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ESR AGES OF THREE LITHUANIAN MID-LATE PLEISTOCENE INTERGLACIALS METHODICAL AND STRATIGRAPHICAL APPROACH

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Abstract: The electron spin resonance (ESR) dating was used for freshwater mollusc fossils taken from interglacial deposits at the Gailiūnai and Neravai sites (Butėnai/Holsteinian Interglacial), Valakampiai site (Snaigupėlė/Drente-Warthe Interglacial), Jonionys and Netiesos sites (Merkinė/Eemian Interglacial) in Lithuania. Freshwater mollusc samples from the Butėnai/Holsteinian and Merkinė/Eemian Interglacials estimated by ESR yielded different ages: Butėnai – 455.0 to 307.0 ka and Merkinė – 112.5 to 101.5 ka BP. Two ESR dates determined for Snaigupėlė Interglacial deposits suggest an average age of about 113.0 ka. This is therefore younger than expected from the palynological data, and it places Snaigupėlė into the interglacial stage, possibly assigned to the MIS 5d that can likely be correlated with the Merkinė/Eemian Interglacial (*s.l.*). Thus, further studies of the deposits and additional ESR dates are needed to make sure that the Snaigupėlė bed is really much younger than expected (about 200 ka) in all recognized sites in different parts of Lithuania.

1. INTRODUCTION

The dominant Quaternary deposits in Lithuania are barren of datable organics. The occurrence of sediments of all glaciations known in Eastern Europe is a characteristic feature of Lithuania. Up to five interglacials and up to nine independent till beds are distinguished here. There are seven metachronous till formations in Pleistocene cover of Lithuania, left behind by independent glaciations or their major stages (Gaigalas, 1979). These tills are related to advances and degradations of the ice sheets of Katlėriai, Dzūkija, Dainava, Žemaitija, Medininkai and Nemunas glaciations, the latter being represented by two stages: the Grūda and Baltija. The glacial sediments are separated by deposits of normal aquatic (fluvial and lacustrine) sedimentation which originated during various interglacials: Vindžiūnai, Turgeliai, Butėnai, Snaigupėlė and Merkinė, and interstadials of the Last Nemunas/ Weichselian Glaciation. Interglacial lacustrine, boggy and alluvial sands, silts, gyttja, clay, sapropelite with rare mollusc shells are spread.

The Merkinė/Eemian and Butėnai/Holsteinian interglacial deposits serve as key horizons for the purpose of correlation. They are represented by interglacial organogenic deposits clearly characterized by palaeobotanical data (Kondratienė, 1996). Unfortunately, the spore and pollen spectrum of all other intermorainic layers can not be yet unambiguously interpreted, to provide clear evidence in terms of stratigraphy and chronology. The presence of the Snaigupėlė Interglacial has been discussed by several authors. According to some of them Snaigupėlė Interglacial deposits are pre-Butėnai (pre-Holsteinian) in age (Velichkevich, 1979; Vozniachukh, 1978). At the same time, V. Vonsavičius and Baltrūnas (1974) attributed the Snaigupėlė deposits to the Upper Pleistocene. According to pollen data of O. Kondratienė (1996), the Snaigupėlė Interglacial is younger than the Butėnai/ Holsteinian and older than the Merkinė/Eemian Interglacial that allowed her to correlate it with penultimate interglacial period of isotope stage 7.

2. RESEARCH METHODS

Apparently, the only real possibility to unequivocally solve the problem of the Lithuanian interglacials is the timing of lacustrine and bog deposit formations. For this purpose, the electron spin resonance (ESR) analysis of freshwater mollusc fauna included in Butėnai, Snaigupėlė and Merkinė Interglacial deposits was undertaken. It allowed to determine the absolute age of shell remains and hence, the age of the embedding interglacial deposits.

