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# The last Middle Pleistocene interglacial in Lithuania: insights from ESR-dating of deposits at Valakampiai, and from stratigraphic and palaeoenvironmental data

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The penultimate (Snaigupėlė, oxygen isotope stage (OIS) 7) interglacial has proved controversial in Lithuania because of palynological similarities between Holsteinian, Snaigupėlė and Eemian interglacial deposits in the Lithuanian terrestrial record. Furthermore, no warm interglacial period has been recognised between the Holsteinian (OIS 11) and Eemian (OIS 5) in the neighbouring Baltic countries, Estonia and Latvia. In this study, we provide electron spin resonance (ESR) dates of two freshwater mollusc shell samples collected from lacustrine sediments at the Valakampiai site which are thought to be Snaigupėlė in age. Shells analysed gave mutually consistent dates of 116.0 ± 10.8 and 110.0 ± 12.1 ka with an average age of about 113.3 ka. These dates are thus significantly younger than OIS 7, and more closely correspond to OIS 5 (Eemian). The possible occurrence of this late Middle Pleistocene OIS 7 interglacial episode in Lithuania and other Baltic countries is evaluated with reference to the nearest and most complete long terrestrial sequences from the central and southeastern parts of the East-European Plain.

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## INTRODUCTION

The last third of the Brunhes epoch (*ca*. 300 ka) is characterised by considerable climate changes. Continuous records of these changes can be used for palaeogeographic reconstructions and correlations. According to our data (Gaigalas and Kondratienė, 1976; Gaigalas, 1987, 1994, 1995; Bolikhovskaya, 1995; Molodkov and Bolikhovskaya, 2002) and also the palaeoclimatic proxy record stored in deep-sea (e.g. Shackleton and Opdyke, 1973, 1976; Shackleton, 1987; Bassinot *et al*., 1994; Pierre *et al*., 1999) and terrestrial (Woillard, 1978; Wijmstra and Groenhart, 1983; Guiot *et al*., 1992; Tzedakis, 1993, 1994; De Beaulieu *et al*., 1994; Tzedakis *et al*., 2001) deposits, these changes include cold events (stadials), warm events (interstadials) and the beginning and end of two long and well-studied cold periods known in Lithuania as the Medininkai (Dnieper/Moscovian, Saale) and Nemunas (Valdai, Weichselian) glacials and at least one warm phase such as the Merkinė (Mikulinian, Eemian) Interglacial. Detailed analysis of all available palaeoclimatic and palaeoenvironmental records hints, however, at a more complex palaeoenvironmental history of the last Middle Pleistocene (Saalian) glacial. For instance, in the central part of the East-European Plain this long cold period was interrupted at least once, during oxygen isotope stage 7, when a significant warming of interglacial rank occurred. Furthermore, up to three additional interstadials can be distinguished within OIS 6 during the Dnieper (Saale 2, 3 after Bowen *et al*., 1986) Glaciation (Bolikhovskaya, 1995). At the same time, no traces of this warm interglacial period had been found northward, in the two other Baltic countries — Estonia and Latvia. Consequently, no units corresponding to warm interglacial events occur between the Karuküla (Holsteinian) and Prangli/Rõngu (Eemian) interglacials in the stratigraphical division of the Estonian Pleistocene (Raukas and Kajak, 1995). The same situation is observed when considering the stratigraphical scheme of Latvia (Latvijas stratigrafijas..., 1994) where between Pulvernieki (Holsteinian) and Felicianova (Eemian) only a unit corresponding to the Kurzeme (Saalian) Glaciation is marked.

The Lithuanian Quaternary stratigraphic scheme differs essentially from those of Estonia and Latvia. In many sections in Lithu-

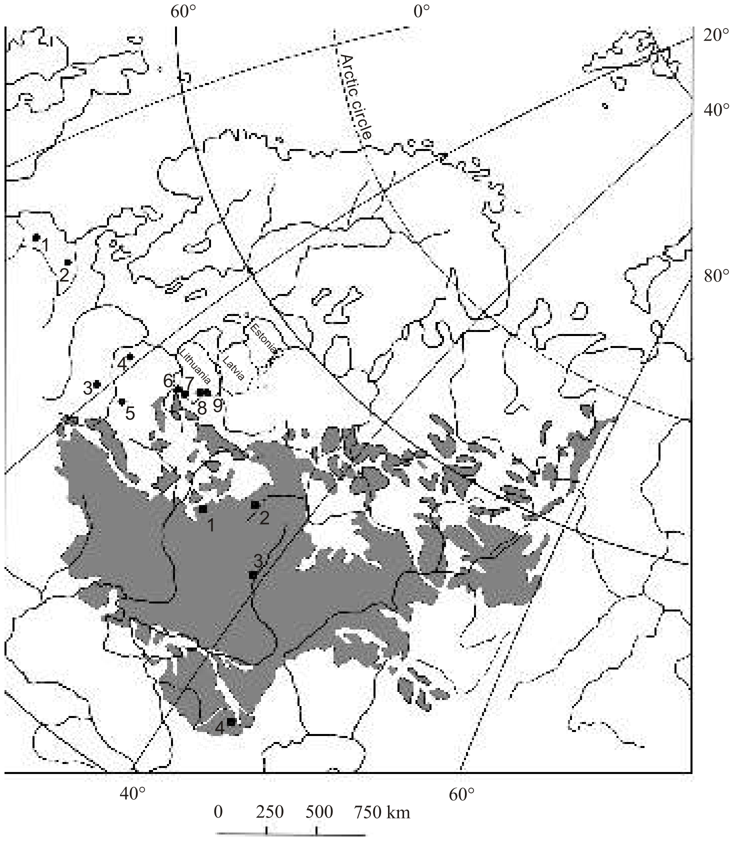



Fig. 1. Map showing the localities mentioned in this paper

Squares: 1 — Arapovichi, 2 — Likhvin, 3 — Strelitsa, 4 — Otkaznoe; circles: 1 — Maastricht-Belvédère, 2 — Schöningen, 3 — Zbójno, 4 — Losy, 5 — Krepiec, 6 — Snaigupėlė, 7 — Mardasavas, 8 — Valakampiai, 9 — Buivydžiai; grey area — distribution of loesses on the East-European Plain

ania, between the Butėnai (Holsteinian) and Merkinė (Eemian) interglacials, one more palaeoclimatic event of interglacial rank, Snaigupėlė (Drenthe/Warthe, after Bowen *et al.*, 1986) Interglacial is recognised, corresponding to oxygen isotope stage 7. The apparent discrepancy between the above-mentioned stratigraphic schemes can be explained either by the absence of this event in the late Middle Pleistocene history of Estonia and Latvia, or by a lack of recognition, to date, of this event in these two Baltic countries. This is entirely possible, given the much better preservation of the Quaternary cover in Lithuania, where up to five interglacial and up to nine individual till beds known in Eastern Europe are distinguished in the Pleistocene (Gaigalas, 1987; Raukas and Gaigalas, 1993). In Estonia and Latvia glacial erosion may have been more intense, with consequently less likelihood of the preservation of previous interglacial deposits.

