-masonry have provided a detailed bed-by-bed stratification of the quarried rocks (Table 3), based on their properties, composition, colour, textural features and usage possibilities. Altogether, 58 beds (Vilbaste 1954; Einasto 2002), ranging from the lower part of the Väo Formation (Lasnamägi Stage) to the lower part of the Kõrgekallas Formation (Uhaku Stage), have been distinguished.

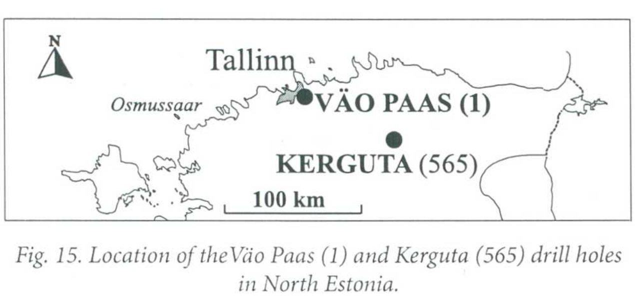


Fig. 15. Location of the Väo Paas (1) and Kerguta (565) drill holes in North Estonia.

The section of building stones (beds 16–56) is well exposed in the Tondi–Väo quarry (Väo deposit) near Tallinn. The Väo Paas (1) drill hole, penetrating beds 15–56 (Table 3) and terminating in the carbonate rocks of the Volkhov Stage (depth 14.8 m), is located to the southeast of the quarry. The Väo Formation, overlain by Quaternary sediments, is well represented and the core section is used as the type section of the formation.

The building stone sequence of medium- to thick-bedded limestones with numerous discontinuity surfaces in northern Estonia was first thoroughly described by Jaansoon-Orviku (1927). The same succession and lithological variation of beds in combination with characteristic discontinuity surfaces can be observed over a wide area (Orviku 1940). Here we try to follow the bed-by-bed stratification of the building stone known from the Väo deposit (Fig. 15) in the Kerguta (565) section at a distance of about 75 km. The parts of the Väo Formation described in the Väo Paas (1) core at a depth of 3.67–10.80 m and in the Kerguta (565) core at 170.4–176.1 m (Table 3; Appendixes 15, 16) are considered in more detail and compared.

Light grey, medium- to thick-bedded, very finely crystalline and finely crystalline limestones with rare marlstone films and interbeds (thickness 0.2–0.5 cm) contain 25–50% bioclasts (Appendix 1, sheet 7), abundant discontinuity surfaces, dolomitized intervals in the lower part of the Väo Formation and pyrite impurities. Generally, the intervals rich in marlstone interbeds are notably thinner in the Kerguta (565) core than in northwestern sections, particularly in two parts of the core: (1) near the boundary of the Lasnamägi and Uhaku stages (beds 44–53), where the limestone section is dolomitized and in places rich in pyrite; these beds are 0.38 m thick in the Kerguta (565) core and 1.40 m thick in the Väo Paas (1) core; (2) in the upper part of the Väo Formation (beds 15–33), where the limestone section is 0.55 m thinner in the Kerguta (565) core.

Sixty-three distinct phosphatized discontinuity surfaces were recognized in the Väo Formation of the Kerguta (565) section (Appendix 4) and about 55 in the Väo Paas (1) core. Pyritized discontinuity surfaces number, respectively, 4 and 10, and are all related to transgressive sediments.

The following main characteristics were considered in the comparison of the sections:

1. The underlying limestones of the Aseri Stage contain iron ooliths. Rare carbonate ooliths are found on the lower boundary of the Lasnamägi Stage (distinct phosphatized discontinuity surface (see Appendix 1, sheet 7).

Table 3. Bed-by-bed correlation of the Kerguta (565) and Väo Paas (1) sections, and characteristics of the building stone

Regional stage	Formation	Depth of the lower boundary (m): Kerguta (565)	Depth of the lower boundary (m): Väo Paas (1)	Bed number	Local bed name	Traditional applications / remarks
Uhaku	Kõrgekallas	?	–	1	Nutu	– / crumbles easily
		?	–	2	Hakantkirju	Masonry / argillaceous, with a PDS
		?	–	3	Topeltkirju	Masonry / argillaceous
		?	–	4	Kollane lõug	Masonry / argillaceous, on the PhDS kukersite-containing
		?	–	5	Ratsatäkk	Masonry / argillaceous, with a hard middle interbed
		?	–	6	Papa	Masonry / argillaceous
		?	–	7	Mamma	Masonry, indoor steps / argillaceous, with a hard middle interbed
		?	–	8	Tussualune (Mapa)	Masonry / argillaceous, with a hard middle interbed
		?	–	9	Tõusandus	Masonry, indoor steps / argillaceous, with a hard middle interbed
		?	–	10	Karvakord	Masonry, internal wall cladding / with a distinct rugged PDS
		?	–	11	Reinukord	Indoor steps in a light traffic area / –
		?	–	12	Seitsmetolline	Indoor steps in a light traffic area / –
		?	–	13	Laksupealne	Indoor steps in a light traffic area / –
		?	3.58	14	Laksu	Indoor steps / with a distinct PDS, very picturesque
		170.40	3.67	15	Nahakord	Internal wall cladding / with two PDSs, very picturesque
	Väo	170.75	3.85	16	Tulikord	Outdoor paving in a heavy traffic area / dark
		170.80	3.90	17	Nahakord	– / crumbles easily
		170.83	4.00	18	Mädakord	– / crumbles easily
		?	?	19	Nõtku	Masonry / brittle
		171.05	4.25	20	Rabandus	Outdoor steps in a heavy traffic area / –
		171.15	4.38	21	Lõhkumine	Outdoor steps in a heavy traffic area / –
		171.40	4.58	22	Paks hall	Outdoor steps in a heavy traffic area / outermost beds crumble easily
		171.55	4.88	23	Kirjukord	Outdoor steps in a heavy traffic area / –
		171.75	5.13	24	Trepp	Masonry, indoor steps in a heavy traffic area / with a distinct PDS?, very picturesque
		171.89	5.29	25	Viiene	Masonry, outdoor paving in a heavy traffic area / with a distinct PDS?
		171.97	5.40	26	Neljane	Masonry, outdoor paving in a heavy traffic area / with a distinct PDS?
		172.05	5.47	27	Pealmine naha-kord (arssin)	Internal masonry / –
		172.24	5.63	28	Tige seitsmene	Wall cladding and flooring / with a hard middle interbed and a PDS in the middle, very picturesque
		172.34	5.67	29	Alumine nahakord	Masonry, outdoor wall cladding / –
		172.65	5.95	30	Pealmine muld-valge	Suitable for all outdoor building applications / thick-bedded
		?	6.25	31	Alumine muld-valge	Suitable for all outdoor building applications / thick-bedded
		?	6.55	32	Kassikord	Outdoor wall roofing tile and steps / split into three, with a hard middle interbed
		172.98	6.80	33	Lutt	– / crumbles easily
		173.09	7.00	34	Laksu-punane	Outdoor usage in severe exposure areas, steps in a heavy traffic area / peculiar vertical sedimentary structures, very picturesque
		173.35	7.21	35	Kirjukärn	Suitable for severe exposure areas / peculiar vertical sedimentary structures, two distinct PDSs, very picturesque
		173.65	7.42	36	Trepp-kalk	Outdoor steps in a heavy traffic area, wall cladding and flooring / with two hard interbeds, set upside down
		173.80	7.64	37	Sauekord	Internal masonry / –
		173.88	7.75	38	Hall arssin	Outdoor usage, flooring in a heavy traffic area, wall cladding / very picturesque