In the present study an advanced version of the ESR-dating method (Molodkov, 1988, 1993 and 1996) was applied to date freshwater mollusc fauna taken from interglacial gyttja at the Gailiūnai and Neravai sites (Butėnai Interglacial), Valakampiai site (Snaigupėlė Interglacial), Jonionys and Netiesos sites (Merkinė Interglacial). The location of sites see **Fig. 1.**

The ESR dating method is based on a direct measurement of the amount of radiation-induced paramagnetic centres (radiation damages), that have been created in shell material due to natural radiation. At the time of formation the lattice of shell biogenic carbonate has no radiation-induced centres, but radiation from the shell itself and the environment (embedding matrix and cosmic) causes their gradual accumulation. A shell sample will therefore have 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. It produces a plot of the microwave absorption spectra where each paramagnetic centre is characterised by specific signals, the amplitude of which is related to the accumulated palaeodose, and hence to the age of the shells. Details of ESR dating of subfossil shells used in the present study are described elsewhere (e.g. Molodkov *et al.*, 1998) Analytical procedure are given below.

ESR-analysis

Shell samples were analysed with an ESR-221 spectrometer (X-band) at room temperature. All the freshwater shells studied were composed of calcite, and displayed typical ESR spectra with a characteristic hyperfine sextet and the forbidden transition associated with the Mn^{2+} in shell carbonate **(Fig. 2).** The phase sensitivity detection (PSD) technique (Molodkov 1988 and 1993) was used to enhance the analytical line at g=2.0012, $\Delta B_{pp} \approx 0.22$ 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 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. Reported results are the average of ten measurements of the 2.0012 signal for each aliquot. Palaeodose for each sample was obtained by fitting with the reciprocal exponential function $-\ln(1-I/I_{max})$, where I and I_{max} are an 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. 3).** Saturation intensity was determined iteratively by optimising the correlation coefficient r. Long-term fading of absorbed palaeodose (Molodkov, 1989) was taken into account proceeding from the estimated time-averaged terrestrial temperature (about 5° C) and thermal stability of the 20012 centres in the shells studied ($\tau \approx 10$ Ma at 5° C).

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 surround-

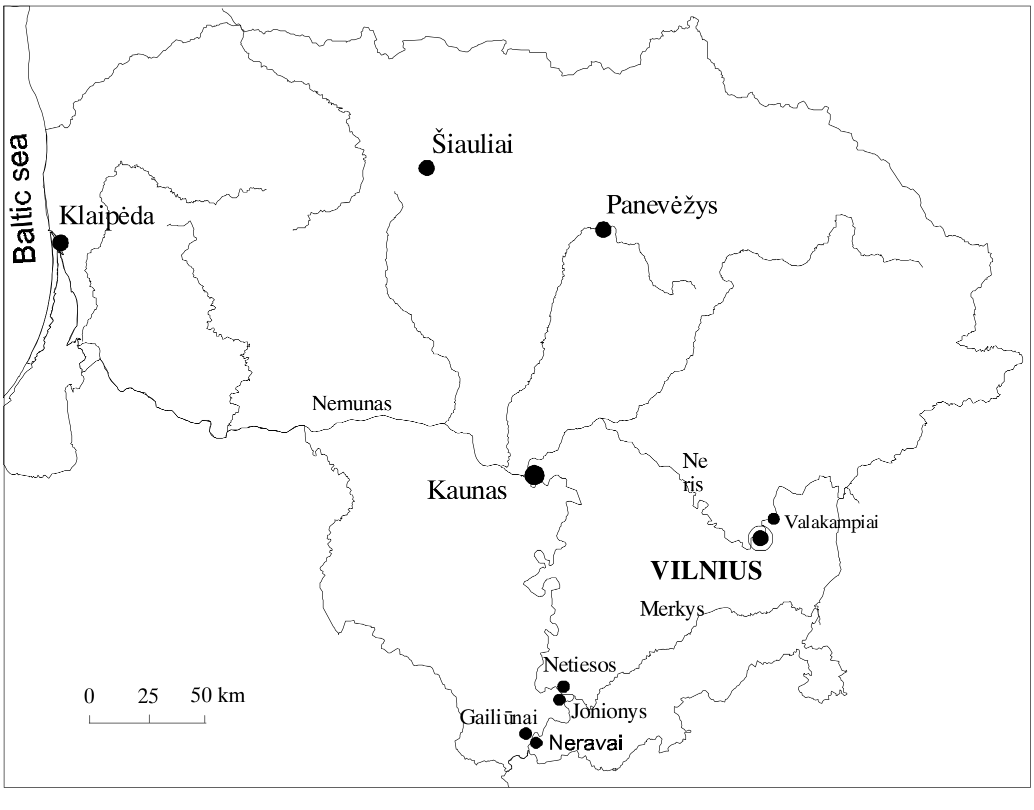

Fig. 1. Location map of investigated sections.

