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Baltica

BALTICA Volume 28 Number 2 December 2015: 89–108
doi: 10.5200/baltica.2015.28.09

Inferences from geochemical characteristics of the upper part of the Middle Pleistocene interglacial deposits in Lithuania

Valentinas Baltrūnas, Bronislavas Karmaza, Rimantė Zinkutė, Valentas Katinas, Stasys Paškauskas, Violeta Pukelytė

Baltrūnas, V., Karmaza, B., Zinkutė, R., Katinas, V., Paškauskas, S., Pukelytė, V., 2015. Inferences from geochemical characteristics of the upper part of the Middle Pleistocene interglacial deposits in Lithuania. *Baltica, 28 (2), 89–108.* Vilnius. ISSN 0067-3064.

Manuscript submitted 26 September 2015 / Accepted 17 November 2015 / Published online 10 December 2015

Abstract The article presents geochemical characteristics of the Middle Pleistocene interglacials stratotype sections: two from the Butėnai Interglacial and two from the problematic Snaigupėlė Interglacial. Geochemical data (the contents of 29 chemical elements, percentages of sediment components) are related to magnetic susceptibility (MS), bedding, lithology and previous palaeobotanical results. Higher content of carbonates and clay in sections of the Snaigupėlė Interglacial can be explained by warmer climate and calmer depositional environment, though the influence of chemical composition of the underlying tills is also obvious. The influence of oxic-anoxic sedimentary environment fluctuations on MS and on the separation between P-Fe and S-Mn is demonstrated. Many geochemical differences between deposits from the intervals of the Snaigupėlė-705 borehole and the Snaigupėlė outcrop sections which presumably include pollen zone S_6 *Carpinus-Quercus* enable the authors to speculate that these deposits were formed during different interglacials.

Keywords *• sedimentary environment • palaeoenvironmental conditions • major and trace elements • sediment components • magnetic susceptibility • Middle Pleistocene*

✉ *Valentinas Baltrūnas (baltrunas@geo.lt), Bronislavas Karmaza, Rimantė Zinkutė, Valentas Katinas, Stasys Paškauskas, Violeta Pukelytė, Nature Research Centre, Institute of Geology and Geography, Akademijos Str., 2, LT-08412 Vilnius, Lithuania*

INTRODUCTION

The area of Lithuania is distinguished by a predominantly thick cover of deposits formed in Pleistocene and various interglacials fixed in it (Guobytė, Satkūnas 2011). Until now, the stratigraphical position of these deposits was mainly based on their palaeobotanical investigations (e.g. Kondratienė 1996; Šeirienė *et al.* 2011) and lithostratigraphical criteria applied to underlying and overlying tills (e.g. Gaigalas 1979, 1995). The differences in evolution of vegetation, particularly forests, during different periods have been determined and specific interglacials have been identified in Lithuania. Recent investigations of the authors have demonstrated that some important information for determination of palaeoenvironmental conditions of Quaternary interglacials and evaluation of their changes can be also obtained from grain size, geochemical composition and magnetic susceptibility of deposits, especially if a complex of statistical methods is used for generalisation of data.

The environmental change is usually understood as a change in precipitation or global temperatures. According to Koinig *et al.* (2003) most studies of freshwater lake sediments are focused on changes in biological proxies. Multi-proxy approach which is often used for this aim nowadays enables to draw more substantiated conclusions. It usually includes magnetic susceptibility and one of several types of geochemical data: (1) stable isotopes, (2) percentages of organic matter and carbonates (sediment components), (3) the contents of organic compounds, (4) main elements related to organic matter (e.g. C, N, their ratio), (5) inorganic geochemical data (the contents of major and trace elements). The latter type is still not often used for reconstruction of palaeoenvironmental changes according to lacustrine sediments. The reason is that element contents there reflect different processes and depend on many factors, e.g. Minyuk *et al*. (2014) basing on Fralick, Kronberg (1997) has noted the following five ones: chemical composition of the provenance, physical and chemical weathering in the catchment, tectonic and aeolian activity, sorting during transport and sedimentation and post-depositional diagenetic changes. They also reflect atmospheric deposition and pollution, sedimentary environment (facies, redox-conditions), transport or leaching of elements. The strength of the geochemical record is that it better than biological record reflects sedimentary environment, gives additional information on environmental changes and is inexpensive. Some researchers use only selected typical elements; other scientists prefer multivariate approach; the representatives of the third group prefer to use elemental ratios (Lopez *et al*. 2006).

The aim of this study is to provide multi-element geochemical characteristics of the stratotype sections of Middle Pleistocene interglacials (Butėnai and Snaigupėlė) and search for the inferences about geochemical provenance, sedimentary environment or palaeoenvironmental changes by analysing the relation between inorganic geochemistry data and other data, i.e. magnetic susceptibility, bedding, lithology and palaeobotanical results of previous researchers. These inferences can either confirm or contradict their hypotheses and statements. Comparison of the results of this research with the data from stratotype sections of the older warm periods (Daumantai, Vindžiūnai and Turgeliai) and of the last (Merkinė) interglacial (Baltrūnas *et al*. 2013a, b, 2014) may also be useful (Fig. 1).

Butėnai Interglacial deposits are presently identified in more than 30 sections of Lithuania (Catalogue... 1993; Kondratienė 1996) (Fig. 2). Butėnai geochronological subdivision has been distinguished by O. Kondratienė (1965) that proposed its stratotype to be the lacustrine deposits from the outcrops on the left bank of the Šventoji River with Butėnai village on its opposite bank; they are in Anykščiai county (eastern Lithuania).

In this locality, the Quaternary section was investigated by boreholes, the gravel and pebble of tills by petrographical method and Butėnai Interglacial deposits by palaeobotanical methods (Kondratienė, Bitinas 1989; Kondratienė 1996). Recently, a correlation between the Butėnai Interglacial and the Mazovian Interglacial in Poland and the Alexandrian Interglacial in Belarus has been determined (Kondratienė 1996; Gaigalas, Satkūnas 1994; Ber 2000, 2006; Lindner *et al*. 2004; Ber *et al*. 2007; Rylova *et al*. 2005; Rylova, Savchenko 2005, 2011; Lindner, Marks 2008; Velichkevich *et al*. 2001; Lindner *et al.* 2013). Butėnai (Mazovian, Alexandrian) Interglacial is mainly correlated with Holsteinian, Likhvinian, Hoxnian and MIS 11 (Kondratienė 1996; Rowe *et al*. 1999; Lindner *et al*. 2013; Shick 2014). However, there are also dating results from Germany (Bossel, Schleswig–Holstein) indicating that Holsteinian sections can be correlated with MIS 9 (Geyh, Müller 2005; Ehlers *et al*. 2011).

At least 20 sections are attributed to the well investigated Merkinė Interglacial (Catalogue... 1993). The section of interglacial lacustrine deposits in the valley of Snaigupėlė Rivulet (2.5 km north-east of Druskininkai) is among them. In 1955, it was discovered by V. Čepulytė. The first palaeobotanical data on this section were published by O. Kondratienė that attributed it to the so-called Riss-Würm Interglacial (Kondratienė 1958). Later O. Kondratienė (1965) attributed these deposits to Merkinė Interglacial having type II pollen diagram, while in 1973 it was distinguished a separate

Palaeomagnetic chron	Division	Subdivision	Formation, subformation	(MIS)
BRUNHES	Holocene			1
	Pleistocene	Upper	Nemunas (Vistulian, Valdaian)	2-5a-d
			Merkinė (Eemian, Mikulinian)	5e
		Middle	Medininkai (Wartanian, Moskovian)	6
			Snaigupėlė (Lubavian, Odintsovian)	7
			Žemaitija (Odranian, Dnieperian)	8
			Butėnai (Mazovian, Likhvinian)	9-11
			Dainava (Sanian 2, Okaian)	12

Fig. 1 Stratigraphic correlation scheme for the upper part of the Middle Pleistocene and Upper Pleistocene of Lithuania, based on data of O. Kondratienė (1996) and A. Ber (2000). Note: formations of warm periods are written in bold

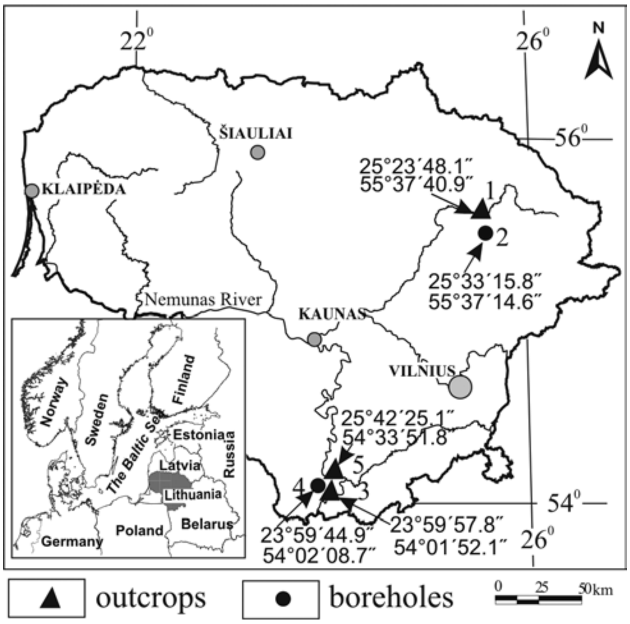

Fig. 2 Scheme of location of the studied sections: 1 – Butėnai outcrop (25°23´48.1˝; 55°37´40.9˝); 2 – Jononys-937 borehole (25°33´15.8˝; 55°37´14.6˝); 3 – Snaigupėlė outcrop (23°59´57.8˝; 54°01´52.1˝); 4 – Snaigupėlė-705 borehole (23°59´43.6˝; 54°01´52.1˝); 5 – Netiesos outcrop of Merkinė (Eemian) Interglacial deposits (24°03´04.4˝; 54°10´39.4˝)

geochronological subdivision (interglacial) to them (Kondratienė 1973). According to the author, this subdivision is certainly older than Merkinė Interglacial and most probably younger than Butėnai Interglacial.

