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Vasavere ancient valley, its morphology, genesis and importance in the economy of North-East Estonia

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Abstract There are existing different hypothesis about the genesis of palaeoincisions. Well studied Vasavere buried incision in NE Estonia is an excellent example of pre-glacial fluvial valley. Later it was overdeepened by glaciers and filled with glaciofluvial and glaciolacustrine deposits. Fluvial genesis is stressed in its structure and morphology. The valley was initially formed probably in Late Paleogene and contains big reserves of building sand and gravel, and high-quality underground water. Due to lack of topmost till or clay the groundwater in the valley is weakly protected against surface pollution. The water is influenced also by oil shale mining activities.

Keywords *Ancient valley, palaeoincision, glacial erosion, glaciofluvial and glaciolacustrine deposits, OSL dating, groundwater pollution.*

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INTRODUCTION

On the territory of Estonia, as well as on the territories of neighbouring countries a lot of deep valley-like incisions exist. Most of them were probably initially formed in the Late Paleogene some 30 Ma ago when the Earth`s crust surface was much higher than at present due to the riftogenesis in the North-Atlantic region. Incisions have different orientation, morphology and structure. In North-Estonia some of them are prevailingly filled by glaciolacustrine deposits, some by glaciofluvial ones. There are also many incisions where one till bed at the bottom is overlaid by glaciofluvial or glaciolacustrine deposits. In South-Estonia there are often incisions with a complicated structure in which several till beds alternate with deposits of various genesis (Tavast & Raukas 1982). The genesis of incisions is explained in different way, mainly as the result of erosion of preglacial or interglacial rivers or subglacial meltwaters. Meridionally oriented incisions are overdeepened by glaciers (Raukas & Tavast 1984). The contemporary river drainage is supposedly inherited from the ancient pre-Quaternary fluvial system and depends on the tectonic joints in the bedrock (Miidel 1966, 1971). In this paper we shall describe the morphology, structure and genesis of Vasavere buried valley, because it is investigated in most detail and has the greatest economical importance.

MORPHOLOGY AND GENESIS OF VASAVERE VALLEY

Palaeoincisions have been studied in most detail in northeastern Estonia which is the best investigated portion in the Baltic States because of extensive exploration for oil shale and phosphorite, having more than 10 000 boreholes per 2900 sq.km. Figure 1 shows a typical network of boreholes in the vicinity of Vasavere buried valley located in Ida–Viru County in the north-eastern corner of Estonia (Fig. 1). At the beginning, it is eroded into the carbonate rocks of the upper part of the Middle Ordovician Haljala Stage. The central parts of the valley, which are situated under the Kurtna Kame Field expose carbonate rocks of the Middle Ordovician Kunda Stage (Fig. 2a). The longitudinal profile of the valley bottom is uneven (Fig. 2b) and, therefore, younger rocks up to the Uhaku Stage are occasionally exposed. In the Ahtme zone of disturbances (Puura et al. 1986), the valley floor is in the clayey rocks of the Lower Cambrian Lükati Formation. In the vicinity of Voka settlement the valley floor is already in the clastic rocks of the Ediacaran Kotlin and Gdov formations (Fig. 3).

Since deposits from the Upper Devonian through Neogene are absent in Estonia the reconstruction of the tectonic movements are to a great extent based on the analyses of the bedrock topography. The latter has been regarded as consisting of polygenetic planation surfaces of different age (Miidel & Vaher 1997). It has been suggested that not only Mesozoic and Paleogene, but also different Miocene-Pliocene planation surfaces are found in the bedrock topography of Estonia. If the formation of palaeoincisions in Estonia really started in Late Paleogene their formation with no doubts was prolonged in Neogene, because the total Neogene-Quaternary uplift reaches at least 200 m.