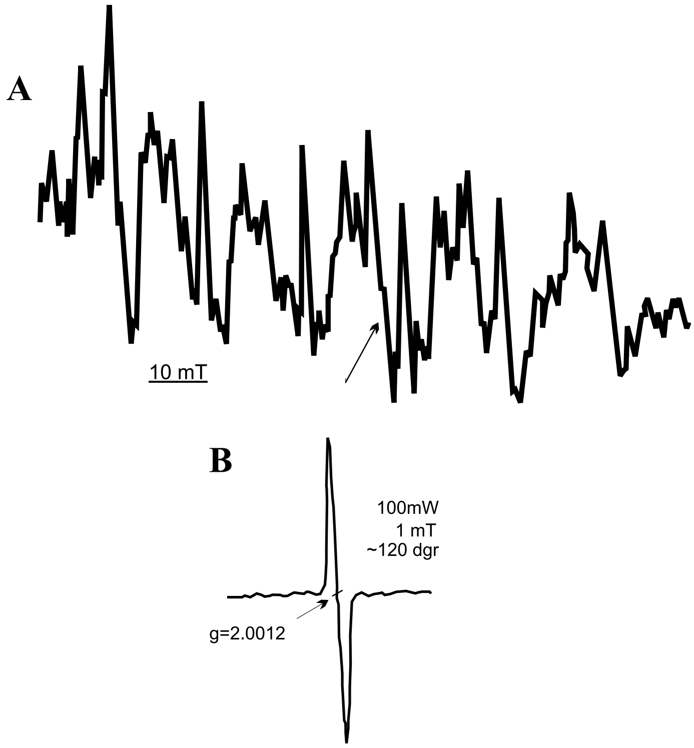

Fig. 2. Typical ESR-spectrum of calcite freshwater mollusc shells from Butėnai lacustrine deposits about 330 ka in age (Neravai site). Radiation-induced signal (arrow) is super-imposed by forbidden Mn^{+2} transition line (A). Analytical line at g=2.0012 (B) is separated by phase sensitive detection (PSD) technique.

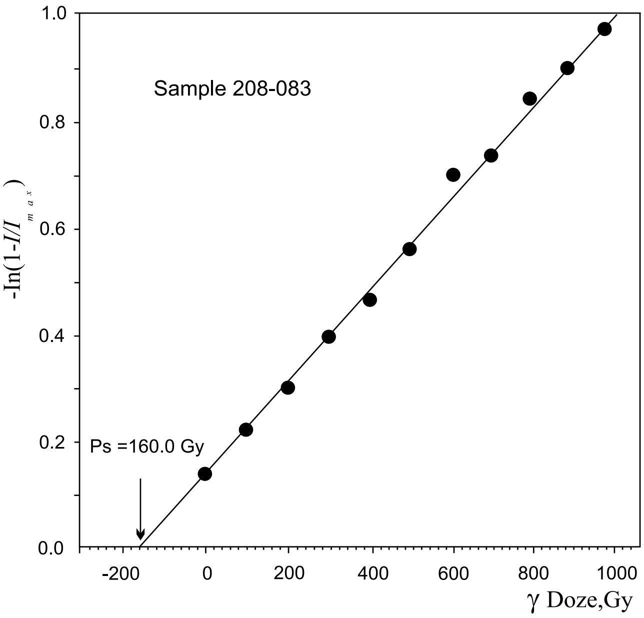

Fig. 3. Dose responses of the paramagnetic centres at g=2.0012 in freshwater mollusc shells from the Butėnai lacustrine deposits. The solid line show the best logarithmic fit for experimental data poins (circles), obtained by phase sensitive detection (PSD) technique; each point is the mean of 10 read-out values.

ing matrix a multichannel gamma-ray spectrometer with a 100 x 150 mm dia low background sodium iodide crystal was used. For better statistical accuracy up to five samples about 1 kg each were taken within the sphere with R~30 cm for assessment of the gamma and beta contribution to the external dose rate. Estimates of the cosmic dose (Yokoyama *et al.*, 1982) were based on the half of the present depth of burial 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. Water content in the sediments was also taken into account. Internal dose rate was calculated basing 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). Alpha efficiency was assumed to be 0.15. The shell material was distributed uniformly in embedding matrix (gyttja). In terms of the natural radionuclide content the latter was rather homogeneous.