15 main stratigraphical units of the Pleistocene were described and correlated for the area of southeastern Poland and northwestern Ukraine (Lindner *et al.*, 1998). Eight of these units represent glaciations (Narevian, Nidanian, Sanian 1, Sanian 2, Liviecian, Odranian, Wartanian and Vistulian), and seven are interglacials (Podlasian, Małopolanian, Ferdynandovian, Mazovian, Zbójnian, Lublinian and Eemian).

But despite the apparent orderliness of the Lithuanian stratigraphic scheme and the regularity of the Snaigupėlė Interglacial position within “warm” oxygen isotope stage 7, the organic deposits, attributed to the penultimate (Snaigupėlė) interglacial remain highly problematic because of the palynological similarities between Holsteinian, Snaigupėlė and Eemian interglacial deposits in the Lithuanian terrestrial record. Thus the only unequivocal solution lies in the reliable dating of the deposits. Until now, this has proved difficult because of a paucity of dateable material and the limited time range of applicability of available methods. In this study, we have carried out the electron spin resonance (ESR) analysis of freshwater molluscs within ancient lacustrine deposits regarded as Snaigupėlė in age. This has allowed us for the first time to determine the chronological age of the freshwater shells and, hence, the age of the supposed Snaigupėlė deposits. We also consider how climate evolved through time in Lithuania and neighbouring areas. Together with ESR-dating this can help to resolve the apparent conflict between different localities as regards both the existence and the timing of the penultimate interglacial within OIS 7 and the details of climate fluctuations in this interval.

## GEOLOGICAL FRAMEWORK

There are seven metachronous till formations in the Pleistocene cover of Lithuania, left by separate glaciations or their major stages (Gaigalas, 1979). These tills are related to advances and retreats of the ice sheets of the Katlėriai, Dzūkija, Dainava, Žemaitija, Medininkai and Nemunas glaciations (together with the Grūda and Baltija stadials). The glacial sediments are separated by deposits of normal aquatic (fluvial and lacustrine) sedimentation which took place during the various interglacials: Vindžiūnai, Turgeliai, Butėnai, Snaigupėlė and Merkinė, and the interstadials of the Last (Nemunas/Weichselian) Glaciation.

The Merkinė/Eemian and Butėnai/Holsteinian interglacial deposits serve as key horizons for the purpose of correlation. They are represented by interglacial organic lacustrine and fluvial deposits clearly characterised by palaeobotanical data (Kondratienė, 1996).

The deposits of the intermediate Snaigupėlė Interglacial occur in exposures in the eastern and southern parts of Lithuania (Fig. 1). The stratotype deposits of the Snaigupėlė palaeobasin have been thoroughly studied in South Lithuania near Druskininkai. The Valakampiai site, Buivydžiai and Mardasavas are parastratotype sections of the Snaigupėlė Interglacial.

The development of the flora of the Snaigupėlė Interglacial is most similar to that of the succeeding Merkinė (Eemian) Interglacial (Kondratienė, 1996). The former (Snaigupėlė) differs from the latter (Merkinė) in some features (Kondratienė, 1996). Oak appeared and spread simultaneously with broad-leaved trees (except hornbeam), much earlier than hazel, during the Snaigupėlė Interglacial. The maximum of lime occurred before hazel and was much less pronounced. Oak had two maxima: at the beginning of the climatic optimum of the Snaigupėlė Interglaciation and at the beginning of the expansion of hornbeam. Simultaneously, there are features reminiscent of the Butėnai/Holsteinian (Voznyachuk, 1981; Satkūnas, 1997) or even still older (Kondratienė and Vishnevskaya, 1974; Kondratienė, 1996) interglacials. The spore and pollen spectra can not be yet unambiguously interpreted to provide clear evidence of stratigraphy and chronology. The "warm" Snaigupėlė bed has not yet been identified in a section associated with a reliably identified Merkinė/Eemian or Butėnai/Holsteinian interglacial deposits. Given the fragmentary nature of the palaeobotanical evidence, the stratigraphical position of this interglacial deposit remains in doubt.

To help solve the problem we have collected freshwater molluscs of the Snaigupėlė Interglacial at the long-studied (see e.g. Kondratienė, 1959, 1965; Kondratienė and Vishnevskaya, 1974) Valakampiai site, Eastern Lithuania. The interglacial deposits at Valakampiai are present in northern Vilnius. The interglacial layer occurs in the socle of the first terrace above the flood plain of the Neris River. This Snaigupėlė parastratotype section has been subdivided into 9 pollen zones, characteristic plants being *Caulinia lithuanica* Rišk., *C. tenuissima* D. Benn., *C. goretskyi* Dorof. and *Brasenia* cf. *borysthenica* Wieliczk. (Riškienė, 1979; Velichkevich, 1979). The Snaigupėlė pollen diagram of the Valakampiai section shows some similarity to Merkinė/Eemian spectra (Kondratienė, 1973). Therefore, it was initially assigned to the Last Interglacial (Kondratienė, 1959). Later, on the basis of new palynological data (Kondratienė, 1996), the deposits at Valakampiai were attributed to the preceding Snaigupėlė Interglacial. The correlation of the Snaigupėlė Interglacial with OIS 7 is widely supported in Lithuania.

## SITE DESCRIPTION AND SAMPLES

A natural exposure of interglacial deposits at the Valakampiai site, which is located in the left bank of the Neris River in Vilnius, was used for sampling. The exposed 5 m thick section consists of several alternating layers (Fig. 2). The lowest one comprises shell-bearing gyttja, the top of which is about 1.7 m above the Neris River level. The gyttja is overlain by a 0.8 m thick layer of lacustrine sand. The uppermost part of the section is represented by alluvial sand, the base of which lies at about 2.5 m above the river level. Two samples for ESR-dating were taken from the interglacial gyttja which is thought to be of penultimate (Snaigupėlė) interglacial age correlating with OIS 7. One of the dated freshwater mollusc shell samples (TLN 260-100), represented by an unbroken shell valve, was collected on-site directly from the gyttja. The second one (TLN 259-100), consisting of shell fragments belonging to the same species, was taken in the lab from a sample of the enclosing sediments.

