



MIDDLE PLEISTOCENE STRATIGRAPHY IN THE LIGHT OF DATA FROM THE VILKISKES SITE, EASTERN LITHUANIA

Jonas SATKUNAS¹, Anatoly MOLODKOV²

Abstract. The Vilkiskes outcrop is approximately 40 metres high section of Quaternary sandy sediments, exposed in the slope of the Neris River valley and is located 15 km upstream from the city of Vilnius. The section is composed mainly of sand with one till layer in the middle part. The outcrop is of particular interest due to typical section of sandy formation presumably of lacustrine origin, occurring under the till. This formation is widely distributed in the vast area in between Vilnius city and Nemencine town, according to the data of geological mapping, and represents a particular period of nonglacial sedimentation of Saalian time. The new optically stimulated luminescence (OSL) dates (determined by A. Molodkov), obtained from the Vilkiskes section, fall into the time span of 307–230 and 147–137 ka. The age of the lower part of Vilkiskes lacustrine section (dated 307–230 ka by OSL) looks closest to the two ice free stages, which can be correlated with oxygen isotope stages (OIS) 7 (236–186 ka) and OIS 9 (328–301 ka). Ages of about 147.1 and 136.7 ka are obtained near the immediate contact with the underlying glacial lithocomplex. Assuming OSL ages, conditions of occurrence and palaeopalynological characteristics, the interval of the Vilkiskes outcrop with OSL dates falling into the time span 236–186 ka (OIS 7) can be introduced as the last Middle Pleistocene (Drenthe–Warthe) ice free interval in Lithuania, most probably, separating the Zemaitija and Medininkai stadials. The interval dated 147.1 and 136.7 ka is interpreted as the Pamarys Interstadial that tentatively can be correlated with the Zeifen Interstadial in the Kattgat Depression suggesting the existence of a “Younger Dryas”-type climate oscillation just prior to the OIS 6/5e boundary.

Key words: lacustrine sedimentation, sandy deposits, OSL dating, Drenthe–Warthe Interstadial, Vilkiskes ice free interval, Quaternary, eastern Lithuania.

INTRODUCTION

Territory of Lithuania can be regarded as one of classical regions with Quaternary cover formed during continental glaciations and interglacial periods (Quaternary..., 2002). The average thickness of Quaternary cover is approximately 80–120 m and varies from 10–30 m in the northern part of country — the area of prevailing glacial erosion — up to 200–300 m in marginal highlands and the buried valleys or palaeoinscisions. Through the Quaternary period Lithuania has been covered by continental ice sheets originated in Fennoscandinavia which corresponds to most glaciations known so far in Eastern Europe, thus causing very complicated structure of the Quaternary cover. The sediments and landforms of at least of 6 glacial stages and 8 ice free periods could be revealed and observed in the stratigraphic cross-section of the Quaternary of Lithuania.

The Vilkiskes outcrop is situated in the Neris River valley some 15 km upstream from the city of Vilnius and downstream from the Nemencine town (coordinates: 25°22'35" N, 54°50'16" E).

The outcrop is approximately 40 m high section of Quaternary sandy sediments, exposed in the slope of the Neris River valley. The section is composed mainly of sand with one till layer in the middle part of the section. The outcrop is of particular interest due to typical section of sandy formation presumably of lacustrine origin, occurring under the till. This formation is widely distributed in the vast area in between Vilnius city and Nemencine town according to the data of geological mapping (Satkunas, 1993). The size of the Vilkiskes palaeolacustrine depression, filled by sandy sediments, is approximately 12 km x 10 km. The depression is located in between morainic uplands formed presumably by Middle Pleistocene tills (Fig. 1). The Vilkiskes section tentatively is one of possible key section for solving of problems of Middle-Late Pleistocene stratigraphy and therefore it was demonstrated during the field excursion of the 5th Conference of the Baltic Stratigraphic Association in 2002 (Quaternary..., 2002).

¹ Geological Survey of Lithuania, Konarskio 35, LT 03123 Vilnius, Lithuania; e-mail: jonas.satkunas@lgt.lt

² Institute of Geology, Tallinn University of Technology, Estonia Blvd. 7, 10143 Tallinn, Estonia; e-mail: molodkov@gi.ee

