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The development of Belarusian lakes during the Late Glacial and Holocene

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Abstract. Sediment cores from six lakes in northern, central, and southern Belarus were examined to establish correlations between changes in lake conditions and catchment evolution since the Older Dryas. Detailed studies were conducted in three areas with highly different landscape development history. Common patterns and synchronism in lake sedimentation and fluctuations are more diverse during the Late Glacial and early Holocene, mainly due to the general tendency of climate warming at the beginning of the postglacial epoch and disappearance of permafrost, which led to the increase in infiltrating processes. During the latter half of the Holocene lake level changes were asynchronous in different regions of Belarus. At that time most of the existing differences were caused by local factors.

Key words: lake level fluctuation, lake sediments, lithology, Late Glacial, Holocene, Belarus.

INTRODUCTION

Data on the development of lake sediments are of great importance in the reconstruction of palaeogeographic events. The results of complex examination of lake deposits will enable reconstruction of the history of relief, climate, and vegetation, determination of the development of lakes and their water level, and definition of the character of lake sediment genesis. Respective studies were conducted for separate stages of the Late Glacial and Holocene periods in a wide area of Belarus, where the glaciations might have had very different impact on the development of lakes and sediments. Hence, the water balance of reservoirs is directly connected with changes in climatic conditions and with the geological and geomorphological factors determining seepage or change in the structure of surface waterbodies. Therefore, it is essential to carry out detailed research of lakes of different regions and inter-regional correlation of regressive–transgressive phases, which will allow distinction of water level fluctuations connected with climatic changes, geological-geomorphological sedimentary framework, and other factors. Data on lake level fluctuations have been widely applied in the reconstruction of palaeoclimate in the Late Glacial and Holocene (Digerfeldt 1988; Harrison et al. 1991, 1998; Starkel et al. 1998; Tarasov et al. 1996; Punning et al. 2003; Magny 2004). The information obtained in Belarus is also important for understanding the development of natural systems in different areas of the republic.

However, it is necessary to note that earlier studies mostly deal with specific problems of lake sedimentation, concerning water levels of separate reservoirs. Most of the works listed were published in the 1980s–1990s. In this article we make an attempt, taking into consideration new stratigraphical views, to reveal and generalize inter-regional regularities of lake sedimentation and the course of lake level changes in the postglacial period on the basis of new and old chronostratigraphical and lithological-geochemical material on lakes in different physiographic areas of Belarus. For this purpose we chose two lakes from each physiogeographic area, which allowed us to cover almost the entire territory of the republic: Lozoviki and Krivoe for the northern district (Poozerye); Mezhuzhol and Sudoble for the central district (Central Belarus); Bobrovichskoe and Oltushskoe for the southern district (Polesye) (Fig. 1).

In this article we provide the data obtained from the best studied reference cores from various districts of Belarus: lakes Lozoviki (palynologic, radiocarbon, and isotope-oxygen data) (Zernitskaya et al. 2001), Krivoe (palynologic and radiocarbon data) (Elovicheva 1993), Mezhuzhol (palynologic and radiocarbon data) (Zernitskaya & Kolkovskij 2003), Sudoble (palynologic and radiocarbon data) (Elovicheva & Bogdel 1987), Bobrovichskoe (geochemical, palynologic, and radiocarbon data) (Makhnach 2007), and Oltushskoe (geochemical, palynologic, and radiocarbon data) (Zhukhovitskaya et al. 1998).

Fig. 1. Location of the studied sites.

REGIONAL SETTING

The territory of Belarus occupied a special position within the East European Plain in the Pleistocene and Holocene. First of all this is confirmed by the fact that the last three glacial epochs, Dnieper (Mindel), Sozh (Riss), and Poozerian (Würm), which are reflected in the modern surface, are represented here (Matveev et al. 1988).

The northern part of the region (Poozerye) experienced the influence of the last (Poozerian, Valdai, Wisla, Würm) glaciations (Fig. 1). Numerous lakes, the hollows of which result from the activity of the last glacier and its outwash, are found in this area. Degradation of the Poozerian (Würm) glacial cover from the territory of Poozerye facilitated the formation of the relief of ridge and ground moraines as well as sander and periglacial reservoirs. The relief created by the Poozerian glacier is complicated by numerous negative depressions formed as a result of exaration, evorsion, subglacial erosion, and glaciokarst processes. Some depressions were later filled with water and turned into lakes (Yakushko 1981).

The area of uplands and plains of Central Belarus is situated in the zone of the more ancient Sozh (Moscow, Riss) glaciations, where denudation ridge–hilly relief and outwash plains with a network of outwash flow hollows prevail. The relief of this area, unlike of the territory of Poozerye, is characterized by the absence of young glacial forms, a significant erosive partition, and flattened surface. There are no glacial lakes here. During the Poozerian (Würm) glaciation the area of Central Belarus uplands and plains was in periglacial conditions, characterized by thermokarst processes, generation of polygonal-block formations, frozen ground, parabolic dunes, and formation of loess-like deposits. Among fluvioglacial and till plains numerous thermokarst depressions are found (Matveev et al. 1988).

The southern part of the region (Belarusian Polesye) was mainly influenced by the ancient Dnieper (Mindel) glacier. Flat alluvial and lake-alluvial plains with aeolian forms are widespread here. The area is distinguished by the presence of such lake reservoirs as oxbow lake, flat peaty lakes – floods, and small karst funnels. Degradation of the last Poozerian continental glaciation, permafrost, thermokarst, and karst processes, and formation of river channels played an important role in the development of lakes. In most cases the lakes appeared in periglacial conditions of the last glaciation, with the influence of climate and tectonic movements that caused the accumulation of outwash of the Poozerian glaciation in the relief depressions. Though, by the beginning of the Holocene most of the water reservoirs of the Polesye area were drained by the rivers, and on these sites peat bogs were developing. Lakes of postglacial age revived only in the relief depressions. The geological structure of Polesye created prerequisites for the development of karstic processes here (Matveev et al. 1988).

A revised Scandinavian periodization of the Late Glacial–Holocene (Mangerud et al. 1974) based on pollen and radiocarbon data (^{14}C years BP) is traditionally used in Belarus and comparable with the stratigraphic chart of Late Glacial and Holocene deposits of Belarus. The stratigraphic chart of Belarus is based on 43 cores, where deposits have been studied by the palaeofloristic method, and on more than 100 ^{14}C datings (Zernitskaya et al. 2005). It includes the following periods: Late Glacial (Bølling (BÖ), Older Dryas (OD), Allerød (AL), Younger Dryas (YD)) and Holocene (Preboreal (PB), Boreal (BO), Atlantic (AT), Subboreal (SB), Subatlantic (SA)). The main stages of the development of the climate and vegetation of Belarus during the postglacial epoch, determined from the palynological reconstructions, are presented in Table 1 (Yakushko & Makhnach 1973; Elovicheva 1993).

Table 1 shows that in the Late Glacial (more than 10 000 years ago) arctic (Poozerye) and subarctic (Polesye) conditions prevailed on the territory of Belarus and short-term warming (AL) periods alternated with cold periods (YD). The most typical processes were thawing of frozen soils, glaciokarst (in Poozerye), thermokarst, and solifluction (in periglacial areas) processes, and descent of periglacial water reservoirs. Aeolian dune-hummocky relief was formed on sandy lowlands, especially in Polesye, and allochthonous clastogenic material accumulated in primary lake reservoirs (Velichkevich et al. 2002). As seen from Table 1, environment evolution and climatic conditions in all three areas of Belarus were quite similar in the Holocene (less than 10 000 years ago). This situation was reflected both in the peculiarities of lake sedimentation and in the regularities of lake level fluctuations, proving that regional differences in lake level changes of that period were not caused by the climatic factor.

METHODS

A wide range of methods has been applied in the study of lake development in Belarus. In the present paper the distribution of main deposit-forming layers, organic matter, and micro- and macroelements is used as an index of lake development phases. The lithostratigraphical method is mainly employed, based on the proportion of ingredients of organic, chemogenic, and mineral matter in lake deposits. Informativity of geochemical indicators depends on the character of the sediment complex in the catchment area, genesis of the lake depression, and location of the study site (Zhukhovitskaya et al. 1998).

Table 1. Climate and vegetation in Belarus during the postglacial period

Chrono-zone	Age, cal yr BP	Climate	Vegetation
SA	2 600–0	Close to the modern one	Mixed pine–spruce–birch forests with deciduous trees
SB	5 700–2 600	Warm and dry	Pine–spruce–deciduous forests with birch
AT	8 900–5 700	Warm and humid	Pine forests, pine–deciduous with birch and spruce, deciduous forests
BO	10 200–8 900	Warm and dry. Humidification at the end of the period	Mixed pine–birch forests with deciduous trees
PB	11 500–10 200	Warm and dry	Mixed pine–birch forests
YD	12 900–11 500	Cold snap. Subarctic climate	Forest-tundra associations
AL	13 800–12 900	Appreciable warming, dry as before	Birch–pine and spruce forests (Poozerye) and pine forests with birch (Central Belarus and Polesye)
OD	<13 800	Cold arctic (Poozerye) and subarctic (Polesye)	Forest-tundra associations (Poozerye) and mixed pine–birch forests with some sections of forest-tundra (Central Belarus and Polesye)

The lithological parameters of Belarusian lake sediments are unified according to the international terminology. For describing the areas the composition of sediments has been used: sands, clays, lacustrine chalk, marl, sandy gyttja, clayey gyttja, detritus gyttja, calcareous gyttja, and peat. Detritus gyttja is characterized by a higher content of organic matter (more than 50%), which, except for remains of macrovegetation, is mostly of planktonic origin. The main mineral component of gyttja is SiO_2 (about 50–80%), with overall decrease in organic matter (less than 50%). Sandy gyttja is characterized by a low content of organic matter (less than 15%), with the prevalence of SiO_2 (more than 80%). Clayey gyttja is rich in clayey or pelitic particles, with an increased content of Al_2O_3 (up to 10–12% in the mineral part) and simultaneous decrease in SiO_2. The content of organic matter in it does not exceed 15%. The main mineral component of calcareous gyttja is $CaCO_3$ (30–70%) (Zhukhovitskaya & Generalova 1991).