## RESEARCH METHOD

In this study an advanced version of the ESR-dating method (Molodkov, 1988, 1993, 1996) was used. This approach allows determination of the age of freshwater mollusc shells the ESR spectra of which are strongly affected by the presence of intense $Mn^{2+}$ lines that interfere with the peak (g = 2.0012, Molodkov, 1988) used for numerical dating.

The ESR palaeodosimetric dating method is based on direct measurement of the amount of radiation-induced paramagnetic centres (radiation damage), formed in the matrix of shell material exposed to natural radiation. At the time of formation the shell carbonate lattice has no radiation-induced centres, but ionising radiation from the shell itself and the environment (enclosing matrix and cosmic) causes their gradual accumulation. A shell sample will therefore have long-lived (~$10^6$–$10^8$ years, Molodkov, 1988, 2001) paramagnetic centres, the amount of which relates directly to the total radiation dose that the shell has received. The presence of paramagnetic carbonate centres in mollusc shell material can be detected by ESR spectrometry. This produces a plot of the microwave absorption spectra where each paramagnetic centre is characterised by a specific signal (line), the amplitude of which is related to the accumulated palaeodose, and hence to the age of the shells. The ESR-dating technique which we use has been detailed elsewhere (e.g. Molodkov, 1993; Molodkov *et al*., 1998). A brief outline of the analytical procedure is given below.

## EXPERIMENTAL PROCEDURES

### ESR-ANALYSIS

Freshwater shell samples were analysed with an *ESR-221* spectrometer (X-band) at room temperature. All the freshwater

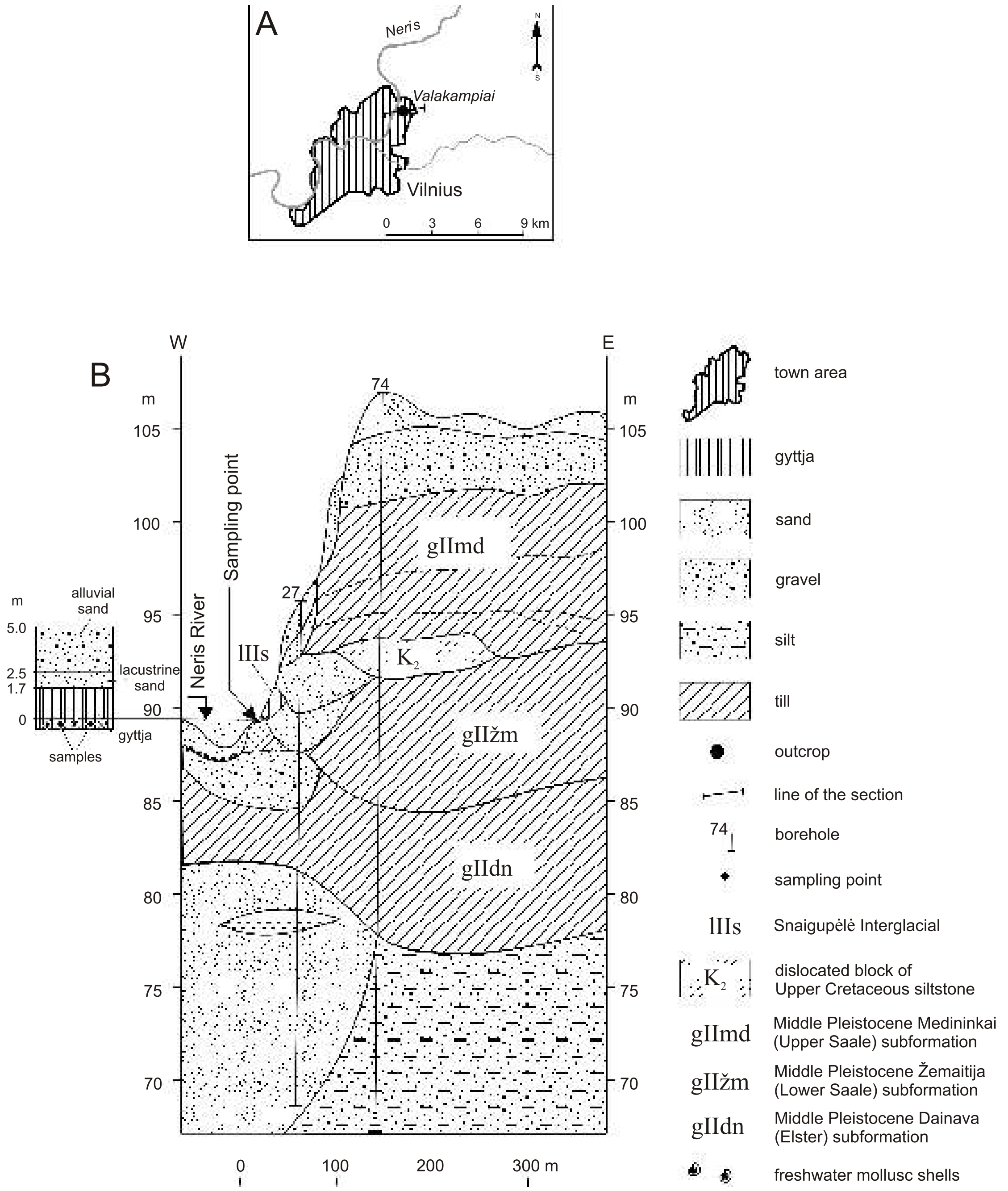



Fig. 2. Valakampiai section in Vilnius

A — location map; B — geological section (after Satkūnas, 1993)

shells studied were composed of calcite, and displayed typical ESR spectra with a characteristic hyperfine sextet and the forbidden transition associated with $Mn^{2+}$ in shell carbonate (Fig. 3). The phase sensitivity detection (PSD) technique (Molodkov, 1988, 1993) was used to enhance the analytical line at g = 2.0012, $B_{pp} \approx$ 0.22 mT and to suppress the manganese signals as well as the interfering radiation-induced signals in the region of g = 2.00. ESR spectra of the shell samples were recorded with a sweep width of 2000 mT, a scan time of 1620 s in the region of g = 2.00, and a time constant of 0.01 s. The microwave power used for dosimetric reading was 2 mW with 100 kHz magnetic field modulation at 1 mT. The reported results are the average of ten measurements of the 2.0012 signal for each aliquot.