The results of the 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.

3. DATED SAMPLES OF INVESTIGATED SECTIONS AND DATING RESULTS

For numerical dating of the Butėnai, Snaigupėlė and Merkinė organogenous lacustrine and boggy deposits fifteen shell samples were taken. Three samples were collected from the Gailiūnai section and three samples from the Neravai section of Butėnai Interglacial. Two samples were taken from the Valakampiai section of Snaigupėlė Interglacial, as well as two samples from the Jonionys section and seven samples from the Netiesos section of Merkinė Interglacial.

The shells were represented by freshwater Pelecypod and Gastropod species. *Valvata cristata* Müller, *Lymnaea peregra* Müller, *Anisus leucostomus* Millet, *Valvata piscinalis* Müller, *Pisidium nitidum* Jenyns, *Pisidium sp*., *Armiger crista* L., *Sphaerium corneum* L., *Pisidium moitessierianum* Paladilhe are the most common species of Butėnai (Holsteinian) Interglacial in the Neravai section (Sanko, 1999). The shells of Merkinė (Eemian) Interglacial in the Netiesos section were represented by *Valvata piscinalis* Müller, *V. cristata* Müller, *Bithynia tentaculata* Linné, *Radix limosa* Linné, *Radix auricularia* L., *Lymnaea stagnalis* L., *Acroloxus lacustris* L., *Gyraulus albus* Müller, *G. laevis* Ald. and *Sphaerium corneum* Linné species.

The mammalian fauna of the Butėnai Interglacial from the Neravai section is characterised by the occurrence of *Arvicola mosbachensis* Schmid., *Microtus sp., M. agrestis* L*, Clethrionomys aff. Glarealus* Schreber and other species (Vozniachuk *et al.*, 1984).

Table 1. *ESR results and radioactivity data for shell samples from Lithuanian interglacial deposits*

No.	Lab No.	Field No.	Site	Altitude [m a.s.l.]	Depth [m]	Uin [ppm]	U [ppm]	Th [ppm]	K [%]	Dc [μGy/a]	Dint [μGy/a]	Dsed [μGy/a]	DΣ [μGy/a]	Ps [Gy]	ESR-age, T [ka]
1	221-095	Sample 1	Netiesos	86.3	8.2	0.11	0.72	0.74	0.29	93	24.6	525.2	642.2	57.9	90.5 ± 8.8
2	225-095	Sample 2	Netiesos		8.2	0.24	0.55	1.12	0.3	89	58.8	520.7	668.8	75.5	112.5 ± 10.8
													Mean age		101.5 ± 11.5
3	222-095	Sample 1	Netiesos		8	0.11	1.32	3.62	0.97	76	26.1	1550.5	1652.9	164.9	103.3 ± 9.8
4	197-083	Sample 1	Jonionys	76.5	6	0.5	0.7	1.79	0.88	100	83	1182	1365	140.8	101.0 ± 11.0
5	198-083	Sample 1a	Jonionys		6	0.56	0.6	1.44	0.87	100	105	1112	1317	155.4	118.0 ± 12.0
													Mean age		109.5 ± 8.5
6	220-095	Sample 2	Netiesos		12.2	0.24	0.55	1.12	0.3	89	58.8	521	668.8	75.5	112.5 ± 10.8
7	222-095	Sample 3	Netiesos		13	0.11	1.32	3.62	0.97	76	26.1	1550.5	1652.9	164.9	100.3 ± 9.8
8	223-095	Sample 4	Netiesos		13	0.34	1.31	2.7	1.1	76	75.1	1625.6	1777	155.7	88.0 ± 8.5
9	224-095	Sample 5	Netiesos		13	0.23	1.34	3.14	0.98	76	62.9	1543.3	1682.6	247.1	148.0 ± 14.4
													Mean age		112.1 ± 25.9
10	259-100	Sample 1	Valakampiai	88.0		0.42	1.23	3.45	1.11	110	122.6	951.3	1183.5	129.7	110.0 ± 12.1
11	260-100	Sample 2	Valakampiai			0.21	1.23	3.45	1.11	110	65.7	784.1	959.3	110.9	116.0 ± 10.8
													Mean age		113.0 ± 3.0
12	101-079	Sample 1	Gailiūnai	81.0		<0.1	0.76	1.76	0.25	90	10	546	646	95	118.0 ± 15.0
13	103-079	Sample 3	Gailiūnai			2.1	1.7	5.35	0.61	70	777	1289	2136	587.5	307.0 ± 32.0
14	206-083	Sample 1/1a	Neravai	83.2	5.2	0.04	0.39	0.46	0.16	120	11	244	375	110	298.0 ± 28.0
15	207-083	Sample 1b/2	Neravai		5.2	0.06	0.38	0.73	0.17	120	17	324	461	152.5	336.0 ± 30.0
16	208-083	Sample N1/N2	Neravai		5.2	0.05	0.38	0.73	0.17	120	14	324	458	160	356.0 ± 34.0
													Mean age		330.0 ± 24.1
17	102-079	Sample 2	Gailiūnai			1.5	0.41	2.23	0.23	70	631	539	1240	565	455.0 ± 40.0