Radiocarbon datings of organic matter were made in the Institute of Geological Sciences, National Academy of Sciences of Belarus (IGSB), in Kiev Radiocarbon Laboratory (Ki), in Vilnius Radiocarbon Laboratory (Vs), and Tartu Radiocarbon Laboratory (TA) (Table 2).

Table 2. Radiocarbon dates of cores from six Belarusian lakes

Core name	Core depth, cm	Radiocarbon laboratory No.	Age, ^{14}C yr BP	Calibrated age at one sigma, cal yr BP	Material
Lozoviki	50–60	IGSB-502	110 ± 30	260–30	Peat
Lozoviki	245–255	IGSB-501	1 030 ± 50	1 050–835	Peat
Lozoviki	350–360	IGSB-498	2 510 ± 32	2 720–2 500	Peat
Lozoviki	480–495	IGSB-504	3 460 ± 130	3 890–3 565	Peat
Lozoviki	605–620	IGSB-506	4 995 ± 725	6 600–4 830	Detritus gyttja
Lozoviki	680–690	IGSB-496	5 746 ± 271	6 890–6 280	Detritus gyttja
Lozoviki	760–770	IGSB-505	6 710 ± 588	8 165–6 950	Calcareous gyttja
Lozoviki	890–900	IGSB-508	8 050 ± 179	9 195–8 640	Calcareous gyttja
Lozoviki	990–1000	IGSB-509	9 190 ± 250	10 735–9 935	Calcareous gyttja
Lozoviki	1030–1040	IGSB-507	9 370 ± 95	10 725–10 430	Peat
Lozoviki	1150–1170	IGSB-464	13 739 ± 854	17 664–15 194	Peat
Krivoe	410–440	Vs-107	10 280 ± 120	12 365–11 820	Peat
Mezhuzhol	130–140	IGSB-800	2 950 ± 80	3 240–2 995	Detritus gyttja
Mezhuzhol	230–240	IGSB-801	6 520 ± 110	7 555–7 325	Detritus gyttja
Mezhuzhol	280–290	IGSB-802	10 110 ± 130	11 975–11 405	Detritus gyttja
Sudoble	140–160	TA-1219	2 360 ± 80	2 690–2 315	Detritus gyttja
Sudoble	280–300	TA-1220	3 930 ± 80	4 510–4 245	Detritus gyttja
Sudoble	380–400	TA-1221	4 960 ± 70	5 840–5 605	Detritus gyttja
Sudoble	485–500	TA-1222	5 950 ± 80	6 880–6 675	Detritus gyttja
Sudoble	580–600	TA-1223	8 510 ± 70	9 540–9 470	Detritus gyttja
Sudoble	680–700	TA-1224	9 080 ± 90	10 395–10 175	Detritus gyttja
Sudoble	770–790	TA-1225	11 160 ± 100	13 140–12 955	Sandy gyttja
Sudoble	875–885	TA-1226	11 550 ± 100	13 490–13 275	Peat
Bobrovichskoe	100–110	IGSB-805	420 ± 80	530–325	Detritus gyttja
Bobrovichskoe	200–210	IGSB-806	700 ± 80	720–560	Detritus gyttja
Bobrovichskoe	390–400	IGSB-807	3 450 ± 80	3 835–3 630	Detritus gyttja
Bobrovichskoe	620–630	IGSB-809	4 470 ± 90	5 280–4 975	Detritus gyttja
Bobrovichskoe	710–720	IGSB-811	4 820 ± 90	5 650–5 335	Detritus gyttja
Bobrovichskoe	820–830	IGSB-812	4 800 ± 80	5 605–5 335	Detritus gyttja
Bobrovichskoe	920–930	IGSB-813	5 630 ± 90	6 490–6 310	Calcareous gyttja
Bobrovichskoe	980–990	IGSB-810	6 230 ± 80	7 250–7 020	Calcareous gyttja
Bobrovichskoe	1370–1380	IGSB-882	9 380 ± 180	11 065–10 290	Calcareous gyttja
Bobrovichskoe	1490–1500	IGSB-883	11 320 ± 190	13 370–13 030	Calcareous gyttja
Oltushskoe	0–20	Ki-3193	350 ± 50	475–320	Detritus gyttja
Oltushskoe	50–60	Ki-3192	900 ± 50	905–745	Detritus gyttja
Oltushskoe	70–80	Ki-3191	2 100 ± 50	2 130–2 000	Detritus gyttja
Oltushskoe	100–110	Ki-3190	2 500 ± 50	2 720–2 490	Detritus gyttja
Oltushskoe	190–200	Ki-3391	6 130 ± 50	7 150–6 940	Detritus gyttja
Oltushskoe	360–380	Ki-3392	8 650 ± 50	9 660–9 545	Gyttja
Oltushskoe	380–400	Ki-3393	9 230 ± 50	10 490–10 295	Peat with gyttja
Oltushskoe	420–440	Ki-3394	9 870 ± 50	11 310–11 225	Peat

The radiocarbon dates were converted to calibrated ages (cal yr BP) at one sigma using the IntCal04 calibration curve (Reimer et al. 2004). All ages mentioned in text refer to ^{14}C years BP.

MORPHOMETRICAL AND LITHOSTRATIGRAPHICAL CHARACTERISTICS

Sediment cores from six lakes of Belarus – Lozoviki and Krivoe in Poozerye, Mezhuzhol and Sudoble in Central Belarus, and Bobrovichskoe and Oltushskoe in Polesye – were studied to establish correlations between changes in lake conditions and catchment evolution throughout the Late Glacial and Holocene.

Lozoviki (55°16′N, 28°07′E) is a dystrophic lake, situated in a glacial hollow in the terminal moraine ridge of the Poozerye district and belonging to the Western Dvina River basin (Fig. 1). The area of the lake is 0.006 ha, length 0.035 km, maximum width 0.02 km, catchment area less than 100 ha, maximum depth about 1 m. The absolute height of the lake is 173.7 m. The lake depression is of glacial origin (Yakushko 1981). The coring was made from a floating mat on the north-western side of the lake (Fig. 2a). The total thickness of organic sediments in the core is 11.6 m (Fig. 3a). The basal horizon of peat is lying on yellow sands with gravel and was accumulated at the beginning of the Late Glacial, according to the radiocarbon data (Zernitskaya et al. 2001). At the end of the Preboreal (PB), the formation of calcareous sediments with a high content of terrigenous material began ca 10 735–9935 cal yr BP (9.3–9.1 ka BP), which shows rise in the lake level (Fig. 3a). In Boreal (BO) time these sediments were replaced by calcareous gyttja with a low content of terrigenous material, which witnesses to a low flowage of the lake basin and either stabilization or lowering of the water levels in the middle of the BO as a result of the aridization of the climate. From the end of the BO up to the middle of the Atlantic (AT), the content of organic matter in sediments increased. The δ^{18}O and δ^{13}C values in calcareous sediments show rise in the lake level in the second half of the PB and lowering at the beginning of the AT (Makhnach et al. 2000, 2004). In the middle of the AT detritus gyttja with a high content of organic matter was formed in the lake, and already at the beginning of the Subboreal (SB) (Fig. 3a) woody peat started to accumulate. Peat alternates with layers of fine detritus gyttja, which shows instability of water regime. Short-term rise in the lake level fixes the horizon of detritus gyttja at a depth of 4.75–4.55 m, dated to ca 3890–3565 cal yr BP. During the early and middle Subatlantic (SA) woody peat was still accumulating, while at the end of this time sedimentation of *Sphagnum* peat began.

Krivoe (55°08′N, 29°04′E) is a mesotrohpic lake, which is situated within the terminal moraine ridge of the Poozerye district and belongs to the Western Dvina River basin (Fig. 1). The absolute height of L. Krivoe is 131.1 m. The area of the lake is 450 ha, length 6 km, maximum width 1.1 km, maximum depth about 31.5 m, and catchment area 6540 ha (Vlasov et al. 2004). The catchment area is a combination of till uplands and esker ridges with lake depressions and low boggy areas. The lake depression consisting of several stretches is of glacial origin (Yakushko 1981). The lakesides are up to 20 m high and with steep slopes, up to 30 degrees. The coring was made in the northern sublittoral part of the lake at a water depth of 3.5 m (Fig. 2b). The total thickness of organic sediments in the core is 4.4 m (Fig. 3b). The basal horizon, peat, an indicator of low water level, is lying on fluvioglacial sand and accumulated in the early Holocene, ca 12 365–11 820 cal yr BP. From the middle of the PB (Fig. 3b) fine detritus gyttja began to accumulate, witnessing to the rise in the water level. On the BO and AT boundaries detritus gyttja was replaced by gyttja, which can be another indicator of lake level rise. Palynological analysis (Fig. 3b), compared with the data of the Lozoviki core (Fig. 3a), revealed that such type of sediments was formed up to the beginning of the SA. Afterwards the formation of clayey gyttja began and is still continuing nowadays.