## DOSE RATE MEASUREMENTS

The external beta and gamma contributions to the total dose rate were estimated from the contents of natural radioactive elements, $^{238}U$ + $^{235}U$, $^{232}Th$ and $^{40}K$ in the surrounding sediments. For detecting and identifying naturally occurring radioactive elements in the surrounding matrix a multichannel gamma-ray spectrometer with a 100 × 150 mm dia low background sodium iodide crystal was used. For better statistical accuracy up to four samples about 1 kg each were taken within a sphere of R~30 cm for assessment of the gamma and beta contribution to the external dose rate. Sediment samples were sealed on-site to preserve prevailing moisture needed further to correct for natural dose rate calculation. 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 thickness of the deposits during the controlled time interval. The dose rate conversion factors of Adamiec and Aitken (1998) were used. The percentage of the beta dose was estimated according to the shell geometry and proportions etched off. The water content of the sediments was also taken into account. The internal dose rate was calculated based on the determination of U-concentration in the shells by NAA taking into account the in-growth of $^{230}$Th with daughters in the shell during its buried state (Ikeya, 1985; Molodkov, 1986; Molodkov *et al*., 1998). The defect formation efficiency for alpha-particles was assumed to be 0.15.

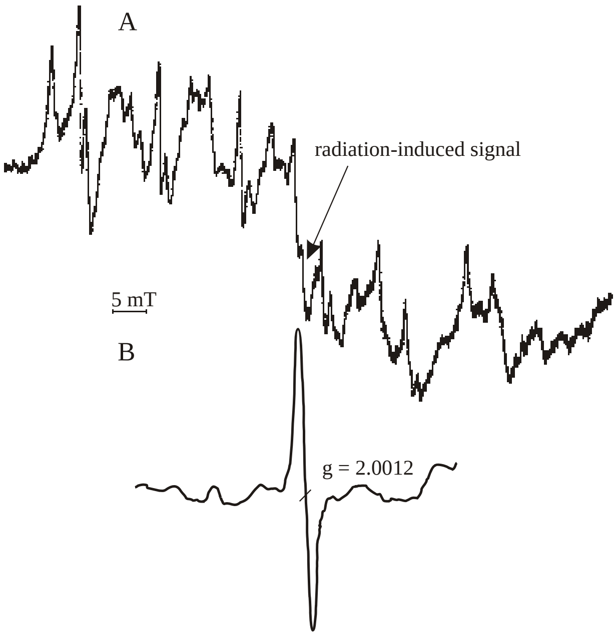



Fig. 3. A — typical ESR derivative absorption spectrum of freshwater mollusc shells from the Valakampiai site; B — analytical line at g = 2.0012, separated by phase sensitive detection (PSD) technique

## DATING RESULTS

The age of the enclosing deposits was determined on two samples of freshwater shell material taken from the same stratigraphical level. The palaeodose for each sample was obtained by fitting with the reciprocal exponential function $-\ln(1-I/I_{max})$, where $I$ and $I_{max}$ are the ESR signal intensity and that of the level at saturation dose, respectively. The accumulated palaeodose, $P_s$, was estimated by extrapolation of the regression line to the zero ESR intensity (Fig. 4). Saturation intensity was determined iteratively by optimising the correlation coefficient r. Long-term fading of the absorbed palaeodose (Molodkov, 1989) was taken into account, proceeding from the estimated time-averaged terrestrial temperature (about 5°C) and thermal stability of the 2.0012 centres in the shells studied (τ ≈ 10 Ma at 5°C, Gaigalas and Molodkov, 1996). The results of radiometric and ESR analyses are given in Table 1. At present the dating method applied in this work usually provides overall analytical precision of up to about 10%, when taking into account the standard errors assumed for every parameter used in the age calculation. The ESR analysis of the shells yielded mutually consistent dates of 116.0 ± 10.8 and 110.0 ± 12.1 ka with an average age of about 113.3 ka.

## DISCUSSION

The numerical ages obtained suggest correlation with the Last (Merkinė/Eemian) Interglacial that, from palynological analysis of the Arapovichi reference section (Figs. 1 and 5) and ESR-chronostratigraphic studies over the marginal areas of Eurasian north (Molodkov and Bolikhovskaya, 2002) date from a time interval between approximately 145 to 70 ka. Our dating results are indirectly corroborated by the results of another study (A. Bitinas, pers. comm., 2002) which suggest that

Table 1

**ESR results and radioactivity data for mollusc shells and sediment samples from the Valakampiai site**

| No. | Lab No. | Field No. | d [mm] | $U_{in}$ [ppm] | U [ppm] | Th [ppm] | K [%] | $D_c$ [μGy/a] | $D_{int}$ [μGy/a] | $D_{sed}$ [μGy/a] | $D_\Sigma$ [μGy/a] | $P_s$ [Gy] | ESR-age, T [ka] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | TLN 259-100 | Sample 1 | 1.5 | 0.42± 0.01 | 1.23± 0.05 | 3.45± 0.16 | 1.11± 0.02 | 109.6± 22.0 | 122.6± 12.3 | 951.3± 47.6 | 1183.5± 56.8 | 129.7± 12.8 | 110.0 ± 12.1 |
| 2 | TLN 260-100 | Sample 2 | 3.0 | 0.21± 0.01 | 1.23± 0.05 | 3.45± 0.16 | 1.11± 0.02 | 109.6± 22.0 | 65.7± 6.6 | 784.1± 39.2 | 959.3± 50.0 | 110.9± 8.6 | 116.0 ± 10.8 |
| Weighted mean age | | | | | | | | | | | | | 113.3 ± 8.1 |

d — the shell thickness, $U_{in}$ — the uranium content in shells, U, Th, K — the uranium, thorium and potassium content in sediments, $D_c$ — the cosmic dose rate, $D_{int}$ — the time-averaged internal dose rate, $D_{sed}$ — the sediment dose rate, $D_\Sigma$ — the total dose rate, $P_s$ — the palaeodose