The ca 26-km-long meridional Vasavere buried valley starts from the southern boundary of the Kurtna kame field in the vicinity of Raudi village. The valley has here several branches (Fig. 1). One of those, established by borehole data, is ca 4 km long, 300 m wide and 8–10 m deep. At the beginning of the valley, its bottom is 30–37 m a.s.l. The depth of the valley increases northward. For instance, the height of the bottom is +11 m

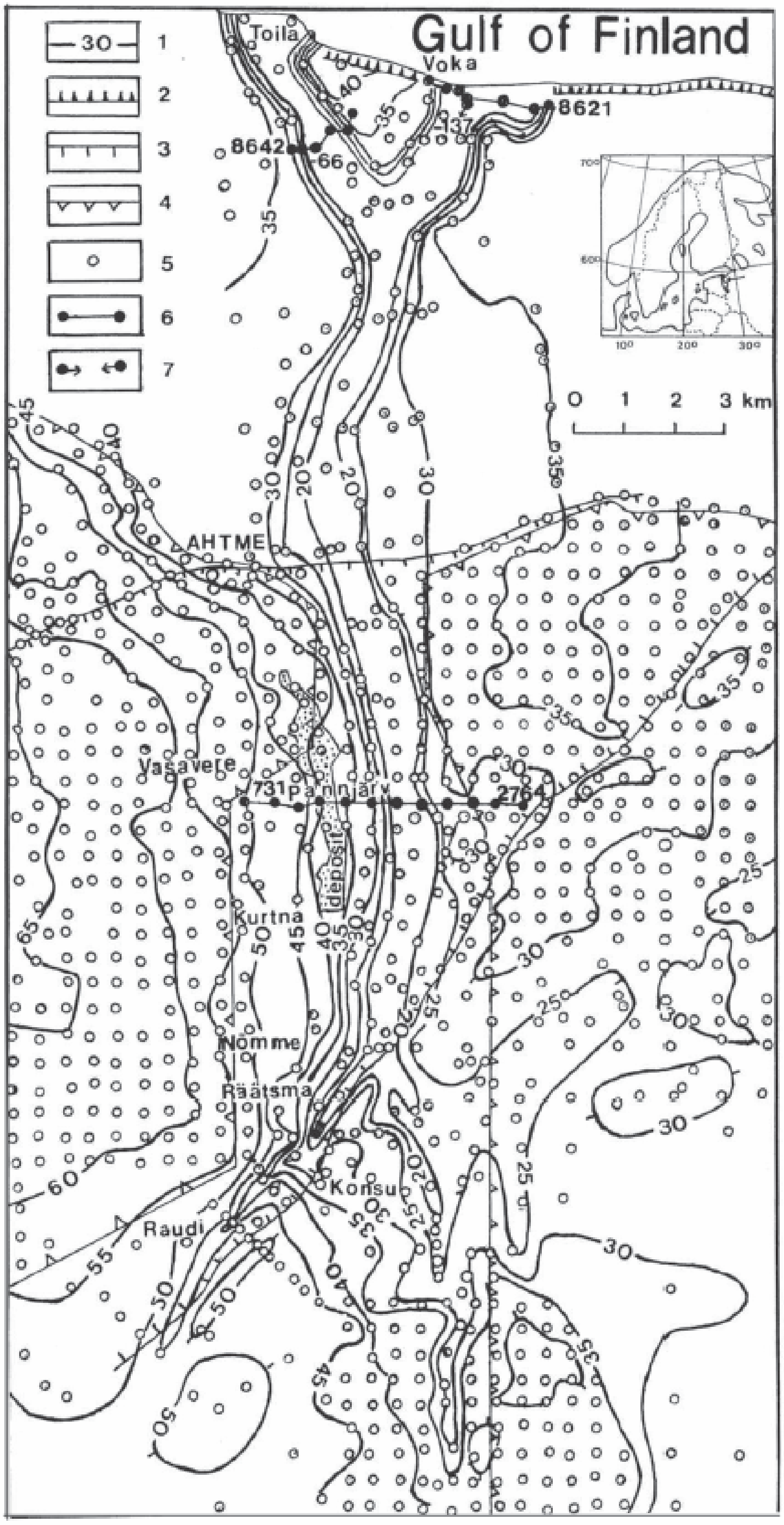

Fig. 1. Location and configuration of the Vasavere buried valley. 1 – contour on the top of bedrock, interval 5 m; 2 – klint; 3 – flexure above a basement fault; 4 - boundary of the mine fields; 5 – borehole; 6 – location of cross section; 7 – location of longitudinal section.

in the vicinity of Lake Räätsma, a kilometre farther north – near Lake Nõmme – it is +2 m, and in the area of Pannjärv sand pit –4 m. In the vicinity of Vasavere village, the bedrock is at a height of -17 m (Fig. 2a). Three similar depressions occur farther north. In one of those, which is situated close to the Ahtme tectonic structure, the bedrock surface is 28.5 m b.s.l. Relative height between the valleys and adjoining elevations reaches 56 m. The depth of the valley increases especially rapidly in Cambrian and Ediacara terrigenous sedimentary rocks (Fig. 3b) reaching 161 m (137 m b.s.l) in the Voka settlement at the sea (borehole 8618). Some 4.5 km to the south, the depth is still rather big, but does not exceed 60 m. Thus, the longitudinal profile of the valley is irregular in shape (Fig. 2b).

