PALAEOHYDROLOGY OF THE TEMPERATE ZONE II

Lakes

IUGS
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" Palaeohydrology "

Academy of Sciences of the Estonian S.S.R.

Institute of Geology

International Geological Correlation Programme
Project No. 158

Soviet Working Group

PALAEOHYDROLOGY OF THE TEMPERATE ZONE

Vol. II - Lakes

Tallinn "Valgus" 1987

Академия наук Эстонской ССР
Институт геологии

Советская рабочая группа проекта № 158
Международной программы геологической корреляции

ПАЛЕОГИДРОЛОГИЯ УМЕРЕННОЙ ЗОНЫ

II том - Озера

Таллин "Валгус" 1987

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English text revised by Helle Kukk

Cover by H. Puzanov

P $\frac{1904040000 - 225}{902(15) - 87}$ Tellitud

Выпущено по заказу Академии наук Эстонской ССР

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PRELIMINARY RESULTS OF THE INVESTIGATION OF REFERENCE SITES AND TYPE REGIONS IN THE EUROPEAN PART OF THE SOVIET UNION

L. Saarse, A. Raukas, D. Kvasov

On the basis of vegetational, climatic and soil peculiarities and geological and geomorphological conditions in the European part of the USSR the biotic zonation and natural-geographical subdivision of the territory have been carried out in accordance with the demands advanced by the IGCP Project No.158 (Berglund, 1979). In the European part of the USSR the territory of which surpasses the total area of West-European countries, according to E. Lavrenko and V. Sochava (Лавренко; Сочава, 1954), the tundra, woodland tundra, northern, central and southern taiga (Boreal), mixed forest (Boreo-nemoral), broad-leaved forest (Nemoral), woodland steppe, steppe and steppe desert (semidesert) zones and subzones have been distinguished. In these biotic zones and subzones 88 natural-geographical regions (type regions by B. Berglund) in all with 103 reference sites have been suggested (Fig.).

The Kola Peninsula with the area of 144,900 sq.km locates approximately 111,600 lakes in the tundra, woodland tundra and northern taiga subzones which are characterized by extremely poor mineralization of lake water. Most of the lakes are less than 1 sq.km in area, they are in oligotrophic stage of development showing distinct features of eutrophication. The lithology of lacustrine deposits varies with different parts of the peninsula. Thus, in the lakes located on the Barents Sea lowland, minerogenous deposits are prevailing, whereas siliceous-rich (diatomite) muds are common for the western part of the peninsula and the Rybachiy peninsula. The lakes in the central part of the Kola peninsula are also rich in siliceous muds with ferromanganese crusts and nodules in the profundal, those in the southern part are dominated by peaty gyttja (Штеренберг, 1979). Since the Kola peninsula lies north of the limits of calcareous sedimenta-

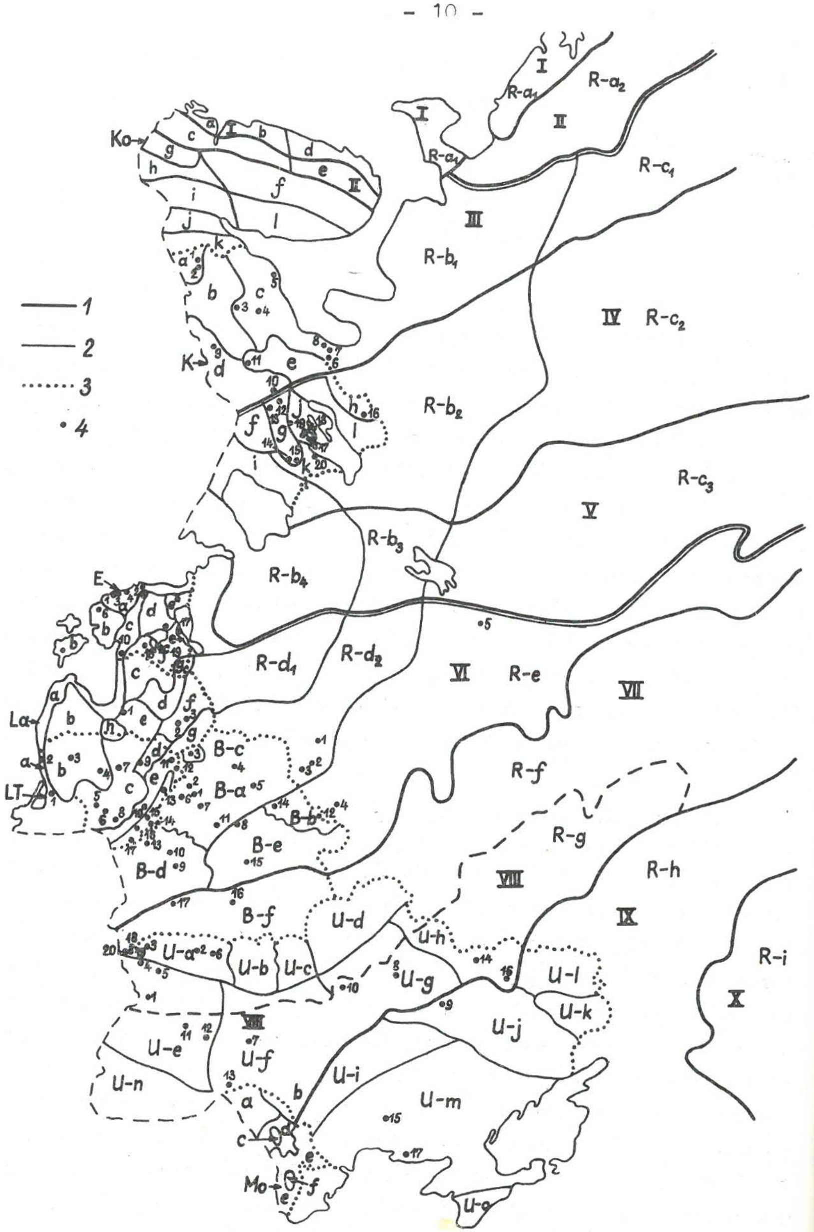

Fig. Type regions and reference sites of the European part of the USSR. Legend on the page 11.

Fig. Type regions and reference sites of the European part of the USSR. Boundaries: 1- between biotic zones, 2- between natural-geographic regions; 3- frontier of republics; 4- reference sites. I-X - biotic zones and subzones: I- tundra, II- woodland tundra, III - northern taiga, IV- middle taiga, V- southern taiga, VI- mixed forests, VII- broad-leaved forests, VIII- woodland Steppe, IX- Steppe, X- Steppe Desert. Ko- Kola peninsula: a- northern coastal, b- western Murmansk, c- north-western mountain, d- eastern Murmansk, e- central, f-Khibins and Lovozero, g- Notozero depression, h- central mountain, i- southern depression, j- Kandalaksha, k- Kovdozero Lowland, l- Terski. K- Karelian ASSR: a- north-western mountain, b- lake district, c- White Sea Lowland, d- West-Karelian Uplands, e- Onega-White Sea watershed, f- Äänisjoki-Suojoki, g- Suna-Shuja watershed, h- Polovenets Inlet-River Vyg watershed, i- Ladoga basin, j- Onega basin, k- Onega-Ladoga watershed, l- Vodlozero basin. E - Estonian SSR: a- North, b- West, c- Intermediate Estonia, d- Central-Estonian watershed, e- Peipsi and Vórtsjärv Lowlands, f- Middle Devonian Plateau, g- Upper-Devonian Plateau. La- Latvian SSR: a- Coastal Lowland, b- Kurzeme Uplands, c- Middle-Gauja Lowland, d- East-Vidzeme and Aluksne Uplands, f- Lubano and Middle Daugava Lowland, g- Latgale Uplands, e- Central Latvian Plain, h- Zemgale. Lt- Lithuanian SSR: a- Baltic coast Lowland, b- Zhemaitiya Uplands, c- Middle Lithuanian Plain, d- West Auksthaitaya Plateau, e- Baltic ridge, f- South-eastern fluvioglacial Plain. BR- Byelorussian SSR: a- Byelorussian Valdai, b- East, c- East Baltic, d- West Byelorussia, e- Predpolesje, f- Polesje. U- Ukrainian SSR: Polesje: a- Volynia, b- Zhitomir, c- Kiev, d- Levoberezhnoye; woodland steppe: e- Volyno-Podolya, f- River Dnieper, g- Levoberezhnaya, h- Central Russian; Steppe: i- northern Pravoberezhnaya, j- northern Levoberezhnaya, k- Donetskaya, l- Starobelskaya, m- Black Sea and Tauria, n- the Carpathians, o- the Crimea; Mo- Moldavian SSR: a- woodland Steppe, b- Prednestr, c- Kodr Uplands, d- Kodr, e- South-Moldavian and Bessarabian Plain, f- Tiche Uplands. R- Russian SFSR: a- north-eastern lake district: a_1- tundra, a_2- woodland tundra; b- north-western lake district: b_1- lakes of the Valdaian glaciation of northern taiga, b_2- middle taiga, b_3- southern taiga, b_4- lakes on the catchment area of the Gulf of Finland; c- taiga lakes outside of the Valdaian glaciation: c_1- northern taiga, c_2- middle taiga c_3- southern taiga; d- lakes on the north-western part of Boreo-nemoral zone: d_1- lakes on the catchment of rivers Velikaya and Lovat, d_2- lakes on the Valdaian ice marginal zone; e- lakes on the Middle Pleistocene and periglacial area; f- lakes of northern Nemoral zone; g- lakes of woodland Steppe; h- lakes of Steppe; i- lakes of Steppe Desert zones.

Reference sites: Karelian ASSR: 1- Ptichye, 2- Neinasuo, 3- Zapovednoe, 4- Shombasuo, 5- Solnechnoe, 6- Zarutskoe, 7- Nyhchinski mokh, 8- Primorskoe, 9- Nosuo, 10- Mini-Tumba, 11- Rugozero, 12- Punozerka, 13- Severnoe Sovdozerskoe, 14- Nenazvannoe, 15- Mustusuo, 16- Verstovaya gorka, 17- Gotnavolok, 18- Dlinnoe, 19- Koppalasuo, 20- Hiilisuo. Estonian SSR: 1- Harku, 2- Käsmu, 3- Vaharu, 4- Kahala, 5- Karujärv, 6- Tänavjärv, 7- Viitna Suurjärv, 8- Viitna Väikejärv, 9- Laukasoo, 10- Nigula, 11- Raigastvere, 12- Soitsjärv, 13- Elistvere, 14- Pikkjärv, 15- Visusti, 16- Ümarjärv, 17- Saviku, 18- Päidre, 19- Mähe, 20- Tuuljärv, 21- Vällamäe. Latvian SSR: 1- Lubano, 2- Dlinnoe Shidzinyas, 3- Vorkaly, 4- Rudushkoe. Lithuanian SSR: 1- Shventele, 2- Shventoi, 3- Sietuva, 4- Tutuvenu tyrelis, 5- Nopaitis, 6- Gabiarishkis, 7- Ezherbala, 8- Zhuviantas, 9- Shepeta, 10- Bebrukas, 11- Kriaunelis, 12- Drukshiai, 13- Gruodishkis, 14- Glukas, 15- Varenis, 16- Glebas, 17- Chepkeliai. Byelorussian SSR: 1- Naroch, 2- Glubelka, 3- Dit, 4- Krivoe, 5- Zerinskoe, 6- Voroby, 7- Kobuzi, 8- Sudoble, 9- Koldychevskoe, 10- Svityas, 11- Maloe, 12- Svyatoe, 13- Poteh, 14- Bezymyanskoe, 15- Lochinskoe, 16- Chervonoe, 17- Bobrovichkoe, 18- Oltuchkoe, 19- Grekhovskoe, 20- Mochno. Ukrainian SSR: 1- Makovich, 2- Svyatoe, 3- Hobit, 4- Ostrovenskoe, 5- Mezhleskoe, 6- Dvirskoe, 7- Baby Mokh, 8- Zgar, 9- Girlovoe, 10- Plav, 11- Vily, 12- Kuschevka, 13- Muravskoe, 14- Mokhovatoe, 15- Troitskoe, 16- Andreyevski Sukhoi Liman, 17- Kardashinskoe, 18- Stoyanov, 19- Zaloźtsy, 20- Gelmiazevskoe. Russian SFSR: 1- Mutnoe, 2- Kasklya, 3- Chistic, 4- Gubinskoe, 5- Nero.

tion (in the Soviet Union calcareous deposits are common between 52° and 62°N) lacustrine lime is absent in these lakes.

Beside the above-mentioned three biotic zones 12 natural-geographical regions have been distinguished. The northernmost type regions (Ko a-e, Fig. 1), located in the tundra and woodland tundra subzones, are characterized by socle deeply disjointed peneplain on Precambrian crystalline rocks covered by glacial and aqueoglacial deposits.The accumulation of peat deposits here started only in the Subboreal period, at least it was so in the Ura-Guba mire (Lebedeva, 1987). The western part of the Kola peninsula is characterized by hummocky relief with rocky heights. In this region the accumulation of peat deposits in the vicinity of Imandra lake started in the Boreal (Lebedeva, 1987). The stratigraphy of lacustrine deposits has been studied at the boundary of the type regions Ko-e and Ko-j on Kovdor tableland (Евзеров, и др., 1983). In the northwestern part of the Imandra lake basin a thick diatomite layer (12-13 m) has been discovered and its bottommost part has been studied in detail. According to palynological and microfossil data the deposition of diatomite started in the Atlantic period. Among diatoms prevails Fragilaria (90-95%), among pollen and spores - Lycopodium (73%). During the Atlantic period pine and birch forests were dominating.

In the Khibines and in Lovozero region the middle block-mountains with intensive glacial and nival activity traces are widely spread in the western part, whereas socle ouval plains, limnoglacial and lacustrine alluvial lowlands are characteristic of the eastern part. According to R. Lebedeva (1987) the accumulation of peat deposits in Umbozero region started in Atlantic period. The territory of the Terski region (Ko-e) is mostly covered by limnoglacial and alluvial lacustrine deposits with kames and moraine hills. In the mire in the middle course of the Olenitsa River organogeneous accumulation started not until the Atlantic period.

Related accumulation of lacustrine and peat deposits is caused by the fact that the whole peninsula was released from ice during the Preboreal and Early Boreal only. After the retreat of ice and marine water the primary vegetation started to form, which by the end of the Boreal became differentiated into tundra, woodland tundra and northern taiga communities. During the Holocene climatic optimum the forest limit extended nearly as far as the Barents Sea coast (Лебедева, 1983). The vegetation was dominated by birch with pine acting as a subdominant. Due to the climatic deterioration in the Subboreal the tundra and woodland tundra area increased and their boundaries shifted southwards reaching their present-day position in Subatlantic period (Elina, 1987).

The Karelian ASSR lies within the northern and middle taiga subzones. It has an area of 173.300 sq.km, the number of lakes 61,855 with their total area reaching 16,000 sq.km. Typical components of the Karelian landscape are coniferous forests, lakes (19.2%) and mires (30%). Mesotrophic lakes with medium mineralization degree of lake water are prevailing. The share of organic matter and organogeneous lacustrine deposits has increased in comparison with that on the Kola peninsula. The main types of lacustrine deposits are gyttja, peaty gyttja, clay gyttja with ferromanganese crusts and nodules in the upper part of sequences (Штеренберг, 1979). Terrigenous deposits are found in the littoral zone of large lakes.

During the previous hundred years the largest lakes, Ladoga and Onega, were subjected to a great number of geological and palaeogeographical studies, and so the history of these lakes has been elucidated. At the same time there is almost no material available in scientific literature concerning the geological history of small lakes. The studies on small lakes started only some years ago in the northern and western parts of Karelia in the frontal zone of Salpausselka I and II (Экман и др., 1983) . Two main types of bottom deposits have been distinguished: 1) the lakes with continuous sedimentation and transitional contact between sand, silt and gyttja without any traces of hiatus, and 2) the lakes with a sharp contact between the minerogenous and organogenous deposits, sometimes with a peat layer between them (Экман и др., 1983). The lakes mentioned first, are characteristic of glaciodepressions covered by tillbeds,the latter are located in the kettle holes of outwash plains and kame fields.

In Karelia, as in all the regions, once covered by ice, the formation of lake basins is closely connected with the deglaciation of the area. As it has been elucidated in the marginal zone of Salpausselkä I the development of lake basins started 10,800-10,700 B.P., in the Salpausselkä II zone - about 9800 B.P. In the hummocky relief, where buried ice preserved in hollows, the lake basins formed later, 9500-9300 B.P., in typical kettle holes (glaciokarstic hollows) - 8100-7400 B.P. (Экман и др.,1983). Due to the above-mentioned reasons only the overgrown lakes and mires (altogether 20) have been suggested as reference sites by G. Elina. Five type regions (Ka a-e) with 11 reference sites are located in the northern taiga subzone with moraine plains, frontal marginal formations, eskers and undulating denudational-tectonic and structural-denudational relief in the western part, limnoglacial plains and marine aggradational and abrasion-aggradational plains in the east (Lukashov, Ekman, 1982). According to the data available (Элина, 1981) four of these reference sites (Solnechnoe, Nosuo, Mini-Tumba, Rugozero) are overgrown lakes, the others are mires in which the sedimentation of organic deposits started at different time between the Preboreal and Atlantic periods.

In South Karelia within the middle taiga subzone 7 type regions (Ka f-l) with 9 reference sites have been selected out, among which Punozerka, Nenazvannoe, Mustusuo, Verhovoi, Gotnavolok, Dlinnoe and Koppalasuo are overgrown lakes. The moraine plains with eskers, ice dividing aggradational uplifts and limnoglacial plains are the most common relief forms here (Lukashov, Ekman, 1982). As the main results obtained through the investigation of the above-mentioned reference sites are presented by G. Elina and L. Filimonova (1987) we would like to confine ourselves with mentioning that the formation of minerogenous deposits started probably in the Alleröd (Shombasuo, Gotnavolok) however, the onset of the accumulation of the organogenous deposits commonly falls into the Boreal, more seldom into the Preboreal.

In the Estonian SSR there are approximately 1500 lakes and 20,000 bog-pools with an area of 2130 km^2, which makes up 4.8% of the total area of the republic. At the beginning of the Holocene the area of lakes was thrice as much as it is nowadays, since 40% of mires formed due to the overgrowing of lakes (Veber, 1970). The overwhelming majority of Estonian lakes are of glacial origin, at the same time the number of relict lakes resulting from neotectonic uplift of the Earth's crust in the coastal area of the Baltic Sea, is also remarkable. Estonia belongs to the Boreo-nemoral biotic zone of mixed forests in the West and East Baltic region with their boundary being quite close to that of Lower and Upper Estonia (Tammekann, 1933). The former comprises the lower coastal area and inland depression, which during the late-glacial and Holocene were submerged by the waters of the Baltic Ice Lake and the Baltic Sea. Within these two main units 7 type regions with 21 reference sites have been distinguished (Saarse, Raukas, 1984).

The most profoundly studied lake area of Estonia is the Saadjärv drumlin field with continuous lacustrine sequences from the Older Dryas (Pirrus, et al., 1987). In Estonian lakes the late-glacial part of the sequences is represented by minerogenous deposits, usually by grey or greenish-grey silts and sands, frequently laminated by dispersed organic matter in Alleröd and Bryales moss remnants in Younger Dryas sediments. The lacustrine sediments are underlain by till, fluvioglacial and limnoglacial deposits. The transition from glacial deposits to lacustrine ones is lithologically well marked by replacement of brownish till or varved clay by grey silt or clay. Late-glacial lacustrine deposits are characteristic of the lakes which basins are located on the glacial insular heights, uplands or plains, whereas they are very thin or entirely absent in lakes of outwash plains and kame fields. Organogenous and calcareous sedimentation in Estonian lakes started in the Preboreal or at least in the Boreal, and so the late-glacial and postglacial boundary is rather sharp, marked by the replacement of minerogenous sediments by organogenous or calcareous ones. The most widespread Holocene lacustrine deposits here are gyttja and lacustrine lime and numerous facial varieties between them. In the littoral zone of large lakes one can also meet terrigenous sediments. The total thickness of lacustrine sediments in Estonian lakes is usually 3-5 m, rarely more than 10 m (Soitsjärv, Kariste) with the maximum thickness reaching 18 m in drainage lake Väimela. Some results of the investigation on Estonian lakes are presented in the papers by R. Pirrus et al., J.-M. Punning et al. and E. Ilves, H. Mäemets, in the present volume.

The Latvian SSR. The lakes, about 3000 in number make up about 1.5% of the territory of the republic. Up to now the number of palynologically studied lakes and mires exceeds 100, but unfortunately, they do not meet the demands of IGCP Project No. 158. The oldest lacustrine deposits studied by V. Stelle (Стелле, 1966; Даниланс, Стелле, 1967) have been formed in the Alleröd interstadial (Bata, Shkervelis, Dukulupite). The late-glacial is represented in sequences by minerogenic deposits, according to T. Bartosh (Бартош, 1976), in some places also by calcareous deposits, which at the beginning of the Holocene were replaced by organogenous and calcareous deposits. Lacustrine deposits are underlain by till, fluvioglacial and limnoglacial sediments. On the bottommost part of organogenous lacustrine sediments there is also Hypnum peat, woody Hypnum or hypnum-sedge peat layer with a thickness of 0.1-0.3 m (Мейронс, Страуме, 1979). The most common lacustrine deposits in Latvia are gyttja, peaty gyttja, calcareous gyttja, silty gyttja, lacustrine lime, silt, sand and clay, very rarely coarse minerogenous sediments with their total thickness varying from 0.5-1.0 m up to 6-8 m, maximum 10-14 m (lakes Kivdulju, Rimshu). The lacustrine deposits, usually in shallow lakes with calcareous-rich sediments in the littoral zone, are characterized by a distinct facial transitions of deposits from sublittoral up to profundal zone.

On the basis of pollen and spore diagrams from 34 sites which cover almost evenly the whole territory of the republic an average pollen diagram was compiled and some regional peculiarities in the composition of palynozones in different parts of republic were pointed out (Даниланс, Стелле, 1971).

Research on lakes and mires in Latvia came to a standstill in the seventies, a new rise was observed at the beginning of 1980ies. The researchers from the Institute of Lake Research (Leningrad) performed studies on six small lakes on Latgale Upland (Sergeeva et al., the present volume). Unfortunately, only the Holocene part of these lake sequences has been dealt with. One of the most profoundly studied lake basins in Latvia is that of Lake Lubanas (Fig., La-e) on the lowland of the same name. As a result 10 pollen and spore diagrams were compiled and 38 ^{14}C datings performed (Ильвес, Медне, 1979). The age of 13 dwellings dating back to the Stone age was established (Лозе, Эберхардс, 1983). At the end of the Alleröd the large limnoglacial water body drained and small residual lakes including Lake Lubanas remained. In the Early Holocene ancient dwellings were erected around Lake Lubanas. Lithological, biostratigraphical and levelling data refer to four transgressions in the Early Mesolithic, Early and Middle Neolithic stages and during the Bronze age, and to two regressive phases in the Late Atlantic and at the beginning of the Subboreal. After the Early Mesolithic transgression the formation of lacustrine clay, silt and sand, calcareous rich clay and lake marl took place. Succeedingly, during the next 3000 years the gyttja deposited. In the Late Atlantic period due to high water level the basin of Lake Lubanas started to overgrow and the dwellings were buried under the peat.

In Latvian SSR 8 type regions with 4 reference sites have been selected (Fig.).

In the Lithuanian SSR the number of lakes exceeds 3000 and they make up 1.5% of the territory of the republic. The trophic stage of lakes varies from oligotrophic to ultraeutrophic, and the mineralization degree of lake water shows also differences. Lacustrine deposits are represented by gyttja, peaty gyttja, calcareous gyttja, lacustrine lime, sand, silt, clay and gravel. Ferrogenous and siliceous rich (diatomite) deposits are not typical of this area. The thickness of lacustrine sediments reaches 38.5 m, being 6-8 m on an average.In the majority of lakes the deposition of lacustrine sediments started in the Older Dryas or Alleröd (Zhuvinta, Druksniai, Glukas, Varenis,Sietuva)(Кабайлене, 1969). In the overwhelming majority of lakes the late-glacial sediments are represented by minerogenic deposits but there are a lot of lakes where peat formed during the Alleröd.The Alleröd beds rich in plant remains serve as a stratigraphic marker in the correlation of different sequences.

Since the Lithuanian territory recovered from ice earlier than the other Baltic Republics it is natural that the formation of not only organogenous but also calcareous deposits started here earlier - in the Younger Dryas or in the Alleröd. Intensive calcareous sedimentation took place in the Preboreal and Boreal periods which in the Atlantic period in the majority of lakes was replaced by organogenous sedimentation with its maximum falling to the Subatlantic period (Гарункштис, 1975).

Considering the peculiarities of topography six type regions

with 17 references sites have been suggested by M. Kabailiene and J. Tamoshaitis. These sites include mires, overgrown and modern lakes. Mostly the data on these reference sites have been published already (Кабайлѐне, 1969;Кабайлене, 1983; Kabailiene et al.,1987; Tamoshaitis, 1987). According to the results obtained in the Older Dryas the territory was covered by stunted tundra and woodland tundra species with rare Betula and steppe elements. The lake basins were fulfilled with dead ice blocks buried under tills and aqueoglacial deposits. In the Alleröd the intensive melting of buried ice and sinking of lake basins took place. Sand, silt, calcareous mud and peat accumulated in lake basins. Pine and birch were spread, and formed evidently forests. Due to Younger Dryas cooling the glaciokarst processes decreased and the sedimentation of organogenous-rich lake deposits developed. Minerogenic sedimentation in lakes represented by silt, sand and clayey deposits continued. In the local vegetation the forestless communities were prevailing with sparse birch. Diatoms were dominated by Fragilaria, Navicula and Amphora sp. In the Preboreal after the final amelioration of climate glaciokarst processes and the formation of kettle holes came to an end. In lakes the sedimentation of gyttja or lacustrine lime prevailed with diatom flora characteristic of oligotrophic lakes. Pollen spectra were dominated by birch with pine acting as a subdominant. All these processes continued in the Boreal being accompanied by intensive paludification and overgrowing of lakes. The forests consisted mainly of pine, since the second half of the Boreal - from pine and hazel. The amount of diatoms and their taxa, especially planktonic algae decreased, referring to the lowering of water level in lakes. During the Atlantic period the formation of gyttja and peat in the lake basin prevailed accompanied by accumulation of calcareous deposits in the shallow littoral zone. The lake level was presumably high since the diatom flora was abundant. Broad-leaved trees reached their maximum. In the Subboreal the accumulation of organogenous deposits in lakes continued, at the same time these lake basins experienced extensive paludification. The lake level was low as can be judged by the decline in the diatom flora, planktonic and pelagic species in particular. The share of broad-leaved trees decreased with contemporaneous increase in hazel and afterwards in spruce. During the Subatlantic period the above-mentioned processes progressed in lakes, the lake level evidently rose and the number of planktonic diatoms increased. In the forest the share of hazel and spruce diminished due to the prevalence of pine and birch (Кабайлене, 1969, 1983, etc.).

The Kaliningrad province with area of 15,100 sq.km located on the coast of the Baltic Sea, west of Lithuania is rich in lakes as well. Here one can enumerate about 400 lakes with an area less than 10 ha. The main stratigraphical and palaeogeographical features of five lakes have been studied (Шестакова,Еловичева, 1975). Lakes Vysynetskoe, Russkoe, Borovikovo and Rogovoe are located in the southern part of the province in the area of hummocky moraine relief. Lake Uzkoe lies in its north-western part. The deposition of lacustrine deposits started in Lake Uzkoe in the late-glacial, in the most of others - in the Preboreal. According to palynological and lithological data this area was covered in the Younger Dryas by sparse birch and pine, a lot of lake basins were filled with ice and sandy-clayey deposits accumulated in once formed basins. Like in Lithuania the beginning of the Holocene was characterized by intense development of birch as a dominant and pine as a subdominant. The formation of glaciokarst hollows came to an end. Since the two Lithuanian reference sites lie quite close to the borders of the Kaliningrad province they characterize the environmental and climatic changes in the Kaliningrad province as well, and for this purpose no special reference sites have been suggested there.

The Byelorussian SSR lies within the mixed and broad-leaved forest zones. Here proceeds the limit of the Valdai (Weichselian) glaciation. There are about 10,000 lakes in Byelorussia with an area of 2000 sq.km. Without any doubt, it is the region where lakes have been studied more profoundly than in any other part of the Soviet Union. At the same time it is the only republic where mostly modern lakes, 17 altogether, were suggested as reference sites. The main results of deglaciation, formation of lake basins and sedimentary features are discussed in the paper by O. Jakushko (1987), the problems concerning vegetation history and climatic changes during the late-glacial and Holocene with the calculations of climatic parameters are treated in the paper by Y. Elovicheva and I. Bogdel (1987), and the diatom successions in the paper by B. Vlasov and G. Khursevich (1987).

The Ukrainian SSR is located beyond the boundaries of the Valdai glaciation and it belongs to the broad-leaved, steppe and woodland steppe subzones. Lakes, more than 3000 in number, area 2000 sq.km, are located mainly in the northern part of the republic, in the area of the Ukrainian Polesye. Beside such large lakes as Svitjaz, Pulmo, Somino there are also about 300 small lakes with an area below 10 ha. But also these modern lakes are shallow with their basins being fulfilled with sediments and they have reached the age of senility. In the Polesye region S. Turlo and M. Veklich have selected 5 lakes and one lake/mire as reference sites. Due to arid climate, good drainage and smooth surface relief there are a few lakes left in the woodland steppe and steppe zones. They are assembled in river valleys and serve as typical oxbow basins. So it is quite natural that 10 mires have been suggested as reference sites for this area. The thickness of peat deposits in these mires varies from 2.8 m up to 12 m. The formation of mires Zgar, Girlovoe and Troitskoe dates back to the Alleröd, that of the mires Vily and Mokhovatoe - to the Atlantic. The development of mires has been dealt with on the basis of palaeogeographical evidence by Artjushenko et al. (Артюшенко и др., 1984).