Regional stage	Formation	Depth of the lower boundary (m)		Bed number	Local bed name	Traditional applications / remarks
		Kerguta (565)	Väo Paas (1)			
Uhaku	Väo	173.99	7.84	39	Valge arssin	Outdoor usage, paving in a heavy traffic area / –
		174.35	8.20	40	Nahakord (Sajakordne)	– / crumbles easily
		174.55	8.36	41	Tulikord	Indoor steps in a heavy traffic area / crystal size is larger than 0.05 mm, contains pyrite
		174.65	8.47	42	Poriarssin	Outdoor paving / the upper interbeds harder than lower, pyrite-rich
		174.80	8.60	43	Poriarssina alune	Masonry / brittle, pyrite-rich
		174.92	8.75	44	Ristikord	Memorials and carving (sculpture), outdoor usage / –
		?	8.81	45	Nahakord	– / crumbles easily
Lasnamägi		175.15	9.08	46	Raudsüda (Üheksane)	Outdoor usage, wall cladding and flooring / split into three, the middle interbed harder than outer, flexibility values of the bed high
		–	9.24	47	Kuuetolline	Memorials and carving (sculpture) / homogeneous
		–	9.40	48	Seitsmetolline	Memorials and carving / the lower interbed harder than upper, heterogeneous with a PDS in the upper part
		–	9.57	49	Neljane	Outdoor paving / –
		?	9.67	50	Viiene	Outdoor paving / –
		?	9.85	51	Pealmine põhja-valge	Masonry / in the uppermost part a PDS
		?	10.00	52	Alumine põhja-valge	Masonry / pyrite-rich, with marlstone films
		175.30	10.15	53	Põhjatrepp	Masonry, outdoor steps / contains pyrite, often dolomitized
		175.55	10.40	54	Pealmine põhja-punane	Masonry, outdoor steps / hard, porous, dark brown
		175.85	10.55	55	Alumine põhja-punane	Masonry, outdoor steps / hard, porous, dark brown
		176.10	10.80	56	Pukisarv	Masonry / split into three

***PDS** – pyritized discontinuity surface; PhDS – phosphatized discontinuity surface; – bed missing; ? – boundary of the bed not recognized. See also description of thin sections (Appendix 2) and chemical composition (XRF; CaO, MgO, CO_2 and insoluble residue) of rocks (Appendix 5, 7). The boundary of the stages (at 175.0 m) in the Kerguta (565) core was determined on the basis of the distribution of chitinozoans.*

2. The overlying limestones of the Kõrgekallas Formation are more argillaceous and sedimentary structures are thinner, for example above the complex of discontinuity surfaces at a depth of 170.40–170.56 m in the Kerguta (565) core (see Appendix 4).

3. Some distinctive layers are followed over a wide area, for example, dolomitized limestone (175.3–176.1 m) in the lower part and thick-bedded limestones in the middle part (172.65–172.98 m) of the Väo Formation in the Kerguta (565) section (Appendixes 15, 16);

4. Specific discontinuity surfaces (in the Kerguta (565) core at depths of 172.85, 173.1, 173.9 and 174.3 m) and complexes of discontinuity surfaces (171.4–171.9 and 174.7–175.0 m) widespread in northern sections and related to lithological changes in limestones (Appendixes 4, 15, 16).

REFERENCES

Ainsaar, L., Meidla, T. & Martma, T. 1999. Evidence for a widespread carbon isotopic event associated with late Middle Ordovician sedimentological and faunal changes in Estonia. *Geological Magazine*, **136**, 49–62.

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

Ainsaar, L., Meidla, T. & Tinn, O. 2004b. Middle and Upper Ordovician stable isotope stratigraphy across the facies belts in the East Baltic. In: *WOGOGOB-2004 8th Meeting of the Working Group on the Ordovician Geology of Baltoscandia. Conference materials. Abstracts and field guidebook* (Hints, O. & Ainsaar, L., eds). Tartu University Press, 11–12.

Bauert, G. & Bauert, H. 1998. Distribution of chitinozoans in the Tartu (453) core. Appendix 14. In: *Tartu (453) drill core* (Männik, P., ed.), *Estonian Geological Sections*, **1**.

Bauert, H. & Bauert, G. 1996. Kesk-Ordoviitsiumi (Lasnamäe–Keila lade) biostratigraafiline iseloomustus kitinosoade alusel [Chitinozoan biostratigraphy of the Middle Ordovician: Lasnamägi–Keila stages]. In: Tugiläbilõigete täienduurimine [Complementary study of type sections]. Unpublished report of the Geological Survey of Estonia, Tartu, 85–86. [In Estonian].

Bauert, H. & Kattai, V. 1997. Kukersite oil shale. In: *Geology and mineral resources of Estonia* (Raukas, A. & Teedumäe, A., eds). Estonian Academy Publishers, Tallinn, 313–327.

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.

Bergström, S., Finney, S. C., Chen, Xu, Pålsson, C., Wang, Zhi-hao & Grahn, Y. 2000. A proposed global boundary stratotype for the base of the Upper Ordovician Series of the Ordovician System: the Fågelsång section, Scania, southern Sweden. *Episodes*, **23**, 102–109.

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

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.

Dzik, J. 1976. Remarks on the evolution of Ordovician conodonts. *Acta Palaeontologica Polonica*, **21**, 395–455.

Dzik, J. 1994. Conodonts of the Mójcza Limestone. In: *Ordovician carbonate platform ecosystem of the Holy Cross Mountains* (Dzik, J., Olempska, E. & Pisera A., eds), *Palaeontologica Polonica*, **53**, 43–128.

Einasto, R. 2002. Lasnamäe ehituslubjakivi ajaloolised murdmiskihid Tallinna ümbruses. *Tallinna Tehnikakõrgkooli Toimetised*, **1**, 56–69. [In Estonia].

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.

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

Hints, L., Oraspõld, A. & Kaljo, D. 2004. 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, O. & Nõlvak, J. 1999. Proposal for the lower boundary-stratotype of the Keila Regional Stage (Upper Ordovician). *Proceedings of the Estonian Academy of Sciences, Geology*, **48**, 158–165.

Jaansoon-Orviku, K. 1927. Beiträge zur Kenntnis der Aseri- und der Tallinna-Stufe in Eesti I. *Acta et Commentationes Universitatis Tartuensis (Dorpatensis)*, A, XI, **5**, 40 pp.

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.

Kaljo, D. 2004. Diversity of late Ordovician rugose corals in Baltoscandia: role of environmental changes and comparison with other areas. *Proceedings of the Estonian Academy of Sciences, Geology*, **53**, 233–245.

Kaljo, D., Nõlvak, J. & Uutela, A. 1996. More about Ordovician microfossil diversity patterns in the Rapla section, Northern Estonia. *Proceedings of the Estonian Academy of Sciences, Geology*, **45**, 131–148.

Kaljo, D., Kiipli, T. & Martma, T. 1997. Carbon isotope event markers through the Wenlock–Pridoli sequence at Ohesaare (Estonia) and Priekule (Latvia). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **132**, 211–223.

Kaljo, D., Kiipli, T. & Martma, T. 1998. Correlation of carbon isotope events and environmental cyclicity in the East Baltic Silurian. In: *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., Hints, L., Hints, O., Martma, T. & Nõlvak, J. 1999. Carbon isotope excursions and coeval environmental and biotic changes in the late Caradoc and Ashgill of Estonia. In: *Quo vadis Ordovician? Short papers of the 8th International Symposium on the Ordovician System (Prague, June 20–25, 1999). Acta Universitatis Carolinae - Geologica*, **43**, 507–510.

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

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

Kaljo, D., Martma, T. & Saadre, T. Post-Hunnebergian Ordovician carbon isotope trend in Baltoscandia and some similarities with that of Nevada. *Palaeogeography, Palaeoclimatology, Palaeoecology* (submitted).

Kattai, V. 2000. Tapa leiukoht [Tapa oil shale deposit]. In: *Eesti põlevkivi geoloogia, ressurss, kaevandamistingimused* [Estonian Oil Shale geology, resource, mining] (Vingisaar, P., ed.). Eesti Geoloogiakeskus, Tallinn, 124–128. [In Estonian with English summary].