Notes:
U in is the uranium content in shells; U, Th and K are the uranium, thorium and potassium content in sediments; Dc is the cosmic dose rate, Dint – the time-averaged internal dose rate; Dsed – the sediment dose rate; DΣ – the total dose rate; Ps – the palaeodose. Uncertainties: U, ± 2-3%; Th, ± 3-4%; K, ± 1-2%; U in the shells, ± 1-3%; gamma irradiation, ± 3-5%.

Butėnai Interglacial. Gailiūnai and Neravai outcrops near Druskininkai town (South Lithuania) are parastratotypes of the Butėnai (Holsteinian) Interglacial. Interglacial deposits are represented here by lacustrine, boggy and alluvial sands, silts, clays, peat, sapropelite and gyttja (**Fig. 4**). The Gailiūnai exposure opens the socle of the first above-flood plain terrace of the Nemunas River (Gaigalas and Molodkov, 1996).

The vegetation of the Butėnai Interglacial is of forest type. *Taxus baccata* L., *Picea omorica* L., *Ilex aquifolium* L., *Abies alba* Mill., *Brasenia holsatica* Web., *Najas macrosperma* Wielczk., *Nymphaea cinerea* Wieliczk., *Azolla pseudopinnata* Nikit., *Osmunda claytoniana* L. are the most common species (Riškienė, 1979; Kondratienė, 1965).

The total weight of the pelecypod shells from the Neravai section (sample No. 206-083) was 600 mg, and that of the gastropod shells (No. 207-083) 250 mg. In the laboratory, the mixture of broken shell fragments of unidentified species with a total weight of 880 mg (208-083) was separated from the sediments taken from the same layer 6 m apart. Available amount of the shell material from the Gailiūnai section was 2700 to 1300 mg. The uranium content in the Neravai shells proved to be low ranging from 0.04 to 0.06 ppm. The relatively low U content in the shells compared to the 0.1 to 0.5 ppm of living shells indicates that little or no post-depositional U enrichment has occurred in these shells. The content of natural isotopes in embedding matrix at the Neravai site was unusually low. As a result, the dose rate derived from radiation measurements in the environment of the shells turned out to be also rather low – about 300 μGy a^{-1}, which is much lower than in Gailiūnai sediments (539 to 1289 μGy a^{-1}). The internal time-averaged dose rate due to U and daughters ranged from 11 to 17 μGy a^{-1} in the Neravai and from 631 to 777 μGy a^{-1} in the Gailiūnai samples.

The high thermal stability of the 2.0012 centre in the shell substance allows to date the lacustrine deposits up to 1.5-2.0 Ma in age. In the range up to 0.5 Ma the dating of the shells should present no difficulties in terms of thermal behaviour of the signal. The datings obtained on both sites show internal consistency in ESR age estimates and small scattering of the results, although in most cases the age determinations were performed on the mixture of broken shell fragments of unidentified species separated from the matrix material. The ESR analyses of the freshwater shells taken from the sections studied yield mutually consistent dates of 356.0±34.0, 336.0±30.0 and 298.0±28.0 ka (Neravai), 455.0±40.0 and 307.0±32.0 ka (Gailiūnai) for the Butėnai Interglacial that allowed us to correlate this terrestrial climate change with the marine oxygen isotopic stages 9 and 11.