Mezhuzhol (55°00′N, 28°04′E) is a high-eutrophic lake, lying within the fluvioglacial plain of the Central district and belonging to the Dnieper River basin (Fig. 1). The area of the lake is 290 ha, maximum width 1.05 km, maximum depth 3 m, and catchment area 5340 ha. The absolute height is 171.7 m. The surface of the catchment area is gently rolling waterlogged fluvioglacial lowland composed of sands. The lake depression is of residual origin. The lakesides are low, with poorly marked slopes of the depression. The lake is mainly fed by groundwater (Matveev et al. 1988). The total thickness of the studied sediments is 5 m (Zernitskaya & Kolkovskij 2003). The coring was made in the southern part of the depression, 100 m away from the western lakeside at a water depth of 0.5 m (Fig. 2c). Sand, presumably of pre-Allerød (AL) age, is covered by peat with a high content of *Pinus* pollen and some *Selaginella selaginoides* spores (Fig. 4a). The peat is overlain by detritus gyttja with calcareous particles, corresponding to the first part of the Younger Dryas (YD) and giving evidence of lake level rise (Zernitskaya et al. 2005). At the beginning of the PB detritus gyttja started to accumulate in the lake. The change in sedimentation seems to be connected to the warming of climate and

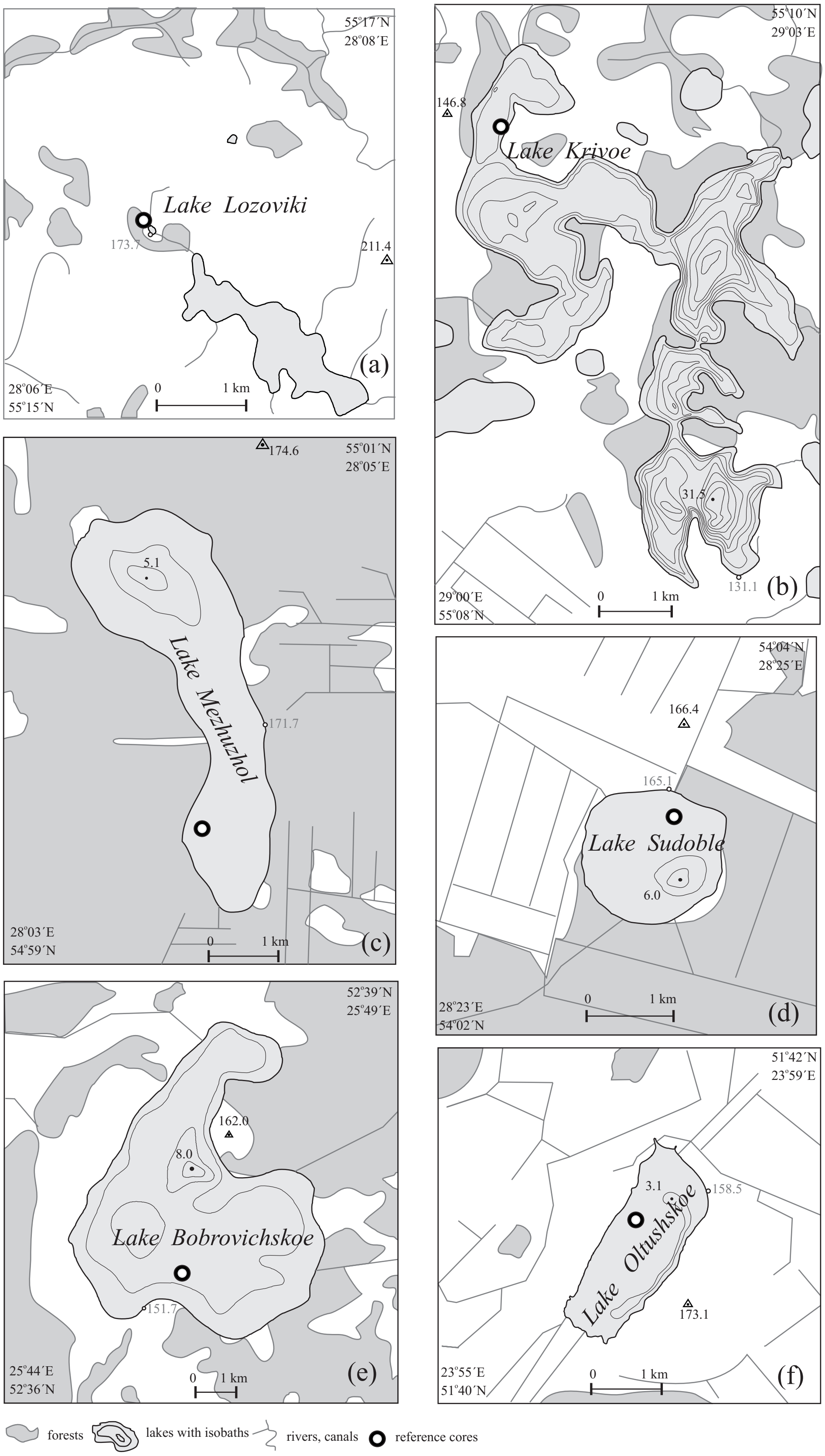

Fig. 2. Bathymetric map and catchment areas of lakes. (a) Lozoviki, (b) Krivoe, (c) Mezhuzhol, (d) Sudoble, (e) Bobrovichskoe, (f) Oltushskoe.

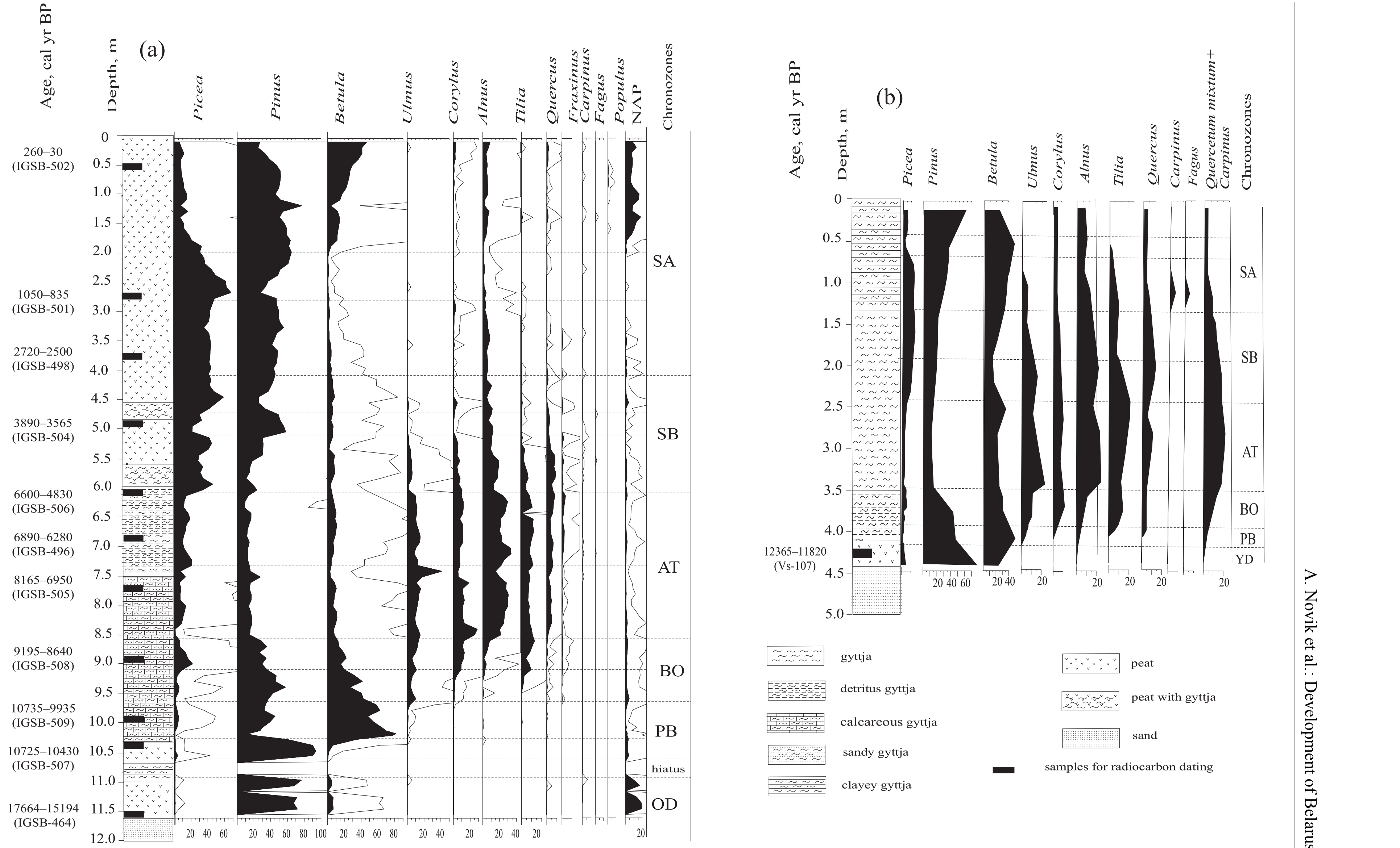

Fig. 3. Lithostratigraphy and pollen diagrams (%) in lakes Lozoviki (a) and Krivoe (b).