The lakes of the Polesye region have been studied by A. Artjushenko (Артюшенко, 1975) and the following survey is based on her paper. As it was mentioned above the lakes in the Polesye region are shallow, 1-1.5 m in depth, the basins are fulfilled with deposits up to 14 m in thickness and all these lakes are at the latest stage of overgrowing. Often the water surface is carpeted by plants and littoral zones are rich in macrophytes. The bottomset beds of the lakes Makovich, Svjatse and Hobit consist of Alnus, Quercus, Tilia,Corylus pollen with the admixture of Picea. Such pollen composition with Artemisia, Chenopodiaceae and Ephedra corresponds to mixed forests. During the Alleröd the pine-birch-oak forests were widely spread in Polesye. Lakes were shallow with quaking Hypnum carpet and moderate planktonic diatoms (less than 15%). In the Early Holocene the western part of Polesye was covered by pine-birch forests with steppe patterns, in the lakes Hypnum moss, Carex, Typha and other macrophytes and cryophytic diatoms were spread. At the end of the Early Holocene the water level rose and several new basins, such as Dvirskoe and Ostrovenskoe were filled with water. In the Middle Holocene the area of broad-leaved forests widened and they spread all over the Northern Ukraine. According to macrofossil analysis the share of Hypnum,Sphagnum, Graminae, Carex, Phragmites, Scheucheria, etc. was also remarkable. The number of planktonic diatoms diminished down to their complete disappearance. Lake sediments were represented by peaty gyttja with Hypnum, Phragmites, Carex, etc. remnants. The next rise in water level occurred in the Late Holocene. The quantity of plant remnants (Nymphea, Potamogeton, etc.) increased, the blue-green algae disappeared and once more the number of planktonic diatoms increased. Paludification of lake basins was in progress and the uppermost part of lake sediments was rich in coarse detritus. Lately the Holocene vegetation history of the whole Ukraine was clarified (Артюшенко и др., 1984).

In view of natural zonality of the European part of the Russian SFSR, geological and geomorphological peculiarities of the relief, resulting from different glaciations, 8 lake districts with several smaller units within them have been distinguished (Квасов, 1987).The overwhelming majority of lakes are located in the area once covered by ice, in steppe, woodland steppe and steppe-desert subzones there are a few lakes left and several of them with brackish water.The formation of lakes of this area continued and came to an end at different time, mostly between 12,000 and 8000 years B.P. in connection with ending up of glaciokarst processes.

<u>The lake district of the Far North-East</u> (Fig. R-a) lies in the tundra and woodland tundra subzones, washed by the waters of the Barents Sea in the north and bounded by the rivers of Usa, Pechora and Tsilma in the south. This area was covered with inland ice,which retreated rather slowly at the end of the Preboreal. There are a great many lakes left in the Bolshezemelskaya and Malozemelskaya tundra regions due to permafrost pattern and disjointed relief, especially in the ice marginal zones. In the coastal area of the Barents Sea the relict coastal lakes, lately isolated from the sea, are common. Their

deposits are represented by gyttja, clayey and sandy deposits with ferromanganese crusts. Unfortunately, those layers haven't been subjected to stratigraphical studies so far.

<u>North-western lake district</u> (R-b) borders on the ice marginal zone of Valdai glaciation along a line which runs through Pskov,Staraya Russa and Vesegonsk and coincides with it in the south-east. In this district several smaller units have been differentiated, first of all the largest lake basins, such as those of Onega and Ladoga, big lake basins, such as Peipsi and Ilmen on the watershed of the Gulf of Finland, and lakes Beloe, Kubenskoe, Vozhe and Lacha on the watersheds of the rivers Sheksna, Sukhona, and Onega. Geological history, bottom deposits and sedimentational peculiarities of these lakes have been studied in detail, but because of their large area they do not meet the demands of reference sites. Lakes on the lowland, on the watershed of the Gulf of Finland (Fig., R-b_4) are scattered over the territory west and south of Lake Ladoga. On the Karelian Isthmus there are approximately 700 lakes, out of which the lakes of Krasnoe, Lopata, Glukhoe, Vuoksa, Blagodatnoe, Vishnevskoe and Maloe Kirillovskoe have been subjected to stratigraphical studies (Малясова,Спиридонова, 1967;Малясова, Соколова, 1967, etc.). According to the data obtained late-glacial freshwater bodies existed here in which the laminated deposition of silt and clay was frequent. At that time the pollen spectrum was dominated by tree pollen, mostly Pinus (maximum 50-70%) with the admixture of grasses and spores up to 40-50%. Among the grasses the pollen of Artemisia, Chenopodiaceae, Gramineae, Plantago, Filipendula, Ephedra, Helianthemum,etc. is remarkable, showing that these sediments are of the late-glacial origin.

In the Younger Dryas the sparse vegetation with birch shrubs and grasses were spread forming 25% of the total amount of pollen.In the Preboreal the intensive distribution of forests began. The northern part of the isthmus became covered by birch forests and meadows with abundant Artemisia and Chenopodiaceae in places. The southernmost part was occupied by pine forests (80% of the pollen) with Carex, Gramineae, etc. among the nonarboreal pollen (NAP). Due to the climatic amelioration in the Boreal the pine expansion continued and it occupied vast areas all over the isthmus. Among NAP Gramineae, Rosaceae, etc. were common. It was a very important phase in the development of lakes as the minerogenous sedimentation became replaced by the organogenous one which has continued up to the present. In the Atlantic period the forests were represented by hazel, birch and broad-leaved trees (5-10%). The composition of grasses remained similar to that in the Boreal. In the Subboreal the pine curve culminated at the background of the decrease in hazel and broad-leaved trees (1-4%) as well as grasses. The same tendency was in progress in the Subatlantic period when pine became again to dominate in the forests.

Lakes in the ice marginal zone of the Valdai glaciation (Fig., $R\text{-}b_{1-3}$) are mostly assembled on the inland heights of Vepsa, Valdai, etc. Most of them are comparatively small with the area less than 0.5 sq.km with moderate mineralization of lake water, that greatly depends on the geological-geomorphological structure of an area. Silt, clay, silty and clayey gyttja with ferromanganesian crusts and nodules and terrigenous facies in the littoral zone are widespread in these lakes. Southward the role of organogenous deposits gradually increases, but this general trend is interrupted in places by differences in sedimentational processes of several lakes. The stratigraphy and geological history of these lakes has not been cleared up. The main features of development of glaciokarst lakes on Vepsa Heights have been elucidated by G. Kulikov and pollen and spore analysis of lake and mire deposits of the Iksha depression have been carried out by E. Devyatova.

There are a few lakes in the district of the taiga zone, beyond the limits of the Valdai glaciation (Fig., R-c). The formation of these lake basins has been predetermined by the processes typical of the periglacial zone. A lot of lakes are of karst origin formed after the melting of permafrost. The lake water is rich in minerogenous compounds, especially in comparison with that in the western area. In general, bottom deposits in northern lakes are represented by peaty gyttja, in southern lakes by algal gyttja. Studies have been performed on the lakes Galichskoe, Ustchemerovo, Sindorskoe and Svetloe (Кордэ, 1956, 1959; Смирнова, 1981, etc.).

The southern and eastern borders of the North-West lake district of Boreo-nemoral (mixed forest) zone (Fig., R-d) coincide with the maximum limits of the Valdaian glaciation. On the watershed of the rivers Velikaya and Lovat ($R\text{-}d_1$) there are a few lakes left, most of them are already overgrown. Their development has been touched upon in the literature very briefly (Lesnenko, 1987). Contrary to Valdai ice marginal zone the Heights of Bezhanitski, Sudomi and the southern part of Valdai Upland are rich in lakes. Lakes Seliger, Mutnoe, Kasplya and mire Chichik have been investigated in greater detail (see Kremen et al., 1987) and the latter three also serve as reference sites. The beginning of the accumulation of lacustrine deposits is dated back to Bölling and Alleröd when the gyttja clay and silts were deposited. In sediments of the Early Holocene age the carbonate content is higher, in sediments of the Middle and Later Holocene the role of organogenous matter has increased. In dependence of the hydrographical regime of lakes the degree of fulfillness is different, in the lakes with slight drainage the thickness of deposits reaches 2-3m in lakes with intensive drainage - 3-5 m (Малясова и др., 1983).

The lake district in the Boreo-nemoral zone in the Middle Pleistocene glaciation area and its periglacial surroundings ($\bar{R}$-e) is poor in lakes. At the same time lakes Nero and Tatischevo investigated here, are of the utmost importance while studying glacial history of the area. 100 m thick core of terrigenous, carbonate and siliceous deposits, and deposits rich in organic matter have been discovered in the depression of Lake Nero formed during the Middle and Late Pleistocene and Holocene (Алешинская, 1974). The area of modern Lake Nero is 517 sq.km, average depth 1m, maximum 4m. It is a highly eutrophic lake with mineralization of water reaching up to 1000 mg/l and with diatom flora typical of this trophic stage (Гунова, Лефлат, 1983). Still at the late-glacial/post-glacial boundary it was a rather deep (ca 20 m) oligotrophic water body with diatom flora typical of periglacial lakes (Алешинская,Гунова, 1975). During the Younger Dryas, Preboreal and Boreal 12 m-thick dark grey and calcareous clay ($CaCO_3$ - 40%) was deposited. At the beginning of the Atlantic period calcareous gyttja started to deposit, in the Subboreal - peaty gyttja (Aleshinskaya et al., 1987).

According to palynological data Lake Nero district was covered in the Alleröd with forest communities which degradated in the Younger Dryas. In the Preboreal the birch forests with meadows culminated. Dense forestation started in the Boreal when the birch and pine forests spread. As in the whole investigated area the broad-leaved trees immigrated during the Atlantic period. In the lakes planktonic diatoms of the Early Atlantic period became replaced by the shallow water taxa. Distinct reorganization of diatom flora took place in the Subboreal simultaneously with the beginning of the formation of detritus gyttja. There appeared significant changes in the constituents of forests as well, first of all the reappearance of spruce forests, which in the Subatlantic period were replaced by mixed forests of pine, birch, spruce and Quercus mixtum (Aleshinskaya et al., 1987).

Despite the general tendency of filling the lake basin with sediments, the transgressive (PB, BOI, ATI, SBI) and regressive (BOII, SBII, SA middle) phases in the history of Lake Nero have been distinguished (Алешинская, Гунова, 1975). Transgressive phases occurred during the humid and cool climate regressive - during the arid and warmer climate.

In Lake Tatischevo which recently underwent complete drainage the sedimentation started at least at the end of the Middle Pleistocene (Семененко и др., 1981). The maximum thickness of gyttja (40 m in Lake Somino) is related to the Holocene (Нейштадт и др., 1965; Хотинский, 1977). The lakes Glubokoe, Nerskoe, Beloe and Kosinskoe in the vicinity of Moscow were also subjected to detailed geological and palynological investigations (Щербаков, 1967; Кордэ, 1959; Успенская, 1980, etc.). The development of these lakes started at the end of the late-glacial or at the beginning of the Holocene when the permafrost melted and karst processes started. In Smolensk region lakes of the Alleröd age have been studied (Kremen et al., 1987). Lakes in the middle course of the Volga River are of oxbow and karst origin. Karst process is going on at present as well.

In woodland steppe (R-g) there are only a few lakes left on the terraces of river valleys. Most of them have overgrown. T. Serebryannaya (Серебрянная, 1976) has studied the stratigraphy of lake deposits on the Central Russian Upland.

Steppe zone (R-h) is characterized by a very small number of lakes among which the oxbow lakes are dominating. Unfortunately their stratigraphy, geology and molluscs fauna have been studied very fragmentarily without any profoundity about their deposits. The same can be said about Steppe-desert (R-i) where are typical oxbow lakes in river valleys and delta plain of the rivers of Volga and Ural. In some lakes the mineralization of lake water is so high that they belong to the brackish lake group. Among them Lake Elton and Lake Baskunchac have been studied more completely (Васильев, 1955; Семихатов, 1933). The thickness of their deposits is over one hundred meters, but their stratigraphy has not been elucidated yet.

Summing up the results obtained through the investigation of lake and mire deposits in the European part of the USSR we would like to outline the importance of these deposits as they carry the information on the late-glacial and Holocene stratigraphy, palaeogeography and climate. In this aspect lake and mire deposits are more completely investigated in Byelorussia, Lithuania, Estonia and Karelia, where the obtained material is also generalized, the regional features of vegetational history in time and space have been elucidated, on the basis of biostratigraphical data (subfossil molluscs, diatoms, macrofossils, etc.) the environmental reconstructions and the calculations of palaeoclimatical parameters are in progress (Klimanov, 1987). In comparison with these, lakes in the north and south of the East-European lowland are studied unsufficiently so far. On the basis of the data obtained we are able to conclude that during the Valdaian (Weichelian) glaciation under the conditions of arid and cold climate the permafrost phenomena spread over a large periglacial area. At that time a lot of proglacial lakes existed but the ice-free area actually lacked small typical lakes. Lakes Nero, Tatishchevo, Elton and Baskunchac and possibly a few more lakes existed there during the Valdaian glaciation. The overwhelming majority of lakes formed during the late-glacial and Early Holocene.

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УДК 551.794:551.8:556.5/212/

ПРЕДВАРИТЕЛЬНЫЕ ДАННЫЕ ОБ ИЗУЧЕНИИ ТИПОВЫХ РАЗРЕЗОВ И РАЙОНОВ В ЕВРОПЕЙСКОЙ ЧАСТИ СОВЕТСКОГО СОЮЗА

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Резюме

Рассматривается история развития озер и болот в Европейской части Советского Союза за последние 15 000 лет. Выявлены наиболее характерные черты развития растительности. Представлено природное районирование рассматриваемой территории и список типовых разрезов, изученных в рамках проекта № 158 МПГК.

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BOTTOM DEPOSITS AND PALAEOLIMNOLOGY OF LAKE NERO

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Lake Nero is situated in the Yaroslavl Volga region in the north of the subzone of mixed coniferous-broad-leaved forests. Its area is 51.7 sq. km, the typical depth - between 0.7 and 1.2 m. The absolute height of the water edge is about 93 m. It is a drainage lake. The sum of the mineral substances dissolved in the lake's water is about 200 mg/liter. By the composition of the water, the lake belongs to the class of hydrocarbonate ones,and by its physico-chemical properties - to eutrophic water basins.

The lake basin in the Rostov depression has existed uninterruptedly since the end of the Middle Pleistocene or, to be more precise, since the period of degradation of the Moscow glacier. A 100-meter layer of deposits has accumulated during that time. On the basis of a comprehensive study of these deposits the history of the lake during 150,000 years has earlier been reconstructed (Алешинская, Гунова, 1976).

This paper is devoted to the results obtained through a detailed study of the 30-meter layer of Lake Nero's deposits that have accumulated during the past 15,000 years. For the study a complex approach was used including granulometric, mineralogical, geochemical, palaeontological (palynological, palaeoalgological and among them diatomic and carpinological), archaeological and radiocarbon analyses.

Four stages characterized by accumulation of different types of deposits may clearly be distinguished in the history of the lake.

The first stage is between 9,000 and 15,000 B.P. (the Early Dryas and Preboreal periods). Dark gray clays with a low content of calcium carbonate (less than 8%) and organic matter (less than 3%) have accumulated in the lake during that time. The thickness of these terrigenous deposits is about 12 m. In the composition of the sand fraction of these deposits, alongside quartz (60 or 70%), there is

a considerable amount of feldspars (between 20 and 25%).

The following cryophitic species predominate in the diatomaceous flora Cocconeis disculus (Schum.) Cl., Navicula scutelloides W.Sm., Melosira scabrosa Ostr., Opephora martyi Herib. and others, which means that at that time the lake had the features of a deep, periglacial oligotrophic basin poor in flora and fauna (Fig. 1).

In the spore and pollen spectra of Preboreal time, as well as in all the above layers, there is a complete predominance of the pollen of arborescent species and a sharp decrease of the grass pollen (Fig. 2). Such a regularity may be traced in many diagrams of the Central part of the East European Plain and it corresponds to the transition from practically treeless landscapes of the Late Pleistocene to the forest landscapes of the Holocene. Judging by the composition of the pollen and spore spectra, in Preboreal time there were mainly birch forests along the shores of the lake. In some parts yernick thickets of dwarf birches and herbaceous groups were preserved. The climate was colder than at present, but it proved changeable. The increase in the share of tundra (low shrub species of birches) and steppe (wormwood and Chenopodiaceae) elements in the spectra of the second half of the period shows that there was a partial restoration of the periglacial plant complex associated with the Pereslavl cooling coming after the Polovetsk warming (Хотинский, 1970).

The second stage is between 8,000 and 9,000 B.P. (the Boreal period). During that time gray carbonate clays about 6 m in thickness formed in the lake. In the first half of the period the content of $CaCO_3$ in them increased up to 45% and in the second half of the period it fluctuated between 35 and 40%. As in the earlier period, the amount of organic C didn't exceed 3%. The granulometric and mineralogical composition was on the whole analogical to that of the underlying stratum. At the beginning of the Boreal tourmaline made the appearance and at the end of the period the share of authigenous minerals and primarily of pyrite increased.

This period marks the beginning of the eutrophication of the lake. Diatoms were dominated by the species of the littoral of transparent oligotrophic basins: Navicula scutelloides W.Sm., Opephora martyi Herib., Melosira italica subsp. subarctica O. Múll., especial-

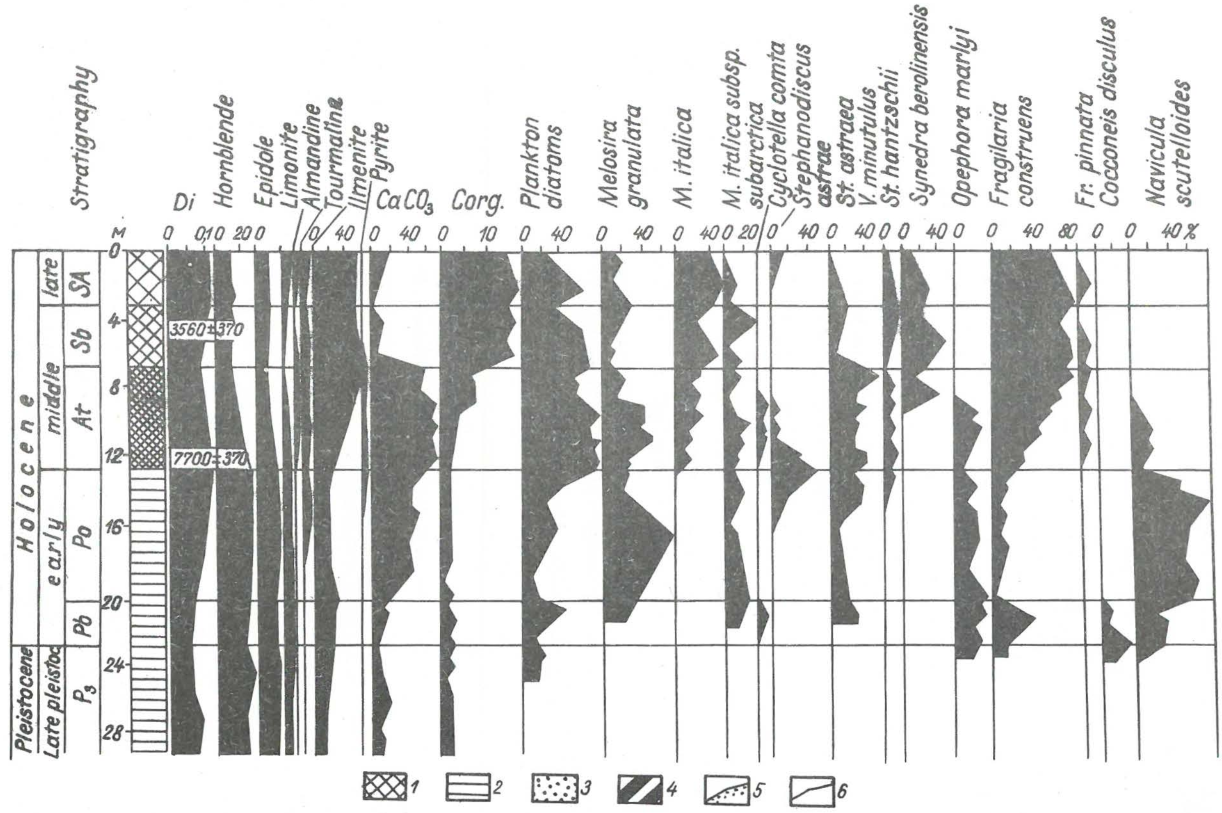

Fig. 1. Mineralogical composition and diatom flora of Lake Nero. Legend: 1 - sapropel (gyttja), 2 - clay, 3 - sand, 4 - arboreal pollen, 5 - polleh of herbs, 6 - spores.

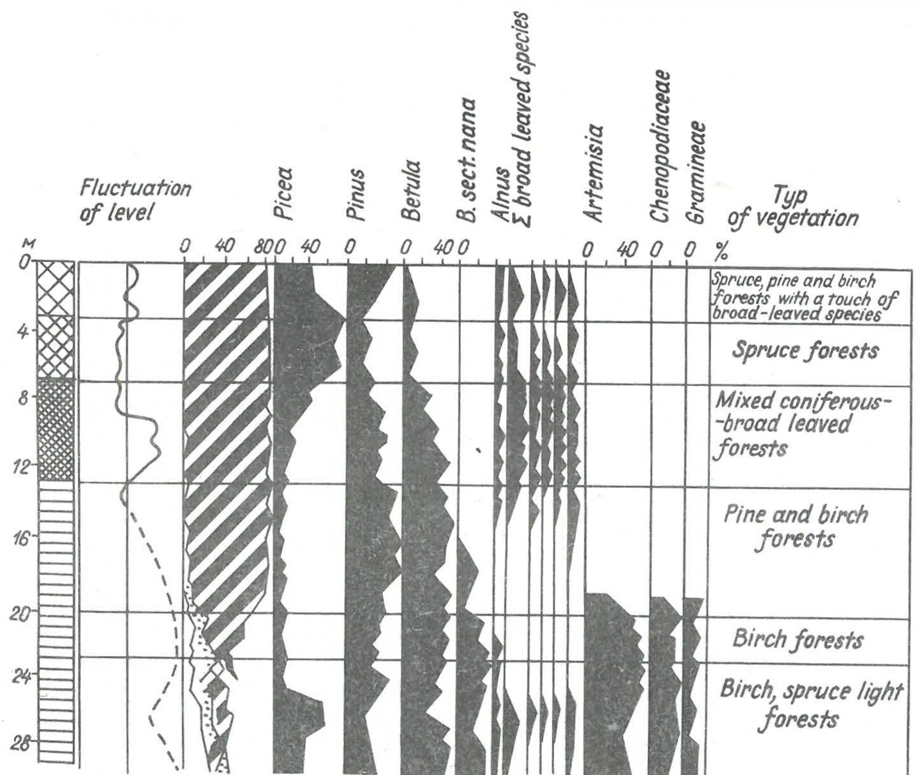

Fig. 2. Lake level fluctuations and vegetational history of Lake Nero. Legend see Fig. 1.

ly in the second half of the period (Fig. 1). At the same time, temperate and temperate-heat requiring plankton species, characteristic of eutrophic basins, became more numerous: Melosira granulata (Ehr.) Ralfs., Melosira italica (Ehr.)Kútz., Stephanodiscus astreae (Ehr.) Grun., especially in the second half of the period. The composition of diatoms allows to presume a higher level of Lake Nero in the first half of Boreal time, when the following species predominated among the planktonic ones: Melosira granulata (Ehr.)Ralfs., Melosira italica (Ehr.)Kútz., Stephanodiscus astreae (Ehr.)Grun. In the second half of the period the level of the lake dropped. At that time littoral and bottom species were very diverse including several temperate and thermophilic ones.

The pollen and spore spectra of the deposits of Boreal time are distinguished by the predominance of pine and birch pollen. The pollen of dwarf birches gradually disappears giving place to that of broad -leaved species. The pollen of herbaceous plants, and above all of xerophytes, is represented by single grains. Forests of pine and birch occupied a dominating position in the studied region. In the second half of the period there appeared an admixture of broad-leaved species. The climate was similar to the present one, but somewhat colder.

The third stage - from 4,500 to 8,000 B.P. (the Atlantic period). Beginning with the Atlantic period carbonate sapropels (6.5 m in thickness) began to accumulate in the lake. The maximum gross content of carbonate in the section is 83%. Changes are observed in the composition of the clay fraction. First of all the role of limonite increases due to transformation of other minerals. The appearance of limonite points to the replacement of the reduction conditions by oxidizing ones. The content of hornblende and epidote sharply decreases. There is also a decrease in the role of disthene, tourmaline, almandine and zircon. As pointed out by E.A. Vinogradova (Виноградова, 1956), the sapropel deposits of Lake Nero from the Atlantic period are considered to be quite peculiar because, alongside the clastic minerals, they include new formations of calcite , dolomite, pyrite , and vivianite.

In the carbonate sapropels of Atlantic time there is the predominance of temperate-heat requiring and heat-requiring planktonic species, among which most abundant are Melosira granulata (Ehr.)Ralfs., Melosira italica (Ehr.)Kútz., Stephanodiscus astreae (Ehr.)Grun.,Stephanodiscus astreae var.minutulus (Kútz.)Grun. typical of eutrophic basins. The diatomaceous flora of the first half of the period is characterized by predominance of such planktonic species, as Melosira granulata (Ehr.)Ralfs., Stephanodiscus astreae (Ehr.)Grun., Cyclotella comta (Ehr.)Kútz. (Fig. 1). In the diatomaceous complex of the second half of Atlantic time the role of benthic species increases due to the development of shallow-water species (mainly the species of the genus Fragilaria). Also the planktonic species are dominated by those distributed in shallow waters. Thus, in the first half of the Atlantic period Lake Nero was rather deep and warm, while in the second half of the period it turned into a shallow-water and well - heated basin rich in flora and fauna.

The deposits of the Atlantic period are distinguished by a maximal content of the pollen of broad-leaved species (up to 30%), represented by the pollen of oak, elm, and, lime-trees. The share of the pine and birch pollen is somewhat lower than earlier (Fig. 2).Up the section there is a considerable increase in the amount of spruce pollen. In the Holocene climatic optimum along the shores of Lake Nero there predominated mixed coniferous-broad leaved forests. At that time the climate was warmer than at present.

The fourth stage embraces the period from 4,500 B.P. till the present time (Subboreal and Subatlantic periods). In Subboreal-Subatlantic time peaty sapropels deposited on the bottom of the lake (thickness - 6.5 m), which were characterized by almost a complete absence of $CaCO_3$ and by a high content of organic C (20%). Quite significant is the appearance of pyrite in the deposits of Subboreal time, which shows that there has been domination of reduction conditions of sedimentation.

In Subboreal time the composition of the diatomaceous flora of Lake Nero undergoes considerable changes. Benthic diatoms become widespread; among them representatives of the genus Fragilaria make up 60 or 70%. The latter are epiphytes or bottom species prevailingly. The occurrence of the littoral and epiphytic species of genera Navicula, Pinnularia, Cymbella, Synedra increases.Among planktonic diatoms Melosira italica (Ehr.)Kútz., Stephanodiscus Hantzschii Grun., Synrdra berolinensis Lemm. dominate (Fig. 1).

All this indicates that the lake becomes increasingly more eutrophicated and shallow. However, against the generally low level of water in the lake there occurred recurrent fluctuations. For instance, early in the period and at the end of its second half there were transgressive phases. The diatomaceous complexes that were formed during the period of a relatively high water level in the lake are characterized by a greater species abundance and by a quantitative development of diatoms and increase of planktonic species,among which the leading ones are Melosira granulata (Ehr.)Ralfs., Melosira italica (Ehr.)Kútz., Cyclotella comta (Ehr.)Kútz. A reverse picture is observed during a transgressive phase in the middle of Subboreal.

The diatomaceous flora of Subatlantic time does not differ much from the previous period and it is close to the present ones. It characterizes Lake Nero as an eutrophic overgrowing water basin, where typical planktonic forms have low values of occurrence. Dominating here are the forms of overgrowth of the genus Fragilaria. Two transgressive phases may be distinguished in the history of Lake Nero during the Subatlantic period judging by the change of the diatomaceous complexes: at the beginning of the first half and approximately in the middle of the period.

In the spectra of Subboreal time the spruce pollen gradually comes to the fore (up to 60%) - "the upper maximum", which indicates that during the period within the studied region spruce forests became widespread (Fig. 2).

In the pollen and spore spectra of the Subatlantic period the amount of spruce pollen (especially in the second half of the period) considerably decreases, giving place to the pollen of pine and birch. As in the previous period, the role of the pollen of broad-leaved species is not great. In the vicinity of Lake Nero quite common are mixed forests of pine, birch, and spruce with an insignificant admixture of broad-leaved species. Their composition is similar to that of the present forests in the Yaroslavl Volga region.

The distinguished stages of sedimentation are universal not only for the Central part of the East European Plain, but also for the

whole zone of the forests of the humid belt in the European part of the USSR. However, the change of sedimentation types was not simultaneous everywhere. For instance, unlike the central region of the East European Plain, in the lakes of Byelorussia, of the Baltic Region and of the North-West carbonate formation went on without interruption since the Early Holocene and especially actively since Boreal time (Бартош, 1976). The change in the character of sedimentation was closely related to the development of the lake and the history of its basin.

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УДК 551.3.051+556.55:551.8 /470.316/

ДОННЫЕ ОСАДКИ И ПАЛЕОЛИМНОЛОГИЯ ОЗЕРО НЕРО

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Резюме

Результаты детального комплексного анализа 30-метровой толщи осадков озера Неро показали, что в истории озера за последние 15 000 лет выделяются 4 этапа осадконакопления. Различные типы

осадков присущи пребореальному, бореальному, атлантическому суббореальному-субатлантическому периодам. Смена осадконакопления происходит в тесной связи с развитием водоёма и историей его бассейна. Выделенные этапы осадконакопления являются общими для всей зоны лесов гумидного пояса Европейской части СССР.

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MINOR LAKES OF SOVIET KARELIA (AGE, TYPES AND COMPOSITION OF SEDIMENTS, GEOGRAPHICAL DEMARCATION)

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Soviet Karelia is a land of lakes. According to recent data (Китаев, 1984) there are 61,855 lakes in the republic. Their total water surface reaches 33,185 km^2, which accounts for 19.2% of the republic's area with regard for lakes Ladoga and Onega (6,000 and 8,000 km^2, respectively)[x)] encompassed within its boundaries. With respect to the area of lakes Soviet Karelia surpasses countries rich in inland water bodies such as Finland (9.4%), Sweden (8.6%) and Canada (about 12%).