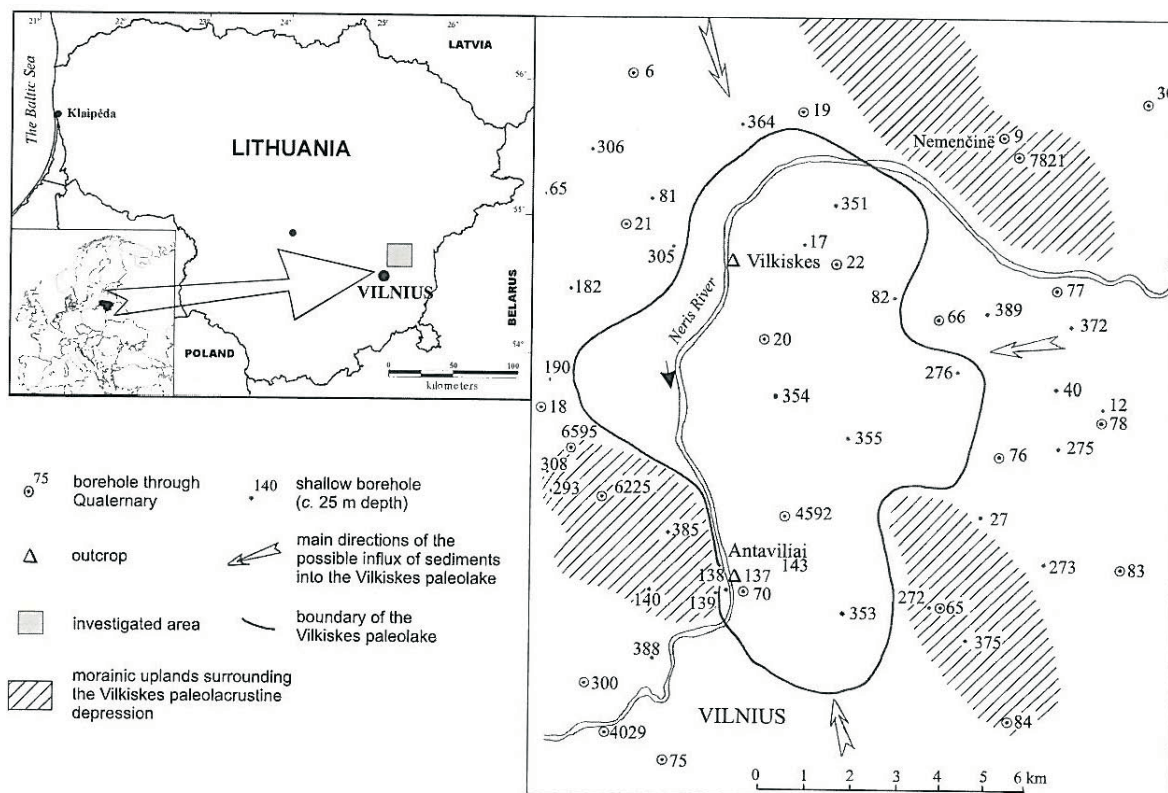


Fig. 1. Location of investigated area

In the vicinities of the Vilkiškes the Neris River flows along the southeastern distal slope of a marginal ridge of Last Glaciation. It crosses the glaciofluvial depression, formed during the Weichselian ice sheet advance and deglaciation. Sandy outwash

and glaciolacustrine deposits cover the depression surface and are drifted to dunes in some places. The river valley uncovers the sediment sequence as deep as 40 m. Totally the thickness of Quaternary in studied Neris River valley course is about 80 m.

FORMER INVESTIGATIONS AND INTERPRETATION OF THE VILKIŠKES SECTION

The lithology of the Vilkiškes outcrop was analysed by Malinauskas (1991), concluding that the sediments under the till were accumulated by saltation of sand grains in running water as an alluvium. The sandy sequence climatostratigraphically was ascribed to pre- or postglacial conditions related to the Merkinė (Eemian) Interglacial. A different conclusion was drawn by Satkunas (1993) on the basis of regional stratigraphic correlation, grain size data and geochemical investigation results obtained from Vilkiškes outcrop. In his opinion, the sandy sequence was accumulated in the lacustrine environment at the beginning of the Butenai (Holsteinian) Interglacial. He distinguished the glacial Zemitija (Saalian *s. str.*) and postglacial aeolian deposits as well.

Sediment sequence of the Vilkiškes outcrop by Barzdziuvienė *et al.* (2000) was subdivided into lithocomplexes that were attributed with the sedimentation events of two glacial-interglacial cycles, including the Butenai (Holsteinian) and of the Merkinė (Eemian) interglacials.

The dating by thermoluminescence (TL) method of deposits from the Vilkiškes section was performed by S. Fedorowicz in laboratory of Gdansk University (Gaigalas *et al.*,

2002). On the basis of the results obtained (lower part: 253.0 ± 38.0 – 280.6 ± 42.0 ka and upper part: 182.3 ± 28.0 – 192.0 ± 28.8 ka) the fine grained sands of aquatic origin in lower part of the Vilkiškes exposure were attributed to the Middle Pleistocene Snaigupele (Drenthe–Warthe) Interglacial. TL dates of overlying sediments showed the age of Merkinė (Eemian *s. l.*) Interglacial (103.0 ± 15.0 ka) and in uppermost part of the section — the time of Nemunas (Weichselian, Vistulian, Valdain) glacial of Late Pleistocene. According to Gaigalas *et al.* (2002), two interglacials — the Early Snaigupele (280.6 to 253.0 ka) and the Late Snaigupele (182.3 to 192.0 ka) — are present in the Vilkiškes outcrop. However, this particular interpretation was not based on any climatostratigraphic or palaeogeographical data, therefore attribution of the dated sediments to the mentioned interglacials is disputable.

It is also worth to mention that the TL datings obtained from similar sands (the same formation according to the geological mapping data) of the Antaviliai section (few km down from the Vilkiškes) gave the age 175 ka (TL 633) and >250 ka (TL 631) (Satkunas, Hütt, 1999).

LITHOLOGY OF THE SECTION

The lithological subdivision of the Vilkiškes outcrop based on detailed investigations by Barzdziuvienė *et al.* (2000) is presented below (Fig. 2).

Lithocomplex I. Fine brownish yellow sand of massive structure in the uppermost part of the bed and subhorizontally laminated in the lowermost. The thickness of laminae is 10–20 cm. The sand is covered by 20 cm of soil cover. The mean component quantities of this lithocomplex show slightly higher amounts of SiO_2 , Al_2O_3 , K_2O and Ba in sediments in comparison with the average levels of all the sequence and the highest mean quantity of Fe_2O_3 .

Lithocomplex III. Brown sandy gravel and coarse sand with gravel and pebbles trough cross-stratified in lenses. The thickness of lenses ranges from 30 to 60 cm, the thickness of cross-beds is up to 12 cm, the dip angle of cross-beds is $10\text{--}30^\circ$ in the direction of $90\text{--}290^\circ$. A palaeosol 10 cm thick covers the bed. The lower surface of the bed is erosional, covered by basal boulders 15–40 cm in diameter, with pebbles and rare rounded rewashed clay lumps.

The sediments from lithocomplex III are the coarsest ones in the sequence. Mean values of maximal (C), mean (X) and median (Md) diameters are 1.52, 0.55 and 0.75, respectively. The sediments represent a wide range of sorting ($S = 0.31\text{--}0.54$, $H_r = 0.64\text{--}0.80$), but often are better sorted than the sediments from lithocomplex I.

The chemical composition of lithocomplex III sediments differs from the others most significantly. Highest levels of Al_2O_3 , MgO, CaO, MnO, Na_2O , K_2O , P_2O_5 , Ba and Sr and the lowest contents of SiO_2 , TiO_2 and Zr are characteristic of the sandy sediments of this lithocomplex.