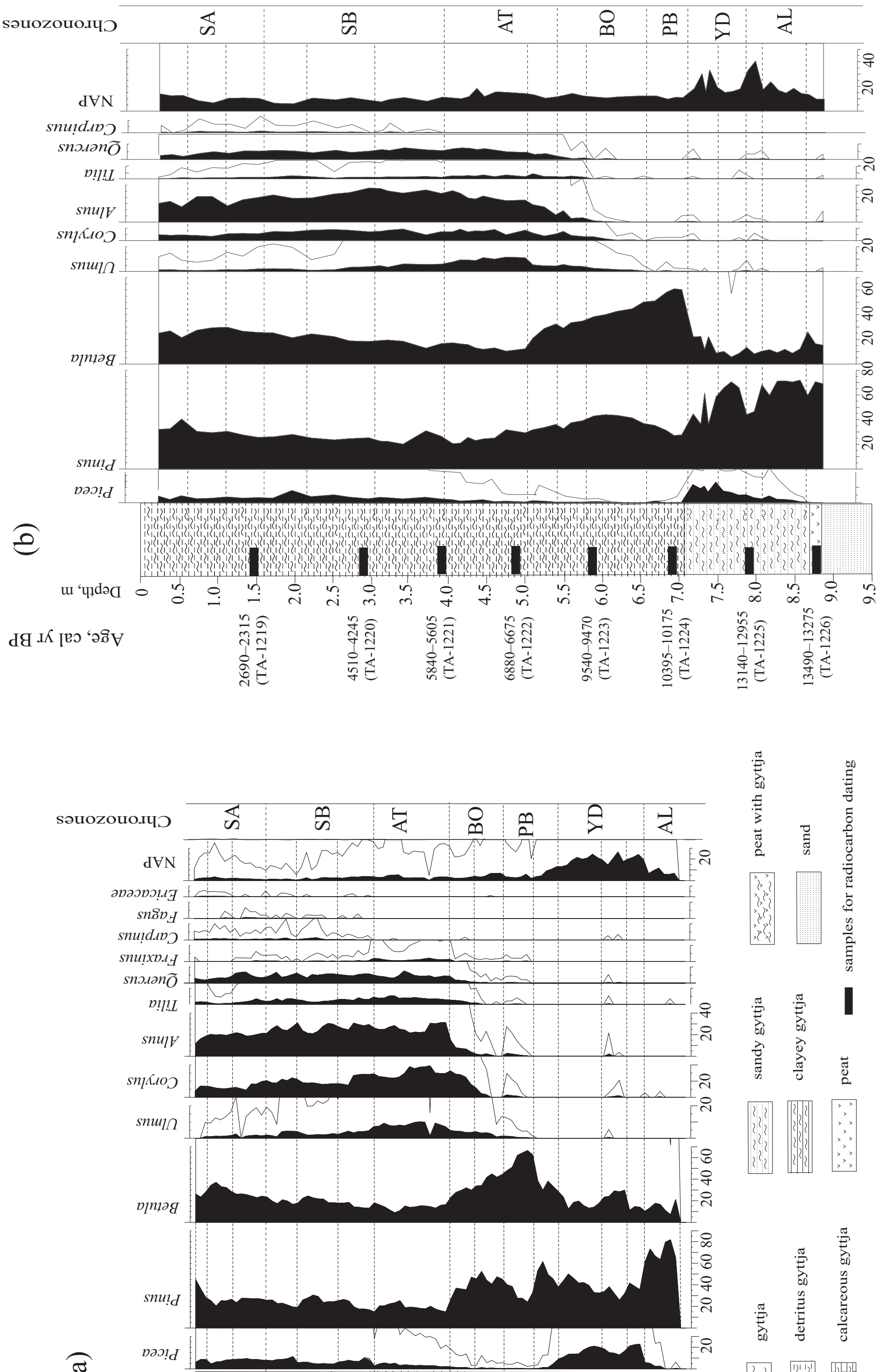

Fig. 4. Lithostratigraphy and pollen diagrams (%) in lakes Mezhuzhol (a) and Sudoble (b).

melting of frozen grounds, which could promote the lowering of the water level. During the PB and BO detritus gyttja, and during the AT black fine detritus gyttja were formed in the lake. At a depth of 2.30 m brown-olive detritus gyttja started to accumulate.

Sudoble (54°03′N, 28°24′E) is a high-eutrophic lake, situated in the fluvioglacial plain of the Central district and belonging to the Dnieper River basin (Fig. 1). The area of the lake is 152 ha, length 1.5 km, maximum width 1.08 km, maximum depth 6 m, and catchment area 2200 ha. The absolute height is 165.1 m. The surface of the catchment area is flat waterlogged and forest-covered lake-alluvial lowland composed of sands, which is partially ameliorated by the present time. The lake depression is of thermokarst origin and mainly fed by groundwater (Matveev et al. 1988). The coring was made in the northwestern part of the lake, 130 m from the lakeside at a water depth of 0.5 m (Fig. 2d). The thickness of the sediment core in the lake is 8.9 m (Fig. 4b). On the base of the core a thin layer of peat lies on fluvioglacial sands of AL age and is covered by sandy gyttja of Late Glacial to early Holocene age (Elovicheva & Bogdel 1987). From the PB onwards detritus gyttja was formed and is still accumulating in the bottom sediments nowadays.

Bobrovichskoe (52°37′N, 25°47′E) is a eutrophic lake, which lies within the lake-alluvial lowland of the Polesye district and belongs to the Nieman River basin (Fig. 1). The area of the lake is 947 ha, length 4.9 km, maximum width 3.3 km, maximum depth 8 m, and the catchment area 7920 ha. The absolute height is 151.7 m. The lake depression is of karst origin (Yakushko 1981). The lakesides are low, waterlogged. The lake is mainly fed by groundwater. The coring was made in the southern part of the lake at a water depth of 2.5 m (Fig. 2e) and a sediment core of 15 m was extracted (Fig. 5a). The layer of calcareous gyttja lies in the lower part. The radiocarbon date ca 13 370–13 030 cal yr BP, received for carbonaceous sediments at a depth of 14.90 m, is probably too old because of the ‘hard water’ effect. Calcareous gyttja at a depth of 14.50–12.20 m deposited during the PB and at the beginning of the BO. In the middle of the BO a peat layer with gyttja accumulated. Peat with gyttja with a high content of total sulphur (up to 7% in ash remains) could be formed as a result of the lowering and following sudden rise of the lake level. From a depth of 10 m, the content of $CaCO_3$ in calcareous gyttja decreases from 55% to 20%, at the simultaneous increase in the organic matter content from 40% to 80% of dry matter (Makhnach 2007). As the calcareous background was being replaced by organic-mineral environment, the content of Fe_2O_3 in ash residues increased gradually from 1.5% to 14% and that of P_2O_5 from 0.5% to 5.5%. From the 1 m depth from the surface mostly sandy gyttja is present in lake sediments. The increase in the mineral fraction in deposits and values of grasses (NAP), among which cultivated cereals were revealed, may be connected to growing human activity.

Oltushskoe (51°41′N, 23°57′E) is a eutrophic lake, situated within the fluvioglacial plain of the Polesye district and belonging to the Western Bug River basin (Fig. 1). The area of the lake is 220 ha, length 2.6 km, maximum width 1 km, maximum depth 3.1 m, and catchment area 30 200 ha (Zhukhovitskaya et al. 1998). The absolute height of the lake is 158.5 m. The surface of the catchment area is waterlogged, made up of sand, and complicated by hill range forms. The depression of L. Oltushskoe is of karst origin (Yakushko 1981). The lake is mainly fed by groundwater (Zhukhovitskaya et al. 1998). The coring was made in the central part of the lake at a depth of 1.5 m (Fig. 2f). The total thickness of lake sediments is about 4.6 m (Fig. 5b). Fluvioglacial sands lying on the base were replaced by silicate-rich (SiO_2 more than 90% in ash residues) clayey gyttja by the end of the YD. Higher in the core the content of sulphur, phosphorus, and iron is increasing and that of silica is decreasing. Gyttja is covered by a layer of *Hypnum* peat, the age of which is estimated to be ca 11 310–11 225 cal yr BP. In the second half of the PB peat begins to alternate with streaks of detritus gyttja, and at the beginning of the BO, accumulation of gyttja with the 40–45% content of organic matter takes place again. During the BO, with the increase in organic matter (from 40% to 75%) and a low silicate content, the influx of terrigenous material from the catchment area decreased and indigenous processes became more active, which witnesses to stabilization of the lake level. The last phase of the BO was marked by the accumulation of calcareous gyttja with a low content of organic matter (about 45%). By the middle of the AT calcareous gyttja was replaced by ferrous detritus containing 55–65% organic matter, up to 30% iron, up to 7.2% phosphorus anomalies, and nickel and cobalt. These data give evidence of a high water level and substantial stagnant water entry from the catchment area (Zhukhovitskaya et al. 1998). A thin layer of fine detritus gyttja with an increased carbonate content ($CaCO_3$ up to 10%) is noted at the border of the AT and SA. During the SB organic detritus gyttja (up to 70% of organics) accumulated. This may be an evidence of lake level rise owing to increase in the humidity of climate, but also of growing human activity in the surroundings of the lake. In the middle of the SA surface deposits are represented again by organic detritus gyttja with a high content of organic matter (more than 75%).