It should be noted that lakes up to 1 km^2 in area account for 97.4% of the total number of water bodies and those up to 10 km^2 in area make up 99.6% (Покровский, Новиков,1959). Thus, lakes of small and medium size clearly predominate, whereas water bodies more than 10 km^2 in area account for only 0.4% of their total number. These include 120 lakes ranging from 10 to 50 km^2 in area and 18 lakes 50 to 100 km^2 in area. In a group of 16 largest freshwater reservoirs with a water surface exceeding 100 km^2 the following storage lakes are remarkable for their size: Vygozero (1159 km^2), Topozero (986 km^2), Segozero (752 km^2), Päozero (659 km^2) and Vodlozero (365 km^2).

The number of lakes in Soviet Karelia and changes resulting from the disintegration of the ice sheet followed by improved climatic conditions in the Holocene that have persisted during the past 10,000 years are of interest. The area occupied by lakes can be determined approximately for some time levels.

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x) The total water surface of Lake Ladoga is 18.4 thousand km^2 and that of Lake Onega is 9.9 thousand km^2. They form a special group of great lakes.

Another important task in studying the evolution of lakes is to estimate the time of their initiation and overgrowing. This can be done by the radiocarbon dating of the organic matter accumulated in bottom sediments. Radiocarbon dating combined with pollen - and-spore analysis makes it possible to evaluate the area occupied by lakes in certain chronologic environments and to determine the sequence of formation and life span of individual groups of reservoirs.

To solve the above problems, it is necessary to study the structure of bottom in detail, in order to establish the main types of their sections characteristic of different-aged deglaciation zones and different geomorphological situations. The scheme of geographical demarcation of Soviet Karelia based on the composition of bottom sediments is interesting from both scientific and practical standpoints. It was made chiefly by means of chemical analyses, determination of diatom flora, some minerals and other properties.

The present paper is based on the voluminous factual material collected while studying bottom sediments in the small and medium-sized lakes of Soviet Karelia. Reconnaissance boreholes were used to investigate sediments in about 76 water bodies. Sections through consolidated bottom sediments were studied by bio- and chronostratigraphic and chemical methods in 32 lakes scattered in groups throughout the republic. Pollen-and-spore diagrams (analyst A.M. Kolkanen) were compiled, and diatom (G.Ts.Lak) and carpological (E.A.Krutous) analyses and 45 radiocarbon datings [x)] performed for these sections.

The basins of the lakes studied were located under different geomorphological conditions, such as glacial depressions, relic basins of glaciolacustrine and swampy plains, basins of undulating and ridge-undulating relief confined to marginal glacial zones and ice-divide uplands, kettle-holes often characteristic of outwash plains, depressions of rills and valleys of discharge of glacial meltwater and tectonic cracks in denudation-tectonic relief. The distribution

[x)] Radiocarbon dating of organic matter was performed in Tartu, Institute of Zoology and Botany, Estonian Academy of Sciences, under the supervision of A. Liiva.

of lakes provided comparative material for establishing the sequence pattern of bottom sediments and the age of the reservoirs depending on the geomorphological structure of the relief in broad sense, and for the genesis of the lake basin in narrow sense. In some cases the lakes were selected in such manner as to obtain information on the effect of the composition of Precambrian rocks in the Baltic Shield on the material composition of the bottom sediments studied.

Numerous examples in Karelia indicate unambigously that lakes came to exist earlier than mires. The most ancient mire biogeocoenoses emerged in depressions of denudation-tectonic relief and glacial morphosculpture in Boreal time by replacing earlier water bodies (Елина, Лийва, 1980; Елина, 1981). In glaciolacustrine or morainic plains mires formed extensively during the Atlantic period. Transgression of peat accumulation onto drainage slopes took place much later and was most intense in Subboreal time. Many investigators (Пьявченко, 1985; Прозоров, 1985, etc.) have indicated that the age of the mires that resulted from the overgrowing of water-bodies is at maximum.

Most investigators are of opinion that water bodies overgrow and have an excess of peat due to sapropel accumulation and shallowing (Сукачев, 1926; Кордэ, 1963; Пьявченко, 1963; Ниценко, 1967; Россолимо, 1967, etc.). However, peat scientists and limnologists are not unanimous in interpreting peat deposition in lakes. The former assume that the leading part is played in this process by the shallowing of reservoirs and the formation of peat deposit at the expense of plants growing in lakes. The latter think that the process is largely triggered by the transport of allochthonous organic matter from paludified drainage areas to lakes (Кордэ, 1960; Россолимо, 1964, 1967, 1976). All authors note that the waterlogging and dystrophication of reservoirs are accompanied by the lack of aeration and oxygen. It has been found that plant and animal remains do not decompose completely because the anaerobic decay of organic substances ceases following the consumption of carbohydrates of easily assimilated protein substances by bacteria (Кузнецов, 1970). These events are concomitant, on the one hand, with accumulation of nondecomposed organic remains and, on the other, with the further decrease in the amount of oxygen. Thus, the overgrowing of lakes acquires a self-stimulating and self-developing pattern.

Assumptions have been made (Кузнецов, 1970; Прозоров, 1985; Пьявченко, 1985) that there is a common reason for the formation of all mires. This is true of the both the overgrowing of water bodies and the water-logging of land. We mean here oxygen deficiency in a natural environment which causes a causative-corollary chain of interrelated events such as anaerobiosis, incomplete decomposition of plant and animal organisms and accumulation of the latter (Прозоров, 1985, p. 13). According to the above concept specific mire energymaterial exchange is due to oxygen shortage rather than increased soil humidity or accumulation of humic substances in a water body.

According to V.N. Sukachev's concept of biogeocoenoses (Сукачев, 1926, 1972, p. 330), each biogeocoenosis on the Earth has its own distinctive index which characterizes a type of "substance and energy exchange between its components and other natural phenomena". Yu.S. Prozorov (Прозоров, 1985) has suggested the following definition: "Biogeocoenoses with an accumulative type of energy-material exchange that is due to oxygen deficiency arising from increasing soil moisture reserves or decreasing inundation of reservoirs ... belong to the category of mire biogeocoenoses". The author defines an accumulative type of energy-material exchange as decelerated turnover of energy and substances at the decomposition stage of higher plant remains and the accumulation of incompletely decomposed organic matter present as peat or peat-mineral deposits in soil or in a body of water (ibid., p. 13-14).

In our opinion, the above theory of formation of a single category of mire biogeocoenoses has an essentially geochemical nature closely related to oxidation-reduction processes which occur in the water bodies and soils of the biosphere (Перельман, 1982, p. 56 - 85, 101-106). The ecosystems discussed are also remarkable for a single process of vital activity in which anaerobes are involved by all means.

Our observations have shown that the initiation, development and overgrowing of lakes were caused and controlled mainly by changes in climatic conditions, the rate and pattern of deglaciation of territory, geologic and tectonic processes and geomorphological setting. Naturally, these major lake-forming factors and processes were interrelated in nature, although their role in the life of reservoirs changed substantially during different time intervals in the late- and postglacial periods. In late-glacial time the climate became warmer, but recurrent changes brought about its deterioration, and resulted in the reciprocating (stepwise) pattern of deglaciation. In connection with such evolution of glaciation the first lakes in the territory of Soviet Karelia emerged in groups at different time following the retreating glacier margin in deglaciation zones of different age (Fig. 1 A). Glacioisostatic uplift and block-faulted tectonic movements acted also during the Holocene by distorting lake basins, changing the base level of erosion, shifting runoff thresholds, deepening the valleys of existing channels and creating a new river drainage. These events, in turn, caused the levels to change and decline permanently. As a result, mires often formed by replacing water bodies. It will be noted while discussing the latest stage of lake formation that in the early half of Atlantic time, when the climate was warm and humid, an abundance of reservoirs confined to glaciokarst basins were formed.

Evidence for the area of mires, which resulted from the overgrowing of reservoirs, is important for correct determination of the area occupied by lakes during certain periods. According to G.A.Yelina (Елина, 1981) about 33% of the area of present mires formed as a result of paludification of waterbodies in which limnic sapropels had accumulated earlier. However, lake sands, loam, silt, clay and varved clay are widespread under peat deposits (Елина , 1981). Some sections have been reported from the Pribelomorskaya depression in which marine muds such as silt, clay and sand occur below thick peat deposits. The analysis of the material has indicated that no less than 45-50% of mires result from the overgrowing of reservoirs. This figure locally is over 60-70% (relatively deep and closed depressions in South and Central Karelia and the shores of the White Sea and large lakes).

Before discussing the problems related to the lake radiochronology and lake area in Soviet Karelia in some time sections it is necessary to present briefly the main types of bottom sediments. The thickness of Holocene sapropels and diatomites is no more than 6-7 m.

Two major widespread sections through bottom sediments have been established: 1 - with gradual transitions from mineral layers (light-grey and grey sands, often laminated silt) to sapropels without any traces of hiatus; 2 - with sharp contacts between mineral and organic horizons, sometimes with a separating brown moss intercalation. There are sections in which sapropels are separated by a 0.2-0.25 m-thick peat layer from the underlying till.

The former type of sequence of limnic sediments is characteristic of lakes located in glacial depressions on the inner side of marginal glacial zones. The latter type of sequence is characteristic of lakes that occupy glaciokarst basins (especially on outwash plains, sandurs and depressions in undulating-moraine and marginal undulating-ridge relief, including those in ice-divide uplands. Shortened sequences are also typical of lakes confined to rills of glacial meltwater discharge, especially in a prefrontal strip and oxbow-lakes. The beginning of organic layer (sapropel) accumulation in such a geomorphological setting is often dated at the late Boreal - middle Atlantic periods (8100 - 6900 years ago).

The third type of sequence has only been reported from the sparse lakes in southern Soviet Karelia. In the bottom sediments of these water bodies Holocene sapropel is underlain by a horizon of sapropel-like layers separated by mineral deposits.

Alleröd and Younger Dryas layers and undivided pre-Alleröd deposits that actually contain no organic material have often been revealed in bottom sediments in southern Soviet Karelia. Radiocarbon datings of 11,500±220 (TA - 1584) and 11,500±150 (TA - 1654) years corresponding to the Alleröd are available. Whether Bölling layers are present is problematic as there are no chrono- and biostratigraphic data to support that. Thus, the initiation of lakes in the Luga-Neva marginal belt and in the outer zone commenced either in pre-Alleröd or Alleröd time (Fig. 1 A). It is only from these areas that the third type of bottom sediment sequences has been reported.

The basal portions of the bottom sediments in the lakes of

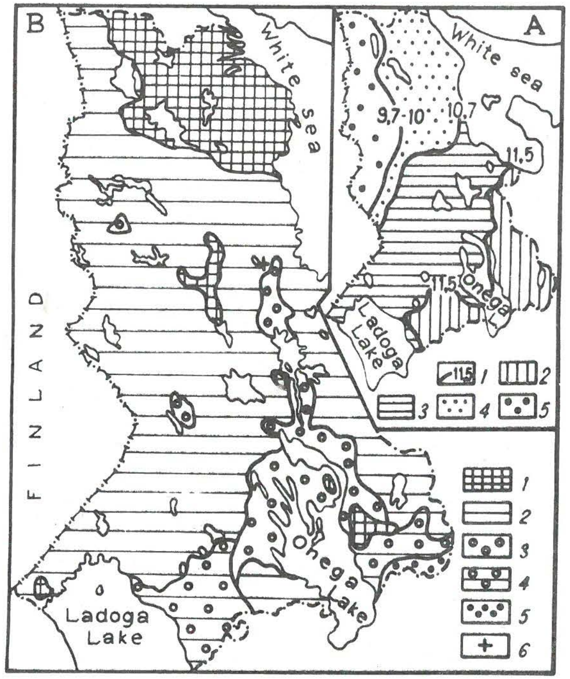

Fig. 1. Geographical demarcation of Soviet Karelia's territory based on the time of emergence of small and medium-sized lakes (A) and the composition of their bottom sediments (B).

A.1. - lake initiation isochrones (numbers are given in millenia) inferred from ^{14}C-dating of organic matter first accumulated in bottom sediments (sapropel; brown moss; other material less common); 2-5 - initial stages of considerable or abundant development of lakes following the retreating ice sheet; 2 - Alleröd - Pre-Alleröd time (11,900 - 11,200 B.P., partly ancient); 3 - Alleröd (11,900-11,200 B.P.); 4 - mid-Late-Dryas (10,800 - 10,400 B.P.); 5 - Preboreal time (10,000 - 9200 B.P.). The development of lakes throughout the republic was most vigorous in the Preboreal period.

B. 1. - area of wide distribution of diatomites (siliceous raw material); 2 - area of predominant occurrence of greenish sapropels often grading into brownish, reddish and yellow-coloured types (often applicable as organic fertilizers) upward in the section; 3 - area of frequent occurrence of dark-grey and black sapropels containing bivalent iron and free hydrogen sulphide (promising as curable mud); 4 - transition (mixed) zone with sapropels characteristic of areas 2 and 3; 5 - hypothetic distribution area of lime (raw material for application of lime to acid soils); 6 - lime sapropel locality.

northern Soviet Karelia are represented by Younger Dryas horizon. The radiocarbon datings obtained from organic material (brown moss, sapropel) vary from 10,640±150 (TA - 1487) - 10,700±150 (TA - 1490) to 10,300±120 (TA - 1742) and 9800±150 (TA - 1488) years. As deduced from pollen-and-spore analysis, Younger Dryas deposits can be divided into three layers. Following the retreating glacier of Salpausselkä - I stage the first lakes came to exist with the accumulation of organic material in glacial depressions about 10,800 - 10,700 years ago (Fig. 1 A). The formation of minor lakes in western Soviet Karelia on the internal side of the marginal glacial zone of Salpausselkä - II stage began ca. 10,000 - 9800 years ago.

In the areas of undulating-morainic relief lakes continued to arise until 9300 - 9000 B.P. Water bodies formed in kettle-holes in the early half of the Atlantic period (8100 - 7400 B.P.). Glacial meltwater started to form simultaneously in the rills of discharge. Shortened types of bottom sediments are characteristic of these groups of small and medium-sized lakes. A sharp contact between mineral rocks and sapropels, often with a separating peat lamina, is observed there (Ekman et al., 1983, 1985).

The beginning of the break in lacustrine sedimentation often corresponds to the chronological boundary between the late- and post-glacial periods which is sliding in both time and space. According to both pollen-and-spore and radiocarbon datings the hiatus varied in length with groups of individual sequences from hundreds of years to millenia, often covering a considerable part of the Holocene (the Preboreal, Boreal and the early half of the Atlantic periods). In some sequences tills or aqueoglacial deposits are directly overlain by sapropels enriched with organic matter that began to accumulate in the late Boreal - early Atlantic periods. Radiocarbon dating has indicated that the accumulation of lacustrine deposits either resumed or was initiated no later than 7400 - 6900 years ago.

As a whole, the intense development (initiation) of lakes and the accumulation of sapropels therein is divided into three chronological epochs: the Alleröd (11,800 - 11,200 B.P.), Preboreal (10,000 - 9200 B.P.) and Early Atlantic (8100 - 6900 B.P.). Such major time intervals in the evolution of lakes and organic sedi-

mentation are controlled by climatic, tectonic and, largely, geomorphological factors. The latter is related to the genesis of a lake basin and its position in a certain morphosculptural complex (Ekman et al., 1981, 1983, 1985, 1986).

The lake area of the republic for some time levels is evaluated as follows. Near the Pleistocene-Holocene boundary (10,300 - 9800 B.P.) when large proglacial lakes and relatively small cold-water lakes occupying practically all closed or semi-closed depressions of the relief were most common, no less than 55-60% of the area under consideration, was covered by water x).

In order to determine the lake area in a certain chronological section of the Holocene one needs data on the area of the mires which resulted from the paludification of water bodies at the boundary in question or within a relatively short time span. All these definitions are fairly rough because the deep structure of the mires is still poorly studied. However, no less than 33-50% of the present mire area of the republic (in some areas up to 60-70%) have resulted from the paludification of water bodies. It is known that the late half of the Boreal period was the first stage of abundant mire formation (Елина, 1981; Елина, Лийва, 1980). The same date is true for 18% of mires in southern Karelia and for 12% in northern Karelia (Лийва, Елина, 1986). The evolution of lakes was at its maximum in the late Preboreal - early Boreal periods (about 9300 - 8900 B.P.). Mires occupy 30% of Soviet Karelia's territory, hence one can determine by simple calculations that at that time the lake area could vary from 26 to 34% in some localities, making up 30-32%, at an average.

During Atlantic time peat was accumulating in an avalanch-like manner: in its early half the paludification increased twice as much and in its late half three times as much as in the Boreal period (Елина, 1981; Лийва, Елина, 1986). 37% of mires in northern Karelia and 30% in southern Karelia formed in the late half of Atlantic time. The rapid extension of Boreal mires was accompanied by the ac-

x) Here also belong the extensive areas in northern Soviet Karelia overlain by the brackishwater White Sea basin (the Portland Sea).

tive formation of new peat deposits predominantly by paludification of water bodies. The early half of Atlantic time (8100 - 6900 B.P.) saw an outbreak in the formation of the lakes confined mainly to kettle-holes and rills of glacial meltwater discharge. However, at that time paludification was far more extensive than the development of new lakes. Therefore, the lake area had reduced substantially by the middle of the Atlantic period (7400 - 6900 B.P.) to account for no more than 22-24% of the republic's territory.

From the late half of Atlantic time onwards no new lakes actually formed. Since then peat accumulation and paludification of reservoirs has continued, with varying intensity, up to now (Елина, 1981). Former lake areas were replaced by extensive peatlands which occupy a large part of the republic's territory.

Despite appreciable differences in size (area, depth etc.) and morphological indices (shape of trough, ruggedness of shoreline etc.) some common evolutionary trends that are due to irregular glacioisostatic compensational uplift of the crystalline basement may be established. These phenomena are primarily connected with the distortion of lake troughs and the transgression of water mass to the area which suffers either uplift or even subsidence lower in amplitude. Regarding the great and large lakes of Karelia such as Onega, Ladoga and Segozero, these events have been widely discussed in the relevant literature (De Geer, 1893; Ailio, 1915; Нуурпя, 1943; Марков и др., 1934; Земляков, 1936; Панкрушев, 1966; Квасов, 1975; Экман и др., 1975; Лак, Экман, 1975, etc.).

Similar transgression of water bodies has been revealed in relatively small lakes such as Lake Lenderskoye, western Soviet Karelia, Lexa river basin. Its surface area is 8.3 km^2. Intense transgression of water to the south-eastern shore was established there by studying sections through bottom sediments made by profile drilling over the entire water area. Pollen-and-spore analyses have shown that it took place during the late half of the Boreal period. This is supported by the radiocarbon date of 8200$\pm$80 (TA - 1121) years. Distribution of water was accompanied by the outwashing of autochthonous peatlands, the formation of abrasion scarps therein and the abundant accumulation of bottom sediments present as allochthonous peat layers no less than 2.2 m in thickness. During the late half of Atlantic time, about 5730$\pm$80 (TA - 1122) B.P., the transgression slows down abruptly, and the level of the reservoir is soon stabilized. Hence the rate of sedimentation decreases, and poorly consolidated sapropels are formed on the lake bottom. The basal layers of superficial peatlands which show a radiocarbon age of 7920$\pm$100 (TA - 959) years occur in shore scarps 2.5 - 3.0 m below the present lake level.

The materials presented for Lake Lenderskoye seem to support the supposition that in early Boreal time irregular glacioisostatic uplift became more intense. As a result, a voluminous body of water was displaced and the amplitude of lake level alterations increased markedly. A decline in the level of reservoirs in an unfavourable topographic setting could be disastrous enough to make them disappear as a result of mire formation. This conclusion is corroborated by the fact that in the Boreal period an abundance of peat deposits developed by the overgrowing of former lakes (Елина, 1981).

In some small lakes the level rose in the late half of Preboreal time (9560 - 9250 B.P.), regressed during the Boreal period (9200 - 7900 B.P.) and increased again in Atlantic time.

The bottom sediments of minor lakes in Karelia are variegated in chemical composition and have a biogenic, chemogenic, terrigenous and polygenic origin. Terrigenous sediments make up the lower portions of sequences, and are represented by grey-coloured silts and fine sands which sometimes show fine varved lamination. Diatomites, a group of sapropels and lacustrine lime that have certain regularities in geographical distribution stand out among biogenic and chemogenic sediments (mud) (Fig. 1 B).

Diatomites. Lacustrine diatomites are widespread in northern Karelia, between lakes Päozero and Topozero in the west and the White Sea shore in the east as far as the mouth of the Pongoma River. Karelian diatomites were studied as siliceous raw material during the late 1920's - early 1930's (Марков, 1933; Порецкий и др., 1934; Варданянц, 1936; Земляков, 1936; Жузе, 1966, etc.). In recent years we continued studying these sediments in minor lakes by specifying their location (Fig. 1 B). They are ubiquitous in the swampy area between lakes Tikshozero and Yeletozero, the lake basins being almost completely filled with diatomite. They are as thick as 7-9 m in places.

Brown and greenish-brown sapropel diatomites and grey (less frequently light-grey) high-siliceous deposits stand out among the sediments in question. When moist, they are clastic, jelly-like and show high water capacity. The "purest" varieties of diatomites are rich in SiO_2 (80.79 - 85.12%) and show low ignition loss (i.l.) values (8.79 - 9.85%)[x]. The SiO_2 content of sapropel diatomites normally varies between 54.57 and 68.3%, i.l. being 26.18 - 35.67%. The sesquioxide content of the sediments is low: Al_2O_3 - 2.46 - 3.97%, Fe_2O_3 - 0.52 - 3.97%. The amount of iron oxide (FeO) is sometimes up to 2.47%. The CaO content varies between 0.96 and 2.89%. Increased quantities of CaO (up to 3-4%) have been reported by Vardanyants (Варданянц, 1936) for diatomites from the White Sea region.

Representatives of the genus Fragilaria are distributed in shallow water in Karelian small lakes and are negligible in size (20-30 microns).

Some theoretical and practical problems related to the geochemistry of silica have been generalized in numerous publications (Геохимия кремнезема, под.ред. Страхова 1966; Порецкий и др., 1934; Птицын, 1934; Гусева, 1975; Перельман, 1982, etc.). An important conclusion has been drawn: water contains a sufficient amount of dissolved silicic acid and a biogenic element such as phosphorus, to say nothing of its other chemical properties. The presence of either crystalline rocks or Quaternary deposits rich in phosphorous in the drainage area of lakes seems to be essential for accumulation of continuous Holocene diatomite sequences.

Commercial diatomite deposits are likely to be discovered in northern Karelia. Occurrences of high-grade biogenic siliceous raw material has already been reported from the area.

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[x] Chemical analyses presented here and below were recalculated to 100% on anhydrous basis.

Greenish and brown sapropels. These varieties of sapropels (muds) are chiefly common in lakes in western and central Karelia (Fig. 1 B). They occur together in bottom sediments. In such cases greenish and dark-grey sapropels often grade into brown sediments upward in the section. Reverse colour relationships have also been reported for sapropels, in that case their upper portions are composed of dark-grey and brownish-green sediments, sometimes with a hydrogen sulphide smell.

Greenish and dark-grey sapropels (muds) are formed under the conditions of oxygen deficiency that initiate a reducing (gley or even hydrogen sulphide) medium in the near-bottom parts of a reservoir (Перельман, 1982). Anaerobic bacteria are involved in geochemical decomposition of plant remains. In the course of these processes trivalent iron is reduced to bivalent iron, and vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$) is often formed. There are olive-green, dark- and dirty-green, brownish-green and dark-grey sapropels (muds). They comprise a fairly large amount of mineral fine sand-pelitic particles.

Chemical analyses have shown that the greenish sapropel (mud) subgroup often has oxides in amounts varying in the following ranges: SiO_2 39.13 -65.48 %; Al_2O_3 4.50 - 13.30; Fe_2O_3 1.33 - 1.70; FeO 1.56 - 3.93 MnO 0.017 - 0.059; MgO 0.74 1.80; CaO 1.09 - 3.19; Na_2O 0.60 - 2.92; K_2O 0.41 - 2.24; ignition loss (i.l.) 12.0 - 48.74%. Green sapropels most rich in organic material contain 3.32% SiO_2, 0.61% Al_2O_3, 0.95% Fe_2O_3, 1.58% FeO, 0.05% MnO, 0.16% MgO, 0.14% CaO, 0.11 Na_2O, 0.14% K_2O, i.l. 93.05%.

Brown and brownish-yellow sapropels are formed in an oxidative medium in which organic substances and ferruginous minerals are oxidized by means of aerobic bacteria. As a result, bivalent iron grades into trivalent iron, oxides and hydrooxides such as hematite (Fe_2O_3), hydrohematite ($Fe_2O_3 \cdot nH_2O$), goethite (FeO • OH) and hydrogoethite (FeO • OH • nH_2O) being formed.

Chemical analyses have shown that the following variations in the amount of individual oxides are characteristic of brown sapropels: SiO_2 14.13 - 54.23%; Al_2O_3 0.89 - 11.28%; Fe_2O_3 0.9 - 5.44%; FeO up to 1.05%, seldom reported; MnO 0.010 - 0.073; MgO 0.1 - 1.40;

CaO 0.63 - 2.52; Na_2O 0.07 - 1.27; K_2O 0.09 - 1.27%; i.l. 42.22 - 80.68%.

Brown sapropels have far greater amounts of organic matter (roughly twofold) than greenish muds. The quantity of total iron in sapropels (muds) does not, as a rule, exceed 5%. The above data suggest the presence of lacustrine sapropels used as organic fertilizers in western and central Karelia.

Bottom sediments of mixed genesis, in which organogenic material is predominant (40-70%) and an essential role is played by the chemogenic constituent, should be regarded as special varieties of the sapropel group in question. They represent a transition to chemical sediments. The terrigenous material, they contain, is of minor importance (7-35%). Distinguished among these essentially polygenic sediments are calcareous (CaO 38.98%), ferruginous (Fe_2O_3, total iron up to 12-16%) and manganous or manganous-ferruginous (MnO up to 2%) sapropels.

Lacustrine limes are unlikely to be found in the eastern part of the Baltic Shield (Бартош, 1976; Шапорев, Кокаровцев,1985). There are, however, a few lakes with calcareous sediments in eastern Finland adjacent to Soviet Karelia (Vasari, Näykki, 1972). They are confined to the distribution areas of carbonate and ultrabasic rocks in the crystalline basement. Groundwater flow is essential in the water balance of these lakes. Carbonate (pure calcite) accumulation was most intense in the early Holocene, i.e. 10,200 - 7800 years ago. Under similar natural geologic and hydrochemical conditions lacustrine limes are likely to be found in Soviet Karelia, including the distribution areas of Jatulian and Ludicovian carbonate rocks. Calcareous sediments known as alms have been reported from the lower part of the bottom sediments in Lake Alinelampi near the village of Pushnoye (Belomorsk district) and from at least one lake in north-western Karelia, near the boundary with the Murmansk region.

Black and dark-grey sapropels. These types are only widespread in southern Karelia (Fig. 1 B), being chiefly localized within the Onega trough, which is a large Proterozoic structure. The latter is known (Кратц, 1963) to be made up of black shungites combined with shungite-bearing (argillaceous, siliceous etc.) rocks, basic and ultrabasic intrusions and lavas and schist deposits with hematite mineralization. These deposits seemed to affect either directly or indirectly the formation of black sapropels enriched by bivalent iron present in minerals such as hydrotroilite ($Fe_2(HS)_2 \cdot nH_2O$), which renders black colour to muds, and vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$. Thus, black sapropels (muds) formed in a reducing medium accompanied by hydrogen sulphide contamination. Such conditions of bottom sediment accumulation are indicated by a hydrogen sulphide smell. This shows that free hydrogen sulphide not related to minerals such as hydrotroilite, is present in sapropels. Such black muds have high water capacity, reek of hydrogen sulphide, contain an abundance of bivalent iron and can, therefore, be used for curative purposes (as fango). Black and dark-grey sapropels are often associated with green, dark-brown, chocolate-coloured, brownish-yellow and yellow sediments.

It will be noted that black, bituminous marine clays and loams (silts) that reek of hydrogen sulphide and were formed in the course of development of the Boreal transgression of the Mikulino (Eemian) Interglacial are fairly common in the Onega syneclize. Marine beds and the overlying freshwater deposits dating from late Mikulino time formed in a reducing environment. In this case the near-bottom water of the existing marine and freshwater basins was contaminated with hydrogen sulphide.

According to available chemical analyses, black sapropels (muds) and dark-brown, yellowish-brown and even yellow-coloured sediments that often accompany them are characterized by appreciable variations in total iron oxide content (from 5-8 to 43-45%) observed vertically in the section. This makes it possible to distinguish mud varieties in terms of iron content, including iron ores (over 30% Fe). According to our data based on analytical material, which is still insufficient quantitatively, no less than two groups of mud sediments may be distinguished in terms of silicate-colloid complexes and organic matter content. The chemical composition of the first group varies within the following range: SiO_2 (36.90 - 55.56%); Al_2O_3 (5.87 - 12.00%); Fe_2O_3 (5.00 - 16.90%); FeO (3.50 - 5.30%); MnO (0.2 - 2.36%); MgO (1.00 - 1.57%); CaO (1.33 - 2.27%); Na_2O (1.04 - 2.55%); K_2O (0.98 - 2.00%); i.l. 9.55 - 20.12%; P_2O_5 (0.65 - 3.05%); S (0.04 -

1.00%). The second group of sapropels shows the following variations in oxide content: SiO_2 (8.60 - 18.35%); Al_2O_3 (1.10 - 4.79%); Fe_2O_3 (2.71 - 21.85%); FeO (10.43 - 27.40%); MnO (0.16 - 0.95%); MgO (0.76 - 1.69%); CaO (0.40 - 1.05%); Na_2O (0.21 - 0.40%); K_2O (0.20 - 0.56%); i.l. 33.64 - 59.89%; P_2O_5 (0.87 - 1.04%); S (0.20 - 0.23%).