The deposits of Snaigupėlė Interglacial are presently identified in six localities; the sections in the valley of the Snaigupėlė Rivulet (South Lithuania) are considered to be their stratotype (Catalogue... 1993, Kondratienė 1996). In 1980, the Quaternary cover in this valley was investigated by boreholes, the interglacial deposits by palaeobotanical methods (Kondratienė, Gaigalas 1982; Gaigalas 1987; Kondratienė 1996) and tills were analysed for determination of geochemical, mineral, petrographic composition and grain size (Baltrūnas, Bitinas 1994; Baltrūnas 1995, 2002). The Snaigupėlė Interglacial is correlated with the Lubavian (Lublinian) Interglacial in Poland (Kondratienė 1996; Ber 2000, 2006; Lindner *et al*. 2004; Lindner, Marks 2008; Lindner *et al.* 2013). Still the Snaigupėlė Interglacial is problematic, because the opinions of the researchers concerning its existence and age in comparison with the Butėnai Interglacial differ, besides, it is presumed that Snaigupėlė and Buivydžiai sections may have different age (Kondratienė 2011).

The newest data from Germany, Poland, Russia and other regions indicate that three cold times and two warm times can be distinguished in the Middle Pleistocene Saalian complex. Two warm times are correlated either with MIS 9 (Wacken/Dömnitz, Zbójnian, Snaigupėlė/Chekalin) and MIS 7 (Lecken, Lublinian/Lubavian, Buivydžiai/Vilkiškės, Gorkinian) (Ehlers *et al*. 2011; Lindner *et al*. 2013; Kondratienė 2011; Satkūnas, Molodkov 2005; Shick 2014) or with MIS 7e and MIS 7c (Stephan 2014). Ber (2000) and other researchers correlated Lubavian and Snaigupėlė Interglacials with the Karlich Interglacial in Germany, but the latter interglacial was considered to be post-Cromer IV and pre-Holsteinian (*sensu stricto*) (Gaudzinski *et al*. 1996).

Understanding the complexity of inter-regional correlation of interglacials, the authors of this research do not aim to analyse this problem, but are concentrated on geochemical comparison of two Middle Pleistocene interglacials (Butėnai and Snaigupėlė).

PREVIOUS STUDIES AND NEW DATA

All study sections are located in the key areas of the spread of the Middle Pleistocene deposits. They were selected basing on detailed palynological investigations by Kondratienė (1996). According to the author, the deposits of the Butėnai palaeolake in the Anykščiai county are found in the area of about 0.8 km^2 (the length of palaeolake was 1.2–1.5 km, the width was 500–700 m and maximum depth could reach 20 m).

Investigations of macroscopic remains by Riškienė (1979) and Velichkevich (1980) have shown the prevalence of coniferous forests (*Pinus, Picea, Larix* and *Juniperus*) during the Butėnai Interglacial. Study of diatoms by Šeirienė (1993) in borehole Jononys-938 indicates that the Butėnai water body was a deep eutrophic lake. The boreholes of Jononys-938 and Jononys-937 boreholes were among those where Kondratienė (1996) distinguished nine palynological zones with the first of which having two subzones (B_{1a} and B_{1b}). The lower boundary of interglacial deposits is between these subzones, and the upper lies between zones B_7 and B_8. The deposits investigated by Kondratienė (1996) show elevated organic matter content and are attributed to gyttja, and their mineral part consists of fine-grained sand or silt. They are underlain by Dainava glaciolacustrine deposits (Fig. 3) consisting of very fine-grained sand and overlain also by fine-grained sand.

O. Kondratienė (1973) has also studied the Butėnai outcrop which like the Jononys-937 borehole is located ca. 21 km north-east of the Anykščiai town, on the left bank of the River Šventoji. Both in the Jononys-937 borehole and in the Butėnai outcrop, the same three zones (B_{1b}, B_2 and B_3) indicate warming of climate. The warmest climate corresponds to B_3 where the percentage of *Abies, Quercus* and *Carpinus*, partly also of *Corylus* increases, while that of *Picea* decreases. The content of *Tilia* and *Ulmus* is low. According to Kondratienė (1996) the climatic

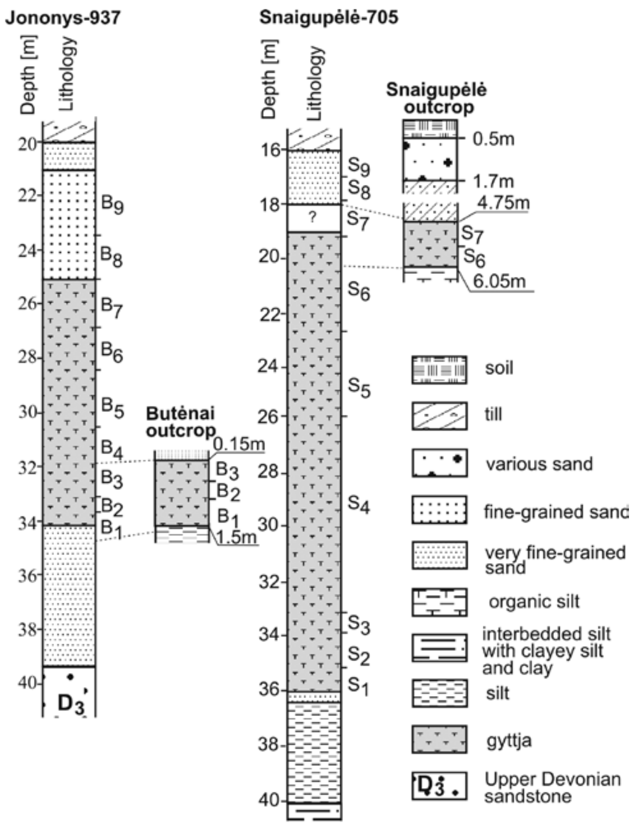

Fig. 3 Lithology and palynological correlation of the sections studied: B_1-B_9 – palynological zones of Butėnai Interglacial, S_1-S_9 – palynological zones of Snaigupėlė Interglacial (according to Kondratienė 1973, 1996). Abbreviations: B_{1b} – *Pinus-Betula,* B_2 – *Picea-Alnus*; B_3 – *Abies*-broad-leaved; B_4 – *Pinus;* B_5 – *Betula-Pinus;* B_6 – *Pinus-Picea* with admixture of *Alnus;* B_7 – *Betula- Pinus;* B_8 – thinning of *Betula-Pinus* forests, B_9 – increase of grassland vegetation; S_1– grassland vegetation, S_2 – *Betula-Larix;* S_3 – *Pinus-Betula;* S_4 – *Quercus-Tilia;* S_5 – *Quercus-Corylus-Alnus;* S_6 – *Carpinus-Quercus;* S_7 – *Picea-Pinus;* S_8 – *Pinus-Betula;* S_9 – *Pinus-Betula* (thin forests). Compiled by V. Baltrūnas and B. Karmaza, 2015

warming and processes of grassland change to forests were rapid. During climatic optimum (B_3) the winter temperature was warmer and the amount of precipitation was higher than in the Atlantic period of Holocene (Kondratienė 1979). After B_3, the climate slightly cooled down as can be seen from B_4 followed by B_5. Then there was the second insignificant climate amelioration as can be inferred from B_6. The next palynological zones B_7, B_8 and B_9 point that after B_6 the climate cooling started again.

The Snaigupėlė-705 borehole (hereinafter - SB) and the Snaigupėlė outcrop (hereinafter - SO) are located 2.6 km north-east of the Druskininkai town, on the right bank of the Rivulet Snaigupėlė. According to Kondratienė (1996) they represent the Snaigupėlė Interglacial. These deposits are found on a smaller area (Fig. 49 in Kondratienė 1996). The length of palaeolake was 600–700 m, the width was 250–300 m. The depth in the initial stage of formation exceeded 30 m (Kondratienė 1996). Such depths are supported by the study of diatoms by Khursevich (1984). According to Kondratienė (1996), SB represents the deep part of the basin. The author has distinguished nine palynological zones in SB section. SO is close to the outcrop investigated by Kondratienė where the zones S_6 and partly S_7 were distinguished belonging to the same Snaigupėlė Interglacial (Kondratienė 1973, 1996).

To represent Butėnai Interglacial, sampling was done from the depth interval of 20.7–39.1 m in the Jononys-937 borehole (JB, 41 sample, five of which are from the interval of 33–35 m corresponding to B_{1b}+B_2 zones) and from the Butėnai outcrop at 0.15–1.5 m relative depth (BO, 28 samples, 21 of which are from the relative interval of 0.4–1.45 m approximately corresponding to B_{1b} and B_2 zones). To represent the Snaigupėlė Interglacial, sampling was done in SB section at 16–40.2 m depth (76 samples, 16 of which are from the interval of 19.1–22.4 m corresponding to S_6 zone) and in SO section at 4.75–6.05 m depth (28 samples, 18 of which are from the interval of 5.15–6.03 m approximately corresponding to S_6 zone). Total 173 samples were taken from four sections for geochemical analysis and determination of magnetic susceptibility. A groove sampling with 0.05–0.1 m vertical scale has been used in the outcrops, and chip sampling done in the boreholes. Chip samples were taken from core repository from the intervals of 0.1–0.8 m with vertical dimension of chips being 0.05–0.1 m.

METHODS

Analysis of bedding

For better evaluation of palaeoenvironmental conditions, the investigation of palaeosurfaces and bedding in the sites of the study outcrops and boreholes was done on the basis of the data of previous geological research supplemented by new material obtained during the project flow. The main source of information was geological mapping data. Geological cross-sections compiled on the basis of these data enabled to understand the bedding and to reveal the cases where the layers are not *in situ* due to glacial erosion activity.

Determination of magnetic susceptibility

Measurements of mass magnetic susceptibility (m^3 kg^{-1}) were done in Nature Research Centre Institute of Geology and Geography (NRC IGG) by kappabridge MFK1-B (AGICO) (http://www.agico.com/). Information was assessed with the SAFYR software (Jelinek 1977).

Determination of total contents of chemical elements

Total contents of chemical elements were determined in NRC IGG by energy-dispersive XRF using SPECTRO XEPOS equipment and the TURBOQUANT calibration method for pressed pellets. Sample preparation is described in Baltrūnas *et al*. (2013a, b; 2014). The elements were classified into groups: (1) 11 major elements (Si, Al, Ca, Mg, Fe, K, Na, S, Ti, P, Mn); (2) 18 trace elements (As, Ba, Br, Cr, Cu, Ga, Hf, Mo, Nb, Ni, Pb, Rb, Sr, Th, V, Y, Zn, Zr).