The ESR age of 118.0±15.0 obtained for a sample No. 101-079 taken from a recently-fallen block of peaty sandy loam in the vicinity of the studied bed of the Gailiūnai section indicates that the dated sample evidently belongs to the stage 5 complex and can confidently be correlated with the rest of the Merkinė age deposits studied.

Snaigupėlė Interglacial. The freshwater mollusc fauna of the Snaigupėlė Interglacial was taken from gyttja at the Valakampiai site (Eastern Lithuania; **Fig. 4**). The outcrop of interglacial deposits at Valakampiai is located in the northern part of the town of Vilnius and was discovered 45 years ago. Interglacial deposits are represented by 1-m-thick gyttja. The interglacial layer occurs in the socle of the first above-flood plain terrace of the Neris River. The age of the enclosing sediments was determined on two samples of shell material. The ESR analysis yielded mutually consistent dates of 116.0±10.8 and 110.0±12.1 ka BP with an average age of about 113.0 ka BP. The numerical data obtained allow to link the studied Snaigupėlė interglacial layer with the Merkinė/Eemian Interglacial that according to materials of complex palyno-chronostratigraphic investigations (Molodkov and Bolikhovskaya, 2001) can most likely be compared with the time interval from approximately 145 to 70 ka comparable with the whole of MIS 5 rather than the period of optimum conditions in oxygen isotope substage 5e (Eemian, *s. s.*).

The development of flora at Snaigupėlė is most similar to that at Merkinė (Liivrand, 1991 and 1998). The Snaigupėlė stratotypical section is subdivided into 9 pollen zones with characteristic plants: *Caulinia lithuanica* Rišk., *C. tenuissima* D. Benn., *C. goretskyi* Dorof., *Brasenia cf. borysthenica* Wieliczk. (Riškienė, 1979; Velichkevich, 1979). The Snaigupėlė pollen diagram of the Valakampiai section also displays some similarity to the Merkinė/Eemian ones. Therefore, Snaigupėlė was initially assigned to the last interglacial (Kondratienė, 1959). Later on, according to new palynological data (Kondratienė, 1996), the deposits at Valakampiai have been attributed to the independent Snaigupėlė Interglacial, which is younger than the Butėnai/Holsteinian and older than the Merkinė/