The cross-section of the valley is prevailingly asymmetric (Fig. 2a), except the segment close to the Gulf of Finland (Fig. 3). Usually, the western slope is higher, but gentler. In accordance with this, the incutting is different with respect to the surrounding topography. The calculations based on the left (western) slope yield 50–65 m for the depth of the valley, while those based on the right (eastern) slope suggest that the depth won't occasionally amount to 30 m, although in some cases it may even reach 45 m. In the vicinity of the Gulf of Finland, the cross-section of the valley is symmetric (Fig. 3b). The width of the valley is rather stable, being 2.5–3.5 km on the rim. In the vicinity of Lake Räätsma it decreases to 2.0–2.5 km. Before the valley falls into two branches, it is only a kilometre wide. The width of the valley bottom ranges between 100–500 m (Miidel et al. 2006).

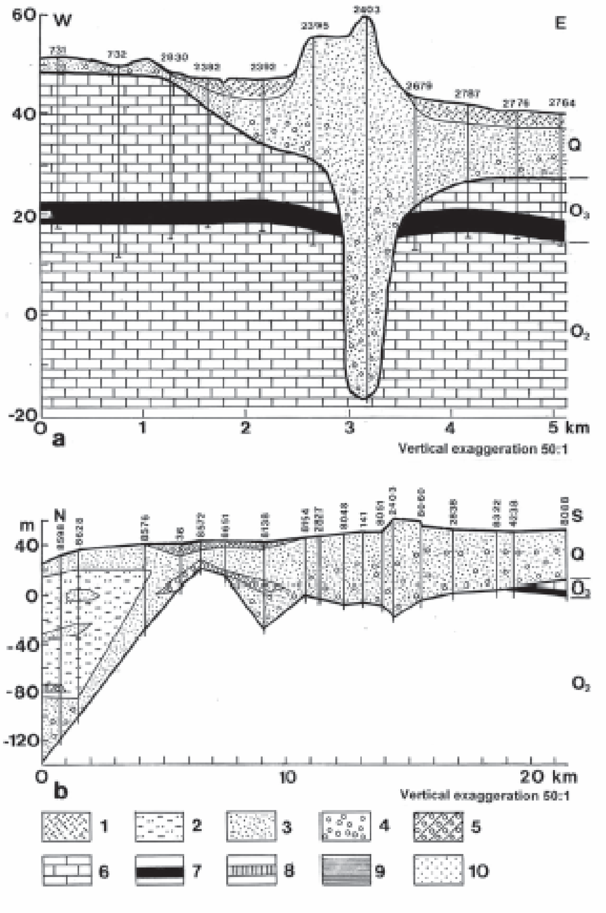

Fig. 2. Vasavere buried valley, cross section in the Kurtna Kame Field (a) and longitudinal section (b). A legend for the figures 2–3: 1 – peat; 2 – silt; 3 – sand; 4 – gravel; 5 – till; 6 – carbonate rocks; 7 – oil shale seam; 8 – Dictyonema argillite; 9 – claystone; 10 – sand- and siltstone. Q – Quaternary; O_1, O_2, O_3 – Lower, Middle and Upper Ordovician; Ca – Cambrian; NP_3 – Ediacara. Data from the Geological Survey of Estonia.

VALLEY FILLINGS

The thickness of the Quaternary sediments in the valley is rather changeable. At the beginning of the valley it is 10–12 m, but within the Kurtna kame field, located on the Vasavere ancient valley (Tavast & Raukas 1978), the total thickness of Quaternary sediments exceeds 75 m, being 45–50 m on an average (Fig. 2a). In the deeper eastern branch of the valley at Voka, in the vicinity of the Gulf of Finland, the Quaternary sediments are over 160 m thick (Fig. 3b). In the western branch of the valley, south of Toila, they are 64 m thick (Fig. 3a).