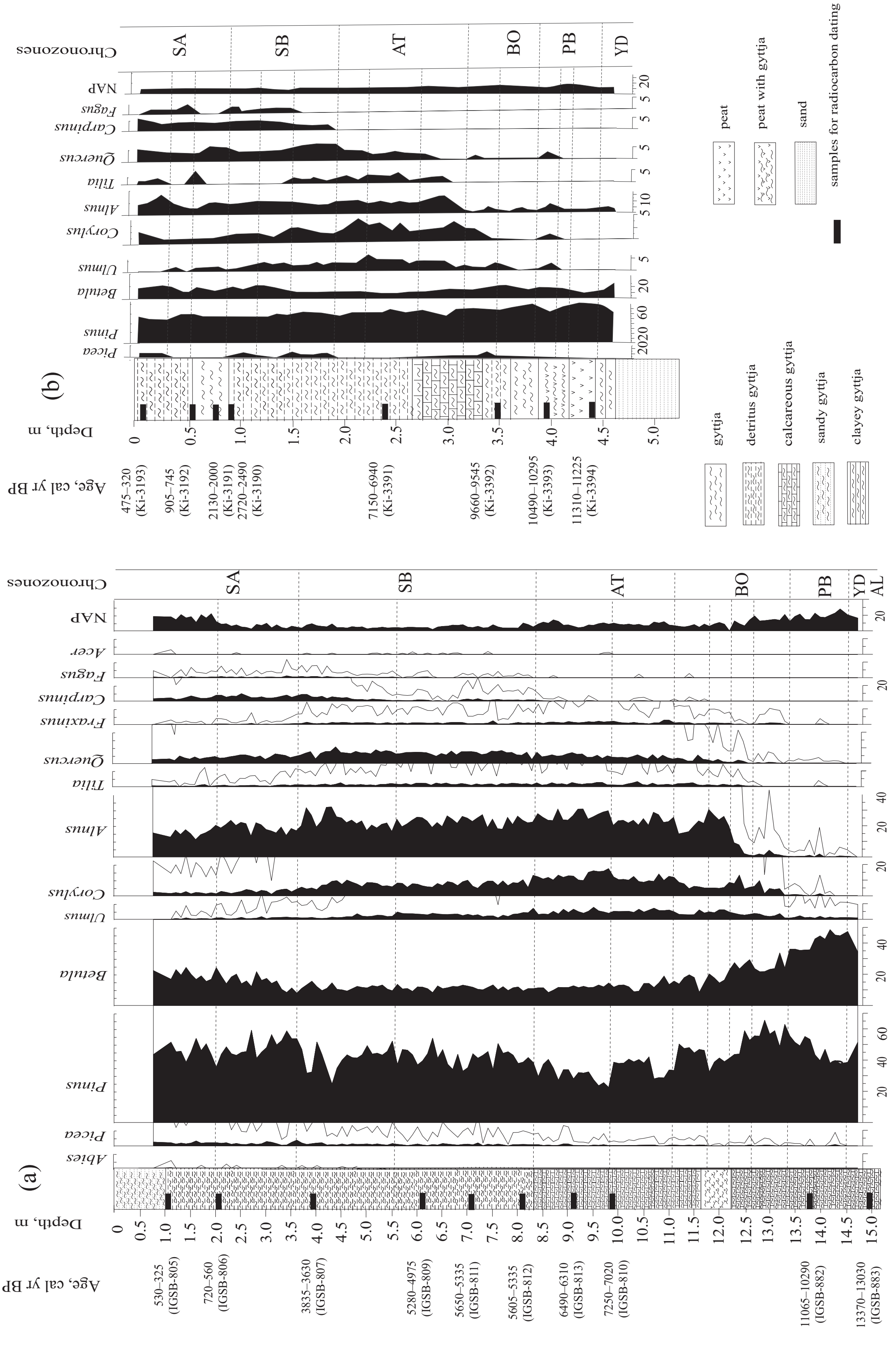

Fig. 5. Lithostratigraphy and pollen diagrams (%) in lakes Bobrovichskoe (a) and Oltushskoe (b).

DISCUSSION

Recurrent changes in climatic conditions during the Late Glacial and Holocene, fixed in pollen diagrams of vegetation, are not always reflected in lake level fluctuations. An attempt was made to reconstruct the lake level changes based on the results of chronostratigraphic and lithologic-geochemical analysis of reference cores of lakes Lozoviki, Krivoe, Mezhuzhol, Sudoble, Bobrovichskoe, and Oltushskoe (Table 3). Certainly, the received information on lake level changes is provisional, since unfortunately, we had for analysis only one core from each lake. More data are not available yet. Therefore, a very important future task will be carrying out additional research on these lakes with the purpose of more exact reconstruction of a history of their development, including lake level changes.

Late Glacial water level changes

As seen from Table 2, the basal sediments of the studied lakes are mostly represented by sands of different grain-size composition. The accumulation of sands took place in the conditions of inclement climate that was characteristic of the Older Dryas–Bølling (OD–BÖ). Vegetation cover was represented by shrub and herb tundra, in the southern area also by subarctic steppe communities (Yakushko & Makhnach 1973; Velichkevich et al. 2002).

A number of common patterns were revealed when reconstructing the general picture of lake level changes during the post-glacial epoch (Fig. 6). During the OD high lake levels were prevailing due to the existence of permafrost impeding intensive infiltration of surface waters into the deposits of the catchment area (Vlasov 2004a, pp. 5–44).

Sand deposits are overlain by a layer of peat confined to sublittoral parts of the lake depression. The formation of peat in some lakes began in the OD, but in most cores the peat began to accumulate in the AL, YD, and PB. In the sediment core of L. Lozoviki peat is dated to ca 17 664–15 194 cal yr BP (13.0 ka BP), in Mezhuzhol and Sudoble to about 13 490–13 275 cal yr BP (11.5 ka BP), and in Krivoe and Oltushskoe to the end of the YD and the beginning of the PB ca 12 365–11 225 cal yr BP (10.2–9.8 ka BP).

Basal peats

The peat of Late Glacial age is found also in other lakes of Belarus: Chervonoe (Polesye) ca 12 108–11 509 cal yr BP (10 190 ± 120 ^{14}C BP (Vs-160)), Moshno (Polesye) ca 11 819–11 343 cal yr BP (10 060 ± 120 ^{14}C BP (Vs-108)); Naroch (Poozerye) ca 12 384–11 985 cal yr BP (10 330 ± 100 ^{14}C BP (TA-223)) (Punning et al. 1988; Elovicheva 1993). Botanical composition of peat in Lake Chernovoe sediments is represented by *Hypnum*, sedge-*Hypnum*, or *Sphagnum–Hypnum* moss (Elovicheva 2001).

Nowadays there is no unanimous view among researchers about the origin of ancient peat found on the bottom of many Belarusian lakes. It is important to note that Belarusian scientists have many different ideas in that respect. One of them relates the genesis of ancient peat to the processes of deconservation of depressions and thermokarst, when as a result of the melting of permafrost, the

Table 3. Main types of Belarusian lake sediments

Chrono-zone	Poozerye		Central Belarus		Polesye	
	Lozoviki	Krivoe	Mezhuzhol	Sudoble	Bobrovichskoe	Oltushskoe
SA	Peat	Clayey gyttja	Detritus gyttja	Detritus gyttja	Gyttja Detritus gyttja	Detritus gyttja Gyttja
SB	Peat	Gyttja	Detritus gyttja	Detritus gyttja	Detritus gyttja	Detritus gyttja
AT	Detritus gyttja Calcareous gyttja	Gyttja Gyttja	Detritus gyttja Detritus gyttja	Detritus gyttja Detritus gyttja	Calcareous gyttja Calcareous gyttja	Detritus gyttja Calcareous gyttja
BO	Calcareous gyttja	Detritus gyttja	Detritus gyttja	Detritus gyttja	Calcareous gyttja Peat Calcareous gyttja	Calcareous gyttja Detritus gyttja Gyttja
PB	Calcareous gyttja Peat	Detritus gyttja	Detritus gyttja	Detritus gyttja	Calcareous gyttja	Peat
YD	Sandy gyttja	Peat Sand	Calcareous gyttja Detritus gyttja	Sandy gyttja	Calcareous gyttja	Clayey gyttja
AL	Sandy gyttja	Sand	Peat	Sandy gyttja Peat	Calcareous gyttja	Sand
OD–BÖ	Peat Sand	Sand	Sand	Sand	–	Sand

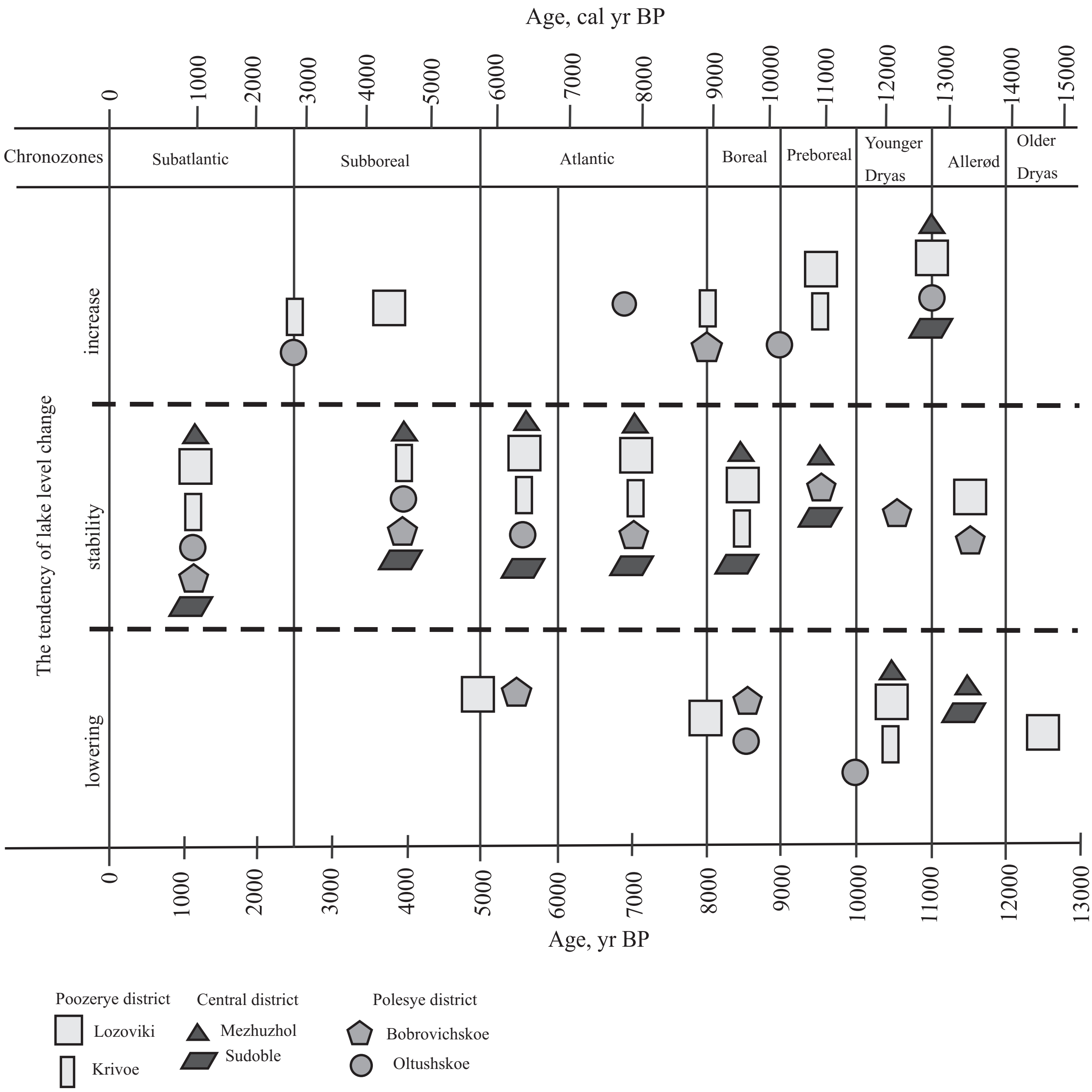

Fig. 6. Reconstruction of lake level changes during the post-glacial period.

overlying peat sunk on the base of the future water reservoir (Yakushko & Makhnach 1973). Another hypothesis suggests that the formation of peat might be linked with the position of the low levels of ground waters, which, in our work, we connect with the low position of lake levels. In this case, after the deconservation of lake depressions and melting of permafrost, the processes of infiltration increased. This promoted the lowering of the ground water level and the formation of ancient peat on low boggy areas at the initial stage of lake formation (Elovicheva 1993; Zernitskaya & Kolkovskij 2003; Vlasov 2004b).