Lithocomplex IV. Yellowish white fine sand horizontally laminated with the thickness of laminae 1–2 mm. The sandy sediments of lithocomplex IV are nearly of the same sorting as those of lithocomplex III ($S = 0.44$, $H_r = 0.70$, $S_o = 1.19$) but some finer ($C = 0.91$, $X = 0.24$, $M_d = 1.60$). Sandy sediments of lithocomplex IV contain the largest amount of SiO_2 and about the same quantity of P_2O_5 as lithocomplex III; however, the content of Al_2O_3 , Fe_2O_3 , MgO, CaO, Ba and Sr is lowest in them.

Lithocomplex V. Brown dense till with gravel and pebbles. The pebble rich basal layer 20 cm thick composes the lowermost part of the till bed.

Lithocomplex VI (Fig. 3):

VI^a. White, yellowish light grey and greenish yellow very fine sand, horizontally, wavy and waving ripple laminated with lamina 2–30 mm thick. Silt and clay in the uppermost part of the bed compose some laminae with limonite pigmentation. The middle part of the bed consists of horizontally and waving ripple laminated white very fine sand, greenish yellow and brownish grey silt. The thickness of sand laminae reaches 30 mm and of silt laminae — 15 mm. The sediments are rich in mica. Abundant admixture, lenses and intercalation of lake marl are frequent in the lower part of the bed.

The sandy sediments of the lithocomplex VI display the highest degree of sorting in general: mean values of maximal (C), mean (X) and median (M) diameters are 0.29, 0.15 and

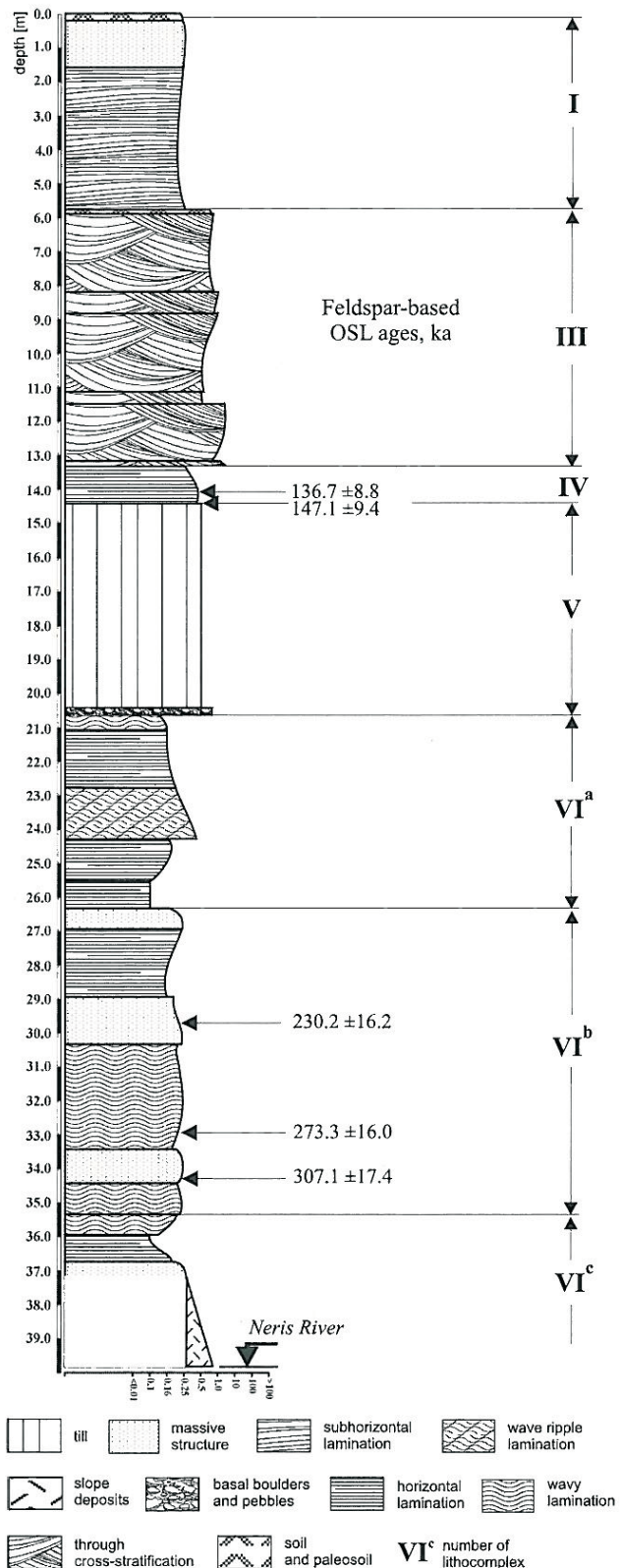


Fig. 2. The Vilkiškes outcrop

Subdivision into lithological complexes according to Barzdziuvienė *et al.* (2000) and the OSL dating results.

1.81, respectively, and represent the sediments as fine and very fine. However, the mean grain size characteristics of the upper, middle and lower parts of lithocomplex VI have some differences. The highest amounts of TiO_2 and Zr and the quantity of SiO_2 exceeding the average level of all the sequence are characteristic of the chemical composition of sandy sediments of lithocomplex VI.

According to the mean values, the sandy sediments of lithocomplex VI^a are finest ($C = 0.27$, $X = 0.14$, $Md = 2.13$) and best sorted ($S = 0.31$, $Hr = 0.70$, $S_o = 1.10$) in lithocomplex VI as well as in all the sequence investigated. The coarsest ($C = 0.29$, $X = 0.16$, $Md = 1.91$) sediments of lithocomplex VI are found in its VI^b part and poorly sorted ($S = 0.47$, $Hr = 0.86$, $S_o = 1.18$) in part VI^c.