Kattai, V. & Reinsalu, E. 1991. Main geological-industrial features and economic value of the Tapa kukersite deposit. *Oil Shale*, **8**, 3, 221–230. [In Russian with English summary].

Kiipli, T. & Kallaste, T. 2002. Characteristics of volcanism. In: *Soovälja (K-1) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, **4**, 17–21.

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. 2005. Characteristics of Ordovician volcanic ash beds. In: *Mehikoorma (421) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, **6**, 27–31.

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.

Lindström, M. 1971. Lower Ordovician conodonts of Europe. *Geological Society of America Memoir*, **127**, 21–61.

Löfgren, A. 1995. The middle Lanna/Volkhov Stage (middle Arenig) in Sweden and its conodont fauna. *Geological Magazine*, **132**, 693–711.

Löfgren, A. 2000. Conodont biozonation in the upper Arenig of Sweden. *Geological Magazine*, **137**, 53–65.

Löfgren, A. 2003. Conodont faunas with *Lenodus variabilis* in the upper Arenigian to Llanvirnian of Sweden. *Acta Palaeontologica Polonica*, **48**, 417–436.

Löfgren, A. 2004. Conodont fauna in the Middle Ordovician *Eoplacognathus psedoplanus* Zone of Baltoscandia. *Geological Magazine*, **141**, 505–524.

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].

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

Männil, R. 1986. Stratigraphy of kukersite-bearing deposits C_Ib-C_{III}. In: *Geology of the kukersite-bearing beds of the Baltic oil shale basin* (Puura, V., ed.). Valgus, Tallinn, 12–24. [In Russian with English summary].

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

Männil, R. & Saadre, T. 1987. Aseri Stage. Lasnamägi and Uhaku stages. Kukruse Stage. Idavere Stage. In: *Geology and mineral resources of the Rakvere phosphorite-bearing area* (Puura, V., ed.). Academy of Sciences of the Estonian SSR. Institute of Geology. Geological Survey of the Estonian SSR. Valgus, Tallinn, 44–56. [In Russian with English summary].

Martma, T. 2003. Carbon and oxygen isotopes. In: *Ruhnu (500) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, **5**, 28–30.

Martma, T. 2005. Ordovician carbon isotopes. In: *Mehikoorma (421) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, **6**, 25–27.

Meidla, T., Ainsaar, L., Backman, J., Dronov, A., Holmer, L. & Sturesson, U. 2004. Middle–Upper Ordovician carbon isotopic record from Västergötland (Sweden) and 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, 67–68.

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

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

Nestor, H. 1987. Porkuni Stage. In: *Geology and mineral resources of the Rakvere phosphorite-bearing area* (Puura, V., ed.). Academy of Sciences of the Estonian SSR, Institute of Geology. Geological Survey of the Estonian SSR, Valgus, Tallinn, 69–71. [In Russian with English summary].

Nestor, H. 1990. 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. Llandovery Series. Juuru Stage. In: *Geology and mineral resources of Estonia* (Raukas, A. & Teedumäe, A., eds). Estonian Academy Publishers, Tallinn, 89–93.

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.

Nõlvak, J. 1987. Rakvere Stage. Nabala Stage. In: *Geology and mineral resources of the Rakvere phosphorite-bearing area* (Puura, V., ed.). Academy of Sciences of the Estonian SSR, Institute of Geology, Geological Survey of the Estonian SSR, Valgus, Tallinn, 63–66. [In Russian with English summary].

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. 1999a. Distribution of chitinozoans. In: *Taga-Roostoja (25A) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, **2**, 10–12.

Nõlvak, J. 1999b. Ordovician chitinozoan biozonation of Baltoscandia. *Acta Universitatis Carolinae. Geologica*, **43**, 287–290.

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

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

Nõlvak, J. 2002b. Bentonite in the uppermost Kukruse Stage in North Estonia. In: *The Fifth Baltic Stratigraphical Conference, Basin Stratigraphy – Modern Methods and Problems: Extended abstracts* (Satkūnas, J. & Lazauskienė, J., eds). Vilnius, Lithuania, 149–151.

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

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

Nõlvak, J. & Goldman, D. 2004. Distribution of *Nemagraptus* in the East Baltic Ordovician. In: *WOGOGOB-2004 8th Meeting of the Working Group on the Ordovician Geology of Baltoscandia. Conference materials. Abstracts and field guidebook* (Hints, O. & Ainsaar, L., eds). Tartu University Press, 77–78.

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.

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

Orviku, K. 1940. Lithologie der Tallinna-Serie (Ordovizium, Estland) I. *Acta et Commentationes Universitatis Tartuensis (Dorpatensis)*, A, XXXVI, **58**, 137–212.

Paris, F. 1981. Les Chitinozoaires dans le Paléozoique du Sud-ouest de L'Europe. *Mémoire de la Société Géologique et Minéralogique de Bretagne*, **26**, 1–412.

Põldvere, A. 1999. Overview of kukersite oil shale beds. In: *Taga-Roostoja (25A) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, **2**, 18–19.

Põldvere, A. 2001. Core description and terminology. In: *Valga (10) drill core* (Põldvere, A., ed.), *Estonian Geological Sections*, **3**, 4–5.

Põldvere, A. & Saadre, T. 1996. Kerguta (565) puurläbilõike makrolitoloogiline kirjeldus [Description of the Kerguta (565) core]. In: Tugiläbilõigete täienduurimine [Complementary study of type sections]. Unpublished report of the Geological Survey of Estonia, Tartu, 74–84. [In Estonian].

Põldvere, A., Meidla, T., Bauert, G., Bauert, H. & Stouge, S. 1998. Ordovician. In: *Tartu (453) drill core* (Männik, P., ed.), *Estonian Geological Sections*, **1**, 11–17.

Põlma, L. & Haas, A. 1987. Oandu Stage. In: *Geology and mineral resources of the Rakvere phosphorite-bearing area* (Puura, V., ed.). Academy of Sciences of the Estonian SSR, Institute of Geology, Geological Survey of the Estonian SSR, Valgus, Tallinn, 61–63. [In Russian with English summary].

Raukas, A. & Kajak, K. 1997. Quaternary cover. In: *Geology and mineral resources of Estonia* (Raukas, A. & Teedumäe, A., eds). Estonian Academy Publishers, Tallinn, 125–136.

Saadre, T., Mardim, T., Morgen, E., Põldvere, A., Vaher, R, Suuroja, K. & Saaremets, V. 1984. Otčet o kompleksnoj gruppovoj geologo-gidrogeologičeskoj s"emke maštaba 1:50 000 i doizučenii ranee zasnjatyh ploščadej Rakvereskogo fosforitonosnogo rajona (v 5-i tomah) [Report on the complex geological-hydrogeological mapping at a scale of 1:50 000 and complementary study of formerly investigated fields of the phosphorite-bearing sediments of Rakvere district (in 5 volumes]. Unpublished report of the Geological Survey of Estonia, Keila, 472 pp. [In Russian].

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.

Sjöstrand, L. 2003. Early to early Middle Ordovician conodont biostratigraphy of the Tamsalu drill core, central Estonia. *Examensarbete i geologi vid Lunds universitet, Berggrundsgeologi/Historisk geologi och paleontologi*, 156, 1–20.

Sturesson, U. & Bauert, H. 1994. Origin and paleogeographical disribution of the Viruan iron and phosphatic ooids in Estonia: evidence from mineralogical and chemical compositions. *Sedimentary Geology*, **93**, 51–72.

Vandenbroucke, T. 2004. Chitinozoan biostratigraphy of the Upper Ordovician Fågelsång GSSP, Scania, southern Sweden. *Review of Palaeobotany and Palynology*, **130**, 217–239.

Viira, V. 1974. *Ordovician conodonts of the East Baltic.* Valgus, Tallinn, 142 pp.