We suppose that the second hypothesis is true. The reasons for our assumption are briefly presented below.

– Peat is found in the entire periphery of the lakes, including their deep-water parts. The peat layer is continuous in the central parts of the lakes and is characterized by an undisturbed structure (Elovicheva 1993; Vlasov 2004b). If peat was formed above permafrost, there would be breaks in the structure and layers, and peat would be absent in the central part of the lake.

- If peat was formed above glacio- or thermokarst, layers of mineral material (sand, etc.), formed as a result of permafrost melting, should occur above the peat horizon. The cores studied by us revealed no such layers. On the contrary, higher in the core, peat is usually replaced by organic or carbonate gyttja.
- In several cores studied (Lozoviki, Oltushskoe) organic gyttja is found not only above, but also under ancient peat, which is a proof of lake sediment accumulation before peat formation. This does not support the above-mentioned permafrost genesis of the peat.
- According to radiocarbon dates, in a number of southern lakes of Belarus (including Oltushskoe) peat was formed in the PB as well. According to Voznyachuk (1985), however, the process of permafrost melting on these territories was over already in the AL.
- We should say that peat accumulation took place at excess damping. It was promoted by warm climate of the AL and PB and the low position of lake levels resulting from increase in infiltration processes. All that promoted the waterlogging of lake depressions. So, the sediments of L. Mezhuzhol were characterized by a high concentration of *Myriophyllum spicatum*, *Typha latifolia*, *Polygonum amphibium*, and *Cyperaceae* pollen, as well as diatoms *Pediastrum boryanum*. Close location of the coastline is witnessed by the presence of horse-tale (*Equisetum fluviatile*) and fern (*Polypodiaceae*) spores. In the given example, if peat were formed over glaciokarst, it would have a different composition and, at least, high bog genesis (*Sphagnum*), but there is no evidence of these features. By the beginning of the YD the rise in ground water level and, as a result, in lake level, was connected with the fall of temperature and increase in the humidity, too. At that time the accumulation of gyttja in the lake began. On the pollen diagrams this set of sediments is characterized by the *Picea*–NAP zone (herbage) (Zernitskaya & Kolkovskij 2003).

In our opinion the process of peat formation was approximately as follows. Owing to deconservation of depressions, lakes began to develop on the then existing small peatbogs in the most deepened areas of the lake bottom. The peat sets they are made of were formed in the water-air bog conditions. The peat is, in this case, represented by *Hypnum*, sedge-*Hypnum*, or *Sphagnum*–*Hypnum* moss (Elovicheva 2001). Those were well-waterlogged moss (eutrophic) bogs, which, as a result of ground water rise, were soon covered by water and the sedimentation of lake deposits above peat began (Elovicheva 1993). This mechanism of peat formation agrees with the latest studies carried out in Belarus (Zernitskaya et al. 2001) and Poland (Żurek et al. 2002).

According to palynological and radiocarbon reconstructions, the melting of permafrost in lake depressions came to an end probably in the BÖ and was intensified in the AL, as supported by dates for peat. However, it cannot be excluded that the beginning of peat accumulation in the studied lakes is not connected with ground ice melting in the substratum, but with a rise in groundwater table or lake-water level in the neighbourhood. Therefore, it cannot be determined whether this initial stage of peat formation is connected only with the melting processes and when it came to an end. The current state of knowledge does not allow us to choose any of the alternatives represented by the Late Glacial and early Holocene periods (Nowaczyk 1994; Zernitskaya 1997; Żurek et al. 2002).

The composition of peat layers shows that low-water periods existed in the development of lakes of Belarus during the second half of the Late Glacial (Yakushko 1981; Vlasov 2004b). However, the biostratigraphic data based on pollen analysis show a different age of this peat, according to which continuous accumulation of terrigenous-chemogenic sediments started in the OD–BÖ (Elovicheva & Bogdel 1987; Zernitskaya 1997; Zernitskaya et al. 2001). One reason for asynchronous development of lake depressions and their low water level might be glaciokarst (in the zone of the last glaciation) and thermokarst (outside the zone of glaciation) processes that took place in the Late Glacial, and synchronous regression of lake levels caused by the warming of climate and final degradation of frozen grounds in the YD and PB. Asynchronous development of lake depressions and water level fluctuations from BÖ to YD has been fixed in northwestern Russia (Wohlfarth et al. 2007), Lithuania (Kabailienė 2006; Stančikaite et al. 2008), and Poland (Nowaczyk 1994; Starkel et al. 1998).

During the periods of climate warming of AL time and at the beginning of the Holocene (early PB) large amounts of water were released from melted permafrost (Yakushko & Makhnach 1973). This caused the lowering of lake levels due to increasing infiltration of water into friable sediments, predominantly represented by fluvioglacial sands in most of the studied cores.

Younger Dryas water level

The cold period during the YD was probably accompanied by increase in the humidity of climate. In the first half of the YD the water levels in lakes Lozoviki, Mezhuzhol, Sudoble, and Oltushskoe rose. The diagrams of lake level changes in the Late Glacial and Holocene presented in a number of recent papers (Magny & Ruffaldi 1995; Starkel et al. 1998; Zernitskaya et al. 2001; Zernitskaya & Kolkovskij 2003) reveal tendencies towards high levels in the first half of the YD (the interval between 12 900 and 12 000 cal yr BP). These data are proved by isotope-oxygen analysis made by a Belarusian scientist N. Makhnach for the cores studied from the same region with the lakes considered herein (see Makhnach et al. 2004). In most cases such a tendency was determined by drop in temperature and decrease in evaporation. In spite of the decrease in the general quantity of precipitation, these processes led to the initial increase in the humidity and strengthening of fluvial activity in that epoch (Voznyachuk 1985; Starkel et al. 1998; Velichkevich et al. 2002). This might also be explained by the fact that the succeeding lake level fluctuation occurred with some lag as compared to climatic changes. The tendency towards lake level lowering appeared only in the second half of the YD and at the beginning of the Holocene (20 000–11 100 cal yr BP) due to continuing decrease in humidification in that cold epoch and recurrent strengthening of thermokarst processes. Intensive inflow of groundwater during the first half of the YD transported carbonaceous and terrigenous sediments, and caused the disappearance of peat and the beginning of the formation of lake sediments in reservoirs of Mezhuzhol and Lozoviki. Owing to the character of sediments, at that time the water level was high also in lakes Sudoble and Oltushskoe (Fig. 6). According to the reconstruction of lake level, the most notable changes in lake depth occurred around the Late Glacial–Holocene transition; around 12 400 cal yr BP the level was very high (Starkel et al. 1998).

Holocene

In lakes Lozoviki, Mezhuzhol, Bobrovichskoe, and Oltushskoe the mineral and organic Late Glacial sediments are covered by carbonate-rich sediments. The formation of carbonate sediments reflects an important stage of lake development, connected with a considerable general warming of the climate at the beginning of the Holocene. Simultaneously with climate warming the leaching of calcareous till was increasing (Table 2).

At the time of intensive sedimentation of calcareous deposits the lakes were oligotrophic-mesotrophic and the sediments were poor in organic matter (Zhukhovitskaya et al. 1998). Morphological peculiarities of the lake depression and the lithology of the catchment area layers were of great importance (Vlasov 2004b).

The process of carbonate accumulation within the Poozerye, Central, and Polesye districts of Belarus during the last glacial time was of variable intensity, which should not be associated with climatic reasons only. The azonal factor – geomorphologic structure of the territory, geological structure of the catchment and its hydrogeological peculiarities, neotectonic vertical movements of the earth's crust, and inlake processes – is obviously of primary importance here. High accumulation of carbonates creates favourable conditions for circulation of ground water, the outflow of which in the layers is directed towards the local basis of erosion (Zhukhovitskaya & Generalova 1991). In the conditions of flat depressed relief of the lowlands, the intensity of underground feeding is very low. However, in the southwestern part of the southern district of the republic, upward movement of ground water from karst springs prevails, because (as already mentioned) the geological structure of Polesye has created preconditions for the development of karstic processes in this area. That is why the determining factor of carbonate-calcium sedimentation here is the hydrochemical regime of subsoil waters (Makhnach et al. 2001).

From the second half of the YD, the prevailing high lake levels were changed to predominantly low ones between ca 12 000 and 11 100 cal yr BP in lakes Lozoviki, Mezhuzhol, and Krivoe. The decrease in water levels after about 12 000 cal yr BP suggests deteriorating climatic conditions similar to those registered globally as the Younger Dryas cooling (Makhnach et al. 2004).