The chemical composition of the sediments from lithocomplex VI^a is characterised by a higher content of Al_2O_3 , Fe_2O_3 , MgO , CaO , Na_2O , K_2O , TiO_2 , P_2O_5 , Ba, Sr and Zr. In this case, most significant differences compared with the chemical composition of the deposits from the middle part of the whole sequence of lithocomplex VI has been stated (Barzdziuvienė *et al.*, 2000).

VI^b. White and yellowish light grey very fine massive, horizontally and wavy laminated sand, with the lamina thickness of 5–20 mm in the uppermost part of the bed. The horizontal intercalation of white very fine sand of massive structure and greenish yellow and brownish grey silt with the bed thickness of 5–20 cm in the lowermost part of the bed. The MnO pigmentation and limonite concentration in contacts of the lamina crop up the wavy laminated series near by every half a meter in vertical sequence. The sediments are calcareous in separate laminas of the bed.

Sandy sediments from lithocomplex VI^b contain the highest quantity of SiO_2 in the whole lithocomplex VI. Other components in this middle part of the lithocomplex usually are contained in lower quantities in comparison with the average levels of all the sequence. Also, the least amounts of Al_2O_3 , Fe_2O_3



Fig. 3. The lower part of the Vilkiskes outcrop (lithocomplex VI)

MgO , CaO , Na_2O , K_2O , TiO_2 , Ba, Sr and Zr in the chemical composition of lithocomplex VI have been fixed.

VI^c. Greenish yellow and yellowish grey fine sand with dark green silt laminas intercalated. The sediment colour changes to grey and the wavy lamination originated by laminas 1–5 cm thick shifts to a massive structure down the bed.

The chemical composition of sediments from lithocomplex VI^c also differs to a certain degree from the composition of the whole sequence of lithocomplex VI. Sediments from this lower part of lithocomplex VI are characterised by higher amounts of Al_2O_3 , Fe_2O_3 and Zr. The mean component quantities of the lithocomplex show slightly higher amounts of K_2O , TiO_2 and Zr in the sediments in comparison with the average levels of the whole sequence.

From the depth of 37.2 m the slope deposits cover the outcrop face.

INTERPRETATION OF SEDIMENTATION

The lithofacies of trough cross-stratified coarse sediments are dominating in lithocomplex III of Vilkiskes outcrop, where sand of different grain size and gravel comprise medium and large sets with the cross-bed inclination up to 30°, mostly to the south-west – south-east directions. Such stratification is characteristic of three-dimensional dunes originated by braided streams or strong secondary currents resulting in spoon-shaped scours (Zieliński, 1992). The variance of sediment grain size and sorting represents a changeable complicated flow regime. The chemical data represent sediments of a non-matured composition characteristic of glacial ones in particular. Summarising the investigation results from lithocomplex III, the proglacial glaciofluvial sedimentary sub-environment was stated (Barzdziuvienė *et al.*, 2000).

Almost horizontal or low-angled lamination of fine sand in lithocomplex I is analogous to that on the windward slopes, flanks and near the summits of aeolian sand dunes or coversands. A palaeosoil covered by sand supports this inter-

pretation. The chemical maturity of sand is higher and the highest quantity of Fe_2O_3 in sediments reflects a high oxidation potential during sedimentation.

Event of glacial sedimentation is represented by brown dense till from lithocomplex V. It covers the sediments of lithocomplex VI.

Due to their high chemical maturity the greater part of sediments of lithocomplex VI can be hardly related with glacial or periglacial environments. Prevailing white or at least light-coloured well-sorted fine or very fine sand tends to non-glacial conditions of sedimentation closely related with some interglacial. The predominant horizontal and wavy lamination of sediments with thin laminas suggests a calm lacustrine subenvironment of sedimentation. The highest chemical maturity of sediments is observed in the medium part of the lithocomplex (VI^b). The sediments from the upper and the lowermost parts of this sequence contain the larger amount of chemical components characteristic of glacier-related deposits.

It can be related with component migration due to underground water circulation indicated by an increase of Fe_2O_3 . Also, the influx of glacial material into the basin during the initial and final stages of lacustrine sedimentation was possible.

Lithocomplex IV in the Vilkiskes outcrop can be marked by the same characteristics of sediments as lithocomplex VI.

The chemical maturity of the material is even higher compared with the mean chemical component values of the sediments from lithocomplex VI, and it greatly differs from covering material of lithocomplex III. Such characteristics infer the same conditions of sedimentation, i.e. non-glacial lacustrine (interglacial?) palaeoenvironment.

PALAEOBOTANICAL DATA

In the course of geological mapping the lithocomplex VI (below the till Vilkiskes outcrop) was sampled for pollen and spores analysis (Satkunas, 1993). 17 samples were taken from the lower part of the outcrop (depth 21–36 metres), one sample representing 0.3–0.5 m interval of the section. The pollen and spores analysis was performed by O. Karveliėne at State Geological Enterprise in Vilnius. The analysis showed very few pollen and spores grains in the taken samples. The pollen of *Pinus*, *Picea* and *Alnus* was found from single grains to maximum amount of 52 grains per sample. Such absence of pollen and spores grains may indicate not only palaeoenvironments not suitable for vegetation (e.g. cool interstadial) but also the particular hydrodynamic conditions when the pollen grains were washed out or dissolved from the sands. However, the latter assumption seems less feasible.

The same samples were submitted for analysis of diatoms. The determination was performed by Vaida Seirėne at Geological Institute in Vilnius. General conclusions were done about very low amount of diatoms, however single grains of *Aulacosira granulata* and *A. italica* have been determined. According to Vaida Seirėne (pers. comm.) the detected species of the diatoms are characteristic for eutrophic palaeobasins.

Generally, the palaeobotanical data are very sparse and insufficient for reasonable palaeoenvironmental reconstructions. However, on the other hand, the data do not allow to conclude about warm interglacial palaeoenvironment during the formation of sands of the complex VI. The data available may indicate interstadial conditions rather than interglacial.

