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.

The study was partly supported by the Estonian Science Foundation (grant No. 6127). This report is a contribution to IGCP project No. 503.

## 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

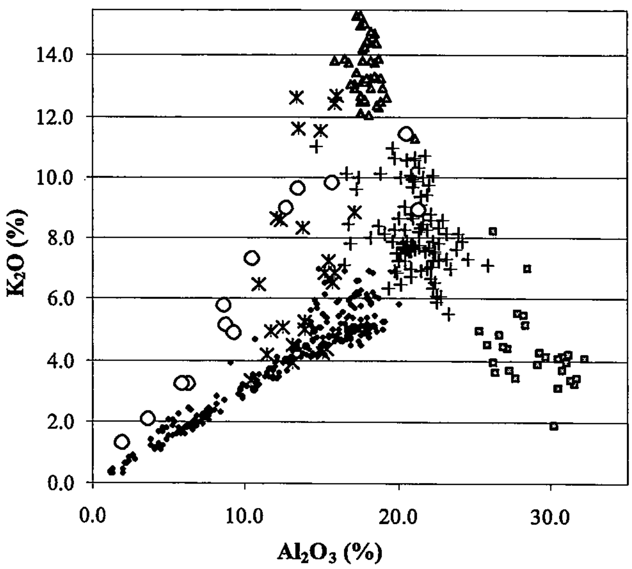


*Fig. 5. Comparison of $K_2O$ and $Al_2O_3$ contents of K-bentonites and common sedimentary rocks of the Kerguta (565) and other Estonian and Latvian sections. Black dots – limestones, marlstones and shales, crosses – volcanogenic K-bentonites (illite-smectite dominated), triangles – volcanogenic feldspathites (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

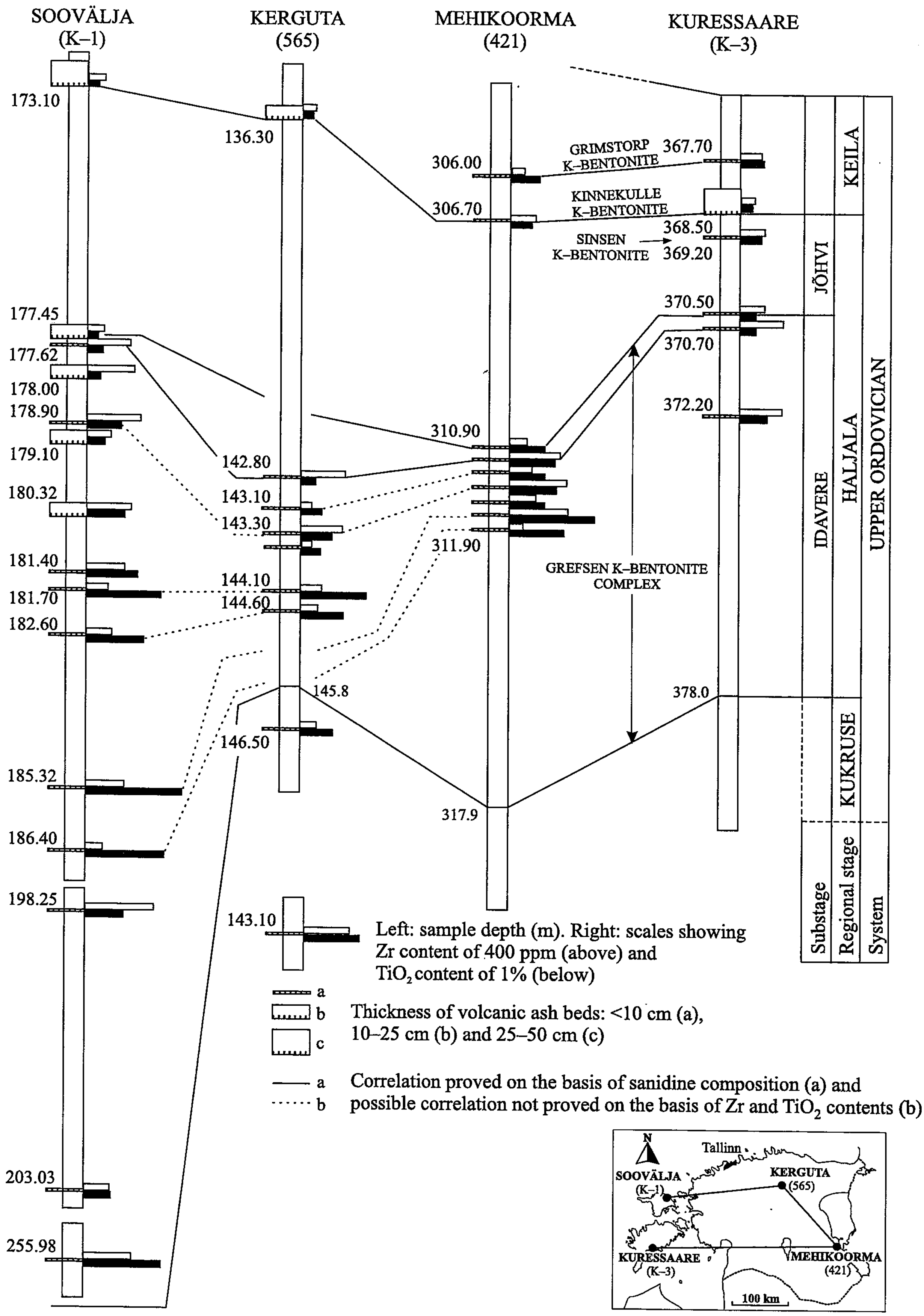


*Fig. 6. Correlation of the Upper Ordovician volcanic ash beds shown in schematic columns of the Soovälja (K–1), Kerguta (565), Mehikoorma (421) and Kuressaare (K–3) cores (see Kiipli & Kallaste 2002, 2005 for details) and location of the drill holes. The Grefsen K-bentonite complex and the Sinsen, Kinnekulle 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 km²). 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).

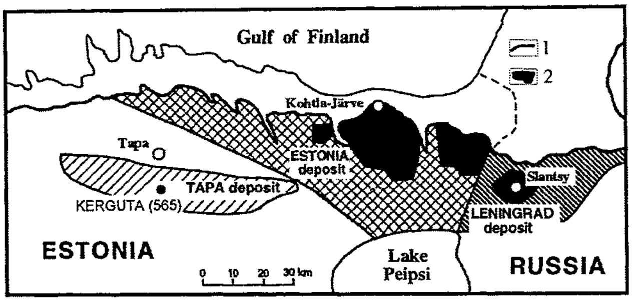


*Fig. 7. Location of oil shale deposits in the Baltic Oil Shale Basin (after Bauert & Kattai 1997). 1 – recent erosional boundary of kukersite oil shale; 2 – mined-out areas and fields of active mines.*

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