The beginning of the Holocene is marked by further stabilization or lowering of the water level in lakes of the Poozerye (Lozoviki and Krivoe) and Polesye (Oltushskoe) districts. As a rule, from the end of the PB a slow steady rise in lake levels with no substantial fluctuations is noted. When some balance was achieved between lake levels and subsoil water level, lake sediments were gradually filled with lacustrine sediments (organic and calcareous gyttja). From the second half of the PB, high levels were observed in these lakes, revealed by the substitution of peat sediments by lake deposits (Krivoe), but also by $\delta^{18}O$ and $\delta^{13}C$ in calcareous deposits of L. Lozoviki (Makhnach et al. 2004).

Sediment accumulation during the BO and AT was strongly influenced by climatic (increase or decrease in aridization) and lithologic (leaching of the catchment area sediments) factors, as well as by the development of water reservoirs, revealed in the increase in their trophicity (Vlasov 2004a, pp. 5–44). The combination of those processes contributed to a gradual change in sediment accumulation in a number of lakes, where by the middle of the AT the carbonate component prevailing since BO time was replaced by the organic-mineral one.

From the middle of the BO, peat formed in L. Bobrovichskoe and the content of organic matter grew substantially in the deposits of L. Oltushskoe, which witnesses to prevalence of low water levels in southern lakes of Belarus. From the end of the BO up to the middle of the AT, the content of organic matter in calcareous gyttja of L. Lozoviki rises. Together with changes in $\delta^{18}O$ and $\delta^{13}C$ values, it confirms the tendency of water level to decrease in this lake (Makhnach et al. 2004).

At the same time, in lakes Krivoe and Bobrovichskoe, decrease in organic matter in deposits witnesses to increase in water levels.

At the end of the AT the carbonate content of sediments decreased and organic-mineral matter became prevailing in lakes Bobrovichskoe, Oltushskoe, and Lozoviki. The reason for regionally and supraregionally consistent replacement of carbonate sediments by organic gyttja in the vertical section was complex. The change in the type of lake sedimentation was, to a certain degree, determined by exhaustion of carbonate content in the deposits of drainage areas (lixiviation), which entailed decrease in hard water inflow by simultaneous rise in lake levels (Makhnach 2007). Among the factors that determined the cessation or slowdown of lake carbonate formation, the fall of temperature at the end of the AT and climate-induced changes in subsoil waters are mentioned. In many lakes the phenomenon discussed could be connected with the rise in the trophic status as a result of the 'ageing' of the lakes (Makhnach 2007). The process of lake eutrophication intensified in the middle Holocene as a result of continued warming of climate and development of plant and animal life in the lakes (Vlasov 2004a, pp. 5–44). This resulted in considerable accumulation of dead organic remains in the hypolimnion, the decomposition of which was accompanied by oxygen consumption and emission of free carbon dioxide (Makhnach 2007). Simultaneously with the decrease in the influx of carbonate products by surface and subsurface waters as a result of considerable lixiviation of till layers, carbonate balance in lake water was disturbed: oversaturation was replaced by undersaturation and the stage of SiO_2 prevalence in the ashy part of bottom deposits and formation of organic-mineral gyttja began. This process is continuing nowadays as well (Yakushko 1981). Total thickness of organic-mineral gyttja quite often exceeds 4–5 m, and in the upper part of the organic-mineral layer the content of carbonates is always low and does not exceed 5–6% (Elovicheva 2001).

In the late AT some increase in organic matter in deposits of L. Bobrovichskoe was recorded, which could be explained by lowering of the water level (Zernitskaya 1997; Vlasov 2004a, pp. 5–44). In the SB, sediment layers with a decreased concentration of organic matter by simultaneous increase in terrigenous matter are noted in bottom deposits of the lakes of the Poozerye district, which could be connected with the rise in the water levels. At the end of the SB and beginning of the SA high water levels occurred in lakes Krivoe and Oltushskoe, evidenced by the reduction of organic matter and increase in terrigenous sediments in bottom deposits of these lakes (Fig. 6).

At the beginning of the SB peat started to form in sediments of L. Lozoviki. This also serves as an evidence of a low water level. Later on sediments of gyttja in the upper part of the Lozoviki core were covered by SB and SA peat. The formation of peat can be explained by gradual overgrowing of the reservoir and its turning into a peatbog. Detritus gyttja with peat layers of SB age of ca 3890–3565 cal yr BP (about 3.4 ka BP) were discovered in the peat core, which speaks for increase in lake level. During the early and middle SA woody peat accumulated in the nearshore part of the lake, which at the end of the SA ca 1050–835 cal yr BP was replaced by *Sphagnum* peat. The appearance of a floating *Sphagnum* mat could be an evidence of the modern transgressive stage of lake development (Zernitskaya et al. 2001).

During SA time the levels of most lakes remained stable, indicating homogeneous structure of sediments in the investigated lakes. The increase in mineral fraction of L. Bobrovichskoe deposits is probably connected with growing anthropogenic influence.

CONCLUSIONS

A number of considerable regularities were recorded in the character of sediment accumulation and, as a result, in water levels of Belarusian lakes during the entire post-glacial epoch. Common patterns and synchronism of lake level changes during the Late Glacial and early Holocene did not reveal significant regional variations. Synchronism in natural-climatic conditions in all three regions studied is first of all connected with the general trend of climate warming at the beginning of the post-glacial epoch and disappearance of permafrost. This led to the increase in infiltration processes, which occurred with similar intensity on the whole territory of Belarus. Radiocarbon dating of organic matter and pollen composition showed that the water level rose in many lakes during the first half of the Younger Dryas (between 12 900 and 12 000 cal yr BP). Regression of the water level in the majority of lakes followed during the second half of the Younger Dryas and the early Holocene (between 12 000 and 11 100 cal yr BP). From the second half of the PB (about 11 100 cal yr BP), high levels were observed in most of the lakes and several lakes experienced transgressions during the Boreal (about 9000 cal yr BP). Further stagnation of lake levels was promoted by the processes of filling and establishment of hydrostatic balance with the position of subsoil water level. From the latter half of the Holocene (less than 9000 cal yr BP), lake level fluctuations were asynchronous in different regions of Belarus (Fig. 6). At that time the general role of the climate decreased and geochemical and lithological differences were mainly caused by other local factors (morphologic structure of the catchment area, lithology of the bedrocks, genesis and shape of lake depressions, intensity of the water cycle, position of the subsoil water level, etc.). It should be noted that the location of the Poozerye lakes in well-defined deep depressions as well as the presence of uplands in their catchment areas created the regime of water level fluctuations most sensitive to climatic changes (decrease in evaporation, increase in precipitation). And vice versa, Polesye lake basins, feebly marked in the relief, have low waterlogged and forest-covered catchment areas that did not provoke sudden rises in water level. It should also be mentioned that in all studied lakes the degree of water infiltration was decreasing as water reservoirs were filling up with lacustrine sediments. First of all it happened in lakes with thick layers of solid carbonate sediments. The Poozerye lakes, where the catchment areas were formed of solid loamy till, were most susceptible to the weakening of infiltration processes.

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REFERENCES

Digerfeldt, G. 1988 Reconstruction and regional correlation of Holocene lake level fluctuations in Lake Bysjön, South Sweden. *Boreas*, **17**, 165–182.

Elovicheva, Ya. K. 1993. *Palinologiya Pozdnelednikovja i Golotsena Belorussii* [*Palynology of Late Glacial and Holocene of Belarus*]. Nauka i tekhnika, Minsk, 94 pp. [in Russian].

Elovicheva, Ya. K. 2001. *Evolyutsiya prirodnoj sredy Antropogena Belarusi (po palinologicheskim dannym)* [*Evolution of natural environment of Anthropogen of Belarus (according to palynological data)*]. Institut Geologicheskikh Nauk, NAN Belarusi, Minsk, 292 pp. [in Russian].

Elovicheva, Ya. K. & Bogdel, I. 1987. Reconstruction of palaeoclimate and vegetation of the Byelorussian Holocene using bog and lake deposit data. In *Palaeohydrology of the Temperate Zone III, Mires and Lakes* (Raukas, A. & Saarse, L., eds), pp. 152–156. Institute of Geology, Academy of Sciences of the Estonian SSR, Tallinn.

Harrison, S. P., Saarse, L. & Digerfeldt, G. 1991. Holocene changes in lake levels as climate proxy in Europe. In *Evaluation of Climate Proxy Data in Relation to the European Holocene* (Frenzel, B., ed.), pp. 159–169. Gustav Fischer, Stuttgart.

Harrison, S., Frenzel, B., Huckriede, U. & Weiß, M. M. (eds). 1998. *Palaeohydrology as Reflected in Lake Level Changes as Climatic Evidence for Holocene Times*. ESF Project "European Palaeoclimate and Man" 17; Paläoklimaforschung, 25, Special issue; Gustav Fischer Verlag, Stuttgart, 180 pp.

Kabailienė, M. 2006. Late Glacial and Holocene stratigraphy of Lithuania based on pollen and diatom data. *Geologija (Vilnius)*, **54**, 42–48.

Magny, M. 2004. Holocene climate variability as reflected by mid-European lake level fluctuations and its probable impact on prehistoric human settlements. *Quaternary International*, **113**, 65–79.

Magny, M. & Ruffaldi, P. 1995. Younger Dryas and early Holocene lake-level fluctuations in the Jura mountains, France. *Boreas*, **24**, 155–172.

Makhnach, A. S., Garetskij, R. G. & Matveev, A. V. (eds). 2001. *Geologiya Belarusi* [*Geology of Belarus*]. Institut Geologicheskikh Nauk NAN Belarusi, Minsk, 815 pp. [in Russian].

Makhnach, N. 2007. *Autigennye karbonatnye mineraly v chetvertichnykh otlozheniyakh Belarusi* [*Authigenic carbonate minerals in Quaternary deposits of Belarus*]. Nauka, Minsk, 215 pp. [in Russian].