OSL DATING

OSL dating methods is based on the measurement of the amount of radiation-induced charges trapped in minerals (e.g. quartz, feldspar) and created by the natural radiation resulting from radioactivity in the mineral itself and from the environment (enclosing matrix and cosmic) after they are exposed to sunlight during transportation. A mineral sample will therefore have trapped charges the amount of which relates directly to the radiation dose the mineral has received after the last deposition of the grains and burial under subsequent deposits of sediment. The total radiation dose that is accumulated in this way is called the palaeodose (P_s). Deposits (if greatly simplified) are dated by measuring the palaeodose, needed to produce the observed OSL signal, and the environmental dose rate (D), affecting the mineral-palaeodosimeter during burial.

The sediments taken from Vilkiskes for OSL dating in the Research Laboratory for Quaternary Geochronology (RLQG), Institute of Geology, Tallinn University of Technology were prepared according to established laboratory procedures. Briefly, coarse potassium feldspar grains were extracted from the sediment by a procedure including wet sieving, heavy liquid flotation (collecting 2.54–2.58 g/cm³ fraction), and treatment by 20 to 40% HCl acid to remove carbonates. The alpha-activated surface layer was removed by etching in 10% HF for 15 min. The OSL measurements were made with a computer-controlled Ingrid-Type SLM-1 reader using 860 nm stimulation. The IR stimulated luminescence decay curves were measured in the 410 nm emis-

sion range. For artificial irradiation a precisely calibrated ⁶⁰Co radiotherapy unit delivering $c. 6 \times 10^{-2} \text{ Gy s}^{-1}$ was used. After irradiation all aliquots were stored at room temperature for at least one month before measurement to allow fading of possible short-lived laboratory-induced OSL signals in the observed emission band. The problem of anomalous fading in the samples dated will be considered in details elsewhere (Molodkov *et al.*, 2004).

Reconstruction of palaeodose was performed by extrapolating the regression lines to zero OSL intensities. The multiple-aliquot additive-dose (MAAD) protocol was applied for luminescence measurements in RLQG using three different K-feldspar grain fractions spanning the size range of 50 μm in a size window between 150 and 250 μm . Additive dose response curves were constructed using up to 11 sets of artificially irradiated aliquots. Each data point on the dose response curve represents the average from 5–6 aliquots.

The external beta and gamma contributions to the total dose rate were estimated in the laboratory from the contents of natural radioactive elements, ²³⁸U + ²³⁵U, ²³²Th and ⁴⁰K in the surrounding sediments using the dose-rate conversion factors of Adamiec and Aitken (1998). Estimates of the cosmic dose (Yokoyama *et al.*, 1982) were based on half of the present depth of burial in order to take into account the increase in the thickness of the deposits during the controlled time interval. The *in situ* water content of the samples was used to calculate water-content attenuation factors.

INTERPRETATION OF RESULTS AND DISCUSSION

Due to course of geological mapping of Quaternary in Lithuania and other investigations new data for improvement of the Middle Pleistocene stratigraphic subdivision became available. First of all new interpretation of the Middle Pleistocene Snaigupele Interglacial must be concerned. The Snaigupele Interglacial was introduced and so far regarded as independent Middle Pleistocene interglacial (Kondratienė, 1996), separating Zemaitija and Medininkai (Saalian) glacials (climatoliths). Despite of the fact that during more than twenty year long investigations it has not been possible to find certain analogs to the Snaigupele site as to the independent interglacial in other Baltic countries (Liivrand, 1997). Recent studies of the palaeocarpological complexes (Kisieliene, 2002) led to conclusion that there is no big difference between the Butenai and the Snaigupele Interglacial florae. Moreover, some of correlative Snaigupele type florae are richer in exotic species than the Butenai florae, and can be attributed to older period than the Zemaitija Glacial (*op. cit.*). The application of lithostratigraphic criteria to the Zemaitija and Medininkai tills showed the stadial rank of these both tills (Satkunas, Bitinas, 1994). Besides that, practically all sections of the deposits of Snaigupele Interglacial has the signs of dislocations and therefore can be regarded as occurring *in situ*. Taking into account all above mentioned conclusions and assumptions, the Snaigupele should be abolished from the designations of Lithuanian interglacials.

The Vilkiskes outcrop is of particular interest due to typical section of sandy formation presumably of lacustrine origin as discussed above, occurring under the till. This formation is widely distributed in the vast area in between Vilnius city and Nemencine town, as mentioned above, and represents a particular period of nonglacial sedimentation predating penultimate glaciation (OIS 6).

Samples from the lower part of the Vilkiskes section at a depth from about 22 to 37 m were taken for luminescence analyses in 2001 by A. Gaigalas, and dated independently in two different laboratories. Two samples from the lower part of the section were analysed in the Luminescence Dating Unit of the Department of Radioisotopes, Institute of Physics, Silesian University of Technology by A. Bluszcz, and seven samples — in TL laboratory of Gdansk University by S. Fedorowicz. The luminescence measurements in Gdansk were done on 80–100 μm quartz fraction using MAAD protocol, in Gliwice — on quartz grain extracts (125–200 μm) applying a single aliquot regeneration (SAR) protocol.

On the basis of TL datings (lower part: 280.6 \pm 42.0 to 253.0 \pm 38.0 ka; overlying deposits: 188.4 \pm 28.0 to 182.3 \pm 28.0 and 192.0 \pm 28.8 ka) the fine grained sands of aquatic origin were attributed to the Snaigupele (Drenthe–Warthe) Interglacial of Middle Pleistocene in lowermost part of Vilkiskes outcrop (Gaigalas *et al.*, 2002).