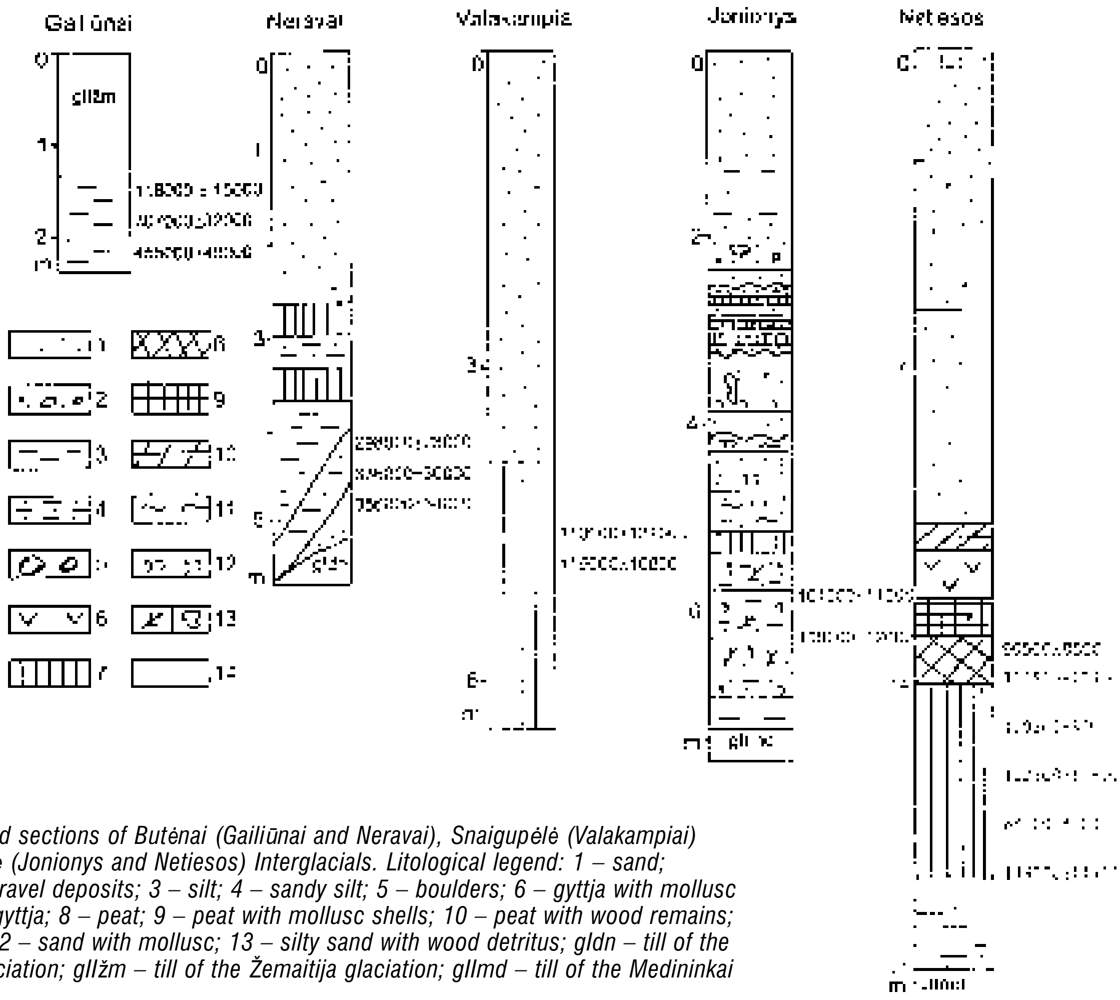

Fig. 4. *Dated sections of Butėnai (Gailiūnai and Neravai), Snaigupėlė (Valakampiai) and Merkinė (Jonionys and Netiesos) Interglacials. Litological legend: 1 – sand; 2 – sandy-gravel deposits; 3 – silt; 4 – sandy silt; 5 – boulders; 6 – gyttja with mollusc shells; 7 – gyttja; 8 – peat; 9 – peat with mollusc shells; 10 – peat with wood remains; 11 – clay; 12 – sand with mollusc; 13 – silty sand with wood detritus; gldn – till of the Dainava glaciation; gIIžm – till of the Žemaitija glaciation; gIImd – till of the Medininkai glaciation.*

Eemian Interglacial. The presence of independent Snaigupėlė Interglacial within the MIS 7 is also supported by many other investigators in Lithuania. Nevertheless, the results obtained in the present work indicate that the problem of whether the independent Snaigupėlė Interglacial really exists should still be open for debate.

Merkinė Interglacial. The Jonionys section is the stratotype of Merkinė Interglacial. The exposure is located on the left bank of the Nemunas River about 3 km west from Merkinė. The Jonionys section reveals the socle of the second above-flood plain terrace of the Nemunas River (Fig.4). The stratigraphy from waterline of the Nemunas river to the top of the terrace is divided into 20 units (Gaigalas and Hütt, 1995). The age of freshwater mollusc shells from lake-and-bog deposits of the Merkinė Interglacial parastratotype in the exposure of Netiesos on the right bank of the Nemunas River, about 6 km downstream from the town of Merkinė, was determined as 112.1±25.9 and 101.5±11.5 ka (for samples from the lower and upper units, respectively). The continental Merkinė deposits are composed mostly of peat, gyttja and sandy sediments with rare mollusc shells of lake origin (Gaigalas and Hütt, 1997). Palynological analyses of peat and gyttja samples from Netiesos were carried out by O. Kondratienė (1996) and resulted in a diagram. She found spore-and-pollen zones from M_1 till M_4. The zone M_5 was not studied, because this zone is absent in the upper part of the outcrop described at Netiesos. Flora from Netiesos in its renovated form is the richest among all flora of the Merkinė Interglacial in Lithuania known at present and, owing to the taxonomic revision, it may be considered as a standard for the whole group of flora of this age.