Determination of sediment components

In air-dried, homogenised and milled by a MM 400 mixer mill samples, the percentages of organic matter (OM) and of total carbonates (TCR), calculated as $CaCO_3$, were determined by loss on ignition (LOI) at 550°C and 950°C, respectively (Santisteban *et al*. 2004). The amount of non-carbonate minerals (NCM) was calculated as 100%-OM%-TCR%.

RESULTS

The palaeosurfaces and bedding

Based on the earlier surveys and drilling data, the scheme of sub-Quaternary surface (Fig. 4) (Šliaupa 2004) and geological cross-sections characterising the structure of the Quaternary deposits are presented (Figs 5, 6) (Kondratienė, Bitinas 1989; Baltrūnas, Bitinas 1994; Baltrūnas 1995, 2002; Kondratienė 1996).

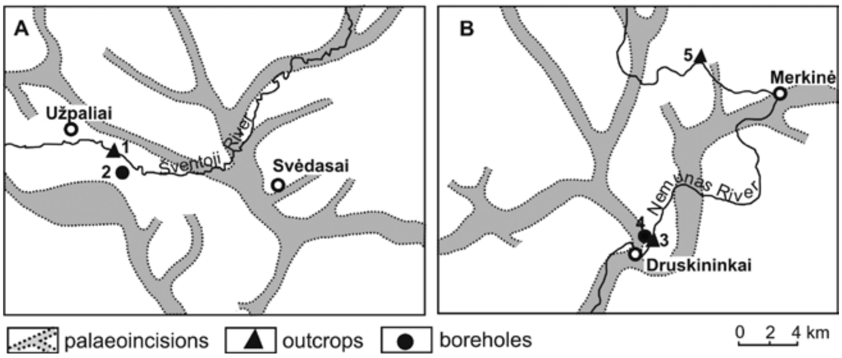

Fig. 4 Sub-Quaternary surface near Užpaliai and Svedasai (Anykščiai district) (**A**) and near Druskininkai and Merkinė (Varėna district) (**B**) (according to Šliaupa 2004). Sections of interglacial deposits: 1 – Butėnai outcrop, 2 – Jononys-937 borehole, 3 – Snaigupėlė outcrop, 4 – Snaigupėlė-705 borehole, 5 – Netiesos outcrop of Merkinė (Eemian) Interglacial deposits

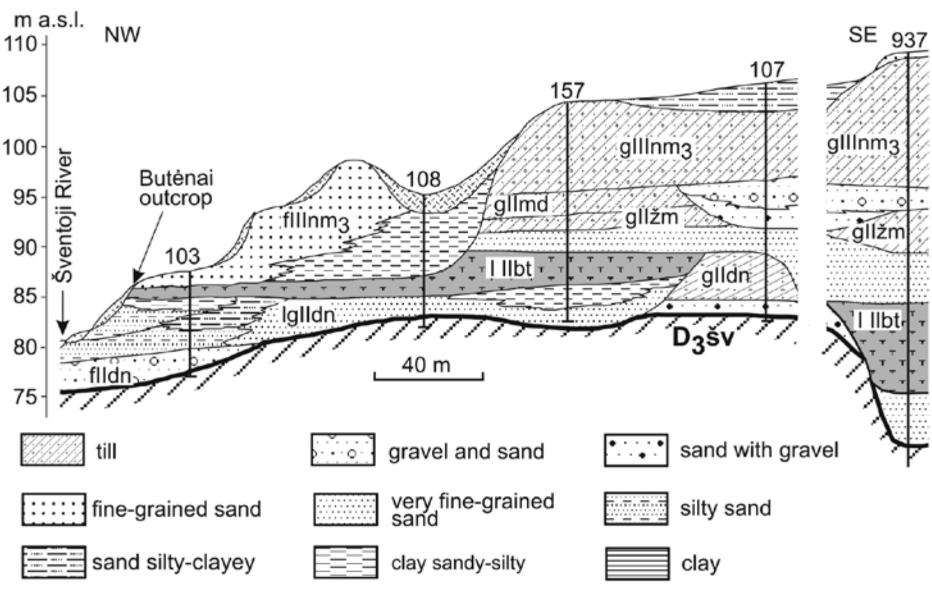

Fig. 5 NW-SE geological cross-section of Quaternary deposits in the site of Butėnai outcrop and Jononys-937 borehole (according to Kondratienė, Bitinas 1989; with additions). Stratigraphical indexes of glacigenic deposits: g, f, lgIIdn – Dainava; gIIžm – Žemaitija; gIImd – Medininkai; f,gIIInm$_3$ – Upper Nemunas; lIIbt – limnic sediments of Butėnai Interglacial

The analysis of the bedding of Butėnai Interglacial deposits in the site of Butėnai outcrop and the Jononys-937 borehole evidences the existence of the same palaeolake, the sediments of which covered the elevation of the sub-Quaternary surface near the palaeoincision (Figs. 4A, 5). They are widespread and overlie the Dainava glaciolacustrine sediments, the stratigraphic dependence of which is identified by the data of adjacent sections. Interglacial deposits are covered by a complex of tills, the stratigraphical subdivision of which is based on data of petrographical composition of gravel and pebble (Kondratienė, Bitinas 1989).

Younger Snaigupėlė Interglacial deposits in the site of the Snaigupėlė-705 borehole and the Snaigupėlė outcrop are characterised by different bedding, although these sections are in close proximity. The deposits cover the elevation of sub-Quaternary surface located near the palaeoincision and both their underlying and their overlying tills are different (Fig. 4B). Interglacial deposits in the borehole section are deeper and thicker than interglacial deposits in the outcrop (Fig. 6).

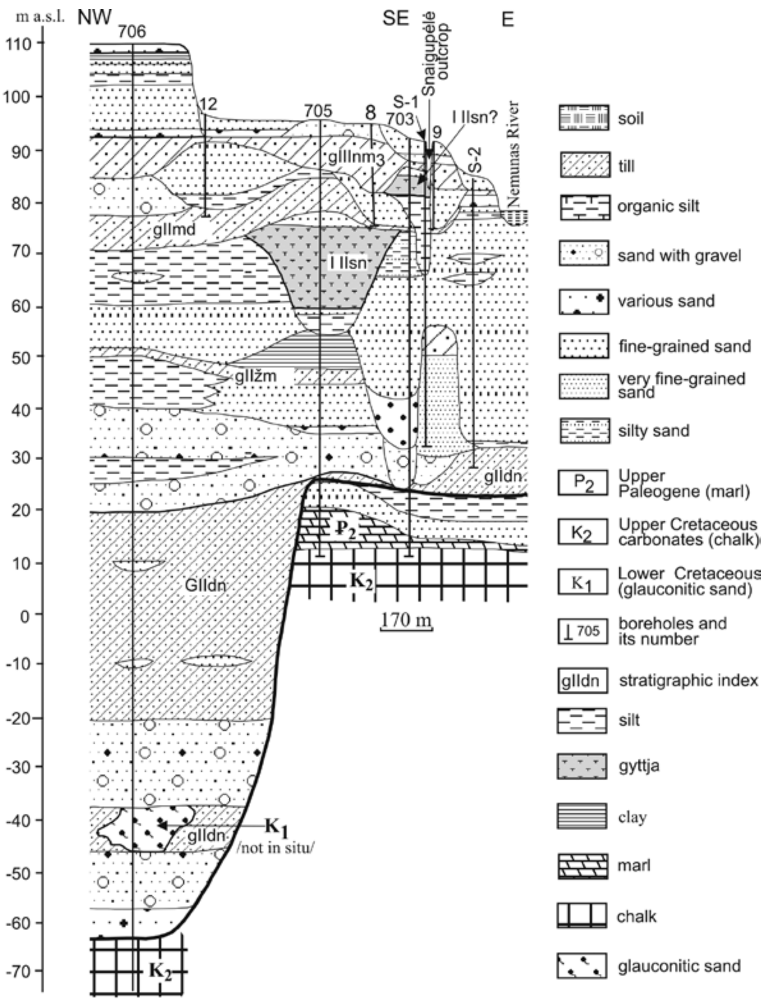

Fig. 6. NW-SE-E geological cross-section of Quaternary deposits in the site of Snaigupėlė outcrop and Snaigupėlė-705 borehole (according to Baltrūnas 2002; with additions). Stratigraphical indexes of till: gIIdn – Dainava, gIIžm – Žemaitija, gIImd – Medininkai, $gIIInm_3$ – Upper Nemunas; l IIsn – limnic sediments of Snaigupėlė Interglacial

Groups of elements and sediment components

Pearson correlation matrix between major element contents and the percentages of sediment components enabled to reveal four groups: (1) Al, K, Ti related to clay minerals (CL-group), (2) Ca, Mg related to carbonates (CA-group, significant positive correlation with TCR), (3) Si, Na related to sand minerals as quartz and plagioclases (SA-group), and (4) Fe, Mn, P, S related to OM (significant correlation with OM), possibly to oxy-hydroxides of Fe and Mn or sulphides (OMHS-group). Elements of CL-group are significantly positively correlated with elements of CA-group (and TCR) indicating that sedimentation of clay minerals and carbonates in sections often coincides. By contrast, correlation of Si from SA-group with members of CL-group and CA-group is either insignificant or significant negative. Significant positive correlation of Na with members of CL-group and CA-group possibly reflects joint sedimentation of plagioclases and clay minerals. Significant positive correlation of NCM with members of SA-group and significant negative or insignificant with members of other groups shows that sand minerals comprise the main part of NCM. All members of OMHS-group, except P and S, are significantly positively correlated, while their correlation with elements of other groups is insignificant or significant negative. So distribution of OMHS-group greatly differs from other groups.