The chemical composition of the Gabozero mud used for curative purposes in the Marsian Waters resort was determined by V.V. Ivanov and Ye.V. Rengarten (1935) and published in relevant literature (Вишневский, 1957). Leaving out the complete composition of the mud, we will mention only the quantities of some components distinguished in the colloid complex (in g per 100 g wet mud): SiO_2 - 0.910 g; Al_2O_3 - 0.439; Fe_2O_3 - 0.662; FeO - 4.787; Fe $(HS)_2 \cdot nH_2O$ - 0.169; organic carbon (C) - 1.072; nitrogen - organic compounds - 0.014; humic acids - 0.807 g. The Gabozero mud is also remarkable for high humidity (86 g water per 100 g fresh mud) and high heat capacity.

The chemical analyses presented made by various techniques most probably indicate that black sapropels (muds) collected at different localities in their distribution area are similar. Within the Onega trough there may exist curative muds more saturated with free hydrogen sulphide and bioactive iron, those currently used at the Marsian Waters resort.

Lacustrine lime (alm). These types of lacustrine sediments may be found in the water bodies situated in the narrow strip along the SE extremity of the republic near the boundary with the Vologda region (Fig. 1 B). Structurally, the locality coincides with the Carbon glint which is fairly promising and contributes to the formation of lacustrine carbonates in the north-west of the Chernozem-free zone of the USSR (Котлукова, 1969; Бартош, 1976; Шапоров, Кокаровцев 1985).

It can be stated in the light of the above data that the matter composition of bottom sediments seems to depend fairly definitely on the composition of the rocks that make up the crystalline basement or Paleozoic sedimentary sequences as well as Quaternary deposits. In addition to this important factor, there is, no doubt, quite a number of other factors affecting the pattern of sedimentation and the substance composition of the layers. Climatic factors, the che-

mism of water, the nutritive type (underground, surface and mixed) of a water body, the activity of microorganisms and structural-tectonic and geomorphological factors can be distinguished.

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УДК 551.312+551.794:551.89

МАЛЫЕ ОЗЕРА СОВЕТСКОЙ КАРЕЛИИ
ВОЗРАСТ, ТИП И СОСТАВ ОСАДКОВ, РАЙОНИРОВАНИЕ

И.М. Экман

Резюме

На основании комплексного био- и хроностратиграфического изучения разрезов донных осадков малых и частью средних озер, расположенных в разных частях территории Карельской АССР, установлены возраст, тип и состав осадков в зависимости от гео-

лого-геоморфологических условий и деградации последнего ледникового покрова. Эти данные позволили установить время зарождения, развития и умирания озер, оценить озерность территории в разные хронологические срезы. Дано районирование территории республики по составу донных осадков, среди которых выделены диатомиты, разные группы сапропелей и известковые осадки. Дана оценка их практического использования. Рассмотрены вопросы заболачивания озер.

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SEDIMENT SEQUENCE OF LAKE LADOGA

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Lake Ladoga was formed after the deglaciation of its depressio about 13,000 years ago. It has had its modern shape and size not more than for 1500 years (Квасов, 1975; Курочкина, 1982).Three ma genetic types of bottom sediments are observed in the lake: glacia limnoglacial and lacustrine ones. The first one is represented by till which consists of clay, sand, gravel, pebbles and boulders of different size. Limnoglacial sediments are represented by aleuropel tic varved clays. They are characterized by the alteration of colo red layers which often mask their varved structure. Lacustrine sed ments are grey or greyish-brown homogenous clays and greenish-grey pelitic silts. Silts cover ~ 50% of the lake bottom surface, 49% a covered by sands. They are distributed in nearshore zone along th western and eastern shores and in the southern shallow part of the lake. Small areas with strong water action in near-bottom layer whe sediment erosion process takes place,are represented by till. Suc places were discovered in a near-shore zone and on underwater slop of deep-water depressions in the north-western part of the lake (C меновнч, 1966).

Stratigraphy of sediments in Lake Ladoga depression is based data obtained through the studies on sediment cores and geological boring of the lake depression and surrounding territory. During t last 5 years 75 sediment cores taken with 1.5 m sampler and 8 co taken with 4 m sampler in different parts of the lake were investi ted (Fig.). Geological drilling was performed down to the depth o 30 m in the south-western part of the lake in 1934 (Краснов,Рейне 1936). Two till horizons were drilled through but the full thickn of glacial deposits was not revealed. Interglacial sediments were of glacial deposits was not revealed. Interglacial sediments were ly 3-4 m thick and consisted of grey varved clays, brown sandy cl with vivianite inclusions and dark greenish-grey clays with the r nants of marine mollusc fauna. Brown varved clays underlie the up

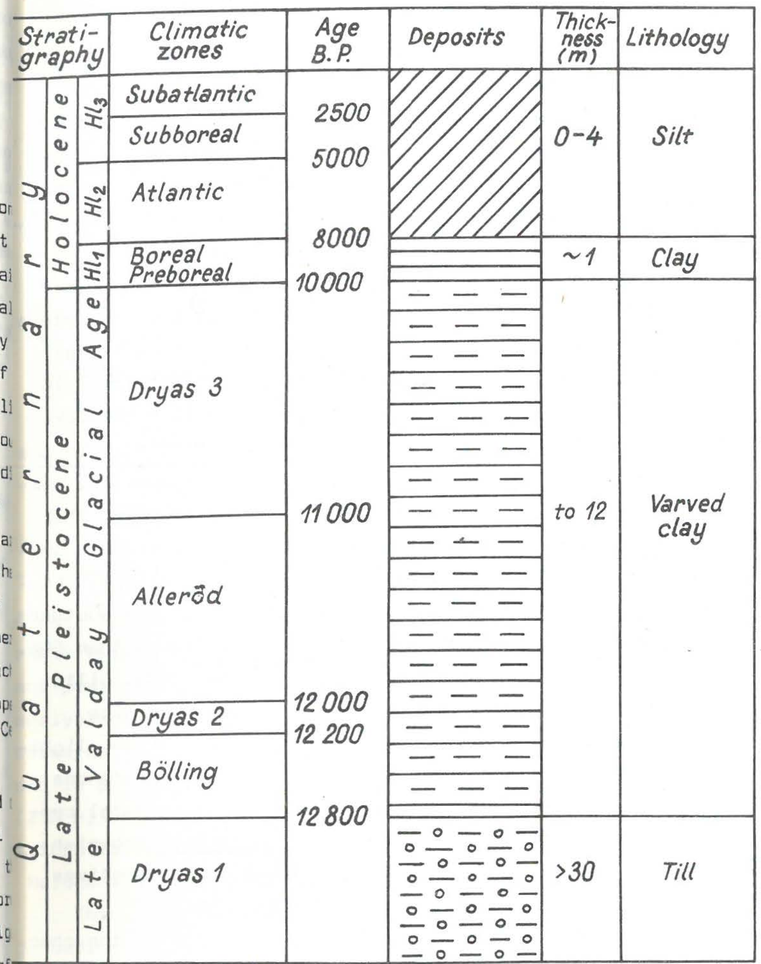

Fig. Stratigraphy of bottom sediments of Lake Ladoga.

till layer. Interglacial clays are enriched with organic matter and contain combustible gases which spurt up during and after the boring. Till of the last glaciation is covered by greyish varved clays the thickness of which varies from 0 to 15 m in Ladoga depression. The thickness of a pair of varves increases down the section and reaches 3-5 mm. Varved clays are spread all over the lake depression.

Varved clays are gradually replaced by homogenous clays deposited during the Preboreal and Boreal. Their thickness varies between 0.4-0.8 m. These are rather dry pelitic or aleuropelitic varved clay with sand and gravel inclusions. Their colour varies from grey to brownish-grey, and brown with rare inclusions of hydrotroilite. In deep-water regions of the lake clays are covered by silt, the thickness of which varies from some cm to 4 m and may be even more in th deepest depressions of NW part of the lake. Silts are aleuritic, aleuropelitic and pelitic with the admixture of sand and gravel. Their density increases downwards, often they gradually pass over to homogenous clays, but sometimes there is a fine sand layer at the contact of silt and clay. It's especially characteristic of the souther part of the silt zone of the lake with water depth not more than 50m It was obviously a nearshore zone at the end of Boreal time. Silts are rich in black hydrotroilite inclusions, sometimes vivianite grains are found. Silts are prevailingly greenish-grey, often light brown. It caused by the concentration and state of some substances: organic matter, chlorophyll "a" and iron. The uppermost several centimetres of sediments are related to the oxydized zone of brownish colouring. Orange-brown upper layers overlie black ones. Sometimes there are several such layers in the topmost 10 cm.

Differences in the structure of sediments are caused by the changes in the lake environment during Holocene time. There are considerable fluctuations in granulometric and chemical compositions, organi matter content in silts, homogenous and varved clays (Table 1). Silt are characterized by the highest organic matter content and consist of coarser material than homogenous clays and varved clays.

Geochronological division of sediments is based on palynologic data (Абрамова и др. 1967), counting of sedimentation rate (Курочкина, 1982) and palaeomagnetic data (Писаревский, 1983). The characteristics of environmental changes in the lake during late-glacial and post-glacial times were reconstructed by using the data of diatom analysis (Давыдова, 1968, 1985). Diatoms were studied in 18 sediment cores up to 1 m in length, in 4 cores taken with 1.5 m bottom sampler and in one core with the length of 4 m from the deepest depression (230 m) of NW part of Lake Ladoga. Detailed characteristics were obtained for late-glacial time (Dryas 2, Alleröd, Dryas 3) and for the Holocene up to the modern time.

Table 1

Main chemical and granulometrical characteristics of Lake Ladoga sediments

Characteristics	Silts	Homogenous clays	Varved clays
Carbonates (%)	4.08	0.55	0.46
Nitrogen (%)	0.26	traces	traces
SiO_2 aut. (%)	15.5	5.0	3.2
Ignition losses (%)	10.3	3.6	2.3
Moisture content (%)	70	45	49
Fractions: sand (%)	5-10	9	4
aleurite (%)	40-55	8	19
clay (%)	35-55	83	77
the main size	0.05-0.01	<0.001	<0.001
(%)	40	52	55

There are 346 species and varieties of diatoms in Lake Ladoga sediments. They are mainly fresh-water oligogalobes. Sporadically there were found 5 species of marine diatoms, eugalobes in different horizons of sediments: Paralia sulcata (Heib.) Sim., Rhabdonema arcuatum (Lyngb.) Kútz., Actinoptychus undulátus (Bail.) Ralfs, Thalassiosira gravida Cl., Th. excentrica Cl. They have been redeposited into the lake sediments from interglacial Mikulian marine deposits, rather widely spread in the eastern part of the lake surroundings and eroded by rivers. Fresh-water diatoms dominate in all the horizons and in all kinds of lake sediments.

Species composition and concentration of diatom frustules are poor in Late Pleistocene varved clays. Aulacosira islandica ssp. hel- vetica is the only abundant diatom in them. This boreal freshwater planktonic diatom is the most typical dominant in phytoplankton of large deep-water oligotrophic lakes Ladoga and Onega, and big Fenno- scandinavian lakes. It's the most abundant planktonic diatom in Lak Ladoga sediments from late-glacial time up to now. The enrichment o diatom complexes in lake sediments takes place in the Boreal,when th diatom concentration increases up to 4000 per gramm of air-dry sedi- ment. In the Atlantic it becomes 2.5 million. Also the composition o dominant species becomes diverser (Table 2) during the Holocene cli- matic optimum. The cosmopolitic diatoms become as rich in species a the Boreal ones. There are 3 million frustules of diatoms in Subbo- real sediments which were deposited during the so-called Ladoga transgression when the lake level rose more than 10 m above the modern one.

The amount of frustules in sediments is the highest in the Subat- lantic, especially in its uppermost part (7 million). It caused by the growth of eutrophication rate in combination with improvement o climatic conditions after the cold period of the European medieval time.

The main results obtained through the studies on Lake Ladoga se- diments are as follows:

A deep oligotrophic fresh-water basin was formed in the depres- sion of Lake Ladoga in late-glacial time and it has existed there persistently up to now.

The waters of the Yoldia Sea never penetrated into Lake Ladoga.

In Boreal time Ladoga depression was the easternmost part of th Ancylus Lake.

In the Atlantic the Litorina transgressions didn't reach Ladoga It was connected with Baltic by the river in the northern part of th Karelian Isthmus.

In Subboreal time the continuing isostatic uplift of the north- ern part of Ladoga depression and surrounding territory caused the increase in Lake Ladoga level (the so-called Ladoga transgression).

Table 2

Dominant diatoms complexes in sediments of Lake Ladoga

Climatic period	Dominants	Subdominants
SA3	Aulacosira islandica ssp. helvetica (O. Müll.) Sim. Asterionella formosa Hass.	Aulacosira distans var. alpigena (Grun.) Sim. A. italica (Ehr.) Sim. Stephanodiscus rotula var. minutula (Kütz.) Ross a. Sims
SA2	Aulacosira islandica ssp. helvetica	S. rotula (Ehr.) Hendey S. rotula var. minutula Tabellaria fenestrata (Lyngb.)Kütz.
SA1	A. islandica ssp. helvetica	Aulacosira italica A. distans var. alpigena
SB	A. islandica ssp. helvetica A. distans var. alpigena	A. italica
AT	A. islandica ssp. helvetica	Cyclotella comta (Ehr.) Kütz. C. vorticosa A. Berg
BO	A. islandica ssp. helvetica	C. comta
PB	A. islandica ssp. helvetica	-
DR3	A. islandica ssp. helvetica	C. comta C. vorticosa Stephanodiscus rotula
AL	A. islandica ssp. helvetica	Cyclotella vorticosa Stephanodiscus rotula S. niagarae Ehr.

At the beginning of the Subatlantic the level of Lake Ladoga rose, it led to the destruction of the watershed of the rivers Mga and Tosna and to the formation of the Neva River in the 7-8th centuries.

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УДК 55I.8+55I.48I+56I.26

СВОДНЫЙ СТРАТИГРАФИЧЕСКИЙ РАЗРЕЗ ДОННЫХ ОТЛОЖЕНИЙ ЛАДОЖСКОГО ОЗЕРА

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Резюме

Ладожское озеро образовалось около I3 тыс. лет назад. Его донные отложения представлены 3 типами: ледниковым /морена/, озерноледниковым /ленточные глины/ и озерным /гомогенные глины, илы, прибрежные пески/, различающимся по гранулометрическим и химическим параметрам. В котловине вскрыто 2 моренных горизонта и межледниковая толща до 4 м мощности. Позднеледниковые ленточные глины достигают I5 м мощности, гомогенные глины, сформировавшиеся в пребореале и бореале, - до 0.8 м, илы среднего и верхнего голоцена - до 4 м. Состав диатомовых водорослей в отложениях свидетельствует, что начиная со среднего дриаса и до современности озеро населяли пресноводные диатомеи. Водоем был глубоким, холодноводным, олиготрофным. Морские воды в поздне- и послеледниковое время в Ладогу не проникали.

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EVOLUTION OF LAKES OF PSKOV REGION IN THE HOLOCENE

V. Lesnenko

The present-day relief of Pskov region was formed as a result of the exaration and accumulative activity of the Valdai glacier.However, glacial morphogenesis was greatly influenced by the pre-Quaternary relief. Macro- and mesoforms of the pre-Quaternary surface determined the directions of the movement of ice streams, their differentiation into glacial lobes and tongues of various rank. During the degradation of ice positive and negative macro- and mesoforms had a different effect on the glacial morphogenesis. In low places of the pre-Quaternary relief the frontal retreat of the glacier was rather active, areas of passive or dead ice were formed on higher parts of relief.

A number of lowlands and elevations, lineary elongated escarps, and other forms can be observed in the pre-Quaternary relief of Pskov region. The most important of them are the Pskov and Preilmen lowlands, the Strugo-Krasnensk and Bezhanitsk elevations.Deep hollows in the pre-Quaternary surface are evidently ancient river valleys,inherited, to one or other extent, by recent river systems, e.g., the rivers of Plyusskaya, Velikaya, Shelon, etc.

The Valdai glacier occurred in the territory of Pskov region in the form of two glacial lobes (the Velikoretsk L. and the Lovatsk L. belonging to the Peipsi and Ladoga glacial streams. The above-mentioned glacial lobes occupied the Pskov and Preilmen lowlands, respectively. Their retreat resulted in the formation of the complex of aqueoglacial plains, insular uplands and marginal relief forms.In many cases mesoforms of pre-Quaternary surface determined the site of aqueoglacial accumulative relief forms, morainic hills, eskers,kames, subglacial grooves, rills of meltwater discharge.

The main large macroforms of lowlands, uplands, elevations are prominent in the relief of Pskov region. The Pskov and the Preilmen lowlands in the west and east occupy a greater part of the region.

Their absolute heights vary from 30-60 to 100-120m. The lowlands are represented by undulating limnoglacial and morainic plains. The thickness of pre-Quaternary deposits increases from north to south from 2-10 to 20-40 m. Zones of marginal formations (the Pskov lowland),river systems, lakes and swamps, local karst and eolian landforms are characteristic of the surface of lowlands.

The area of the insular uplands (the Luuga,Sudomy and Bezhanitsk uplands) stretch from north to south almost meridionally. The prevailing absolute heights on the Luuga upland are 100-140 m, on the Sudomy upland - 170-200 m and on the Bezhanitsk upland - 200-250 m. The thickness of Quaternary deposits fluctuates from 40-60 to 170-200 m. The surface of uplands is composed of large massives and glaciodepressions with hills, ridges, hollows, linear depressions.

In the southern part of the region in latitudinal direction stretch the Velikiye Luki and the Sebezhy elevations being a part of the main ice marginal zone. The absolute height of the elevations fluctuates from 130 to 200 m. The thickness of Quaternary deposits ranges from 20-40 to 80-120 m. The surface of the elevations is complicated by hummock-and-hollow topography. Alongside with hills and ridges lake systems are widely spread.

The Pskov region is rich in lakes, their number reaches 4000. The formation of lakes is, first of all,related to accumulation of till and aqueoglacial deposits. Lakes of erosional and karst origin are characteristic of the locality.

The most widespread lakes in Pskov region are those of glacial origin, their basins were formed in the place of blocks of buried dead ice as a result of the inversion of glacial relief. That was the way insular uplands, marginal formations, outwash plains came into being.

A characteristic feature of glacial lakes is a jagged shore-line, disjointed bottom relief, numerous islands. These are the deepest lakes of the region. Morphology of glacial lakes of insular heights, marginal formations and outwash plains differs. So the basins of glacial lakes of outwash plains are less complicated and bigger in size.

Channel lakes developed in the place of rills of meltwater discharge. Such hollows were formed as a result of the subglacial drai-

Table 1

The morphometric characteristics of the main types of lakes of Pskov region

Types of lakes	Area, km^2	Depth, m mean	max.	Type of relief
Glacial lakes of				
a) morainic-hilly uplands	0.5-8.0	4-9	25-35	hilly morainic uplands, outwash plains
b) outwash plains	1-15	4-6	10-15	
Kettle-holes	1-5	4-8	20-26	outwash plains
Dammed lakes	1-8	3-4	8-10	outwash plains
Residual lakes	0.1-10	2-3	5	gently undulating morainic limnoglacial plains
Erosional glacial lakes	0.1-2	4-5	17	limnoglacial plains

nage of the melting glacier along the ice margin and radial fissure in its body. Quite frequently the location and the direction of cha nels were determined by the ancient river drainage. Channel lakes b came widely spread during the transitional stage from hilly-moraini to outwash plain relief (Table 1).

Channel lakes are of remarkably elongated shape. The ratio o length to width is 10:1 or 15:1. Usually such lakes are situated i groups following one another. Joint by river arms they form lake-ri ver systems stretching over tens of kilometres (e.g. Usmin - Gorodn Ozeronsk, the Usvecha - Ushansk, the Mogilno - Sutonsk and other sy tems.

Residual lakes still exist on the site of pro-glacial water b dies, which became dry as the glacier retreated. The formation of the basins of residual lakes is caused by the ruggedness of bedroc relief and irregular accumulation of till. The characteristic featu of residual lakes is their round and oval form, a slight jaggednes of low and often paludified slopes, shallow water (Table 1).

Dammed and erosional glacial lakes are less spread in the re gion. Dammed lakes were formed as a result of the obstruction of g cial meltwater streams by morainic and aqueo-glacial hills and ri

ges. The lakes fill in low places of hummock-and-hollow and ridge relief. Meltwaters, buried ice, rugged forms of pre-glacial relief have contributed to their formation. The structure of dammed lakes has much in common with that of glacial lakes.

Erosional glacial lakes were formed in pre-glacial river valleys on the territory where the thickness of Quaternary deposits was not considerable and ancient valleys are well expressed in modern relief. This is typical of abrasion-accumulative limnoglacial plains.

After the retreat of the glacier such valleys turned out to be filled by till forming dams here and there, and giving rise to lakes. Usually such lakes are elongated in shape and are of mean depth. In valleys they form chains of lakes connected by a rivulet. For instance, there is a group of lakes in the valley of the Mitkovka River, e.g. lakes Utye, Usovsk, Kuchinsk, Troitsk, etc.

The above-mentioned genetic types of lakes are related to two main stages of relief: hilly-morainic uplands and fluvioglacial plains (lowlands). It has determined the morphology of lake basins first of all, their depth, telling upon the development of lakes in the Holocene.

Beside the above types of lakes in Pskov region one can come across flat-bottomed, delta and karst lakes. They are quite few that is why we do not give their characteristics.

On the territory of the region the lakes are spread unevenly which is determined by the character of the relief. Most of the lakes are to be found on hilly-morainic and outwash plains, where from 4 to 8% of the surface is taken up by lakes. A small number of lakes - less than 1% is typical of slightly undulating morainic and limnoglacial plains.

According to palynological data lacustrine hollows were formed on the territory of Pskov region in late-glacial period (Геоморфология четвертичные отложения Северо-Запада Европейской части СССР, 1969; Шульц и др., 1963). So in the floodplain of Lake M.Ivan beneath the lake marl of the Holocene age at the depth of 1.3 m silts of the Alleröd age were discovered. The same is observed in the floodplain of Lake Usvyatskoye. On the Sudomy Uplands lake basins existed already in the Subarctic period though being the waterbodies of local limnoglacial type.

The reconstruction of ancient lakes by means of palynological methods on the territory of Pskov region testifies to the fact that primarily lakes made up 20% of the surface. Nowadays they account fo 6% only.

The main reason of the mass drainage of the lakes at the begin-ning of the post-glacial period lies in the drainage of the lakes b the river systems. Kunskas (Кунскас, 1975) states that a newly for-med rivermouth lowers the level of a lake as much as 1-3 m. The con-jugated character of the lake and river terraces also testifies t the lowering of the level of the lakes (Лесненко, 1976). The data concerning the history of the development of the river system of t north-west of the East-European plain testify to the fact that the main river systems began to form here in Preboreal time, and - a b later their tributaries formed. The valleys of the rivers were form on the site of the hollows along which glacial waters used to flow down or inherited the pre-Quaternary hydrographic system. The first river terrace above the floodplain is related to the second lake shore terrace, the high flood plain terrace of the rivers to the first lake-shore terrace, the lower flood plain terrace of the rive to the lacustrine flood plain terrace.

The development of the lake basins was influenced by the chang in the climatic conditions and the processes of the formation of la-custrine deposits. The Holocene is characterized by the alternatio of dry and humid climatic periods. The dryness of the climate in th Preboreal and Subboreal periods caused the shallowing and overgrow of the lakes. According to investigations (Гарункштис,1959) the le vel of the lakes in dry periods sank 2-3 m. In the Atlantic and Su atlantic periods the level of the lakes rose and, consequently, t drainage of the river systems grew.

Both the quantity and quality of the accumulation of the lacu rine deposits are connected with the changes in climatic condition Humid periods resulted in the increasing inflow of terrigeneous de sits, whereas dry warm periods favoured the inflow of calcareous a organogeneous deposits. The total thickness of lacustrine deposit in the mires of the lacustrine origin is 3-5 m, while in the prese

day lakes of the hilly-morainic uplands it is 2-3 m, on outwash plains it ranges from 2-3 to 5-6 m, being 4-9 m on limnoglacial plains.

Under the joint influence of the above-mentioned factors in the Holocene some of the lakes disappeared, others became shallow and are turning into mires at present, whereas the remaining ones have preserved their original character. The degree of the preservation of the lakes depends on the type of the relief which determines the depth of the lake basins.

Shallow lakes were formed on limnoglacial plains, prevailingly. Their primary depth usually did not exceed 6-10 m. In these places river systems started to develop earlier, and, consequently,the drai-nage went on at a higher speed. The accumulation of deposits also stimulated the process of shallowing and overgrowing of lakes. The drainage of the lakes was especially intensive in dry periods.The Es-tonian researcher U. Valk (Валк, 1971) has pointed out that on the territory of Estonia in the Preboreal period the number of mires for-med was 8 times as much as during the second half of the Boreal.

It equally concerns Pskov region, where the greater part of the lakes of slightly undulating, morainic and limnoglacial plains has turned into bogs. The peat deposits of the large raised bogs some tens of square kilometres in area (Nikandrovsky - 10 sq.km, Tsavny Kokty - 1 sq. km, Bolshoy Mokh - 59 sq. km, Linovy Mokh - 54 sq. km and ot-hers) are, as a rule, underlain by lacustrine deposits.According to J. Tamoshaitis (Тамошайтис, 1970), V. Lesnenko (Лесненко, 1976) and others, the ancient lakes 6-8 metres deep turned into bogs in the Holocene. Judging by the area of the bogs one may come to the conclu-sion that the number of lakes of slightly undulating morainic and limnoglacial plains has reduced ten times.

Outwash plains taking up a great part of the area of the extra-marginal zone of the Velikiye Luki and Sebezhy marginal formations are of aqueoglacial origin. A peculiar feature of the outwash relief is a great number of lakes - 6-8%, which is determined by a watershed situation of the territory, a weak indentation of the river system, the lakes are deeper as compared to those of limnoglacial plains. Here, too, the majority of the largest lakes of the region is located.

The lake basins of outwash plains are mainly of glacial origin, less often they are represented by kettle-holes or dammed hollows. They have all the features of maturity: a smaller indentation of the coast line than that of the lakes of hilly-morainic uplands, the littoral zone is well formed, the bottom relief of the lake basins is flat-rolling.

The river system of the outwash plains is most often presented by small river channels, the depth of the downcutting of which is 2-3 m. The formation of the river system stimulated the drainage of shallow lakes 5-6 m deep, which later turned into peatland, several kilometres in area. The paludified area of outwash plains makes u 6-10%. The area of considerably large lakes has reduced by one thir (L. Osino - 8 sq.km, L. Big Olbyto - 8.4 sq.km, L. Beloye - 3.7 sq. km, etc.).

Shallow lakes, up to 2 metres deep account for 15% of the are of outwash plains. Their basins are filled with a 4-5-metre-thick layer of deposits. As a matter of fact, these are overgrowing lakes

With respect to the area hilly-morainic uplands come next aft limnoglacial plains. Due to remarkable water depth the process of the drainage of the lakes of hilly-morainic uplands was slower th that on the aqueoglacial plains. According to our data the lake ar reduced by one fourth in the Holocene. In our epoch the lakes take 3-4% of the uplands, while the mires account for 2-6%.

The lakes of the uplands are remarkable for their depth and complicated structure of the lake basins characterized by strongl intended banks, dissected relief of the base of lake basins. The sl pes of the lakes come down abruptly towards the shore of the lakes rising 15-20 m above water level. Juvenile landscapes are characte ristic of the lakes of uplands.

The lakes related to hilly-morainic relief vary in depth. He we may distinguish three groups of lakes: shallow - 2-4m, average 5-10 m, deep - more than 10 m. Only the first two groups are typic of the fluvioglacial plains.

The distribution of lakes according to their depth testifies the fact that about 50% of the lakes or, to be more exact, lake b

sins of the hilly-morainic uplands have reached their maturity. If to reckon less than 2-metre-deep lakes among overgrowing ones, they will account for about 13%.

Thus, the speed of the disappearance and paludification of lakes depends, to a great extent, on the type of relief. In the Holocene, under the hilly-morainic relief conditions the depth of lakes reduced 2-2.5 times, whereas on limnoglacial plains it reduced 5 times. According to our calculations the lifetime of recent 1.5 m deep lakes in natural environment is about 750-800 years (Лесненко, 1975).

Consequently, forecasting the development of the lakes of the territory under study one may assert the fact that in the nearest future the character of the lakeland is not likely to change since it will take hundreds of years before they overgrow. However, these calculations do not take into account human impact which can either noticeably increase the process of paludification or, on the contrary, prolong the lifetime of lakes.

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ЭВОЛЮЦИЯ ОЗЕР ПСКОВСКОЙ ОБЛАСТИ В ГОЛОЦЕНЕ

В.К. Лесненко

Резюме

Эволюция озер находится в тесной зависимости от типа лед-никово-аккумулятивного и водно-ледникового рельефа. В послелед-никовое время резко сократилась озерность озерно-ледниковых равнин и менее всего - холмисто-моренных возвышенностей. Темп развития озерных котловин зависит прежде всего от их глубины. В современную эпоху заболачивание озер наиболее интенсивно проте-кает в условиях водноледникового рельефа, особенно на озерно-ледниковых равнинах.

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PHYSIOGRAPHY OF THE CENTRAL PART OF SAADJÄRV DRUMLIN FIELD WITH SPECIAL REFERENCE TO LAKE RAIGASTVERE AND ITS SURROUNDINGS

A.-M. Rõuk

Introduction. Saadjärv drumlin field or Vooremaa ("Drumlin area", "Drumlinland") serves as a lake stratotype area in Estonia. For these purposes it proved necessary to present a more detailed survey on natural conditions of the area with special reference to Lake Raigastvere and its surroundings.

Saadjärv drumlin field is located in the central part of eastern Estonia between the towns of Jõgeva and Tartu (Fig. 1). The drumlin field is bounded by different landscapes; in the east it borders on flat and densely forested Alutaguse area, in the north on the rich-in-fields Pandivere Uplands, in the west on largely cultivated Central Estonian Plain, in the south-west on the boggy basin of Lake Võrtsjärv, in the south and in the south-east on the rich-in-fields South-East Estonian Plateau. The transitional zone between Saadjärv drumlin field and Pandivere Uplands includes the upper course of the Pedja River with abundant woods and bogs, in the east and south-east it is bounded by almost continuous belt of hilly moraine relief and kame fields being of little importance for agricultural purposes.