Four samples of lake sand deposits which covered the organogenic sediments of Merkinė Interglacial (pollen zone M_1-M_4 in Netiesos outcrop) were OSL dated by G. Hütt (Gaigalas and Hütt, 1997). Their deposition probably took place just before the last glaciation. The dates of Merkinė Interglacial correlate well with our ESR results obtained on the Eemian deposits in the Meetkerke section (Belgium) – 104.4±9.5 and 97.1±8.9 ka BP (Gaigalas and Molodkov, 1997), as well as with the dating result of 109.5±8.5 ka on the Merkinė Interglacial in the Jonionys stratotypes section (South Lithuania). The stratotype of Merkinė Interglacial is the Jonionys-Maksimonys area 3 km downstream from Merkinė town on the left (Jonionys) and right (Maksimonys) sides of the Nemunas River. Characteristic for the Merkinė Interglacial are *Tilia tomentosa* Moench., *T. platyphyllos* Scop., *Acer campestra* L., *A. platanoides* L., *Carpinus betulus* L., *Lycopus intermedius* Dorof., *Trapa europae* Fler., *Salvinia natans* (L.) All., *Osmunda cinnamonea* L. (Riškienė, 1979).

4. CONCLUSIONS

Freshwater mollusc samples from the Butėnai/Holsteinian and Merkinė/Eemian Interglacials estimated by ESR yielded different ages: Butėnai – 455.0 to 307.0 and Merkinė – 112.1 to 101.5 ka BP. The ESR age of mollusc shells from Snaigupėlė Interglacial deposits (about 113.0 ka BP) can most likely be correlated with the Merkinė Interglacial. Nevertheless, further studies of the deposits and additional ESR dates are needed to make sure that the Snaigupėlė bed recognised in different parts of Lithuania is really Merkinė in age, because the place of penultimate interglaciation of isotope stage 7 remains still vacant.

The data produced for the Neravai and Netiesos sections are internally consistent and in agreement with other evidence, e.g. the age of the organeous horizon in the Gailiūnai and Jonionys sections and independent palaeontological and geological data from these sites. A comparison of the results obtained on the upper part of the Butėnai Interglacial lacustrine deposits in the Gailiūnai section (307 ky BP) and those of the Neravai section (330 ky BP) shows a good agreement between age estimates at two different sites. Dates from Netiesos correlate with our ESR results obtained on Eemian deposits in the Meetkerke section (Belgium) – 104.4±9.5 and 97.1±8.9 ka BP (Gaigalas *et al.*, 1994), as well as with the results on the Merkinė Interglacial in the Jonionys stratotype section – 109.5±8.5 ka BP.

Our present and previous studies show that the Neravai site is undoubtedly Butėnai and Netiesos-Merkinė Interglacial in age. This, in its turn, provides a basis for the conclusion that, in all probability, the Butėnai Interglacial may be ascribed at least to Stage 9 of oxygen-isotope scale and correlated with the upper part of Holsteinian (*s.l.*) markerbed traced in NW and Central Europe. On an Arctic island, marine deposits correlated with the Holsteinian Interglaciation and Stage 9 were dated by ESR to about 300 ka BP (Molodkov *et al.*, 1992). The deposits studied contain very warm for that region spore-and-pollen complex and the boreal foraminifera association of *Miliolinella pyriformis* zone similar to those found in marine facies of the Holsteinian Interglacial in Germany. The questions whether the Butėnai Interglacial is also equivalent to Stage 11 and whether it should be therefore subdivided into two ice-free periods (or into two independent interglacial as has been suggested in studies elsewhere, e.g. Bolikhovskaya, 1995), separated by a sharp climatic cooling, remains open yet because of the lack of geochronological data on the oldest lacustrine deposits in Lithuania.

The data obtained in Lithuania by the ESR method on younger deposits have provided more certain numerical chronology for the Pleistocene interglacials. Combined with the independent stratigraphic investigations, ESR can be considered as a promising approach for the study of climatic changes, sedimentary dynamics, palaeoenvironmental reconstructions and correlation of Quaternary deposits over broad geographical areas.

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