In the same year three samples of the sediments from Vilkiskes section were independently collected and submitted by Satkunas to RLQG. It turned out that dates obtained in Gdansk, Gliwice and Tallinn (307.1 \pm 17.4 to 230.2 \pm 16.2 ka; **Tab. 1**) on the deposits from the lower part of the section are in good agreement (an obviously underestimated age of about 128 ka (see Fedorowicz, 2003) at a depth 33 m is explained by sliding of the overlying sediments down the exposure (A. Bluszcz, pers. comm.) and clearly indicate that the sediments dated in the range of 211 to 307 ka were deposited during the glacial-interglacial cycle(s) predated the last one. This part of the section can evidently be attributed to one or even two cycles of sedimentation inclusive of two interglacials correlated to OIS 9 and OIS 7. Sediments of one of those cycles constrained by two OSL dates at 211.0 \pm 16.0 and 230.2 \pm 16.2 ka can most likely be attributed to the penultimate interglacial (OIS 7).

According to European time division (Bowen *et al.*, 1986), the age of the Vilkiskes lacustrine section looks closest to the Drenthe–Warthe ice free stage, which is recognised within oxygen isotope stage 7 (186–236 ka, 1994). Some palyno-chronostratigraphical studies from the eastern part of Northern Eurasia (Molodkov, Bolikhovskaya, 2002; Molodkov *et al.*, 2002) indicate the significant warming in a rank of interglacial and the corresponding global high sea-level stand recorded by electron spin resonance (ESR) dating on marine mollusc shells in the time range about 220 ka (OIS 7) which falls within the interval classified in Western Europe as Saalian (Bowen *et al.*, 1986).

Judging from the palynological evidence from the classical Likhvin section (situated *c.* 700 km east of the Vilkiskes site), which is the longest and best documented continuous terrestrial proxy climate record of the East-European Plain, the most probable analogue of this event in the central part of the plain is the Cherepetian (Drenthe–Warthe) Interglacial

Table 1

OSL results and radioactivity data for sediment samples from Vilkiskes site

No	Lab. No.	Depth, m	P _s [Gy]	U [ppm]	Th [ppm]	K [%]	D _Σ [μGy/a]	OSL-age [ka]
1	1450-092	34.5	420.50	0.18	0.99	0.65	1237	307.1±17.4
2	1451-092	33.0	414.10	0.75	1.21	0.76	1511	273.3±16.0
3	1452-092	29.5	322.70	0.46	1.39	0.70	1398	230.2±16.2
4	1453-092	14.3	300.40	0.69	4.23	0.83	1842	147.1±9.4
5	1454-092	14.0	262.40	0.25	1.55	1.01	1705	136.7±8.8

P_s — palaeodose; U, Th, K — uranium, thorium and potassium content in sediments; D_Σ — total dose rate.

Uncertainties: U determination — \pm 2–3%; Th determination — \pm 3–4%; K determination — \pm 1–2%; gamma irradiation — \pm 3–5%.

during which bog gleyed soil was developed; its optimum phases are marked in this section by hornbeam-oak and coniferous/broad-leaved forests with *Pinus s. cembra*, *Pinus sylvestris*, *Betula pendula*, *B. pubescens*, *Carpinus betulus*, *C. cf. orientalis*, *Ostrya sp.*, *Quercus robur*, *Q. cf. pubescens*, *Tilia cordata*, *T. tomentosa*, *Ulmus laevis*, *U. campestris*, etc., among characteristic taxa (Bolikhovskaya, 1995).

It is noteworthy here that the significant warming in a rank of interglacial within OIS 7 is established by other independent indications as well. For instance, according to data on uplifted marine terraces from tectonically stable areas, the global sea level during OIS 7 was higher than at present due to melting of major ice sheets (Zazo, 1999). The evidence of an intra-Saalian warm period with an interglacial type of vegetation is also confirmed by the Velay, Massif Central, France (de Beaulieu *et al.*, 2001) and the Schöningen, Lower Saxony, Germany (Urban, 1995) sequences. Similar data come also from Poland (Krepiec, Losy and Zbójno sites) where Lindner and Marciniak (1998) provided new evidence for intra-Saalian Lubavian (Lublinian) Interglacial *c.* 242–238 to 211 ka in age (Lindner *et al.*, 1998), from Belarus and Ukraine (Lindner *et al.*, 2004), and from the Netherlands (Maastricht–Belvédère OIS 7 site) where Belvédère Interglacial was identified (Vandenberghe, 1995). Both warm stages (Belvédère and Lubavian) are correlated with the Schöningen (Drenthe–Warthe) Interglacial (Urban, 1995). This suggests that the warm-climate event within OIS 7 is of a great transcontinental, or even hemispherical, significance rather than being a local phenomenon in the localities mentioned above (Molodkov *et al.*, 2002).

However, there are also other palaeoclimatic interpretations of the Drenthe–Warthe stage. The sediments of contemporaneous Odra–Warta interstadial interval are known from the classical area of the margin of the Warta Glaciation in central Poland and are characterised by pollen assemblages of interstadial type (Goździk, Balwierz, 1994). So, assuming similar TL and OSL age, conditions of occurrence and palaeopalynological characteristics, the correlation of the Vilkiskes section with the Odra–Warta interstadial can be considered as well.

Therefore, it seems that deposits recognised in the Vilkiskes section can really be related to time span preceding the penultimate Saalian Glaciation, however its palaeoclimatic characterisation still remains open.

If further research of this sandy complex will confirm its chronostratigraphic position and palaeoclimatic conditions proper to interglacials, the Vilkiskes ice free stage can be introduced as the new Middle Pleistocene Interglacial and its relation to the Snaigupele Interglacial must be revealed. On other hand, if the Vilkiskes stage would be firmly characterised as interstadial, this interval would give new palaeoclimatic interpretation and should be introduced as the interstadial separating the Zemaitija and Medininkai stadials.

It is also worth to note here that judging by our date of 307.1 ±17.4 ka (and also by the Gdansk date of more than 270 ka), the lowermost part of the section can represent the sed-

imentation that occurred during the antepenultimate interglacial, i.e. the first past-Butenai *s. str.* (past-Holsteinian *s. str.*, OIS 11) Interglacial correlated to OIS 9 (Molodkov *et al.*, 2002). Although up till now in Lithuania no evidence has been obtained testifying the existence of an interglacial within OIS 9, such conditions are widely detected in other regions around the world (see e.g. Tzedakis *et al.*, 2001; Bolikhovskaya, Molodkov, 2002; EPICA..., 2004). The non-glacial conditions of sedimentation have also been discussed above.