Hypsometrically Saadjärv drumlin field represents a water-shed upland which south-eastwards turn gradually narrower and lower. This area forms a relatively well-defined physiographic (landscape) region (Granö, 1922; Varep, 1964, a.o.). The length of the drumlin field from north-west to south-east is about 55 km and from north-east to south-west (at the widest place) 27 km, its area totals 1200 km^2.

Unlike the Pandivere Uplands which has a limestone core, the Vooremaa Area as a large relief form is composed of loose Quaternary deposits with their total thickness usually not exceeding 60-70 m, however, while related to buried valleys, it may amount to 100 m and even more. In the northern part of the drumlin field the basement is

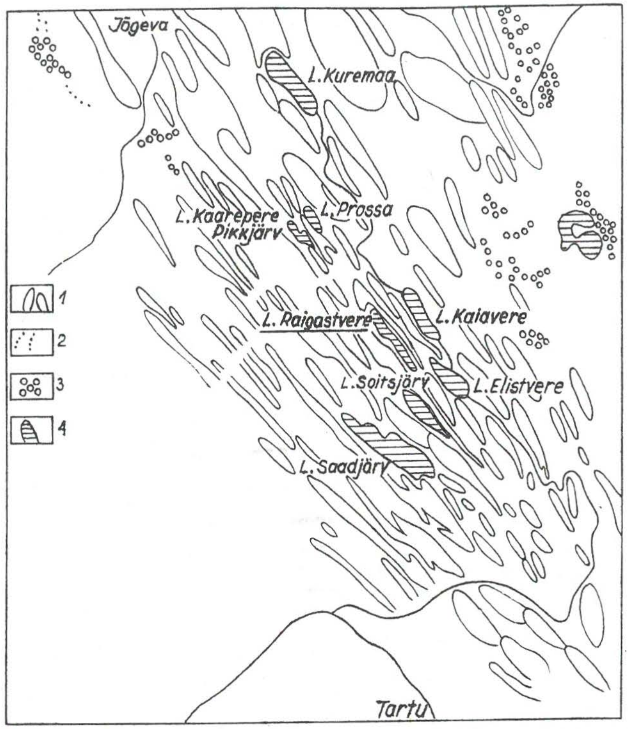

Fig. 1. Map of the investigation area - the central and southern part of Saadjärv drumlin field - showing the situation of L. Raigastvere. 1 - drumlins and drumlin-like ridges; 2 - the main esker chains; 3 - the main kame fields; 4 - lakes.

composed of carbonate rocks, in the southern part it is made up from Devonian rocks prevailed by sandstones (e.g. Каяк, 1965).

Saadjärv drumlin field is notable for the remarkable size of drumlins. Their number totals 100, they are of NW-SE orientation. For the most part they are 2-5 km long, 0.5-0.8 km wide and 20-40 m high, belonging to the largest typical drumlins on the Earth. In the highest, northernmost part of the drumlin field (up to 144 m a.s.l.) prevail especially large, but flat and slightly elongated gigant and shield drumlins (up to 13 km in length, and 3.5 km in width).The lower, but more dissected central and southern parts are dominated by

smaller and more elongated drumlins with steep slopes (Róuk, 1974, 1976). In addition to drumlins and interstitial troughs there occur small undulating moraine plains, eskers, moraine hills and kettleholes. Small dunes and other relief forms are rare.

Saadjärv drumlin field is a densely populated area, and for the most part the drumlins and moraine plains have been turned into fields, whereas the majority of boggy troughs between drumlins serve as hayfields and grazing grounds. The forests, once widely distributed on elevations, have survived only in places on steep slopes and sandy-gravelly soils less suitable for tillage.

The deep interstitial troughs contain several eutrophic lakes elongated in parallel to the drumlins. In view of the genesis, they are considered as a separate group of drumlin lakes (Pirrus, Róuk, 1979; Kask, 1984). Keeping in mind, that the local bedrock relief has practically not affected the drumlinization, these drumlin lakes may be considered as classical in the world, and therefore the structure of these lake basins is of great scientific interest. One should add here that the most typical and richest-in-lakes southern part of the drumlin field has served as a landscape reserve since 1964. The physiographical features, characteristic of this area will be dealt with below in more detail.

Topography and Geology. The area under consideration, i.e. the Central South Vooremaa Area extends from L. Kaarepere Pikkjärv up to lakes Saadjärv and Soitsjärv in the south-east (Fig. 1). The surroundings of L. Raigastvere and adjacent lakes represent a streaky classical landscape of big drumlins of NW-SE orientation. As beside large well-developed drumlins, characteristic of this area, one may come across small drumlin-like ridges; the relative heights fluctuate from some metres to 45 m, however, if measured from the bottom of lake basins (from till surface) partially filled with recent sediments, it may amount to 75 m.

In the northernmost part of the area the bedrock is composed of limestones and dolomites of the Lower Silurian Raikküla Stage. Southwards they are replaced by sandstones, silts, dolomites and domerites of the Middle Devonian Pärnu Stage, followed by the Narva Stage with diverse composition within which the alternation of domerite, dolomite, clay, silt, sandstone and marl layers is observed, the southernmost area is prevailed by silt- and sandstones of the Arukúla Stage (Aaloe et al., 1960; Rõõmusoks, 1983). In the study area the bedrock is overlain by relatively thick Quaternary cover and is not exposed anywhere.

With respect to pre-Quaternary relief the central part of the southern Vooremaa area is located on the southern slope of the Pandivere Upland rising from the Viru-Harju Plateau, and on Central Estonian Plain. The absolute height of the basement decreases accordingly from north to south from 50 m to about 20 m. The data obtained through boring show that the ancient relief is quite modestly dissected. From smaller relief forms one has to mention a buried valley intersecting the floor of the Central Estonian Plain in NE-SW direction. The floor of the valley lies in places lower than 10 m below sea level (e.g. Таваст, Раукас, 1982).

The bedrock is prevailingly covered with till, in which one can distinguish two layers with different lithological composition, most likely related to Valdai and Moscow glaciations (Late Pleistocene).In places, first of all, in a buried valley near L. Saadjärv one may come across still older till related to Dnieper glaciation (Middle Pleistocene) and may be even to Early Pleistocene glaciation (e.g. Каяк 1965; Раукас, 1978). The share of fluvio- and limnoglacial deposits located between till layers of different age, is not remarkable.Lateglacial deposits are represented by varved clays, silts and sands (first of all in troughs between drumlins), and pebbles, gravel and sand (in marginal formations). Holocene sediments are prevailed by sapropel, lake lime and peat in interstitial troughs.The thickness o Quaternary cover ranges from 20 m to 40 m in the area of smaller drumlins, in the region with big drumlins it amounts to 60-70 m, be ing limited to 10-15 m in interstitial troughs.

In the area under consideration the till is of yellowish-gray colouring, rich in lime, consisting of clayey sand or sandy clay,pre vailingly, the content of stones is lower than in North Estonian til The coarse till fraction is prevailed by carbonate rocks, pebbles o crystalline rocks are rather rare. As a result of clearing the ston from fields, the boulders are rare in cultivated areas, small ston

fields mark usually ancient coastlines.

According to A. Raukas (Раукас, 1978) the content of crystalline rocks in the pebble fraction of till fluctuates from 5 to 20% in the drumlin field, whereas the content of Devonian sand- and siltstones ranges from 0 to 2%. The vast majority of carbonate rocks in till comes from the region north of the study area where Quaternary cover is thinner. The content of carbonates (calcite and dolomite) in fine sand fraction reaches 60% in the northern part of the drumlin field, being only 20% in its southern part.

Comet drumlins with a characteristic high stoss end and relatively steep slopes occur in the central part of the drumlin field. Elongated and often rather deep troughs are located between drumlins. The length/width ratio of drumlins is usually 6:1 - 8:1, whereas their length ranges from 3 to 8 km, and relative height from 10 to 40 m. Initially, before the accumulation of sediments in troughs,the difference in relative heights was considerably greater amounting to 75 m, as it was mentioned above. Of the greatest height is the top of Nava drumlin (96.9 m a.s.l.) between the lakes of Pikkjärv and Prossa.

About 3.5 km to the north-west of L. Raigastvere a ridge of marginal eskers, esker-kames and kames composed of glaciofluvial sands and gravel crosses the drumlins and drumlinoids. Here and there the drumlins are intersected by peculiar water-gaps and hanging valleys of NE-SW direction, to which sometimes small gravel and sand accumulations are related.

Since lake basins have developed between drumlins in the course of drumlinization, and almost simultaneously with drumlins,they are not only elongated in the same direction with the latter, but also their shape and other morphological characteristics are in relatively good agreement with the morphological characteristics of surrounding drumlins (Рыук, 1983; Пиррус, Рыук, 1983). For these purposes the basin of L. Raigastvere which is located between strongly elongated, close-lying drumlins with steep slopes, characterized by wider stoss part and long slowly narrowing and lowering tail, is relatively narrow with steep banks and resembles a valley. It is bounded by Raigastvere twin-drumlin (abs. height 91.0 m, relative height

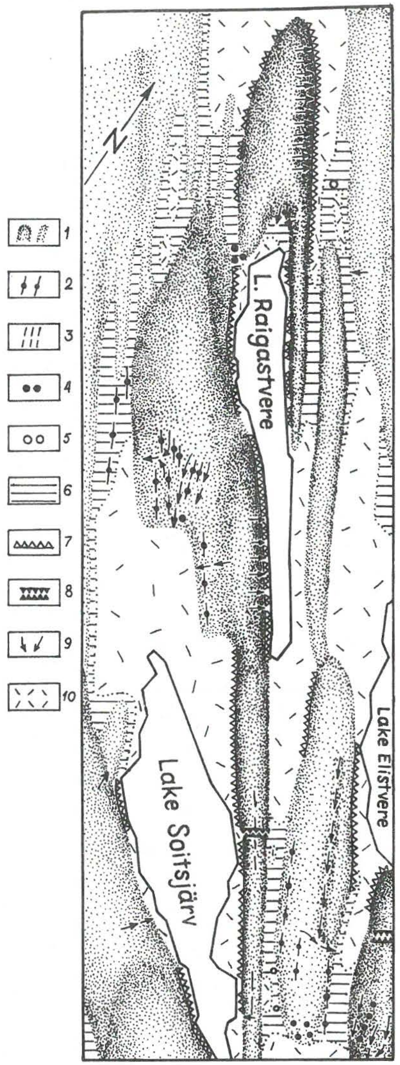

Fig. 2. Landforms in surroundings of L. Raigastvere. 1 - drumlins and drumlin-like ridges; 2 - small flutings; 3 - glacially sculptured grooves; 4- moraine hillocks; 5 - kame hillocks; 6 - glaciolacustrine and lacustrine plains; 7 - wave-cut scarps; 8 - water-gaps and "hanging" valleys; 9 - small valley-like landforms; 10 - bog plains.

38.8 m) in the south-west and by Praaklima drumlin (abs. height 90.7 m, relative height 38.5 m) in the north-east. A bit farther to the east and south-east are situated the low Elmiku drumlin and relatively flat Elistvere drumlin (Fig. 2).

According to recent data (Раукас и др., 1971) the continental ice retreated from the central part of Saadjärv drumlin field more than 12,250 years ago. Immediately after the retreat of the ice the area was inundated by the waters of ice-dammed lakes, only the tops of higher drumlins emerged from the water (Róuk, 1976). With the recession of the glacier from the adjacent areas farther to the north-west, the level of ice-dammed lakes sank and by the end of the late-glacial the troughs between drumlins were occupied by cold-water lakes in which the accumulation of sediments with a little content of organic matter started. About water level fluctuations evidence wave-cut scarps and stone fields located at different heights.On the eastern slope of Raigastvere drumlin they are tracable up to height of about 15 m above present lake level. Higher than 60 m a.s.l. they have been disturbed by ploughing and prove, thus, unreliable for evaluating ancient water level fluctuations. Wave-cut scarps are more distinct at heights 1.5 and 4.0 m, the latter level is in places marked by small stone fields.

Climate. Estonian climate is somewhat intermediate between marine and continental ones. According to the continentality of the climate, the area under the immediate effect of the Baltic Sea and that of Interior Estonia are distinguished. As Saadjärv drumlin field is located at the distance of 140-150 km from the sea,its climate has obtained some signs of continentality with respect to coastal areas (e.g. winters are colder and summers are warmer). As within the boundaries of any landscape region there develop its own characteristic system of microclimates and local climate, then according to Estonian climatic zonation scheme (Raik, 1967) Saadjärv drumlin field serves as an independent unit in the North Estonian subregion of Interior Estonian climatic region.

As Saadjärv drumlin field lies in the region actively influenced by North Atlantic cyclones, its climate is humid and the weather is rather changable, especially in autumn and winter.Winters are moderately mild but long, summers cool and short. The lowest temperature recorded is $-43^{\circ}C$, it is related to the invasion of cold air masses from the north and north-east. In spring the weather is usually clear and dry. The main climatic characteristics are presented in Fig. 3.

The coldest month of the year is February (the mean air temperature is $-7^{\circ}C$). The highest mean air temperature ($16-17^{\circ}C$) is related to July. The mean annual air temperature ($4-4.5^{\circ}C$) is a bit lower than in surrounding areas since the absolute height of the drumlin field is greater. With respect to other Estonian regions, Saadjärv drumlin field is characterized by relatively great air temperature fluctuations and the shortest period without night frosts (it lasts only for 110-120 days). The vegetation period (average temperature above $5^{\circ}C$) lasts mostly for 170-175 days, the period favourable for the growth of thermophilic plants (average temperature above $15^{\circ}C$) lasts for 40-45 days only, and the sum of active temperatures ranges from $1650-1750^{\circ}C$. The spring frosts are likely to occur here earlier than in other parts of Estonia. If on the islands and on the western coast the last frosts occur towards the end of April, then here they continue for a month longer; the autumn frosts begin a month earlier than on the western coast (Eesti NSV agroklimaatiline..., 1962; Tooming, Arold, 1977; Агроклиматические ресурсы..., 1974).

Like in Estonia, as a whole, the prevailing winds in Saadjärv drumlin field are south-westerly which bring from the Atlantic Ocean relatively cool and humid air masses. The mean annual precipitation is 600-650 mm. Due to the vicinity of the Pandivere Uplands and evidently because of greater absolute height, precipitation is a bit heavier than in surrounding lower-lying areas. About 60-65% of annual precipitation falls in the vegetation period. August is the most rainy month and March is the driest one. Permanent snow cover lasts for over 110 days, it becomes established usually on the 5-15th of December and melts at the end of March. The snow is usually the deepest (generally 30-40 cm) at the end of February and early in March, reaching sometimes 90 cm. There are 50-60 foggy days a year. Due to the shortage of forests strong winds make themselves felt in Saadjärv drumlin field more than in surrounding areas (ENSV agroklii-

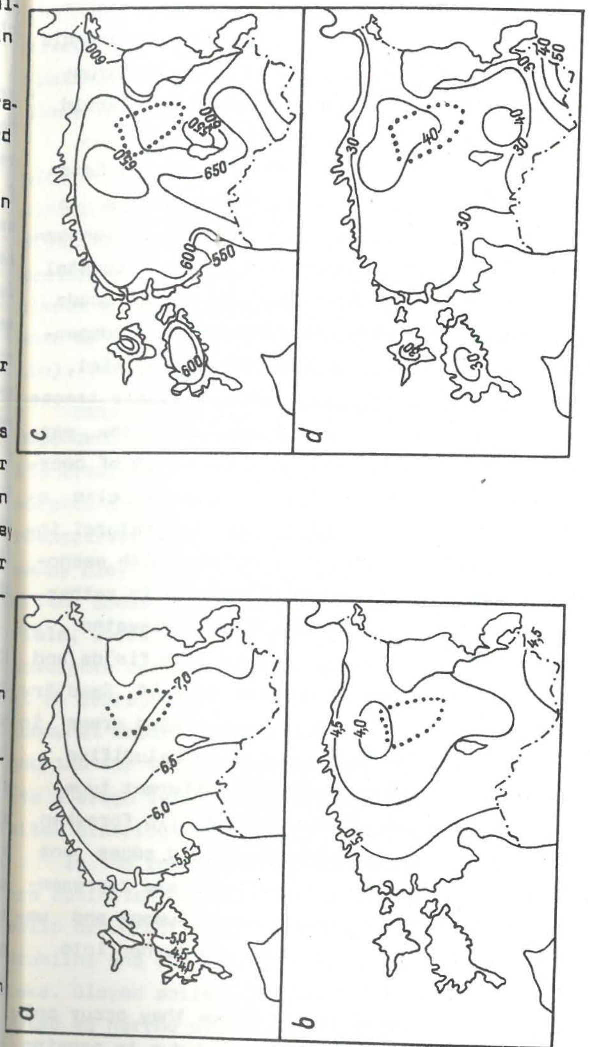

Fig. 3. Some main features of the climatic conditions of Saadjärv drumlin field. a - the mean temperature in February (in $^{\circ}C$); b - the mean annual temperature (in $^{\circ}C$); c - the mean annual precipitation (in mm); d - the average thickness of snow cover during the snowiest ten-day period of winter. (Position of Saadjärv drumlin field is shown by dotted lines)

ma..., 1962; Tooming, Arold, 1977).

Due to dissected relief microclimatic conditions reveal regular variations within the boundaries of the drumlinland. Microclimatic differences between drumlins and interstitial troughs are remarkable. Thus, the difference between maximum air temperatures on the drumlins and in boggy troughs may be 5-6^{o}C at calm clear nights (Arold, Jõgi, Raik, 1976; Tooming, Arold, 1977).

Vegetation. According to geobotanical subdivision of the Estonian territory (Laasimer, 1965) Saadjärv drumlin field belongs to the East-Baltic geobotanical subprovince with the species of western provenance being of much more limited distribution than in coastal areas. It is related to the East and Central Estonian spruce woods and mixed spruce forests area where it is considered as an independent subregion. The area has been inhabited from time immemorial, people have lived here for thousands of years, and left their traces on the development of plant cover almost everywhere. If in the marginal zone of the drumlin field one may come across a patch of poor or rich-in-species spruce wood, and on the eastern boundary also across small stands of pine, then in the central part the natural intact plant cover is almost lacking, the area is covered with secondary natural plant communities, and the share of forests is rather small. About 4/5 of the territory, i.e. almost all its elevated areas and easily drainable troughs have been turned into fields and cultivated meadows. Thus, the south of the central part of Saadjärv drumlin field serves as one of the most largely cultivated areas in Estonia. The troughs between drumlins are occupied by paludified poor-in-species meadows, minerotrophic meadows of different type, birch stands and, in places, by mixed spruce forests. In forsaken areas, fallows, coppices used for grazing, and on field edges one can meet small shrubberies of Alnus incana. Wetlands are represented mainly by eutrophic mires, raised bogs are rare. Swamps and waterlogged mineral lands have been mostly drained and turned into cultivated meadows (grasslands).

The forests are small. On elevated relief forms they occur on steep slopes where land cultivation is aggravated due to erosion and also in sandy and gravelly areas. In the immediate vicinity of

L. Raigastvere pine woods are spread only north-west of it, on Nava and Ehavere ice-marginal formations. To the north of the latter, in the environs of Luua settlement one comes across a more extensive mixed woodland area with abundant broad-leaved tree species, e.g. Fraxinus excelsior, Acer platanoides, Quercus robur, Tilia cordata, Ulmus laevis, etc.

For the most part, L. Raigastvere is surrounded by a 20-50 m-wide and more or less continuous Alnus incana belt, which in places, contains Alnus glutinosa as well. Salix sp. and Betula pubescens are distributed on low paludified shores in the south-eastern and north-westernmost parts of the lake. The surrounding drumlins have been almost entirely turned into fields with only their steep slopes being used as grazing grounds (e.g. the eastern slope of Raigastvere drumlin). The area adjacent to the lake is relatively densely populated.

Soil Conditions. Saadjärv drumlin field is considered as an independent soil microregion (see: Eesti NSV mullastik..., 1974). Of its area, as a whole, automorphic soils account for 40%, subhydromorphic soils and hydromorphic soils (bog soils) make up 35% and 25%, respectively. In view of the texture of soil, clayey sandy soils and sandy clay soils (making up 70% of the area of soils, as a whole)are of the widest distribution. In the southern part of the drumlin field, where the drumlins lie close to one another, the share of automorphic soils is higher and that of hydromorphic soils lower than at an average. Also the contribution of subhydromorphic soils is somewhat modest in the southern part of the drumlin field. It is accounted for by the circumstance that here the slope gradient exceeds its average value, and temporarily excessively moist areas are of limited distribution at the foot of the drumlins.

In the immediate vicinity of L. Raigastvere automorphic soils are dominated by brown soils, lessivaged brown soils and pseudopodzolic brown soils which are related to the tops and slopes of the drumlins and undulating moraine plains located north-west of the lake. Gleyed soils and gley soils (subhydromorphic soils) are distributed as narrow strips on the foot of drumlins, in lower parts of plains and in the elevated marginal areas of troughs. The troughs between the drumlins are occupied unexceptionally by soils of floodplain only (Fig. 4). On steeply dipping drumlin slopes soils may be from weakly to averagely eroded, the thickness of the overlying deluvial soil layer does not exceed 1 m.

In Saadjärv drumlin field the vast majority of automorphic soils belongs to the most fertile soils in Estonia. If to use a 100-point scale, the productivity of fields in this area may be estimated as 45-48, in places even 55 points.

The Present State of Lake Raigastvere. There are 12 lakes with- in the boundaries of Saadjärv drumlin field, of which 10 are locate in its southern part. These are the lakes Prossa, Kaarepere Pikkjär Ilmjärv, Raigastvere, Kaiavere, Elistvere, Soitsjärv, Saadjärv, Pu- pastvere Umbjärv and Vasula. By now L. Pupastvere has practically ceased to exist, L. Ilmjärv is situated on the floor of a transvers gap-valley, and L. Vasula near Tartu belongs rather to valley lakes. The rest of the lakes are typical drumlin lakes elongated in paral- lel to drumlins in the NW-SE direction. They are rather unique, may be even the only drumlin lakes in Europe which basins have develope only due to the moulding action of the glacier. L. Raigastvere is prominent for its strongly elongated shape. Especially its south- eastern part resembles (but it only resembles!) a valley lake, th north-western part is wider and reminds a typical drumlin lake.Thus in view of its shape L. Raigastvere serves as a "negative" of adj cent drumlins.

Lake shores, especially the western and north-eastern ones are steep, stony or sandy (due to the erosion of till), elsewhere low and turfy, in the south-easternmost and north-westernmost parts p ludified. Although the shores are relatively steep, the lake floor is rather flat (Eesti järved, 1968). The coastline is weakly inden- ted, poor in peninsulas, capes and bays as is the case with the ma- jority of other drumlin lakes as well.

Hydrography. Lake Raigastvere belongs to the drainage area o the Amme River, which is the tributary of the Suur-Emajõgi River.T main morphometric data of the lake date from the period after the lowering of the water level by 0.5 m, and they are as follows: abs lute height 51.8 m, length 3.7 km, maximum width 0.5 km (in the south-eastern part 0.25 km), area 1.2 km^2, average depth 2.7 m, ma

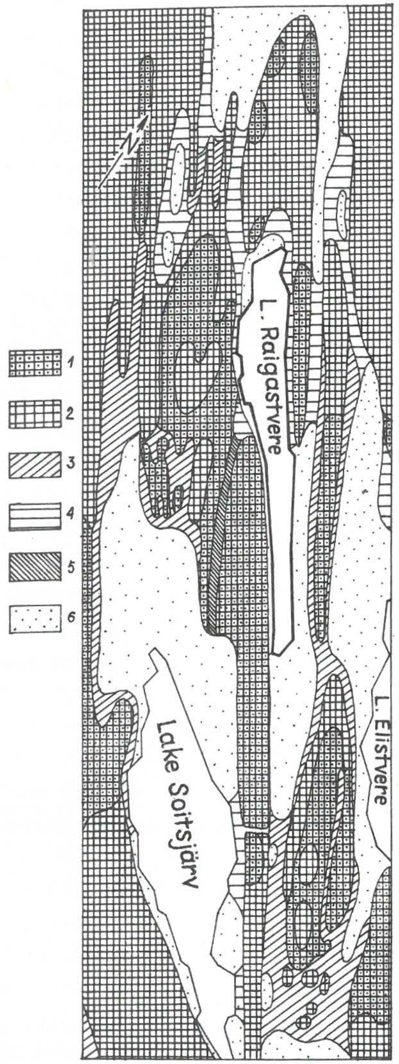

Fig. 4. The main soil types in environs of L. Raigastvere. 1 - brown and lessivaged brown soils; 2 - pseudopodzolic brown soils; 3 - gleyed soils; 4 - gley soils; 5 - deluvial soils; 6 - bog soils.

ximum depth ca 4 m, volume ca 3.6 million m^3. The greatest depth is related to the area lying a bit south-west of the central part.

The inflow of water into the lake takes place through Nava brook which has been remarkably straightened and dredged. It discharges into the lake about in the middle of its eastern shore. In addition, there are several ditches and numerous springs on the floor and shores of the lake contributing to its water supply. In summer the ditches are usually dry. The outflow of the water proceeds through a brook (it has been turned into a ditch) in the sout -eastern part of the lake which falls into L. Elistvere. During the high water the low north-eastern and south-western shores are floo- ded at a width of about 10-15 m (Eesti järved, 1968).

Basin Topography and Sediment Thickness. The lake occupies the deepest, north-western part of a long trough between drumlins. The trough stretches from L. Raigastvere at the length of 3 km south- eastwards where it joines with the basin of palaeolake once located at the site of the present Lavasoo bog. In the part of the trough under consideration, Holocene lacustrine sediments are lacking (wit the exception of a narrow belt near the south-eastern tip of the la- ke). The north-western part of the trough, where the modern lake i situated, is for the most part filled with sediments. Within the li- mits of the modern lake the initial basin, fixed after the till sur- face, resembles a steeply and evenly deepening channel with its south-eastern slope having a steeper gradient than the north-wester one. The floor of the initial valley is dissected by shallow depres- sions and elevations, in the north-western part there are 2 ridge up to 5 m in height which resemble drumlins and are entirely covere by lacustrine sediments.

Near the western and south-western shore the lake bottom is sandy, being otherwise covered with mud. The thickness of sapropel reaches 9 m. Sapropel is underlain by late-glacial terrigenous la- custrine and glacio-lacustrine sediments with the thickness of abo 1 m and at least 5.6 m (in the deepest part of the lake), respecti- vely (see Pirrus, Róuk, Liiva in the present collection). Peat (i places 4 m thick) fills the basin in the vicinity of the north-wes- tern and south-eastern tips of the lake and within a relatively

small area. Within the boundaries of modern lake the volume of the basin has reduced on account of these sediments by about 3/4 as regards its initial value.

Macrophytes. Phyto- and Zooplankton. In 1951 the vegetation was scanty, however, the number of plant species reached 20 and plants covered about 15% of the lake's surface. The observations performed in the north-western area of the lake in 1984 showed that the situation has not changed much during the past 30 years.

Shore vegetation, occuring as a comparatively narrow and interrupted belt, is dominated by Phragmites communis and Schoenoplectus lacustris, followed by Equisetum limosum, Typha angustifolia, Acorus calamus, a.o. (Fig. 5). Floating-leaved vegetation, related mainly to the north-western and south-eastern parts of the lake, is prevailed by Nuphar luteum, followed by Potamogeton natans and Polygonum amphibium. Also ephydate vegetation is concentrated, for the most part, into the north-western tip of the lake, prevailingly. More abundant were Charophyta, Elodea canadensis, Potamogeton perfoliatus, P. pectinatus, P. lucens, Ranunculus circinatus, etc. Submerged vegetation occurred, in places, among shore vegetation as well, forming sometimes independent patches (Eesti järved, 1968; Mäemets, 1977).

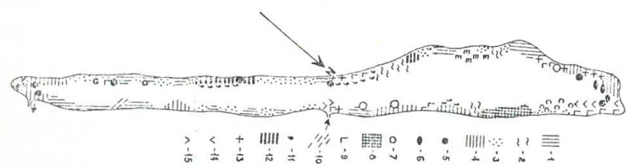

Fig. 5. Map of the vegetation of L. Raigastvere (compiled after H. Tuvikene - Eesti NSV järved, 1968). 1 - Phragmites communis; 2 - Elodea canadensis and Batrachium foeniculaceum; 3 - Schoenoplectus lacustris; 4 - Phragmites communis and Schoenoplectus lacustris; 5 - Nuphar luteum; 6 - Potamogeton natans; 7 - Polygonum amphibium; 8 - Potamogeton pectinatus, Charophyta and Elodea canadensis; 9 - Equisetum limosum; 10 - Carex; 11 - Elodea canadensis; 12 - Acorus calamus and Schoenoplectus lacustris; 13 - Typha angustifolia; 14 - Stratiotes aloides; 15 - Potamogeton perfoliatus and Batrachium foeniculaceum.

Phytoplankton is rather rich and causes "the blooming of water" in summer (Mäemets, 1977; Порк, 1958). Relatively abundant zooplankton is dominated in summer by cladocerans (Chydorus sphaericus, Daphnia cucullata) and copepods. Beside eutrophic lake species (Chydorus sphaericus, Bosmina c. coregoni, a.o.) zooplankton is represented also by species preferring nutrients-poor water (Daphnia cristata, a.o.) (Eesti järved, 1968; Mäemets, 1977).

Hydrochemistry. The main chemical water characteristics for Lake Raigastvere are published in the collection "Estonian Lakes" (Eesti järved, 1968), and they are based, for the most part on the studies performed in 1951 and 1957 (Table). In the winter of 1985 the water electric conductivity was measured in L. Raigastvere and adjacent lakes.

Table

Chemical and physical water characteristics in the lakes Raigastvere, Soitsjärv, Elistvere, Saadjärv and Kaiavere.