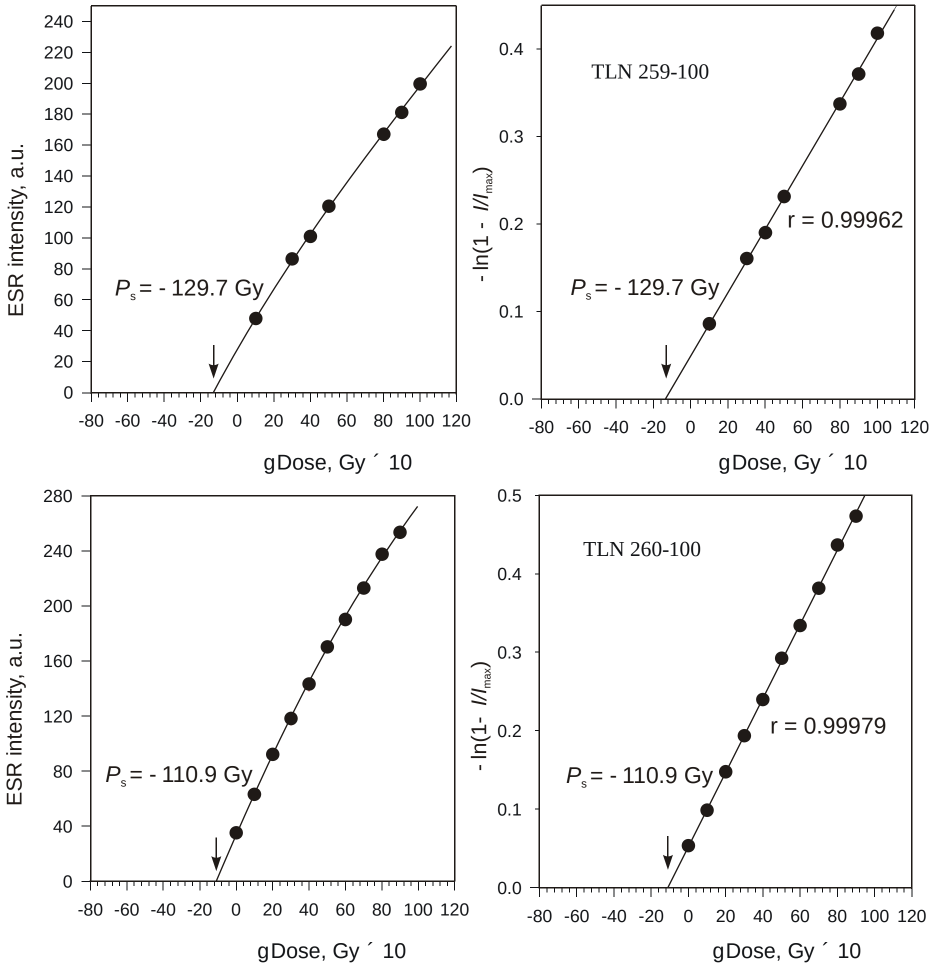



Fig. 4. Dose response curves of TLN 259-100 and TLN 260-100 samples from the Valakampiai section and evaluation of the accumulated palaeodose, $P_s$, by the exponential (left) and the logarithmic (right) fitting of the data points

$I$ — ESR intensity, $I_{max}$ — ESR intensity at saturation dose, r — the correlation coefficient

the Valakampiai gyttja is clearly redeposited, as glaciotectonic folds are present in the sand directly under the gyttja, and gyttja was not found in a borehole drilled several metres away from the exposure. This demonstrates that the gyttja layer has a very limited extent. Furthermore, a raft of Mesozoic rocks has been discovered at the same height in the borehole drilled about 100 metres from the outcrop, underlining the prevalence of glacitectonic structures in the Quaternary deposits of this region. During the Last Glaciation the ice sheet may have covered the Neris valley in this area and dislocated older deposits.

At first sight, our results on the parastratotype Valakampiai section would seem to indicate that interglacial deposits of the penultimate interglacial distinguished by O. Kondratienė in Lithuania, including the Valakampiai site, were actually formed during the Last (Merkinė/Eemian) Interglacial stage. Such a conclusion might appear to be also supported by the circumstance that in the other Baltic countries (Latvia and Estonia) an interglacial event between Holsteinian (OIS 11) and Eemian (OIS 5) has not been identified (Latvijas stratigrafijas..., 1994; Raukas and Kajak, 1995). To elucidate whether this penultimate (late Middle Pleistocene) interglacial episode may really have occurred in the Baltic countries, including Lithuania, we decided to consider the general palaeoenvironmental evolution during the late Middle Pleistocene. For this purpose, we have chosen the nearest and palynologically best studied long terrestrial succession, the Likhvin, and two complete successions from the southeastern part of the East-European Plain. They clearly demonstrate the occurrence of greater climatic complexity between the Holsteinian and Eemian than is represented in the stratigraphical schemes of Latvia, Estonia and some other areas of Europe.

## PALAEOCLIMATIC EVIDENCE FROM LONG MIDDLE PLEISTOCENE PROXY RECORDS

### LONG SEQUENCE FROM LIKHVIN

Likhvin is among the longest and best documented continuous terrestrial proxy climate record of the East-European Plain. This section is located approximately 700 km east of Lithuania,