And finally, we would like to draw attention to the fact that within the geological mapping of the maritime region a widely spread deposits of inter-till basin has been determined (Bitinas, 2002). The sediments were locally named Pamarys (Maritime) Interstadial and consist of 20 metres thick fine grained sand with organic interlayers. The climatostratigraphic rank of this unit was determined on the basis of palaeobotanical analysis.

This observation is well corroborated by two feldspar-based OSL dates of 136.7 ±8.8 and 147.1 ±9.4 ka (Tab. 1) obtained in RLQG on the samples taken from the Vilkiskes section at a depth of 14.0 and 14.2 m, correspondingly, near the immediate contact with the underlying lithocomplex representing the brown dense till with gravel and pebbles (Barzdziuvienė *et al.*, 2000), and also by an OSL quartz-based date of 129.0 ±24.0 (Gliwice) for sample taken from the other part of the Vilkiskes exposure by A. Gaigalas at a depth of 14.5 m. The above mentioned older non-glacial deposits dated at 147.1 ±9.4 and 136.7 ±8.8 ka clearly indicate a transition from glacial conditions to interglacial ones, which are attributed to the time interval between 145–140 to 70 ka (Molodkov, Bolikhovskaya, 2002).

Thus, our OSL results support the hypothesis that implies climatic amelioration just below the OIS 6/5e boundary that further was interrupted by a return to a cold climate. And notably, judging from the ESR-dates obtained close to 145 ka (see e.g. Bolikhovskaya, Molodkov, 2002; Molodkov, Bolikhovskaya, 2002; Molodkov, Yevzerov, 2004) and numerous other indications of a drastic warming of the climate in the end of OIS 6, the sea level rise and the global warming may have also started much earlier than *c.* 128 ka ago suggested by the SPECMAP chronology (Imbrie *et al.*, 1984; Martinson *et al.*, 1987).

So, according to the OSL dating, these sediments can be attributed to the pre-Eemian ice free period, presumably to the latest interstadial of the post-maximum Medininkai (Warthanian) Stadial, that could exist during the gotiglacial phase of this penultimate glaciation (OIS 6). The Pamarys Interstadial tentatively can be correlated with the warm Zeifen Interstadial in the Kattegat Depression (Bitinas, 2002) suggesting the existence of a “Younger Dryas”-type climate oscillation just prior to the OIS 6/5e boundary (Seidenkrantz *et al.*, 1996).

Acknowledgements. Authors extend their cordial thanks to Aldona Damusyte for assistance in field sampling of the section and to Regina Norvaisiene for drawing of figures.