Trace elements were classified into analogous groups taking into account Pearson correlation coefficients and the dendrogram (Fig. 7): Zr and Hf to SA-group, Sr to CA-group, Mo, Br, As, Zn to OMHS-group, other 11 trace elements to CL-group which can be subdivided into CL_1-subgroup (Ga, Rb, V, Nb, Ba) more correlated with clay and CL_2-subgroup (Y, Cu, Pb, Cr, Th, Ni) less correlated with clay. Insufficient correlation within SA-group can be explained by occurrence of Zr and Hf in zircon and Si and Na in quartz and plagioclases. Most of information obtained from trace element groups is analogous to that from major elements, so the latter will be the basis for comparison of the sections.

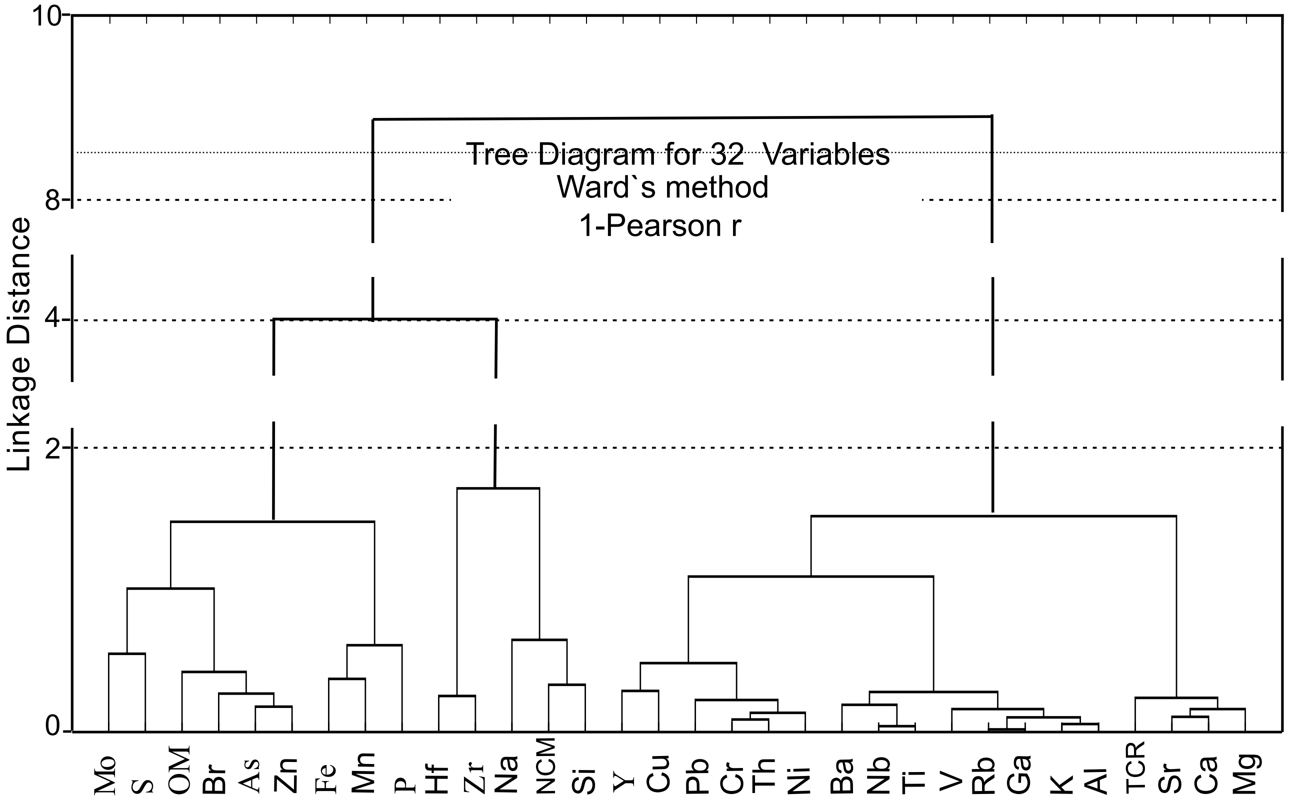

Fig. 7. Cluster analysis dendrogram of major and trace element contents and percentages of sediment components. Percentages of sediment components: OM, of organic matter; TCR, of total carbonates; NCM, of non-carbonate minerals. Compiled by R. Zinkutė, 2015

All chemical elements can be classified into two groups according to variability (coefficient of variation VK) in the study sections: (1) eight more variable (S, As, Mo and Zn with VK>33.3% in all sections and Br, P, Fe, Mn with VK>33.3% in 3 sections, except SO); (2) 21 less variable (Mg, V, Cu with VK>33.3% in JB and BO sections, Zr, Hf, Nb, Y, Ti, Th, Na, Al, Ga, Rb, Ni, Cr, Ca with VK>33.3% only in JB and Si, K, Ba, Sr, Pb with VK<33.3% in all sections). It is obvious that OMHS-group of chemical elements is most variable in interglacial sediments due to variation of different carriers of biogenic-authigenic sedimentation: OM, Fe and Mn oxy-hydroxides, phosphates, sulphides. Study sections compared to older or younger interglacial sections are distinguished by anomalous contents of mainly OHMS-group elements: JB section has maximum content of P (6419 ppm), BO of Fe (210500 ppm), Mn (8847 ppm), Zn (303 ppm), As (89.4 ppm), Br (89.6 ppm), SO of Mo (27.5 ppm). Borehole sections are also distinguished by maximum contents of CL-group elements: JB of Al (89360 ppm), SB of K (30780 ppm), Rb (131 ppm) and Th (14.1 ppm).

Heterogeneity of OMHS-group

Since correlation between S and P is insignificant, as well as correlation of P with trace elements from OMHS-group, it might be presumed that OMHS-group is heterogeneous due to some separation of P from S: P is mostly correlated with Fe, meanwhile S mostly with Mn. This presumption is confirmed by the difference between trace elements attributed to subgroups of CL-group: (1) members of CL_2-subgroup are positively (usually significantly) correlated with some major elements from OMHS-group, but not with S; (2) members of CL_1-subgroup have significant negative or insignificant correlation with major elements of OMHS-group. Separation of OMHS-group from SA, CA and CL groups as well as separation of S-Mn subgroup from P-Fe subgroup is also seen from various factor loading matrices (Table 1). Subgroup S-Mn is opposed to SA-group, subgroup P-Fe to CA-group. Besides, unlike Fe and Mn which sometimes form significant loadings of the same factor, S and P have significant loadings always on different factors.

Differences between sections according to distribution of major element groups

Pearson correlation coefficients between major elements from some groups are significant positive in all sections. There are two such stable groups: SA and CL. In factor loading matrices of each section, members of each group form the significant loadings on the same factor and with the same sign (Table 2). Each section was characterised according to distribu-

Table 1 Variables having significant loadings on factors distinguished in the whole dataset

Factor	Significant positive loadings	Significant negative loadings
Version 1: only major elements, >1 eigenvalues		
F1CLCA	K, Al, Mg, Ti, Ca, (Na)	
F2SMn	S, Mn, (Fe)	Na, Si
F3PFe	P, Fe, (Mn)	(Ca)
Version 2: major elements and sediment components, >1 eigenvalues		
F1	K, Mg, Al, Ti, TCR, Ca, (Na)	(OM, NCM)
F2	OM, (Fe)	Si, Na, NCM
F3	(Si)	Mn, S, (Fe)
F4	P, Fe, (Ti, OM)	(TCR, Ca)
Version 3: Major and trace elements, >1 eigenvalues		
F1	Nb, Ti, Ga, Rb, Al, Th, Ni, K, V, Pb, Ba, Cr, Sr, Y, Mg, Cu, Ca	(Si)
F2	Zn, As, Br, (Cu, Mo, Fe, Y, Ni)	Si, Na, (K)
F3	Zr, Hf, (Y)	(Ca, Sr, Mg)
F4	S, Mn, Mo, (Fe, As, Br)	
F5	P, Fe, (Mn, Cr, Th, Pb)	(Ca)
Version 4: Major and trace elements and sediment components, >1 eigenvalues		
F1	Nb, Ti, Ga, Rb, Th, Al, Ni, Pb, K, Cr, Ba, V, Y, Sr, Mg, Cu, TCR, (Ca)	(NCM, Si)
F2	Zn, OM, As, Br, (Cu, Fe, Y, Mo, Ni)	Si, Na, NCM, (K)
F3	Ca, (TCR, Sr, Mg)	Zr, Hf, (Y, NCM)
F4	(TCR, Ca, Mg)	P, Fe, (Mn)
F5	Mo, S, Mn, (As, Br)	(Si, Na)

Note. Four versions of principal component analysis with varimax rotation were tested (increasing number of variables, therefore also of factors). The factors with >1 eigenvalues were distinguished. Only the variables having most significant ($p<0.0001$) loadings are listed (in descending order of absolute values). Variables in parentheses have higher loading on another factor. OM, TCR and NCM are explained in Fig. 7.