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

Viira, A., Löfgren, A., Mägi, S. & Wickström, J. 2001. An Early to Middle Ordovician succession of conodont faunas at Mäekalda, northern Estonia. *Geological Magazine*, **138**, 699–718.

Vilbaste, G. 1954. *Paetööstus Tallinna kivimurdudes ja jooni rahvapärasest geoloogiast* [Building stone quarries near Tallinn and review of folk geology]. Tallinn, 66 pp. [In Estonian].

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].

Webby, B. D., Cooper, R. A, Bergström, S. M. & Paris, F. 2004. Stratigraphic framework and time slices. In: *The Great Ordovician Biodiversification Event* (Webby, B. D., Droser, M. L., Paris, F. & Percival, I., eds). Columbia University Press, New York, 41–47.

Zhang, J. 1998. Conodonts from the Guniutan Formation (Llanvirnian) in Hubei and Hunan Provinces, south-central China. *Acta Universitatis Stockholmiensis, Stockholm Contributions in Geologi*, **46**, 161 pp.

APPENDIX 1

Description of the Kerguta (565) 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 and members.

CORE BOX NO./FIGURES — Numbers of boxes, location of the intervals of core illustrated on compact disc in read-only memory (detailed core photos marked as D-1...7, thin sections as T-1...45, and Ordovician (Lower, Middle, Upper) and Silurian (Llandovery) photo-log in Appendix 4).

DEPTH/SAMPLES — Depth of the boundaries and sample levels: C, conodonts; Ch, chitinozoans; F, X-ray fluorescence samples; Is, stable isotope analyses ($\delta^{13}C$); K, chemical samples; Ph, physical properties; S, spectral analyses; T, thin sections; X, X-ray diffractometry.

LITHOLOGY — For legend see the next page. The core section is given alternately at scales of 1:200 and 1: 100.

SEDIMENTARY STRUCTURES — According to 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. According to size of nodules: thin-nodular (vertical diameter of nodules < 0.2 cm), medium-nodular (2–5 cm) and thick-nodular (> 5 cm).

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) was estimated visually: 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. Clastic fractions (size of particles; in italics) are described as follows: clay (< 0.005 mm), silt (0.005–0.05 mm), sand (0.05–2.0 mm), gravel (2–10 mm), pebbles (10–100 mm) and cobbles (> 100 mm).

Appendix 1 continued

LEGEND

- cultivated soil
- till
- limestone (in general)
- argillaceous limestone
- dolomitized limestone
- a sandy (a) and b silty (b) limestone
- biohermal limestone
- dolostone
- calcitic marlstone
- sandstone
- kukersite interbed
- a b K-bentonite bed, on (a) or under (b) the boundary
- a b skeletal limestones: grains 10–25% (a) and grains 25–50% (b)
- crypto- and microcrystalline limestone

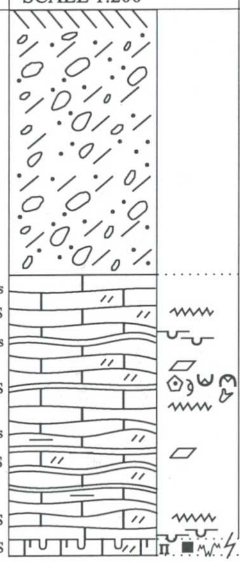
- fine bioclasts, pyritized (0.05–1.0 mm)
- coarse bioclasts, pyritized (> 1 mm)
- a b c horizontal bedding: thin (a), medium (b) and thick bedding (c)
- wavy bedding
- nodular
- thin intercalation
- nodules
- discontinuity surface
- 9 number of discontinuity surfaces between the upper and the lower surface
- veins
- stylolites
- caverns (vugs)
- porous
- burrows
- pyritic mottles

- mottled, red-coloured and yellow streaks
- ooliths
- clastic material
- silt-sized grains
- glauconite grains
- Q quartz grains
- kerogen
- bitumen
- calcite
- pyrite
- brachiopods
- trilobites
- ostracods
- rugosae
- cephalopods
- gastropods
- calcareous algae
- siliceous sponges
- bryozoans
- echinoderms (crinoids)

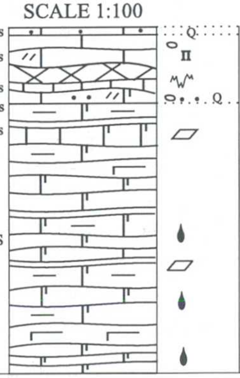
DESCRIPTION OF THE KERGUTA (565) CORE

Location: 59° 07' 40" N, 26° 00' 45" E. Length of the core 192.9 m. Elevation of the top 110.0 m above sea level.

SCALE 1:200

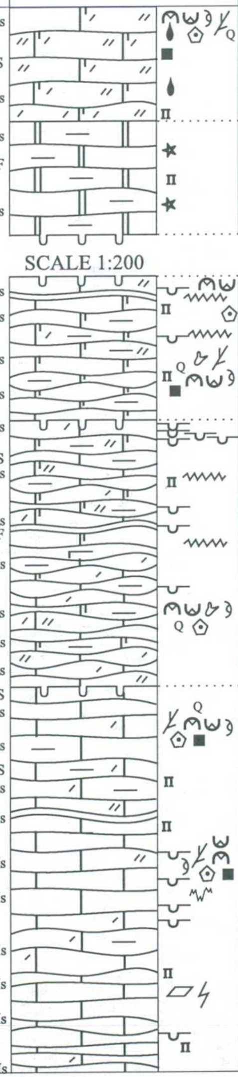
STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Pleistocene, Quaternary		1	Appendix 4	0.0–7.0			! (Core yield 45%)			Cultivated soil cover underlain by beigish-grey till with pebbles and cobbles of carbonate rocks
Llandovery	Juuru Stage, Varbola Formation	2	T-1	7.0	Is, S, Is, Is PhTFS, Is, F S, Is, Is S		Indistinctly nodular and wavy, thin- and medium-bedded (Core yield 50%)	0.3–1.5 cm; (< 0.2 and 2.5 cm) D greenish-grey	20–30	Light grey with green and brown shade, *very finely crystalline* to *finely crystalline* **limestone** (grains < 10%, in places 20–30%) with **calcitic** and **dolomitic marlstone** interbeds. Discontinuity surfaces are pyritized, the lower one is underlain by burrowed marlstone
	Koigi Mb.		T-2	14.0–14.4	Is, Is PhTFS		Indistinctly wavy	< 0.5 (1.5) cm; D greenish-grey	< 5	Whitish-grey, dolomitized, *micro-* and *very finely crystalline* **limestone** with **marlstone** interbeds. The lowermost marlstone beds includes silt and sand grains, and rare bioclasts. The lower boundary of the complex is sharp