The Vasavere buried valley is filled with glaciofluvial and glaciolacustrine sandy sediments and silt, partly with the mixture of gravel (Figs. 2 and 3). This applies, first of all, to the segment of the valley within the Kurtna kame field. The till forms 2–6 m thick isolated beds in the different parts of the val-

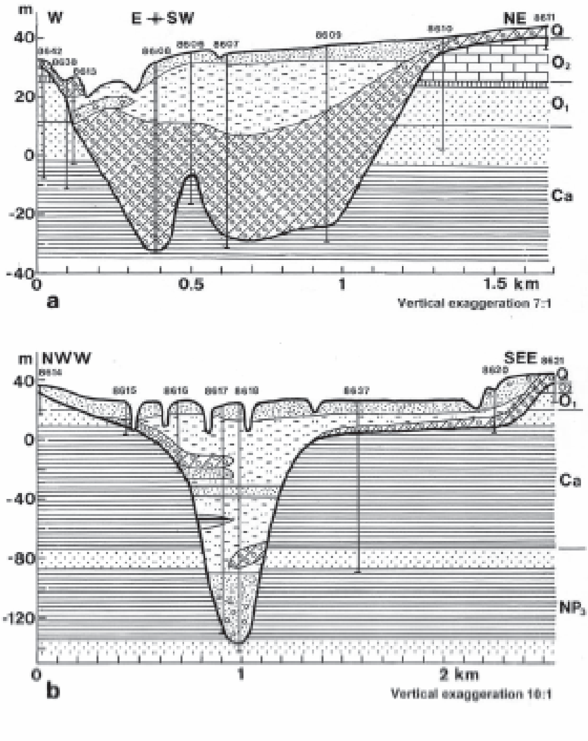

Fig. 3. Vasavere buried valley, cross-section at Voka: western branch (a) and eastern branch (b). For legend see Fig. 2. Data from the Geological Survey of Estonia.

ley. In the branch of the valley running through Voka settlement, till (22.5 m, Fig. 3b) has been established in some places, but the scanty data available indicate that this branch is also mainly filled with fine-grained glaciolacustrine sands and silts. At the same time, in the western branch till has been established in several boreholes with a maximum thickness of 43 m (Fig. 3a). The overlying glaciolacustrine silts are up to 25 m thick.

In the area of the Kurtna kame field, the valley is 1200–1300 m wide and 65 m deep (Fig. 2a). The Pannjärve sand deposit is the biggest of its kind in Estonia (390 ha in area), with active proved reserves of 13.4 million m^3 as of 31.12.2005. The high content of quartz (over 90%) makes the sand suitable for use in concrete and mortar, but also for the manufacture of silica and silicalcite products. In the Vasavere ancient valley within the Kurtna kame field sand and gravel form an up to 80-m-thick layer. Since 1964, when the Pannjärve sand pit was opened, until 1996 15 million m^3 of sand have been excavated there (Helm & Randmer 1996).

THE AGE OF DEPOSITS

The age of the thick sand and silt layer in the valley in the Kurtna Kame Field area has been studied with the OSL method. As there is not clear boundary between kame deposits and valley fillings, we could conclude that most probably all these deposits accumulated during the retreat of the last glaciation. At the same time all dated five samples collected from the medium and coarse sand in the eastern wall of the Pannjärve pit gave different results (Raukas 2004). Two samples at a depth of 5 m, with sampling points located 10 m apart, yielded the ages of 72 000±11 000 and 75 000 ±9000 OSL years. Two samples at a depth of 8 m from the ground surface, spaced 20 m apart, yielded the ages of 9800±1100 and 11 500±1200 OSL years and one sample from a depth of 15 m gave the age of 13 400±1200 OSL years.