Table 2 Factor loading matrices of major elements in study sections

JB section				BO section				SB section				SO section			
	F1	F2	F3		F1	F2	F3		F1	F2	F3		F1	F2	F3
Fe	**0.93**	0.12	-0.11	**Al**	**0.97**	-0.06	-0.01	Fe	**0.89**	**0.25**	**-0.28**	**Al**	**0.96**	-0.08	-0.15
Si	**-0.89**	**-0.32**	-0.15	***Si***	**0.94**	-0.06	-0.26	P	**0.84**	-0.02	**-0.29**	**Ti**	**0.95**	-0.25	-0.02
S	**0.83**	-0.07	-0.22	**Ti**	**0.91**	0.29	0.20	Mn	**0.81**	**0.23**	-0.02	**K**	**0.92**	0.11	-0.21
Mn	**0.82**	-0.11	0.19	**K**	**0.86**	**0.40**	-0.22	Ca	**-0.72**	**-0.41**	0.22	Fe	**0.73**	**-0.57**	0.27
P	**0.76**	-0.20	-0.04	***Na***	**0.82**	0.29	-0.17	S	**0.64**	-0.21	-0.02	P	**0.64**	**0.46**	-0.28
Na	**-0.69**	0.13	-0.11	S	0.19	**0.84**	-0.03	**Al**	0.08	**0.97**	-0.07	***Na***	0.24	**0.86**	-0.05
Al	-0.05	**0.99**	0.05	Ca	-0.01	**0.80**	**-0.55**	**K**	-0.04	**0.92**	**0.23**	S	0.38	**-0.77**	-0.03
Ti	0.19	**0.95**	0.12	Mg	**0.43**	**0.76**	-0.26	**Ti**	**0.24**	**0.90**	-0.16	***Si***	0.02	**0.72**	**-0.63**
K	**-0.32**	**0.90**	0.21	Mn	0.00	**0.68**	0.54	***Na***	-0.05	-0.19	**0.91**	Mg	**-0.56**	**0.71**	-0.35
Ca	0.15	0.01	**0.97**	Fe	-0.19	0.04	**0.97**	***Si***	-0.15	0.08	**0.91**	Mn	0.01	-0.28	**0.92**
Mg	-0.14	**0.42**	**0.88**	P	-0.07	-0.34	**0.90**	Mg	**-0.36**	0.10	**0.78**	Ca	**-0.51**	0.19	**0.81**
FV	38.6	27.8	17.4	FV	39.2	25.7	23.6	FV	29.9	26.9	23.4	FV	39.9	28.0	20.3

Note. Principal component analysis with varimax rotation was used, the factors with >1 eigenvalues were distinguished. F1, F2, F3, factors; FV, factor variance percentage. Significant ($p<0.05$) positive correlation coefficients are in bold, significant negative and in bold and underlined. CL-group elements are in bold, SA-group elements in bold italic, Ca-group elements are underlined.

tion pattern of several indices: (1) concentration coefficients (CC) calculated dividing element content by its median content in all four sections (Figs. 8, 9) (they were compared with relative contents of main sediment components); (2) average concentration coefficients in each group (ACC) which enabled to reveal the dominating composition of sediments, and (3) factor scores determined according to major elements (Table 1, version 1).

Distribution pattern of major elements in each of the stable groups is compatible (Fig. 8). NCM is also associated with SA-group, but its positive correlation with Si and Na is significant only in the sections from boreholes. CA and OMHS groups are less

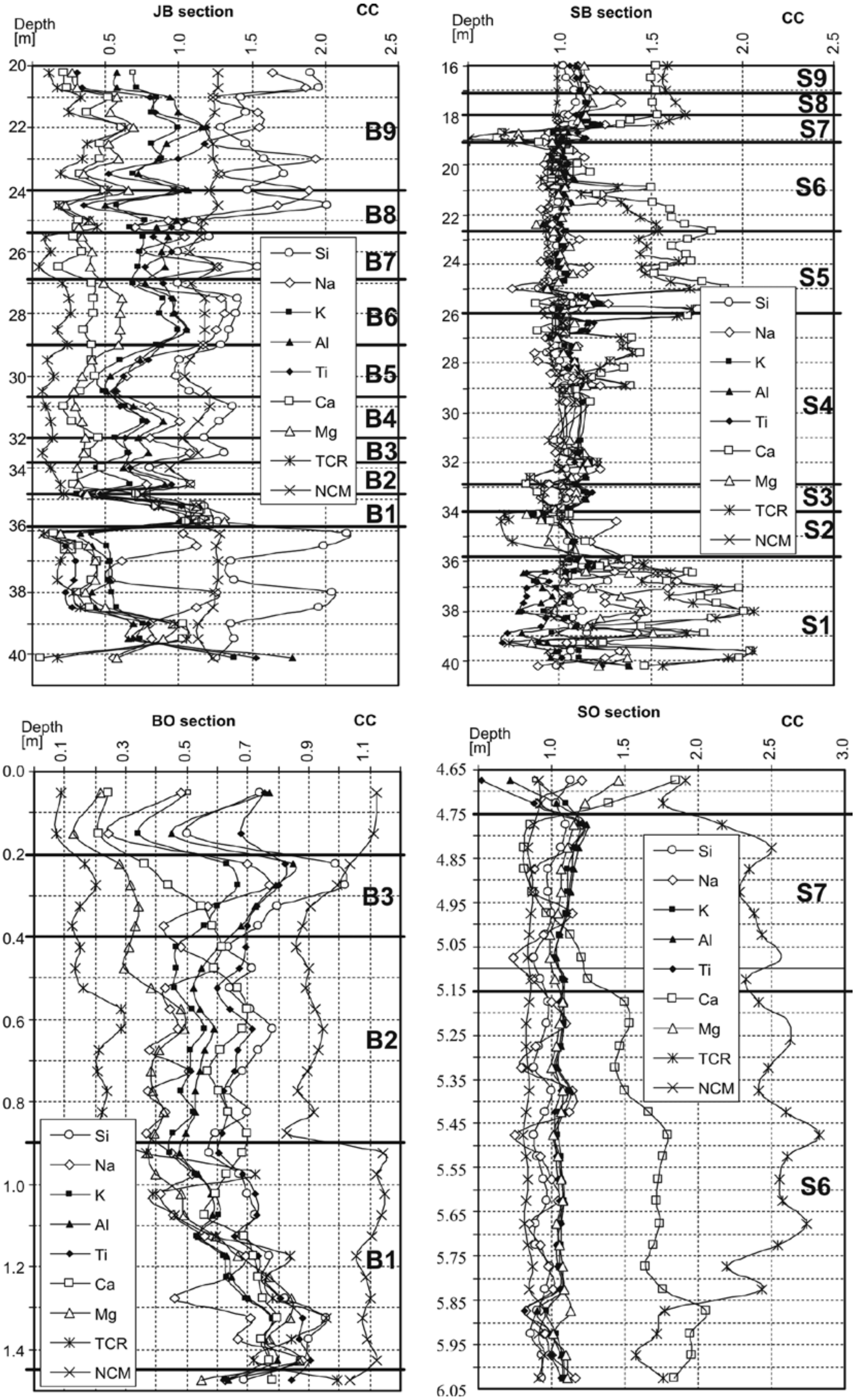

Fig. 8 Distribution of concentration coefficients of major elements from SA, CL and CA groups and relative content of total carbonates and non-carbonate minerals in study sections. TCR, percentage of total carbonates divided by median percentage of total carbonates in all sections; NCM, percentage of non-carbonate minerals divided by median percentage of non-carbonate minerals in all sections. Compiled by R. Zinkutė and B. Karmaza, 2015

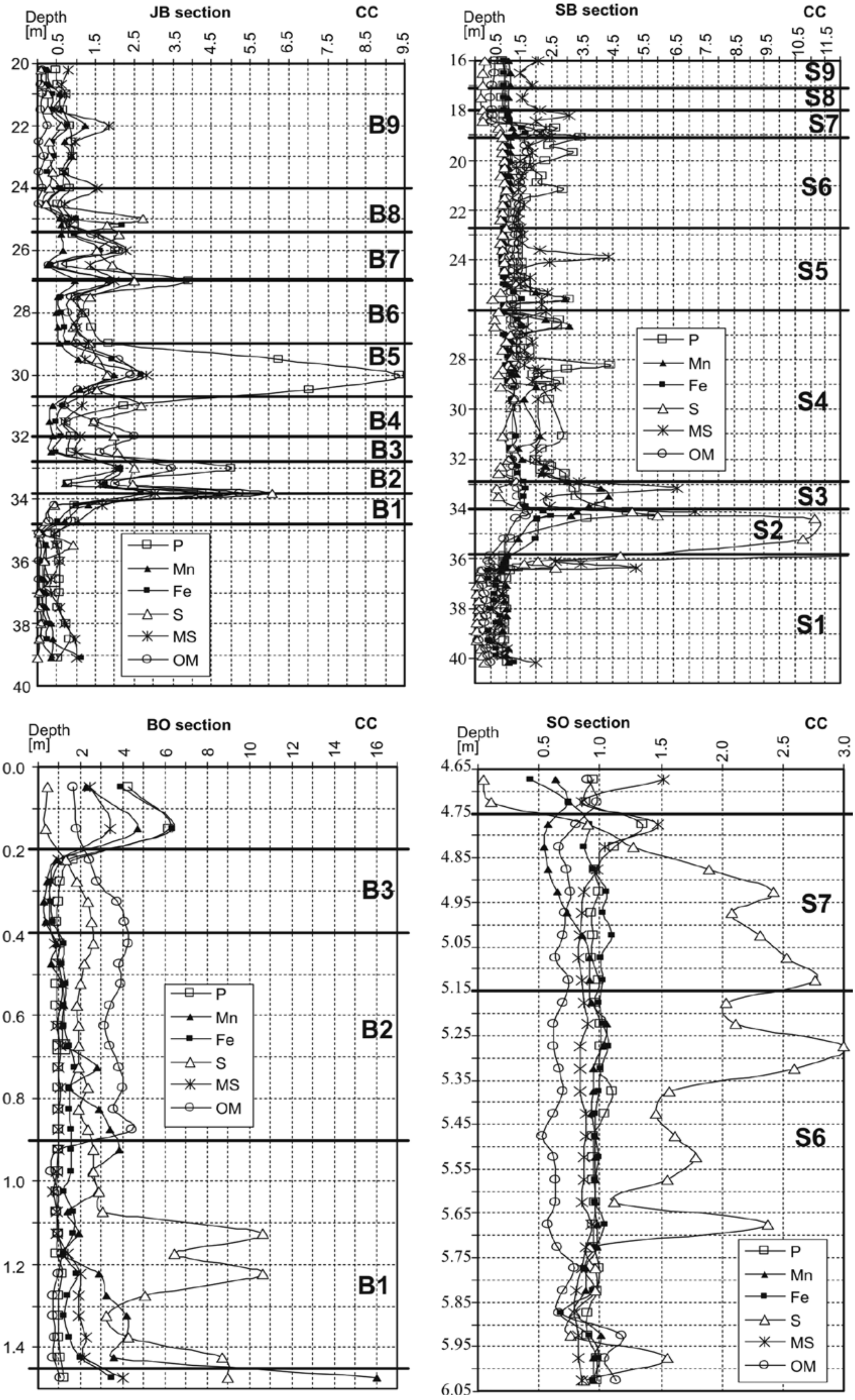

Fig. 9 Distribution of concentration coefficients of major elements from OMHS-group and relative content of organic matter in study sections. OM, percentage of organic matter divided by median percentage of organic matter in all sections. Compiled by R. Zinkutė and B. Karmaza, 2015

stable. Ca and Mg (CA-group) as well as TCR are significantly positively correlated in most sections, except SO. Significant positive correlation between all major elements of OMHS-group as well as OM is observed only in JB section. In both outcrop sections the number of significantly positively correlated elements is the lowest, besides, negative and even significant negative correlation appears, especially between OM and some elements from OMHS-group, so the elements of this group have loadings on different factors (Table 2). The main geochemical characteristics of sections are given in Table 3.