Water quality	Raigastvere	Soitsjärv	Elistvere	Saadjärv	Kaiavere
pH	8.3	9.0	8.4	8.4	8.4
Spec.conductivity $\mu S/cm^2$	130	173	144	92	138
$Ca^{\cdot\cdot}$ mg/l	44.9	21.4	38.5	45.7	49.7
$Mg^{\cdot\cdot}$ mg/l	8.6	7.3	8.9	10.9	9.0
$Na^{\cdot}$ and $K^{\cdot}$ mg/l	2.8	1.8	1.8	5.5	2.3
$Fe^{\cdot\cdot}$ and $Fe^{\cdot\cdot\cdot}$ mg/l	0	0	0	0.04	0
HCO_3' mg/l	161.7	91.5	152.6	177.0	178.8
Cl' mg/l	6.0	3.2	2.8	4.6	5.3
SO_4'' mg/l	11.5	9.6	11.5	7.2	12.5
Σ of ions mg/l	235.5	131.8	210.0	238.4	255.8
P mg/l	0.049	0.038	0	0	0

The values are based on the daily determinations for the period July 13-24, 1951 (according to Eesti järved, 1968). Water samples for special conductivity determination were taken in winter 1985.

In L. Raigastvere the water is greenish-gray, with low transparency (0.9-1.4 m), susceptible to mixing and warming, with alkaline reaction (pH 8.3-8.4), with an average mineral matter concentration (HCO_3' concentration being 162 mg/l), poor in organic matter (dichromatic oxidability 21-23 mg/l O_2) (Eesti järved, 1968; Mäemets, 1977). Hydrochemical classification of Estonian lakes refers Lake Raigastvere to IB group (Mäemets, 1965). It is a typical eutrophic lake. Since 1957 the concentration of organic matter has presumably increased due to human impact.

In all the lakes of Saadjärv drumlin field the mineral matter concentration in water is average or above it, being related to the effect of rich-in-lime soils in the drainage area, flowage and bottom springs (Eesti järved, 1968). The ion-composition has been prevailed by HCO_3' and $Ca^{\cdot\cdot}$ throughout all the hydrological periods. The concentration of iron-compounds was remarkable in bottom water layers only.

In lake water organic matter is represented by both the autochthonous (originating from aquatic plants and thick bottom mud layer) and allochthonous material. The concentration of allochthonous organic matter is low, because the conditions prevailing within the boundaries of cultivated drainage areas of such lakes do not favour the washing out of organic matter by water (e.g. Смирнов и др., 1969). Here organic matter is for the most part of autochthonous origin, and it reveals small seasonal variations; the organic matter composition in water is prevailed by dissolved fraction, whereas the share of colloidal fraction is considerably lower; for these purposes the colouring of the water is not very intensive and oxidation processes are characterized by low values (Simm, 1975). The bulk of the humic matter entering L. Raigastvere comes from flood-plain bogs adjacent to its north-western and south-eastern parts.

Autochthonous organic matter contributes to the enrichment of water bodies with biogenic material and accumulation of mud on the lake bottom. The abundance of nutrients creates favourable conditions for the development of aquatic plants, due to intensive development of phytoplankton the concentration of phosphorus and nitrogen compounds in water decreases to analytical zero (Simm, 1975). The water samples collected in summer show that in 1950ies the concentration of phosphorus in the bottom water layer was 0.049 mg/l, whereas only the traces of phosphorus were detected in the surface layer (Eesti järved, 1968). It refers to the eutrophication of the water basin. The results obtained through the study of the concentration of the compounds of phosphorus in bottom sediments show that in recent years the concentration of phosphorus has increased in the lake.

To a certain extent water quality is revealed through its specific electric conductivity. It was measured in surface water samples taken in February and March 1985. For the seven lakes studied the values obtained proved high, fluctuating from 92 to 173 $\mu S/cm^2$. Water electric conductivity of Lake Raigastvere (130 $\mu S/cm^2$) was rather close to that of L. Kaiavere (138 $\mu S/cm^2$) and L. Elistvere (144 $\mu S/cm^2$). It was considerably higher for L. Soitsjärv (173 $\mu S/cm^2$) subjected to intensive paludification, and L. Vasula (158 $\mu S/cm^2$) experiencing the effect of town Tartu, comparatively lower values were obtained for the deep and large lake of Saadjärv (92 $\mu S/cm^2$) and L. Kuremaa (101 $\mu S/cm^2$).

Lake Raigastvere has reached its present state as a result of long-term development. Its bottom sediments and the results obtained by corresponding studies will be dealt with in the following paper in the present collection (see Pirrus, Róuk, Liiva).

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УДК 991.2/474.2/

ФИЗИЧЕСКАЯ ГЕОГРАФИЯ ЦЕНТРАЛЬНОЙ ЧАСТИ СААДЪЯРВСКОГО ДРУМЛИННОГО ПОЛЯ. ОЗЕРО РАЙГАСТВЕРЕ И ЕГО ОКРЕСТНОСТИ

А.-М.Р. Рыук

Резюме

Разбираются главные черты физической географии Саадъярвского друмлинного поля, являющегося одним из стратотипных районов озерных отложений Эстонии. Основное внимание уделяется центральной, наиболее расчлененной и озерной части друмлинного поля, в частности озеру Райгаствере и его близлежащим окрестностям. Рассматриваются геологическое строение, рельеф, особенности местного климата, растительный и почвенный покровы территории, а также современное состояние и гидрохимия озера Райгаствере.

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GEOLOGY AND STRATIGRAPHY OF THE REFERENCE SITE OF LAKE RAIGASTVERE IN SAADJÄRV DRUMLIN FIELD

R. Pirrus, A.-M. Róuk, A. Liiva

In view of natural completeness and peculiarity Saadjärv drumlin field has been selected as a reference site for stratigraphical subdivision and geocorrelation of Holocene continental lacustrine and peat deposits in the Estonian territory. Saadjärv drumlin field as one of the largest and most representative on the East-European Plain, is an unique landscape area with characteristic big drumlins of NW-SE orientation and intertitial troughs forming a complete geological complex (Fig. 1).

Peculiar relief accounts for particular microclimate, water regime of soils, migration of chemical elements, composition of soils and vegetation as well as land tenure (Róuk, 1976; Arold, 1977). According to landscape (Varep, 1978) and geobotanical subdivision (Laasimer, 1965) Saadjärv drumlin field is regarded as an independent region.

The basin of Lake Raigastvere is chosen for a reference site in Saadjärv drumlin field. It should be pointed out that the dimensions, sedimentation rate and composition of sediments of both the reference area and reference site are in accordance with the recommendations presented by the IGCP Project No 158. Natural geographical characteristics and the results obtained through the studies of Lake Raigastvere and its basin, are also presented (Róuk, 1987). In the present paper the geological structure of sediments filling the lake basin and the development of the lake is dealt with; it also describes pollen zones of Holocene deposits in the reference profile and presents ^{14}C dates and peculiar features of pollen diagrams of the reference area.

Deposits. For the most part the basin of Lake Raigastvere has been filled in with limnoglacial and lacustrine sediments by now. The share of peat deposits is inconsiderable (Fig. 2). On account of

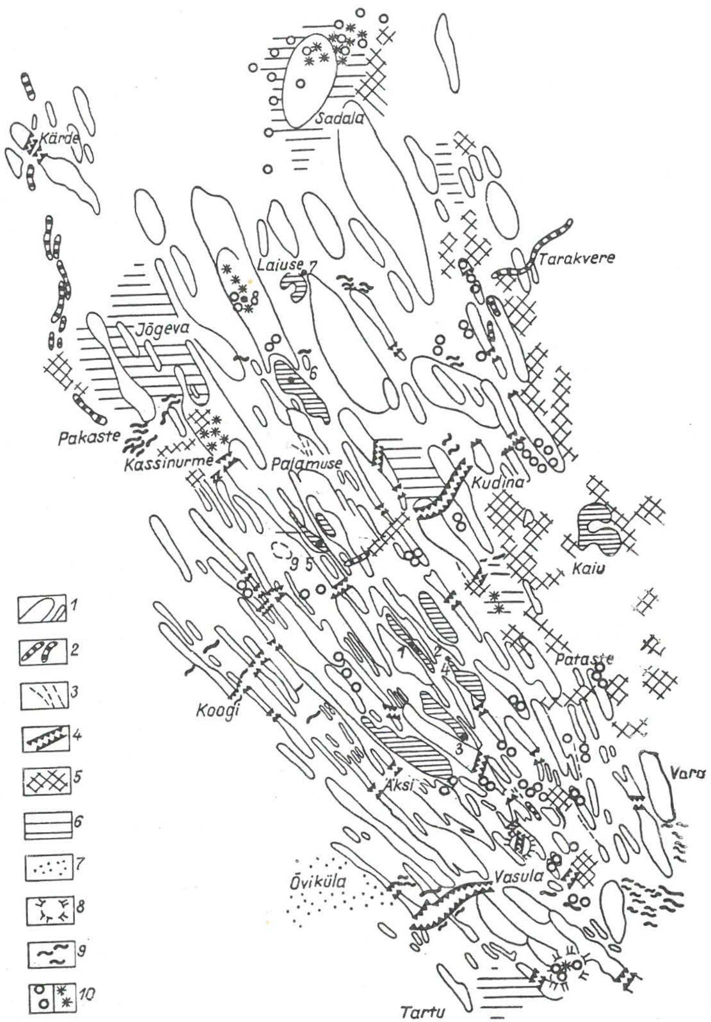

Fig. 1. Geomorphological scheme of Saadjärv drumlin field. Legend on page 103.

Fig. 1. Geomorphological scheme of Saadjärv drumlin field (Rõuk, 1976) and scheme of position of investigated profiles of lacustrine and bog sediments. Conventional signs: 1- drumlins and drumlinoids; 2 - eskers; 3 - radial moraines; 4 - transversal valleys cut into drumlins; 5 - hummocky relief; 6 - undulated moraine plain; 7 - fluvioglacial delta; 8 - gravel hillocks covered by till; 9 - marginal moraine ridges; 10 - kettle-holes and kames.
Arabic numbers: 1 - reference profile of Lake Raigastvere; 2 - R_I 4 profile of L. Raigastvere; 3 - L. Soitsjärv (Pirrus, Rõuk, 1979); 4 - L. Elistvere; 5 - L. Pikkjärv; 6 - L. Kuremaa; 7 - L. Kivijärv (Truu jt., 1964); 8 - kettle-hole Siniallika (Пиррус и др., 1987); 9 - paludified L. Visusi (Пиррус, 1969, 1971).

these sediments the initial volume of the lake basin has decreased by three fourths. The thickness of limnoglacial and lacustrine sediments is over 15 m. Due to its considerably steep coast, L. Raigastvere has underwent only a slight paludification, however, at the same time, the degree of sedimentation is approximately close to that in lakes with remarkably reduced areas.

L a t e - g l a c i a l   d e p o s i t s. Throughout the whole lake basin the basal till is overlain by varved clays with their thickness amounting to 5.6 m in the deepest part of the basin, being about 2 m in shallower areas (Fig. 4, R_{II} 3). According to the results obtained through varve counting the formation of varved clays proceeded about 60 years. In the shallowest part of the intertitial trough, beyond the boundaries of the distribution of lacustrine sediments, where the till surface lies 10-15 m higher, varved clays are lacking and till is overlain by sandy-silt, silt and, in places, by a thin silty-sand layer (Fig. 2, see the profiles, SE of the present-day lake).

In vertical sequence varved clays pass smoothly over into silty clay and pelite silt devoid of rhythmic lamination. Upward the profile the colour of sediments changes quickly from brownish to grey and greenish-grey. This complex represents already late-glacial terrigenous lacustrine sediments and comprises dark layers with somewhat higher organic matter content. Bryales remains are scattered or occur by layers in silty sediments, especially in the upper part of deposits, where silt and sandy-silt layers are more frequent as well. The organic matter content is usually only 2-6%, and it may be a bit

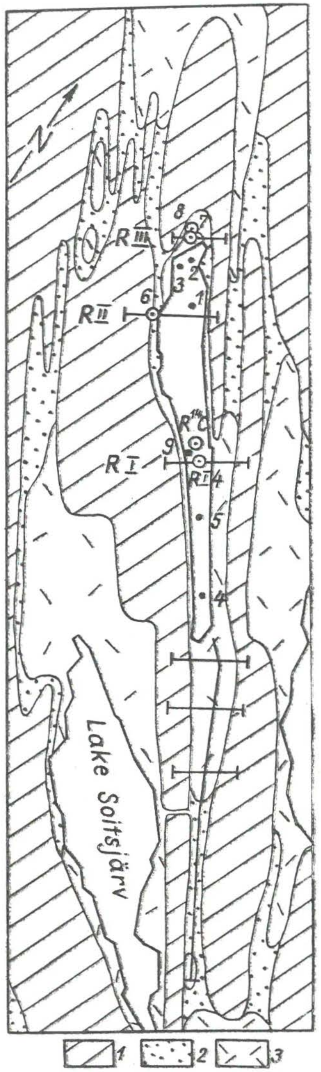

Fig. 2. Scheme of position of bore holes and profiles of the reference site L. Raigastvere.
⊢⊣ - geological profiles; R_I 4, 6, 8, R ^{14}C - palynologically investigated profiles; 1-5 and 9 - single bore holes. 1 - drumlins, 2 - limnoglacial abrasional-accumulative plains; 3 - bogs.

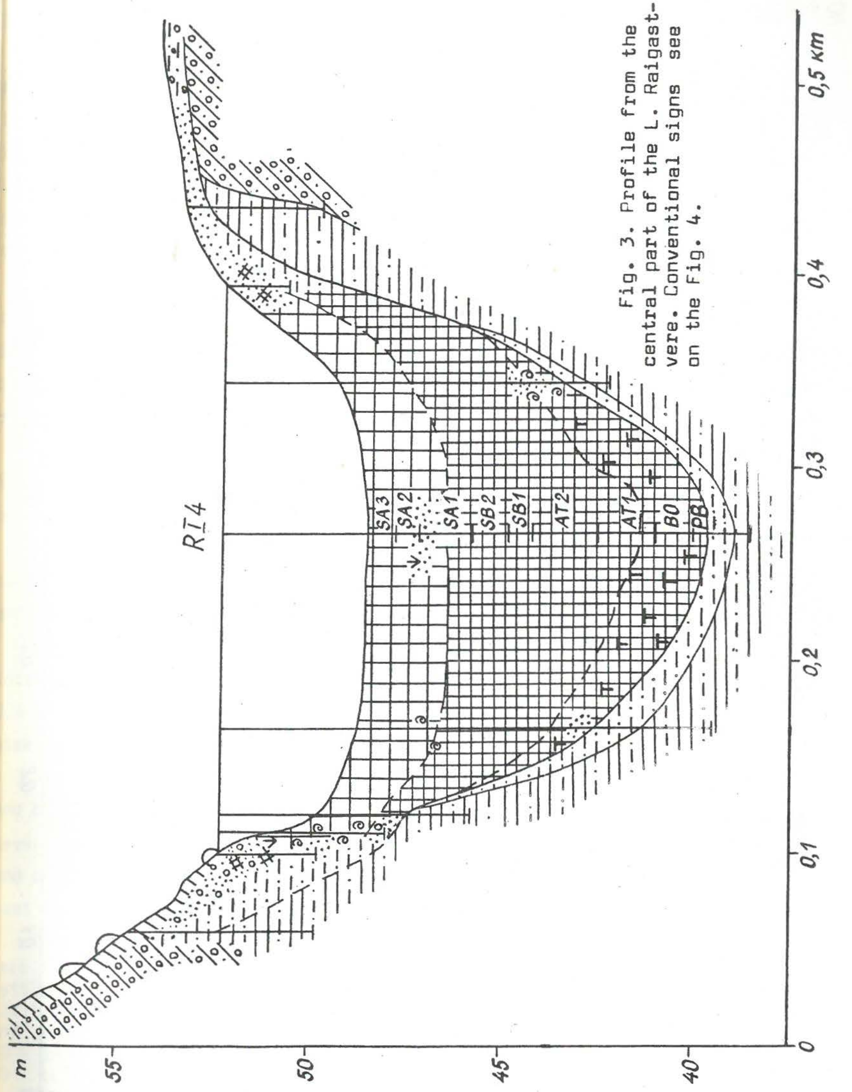

Fig. 3. Profile from the central part of the L. Raigastvere. Conventional signs see on the Fig. 4.

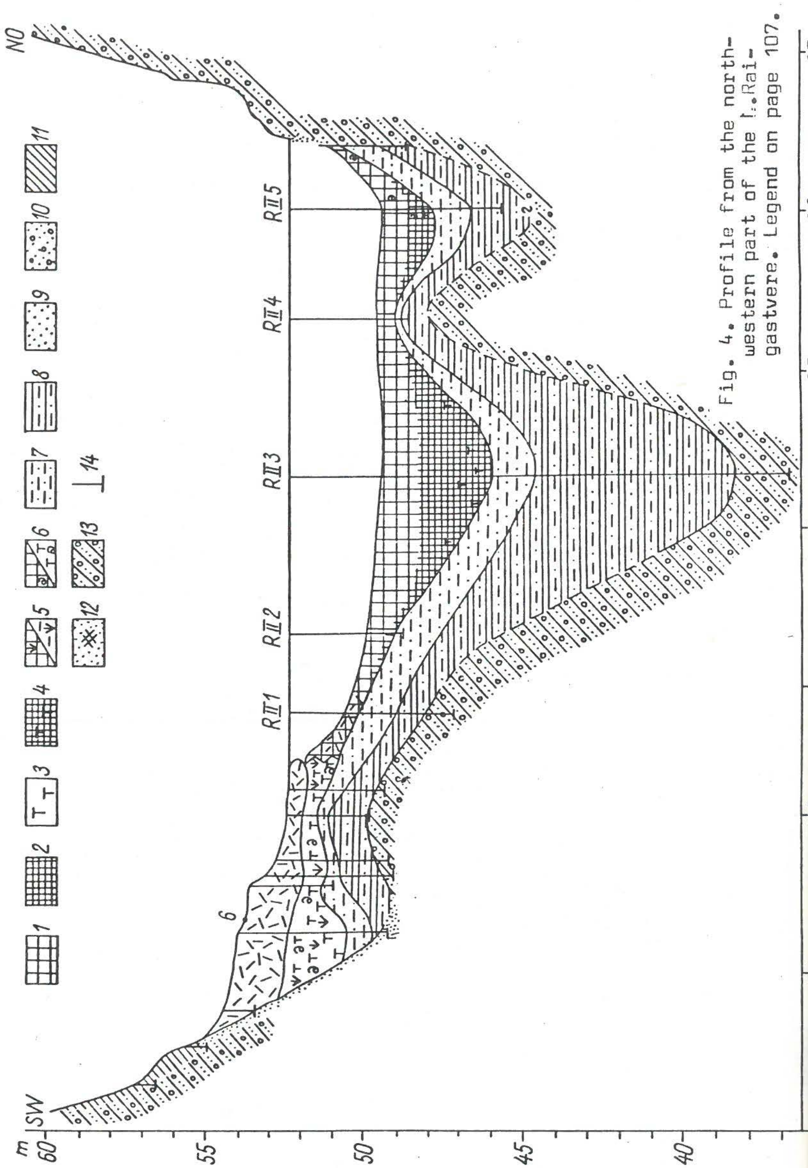

Fig. 4. Profile from the north-western part of the L.Raigastvere. Legend on page 107.

higher only in layers with abundant Bryales remains. The thickness of late-glacial lacustrine deposits is 1 m, seldom it may reach 1.5m (Fig. 3,4).

H o l o c e n e   d e p o s i t s. In the basin of L. Raigastvere Holocene deposits are prevailed by gyttja (Fig. 3,4) up to 11.6 m in thickness (Fig. 2; 6,7). The average thickness of gyttja is 6-9 m, in the north-western and south-eastern tips about 4 m. Gyttja is relatively rich in mineral matter. It may be related to the steep gradient of both the basin and drumlins located in the immediate vicinity of the lake.

Terrigenous component accounts for 60 per cent or even more in the profile (Fig. 5). In the sediments of pollen zones BO1, SB1 and SA2 it amounts to 70-75 per cent, being especially high on the lower boundary of Holocene sediments (78%), whereas towards the upper part of PB it decreases rapidly (to 70%).

In L. Raigastvere gyttja is rather poor in $CaCO_3$, except for BO1 and BO2 pollen zone deposits where it amounts to 15-19%.Lighter, brownish-green colour of gyttja testifies to the lime content.

Organic matter content increases from the lower part of pollen zone SB2 and exceeds 30%. In the deposits of pollen zones AT1, AT2 and SB1 it is about 30%, decreasing downwards to 25% and below it.

In littoral deposits the share of terrigenous component still increases. Silts and sands with their organic matter content being 20% and below it, are distributed in the coastal zone, their grain-size composition and organic matter content change upwards.

In the narrow swampy part of the basin north-west of the lake and on the north-eastern coast of the lake a thin lacustrine lime layer is overlain by fen peat (Fig. 4). In the swampy south-eastern end of the lake gyttja turns in the uppermost part into dy and at last into fen peat as well.

Fig. 4. Profile from the north-western part of the L. Raigastvere. Conventional signs: 1 - slightly compressed and compressed gyttja; 2 - gyttja; 3 - lacustrine lime; 4 - calcareous gyttja; 5 - plant remains in gyttja and silt; 6 - subfossil molluscs in gyttja and lacustrine lime; 7 - silt and clay; 8 - varved clay; 9 - sand; 10 - gravel; 11 - deluvial sediments; 12 - organic matter in sand; 13 - till; 14 - bore holes. PB-SA3 - pollen zones.

Stratigraphical subdivision of sediments and description of lake's development is based on pollen evidence obtained through the study of the sediments from the central, deepest part of the lake (Fig. 2, R_I 4 R ^{14}C; Fig. 6,7) as well as from its paludified and sublittoral areas (Fig. 2, p. 6,7,8,9).

General remarks on lake development. Continental ice retreated from Saadjärv drumlin field during Gothiglacial between Otepää (Luuga) and Pandivere (Newa) stages. During the existence of Póltsamaa I - Peipsi ice marginal lakes the area was covered by their waters, from which the highest drumlins emerged forming an archipelago (Раукас, Ряхни, 1969; Раукас и др., 1971). At that time [it might have been the beginning of the Older Dryas (DR2)] varved clays accumulated in intertitial troughs. The water level of ice-marginal lakes was relatively high. The water level of ice-marginal lakes is marked by abrasion scarps, the latter are low and often disturbed by ploughing terraces. The altitude of an abrasional **scarp** on the slope of a Saadjärv drumlin shows **that at** that time the maximum height of water level might have been 75 m, whereas another, lower abrasional scarp on the slope of a Raigastvere drumlin refers to an height of 65 m. As a result of the retreat of continental ice the ice-dammed lake ceased to exist in the first half of the Older Dryas The water level dropped abruptly and independent lakes were formed in the deepest parts of interdrumlin hollows.

Drumlin field lakes form a peculiar type of glacigenic lakes. In view of their development they may be regarded as relicts of ice-dammed lakes. In the present-day L. Raigastvere late-glacial terrigenous lacustrine sediments started to accumulate in the second half of the Older Dryas (DR2), Alleröd (AL) and Younger Dryas (DR3). The water level of the late-glacial lake seemed to have been a bit higher than at present and it may be related with certain reliability to the development of abrasional scarp at an height of 3-4 m above the present water table. In places it is marked by a boulders belt.

High concentration of terrigenous component in the lowermost deposits of the pollen zone PB may be accounted for by a considerably weak development of vegetation and soils, which favoured the development of erosion. In the swampy south-western part of the troug

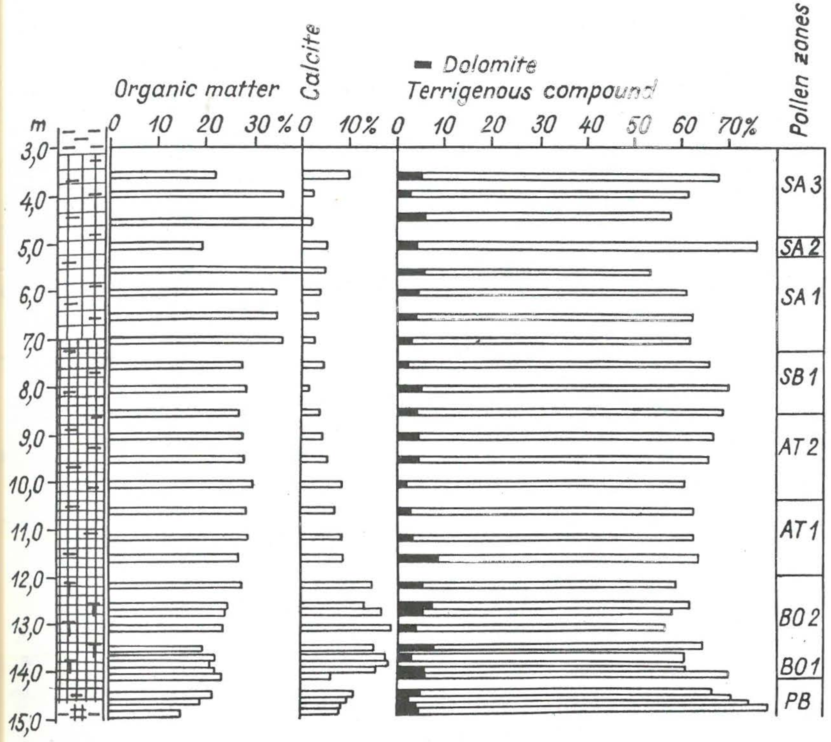

Fig. 5. Containing of organic matter, calcite and terrigenous compounds in the deposits of reference profile Raigastvere. Conventional signs see on the Fig. 4.

(Fig. 2, p. R_{II} 6; Fig. 4) lacustrine lime deposited in the Pollen Zone PB and the lake hereabout underwent paludification at the beginning of the Pollen Zone BO1. At that the contact of lacustrine lime and peat is 0.5 m lower than water level in present-day lake. These indications refer to lower water level than was observed in the above late-glacial lake, however, they do not allow to draw more precise conclusions.

A new rise in the amount of terrigenous component at the beginning of the Pollen Zone BO1 (Fig. 5),break in the sedimentation of gyttja up to the beginning of the AT1 (Fig. 2, p.9), as well as the increase in the amount of SB1 sediments shows that the lake water level must have been a bit lower during the BO1 and SB1 pollen zones. Equally low content of terrigenous component in the sediments of pollen zones AT1 and SA1 refers to a relatively high water level.

The share of terrigenous matter rises abruptly in the sediments of the Pollen Zone SA2 (p. R_I 4, R_I 1, R ^{14}C, R_{II} 3,5), in several profiles it is distinctly marked by the occurrence of fine sand layers and plant detritus. It cannot be explained only by the drop of water level alone, but one has to consider here the man´s agricultural activities which have created favourable conditions for intensive soil erosion on drumlin slopes as well as the input of terrigeneous matter by surface wash. Evidence is derived from pollen finds of Cerealea and weeds since the Pollen Zone SA1, and from an increase in the amount of herbs pollen in sediments.

Reference profile of Holocene sediments of Lake Raigastvere. The reference profile studied is located in the deepest part of the basin of L. Raigastvere, where the thickness of gyttja reaches 11.6m (Fig. 2). The depth of the water is 3.2 m. The description of the profile is as follows:

3.20-3.85 m dark greenish-brown clayey algal gyttja,
3.85-5.20 m greenish-grey clayey algal gyttja successively changing to dark brown,
5.20-8.20 m dark brown clayey algal gyttja. Upper boundary diffused,
8.20-11.70 m brownish-green clayey algal gyttja successively

changing to greenish-brown. Upper boundary diffused,
11.70-14.00 m lighter, brownish-green clayey calcareous gyttja changing to lighter greenish-brown,
14.00-14.70 m dark green clayey algal gyttja.Upper boundary diffused,
14.70-14.80 m dark greyish-green gyttja-clay. Upper boundary diffused.

At the depth of 13.0 m abundant detritus of subfossil molluscs, at depths 3.85-4.0 m, 6.5 m, 9.20-10.20 m, 10.80-10.90 m and 13.0-14.0 m it is of scattered distribution. Plant remains are rare,plant detritus is found at the depth of 5.0-5.10 m.

Pollen stratigraphy. The local stratigraphical scheme of Estonian Holocene mire and lake deposits (Каяк и др., 1976) serves as a basis for subdividing the pollen diagram of L. Raigastvere. It seems to be a justified approach in view of the central position of the study area in Upper-Estonian for which the pollen-zone system has been compiled. Pollen-zone boundary characteristics are relatively well revealed in pollen diagrams compiled for L. Raigastvere and other reference sites in Saadjärv drumlin field.