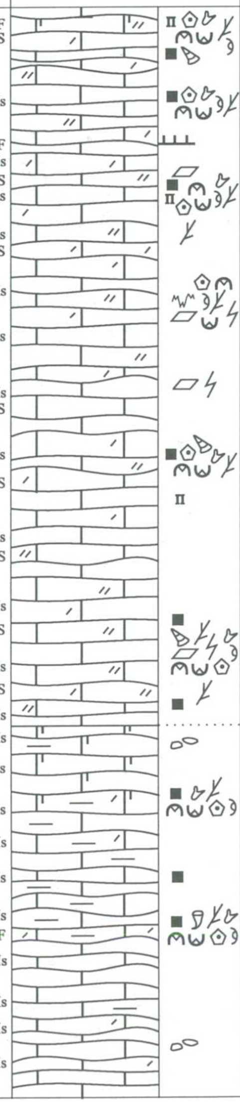
SCALE 1:100

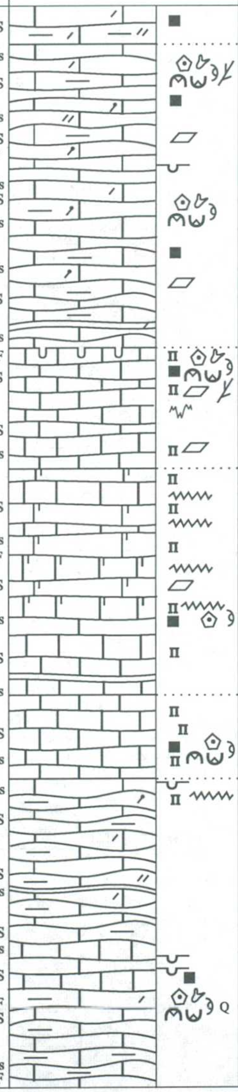
STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician	Ka*	2		14.4–14.5	Is		(Core yield 20%)			Light grey **limestone** with sand grains (in some layers 10–40%, well-rounded) and bioclasts
	Tõ*			14.5–15.4	Is, Is		Indistinctly wavy	< 0.5 cm; D light greenish-grey	< 5	Light grey with yellow shade, *very finely crystalline* to *microcrystalline* **limestone** (grains in places 10–30%) with **biohermal limestone** and **calcitic marlstone** interbeds. Carbonate clasts are 1–3 cm in diameter
	Porkuni Stage, Ärina Formation, Siuge Member	3	Appendix 4	15.4–19.0	Is, Is, S		Medium-bedded, in places indistinctly thin-bedded (Core yield 15%)	Up to 10 cm; IND dark brownish-grey (bituminous) and greenish-grey	< 50	Intercalation of light grey, in places medium argillaceous, dolomitized, *microcrystalline* to *very finely crystalline*, in some layers *finely crystalline* **limestone** (grains < 10%) and **calcitic marlstone**. Indistinct bedding of marlstone interbeds results from vertical changes in rock content. Bed surfaces bear trace fossils and oriented bioclasts

Tõ*– Tõrevere Member; Ka*– Kamariku Member

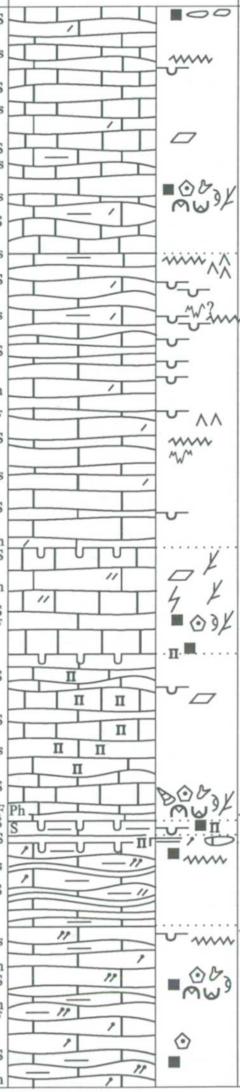
STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Ashgill)	Porkuni Stage; Ärina Formation; Vohilaid Mb.	3	T-3; Appendix 4	19.0	PhTFIs, S, Is		Indistinctly thick-bedded (massive), in places nodular	< 2 cm; IND dark brownish-grey (bituminous)	< 5	Whitish- and beigish-grey (bituminous), dolomitized, *microcrystalline* and *very finely crystalline* **limestone** (grains 10–25%, in places > 50%; bioclasts up to 2 mm in diameter) with rare **calcitic marlstone** interbeds. Clay and carbonate content changes vertically
	Röa Mb.			20.5	Is, S PhF, Ph FIs		Massive, in places indistinctly bedded			Dirty grey, medium argillaceous, *very finely crystalline* **dolostone** (grains in places < 10%)
				22.0		SCALE 1:200				
Upper Ordovician (Ashgill)	Pirgu Stage; Adila Formation	3, 4	T-4, T-5	22.0	PhTFIs, XFSPhFIs, Is, SPhTFIs		Wavy, indistictly medium-bedded and nodular	< 0.3, 0.3–2 (2–4) cm; IND and D dark grey	10–20	Grey with greenish shade, in places slightly argillaceous and dolomitized, *very finely crystalline* **limestone** (grains < 10%, in places 10–25%) with burrowed, in places dolomitic **marlstone** (bioclasts in places 10–20%, up to 3 mm in diameter) interbeds. Discontinuity surfaces are pyritized
		5, 6	T-6	25.8	XFIs, S Is, Is SPhF, Is, SPhTFIs, PhFIs, Is		Indistinctly medium- (thick-) nodular, in places wavy medium-bedded	0.3–2 (< 0.2 and 5) cm, at 31.8–32.8 m 0.5–1 cm; IND dark grey	10–20; < 5	Light grey (in places with green shade), slightly argillaceous, in places dolomitized, *finely crystalline* and *very finely crystalline* **limestone** (grains < 10%, in places 20%) with **marlstone** (bioclasts in places > 10%, up to 3 mm in diameter) interbeds (in the upper part burrowed). Pyritized discontinuity surfaces are mainly distinct, wavy and excavated
	Moe Formation	6, 7, 8	T-7, T-8; Appendix 4	32.8	S, Is PhTF, Is, S, Ph FIs, Is, S PhTFIs, Is, S Ph F Is, Is, S Is, Is		Indistinctly medium- and thick-bedded, in places indistinct nodular interlayers	< 0.2, 0.2–3 (4–5) cm; D dark grey	5	Light grey (in places with brown shade), *finely crystalline* to *microcrystalline*, mainly *very finely crystalline* **limestone** (grains < 10%, in places 30%) with **marlstone** (bioclasts in places > 10%, up to 5 mm in diameter) interbeds and pockets (in the upper part burrowed). Veins are filled with secondary calcite and in places rock is recrystallized. The lowermost part includes pyrite crystals. The volcanic ash containing dolomitized marlstone (K-bentonite) interbed at 46.6 m was found by Tiina Lang in 1983. Fragments of calcareous algae *Palaeoporella*? (=*Dasyporella*) and *Vermiporella* are present, particularly at 48.4–49.6 and 59.0–62.0 m. Pyritized discontinuity surfaces are distinct, wavy and in places excavated



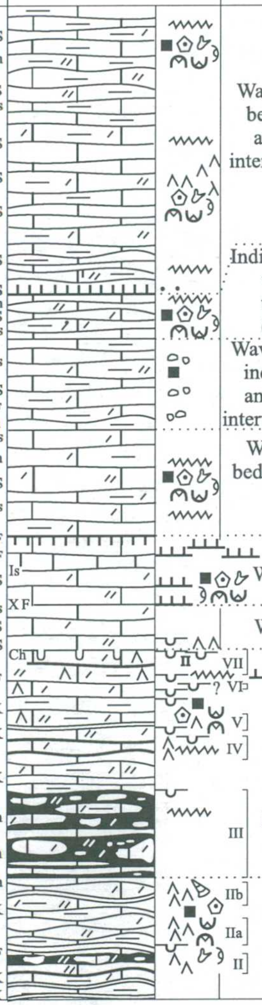
STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO. / FIGURES	DEPTH (m) / SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Ashgill)	Pirgu Stage Moe Formation	8, 9, 10, 11; T-9, T-10, T-11, T-12, T-13, T-14; Appendix 4	PhTF S; PhTS F Is; XF Is; S PhTF Is; Is S; PhTF Is; S Is; Is S; PhTF Is S; XF Is S; Ph F Is S; PhTF Is S Is				5	☞ follow up
	Vormsi Stage Kõrgessaare Formation	12, 13, 14; T-15, T-16	62.0; Is; S PhF Is; PhTF Is; S Is; Ph F Is; S Is PhTF; Is; S Ph F Is Is; S Is; 71.8		Wavy, medium- and thin-bedded, in places nodular intervals	< 0.2, 0.2–1 (4) cm; IND dark grey	5–10	Light grey, in places with green shade and slightly argillaceous, in the uppermost part dolomitized, *finely crystalline* to *very finely crystalline*, in places *microcrystalline* **limestone** (grains < 10%, in places 20–35%) with **marlstone** (bioclasts up to 20%) interbeds. Intercalation of fine bioclast-rich marlstone microbeds and carbonate clasts (diameter 0.1–1.0 mm) is observed in up to 30 cm thick intervals. The middle part contains phosphatic spots up to 0.5 cm in diameter. Pyrite crystals are found