Differences between sections according to major element contents and percentages of sediment components

Presuming that JB and BO represent the Butėnai Interglacial, while SB and SO represent the Snaigupėlė Interglacial, the following peculiarities have been revealed comparing the study sections according to median values and using Mann-Whitney U-test (Table 4, Fig. 10).

TCR percentage and the contents of CL-group and CA-group elements

Their values show more differences between deposits of various interglacials than between sections of the same interglacial. Significantly higher contents of K, Al, Ti, Mg, Ca in both sections representing the Snaigupėlė Interglacial than in both sections of the Butėnai Interglacial indicate higher content of clay and carbonates. The inference about higher content of carbonates in the Snaigupėlė Interglacial deposits is supported by significantly higher TCR percentages in these sections compared to sections of the Butėnai Interglacial.

NCM percentage and the contents of SA-group elements

The contents of SA-group elements show more differences between sections of the same interglacial than from deposits of various interglacials, meanwhile NCM between deposits of different interglacials. Despite insignificant difference between BO and

Table 3 Geochemical characteristics of study sections

Section	Stability of CA-group	Stability of OMHS-group	Prevailing group	General geochemical characteristics
JB	Stable (1, 2)	Stable (1, 3, 4)	SA or OMHS	Interchange between intervals of sandy terrigenic sedimentation and intervals with consistent pattern of authigenic-biogenic sedimentation.
BO	Stable (1, 2)	Unstable (5, 9, 10, 12)	OMHS	Inconsistent pattern of the prevailing authigenic-biogenic sedimentation and much lower influence of terrigenic non-carbonate sedimentation.
SB	Insufficiently stable (though 2, but 5 and 7)	Insufficiently stable (though 1, but 8, 10, 12)	CA or OMHS	Interchange between intervals of carbonate sedimentation and intervals with inconsistent pattern of authigenic-biogenic sedimentation, much lower influence of terrigenic sedimentation.
SO	Unstable (5, 6, 7)	Unstable (5, 11, 13)	OMHS or CA	Interchange between intervals of $CaCO_3$ sedimentation and intervals with inconsistent pattern of authigenic-biogenic sedimentation, in one interval with clayey sedimentation

Notes. Prevailing groups are based on ACC values, loadings of factors are given in Table 2, distribution of CA-group elements in Fig. 8, while of OMHS-group elements in Fig. 9. Stability criteria: 1 – elements of the group are related to the same factor; 2 – correlation of Ca and Mg is significant; 3 – peaks of scores of F2SMn and F3PFe factors coincide in many places; 4 – distribution pattern of OMHS-group elements is very similar. Instability criteria: 5 – elements of the group are related to different factors; 6 – correlation of Ca and Mg is significant negative; 7 – Ca has much higher CC than Mg; 8 – correlation between S and Mn is insignificant; 9 – not all elements of OMHS-group are significantly correlated; 10 – peaks of scores of F2SMn and F3PFe factors do not coincide or coincide only in some places; 11 – local high peaks of factor F2SMn scores usually correspond to local minimum scores of F3PFe, 12 – distribution pattern of OMHS-group elements is different; 13 – distribution of S greatly differs.

Table 4 Median percentages of sediment components in study sections

	JB (N=41)	BO (N=28)	SB (N=76)	SO (N=28)
OM (%)	<u>3.29d</u>	**15.9a**	9.52b	5.23c
TCR (%)	<u>2.40c</u>	3.15c	16.3b	**29.3a**
NCM (%)	**90.4a**	79.8b	76.2b	<u>65.4c</u>

Note. N, number of samples. OM, TCR and NCM are explained in Fig. 7. The highest value is in bold, the lowest one is underlined. The same letter after median contents of a variable in different sections means that the differences between the values of this variable in sections are insignificant. The alphabetic arrangement of letters is in accordance with decreasing median values of a variable.

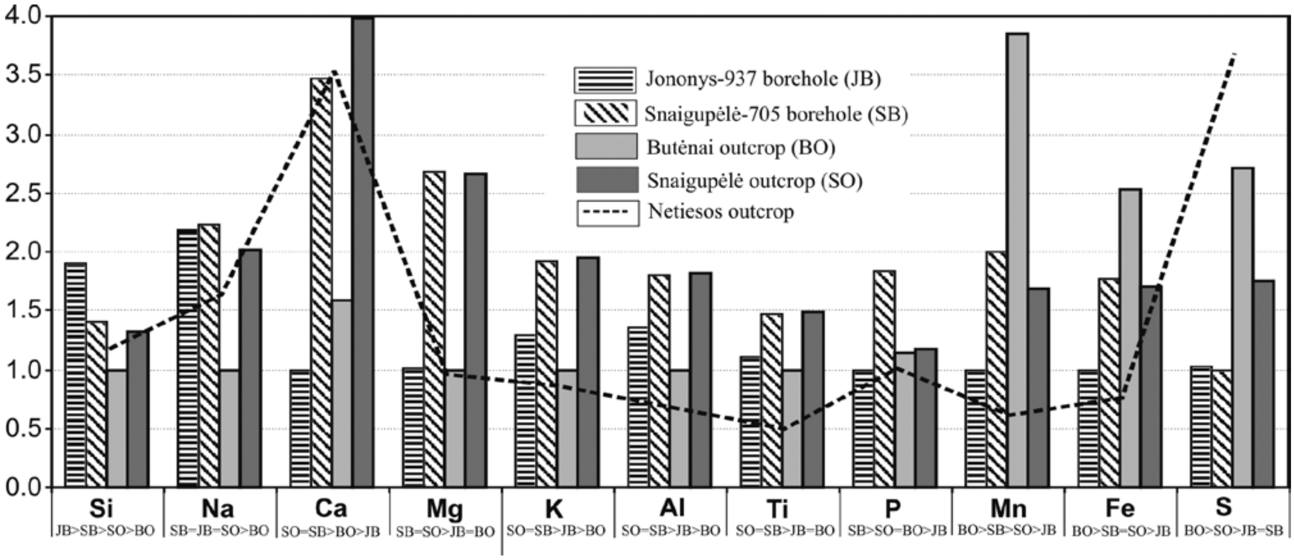

Fig. 10 Relative median contents of major elements in study sections obtained by dividing the median content by minimum median content in all study sections (MIN). Below each element, the sections are arranged according to descending median contents of this element. The equality sign means that the differences between sections according to the contents of this element are insignificant ($p>0.05$). Compiled by R. Zinkutė, 2015

SB according to the NCM percentage, median NCM percentages in both sections of the Butėnai Interglacial are higher that in both sections of the Snaigupėlė Interglacial. In each interglacial the contents of Si and Na are higher in sections from boreholes than in sections of outcrops. This fact corresponds to significantly higher NCR percentage in borehole sections than in outcrop sections of both interglacials. Si is characterised by significant differences of its content in all sections showing that it is important indicator of sedimentary environment. Its significantly highest content in JB section than in other three sections points to high influence of quartz.

OM percentage and the contents of OMHS-group elements

Their values show differences both between different interglacial deposits and between sections of the same interglacial. All sections significantly differ according to OM percentage, besides, this component is extremely variable: in comparison TCR and NCM, it has the highest coefficient of variation in all sections, except BO. The arrangement of sections according to decreasing median OM percentage is as follows: BO, SB, SO, JB. Analogous arrangement for Fe and Mn and significant correlation with OM indicates that these elements are related to OM. Despite significant positive correlation of P and S with OM, the arrangement of sections according to decreasing median content of P (SB, SO, BO, JB) and decreasing median content of S (BO, SO, JB, SB) is different than respective arrangement according to median OM percentages. It confirms high variability and heterogeneity of OMHS-group and indicates that sections of the same interglacial should be compared selecting approximate intervals of respective palynological zones.

Distribution of magnetic susceptibility (MS)

Sections of Butėnai Interglacial are rather similar according to MS, especially median values (Table 5). According to MS statistical parameters, the Butėnai Interglacial deposits are also similar to deposits of the last Merkinė Integlacial, i.e. in Netiesos section

Table 5 Statistical characteristics of magnetic susceptibility ($m^3\ kg^{-1}$) in study sections and Merkinė Interglacial deposits from Netiesos section

Section	Number of samples	Minimum	Maximum	Median	Average	Coefficient of variation, %
JB	41	22.0	200	66.0	75.3	54.9
BO	28	34.5	265	65.7	90.4	62.4
SB	76	39.9	5950	123	250	280
SO	28	52.5	101	56.7	60.2	19.1
Netiesos	184	-3.8	211	60.6	66.4	62.5

which was studied earlier (Baltrūnas *et al*. 2013b), but the latter has slightly lower median and average MS. In most sections, except SO, the distribution of MS is closely related to distribution of Fe (Fig. 9), these components are usually significantly correlated.

SB section is distinguished from other three study sections as well as from Merkinė Interglacial by high MS. On the other hand, the statistical parameters of MS in SO section are the lowest. Such great MS differences between sections which are in close proximity and do not much differ according to Fe content can be either due to differences in dilution by carbonates or in prevailing Fe minerals. Significantly higher TCR in SO section and 1.15 times higher median Ca content in SO compared to SB argues in favour of the first presumption. Due to dilution by very high content of carbonates usual MS values in SO section are low: in greater part of the section their range is 52.5-69.1 $m^3\ kg^{-1}$. Only in the uppermost part (UP, three samples) and in the lowermost part (LP, four samples) where gyttja is mixed with silt, TCR percentage is lower (<25%), meanwhile in the central part (CP) it exceeds 25% and reaches 34.2%. So in comparison with CP, the UP and LP are characterised by higher NCM percentage (>67.7%). In LP, MS values are still low, because median content of Ca there (84065 ppm) is higher than in UP (59960 ppm) and even than in CP (64880 ppm). So two anomalous MS values (97.7 and 100.7 $m^3\ kg^{-1}$) are in UP, despite that median Fe content there (24770 ppm) is lower than in CP (33100 ppm) and LP (31030 ppm). Mineral carriers of Fe in anomalous samples are obviously different: presumably biotite, vivianite or clay minerals. So low magnetic mineral form of Fe prevails in SO section, presumably one of the sulfides, e. g. the range of MS values of troilite is 13–36, of pyrite 1–100 $10^{-8}\ m^3\ kg^{-1}$ (Hunt *et al.* 1995). Comparison of median values of S in three parts of the section (208 ppm in UP, 3565 ppm in CP and 1556 ppm in LP) supports the presumption about the prevalence of sulfides in SO. Significantly higher content of S in SO section than in SB section is also in favour of this hypothesis. The absence of correlation between MS and sediment components and most major elements can be explained by uneven distribution of carbonates in SO.