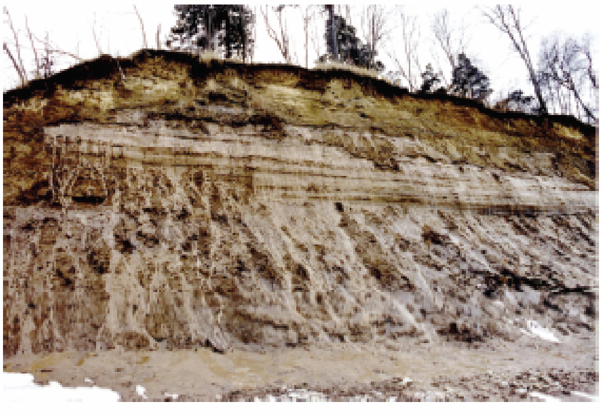

Fig. 4. Outcrop at the Voka site near the Gulf of Finland 16.04.2003. Photo by A. Miidel.

To our mind (Raukas 2004; Raukas & Stankowski 2005) such very heterogeneous results may be explained as resulting from a considerable admixture of unbleached mineral grains from older Quaternary deposits and short duration of the moving medium under sunlight. In and below the ice and in the night time, mineral grains were not exposed to light at all. Even in sunlight, depending on different sediment concentrations, turbidity and depth of water, velocity of outwash streams and transport duration, the extent of bleaching of luminescence signal in the environments studied varies and it is difficult to reconstruct in laboratory, so causing variability of dates. In such conditions even the most accurate measurements of their TL properties will be meaningless and it means that the age determinations of glacioaqueous deposits with OSL method is extremely difficult in practice and all dates are very preliminary, some of them unreliable.

In the Voka outcrop near the seashore, 600 m to the east from the mouth of the Voka River, where the klint bay is 2300 m wide, the Quaternary cover in an exposure is more than 20 m thick (Fig. 4), of that 7.5 metres are formed by fine sand and silt (Miidel 2003). In some places, the sand and silt are underlain by 22.5-m-thick grey till originating, presumably, from the last

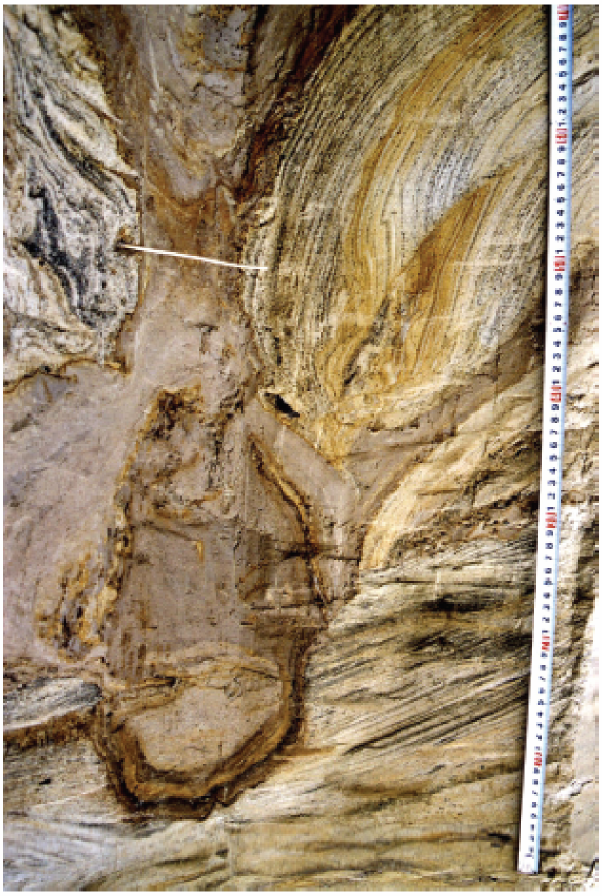

Fig. 5. Typical fine-grained deposits and the deformational structures in the Voka outcrop 16.06.2003. Photo by A. Miidel.

glaciation. The sandy-silty complex comprises at least 4–5 layers with soft-sediment deformation structures (Fig. 5). Taking into consideration the bedding, stratification and grain-size of sediments, but also the height of water basins it was assumed that these sediments were formed in an ice lake at the end of the Late Pleistocene (Miidel 2003). Our OSL dates from the depths 5.5 and 12 m gave the ages 12 530 (18 500) and 25 000 OSL years, respectively (Raukas & Stankowski 2005). However, there are some dates considerably older (Molodkov & Bolikhovskaya 2005).