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO. / FIGURES	DEPTH (m) / SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Ashgill)	Vormsi Stage, Kõrgessaare Formation	14; T-17	71.8; 72.8; Is, Ph F S, Is, PhT F Is S		Wavy, indistinctly medium-bedded, in places thin-bedded	0.2–3 (7) cm; IND dark greenish-grey	5	Dirty greenish-grey, slightly to highly argillaceous, *very finely crystalline* **limestone** (grains 10–25%, some bioclasts up to 3 cm in diameter) with **marlstone** (bioclasts 10%) interbeds
		15; T-18; T-19	Ph F Is, S, Is, Is S, PhT F Is, Ph F Is, Is S, Is		Wavy, medium-bedded, with 10–30 cm thick indistinctly thin- and medium- (thick-) nodular intervals	0.3–1.0 (2–7) cm; D and IND dark grey, in the lower part greenish-grey	5–10	Light grey, in places with brown shade and medium to slightly argillaceous, *very finely crystalline*, in places *crypto-* and *microcrystalline* **limestone** (grains >10%, fine bioclasts often pyritized) with **marlstone** (rounded bioclasts 10–25%, up to 2 mm in diameter) interbeds and pockets. Calcite-filled primary and secondary veins are found. Discontinuity surfaces are pyritized
(Caradoc)	Nabala Stage, Saunja Formation	16; Appendix 4	80.8; PhT F, Is S, S, Is; 84.0		Indistinctly medium- and thin-bedded (Core yield 50%)	< 0.2 (1–2) cm; D light grey	1–2	Light beigish-grey *micro-* and *cryptocrystalline* **limestone** (grains < 10%) with rare **calcitic marlstone** interbeds. Calcite-filled primary and secondary veins and pockets (up to 3 mm across) are found
		17; T-20	Is S, Is Ph F, Is S, PhT F Is, Ch Ph F Is S		Horizontal and wavy, thick-bedded, with 1–3 (10) cm thick indistinctly thin-bedded intervals	< 0.2 (0.2–3.0) cm; D dark grey and brownish-grey	1–2	Light grey, in places pyrite-impregnated and/or dolomitized, *very finely crystalline* to *cryptocrystalline* **limestone** (grains < 10%) with rare **calcitic marlstone** interbeds. Calcite-filled primary and secondary veins are present
		18; T-21	90.0; Ch Is, Ch S, PhT F Is, Ch; 92.2		Indistinctly medium- and thin-bedded (Core yield 50%)	< 0.2 (0.5) cm; D dark grey	1–2	Light grey, with small pyrite mottles, *micro-* to *cryptocrystalline* **limestone** (grains < 10%) with rare **marlstone** interbeds. Calcite-filled primary and secondary veins are found
	Packna Formation	19; 20; T-22	Ch Is, Ch Is S, Ch Ph F Is S, Ch Is, S, Ch Ph F Is, Ch Is S, Ch Ph T F Is S, Ch Is Ph F; 100.3		Indistinctly thick- and medium-nodular, in places medium-bedded	< 0.2, 1–7 cm (0.3 and 10 cm); IND and D dark greenish grey, at 96.8–96.9 and 97.2–97.5 m brownish-grey	20; < 40; 10–20	Grey with green shade, slightly to medium argillaceous, *very finely crystalline* **limestone** (grains < 10%, in places 10–25%, rarely pyritized) with **marlstone** (fine and coarse bioclasts in places > 10%) interbeds. At 96.8–96.9 and 97.2–97.5 m *crypto-* and *microcrystalline* **limestone** interlayers contain calcite-filled primary and secondary veins. Discontinuity surfaces are pyritized and phosphatized

KERGUTA (565) DRILL CORE

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Caradoc)	Nabala Stage, Paekna Formation	20, 21	T-23; Appendix 4	100.3–106.8	Ch Is S; Ch Is; S; Ch PhF Is; Ch S Is; Ch PhTF Is; Ch Is S; Ch Ch Is		Wavy, indistinctly thin- and medium-bedded, in places thin- to medium-nodular	< 0.2, 0.2–0.5 (3) cm; D and IND grey	< 5	Light grey, in places with green and brown shade, rarely slightly argillaceous, *very finely crystalline* and *microcrystalline* **limestone** (grains in places > 10%) with rare **marlstone** interbeds and pockets. Calcite-filled primary and secondary veins are found. The discontinuity surface is pyritized and phosphatized
	Rakvere Stage, Rägavere Formation, Tudu Member	22, 23		106.8–114.6	S; Ch Ph F Is; Ch S; Ch; Ph F; Ch Is S; Ch Ph F Is; Ch Is S		Indistinctly medium-bedded, in places thin- and thick-bedded	< 0.2, 0.2–0.5 (1) cm; D grey	1–2	Light grey with brown shade, *finely crystalline* and *very finely crystalline* **limestone** (grains in places 10–25%) with rare **marlstone** interbeds. Discontinuity surfaces are pyritized, rock impregnation reaches in places 5–10 cm below the surface Light grey with brown shade, *finely* to *very finely crystalline* and *crypto-* to *microcrystalline* **limestone** (grains < 10%, rarely 30%) with rare **calcitic marlstone** interbeds. Calcite-filled primary and secondary veins are found
		23, 24	T-24	114.6–117.4	Ch Ph F S; Ch; Ch Is S; Ph T F		Indistinctly medium- (thin-) bedded (Core yield 70%)	< 0.2, 0.2–0.5, 1–2 cm; D dark grey	< 2	Light grey with small pyrite mottles (missing in the uppermost 40 cm), *crypto-* to *microcrystalline* and *very finely crystalline* **limestone** (grains < 10%, in places 30%) with rare **marlstone** interbeds. Calcite-filled veins are present. Discontinuity surfaces are pyritized
	Piilse Member	24, 25	T-25	117.4–121.8	Ch Is S; Ch Is S; Ph F; Ch Is; Ch Is S		Wavy, indistinctly thin- and medium-bedded, uppermost 0.5 cm thick-bedded	< 0.2, 0.2–0.5 (1) cm; D dark grey	1–2	Light grey with green shade, slightly to medium argillaceous, *very finely crystalline* **limestone** (grains < 10%, in the lowermost 4 cm pyritized grains < 20%) with **marlstone** interbeds and pockets. Calcite-filled veins occur. The discontinuity surface is pyritized
							Indistinctly medium-bedded	< 0.2, 0.2–3 cm; IND and D dark greenish-grey	< 2	
	Oa*, Tõ*, Hi*	25		121.8–122.4	Ch Is T F Ph S; Ch Is S; Ch Is S		Indistinctly bedded	Up to 4 cm; IND dark greenish-grey	> 50	Dark greenish-grey **marlstone** with interbeds and nodules of argillaceous **limestone** (grains < 25%). Bioclasts (shells, etc.) under the pyritized discontinuity surface (depth of impregnation 30 cm) are not oriented
	Keila Stage, Kahula Formation	25, 26		122.4–124.6	Ch Is; Ch Is; Ch Ph F S; Ch Is		Indistinctly medium- to thick-bedded, with micro- and thin-bedded intervals (thickness up to 10 cm)	< 0.2, 0.2–0.5 cm; IND dark greenish-grey	5–10	Light to dark greenish-grey, medium to highly argillaceous, *very finely crystalline* **limestone** (grain content increases upwards up to 25%; shell fragments 0.3–1 cm across) with **marlstone** interbeds and pockets
		26, 27	T-26	124.6–128.8	Ch Ph T F S; Ch F; Ch Is S; Ph F Ch		Indistinctly medium- to thick-bedded, with micro- and thin-bedded intervals (thickness 5–20 cm)	< 0.2, 0.2–0.5 cm; IND (D) dark grey	< 5	Light greenish-grey, mostly slightly to medium argillaceous, *very finely crystalline* **limestone** (grains in places 10–30%; rare bioclasts up to 3 cm across) with **marlstone** interbeds. The discontinuity surface is pyritized