Geochemical differences between palaeobotanically similar parts of sections

Mann-Whitney U-test revealed seven significant geochemical differences between the deposits at the depth intervals of B_{1b}+B_2 pollen zones in two sections of the Butėnai Interglacial (Table 6). These differences exist only for trace elements. Significantly higher contents of Mo, Br, As and Zn in the interval of BO section may be related to deeper facies where the content of S and Mn is higher (though insignificantly), significantly higher contents of Pb, Th, Ba in JB to near-shore facies where the content of Si, Na and NCM is higher (though insignificantly). There are much more (17) significant geochemical differences between the deposits at the depth intervals of S_6 pollen zones of SB and SO sections. They are characteristic not only of trace elements from OMHS and CL groups (four and two elements, respectively), but of all three sediment components and eight major elements (three of OMHS-group, two of CA-group and one of SA-group). The latter fact confirms greater geochemical differences between deposits corresponding to depth intervals of S_6 pollen zones of SB and SO than between deposits corresponding to depth intervals of B_{1b}+B_2 zones of JB and BO.

Two geochemical ratios were selected in search of more geochemical differences. Mn/Fe ratio in sediment is low when the sediment becomes anoxic (Koinig *et al.* 2003), so it is a proxy of redox-conditions. Rb/Sr ratio is low in lake sediments during warm and wet interglacials when the surface waters are enriched in Ca, Na, K and Sr resulting in higher contents of these elements in lake sediments (Minyuk *et al*. 2014), so this ratio is a proxy of chemical weathering in the catchment.

The difference between Mn/Fe values in JB and BO deposits from intervals including B_{1b}+B_2 zones is insignificant, also the difference between Rb/Sr values is insignificant. Comparison the deposits of SB and SO sections from the depth intervals with S_6 zone showed insignificant differences according to Rb/Sr values, but significant according to Mn/Fe values.

DISCUSSION

Unlike the Butėnai Interglacial deposits (JB and BO), deposits from SB and SO are characterised by much higher concentration coefficients (CC) of Ca than of Mg. Significantly higher TCR values and therefore lower NCM values in SB and SO in comparison with the Butėnai Interglacial deposits indicate accumulation of calcite. The **first** explanation of this finding presumes that both elements are allothigenic and were transported to lake as a result of the erosion of underlying glacial deposits which differ according to relative content of Ca and Mg. Study objects JB and BO are in the region of spreading of the Devonian dolostones and sandstones, while SB and SO in the region of the Cretaceous and the Paleogene carbonate rocks (chalk, marl) and tills enriched in $CaCO_3$. Regional charts of petrographical analysis of 7–10 mm fraction of tills (Gaigalas 1979) show higher total percentage of carbonates, especially limestone and marl in the Žemaitija till from surroundings of Drus-

Table 6 Medians of variables in deposits from depth intervals of respective zones

Var. (dim.)	JB(B_{1b}+B_2), N=7	BO(B_{1b}+B_2), N=25	SB(S_6), N=16	SO(S_6), N=26
MS (m^3 kg^{-1})	**110**	65.8	**96.2**	56.6
OM (%)	15.1	8.59	**11.9**	5.15
S (ppm)	4638	4908	1724	**2996**
Fe (ppm)	57890	47760	33330	32635
Mn (ppm)	731	1403	**631**	518
P (ppm)	671	636	**1461**	664
Mo (ppm)	2.3	**8.2**	2.6	**5.25**
Br (ppm)	7.2	**41.0**	**8.9**	7.0
As (ppm)	10.9	**60.9**	**4.6**	2.0
Zn (ppm)	141	**250**	**118**	82.9
NCM (%)	82.5	81.3	**74.0**	65.3
Si (ppm)	211000	138800	**187850**	185250
Na (ppm)	2050	1227	2535	2530
Zr (ppm)	288	338	204	208
Hf (ppm)	7.3	7.5	6.1	5.9
Ti (ppm)	4058	2909	4376	4476
K (ppm)	14730	11720	22500	**23790**
Al (ppm)	45590	28210	52150	**54335**
Y (ppm)	20.5	21.2	22.1	21.8
Cu (ppm)	13.8	14.1	18.9	19.0
Pb (ppm)	**12.4**	9.5	14.8	13.9
Cr (ppm)	47.2	40.1	55.4	56.7
Th (ppm)	**9.1**	8.0	10.8	10.8
Ni (ppm)	19.9	20.0	31.9	**32.0**
Ba (ppm)	**390**	292	415	**437**
Nb (ppm)	9.5	7.4	11.1	11.9
V (ppm)	29.8	22.8	75.9	70.5
Ga (ppm)	9.0	5.5	13.4	14.0
Rb (ppm)	52.3	41.8	100	102
Mg (ppm)	6075	7800	16205	**17195**
Ca (ppm)	30890	29460	51325	**68615**
Sr (ppm)	51.6	49.9	108	105
TCR (%)	2.66	4.45	13.0	**29.5**
Rb/Sr	1.014	0.831	0.923	0.939
Mn/Fe	0.022	0.026	**0.018**	0.016

Note. Var. (dim.), variable and dimension, N, number of samples in the depth interval. OM, TCR, NCM are explained in Fig. 7. For each variable the higher of two medians in B_{1b}+B_2 zones of 2 sections, also in S_6 zones of two sections is in bold if this variable is significantly higher.

kininkai than in the Dainava till from north-eastern Lithuania. So deposits in SB and SO could have been influenced by high content of calcite and clay in the underlying Žemaitija till and have higher CC of Ca than of Mg. The **second** explanation presumes that authigenic sedimentation with accumulation of calcite prevails during the interglacials. This explanation could give evidence that deposits of SB and SO were formed during warmer climate than deposits of the Butėnai Interglacial. Higher median content of P in the sections SB and SO compared to medians in the sections of the Butėnai Interglacial can also indicate higher productivity and warmer climate. A wide spread of *Quercus*, *Tilia* and *Carpinus* pollen in SB and SO sections confirms warmer climatic conditions than during Butėnai Interglacial (these species are rare in JB and BO).

Higher content of CL-group elements in SB and SO sections than that in JB and BO sections can be explained either by higher enrichment of underlying glacial deposits in clay and wider spreading of clayey rocks in south Lithuania or by calmer depositional environment.

The most variable OMHS-group is heterogeneous, i.e. its major elements can be subdivided into P-Fe and S-Mn subgroups. Separation of Fe and Mn is lower than of S and P, because their correlation is significant positive in all four sections. This result as well as significant correlation of Mo with Fe and Mn correspond to the findings of Dean *et al.* (1993) that in freshwater lake sediments due to lower sulphate concentrations in interstitial waters the separation between Fe and Mn is not so pronounced as in deep-sea sediments where Fe and Mo has mainly sulfide residence and Mn predominantly oxyhydroxide.

Separation of S and P is much more pronounced: their significant positive correlation has been found only in borehole sections, while in outcrop sections it was insignificant and even negative. Such separation is also noticed from factor analysis results of the older interglacials. It can be related either to different types of sedimentation or to differences in depositional environment, e.g. redox conditions.

The previous research has shown that S is a good proxy of biogenic sedimentation, i.e. from major elements of OMHS-group it is most of all correlated with OM or total organic carbon (TOC) (Baltrūnas *et al.* 2013b, 2014). From trace elements, the following were best of all correlated with OM: As, Br, Mo, Zn (Zinkutė *et al.* 2015). The present study also shows that S, Mo, Br, As and Zn are in the same group with OM (see Fig. 7).

But P is also related to biogenic sedimentation as indicate some facts of our study: (1) Pearson correlation coefficient of OM with P in database of all four sections is significant, while with S insignificant; and (2) in SB section, OM is more correlated with P than with S. Results of other researchers support it, e.g. Garunkštis (1975) mentions N and P as biogenic elements related to phytoplankton, Leonova *et al.* (2011) state that the contents of P, also Br and Zn in contemporary sapropel from West Siberian lake are greatly influenced by concentration of these elements in zooplankton, i.e. their biogenic input is 95-53%.

Due to relationship of both S and P to OM (indicator of biogenic sedimentation), the interpretation of factor analysis results is complicated. The reason is that biogenic and authigenic sedimentation processes often take place simultaneously (Zinkutė *et al.* 2015). The statement of Garunkštis (1975) that contemporary Lithuanian lakes have a zone of intensive chemical and biological sedimentation supports possible overlap of these processes. But most probably, factors significantly loaded by S and Mn are more related to biogenic sedimentation, while factors significantly loaded by P and Fe to authigenic. This is in accordance with the statement of Tribovilard *et al.* (2006) that the use of P as productivity proxy is not straightforward, though P is essential to biota and its distribution in sediments is linked to the supply of OM: on one hand, P may be enriched in sediments even in the absence of high surface-water productivity (e.g. P sorption onto iron-oxyhydroxide coatings and Fe-P co-precipitation), on the other hand, the sediment in surface waters with high productivity may be not enriched in P. This present study shows that even S not always helps to distinguish biogenic sedimentation: in the outcrops its correlation with OM is significant negative.

More likely, S and P are proxies of redox conditions. The separation of redox proxies Fe and Mn in different factors and well-known possibility of S residence in sulphides support such presumption. It corresponds to the findings of Nowaczyk *et al.* (2007) that low TOC and total S values represent oxic phases (severe degradation of OM, good preservation of magnetite and high MS); while high TOC and S values indicate anoxic conditions (good preservation of OM and S, but strong reductive dissolution of magnetite and low MS).