P o l l e n Z o n e PB (B e t u l a Z o n e). On the basis of L. Raigastvere second pollen diagram (R_I 4) and a pollen diagram compiled for the stratotype profile of Estonian late-glacial sediments located in Saadjärv drumlin field (Пиррус, 1969, 1971) it may be stated that in Raigastvere reference profile Pollen Zone PB is completely represented. The lower boundary of the Pollen Zone PB is placed at the strong and rapid decrease of the content of the pollen of herbs and Betula nana. The curve of tree pollen shows a simultaneous increase. It is mainly Betula pubescens. Among herbs Artemisia and Chenopodiacea frequencies are distinctly and rapidly decreasing. In the PB pollen zone Betula is dominating over Pinus, reaching a maximum in the middle of the zone (89%). In the zone Pinus frequency ranges from 10 to 22%. The representation of other trees (Alnus, Ulmus) is uncommon and fragmentary. The pollen zone can be divided into three subzones: a)Betula frequency is slightly lower and that of Pinus higher than in the subzone PBb. The value of

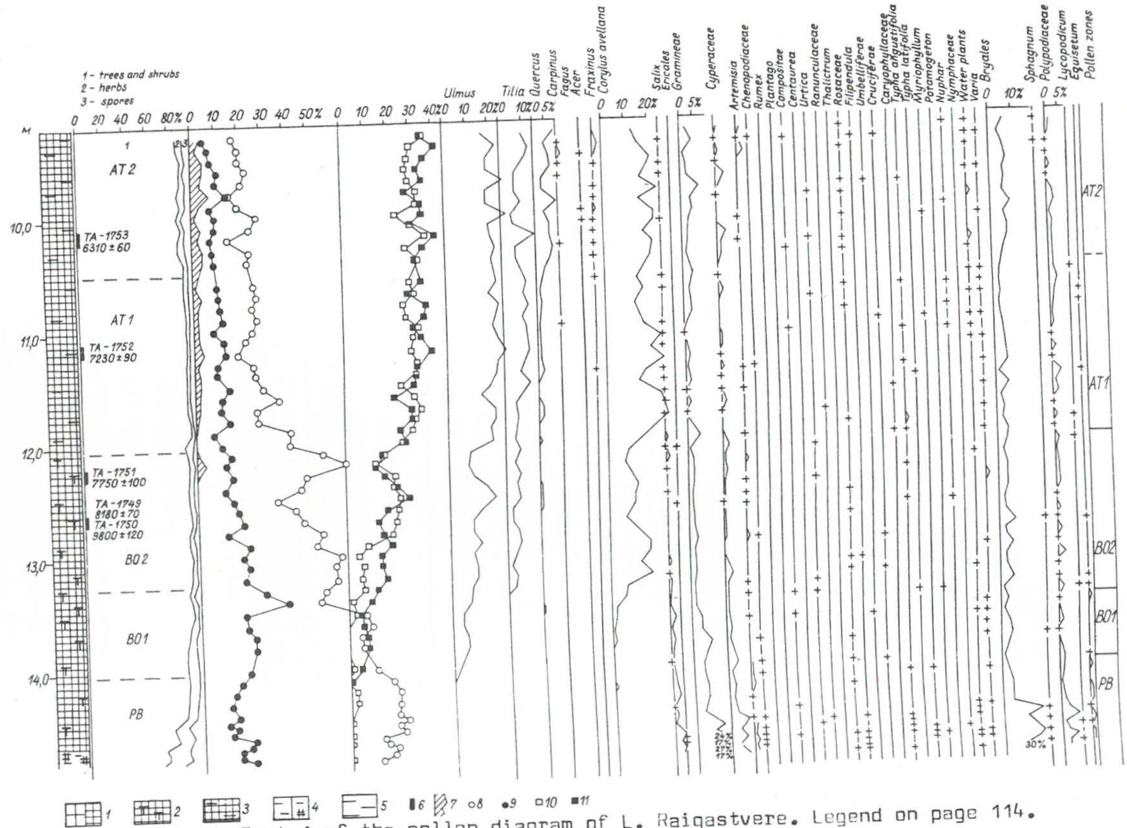

Fig.6. Part 1 of the pollen diagram of L. Raigastvere. Legend on page 114.

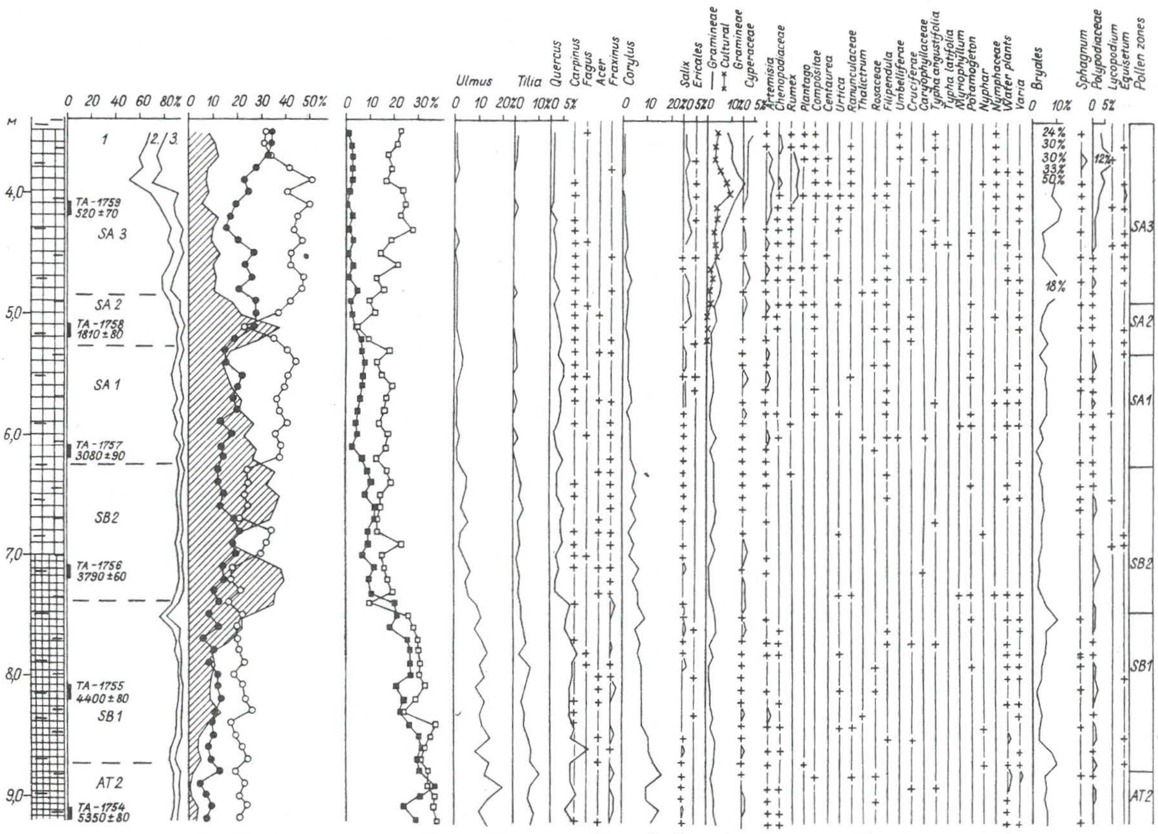

Fig. 7. Part 2 of the pollen diagram of L. Raigastvere. Legend on page 114.

the sum of herbaceous plants is relatively high - 17-22%. The frequency of Gramineae is 17-27%, Cyperaceae - 4-8%, Betula nana - 2-3%, Artemisia - 1-2%, Chenopodiaceae pollen is found regularly in low frequencies. The representation of Salix is continuous (3-5%); b) subzone is characterized by a Betula maximum and high values of Betula reaching 86-89%. The frequency of herbaceous plants and Salix decreases. The finds of Artemisia and Chenopodiaceae are rare; c) Betula and herbaceous plants curves are falling. Their values form 78-83% and 8-10%, respectively. The Pinus curve shows a slight rise. The zone boundary PB/BO1 is fixed at the empiric limit of Ulmus and slight, but distinct rise of the Pinus curve.

Pollen Zone BO1 (Pinus Zone). In this diagram and in the others compiled for the reference area as a whole, the Pinus curve is rising and reaches its post-glacial culmination amounting to 37%. Nevertheless, Betula remains dominate constituting 52-57%. Ulmus and Corylus frequencies increase towards the end of the zone, the empiric limit Corylus and Alnus fall within the zone. Salix is represented in low and constant values.

The zone boundary BO1/BO2 is fixed at the rational limits of Ulmus and Corylus. Characteristic is the empiric limit of Tilia.

Pollen Zone BO2 (Corylus Zone). As before, Betula dominates over Pinus, but its frequency decreases. The Pinus curve shows a distinct fall at the lower boundary of this zone and it continues towards the end of the zone. Among Quercetum mixtum constituents Ulmus forms about 15%. The Corylus curve is rising, and reaches 18%, being over 10% as an average. Considerable is the fall of Corylus curve in the uppermost part of the zone.

Characteristic feature of the zone boundary is a distinct increase of Ulmus and Alnus and decrease of Betula frequency. The Pinus

Fig. 6. Pollen diagram of reference profile Raigastvere - R ^{14}C (PB - AT2). Conventional signs: 1 - slightly compressed and compressed gyttja; 2 - calcareous gyttja; 3 - clayey gyttja; 4 - silt and clay and organic matter in these; 5 - water; 6 - samples for ^{14}C dating. 7 - Picea; 8 - Betula; 9 - Pinus; 10 - Alnus; 11 - Quercetum mixtum.

Fig. 7. Pollen diagram of reference profile Raigastvere - R ^{14}C (AT2 - SA3). Conventional signs see on Fig. 6.

curve continues to fall. The Corylus curve is rising.

Pollen Zone AT1 (Ulmus Zone). Betula is dominating only in the lower part of the zone. For the most part its frequency is about 25%. The representation of Pinus shows still a slight decrease. Quercetum mixtum and Alnus are found in high frequencies throughout the zone. Their amount range between 24-34 and 24-33%, respectively. In the main part of the zone they are dominating. The Quercetum mixtum constituents are still dominated by Ulmus, making up 20%, sometimes even 26%. In the lower part of the zone the Tilia curve is rising. At the same level the empiric Quercus limit is found. Post-glacial culmination of Corylus can be established in the middle part of the zone, reaching 20-26%. The Picea empiric limit is found above the zone boundary.

The zone boundary AT1/AT2 is fixed with a distinct increase of the share of Quercetum mixtum. The rational limit of Quercus is observed. Fraxinus becomes regularly represented in very low values.

Pollen Zone AT2 (Tilia Zone). In this zone Quercetum mixtum and Alnus reach their post-glacial culmination, amounting to 41 and 37%, respectively. They continue to dominate as in the preceeding zone. Betula and Pinus frequencies are still slightly decreasing. Among the Quercetum mixtum constituents Ulmus is still dominating, reaching 28% in the middle of the zone. The representation of Tilia rises, reaching 14%. The Quercetum frequency increases, ranging from 5 to 10% during the zone. Fraxinus becomes regularly represented in low frequencies. Single pollen grains of Acer and Carpinus appear in this zone. Corylus is represented about in the same or somewhat lower frequency than before. The Picea curve shows smaller fluctuations and a very slight rise. The zone boundary AT2/SB1 is fixed with a rather distinct decrease of Quercetum mixtum (Ulmus, Tilia) and Corylus. The Quercus curve is rising.

Pollen Zone SB1 (Quercus Zone). Among the Quercetum mixtum constituents Ulmus and Tilia curves are slowly falling towards the upper part of the zone. The same may be said about Alnus and Corylus. Quercus reaches 15% and has its post-glacial culmination in this zone. The Picea frequency shows a slight increase and amounts to 20% in the upper part of the zone. Fraxinus is found regularly in low frequency. The representation of pollen grains of Carpinus and Acer are not frequent. Single pollen grains of Fagus appear for the first time in the middle of this zone.

The zone boundary of SB1/SB2 is fixed with distinct increase of Picea and contemporary decrease of all the components of Quercetum mixtum constituents and Alnus.

P o l l e n Z o n e SB2 (L o w e r P i c e a Z o n e). In this zone Picea has its first post-glacial culmination, reaching 40%. The peculiarity of the diagram of the Raigastvere reference site and some others of Saadjärv drumlin field reference area is the decrease in the Picea frequency in the middle part of the zone, and further new culmination. Contemporaneously with this Picea frequency decreases, Betula starts to dominate and a slight increase of the Alnus and Pinus frequencies is observed.

In the main part of the zone Picea is dominating, reaching 32-40, Betula amounts to 16-24, Alnus - 14-19, Quercetum mixtum - 7-12 and Corylus - 3-6%. Fraxinus is represented regularly in very low frequency. Pollen grains of Carpinus are frequent, Fagus and Acer are rarer.

The zone boundary SB2/SA1 is fixed with distinct decrease of Picea and increase of Betula frequency.

P o l l e n Z o n e SA1 (P i n u s - B e t u l a Z o n e). Betula becomes dominating, reaching 35-40%. The representation of Pinus shows a slight increase. Alnus has been established in the zone in about the same frequency as during the upper part of the proceeding zone. Quercetum mixtum and Corylus curves are falling. Only Quercus is represented during the zone in the same amount as before. The Picea curve is falling towards the uppermost part of the zone. Carpinus is established regularly in very low amounts. Fagus, Acer and Fraxinus are rare.

The zone boundary SA1/SA2 is fixed with distinct increase of Picea and decrease of Betula and Alnus frequencies.

P o l l e n Z o n e SA2 (U p p e r P i c e a Z o n e). In this zone Picea has the second pronounced maximum, reaching 38%. Common amount ranges from 21 to 38%. In this diagram the zone is compressed. The Pinus curve is rising in the upper part of the zone.

The Betula and Alnus frequencies are decreasing and after the Picea culmination show considerable increase. The Quercetum mixtum curve is continuously falling. Ulmus and Quercus are represented regularly in low frequencies. Carpinus has been established regularly $<1\%$. There occur single finds of Fagus, Acer and Fraxinus.

The frequency of Gramineae increases slightly. Continuous Cerealea curve begins just above the lower boundary of the zone.

The zone boundary SA2/SA3 is fixed with distinct decrease of Picea frequency and a simultaneous increase of Betula and Alnus frequencies.

P o l l e n Z o n e SA3 (B e t u l a - P i n u s Z o n e). In the main part of the zone Betula is dominating. The Alnus curve is rising. The Picea frequency decreases distinctly and ranges from 7 to 13% throughout the zone. Pinus content is rising. Ulmus and Quercus are represented in amounts to 1-4%. Corylus content is regular, but very low. The Cerealea frequency (5-10%) is remarkable. The curve of the herbs is rising. In lower part of the pollen zone the herbs amount to 8 -11%, in uppermost part - to 13-23%.

Radiocarbon dates. Eleven ^{14}C datings have been performed on the sediments from Raigastvere reference profile, ten of them on organic matter and one on carbonates (TA-1750, 9800$\pm$200). The depth of the sample has been measured from the lake level. ^{14}C datings have been carried out by A. Liiva (Department of Biogeochemistry of the Institute of Zoology and Botany, Acad. Sci. Estonian SSR). The list of the datings obtained is as follows (age $^1/2$ 5568 B.P.):

1. Clayey algal gyttja 4.10 - 4.20 m
   TA-1759 520$\pm$70 Middle part SA3
2. Clayey algal gyttja 5.10 - 5.20 m
   TA-1758 1810$\pm$80 Just above SA1/SA2
3. Clayey algal gyttja 6.10 - 6.20 m
   TA-1757 3080$\pm$90 Just above SB2/SA1
4. Clayey algal gyttja 7.10 - 7.20 m
   TA-1756 3790$\pm$60 A little above SB1/SB2
5. Clayey algal gyttja 8.10 - 8.20 m
   TA-1755 4400$\pm$80 Lower part of the middle SB1

6. Clayey algal gyttja		9.10 - 9.20 m
TA-1754	5350±80	Upper part AT2
7. Clayey algal gyttja		10.10 - 10.20 m
TA-1753	6310±60	A little above AT1/AT2
8. Clayey algal gyttja		11.10 - 11.20 m
TA-1752	7230±80	Middle part AT1
9. Calcareous gyttja		12.10 - 12.20 m
TA-1751	7750±100	Just below BO2/AT1
10. Calcareous gyttja		12.60 - 12.70 m
TA-1749	8180±70	Middle part BO2
11. Calcareous gyttja		12.60 - 12.70 m
TA-1750	9800±120	Middle part BO2

Carbonate tills are distributed within the boundaries of Saadjärv drumlin field. For this reason the input of calcareous matter from the drainage area has been considerable throughout the Holocene as a whole. In L. Raigastvere the concentration of carbonates is high only in the deposits of the pollen zones BO1 and BO2. In several lakes, including the shallow parts of L. Raigastvere it was mainly lacustrine lime that accumulated at the beginning of the Holocene, and therefore, the absolute ages obtained by ^{14}C method, especially for the parts of the deposit with high carbonate content, should be taken with certain precaution. Evident is the hard water effect on the age 9800±120 (TA-1750) obtained for carbonates. This age is considerably older than that of the Pollen Zone BO2, into which the sample belongs according to its pollen composition. More reliable seems the age of organic matter from the same sample (8180±70, TA-1749). However, as a whole, ^{14}C dates obtained are in good agreement with the pollen zones boundaries. One should only point out a bit older age obtained within the boundaries of pollen zones SB2, SA1 and SA2 (Fig. 7) in comparison with the average ages of those pollen zones in local stratigraphic scheme (Каяк и др., 1976). It may be accounted for by the input of older organic matter into the lake as a result of human impact. The migration and changes in the distribution of Picea are not synchronous in the Estonian territory, as a whole. However, the boundaries of the pollen zones under consideration, are based just on the changes in Picea frequency prevailingly.

As here we have to do with a reference area, in the nearest future the correlation of ages of pollen zones and ^{14}C dates on peat, providing less sources of errors on radiocarbon dating, are of urgent necessity.

Human impact. The pollen diagram compiled for Raigastvere reference profile shows the signs of the man's early agricultural activities since the beginning of the Pollen Zone SA1. Single finds of Cerealea pollen throughout the whole pollen zone accompanied by a slight rise of the herbs curve indicate to early slash and burn cultivation. Artemisia is continuously represented in small amounts. Chenopodium album, Compositae, Plantago, Urtica, Onagraceae are represented. In the Pollen Zone SA2 Cerealea occur steadily in small amounts, in the upper part of the zone herbs pollen makes up 9%, the Gramineae curve is rising, and in SA1 the frequency of the above herbaceous species increases. In the Pollen Zone SA3, especially in its second half, the landscape has experienced considerable human impact. The Cerealea curve shows a distinct rise, as well as the total curve of Gramineae. The appearance of Centaurea , Plantago, Rumex, Compositae is usual and composition of herbs pollen diverse.

In this connection it may be supposed that man inhabited these areas already earlier and the fall of the Picea curve in the middle of the Pollen Zone SB2, observable in some pollen diagrams for this region is also the result of human impact.

In order to get more open landscape the forest was burnt down in places, and as a result Picea was temporarily replaced by Betula.

Peculiar features of the pollen zones of Saadjärv drumlin field. In addition to Raigastvere reference site (Raigastvere reference profile and Raigastvere R_I 4) there are quite complete pollen diagrams for lacustrine sediments of lakes Soitsjärv (Pirrus, Róuk, 1979), Pikkjärv, Kuremaa, and Elistvere, Siniallika kettle-hole sediments on Laiuse drumlin (Пиррус и др., 1987) and several earlier pollen diagrams, e.g. for lakes Visusi (Пиррус, 1969, 1971), Kivijärve (Truu jt., 1964) a.o. (Fig. 1) occurring within the boundaries of Saadjärv drumlin field. On the basis of these pollen diagrams its possible to point out some peculiar features of the pollen of Saadjärv drumlin field with respect to the major part of Upper-Estonia.

The criteria of pollen zones boundaries are in accordance with the pollen zones boundaries of stratigraphical scheme of local Holocene mire and lake sediments in the Estonian territory (Каяк и др.,1976). Differences concern only the ratios of some trees. The main peculiarities observed in the pollen diagram of the reference area in the drumlin field are as follows:

1) extremely low Pinus frequency in all the Holocene pollen zones;
2) in view of the above the pollen zones BO1 and BO2 are dominated by Betula, not by Pinus as in the most part of Upper-Estonia.However,the frequency of Pinus increases in those pollen zones, serving as a criteria for the differentiation of the pollen zones BO1 and BO2; 3) high concentration of Quercetum mixtum in the pollen zones AT1 and AT2. It is about twice as much as in the vast majority of Upper-Estonian pollen zones; 4) as a result, the amount of Quercetum mixtum is relatively high in BO2 and SB1 and also in SB2 pollen zone.

These characteristic features of the development of vegetation are accounted for by fertail soils in Saadjärv drumlin field, variability of landscape elements, as well as peculiar relief and hydrological conditions.As a result the most favourable conditions were created for rapid migration of broad-leaved trees and formation of broad-leaved forests, characteristic of the Atlantic climatic period.

Pollen diagrams of the drumlin field are most similar to those for small lakes and bogs in the central part of Sakala and Pandivere Uplands. It is quite natural, as Saadjärv drumlin field together with those regions belongs to the same geobotanical region (Laasimer, 1965).

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ГЕОЛОГИЯ И СТРАТИГРАФИЯ ТИПОВОГО МЕСТОНАХОЖДЕНИЯ ОЗЕРА РАЙГАСТВЕРЕ В ПРЕДЕЛАХ СААДЪЯРВСКОГО ДРУМЛИННОГО ПОЛЯ

Р.О. Пиррус, А.-М. Рыук, А.А. Лийва

Резюме

Рассматривается геологическое строение /рис. I-5/ и развитие типового местонахождения озера Райгаствере в пределах ландшафтного района Саадъярвского друмлинного поля. Местонахождение и район в целом являются весьма подходящими для детального стратиграфического расчленения континентальных голоценовых отложений территории Эстонии /рис. 6-7/.

Котловина озера Райгаствере к настоящему времени в значительной мере заполнена озерно-ледниковыми ленточными глинами мощностью до 5,6 м, затем выше по разрезу следуют озерные пелиты и алевриты позднеледникового возраста и сапропели с повышенным содержанием терригенного компонента. Мощность последних достигает II,6 м.

Специфические черты района выражаются в относительно низком содержании пыльцы сосны во всех палинозонах и в высоком содержании пыльцы широколиственных пород в палинозонах AT I и AT 2, а также в палинозонах BO1, SB1.

Признаки хозяйственной деятельности человека обнаруживются в спорово-пыльцевых спектрах начиная с палинозоны SA1.

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ON THE DEVELOPMENT OF LAKE ÕMARJÄRV (NE ESTONIA) IN THE HOLOCENE

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The aim of our investigations based on the study of bottom sediments was to find out some regularities in the development of Lake Õmarjärv in the Holocene. This enclosed lake, in which bottom deposits with a thickness of up to 7 m started to accumulate in the Preboreal, offers a good opportunity to investigate the changes in natural conditions in NE Estonia during most of the Holocene. In this region we have carried out long-term complex investigations on bottom sediments of lakes with different types of feeding as well as on peat deposits. The further aim is to find out the regularities governing geochemical processes in natural and technogenic conditions.

The present paper deals with the results obtained through complex investigations on lacustrine sediments, as well as on lake and bog sediments surrounding the modern Lake Õmarjärv in the NE part of the Estonian SSR, on the southern edge of Illuka kame field. This small lake (with its surface area about 1,6 ha) lies in a deep kettle-hole of evidently glaciokarstic origin. The western shore of the lake borders on a steep-sided kame having an inclination similar to the angle of natural sand deposits, the eastern shore is low and paludified.

At the present time the lake feeds upon ground water. Springs in the western part are well observable. Isotope analyses have revealed the similarity between the $\delta^{18}O$ values of lake water and those of ground water all the year round (-11.2 - -11.5‰) (Вайкмяэ и др., 1985). The water in the lake is clearly stratified with the exception of autumn when total mixing of water takes place. This is most vividly expressed in the profiles of dissolved oxygen (Fig. 1) typical of eutrophic lakes. The data obtained show that oxygen-free conditions prevail on the lake floor for most of the year, accounting for the main regularities in balanced distribution of chemical elements in the water and bottom sediments. Oxygen-free conditions cause a change in the redox potential (Eh), lead to the decrease in the degree of the oxydation of metals and to the reduction of nitrates to ammonia and nitrogen as well as sulphates to sulphides due to bacterial activity. The latter process, leading to the decrease in nitrate and sulphate-ions in the bottom water layers and to the rise in sulphide concentration, was detected in Lake Ümarjärv.

Nutrition on ground water together with its high concentration of HCO_3^- (up to 198 mg/l) cause a slightly alkaline (pH = 7.6 - 8.1) reaction of water. Judging by the constant presence of lake lime in the column of bottom sediments it can be assumed that the hydrochemical conditions and pH of the water have not changed much during Holocene time. This circumstance facilitates the interpretation of the data about variations in chemical elements in bottom sediments.

On the lake floor Holocene deposits are represented by fluvioglacial poorly sorted sands of various grain size and gravel overlain by a thin layer of lake lime (up to 10 cm). The main bulk of sediments (7 m thick) around site 1 has been formed by laminated calcareous sap-

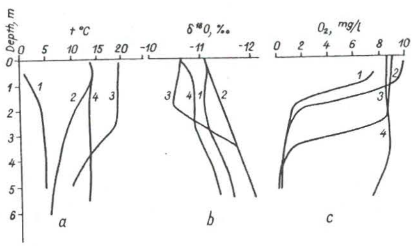

Fig. 1. Changes in temperature (a), $\delta^{18}O$ values (b) and amount of dissolved oxygen (c) in connection with depth in Lake Ümarjärv. 1 - 27.02.85; 2 - 15.05.85; 3 - 04.07.85; 4 - 19.09.85.

ropel (at places with clearly expressed microlamination). Microlamination, revealed by the alteration of dark and light interlayers is characterized by variable rhythm (from some mm to 20 mm). The colour of sediments changes from black in the upper part of the section to greenish-grey in the main part. Fragments of malacofauna were recorded within some intervals.

The sediments on the western shore of the lake indicate frequent and substantial fluctuations of water level in the lake (Figs. 2 and 3). The lower part of the section (3.91 - 6.45 m) is formed by sands with thin interlayers of woody or woody-reed peat overlain (interval 3.82 - 3.91 m) by greenish-beige lake lime containing some mollusc shells and covered (3.71 - 3.82 m) by a layer of calcareous sapropel. Upon the sapropel (3.57 - 3.71 m) a layer of woody-reed peat has accumulated which, in its turn, is covered (3.28 - 3.57 m) by sapropel. The latter is followed by a layer of peat (2.57 - 3.28 m) separated from the underlying sapropel by an interlayer (3 cm) of grey sand. The peat with sand interlayers abounds in wood and reed remains with different decomposition degree (from 30 to 80 %).

Greenish-grey lime with fragments of malacofauna rests upon the peat (interval 2.63 - 2.75 m), and is again followed by sapropel (2.15 - 2.63 m) with interlayers of peat (2.22 - 2.32 m) and sand (2.32 - 2.37 m). This complex provides evidence of abrupt changes in sedimentation conditions and is covered by reed peat (0.00 - 2.15 m) with pieces of wood and grains of sand in its lower part.

Site 3 is situated in the northern part of the lake about 15 m from the shoreline (Fig. 3). 5.07-meter-thick lake and bog sediments rest upon bluish-grey coarse-grained sands. The lower part of the section (5.07 - 4.15 m) is formed by calcareous sapropel with interlayers of plant remains in its upper part. An increase in the content of plant remains (up to 20%) and lake lime is observed at the depth of 4.15 - 3.00 m, fragments of mollusc shells are present throughout the complex. Higher up (3.00 - 2.92 m) lies an interlayer of moss with wood remains which is covered by a complex of lake lime alternating with sapropel rich in plant remains (2.92 - 1.64 m). Peat with fragments of wood at the depth of 1.50 - 1.64 m is overlain by lake lime with a high content (up to 50%) of plant remains (1.50 - 1.33 m) covered by peat (1.33 - 0.00 m).

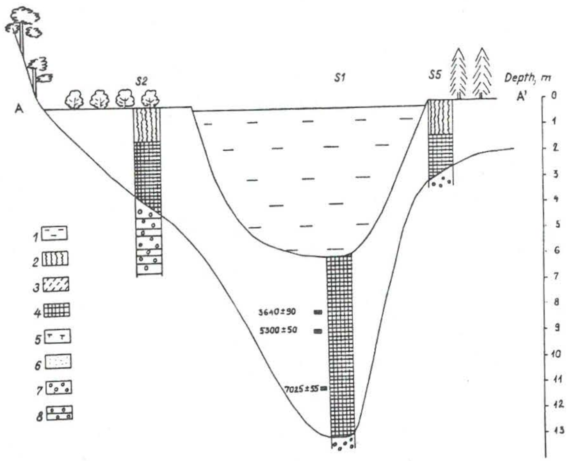

Fig. 2. Cross-section A-Á of Lake Ömarjärv. 1 - water; 2 - Phragmites peat; 3 - Bryales peat; 4 - lake gyttja; 5 - lake marl; 6 - sand; 7 - gravel; 8 - peat with sandy gravel interlayers.

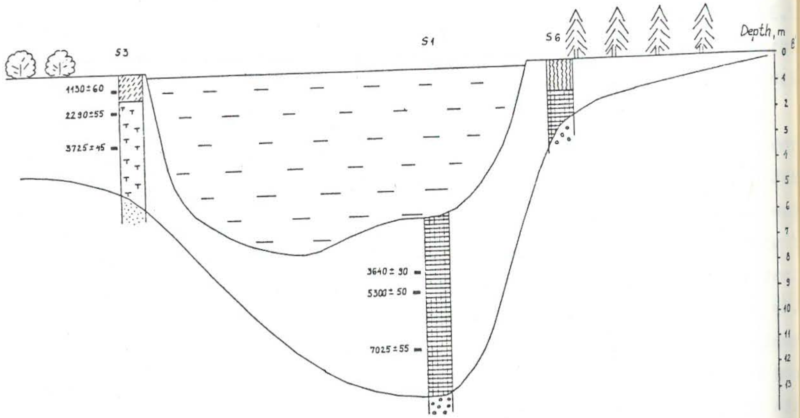

Fig. 3. Cross-section B-B of Lake Ömarjärv. For key to sediment types see Fig. 2.

Chronological scale for the section of bottom sediments (Site 1).

Elaboration of a reliable age scale is an inevitable precondition for palaeogeographical and geochemical reconstructions. For these purposes use was made of radiocarbon and pollen methods. Three ^{14}C datings were carried out on the samples from core 1 (Fig. 4). Extrapolation of the datings on a straight line (considering the statistical error) shows that the upper layers must have accumulated about 4 000 years ago. This can be explained neither by the absence of current sedimentation nor by carrying away of already accumulated sediments. ^{210}Pb investigations of the upper layer revealed that sedimentation has taken place at least for the last hundred years. Taking into consideration the lithological composition of the bottom sediments it becomes evident that the ^{14}C ages obtained are older than the real ones due to the "hard water" effect. In order to estimate the value of this effect detailed isotope and chemical analyses should be carried out.

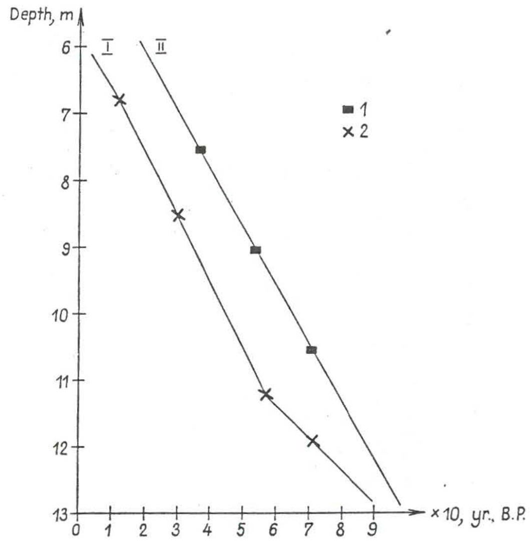

Fig. 4. The depth-age relationships of sediments after 1) ^{14}C dates; 2) palynological analysis. I - extrapolation after pollen data, II - extrapolation after ^{14}C data.