Oa*– Oandu Stage; Hi*– Hirmuse Formation; Tõ*– Tõrremägi Member



STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO.	FIGURES	DEPTH (m)	SAMPLES	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Caradoc)	Keila Stage; Kahula Formation	27, 28	T-27, T-28; Appendix 4	128.8	Ch Is S, PhTF Ch, Ch S Is, Ph F Ch S, X F Ch Is S, PhTF Ch Is, S Is, Ch Ch F S, 4 Ch's	Wavy, indistinctly medium-bedded, with thin-bedded and indistinctly nodular intervals (thickness 2–20 cm)	< 0.2, 0.2–1 cm; IND dark greenish-grey	5–10	Light grey and grey, with green shade, highly (20–30% of rock) to medium argillaceous, in the middle part in some layers slightly argillaceous, *very finely crystalline* **limestone** (grains in lenses and pockets < 30%) with **marlstone** (bioclasts < 25%) interbeds. At 132.9, 133.0 and 133.4 m lie **kerogenous marlstone** interbeds, in places ferriferous. On the lower boundary lies a light grey, with greenish-yellow pockets, biotite flakes and silt-containing **K-bentonite bed** (thickness 20 cm)
	Haljala Stage; Jõhvi Substage; Kahula Formation	29		136.4	XF S Ch, Ch S, Ch PhTF Is	Indistinctly medium-bedded, with thin-bedded and thin-nodular intervals (thickness 10–15 cm)	< 0.2, 0.2–2 cm; IND dark greenish-grey	5	Light greenish-grey, slightly to medium (40% of rock) argillaceous, in the lowermost part dolomitized, *very finely crystalline* **limestone** (grains in places 10–30%, rare bioclasts 3 mm across) with **marlstone** interbeds
			T-29	137.6	Ch Is, Ch S, Ch Ph F, Ch	Wavy, medium-bedded, with indistinctly micro-bedded and thin- to thick-nodular intervals (thickness 30–40 cm)	< 0.2, 1–2 cm; IND dark greenish-grey	> 5	Greenish-grey, slightly to highly (40% of rock) argillaceous, *finely* to *very finely crystalline* **limestone** (grains in places 20–30%, rare bioclasts 0.5 mm across; carbonate clasts < 10%, up to 1 mm across) with **marlstone** interbeds
	Vasavere Mb.	30	T-30	140.0	Ch Is, Ch, Ch PhTF S, Ch Is, 3 Ch's	Wavy, thick- to medium-bedded, with micro- to thin-bedded intervals (thickness 5–25 cm)	< 0.2, 0.2–0.5 cm; IND dark greenish-grey	< 5	Light greenish-grey, slightly to highly (10% of rock) argillaceous, *very finely crystalline* **limestone** (grains in places 20%, rare bioclasts 0.5 mm across; carbonate clasts < 10%, up to 1 mm across) with **marlstone** interbeds
	Idavere Substage; Tatruse Fm.	31	T-31	142.8	XF, XF XF XF, 7 Ch's Ch S, 6 Ch's XF PhTF	Wavy, medium-bedded	< 0.2, 0.2–4.0 cm; IND and D dark greenish-grey	5	Light greenish-grey, *micro-* to *very finely crystalline* **limestone** (bioclasts in places < 40%) with **marlstone** and **K-bentonite** (thickness 3–6 cm) interbeds
				144.6	C Is, 8 Ch's S, Is K S	Wavy, medium-bedded	< 0.2, 0.2–3.0 cm; IND and D dark greenish-grey	1–2	Light grey, in places slightly argillaceous, *micro-* to *very finely crystalline* **limestone** (grains in places 20%) with **marlstone** interbeds. Discontinuity surfaces are pyritized
	Kukruse Stage; Viivikonna Formation; Peetri Member	32	T-32, D-1	145.8	PhF Is K, Ch XF, Ch, Ch C K, C Ch PhTF Is K, Ch PhF Is K, C Ch, Ch, C, Ch	Indistinctly thick- and medium-nodular, in places medium-bedded, kukersite thick-bedded and nodular	<0.2–5 cm; IND and D dark greenish-grey and brownish-grey	10–30	Light greenish-, beigish- and brownish-grey, slightly to medium (highly) argillaceous, in places kerogenous, *very finely crystalline* **limestone** (grains 10–25%, in places < 50%) with **marlstone** and brown **kukersite** (thickness 2–10 cm) interbeds (indexed oil-shale-bearing beds* see below). Burrowed intervals are present. A dark bluish-grey burrowed altered K-bentonite bed occurs at 146.50–146.55 m. Discontinuity surfaces are pyritized
	Maidla Mb.	33	T-33, T-34	151.8	Ch, C, Ch PhTF Is K, Ch C, Ch PhTF, C Ch Is K K	Thin- to medium-nodular and wavy, medium-bedded	0.2–5 cm; IND and D dark greenish-grey and brownish-grey	5–45	Intercalation of light greenish-, beigish- and brownish-grey, slightly to medium (highly) argillaceous, in places kerogenous, *very finely crystalline* **limestone** (grains 10–25%, in places < 50%), **marlstone** (in places kerogenous) and brown **kukersite** (thickness 1 cm) interbeds and nodules (indexed oil-shale-bearing beds* see below). The discontinuity surface is pyritized

Indexed oil-shale-bearing beds* (kerogenous limestone, kukersite (oil-shale) and argillaceous limestone) according to currently accepted stratigraphic nomenclature: **bed VII**, 145.80–146.47 m; **bed VI**, 146.70–146.87 m; **bed V**, 147.50–147.95 m; **bed IV**, 148.10–148.70 m; **bed III**, 149.50–151.80 m; **bed IIb**, 151.95–152.55 m; **bed IIa**, 152.9–153.6 m; **bed II**, 153.80–154.35 m.

STANDARD UNITS	LOCAL STRATIGRAPHIC UNITS	CORE BOX NO. / FIGURES	DEPTH (m) / SAMPLES	LITHOLOGY	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
Upper Ordovician (Caradoc)	Kukruse Stage, Viivikonna Formation, Maidla Member	34, T-35, D-2						☞ follow up
	Kukruse Stage, Viivikonna Formation, Kiviõli Mb.	35, D-3	159.9		Indistinctly thin- to medium-nodular, and wavy, medium-bedded	0.2–3 cm; IND and D dark greenish-grey and brownish-grey	5–15 50 5–15	Intercalation of light greenish-, beigish- and brownish-grey, slightly to medium (highly) argillaceous, in places kerogenous, *very finely crystalline* **limestone** (grains 10–25%, in places < 50%), **marlstone** and brown **kukersite** (thickness up to 3 cm, in the lowermost part 8 cm) interbeds and nodules (indexed oil-shale-bearing beds* see below). Burrowed intervals are present. Discontinuity surfaces are not impregnated (160.15 and 162.40 m) and pyritized (163.5 m)
Middle Ordovician (Llanvirn)	Uhaku Stage, Kõrgekallas Formation	T-36, 36, D-4	163.5		Indistinctly thin- to medium-nodular, and wavy, thin- to medium-bedded	< 0.2, 0.2–2 cm; IND and D dark greenish-grey	5–30	Light greenish- and beigish-grey, slightly to medium argillaceous, in places dolomitized and kerogenous (thickness of interbeds 5–15 cm), *finely* to *microcrystalline*, mainly *very finely crystalline* **limestone** (grains < 25%, mainly fine bioclasts) with **calcitic marlstone** interbeds
	Uhaku Stage, Kõrgekallas Formation	T-37, 37, D-5	166.75		Indistinctly (thin-) medium- to thick-bedded	< 0.2, 0.2–0.5 (1) cm; D greenish-grey	< 5	Light grey, in places slightly argillaceous, *microcrystalline* and *very finely crystalline* **limestone** (grains < 25%, in places < 50%; mainly fine bioclasts, in the lowermost part pyritized coarse bioclasts) with **marlstone** interbeds. Discontinuity surfaces are phosphatized
	Uhaku Stage, Väo Formation; Lasnamägi St.	D-6, 38, Appendix 4, T-38, 39, D-7	170.4		Horizontal, indistinctly medium- to thick-bedded	< 0.2 (0.2–0.5) cm; D grey	1–2	Light grey, in places dolomitized, *microcrystalline to very finely crystalline* and *finely crystalline* **limestone** (grains 25–50%; mainly coarse bioclasts, in places pyritized) with rare **marlstone** interbeds. Most of the discontinuity surfaces are phosphatized. Rare calcareous ooliths are found on the lower boundary
	Aseri Stage, Aseri Fm.	40, T-39	177.3 181.05		Horizontal, indistinctly thick- to medium-bedded, in places thin-bedded intervals	< 0.2 (0.2–0.5) cm; D dark grey	1–2	Light grey with green shade, in places slightly argillaceous and dolomitized, *very finely crystalline* and *finely crystalline* **limestone** (grains 10–50%; in places limonitized) with rare **marlstone** interbeds. Discontinuity surfaces are limonitized, the lowermost one also pyritized. Lenses with iron ooliths (< 10%, in places up to 30%) are found