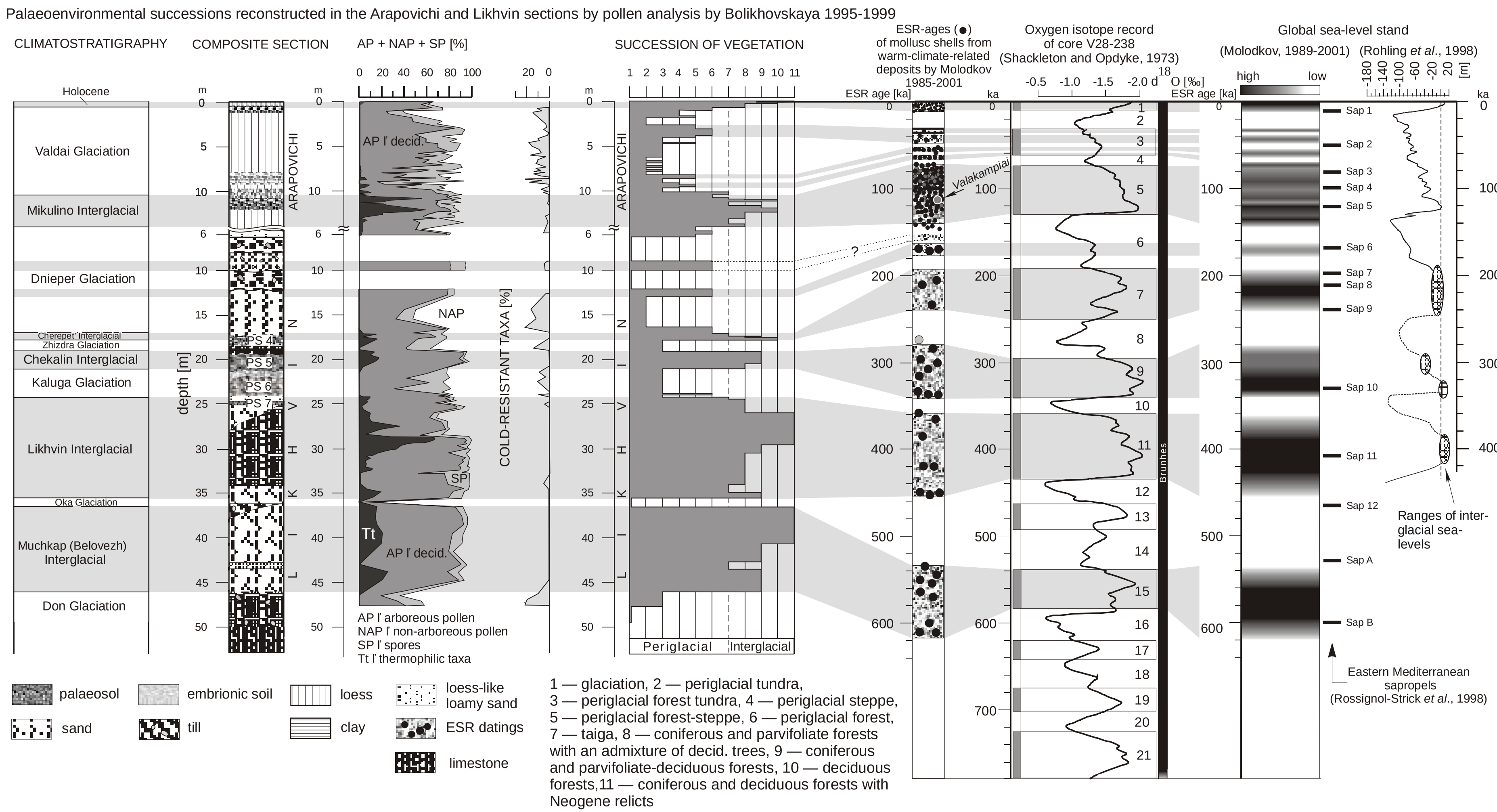



Fig. 5. Chronology and correlation of major palaeoenvironmental events over the last 600 000 years (after Molodkov and Bolikhovskaya, 2002)

Climate warming of the interglacial rank within OIS 7 can be traced in different terrestrial and marine palaeoenvironmental records almost at the same latitude as the Valakampiai site. A 50 m thick sequence of loess, palaeosoils, tills, glacio-lacustrine, alluvial, lacustrine and bog sediments is exposed here in a 2 km long scarp extending along the Oka River (Fig. 1) and in nearby pits and boreholes. The sequence spans the period from the Don (Glacial C of Cromerian complex) Glaciation to the Holocene (Bolikhovskaya and Sudakova, 1996). The composition and structure of the Middle Pleistocene sediments and the majority of palaeogeographic events of this time interval are represented here most completely. According to the results of pollen analysis, six cold and six warm interglacial (Figs. 5 and 6) epochs are represented in the Likhvin section. These include the Chekalin (OIS 9) and Cherepet' (OIS 7) interglacials which occurred between the Likhvinian (Holsteinian) and Mikulinian (Eemian). All Mid-Pleistocene glacial-interglacial cycles are represented here either as complete climatic rhythms of glacial and interglacial rank, or as a considerable portions of climatic-phytocoenotic phases — constituents of the rhythm (Bolikhovskaya, 1995).

To elucidate the possible chronostratigraphic position of the Snaigupėlė Interglacial deposits in the Quaternary formations of Lithuania and their correlation with the interglacial levels of the neighbouring areas, we will consider some features of flora and vegetation of all the intervals between the Oka (Elsterian) and Dnieprian (Saalian) glaciations reconstructed in the Likhvin section. Then, using data from two more complete sections located further to the south-east, we shall briefly characterise penultimate interglacial interval within OIS 7.

The palynozones of the **Likhvinian** (*s. s.*) **stratotypical horizon (OIS 11)**, which is represented in the Likhvin section by the series of alluvial and lake deposits up to 20 m thick (Fig. 5), allowed to reconstruct 11 phases in development of vegetation and climate of the rather long Likhvinian Interglacial (Bolikhovskaya, 1995; Bolikhovskaya and Molodkov, 2002).

The palynoflora of Likhvinian Interglacial deposits includes almost 90 taxa, of which more than 60 taxa are determined up to species level. The characteristic taxa of the Likhvinian flora include such indicative species as *Tsuga canadensis, Taxus baccata, Pterocarya fraxinifolia, Juglans cinerea, Castanea sativa, Ilex aquifolium, Fagus orientalis, Quercus castaneifolia, Buxus* sp., *Osmunda claytoniana, etc.* (see Bolikhovskaya, 1995 for details). According to our data (Bolikhovskaya and Molodkov, 2000; Molodkov and Bolikhovskaya, 2002) the Likhvinian Interglacial was the period of the most prolonged and warm climate in northern Eurasia over the past 600 ka.

The subsequent pre-Dnieprian palaeoenvironmental changes are represented by a *ca*. 8 m thick unit, which consists of alluvial, lake, lake-and-bog clayey and loamy deposits including four horizons of hydromorphous buried soils.

During the **Kaluga cool interval (OIS 10)** the periglacial environments of forest-tundra lacustrine and fluvial deposits, as well as the overlying PS 7 soil and the parent rock of the PS 6 soil (Fig. 5) were formed. Climatostratigraphic units are expressed by five palynozones the amount and variety of which indicate the relatively long duration of the Kaluga cold climatic rhythm.