Makhnach, N., Zernitskaya, V., Kolosov, I., Demeneva, O. & Simakova, G. 2000. $\delta^{18}O$ and $\delta^{13}C$ in calcite of freshwater carbonate deposits as indicators of climatic and hydrological changes in the late-glacial and Holocene in Belarus. *Journal of Geochemical Exploration*, **69–70**, 435–440.

Makhnach, N., Zernitskaya, V., Kolosov, I. & Simakova, G. 2004. Stable oxygen and carbon isotopes in Late Glacial–Holocene freshwater carbonates from Belarus and their palaeoclimatic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **209**, 73–101.

Mangerud, J., Andersen, S. T., Berglund, B. E. & Donner, J. J. 1974. Quaternary stratigraphy of Norden: a proposal for terminology and classification. *Boreas*, **3**, 78–85.

Matveev, A. V., Gurskij, B. N. & Levitskaya, R. I. 1988. *Rel′ef Belorussii* [*Relief of Belarus*]. Nauka i tekhnika, Minsk, 320 pp. [in Russian].

Nowaczyk, B. 1994. *Geomorfologia i osady strefy litoralnej jezior* [*Geomorphology and deposits of the littoral zone of lakes*]. Charzykowy, Institut Badan Czartorzedu UAM, Poznan, 76 pp. [in Polish].

Punning, J.-M., Zhukhovitskaya, A. L., Khursevich, G. K., Rachevskij, A. N., Martma, T. A. & Putnik, H. E. 1988. Paleogeographic conditions of the formation of carbonate deposits of Lake Naroch. In *Litologiya, geokhimiya i stratigrafiya kontinental′nykh kainozojskikh otlozhenii Belarusi* [*Lithology, geochemistry and stratigraphy of continental Cainozoic deposits of Belarus*] (Yakushko, O. F., ed.), pp. 101–110. NAN Belarusi, Minsk [in Russian].

Punning, J.-M., Kangur, M., Koff, T. & Possnert, G. 2003. Holocene lake level changes and their reflection in the paleolimnological records of two lakes in northern Estonia. *Journal of Paleolimnology*, **29**, 167–178.

Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Bertrand, C. J. H., Blackwell, P. G., Buck, C. E., Burr, G. S., Cutler, K. B., et al. 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon*, **46**, 1029–1058.

Stančikaite, M., Šinkūnas, P., Šeiriene, V. & Kisieliene, D. 2008. Patterns and chronology of the Lateglacial environmental development at Pamerkiai and Kašučiai, Lithuania. *Quaternary Science Reviews*, **27**, 127–147.

Starkel, L., Pazdur, A., Pazdur, M., Wicik, B. & Wieckowski, K. 1998. Lake level changes and palaeohydrological reconstructions during the Holocene. In *Lake Gosciaz, Central Poland, a Monographic Study* (Ralska-Jasiewiczowa, M., Goslar, T., Madeyska, T. &

Starkel, L., eds), pp. 158–162. W. Szafer Institute of Botany, Polish Academy of Sciences, Cracow.

Tarasov, P. E., Pushenko, M. Ya., Harrison, S. P., Saarse, L., Andreev, A. A., Aleshinskaya, Z. V., Davydova, N. N., Dorofeyuk, N. I., Efremov, Yu. V., Elina, G. A., Elovicheva, Ya. K., et al. 1996. Lake status records from the former Soviet Union and Mongolia. Documentation of the second version of the Database. *NOAA Paleoclimatology Publications Series*, Rep., 5, 1–224.

Velichkevich, F. Y., Zernitskaya, V. P., Krutous, E. A., Matveev, A. V. Nechiporenko, L. A., Rilova, T. B., Sanko, A. F., Khursevich, G. K. & Yakubovskaya, T. V. 2002. Quaternary. In *Paleogeografiya Kainazoya Belarusi* [*Cainozoic palaeogeography of Belarus*], pp. 121–143. NAN Belarusi. Institut Geologicheskikh Nauk, Minsk [in Russian].

Vlasov, B. P. 2004a. *Antropogennaya transformatsiya ozer Belarusi: geoekologicheskoe sostoyanie, izmeneniya i prognoz* [*Anthropogenous transformation of lakes of Belarus: geoecological conditions, changes and prognosis*]. Belarusian State University, Minsk, 205 pp. [in Russian].

Vlasov, B. P. 2004b. General features of evolution of lakes ecosystems in Byelorussian Lakeland on the basis of study of lakes sediments. *Limnological Review*, **4**, 269–276.

Vlasov, B. P., Yakushko, O. F., Gigevich, G. S., Rachevski, A. N. & Loginova, E. V. 2004. *Ozera Belarusi* [*Lakes of Belarus*]. Minsktipproekt, Minsk, 284 pp. [in Russian].

Voznyachuk, L. N. (ed.) 1985. The problems of glacio-Pleistocene of the East European Plain. In *Problemy pleistocena* [*The problems of Pleistocene*], pp. 8–55. NAN of Belarus, Minsk [in Russian].

Wohlfarth, B., Lacourse, T., Bennike, O., Subetto, D., Tarasov, P., Demidov, I., Filimonova, L. & Sapelko, T. 2007. Climatic and environmental changes in north-western Russia between 15 000 and 8000 cal yr BP: a review. *Quaternary Science Reviews*, **26**, 1871–1873.

Yakushko, O. F. 1981. *Ozerovedenie: geografiya ozer Belorusii* [*Limnology: geography of Byelorussian lakes*]. Belarusian State University, Minsk, 223 pp. [in Russian].

Yakushko, O. F. & Makhnach, N. A. 1973. Basic Late Glacial and Holocene stages of Belarus. In *Problemy paleogeografii antropogena Belorussii* [*Problems of Anthropogen palaeogeography in Belarus*] (Yakushko, O. F., ed.), pp. 76–95. NAN Belarusi, Minsk [in Russian].

Zernitskaya, V. P. 1997. The evolution of lakes in Poles′ye in the Late Glacial and Holocene. *Quaternary International*, **41–42**, 153–160.

Zernitskaya, V. P. & Kolkovskij, V. M. 2003. History of development of Lake Mezhuzhol and stages of vegetation change in plain Verhneberezinskaya in the Late Glacial and Holocene. In *Teoreticheskie i prikladnye problemy sovremennoj limnologii* [*Theoretical and applied problems of modern limnology*] (Yakushko, O. F. & Vlasov, B. P., eds), pp. 155–158. Belarusian State University, Minsk [in Russian].

Zernitskaya, V. P., Zhukhovitskaya, A. L., Vlasov, B. P. & Kurzo, B. V. 2001. *Ozero Dolgoe (sedimentogenez, stratigrafiya donnykh otlozhenij i etapy razvitiya)* [*Lake Dolgoe (sedimentogenesis, stratigraphy of bottom deposits and stages of development)*]. Institut Geologicheskikh Nauk, NAN Belarusi, Minsk, 83 pp. [in Russian].

Zernitskaya, V. P., Matveev, A. V., Makhnach, N. A. & Mikhailov, N. D. 2005. Stratigraphical scheme of the Late Glacial and Holocene deposits of Belarus. *Lithosphere*, 1, 157–165 [in Russian].

Zhukhovitskaya, A. L. & Generalova, V. A. 1991. *Geokhimiya ozer Belorusii* [*Geochemistry of Belarusian lakes*]. Institut Geologicheskikh Nauk, NAN Belarusi, Minsk, 203 pp. [in Russian].

Zhukhovitskaya, A. L., Vlasov, B. P., Kurzo, B. V. & Kuznetsov, V. A. 1998. *Ozernyj sedimentogenez v Golocene Belarusi: geokhimicheskie i biologicheskie aspekty* [*Holocene lake sediments of Belarus: geochemical and biological aspects*]. Institut Geologicheskikh Nauk, NAN Belarusi, Minsk, 276 pp. [in Russian].

Żurek, S., Michczyńska, D. J. & Pazdur, A. 2002. Time record of palaeohydrologic changes in the development of mires during the late glacial and holocene, north Podlasie lowland and Holy Cross mts. *Geochronometria*, **21**, 109–118.

Valgevene järvede areng Hilis-Glatsiaalis ja Holotseenis

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Lähtudes geoloogilisest struktuurist, topograafiast, geomorfoloogiast ja paleokliima arengust, on esitatud materjalid kolme uurimisala (Valgevene Poozerje, Kesk-Valgevene ning Valgevene Polesje) järvede setete akumulatsiooni kohta alates Hilis-Glatsiaalist. Igas uurimisalas valiti välja tüüpjärved, mille setete koostise, akumulatsiooni ja paleobioloogiliste andmete alusel analüüsiti hüdroloogilise režiimi muutuste dünaamikat. Leiti, et uuritud regioonides ilmneb Hilis-Glatsiaalis ja Vara-Holotseenis looduslik-klimaatilistes tingimustes teatud sünkroonsus, mis on seotud üldise kliima soojenemise ning permafrosti kadumisega. Uurimus näitab, et veetaseme tõus oli märgatav kõikides uuritud järvedes (~12 900 – 12 000 cal yr BP), millele järgnes veetaseme langus enamikus järvedes (~12 000 – 11 000 cal yr BP). Veetaseme transgressioon ilmnes osal järvedel (~9000 cal yr BP). Holotseeni teisest poolest ilmnes uuritud järvede veetaseme muutuses asünkroonsus, mis võis olla põhjustatud eri lokaalsete faktorite mõju suurenemisest. Näiteks Poozerje uurimisalal asuvad järved sügavates nõgudes ja on tundlikumad sademerežiimi muutustest tingitud veetaseme kõikumisele. Polesje alal asuvad järved madalates nõgudes ja siin on olulisemad teised faktorid. Ühiseks teguriks, mis mõjutab kõikide järvede arengut, on infiltratsiooni vähenemine järvenõo eelkõige karbonaatsete setetega täitumisel.