Indexed oil-shale-bearing beds* (kerogenous limestone, kukersite (oil-shale) and argillaceous limestone) according to currently accepted stratigraphic nomenclature: **bed I**, 155.15–155.75 m; **bed P**, 156.00–156.40 m; **bed O+N**, 156.90–158.25 m; **bed M**, 158.40–158.80 m; **bed L**, 159.25–159.85 m; **bed K**, 159.95–160.35 m; **bed J**, 160.85–161.30 m; **bed H**, 161.40–161.60 m; **bed G**, 161.75–161.85 m; **bed F_4**, 162.10–162.20 m; **bed F_3**, 162.35–162.40 m; **bed F_{1-2}+E**, 162.50–162.90 m; **bed B+C**, 163.10–163.30 m; **bed A**, 163.45–163.50 m.

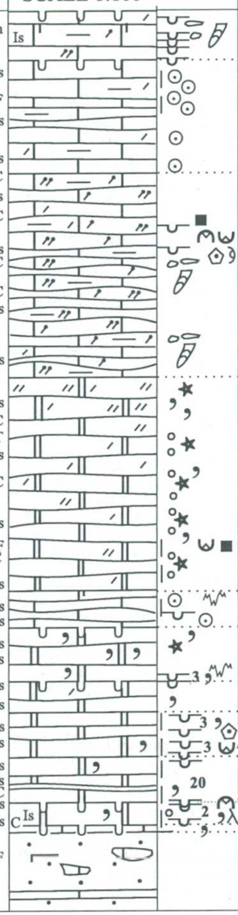
STANDARD UNITS: Middle Ordovician (Llanvirn), (Arenig); Lower Ord.

LOCAL STRATIGRAPHIC UNITS: Kunda Stage – Napa Formation; Loobu Formation – Valgejõgi Member, Nõmmeveski Member; Sil*; Volkhov Stage – Toila Formation – Kal*, T*, Saka Mb.; B*; Hun* – Leetse* – Joa*, M*, P*

CORE BOX NO.: 40, 41, 42, 43

FIGURES: D-7, T-40, T-41, T-42, T-43, T-44, T-45; Appendix 4

LITHOLOGY — SCALE 1:100



DEPTH (m)	SEDIMENTARY STRUCTURES	MARLSTONE BEDS	MARLSTONE PERCENTAGE	SHORT DESCRIPTION
181.05–181.7	Horizontal, indistinctly medium-bedded	< 0.3 cm; D dark grey	1–2	Same as the previous complex. Ooliths are missing, carbonate clasts pyritized. Discontinuity surfaces are mainly limonitized, phosphatized and/or pyritized
181.7–183.2	Wavy, indistinctly medium- to thin-bedded	< 0.3 cm; D dark grey	< 5	Light greenish-grey, with limonitized spots, medium argillaceous, *very finely crystalline* and *finely crystalline* **limestone** (grains <10%) with **marlstone** interbeds. Iron ooliths (in places 10–20%) are found
183.2–185.9	Wavy, indistinctly thin- to medium-bedded, in places indistinctly nodular	< 0.2, 0.3–1.5 cm; D dark grey	< 10	Grey, with green shade, slightly argillaceous, *microcrystalline* to *finely crystalline* **limestone** (grains in places 10–50%, in places pyritized) with **marlstone** interbeds. Carbonate clasts are phosphatized and pyritized, discontinuity surfaces are phosphatized
185.9–188.7	Wavy, indistinctly thin- to medium-bedded	< 0.2, 0.3–1.0 cm; IND dark grey	< 5	Dark grey, in places slightly argillaceous, *medium-* to *finely crystalline* **dolostone** (grains in places 25–50%) with **dolomitic marlstone** interbeds
188.7–189.2	Indistinctly thin- to medium-bedded	< 0.2, 0.2–3.0 cm; D dark grey	< 5	Grey (in the lower part with violetish-brown spots), slightly argillaceous, in places dolomitized, *finely crystalline* **limestone** (grains in places <10%) with **marlstone** interbeds. Iron ooliths (up to 50%) containing interbeds (thickness 1–5 cm) are found. Discontinuity surfaces are pyritized
189.2–189.9	Medium- to thick-bedded	< 0.2, 0.2–1.0 cm; D and IND dark grey	< 2	Greenish-grey, *finely crystalline* **glauconitic dolostone** with rare **dolomitic marlstone** interbeds. Discontinuity surfaces are limonitized
189.9–190.3	Medium-bedded	< 0.3 cm; IND dark grey	< 2	Greenish-grey, *finely crystalline* **dolostone** with rare glauconite grains and **dolomitic marlstone** interbeds
190.3–190.9	Thick- (medium-) bedded	< 0.2 cm; D dark grey	< 2	Greenish-grey, with yellow spots, *medium-* to *finely crystalline* **dolostone** with glauconite grains. Discontinuity surfaces are limonitized
190.9–191.5	Medium- to thick-bedded	< 0.2 (1) cm; D dark grey	< 2	Violetish-brown and yellow mottled, *medium-* to *finely crystalline* **dolostone** with glauconite grains. Most of the discontinuity surfaces are limonitized
191.5–191.8	Medium-bedded		< 5	The same, but with **dolomitic marlstone** interbeds. Glauconite grains < 80%
191.8–191.9				Dark greyish-green, dolomitized **glauconitic limestone**
191.9–192.9	Thick-bedded			Dark greyish-green, weakly and medium-cemented **glauconitic quartz sand-** and **marlstone** with **glauconitic limestone** interbeds (thickness 2–3 cm) and nodules

Hun*– Hunneberg Stage; B*– Billingen Stage; Leetse*– Leetse Formation; Sil*– Sillaoru Formation; Joa*– Joa Member; M*– Mäeküla Member; P*– Päite Member; T*– Telinõmme Member; Kal*– Kalvi Member

Other issues in the series
Estonian Geological Sections:

Tartu (453) drill core (Bulletin 1; 1998)
Taga-Roostoja (25A) drill core (Bulletin 2; 1999)
Valga (10) drill core (Bulletin 3; 2001)
Soovälja (K1) drill core (Bulletin 4; 2002)
Ruhnu (500) drill core (Bulletin 5; 2003)
Mehikoorma (421) drill core (Bulletin 6; 2005)