REFERENCES

- ADAMIEC G., AITKEN M., 1998 — Dose-rate conversion factors: update. *Anc. TL*, **16**: 37–50.
- BARZDZIUVIENE V., SINKUNAS P., JURGAITIS A., SATKUNAS J., 2000 — Pleistocene sedimentation features in Middle Neris palaeobasins. *Litosf.*, **4**: 36–45.
- BEAULIEU de J.-L., ANDRIEU-PONEL V., REILLE M., GRÜGER E., TZEDAKIS C., SVOBODOVA H., 2001 — An attempt at correlation between the Velay pollen sequence and the Middle Pleistocene stratigraphy from central Europe. *Quatern. Sc. Rev.*, **20**: 1593–1602.
- BITINAS A., 2002 — Pre-Eemian basin in the South Eastern Baltic, Lithuanian Maritime region. In: The Seventh Marine Geological Conference. “The Baltic”. Abstracts. Excursion Guide: 21. Kaliningrad.
- BOLIKHOVSKAYA N.S., 1995 — Évoljutsiya lessovo-pochvennoj formatsii Severnoj Evrazii (Evolution of the loess-paleosoil formation of the Northern Eurasia) [in Russian]. Moscow University Press. Moscow.
- BOLIKHOVSKAYA N.S., MOLODKOV A.N., 2002 — Dynamics of Pleistocene Paleoclimatic Events: A Reconstruction Based on Palynological and Electron Spin Resonance Studies in North Eurasia. *Archaeol. Ethnol. Anthropol. Euras.*, **2**, 10: 2–21.
- BOWEN D.Q., RICHMOND G.M., FULLERTON D.S., SIBRAVA V., FULTON R. J., VELICHKO A.A., 1986 — Correlation of Quaternary glaciations in the Northern Hemisphere. *Quatern. Sc. Rev.*, **5**: 509–510.
- EPICA community members, 2004 — Eight glacial cycles from an Antarctic ice core. *Nature*, **429**: 623–628
- FEDOROWICZ S., 2003 — Interlaboratory comparison of TL dating results in the Vilkiskės profile (Lithuania). *Geologija*, **42**: 40–44.
- GAIGALAS A., FEDOROWICZ S., MELESYTE M., 2002 — Thermoluminescence dates of Mid- and Late Pleistocene sediments in Vilkiskės exposure, Eastern Lithuania. *Geologija*, **38**: 31–40.
- GOZDZIK J., BALWIERZ Z., 1994 — Rogowiec — The Sediments of the Odra/Warta Interstadial and the Upper units of the Wartanian complex. In: The Cold Warta Stage — lithology, paleogeography, stratigraphy. SEQS Symposium. Excursion Guide Book: 34. Lodz.
- IMBRIE J., HAYS J.D., MARTINSON D.G., MCLNTYRE A., MIX A.L., MORLEY J.J., PISIAS N.G., PRELL W., SHACKLETON N.J., 1984 — The orbital theory of Pleistocene climate: support from a revised chronology of the marine ¹⁸O record. In: Milankovitch and Climate. (eds. A. Berger *et al.*): 269–305. Reidel Publishing Co. Dordrecht.
- KISIELIENE D., 2002 — Palaeocarpological complexes of Lithuania Quaternary and their stratigraphical significance. Abstract of Ph.D. thesis. Institute of Geology and Geography. Vilnius.
- KONDRATIENE O., 1996 — The Quaternary stratigraphy and paleogeography of Lithuania based on paleobotanic studies [in Russian with English Sum.]. Academia. Vilnius.
- LIIVRAND E., 1997 — Problematic Snaigupele interglacial as a misleading factor in stratigraphical reconstructions in Estonia. In: The Late Pleistocene in Eastern Europe: Stratigraphy, Palaeoenvironment and Climate. Abstract Volume and Excursion Guide of the INQUA–SEQS Symposium: 104. Geological Survey of Lithuania. Vilnius.
- LINDNER A., MARCINIAK B., 1998 — Middle Pleistocene lake deposits in southern Podlasie (eastern Poland). *St. Geol. Pol.*, **113**: 65–83.
- LINDNER L., WOJTANOWICZ J., BOGUTSKY, A., 1998 — Main stratigraphical units of the Pleistocene in southeastern Poland and the northwestern Ukraine, and their correlation in Western and mid-eastern Europe. *Geol. Quart.*, **42**, 1: 73–86.
- LINDNER L., GOZHIK P., MARCINIAK B., MARKS L., YELOVICHEVA Ya., 2004 — Main climatic changes in the Quaternary of Poland, Belarus and Ukraine. *Geol. Quart.*, **48**, 2: 97–114.
- MALINAUSKAS Z., 1991 — Structure and composition of inter-till complexes of the Pleistocene in Lithuania [in Russian]. Mokslas. Vilnius.
- MARTINSON D.G., PISIAS N.G., HAYS J.D., IMBRIE J., MOORE T.C., SHACKLETON N.J., 1987 — Age dating and the orbital theory of the ice ages: Development of a high-resolution 0 to 300,000 year chrono-stratigraphy. *Quater. Res.*, **27**: 1–29.
- MOLODKOV A., BOLIKHOVSKAYA N., 2002 — Eustatic sea-level and climate changes over the last 600 ka as derived from mollusc-based ESR-chronostratigraphy and pollen evidence in Northern Eurasia. *Sediment. Geol.*, **150**: 185–201.
- MOLODKOV A., YEVZEROV V., 2004 — ESR/OSL ages of long-debated sub-till fossil-bearing marine deposits from the southern Kola Peninsula: stratigraphic implications. *Boreas*, **33**: 123–131.
- MOLODKOV A., BOLIKHOVSKAYA N., GAIGALAS A., 2002 — The last Middle Pleistocene interglacial in Lithuania: insights from ESR-dating of deposits at Valakampiai, and from stratigraphic and palaeoenvironmental data. *Geol. Quart.*, **46**, 4: 363–374.
- MOLODKOV A., JAEK I., VASILCHENKO V., 2004 — Anomalous fading of IR-stimulated luminescence from feldspar minerals: some results of the study. *Geochronom.* (submitted).
- SATKUNAS J., 1993 — Peculiarities of occurrence, structure and genesis of Interglacial deposits of Eastern Lithuania. Abstract of Ph.D. thesis [in Lithuanian]. Vilnius University, Vilnius.
- SATKUNAS J., BITINAS A., 1994 — The lithological composition of Saalian tills in Lithuania as a criterion for lithostratigraphical subdivision. The Cold Warta Stage. *Acta Geogr. Lodz.*, **68**: 173–180.
- SATKUNAS J., HÜTT G., 1999 — Stratigraphy of the section Antavilčiai, Eastern Lithuania, and its implication for the Upper Weichselian climatostratigraphic subdivision. *Geol. Quart.*, **43**, 2: 213–218.
- SEIDENKRANTZ M.-S., BORNMALM L., JOHNSEN S. J., KNUDSEN K.L., KUIJPERS A., LAURITZEN S.-E., LEROY S.A.G., MERGEAI I., SCHWEGER C., VAN VLIET-LANOË B., 1996 — Two-step deglaciation at the oxygen isotope stage 6/5e transition: the Zeifen-Kattegat climate oscillation. *Quatern. Sc. Rev.*, **15**: 63–75.
- TZEDAKIS P.C., ANDRIEU V., BEAULIEU de J.-L., BIRKS H.J.B., CROWHURST S., FOLLIERI V., HOOGHIEMSTRA H., MAGRI D., REILLE M., SADORI L., SHACKLETON N.J., WIJMSTRA T.A., 2001 — Establishing a terrestrial chronological framework as a basis for biostratigraphical comparisons. *Quatern. Sc. Rev.*, **20**: 1583–1592.
- URBAN B., 1995 — Palynological evidence of younger Middle Pleistocene interglacials (Holsteinian, Reinsdorf and Schöningen) in the Schöningen open cast lignite mine (eastern Lower Saxony, Germany). *Meded. Rijks Geol. Dienst*, **52**: 175–185.

- VANDENBERGHE J., 1995 — The Saalian complex and the first traces of human activity in the Netherlands in a stratigraphic and ecologic context. *Meded. Rijks Geol. Dienst*, **52**: 187–194.
- QUATERNARY stratigraphy and palaeobasins of Vilnius environs — the area of maximum boundary of the Last (Weichselian) Glaciation, 2002 — *In*: 5th Baltic Stratigraphic Conference “Basin stratigraphy — modern methods and problems”. Excursion guide (ed. J. Satkunas): 1–21. Geological Survey of Lithuania. Vilnius.
- YOKOYAMA Y., NGUYEN H.V., QUAEGEBEUR J.P., POUPEAU G., 1982 — Some problems encountered in the estimation of annual dose rate in the electron spin resonance dating of fossil bones. *Pact*, **6**: 103–115.
- ZAZO C., 1999 — Interglacial sea levels. *Quatern. Internat.*, **55**: 101–113.
- ZIELIŃSKI T., 1992 — Proglacial valley facies of the Silesian upland — genetic factors and their sedimentological effects. *Geol. Sudet.*, **26**: 83–126.