Phosphorus seems to have different behaviour than S. According to Tribovilard *et al.* (2006), P comes to the sediments mainly with phytoplankton necromass, but usually it is released from decaying OM and later can either escape or be trapped within the sediment; under anoxic conditions it mostly escapes, but under certain conditions, P concentrations in pore water can increase and authigenic phases of P can precipitate, such precipitation is conditioned by alkalinity, pH, Eh and bacterial activity. In environments with at least intermittently oxic bottom waters, Fe-oxyhydroxides can scavenge phosphate from pore waters; meanwhile in permanently anoxic environments with sulfidic bottom waters, Fe-oxyhydroxides do not precipitate reducing the adsorption of P (Tribovilard *et al.* 2006). Thus, redox conditions greatly influence the content of remineralised organic P in sediments and its content is well related to the content of Fe explaining the stability of P-Fe association in our study: significant positive correlation between P and Fe is observed in all sections, except SO. Hence, most probably SO is characterised by permanently anoxic sedimentary environment.

It seems that mainly the fluctuation of oxic and anoxic conditions results in separation of P-Fe and

S-Mn, i.e. in inconsistent distribution pattern of OMHS-group major elements in most sections, except JB where oxic conditions prevail. However, Suplee, Cotner (2002) basing on Caraco *et al.* (1989) state that most lacustrine and oceanic surficial sediments are aerobic and give other explanations of P release from sediments (separation of S and P): (1) sulfate may compete with phosphate for anion sorption sites; and (2) at low sulfate concentrations, sediment P release may be directly related to bacterial sulfate reduction rates.

The findings of Nowaczyk *et al.* (2007) about S confirm that it is well related to OM and show that sedimentary conditions in lakes depend not only on OM supply, but also on its degradation. It can be inferred that good preservation of OM and S is usually possible in deeper parts of the lakes. On the other hand, the findings of Engstrom, Swain (1986) about P indicate its selective deposition in shallower parts of the basin.

Comparison of the whole JB section with BO section revealed significantly higher contents of S (also Fe and Mn) in BO and significantly higher contents of P and Si in JB (Fig. 10) enabling to presume the location of BO in deeper part of palaeolake. When respective parts of the sections including the same pollen zones B_{1b}+B_2 were compared, higher contents of NCM, Si and Na, also P and Fe in JB and higher contents of S and Mn in BO confirmed this presumption (the absence of significant differences for major elements can be explained by gradual lateral changes in redox conditions in the same lake with increase of depth). It also confirms that the intervals of both sections represent the same palaeolake and the same period of the same interglacial.

Comparison of the whole SB section with SO section revealed significantly higher content of S in SO and significantly higher content of P (also Fe, Mn, Si) in SB. Analogous results were obtained when respective parts of the sections with pollen zone S_6 were compared, but the content of Fe was not significantly higher in SB. Significantly higher content of S and Mo in SO than in SB interval of S_6 zone distinguished by Kondratienė (1973, 1996) as well as significantly lower content of Mn and P can be explained by anoxic conditions in SO. Such differences in redox conditions as well as significantly higher values of TCR, Ca, Mg, Ba and significantly lower of OM and NCM in SO enable to speculate that the intervals of both sections represent not only different palaeolakes, but probably also different interglacials. The finding about significantly higher content of Mo in SO than in SB corresponds to earlier inference that Mo is more related to carbonates than to OM (Zinkutė *et al.* 2015). Presumption about different interglacials is first of all based on different stratification of these sections: in SB they are underlain by the Žemaitija glacial sediments, meanwhile in SO by the Medininkai glacial sediments. Though according to Guobytė, Satkūnas (2011), composition of Žemaitija and Medininkai tills is very similar, the 7–10 mm fraction of the Medininkai till near Druskininkai contains more dolomites and limestones than the Žemaitija till (Gaigalas 1979). Despite geochemically similar source of erosion and the intervals which presumably correspond to S_6 distinguished by Kondratienė (1973, 1996), sedimentary conditions in SO and SB greatly differed.

The finding of Nowaczyk *et al.* (2007) that MS is a proxy neither for lithogenic input, nor for biogenic dilution, but for oxic or anoxic conditions enables to explain significantly lower MS value in SO(S_6) (anoxic conditions) in comparison with SB(S_6). The contrast between low MS median in SO and high MS in the whole SB section is even more striking (see Table 5).

However, comparison of JB and BO sections in depth intervals with respective sequence of pollen zones (B_{1b}+B_2) also shows that MS is significantly lower in BO, despite that both sections are from the same palaeolake, represent the same interglacial and median MS value in BO is rather similar to median in the whole JB section. Significantly higher contents of trace elements from OMHS-group in BO interval B_{1b}+B_2 than in respective depth interval of JB indicate the tendency to anoxic conditions in BO due to its location in deeper part of the lake. So not only the temporal variability of MS in JB section is obvious, but also the lateral changes between JB and BO are detectable due to facial differences according to depth. This fact probably indicates that MS is very sensitive even to small changes in redox conditions.

Though in deeper part of the same Butėnai palaeolake the geochemical focussing of Mn is possible (Schaller, Wehrli 1997), it is not so well expressed, i.e. Mn content in sediments of JB and BO from depth interval of B_{1b}+B_2 zones differs insignificantly. Still unlike SB and SO sections, correlation between the contents of S and Mn in the sections of the Butėnai Interglacial deposits is significant indicating that subgroup S-Mn is predetermined by joint accumulation of these elements in deeper parts of palaeolakes.

Similarity of redox conditions (Mn/Fe) and degree of chemical weathering (Rb/Sr) in JB and BO section intervals with respective sequence of zones B_{1b}+B_2 gives evidence that the deposits belong to the same interglacial. Significantly lower values of Mn/Fe ratio in deposits of SO section including S_6 zone than in respective interval of SB section are in favour of the presumption that the deposits belong to different interglacials.

Certainly, not *in situ* bedding of SO deposits may be explained by glacial erosion activity and such great geochemical and MS differences between SB and SO may be simply differences between two lakes lying apart. Much higher content of carbonates in SO compared to SB may be explained by their formation in shallower lake zone where maximum sedimentation of carbonates takes place (Garunkštis 1975). However, according to geochemical results it is doubtful whether this zone is shallow.

Besides, up-to-date results of ^{230}Th/U dating and palaeomagnetic investigations of organic deposits in SO indicate that these deposits most likely should be attributed to the Last (Eemian) Interglacial (Baltrūnas *et al.* 2015). ^{230}Th/U dating performed in the St.-Petersburg State University was based on paired use of two techniques of chemical treatment of samples for isochronous correction: leaching (L/L) and total sample dissolution (TSD) (Maksimov *et al.* 2012; Kuznetsov, Maksimov 2012). The highest compatibility of models is obtained for combination of samples from depths 505–515, 515–525, and 535–545 cm. The results of the dating given in Baltrūnas *et al.* (2015) are as follows: 127^{+18}_{-14} ka for L/L model (ЛУУ-833L/L) and 132^{+22}_{-16} ka for TSD model (ЛУУ-833TSD). Palaeomagnetic investigations show (Baltrūnas *et al.* 2015) that samples in the lower part of the Snaigupėlė outcrop have reversed magnetic polarity and in the upper part normal magnetic polarity and are related with the Blake Event in the Eemian Interglacial. The cases when due to groundwater influence on radioisotope concentrations too young age is attributed to the deposits occur only sometimes. Therefore, it is quite probable that the deposits in SB and SO belong to different interglacials.

CONCLUSIONS

The bedding of the Butėnai (Holsteinian, Mazovian) Interglacial deposits in the Butėnai outcrop and the Jononys-937 borehole based on previous palynological investigations of interglacial deposits and petrographic investigation of gravel and pebble from underlying and overlying tills evidences for the existence of the same palaeolake. Few geochemical differences between sediments from the intervals of two sections with pollen zones *Pinus-Betula and Picea-Alnus* are mainly related to content of sand and reflect the influence of different facies of the same lake.

The deposits in the Snaigupėlė-705 borehole and the Snaigupėlė outcrop attributed by Kondratienė (1973, 1996) to the Snaigupėlė (Lubavian) Interglacial are characterised by different bedding because previous petrographic investigations have shown that both tills, underlying and overlying, differ. Geochemical differences between deposits from intervals of the sections corresponding to pollen zone *Carpinus-Quercus* are more pronounced, indicating different sedimentary environment and enabling to presume that different palaeolakes were formed during different interglacials.

High variability of magnetic susceptibility (MS) in the Middle Pleistocene interglacial deposits, also separation of P peaks from S peaks in most sections and therefore of P-Fe and S-Mn subgroups of major elements is related to fluctuation of oxic and anoxic conditions. Though significantly lower MS values in the Snaigupėlė outcrop compared to the Snaigupėlė-705 borehole can be due to dilution by high amount of carbonates, they are also influenced by stable anoxic sedimentary environment which is reflected in significantly higher content of S most probably indicating greater euthrophication of lake during different interglacial. Significantly lower MS values in the Butėnai outcrop section than in the interval of 2 pollen zones (*Pinus-Betula* and *Picea-Alnus*) from the Jononys-937 borehole indicate the tendency to anoxic sedimentary environment in the deeper facies of the lake.

The main geochemical differences of the deposits attributed by Kondratienė (1996) to the Snaigupėlė Interglacial from the deposits of the Butėnai Interglacial are related to higher content of carbonates and clay and can be explained either by the differences in chemical composition of the provenances and underlying tills or by warmer climate and calmer depositional environment. Palynological results by Kondratienė (1996) confirmed that climate during the Snaigupėlė Interglacial was warmer.

ACKNOWLEDGEMENTS

Authors are grateful to Professor Vitālijs Zelčs (Rīga) and Habil. Dr. Ona Kondratienė (Vilnius) for constructive remarks that substantially helped to improve the manuscript. This research was performed within the framework of project the „Cyclicity, Dynamics and Models of Palaeoenvironmental Changes during Quaternary Warm Periods“ (“Ciklas”) (No. LEK-12007, agreement No. LEK-06/2012) funded by the Research Council of Lithuania.

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