The **first post-Likhvinian — Chekalin (OIS 9) — interglacial** has been recorded in a pedocomplex including paraburozem PS 5 and podzolic PS 6 soils with lacustrine clay between them. Characteristic taxa of palynoflora of the Chekalin Interglacial are *Picea s. Omorica, P. excelsa, Pinus s.Cembra, P. sibirica, P. sylvestris, Betula pendula, B. pubescens, Carpinus betulus, Quercus robur, Tilia cordata, T. platyphyllos, T. tomentosa, Acer* sp., *Ulmus laevis, U. glabra, U. campestris* and others.

It is noteworthy that up till now, in Lithuania no evidence has been obtained suggesting significant temperature drop during the time interval correlated with OIS 10 or of the existence of two interglacials within OIS 11 and OIS 9, although such evidence has been detected in other regions (Gaigalas and Molodkov, 1996).

The **Zhizdra cooling event (OIS 8)** is distinguished by the pollen spectra of the overlying 1 m thick lake and bog deposits. During this severe cooling periglacial steppes were replaced by periglacial tundras. Shrub formations (*Juniperus* sp., *Betula fruticosa, B. nana, Alnaster fruticosus, Salix* sp.), meadow-swamp phytocoenoses and sparse-soddy habitats occupied by *Ephedra* sp., *Artemisia* spp., *Cannabis sativa* and other xerophytes prevailed.

The **penultimate — Cherepet' (OIS 7) — interglacial** which falls within the interval classified in Western Europe as Saalian (Fig. 6), is represented in the Likhvin section by a bog gleyed soil. At the time of its formation, forests dominated the landscape of the Upper Oka basin undergoing the following transformations during the interglacial (palynozones Chr1–Chr5):

— Chr1 — pine-birch forests with an admixture of *Quercus robur, Q.* cf. *pubescens, Ostrya* sp.;

— Chr2 — hornbeam-oak forests with an admixture of *Tilia cordata, T. tomentosa, Carpinus orientalis, Ostrya* sp. and birch forests;

— Chr3 — birch-pine with an admixture of elm forests and osier-beds (endothermal cooling);

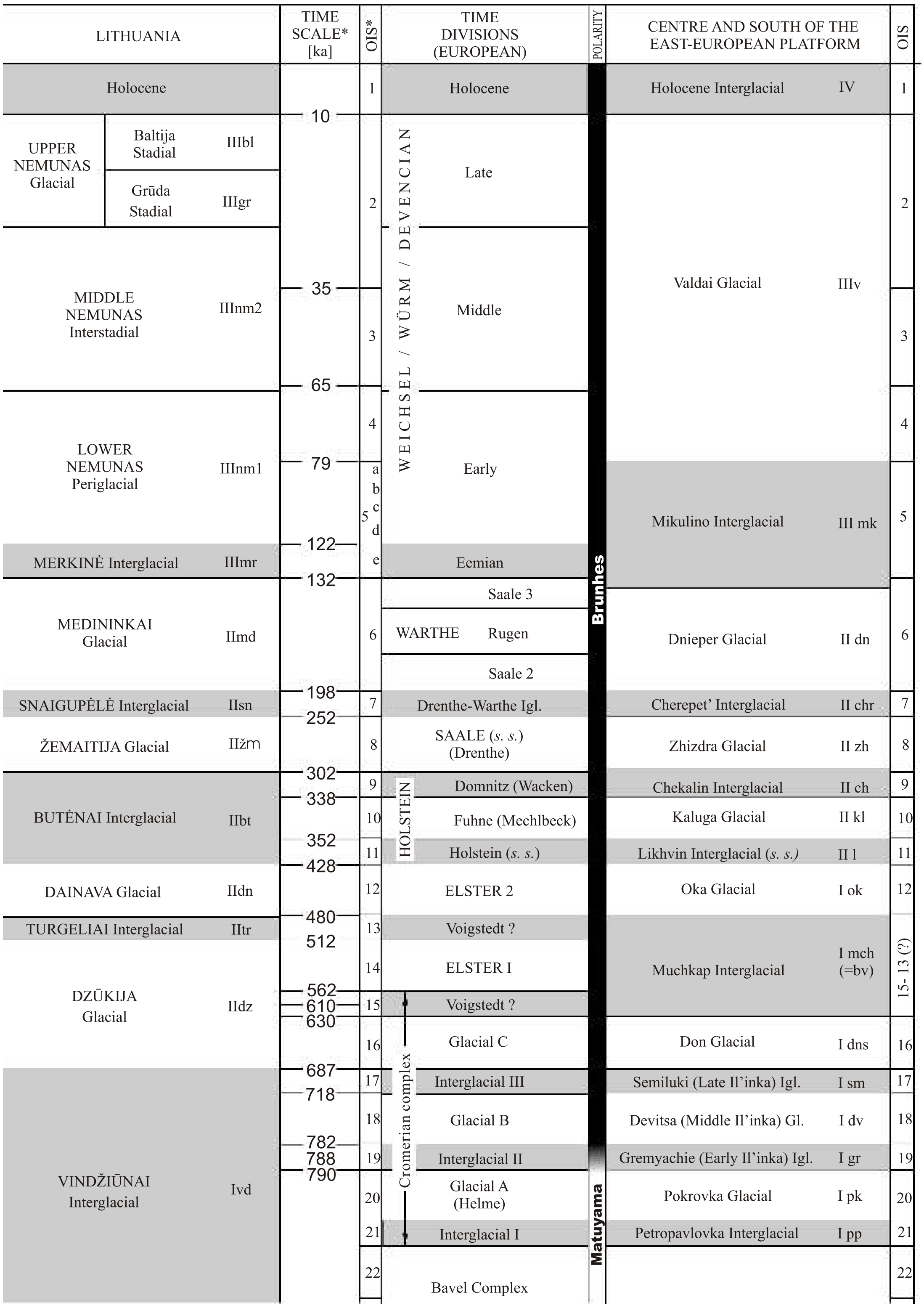
— Chr4 — cembran pine, pine-birch and elm-oak forests; and osier-beds;

— Chr5 — pine-birch forests with an admixture of elm and lime.

Optimum phases of the Cherepet' Interglacial are marked by the spread of hornbeam-oak and coniferous/broad-leaved forests with *Pinus s. Cembra, P. 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.