Recently (Molodkov 2007; Molodkov et al. 2007) from the same section a series of dates from about 31 000 up to about 115 000 OSL years were obtained. The authors concluded that in the section the greater part of the Upper Pleistocene, including last interglacial Sediments, is presented. However, biostratigraphically the age of sediments in the Voka section is not enough grounded. To our mind the pollen grains in the water-laid glaciolacustrine sediments are redeposited and clear pollen zones here are absent. It means that the age of sediments in the Vasavere buried valley is still opened. Most probably these sediments were mainly accumulated at the end of last glaciation.

GROUNDWATER MANAGEMENT AND HUMAN IMPACT

As the filling sediments in the Vasavere valley are presented by glacioaqueous formations they serve as a productive resource for groundwater use and supply. The Vasavere water intake is operating since 1972 with a pumping rate of up to 10 000 m^3/d. The groundwater of this Quaternary aquifer system is of the HCO_3-Ca-Mg-type with TDS up to 0.5 g/l (Savitsky 2000). The groundwater consumption from this intake exerts an obvious influence on the Kurtna area, where the water level in several lakes has dropped (Fig. 6). On the other hand, the hydrological regime in the valley has been influenced by shale mining (Vesiloo 1987). The comparatively intensive and uneven water exchange with surrounding mines has been clearly caused by the uneven bedrock topography.

Groundwater in Vasavere valley is weakly protected against surface pollution due to the lack of topmost till or clay. Very complicated is the situation in the area of Kurtna Kame Field, situated in the northeastern part of the Estonian oil shale deposit, where the ancient valley cuts the oil shale seam (Fig. 2a). The kame field is surrounded by oil shale mining both on west and east sides (Fig. 1). In the west the kame field borders on an oil shale mine, in the east on an oil shale open pit. The area (30 km^2) contains 40 lakes, which are more or less influenced by mining. The state of the lake ecosystems is, first of all, determined by the groundwater regime in the ancient valley.

Until 1946, the changes in the hydrological and hydrogeological regimes were caused mostly by peat cutting drainage. Since the fifties the water level has fallen considerably in 24 lakes because of the drainage of the oil shale pit in Sirgala, peat cutting in Oru, oil shale extraction in the Ahtme mine, sand production in the Pannjärve sand pit and water consumption (Kink et al. 2001).


Fig. 6. Lake Aherjärv in the Kurtna Kame Field has been lowered due to the mining activities 09.06.2004. Photo by A. Miidel.

The content of sulphate in the surface and groundwater in North-East Estonia indicate directly the influence of the mining water (Erg 2003). Oxidation of the pyrite contained in Ordovician rocks, serves as a source of this compound, and concentrations up to 500 mg/l have been found in mining water. In 1937 the lakes in Kurtna kame field were in natural condition, the sulphate was in the range of 1.0-6.7 mg/l. In recent years the sulphate content has increased sharply both in the closed lakes and in those influenced by mining waters. When, for example, in 1937 the sulphate content in lakes Nõmmejärv and Konsu was 5.8 and 2.9 mg/l, then in 1996 the corresponding values were 273 and 190 mg/l, respectively (Kink et al. 2001).

In Estonian Environmental strategy, priority has been given to the problems of groundwater protection, the most important being elimination of sources of groundwater pollution and regulation of groundwater use. Our investigations in the Vasavere ancient valley area clearly demonstrate that this area needs its own nature protection strategy and specific monitoring system.

CONCLUSIONS

Vasavere incision is most probably the pre-Quaternary river valley reworked by the Pleistocene glaciers. Unfortunately we have not river deposits in the valley bottom, because they were carried away by the repeatedly advanced glaciers, which caused irregular longitudinal profile of the valley. On the fluvial genesis of the valley shows dividing it into branches in the beginning of the valley and before the falling into the Gulf of Finland. Deposits in the valley are investigated sedimentologically, palynologically and chronologically, but their age is up to now unclear. The opinion, that in the Voka section there are two intervals of severe climate and two intervals of milde climate (Molodkov et al. 2007), needs better argumentations. The Vasavere valley contains big sand and gravel resources and high quality groundwater. Due to lack of topmost till and clay the groundwater in the valley is weakly protected against surface pollution. It intersects also the Estonian Oil Shale Deposit and hampers the use of it resources. Taking into consideration the importance of the Vasavere valley in the water supply and nature protection, its investigation must be followed.

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