## COMPLETE SUCCESSIONS FROM STRELITSA AND OTKAZNOE

To the south-east, in the Strelitsa section (the area of the Upper Don, Fig. 1) all Middle and Upper Pleistocene deposits are represented. During the penultimate (Cherepet') interglacial (or Romny according to the scheme of Velichko and colleagues (Climate and Environmental Changes …, 1999)) the humus horizon of the Romny soil formed here. Our palynological data and environmental reconstructions (Bolikhovskaya, 1995; Virina *et al*., 2000) indicate that the Romny soil was formed under warm interglacial conditions. In the forest vegetation, which dominated during the whole interglacial, the following succession has been established:




* Time scale and oxygen isotope stages (OIS) are after Bowen *et al*., 1986

Fig. 6. Correlation between palaeoenvironmental late Middle Pleistocene events in Lithuania (after Satkūnas and Kondratienė, 1995), West Europe (after Bowen *et al*., 1986) and the East-European Plain (after Bolikhovskaya, 1995)

— Chr1— shrub hornbeam-oak with an admixture of alder forests and pine-birch forests;

— Chr2 — hornbeam-oak forests with *Carpinus orientalis, Ostrya* sp., *Quercus pubescens;* alder and coniferous-birch forests;

— Chr3 — birch-pine forests with an admixture of oak.

The profile contains two phases (Chr1–Chr2) of thermoxerotic (warm and relatively dry) stage and a cold phase (endothermal cooling) (Chr3) of the Cherepet' Interglacial. The soil body of the thermohygrotic stage of this interglacial rhythm has not preserved in this section.

Further south, in the extraglacial zone of the Russian Plain, even more complete Middle and Late Pleistocene strata are presented in the Otkaznoe section, Middle Kuma area (Bolikhovskaya, 1995). Here the characteristic Cherepet' Interglacial pollen assamblages are preserved in a well-developed palaeosol complex reflecting a domination of xerophytic open woodlands and temperate shrubs, in the following succession:

— Chr1 — oak sparse forests;

— Chr2 — birch forests and shrub hornbeam groves (endothermal cooling);

— Chr3 — oak-hazel sparse forests, shrub hornbeam groves and birch forests.

Characteristic taxa of the Cherepet' Interglacial in the Otkaznoe profile comprise *Pinus s.g. Haploxylon, Betula raddeana, Carpinus betulus, C. orientalis, Ostrya* sp., *Corylus colurna, Quercus robur, Q. pubescens, Q. ilex, Q. petraea, Tilia cordata, T. platyphyllos, T. tomentosa* (Bolikhovskaya, 1995).

The most distinctive feature of the penultimate (Cherepet', OIS 7) interglacial palynoflora is that, at all three sites considered, representatives of xerophytic broad-leaved forests and shrub formations — *Carpinus orientalis, Ostrya* sp., *Quercus pubescens, etc*. — are characteristic. In the latter two areas, *Carpinus orientalis* had even been among the forest-forming species. The broad-leaved forests, representing the climatic optimum of this penultimate warm stage at all sites considered, have representatives today in the Caucasus, Crimea, Moldavia and other regions of southern Europe.

A warm phase of interglacial rank within OIS 7 has been independently established. For instance, sea-level rise due to melting of global ice is recorded by ESR data at about 220 ka from raised marine deposits (Molodkov, 1995), thus predating the Merkinė (Eemian). According to data on uplifted marine terraces on tectonically stable areas, the sea level during OIS 7 was higher than at present (Zazo, 1999). Evidence of an intra-Saalian warm period with interglacial type vegetation has also been found in the Velay, Massif Central, France (De Beaulieu *et al*., 2001) and the Schöningen, Lower Saxony, Germany (Urban, 1995) successions. Similar data come also from Poland (Krepiec, Losy and Zbójno sites) where Lindner and Marciniak (1998) provided new evidence for an intra-Saalian Lubavian (Lublinian) Interglacial, *ca*. 242–238 to 211 ka in age (Lindner *et al*., 1998), and from Netherlands (Maastricht-Belvédère OIS 7 site) where the Belvédère Interglacial has been identified (Vandenberghe, 1995). Both warm stages (Belvédère and Lubavian) are correlated with the Schöningen (Drenthe/Warthe) Interglacial (Urban, 1995).

These palaeoenvironmental proxy records suggest that this warm-climate event within OIS 7 is of broad transcontinental, or even hemispherical, significance rather than being a local phenomenon in the centre of the East-European Plain. Therefore, further studies are needed to determine the Snaigupėlė deposits recognised in different parts of Lithuania are really related to the penultimate (Snaigupėlė) interglacial, in contrast to the gyttja dated at the Valakampiai site.

## CONCLUSION

ESR-dates obtained on freshwater mollusc shells from deposits previously attributed to the penultimate (Snaigupėlė) interglacial deposits at Valakampiai are in fact Merkinė/Eemian in age. In general, the stratigraphy of such Pleistocene deposits is uncertain because of the fragmented nature of the record, and this particularly effects the Snaigupėlė Interglacial deposits of Lithuania. To obtain a perspective on the late Middle Pleistocene palaeoenvironmental history of the region, and to estimate the probability of the occurrence of this interglacial event in Lithuania and other Baltic countries, we have considered the nearest and most complete long terrestrial sequences from the central and southeastern parts of the East-European Plain.

The reference sections selected for illuminating the question are located in to the east of Valakampiai, almost at the same and lower latitudes, and they provide a record of palaeoclimatic change through the entire Middle and Late Pleistocene; all these sections have been directly studied in detail by one of us (N. Bolikhovskaya).

According to our data (Molodkov and Bolikhovskaya, 2002), at least two interglacial intervals accompanied by a relatively high sea-level stand, dated by ESR to between about 340 and 280 ka ago (stage 9, initial part of stage 8), and at *ca*. 220 ka (stage 7), are distinguished during the late Middle Pleistocene after the warm period of the Likhvinian *s. s.* (Holsteinian *s. s.*) Interglacial. The last of the optimum phase conditions is reflected in the Likhvin reference section by hornbeam-oak and coniferous/broad-leaved forests clearly indicating an episode of warm interglacial climate within OIS 7. The different palaeoenvironmental proxy records including palynological evidence suggest that this warm-climate event within OIS 7 is of a broad transcontinental, or even hemispherical significance. Thus, corresponding deposits of this penultimate interglacial should be present in Lithuania as well. New investigations of Snaigupėlė sites are needed to establish whether this is the case. Reliable age control for these interglacial deposits is particularly needed, for example from electron spin resonance (ESR) and optically-stimulated luminescence (OSL) methods. We hope to pursue this study.

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