Pollen analysis was applied to volumetric subsamples of 2 cm^3. Each sample was prepared by standard chemical procedures, including acetolysis but excluding hydrofluoric acid. Tablets of Lycopodium spores (Stockmarr, 1971) were used to determine the pollen concentration.

Figures 5 and 6 present the pollen stratigraphy diagram and the pollen concentration diagram, correspondingly. The percentage pollen diagram is characterized by constant high percentage of the pollen of Betula (40-60%) and Pinus (about 20%). Against such high over-representation of the percentage values of Betula and Pinus the relatively small changes in the percentage of other species, which would provide important information for stratigraphical reconstructions, can hardly be detected on the diagram (Fig. 5).

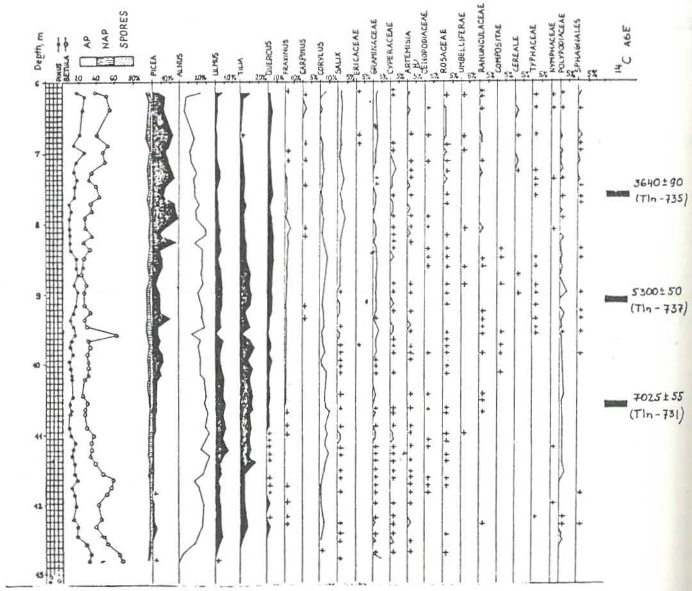

Fig. 5. Pollen diagram and radiocarbon data for site 1 of Lake Õmarjärv. For key to sediment types see Fig. 2.

In view of the above on stratifying the deposits of site 1 we made use of an approach presented on the international symposium "Methods for the investigation of Lake Sediments: Palaeoecological and Palaeoclimatological Aspects", held in Vilnius in September, 1986 (Punning, 1986; Varvas et al., 1987). A column of organogenic deposits from the raised bog of Liivjärv, about 20 km northwards, was chosen as a type section. The pollen data of the raised-bog peat samples were subjected to principal components analysis and local pollen assamblege zones (PAZ) were determined (Пуннинг и др., 1985).

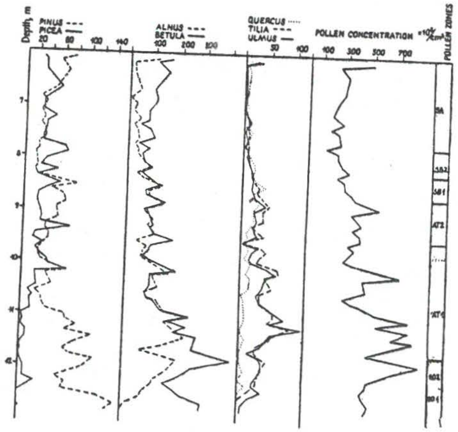

Fig. 6. Pollen concentration diagram of site 1 of Lake Õmarjärv.

The ages of separate local PAZ were fixed by the ^{14}C method. The local PAZ determined likewise in the section of Lake Õmarjärv ($Õ_1...Õ_5$) are in good correlation with the local PAZ in the Liivjärv section, which enables their indirect comparison with the ^{14}C scale. Fig. 4 presents the age data obtained by ^{14}C and pollen analyses. The data show that variously obtained ages of separate layers differ from 1000 to 2000 years. Taking into account the geochemical grounds of the ^{14}C method and the fact that the porosity of sediments grows upwards, the ages obtained by correlating palynozones are more plausible than the ^{14}C datings (the extrapolation curve intersects the ordinate approximately at the contact point of water and sediments).

Essential changes must, evidently, have taken place in the process of sedimentation about 5 500 B.P., the average sedimentation rate was considerably higher than in the first half of the Holocene.

Chemical Composition of Bottom Sediments. Samples for determining the concentration of carbon, nitrogen, hydrogen, Fe_2O_3, Mn and some heavy metals were taken throughout the section of bottom sediments (site 1) of Lake Ümarjärv (Fig. 7). The content of carbon, nitrogen and hydrogen was determined at the Institute of Chemistry, Academy of Sciences of the Estonian S.S.R. by the method of elementary analysis, while heavy metals were analyzed at the Institute of Biochemistry and Physiology of Microorganisms, Academy of Sciences of the U.S.S.R. (Puschino) by the method of atom-absorption spectrometry. The results are shown on Fig. 7 where the data have been presented relative to the weight of air-dried samples.

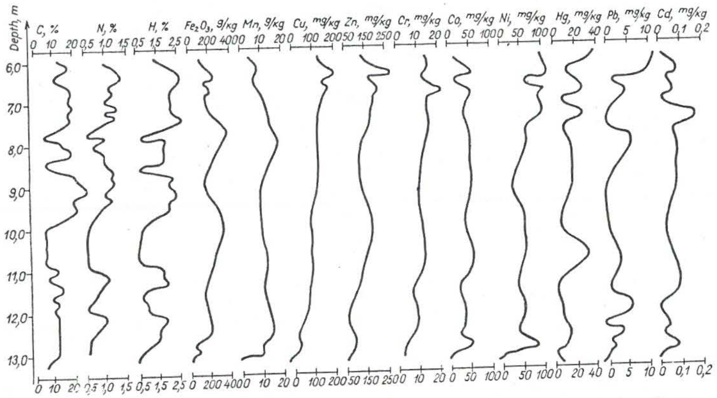

Fig. 7. Content of selected elements in the sediments from site 1 of Lake Ümarjärv.

By the shape the distribution curves of C, N and H are rather similar and reflect changes in the organic matter (OM) content in the column of bottom sediments. The OM content is rather constant and relatively low from the basal layers of the column to the depth of 9.75m with the exception of the depth interval 11.8 - 11.2 m where some in-

crease in the concentration of carbon from 12 to 18% can be noticed. The most remarkable increase starts at the depth of 9.75 m. Constantly high concentration of carbon (20% on the average) is observed to the depth of 8.6 m with its maximum at the depth of 9.1 m. This complex of sediments has accumulated in the time interval of 4 200 - 3 000 B.P. Upwards the column the concentration of carbon diminishes and has an average value of about 15 - 17%. This part of the column has two sharp decreases in the concentration of carbon, which took place about 3 000 and 2 300 B.P.

The distribution peculiarities of the content of C, N and H allow to assume that the rate of bioproduction in the lake during the first half of the Holocene (up to 4 500 B.P.) was the lowest and rather even. The production increased in the end of the Atlantic climatic stage, then reduced again with sharp changes becoming characteristic.

Much more difficult is to elucidate regularities in the distribution of iron, manganese and the microelements under consideration. Their concentrations fluctuate with an amplitude of 100% and more (with the exception of Cu). There is no perceptible correlation with the content of carbon which indicates that OM is not the main agent affecting the concentration of the analyzed elements. Consequently, the concentration of elements is determined by the dynamics of slope erosion and input of elements into the lake, dissolution of input matter, the processes related to metals concentration in bottom sediments and their removal from the deposits depending on the changes in physical and chemical conditions at the contact of water - bottom sediments, i.e. it is associated with the history of the lake.

The redox-potential and pH serve as the main physical and chemical conditions determining the balance between the accumulation and the removal of separate elements. Considering the nutrition type of Lake Ümarjärv and the presence of carbonates throughout the column of bottom sediments, it can be assumed that the pH value of the lake water exceeded 7 during the whole of the Holocene, and, at some stages it reached even 9-10, with neutral-slightly alkaline conditions being predominant. Most remarkable were the changes in the redox conditions. Substantial fluctuations in the content of Fe_2O_3 serve as the most vivid proof of this. High Fe_2O_3 concentration may be accounted for by better aeration conditions. Evidence is derived from the distribution of Mn in bottom sediments as well. In the bottom layers aeration (i.e. oxydation potential) was relatively high about 8 000, 4 500, 3 500 B.P. As at that time the OM content was relatively low, oligotrophic nutrition should have prevailed in those periods. As known, the hydroxides of iron and manganese possess the quality to absorb microelements from the water. In the analyzed column only the concentration of Ni is in positive correlation with those of Fe_2O_3 and Mn.

From other elements analyzed Co, Hg, Cd and Pb revealed the most remarkable fluctuations in concentration. These are the typical indicators of lithophile erosion, however, the data obtained are too few for any definite conclusion. It may be of importance to point out that quite remarkable fluctuations in the accumulation of these elements have also taken place in the pre-industrial (so-called background values) time. The most favourable conditions for the accumulation of the above elements in bottom sediments probably excisted about 8 500 - 8 000, 7 000, 2 500 and 1 500 B.P.

The Development of Lake Ümarjärv. The data obtained enable us to reconstruct the development of Lake Ümarjärv in the Holocene. Sedimentation in the kettle-hole started at the very end of the Preboreal - at the beginning of the Boreal climatic period with the formation of a thin layer of lake lime immediately on the coarse-grained sand and gravel. At that time the water level was evidently rather low, witnessing an abrupt rise to the level of -9 - -10 m relative to the current one in the middle of the Boreal (Fig. 8). This is revealed by increased concentrations of Co, Hg, Cd and Pb in the samples of bottom sediments which have accumulated about 8 000 B.P., but also by improvement of aeration leading to the deposition of Fe_2O_3 and Mn in the sediments. The next sharp rise in water level occurred during the time interval of 7 500 - 7 000 B.P., as a result of which water reached the level of about -7 m with respect to the present one. The Atlantic climatic period is characterized by a constant rise in the water level of the lake. It should be pointed out that against this background some periods of stabilization and even regression of the water

level occurred. This is best reflected by the changes in accumulation on the western shore of the lake where layers of sand and gravel interchange with those containing remains of wood or with interlayers of peat at the depths from 7 to 5 m (site 2). This provides evidences of considerable slope erosion, which is possible only in case of unstable water level. The rate of sedimentation in the lake increases, and OM content reaches its highest value.

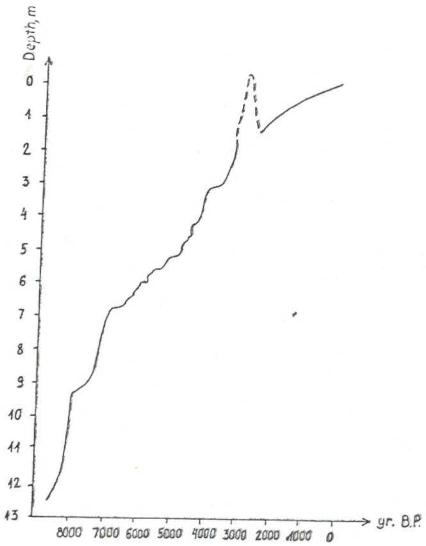

Fig. 8. Time related rising-up dynamics of water-level in Lake Ümarjärv.

At the end of the Atlantic climatic period Lake Ümarjärv became united with Lake Pikkjärv situated to the north of it as the water level reached -5 - -4 m. The elevated part between the two lakes must have been rather shallow-watered and so accumulation of lake lime (site 3) with abundant plant remains (up to 20%) started due to evaporation and photosynthesis.

Beginning from the Subboreal period the history of the lake can be reconstructed on the basis of the data obtained by studying the sediments from site 3. Interlayers of peat embedded in sediments, about 4 000 - 3 000 years in age are related to the periods of stabilized water level. About 3 000 B.P. OM content decreased abruptly, the concentrations of Fe_2O_3 and Mn increased, speaking of a sharp rise in water level accompanied by erosion and improved aeration. Just at that time the area of the lake enlarged remarkably and lake lime started to accumulate on a wide strip around the modern lake. The water level seems to have been close to the present-day one or even to surpass it.

About 2 500 B.P. the water level in the lake sank as much as to separate Lake Ümarjärv finally from Lake Pikkjärv. The lakes remained connected only by a narrow stream. From that time on the rate of the water level rise obviously does not exceed that of the accumulation of reed peat in the inshore area. An insignificant rise in water level took place during the last millennium, as indicated by a lower degree of decomposition of the peat. Simultaneously fluctuations in the concentrations of chemical elements appeared in bottom sediments. However, interpretation of those changes is rather complicated, as the shores of the lake have been paludified for the last thousand years and OM might have been of certain influence on transformation of chemical compounds. Constant rise in the Hg and especially Pb concentrations in the upper layers of bottom sediments may already be a sign of technogenous influence.

The complex investigation of Lake Ümarjärv has made it possible to reconstruct the water level fluctuations in the kettle-hole (Fig. 8). Considerable rise in the water level seems to serve as the main natural factor determining the character and rate of sedimentation as well as the distribution peculiarities of chemical elements in sediments.

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УДК 551.794:551.312.48

О РАЗВИТИИ ОЗЕРА ЮМАРЬЯРВ (СЕВЕРО-ВОСТОЧНАЯ ЭСТОНИЯ) В ГОЛОЦЕНЕ

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Резюме

В статье приводятся данные комплексного изучения донных отложений озера Юмаръярв в Северо-Восточной Эстонии. Изотопные иследования показывают, что из-за множества родников водообмен в озере происходит быстро. В течении большей части года на дне озера существуют бескислородные условия, что снижает степень окисления металлов и вызывает выделение сероводорода (рис. 1).

Для стратификации отложений были использованы радиоуглеродная и спорово-пыльцевая методы. Из-за эффекта "жесткой воды" ^{14}C

возраста явно удревнены, и возрастная шкала опирается на спорово-пыльцевые данные, на основе которых выделены локальные комплекеные биозоны (ЛКВ) которые были коррелированы с ^{14}C методом датированными ЛКБ выделенными по разрезу торфяных отложений на близнаходящем болоте.

Распределение некоторых макро- и микроэлементов в разрезе донных отложений (рис. 7) показывают, что окислительный потенциал в природных слоях был относительно высоким около 8 000, 4 500, 3 500-3 000 лет назад. Из-за интенсивной эровии поступление литофильных элементов (Co, Hg, Cu, Pb) было наивысшим около 8 500--8 000, 7 500, 2 500 лет назад. В результате комплексных исследований реконструирован ход колебания уровня воды в котловине (рис. 8).

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AN OUTLINE OF WATER-LEVEL CHANGES IN SMALL ESTONIAN LAKES

L. Saarse

Introduction. The geological literature abounds in papers on the Holocene climatic fluctuations. L. Starkel (1984) has substantiated a cooling at the beginning of the Younger Dryas, a warming at the Late Glacial/Holocene boundary, a rise in precipitation and a probable cooling at the Boreal/Atlantic, Atlantic/Subboreal and Subboreal/Subatlantic breaks during 10,900-10,600, 10,300-10,000, 8500-8000, 5000-4500, 2800-2400 B.P., and in the XVII - XIX centuries, correspondingly. On the basis of palynological data V. Klimanov (Климанов, 1986) has presumed cooler periods in 10,500, 9500, 8200, 7300, 6400, 5100, 4500, 3600, 3100, 2500, 1500, 1200, 700, 500 and 100 B.P., warmer ones in 10,000, 8500, 7600, 7150, 5500, 5000, 3800, 3500, 2700, 2000, 1300, 1000, 600, 300 and 150 B.P.

The climatic changes are reflected in the lithological composition of bottom deposits of lakes, in the alternation of diatom and molluscs assemblages, in the vegetational succession and water-level changes. The aim of this paper is to elucidate water-level fluctuations in small Estonian lakes on the basis of the levelling of terraces, as well as on lithological, micro- and macrofossils data.

Material and discussion. Among small lakes of Estonia, 1150 in number, more than 70% are of glacial origin. Due to the ice recession and the end of different glacial processes (glaciokarst, exaration, accumulation, erosion, etc.) they were formed at different time of the Late Glacial and Holocene, mainly between 12,200-8000 years B.P. The lakes of other origin (karst, oxbow, bog-pools, coastal, artificial, meteoritic) came into being later, e.g. coastal lakes - in the Holocene, after the transgression of the Yoldia Sea about 9300 B.P., the meteoritic lake Kaali - 3500 B.P. (Kessel, 1981), artificial lakes - mostly in the last and present centuries.

The typical glacial lakes are located in Upper Estonia, in the region which wasn't submerged by the waters of the Baltic Ice Lake.

In South Estonia there are about 150 hollows in the glacial relief occupied by lakes on the Otepää Heights, 175 - on the Haanja Heights and 100 - on the Sakala Uplands. The large lakes (Hino, Pulli, Kirikumäe, Púhajärv, Pangodi) were formed in glaciodepressions, which during the Older Dryas were filled in with ice-marginal lakes. After the recession of the ice and lowering of the water level they turned into isolated water bodies. Small glaciokarst lakes (Kurgjärv, Väinjärv, Mähe, Päidla) between the hills and hummocks of insular heights were formed at different time of the late- and postglacial.

According to the macrofossil data from the littoral zone of the present-day and overgrown lakes, the water-level in South-Estonian lakes was extremely low about 8000 B.P. and the highest in the Late Atlantic period, with a tendency of lowering at the beginning of the Early Subatlantic and rising between 2700-2400 and 1100-1000 B.P. (Ilves, Mäemets, 1987; Пуннинг и др., 1985). These data are in good accordance with the molluscs analyses and the age of peat layers, interbedded in lacustrine lime (Мянниль, 1964, 1967), which also refers to the relatively low water-level in the Early Boreal and Early Atlantic periods. According to the degree of humification of peat accumulated in kettle-holes, M. Ilomets concluded, that there was high water-level about 9000-8200, 7500-7000, 6500-5500, 3200-1500 B.P. and relatively low in 8200-7500, 7000-6500, 3500-3200, and since 1500 B.P.

Drainage valley lakes on the Sakala Uplands are elongated, located in the depressions of ancient valleys. Their floor is uneven, sediment composition heterogenous. Subfossil molluscs from bottom deposits of the present-day and overgrown lakes Päidre, Polli and Pirmastu indicate the low water-level in the Early Preboreal with a tendency to rise in the Middle Preboreal and sink again at the end of the Preboreal. In some lakes it stayed low also during the Early Boreal, as is evidenced by the abundance of shallow-water molluscs Physa fontinalis, Planorbis planorbis, Armiger crista, Hippeutis complanatus, etc. (Мянниль, 1964). The occurrence of lacustrine lime in the profundal part of L. Vóistre, at the depth where calcareous deposits are commonly absent, refers to low water-level in the second half of the Boreal and in the first half of the Atlantic as well.

Litho- and biostratigraphy, vegetational succession and lake development have been studied in detail in the Central-Estonian lakes located on the gently rolling moraine relief and in the Saadjärv drumlin field (Pirrus, Róuk, 1979; Pirrus et al., 1987). The studies on water-level changes are in progress. Some evidence such as the height of terraces, transgressive bedding of gyttja, composition of macrofossil remnants and lithological composition of bottom deposits indicate, that water-level was higher during the Alleröd, first half of the Atlantic and Subatlantic periods, lower - during the Early Boreal, Subboreal and in the middle of the Subatlantic periods (Pirrus et al., 1987). The lake basins themselves were formed about 12,200-12,400 years B.P. after the Otepää stage, contemporaneously with the formation of the drumlin field. Their separate development started later, at the end of the Older Dryas, when the local proglacial lake drained and its water-level dropped.

North-Estonian lakes are of various origin. There are a lot of glaciokarst lakes in kame fields and eskérs, glacial lakes formed due to the irregularities of glacial drift, residual and accumulative coastal lakes, which diatom assemblage, molluscs fauna and lake development have been subjected to relatively profound studies. On the basis of lithostratigraphical, geomorphological and biostratigraphical data it was elucidated that water-level changes amounted to 4 m in the lakes of Illuka kame field (Saarse, 1987). It stayed low at the beginning and end of the Preboreal, in the first half of the Boreal and Atlantic and on the boundary of the Subboreal/Subatlantic periods, being high in the middle of the Preboreal and in the Late Atlantic (Saarse, 1987). According to J.-M. Punning et al. (1987) in L. Úmarjärv (south from Illuka kame field) water-level rose about 8000 B.P. and stayed high throughout the whole Atlantic.

From several lakes of the Pandivere Uplands, with calcareous sedimentation prevailing throughout the Early and Middle Holocene, we have plenty information about subfossil molluscs (Männil, 1961), which show a low water-level in the first half of the Preboreal. During this time the number of shallow water species was high. In some lakes water-level stayed low for a long time - from the beginning of the Boreal up to the second half of the Subboreal, in the others a remarkable lowering of water-level took place in the Boreal, the first half of the Atlantic and Subboreal and at the end of the Subboreal with a noticeable rise during the second half of the Atlantic and on the boundary of the Early and Late Subboreal periods. There are lakes with only one deepwater phase in the middle of the Boreal (Männil, 1961). Several fluctuations mentioned above are of local importance, caused mainly by the changes in feeding conditions.

Coastal lakes in north-western Estonia and on the islands have come into existence where rising land has cut off an arm of the sea. Of coastal lakes, subjected to studies, the oldest is L. Kahala which became isolated from the Joldia Sea at the end of the Preboreal (Кессел и др., 1982). According to the bedding conditions, radiocarbon data (8595±75, TA-59, Ильвес и др., 1974) and pollen spectra of peat, buried under a coastal bar, the water-level after the transgression of the Ancylus Lake in L. Kahala was 5 m lower than in the present-day lake. It gradually rose, but stayed relatively low up to the second half of the Atlantic. The sharp transformation of sedimentation and composition of the diatom spectra took place in the Late Atlantic period, when the sediments with high organic matter content (50-70%) started to accumulate. It denotes the deepening of sedimentational basin. The altitude of the foot of the bar, buried under peat shows that water-level was 2 m lower in comparison with the present-day L. Kahala level.

L. Ülemiste, located on the terrace of the Ancylus Lake, became isolated from the Baltic before 8300 B.P., as the organic deposits (peaty gyttja) contact with sand was dated to 8300±90 (TA-691, Ilves, 1980). Water-level fluctuations in L. Ülemiste are in good accordance with those of glacial lakes. Extremely low water-level in Ülemiste basin was fixed in the Early Boreal - 8 m lower than that in the present-day lake. The lake was shallow, its depth did not exceed 0.5-1 m, and overgrown with Drepanocladus fluitans, D. lycopodioides, Scorpidium scorpioides, Sphagnum fimbriatum, etc. However, this is contradicted by the abundance (more than 50%) of planktonic diatoms, mainly on account of Melosira ambiqua and Tabellaria fenestrata. Since the end of BO1 up to the AT2, when calcareous-rich gyttja deposited, the share of planktonic diatoms, dominated by

bottom diatoms (70%), rapidly decreased. All this evidences about low water-level in Ülemiste basin. Against the background of low level, several smaller fluctuations are traceable according to diatom data. The transgressive phases are noticeable at the end of BO1, at the beginning of AT2 and SB2 and in the middle of SB1. During these periods the species and number of diatoms were high with rapid increase of planktonic ones, among which Melosira ambiqua, Cyclotella comta, etc. prevailed. The water-level started to sink again at the end of the Subboreal.

Lakes studied on the neotectonically active West-Estonian coast, on the terraces of the Baltic are located on the mainland as well as on the archipelago. In these lakes (Karujärv, Siplase, Kasesoo, Järvesoo, Ermistu) the sedimentation of organogenous calcareous lacustrine deposits began not earlier than in BO1 (Мяннил, 1963). The lithostratigraphy and mollusca of the overgrown lakes Jõempa, Kihelkonna, Kasesoo, Järvesoo and Siplase denote that all these basins, located above the highest Ancylus Lake shore displacement, were during the Early Boreal shallow swampy hollows with low water-level. At the end of the BO1 the water-level rose remarkably and lacustrine lime with deepwater molluscs (Pisidium nitidum, Bithynia tentaculata, Radix peregra, etc.) accumulated (Мяннил, 1963). Water-level sank again in the Early Atlantic and rose in the Late Atlantic.

Diatom spectra, in particular the increase of the share of planktonic species in the beds of L. Karujärv refer to smaller water-level fluctuations in the Subboreal and Subatlantic.

The overgrown L. Kõivasoo on Hiiumaa Island is also profoundly studied (Sarv et al., 1982). Diatom analyses allowed to distinguish three stages in the development of the ancient Kõivasoo water body: a relatively deep lagoon of Ancylus Lake with characteristic plankton complex (Melosira islandica subsp. hevetica and Stephanodiscus astrae); relatively shallow halotrophic coastal lake in the Late Boreal with halophilous and boreoalpine freshwater species and alkalitrophic shallow coastal lake in the Early Atlantic. Afterwards in this basin the lacustrine conditions disappeared and the ancient lake was completely overgrown (Sarv et al., 1982).

L. Tänavjärv in the north-western part of the mainland was isolated from the Baltic about 5300 B.P. Diatoms from the bottommost sand and silt indicate marine and brackish-water conditions with the dominance of bottom-living forms. The overlying gyttja with shallow-water species (Fragilaria, Navicula, Pinnularia, Cymbella) prevailing, is the indicator of low-water conditions since the Subboreal.

Conclusions. From the above follows that the data on water-level changes in the small Estonian lakes are both scanty and contradictory. It was found out that not all the small lakes provide a good basis for the solving of the problem of water-level fluctuation. In particular it concerns the small glaciokarst lakes which were formed in Boreal time. The deepening of these basins within the above-mentioned time interval was not due to water-level rise, but to the final thawing of buried ice blocks. However, the solving of the problem concerning the formation of glaciokarst lakes during Boreal time in our region insists upon some more momentous pieces of evidence than those we have at present. The most reliable and complete data on water-level changes related to the climatic fluctuations, can be obtained through the study of exaration-accumulation lakes of Saadjärv drumlin field and glaciodepressional lakes of insular heights (Pangodi, Pulli, Pühajärv, Kirikumäe, etc.). As for the other genetic types of lakes (karst, fluvial, coastal, etc.) the influence of local factors sometimes shelters the main tendency of water-level changes completely.

However, on the basis of obtained data it may be concluded that in our lakes the water-level was low at the beginning and end of the Preboreal, in the first half of the Boreal and Atlantic, with a tendency to rise in the mid-Preboreal and in the Late Atlantic. The data on the Late Boreal are contradictory. During BO2 water-level was extremely low in the South-Estonian glacial lakes, but rather high in the lakes of Saaremaa Island. In the Subboreal, due to the dry climate, the water-level dropped again and the lakes turned into shallow basins. In the mid-Subboreal water-level rose, being also rather high at the beginning and in the mid-Subatlantic (Fig.). These are only the most general trends not traceable in all the lakes studied.

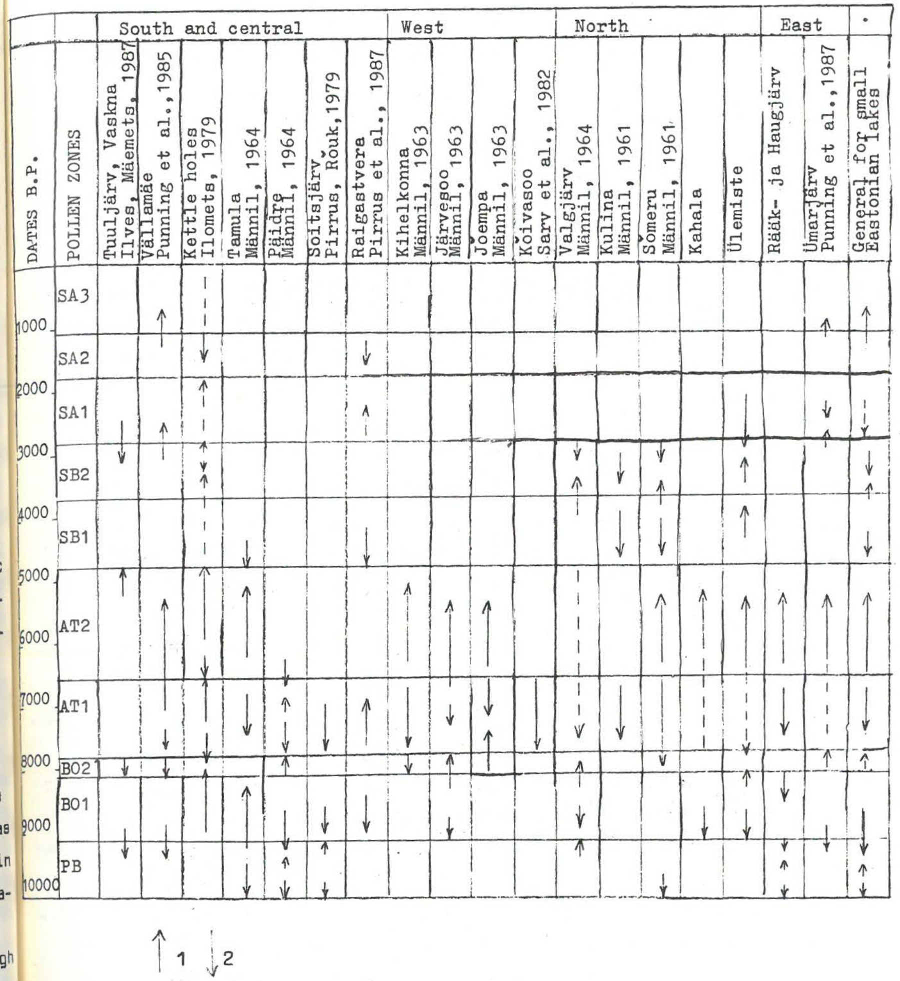

Fig. Water-level changes in small Estonian lakes. Legend: 1 - high water-level; 2 - low water-level.

Aknowledgement. The pollen analyses were carried out by Aino Sarv (Tallinn), the diatom analyses by Evgenya Vishnevskaya (Leningrad). The English manuscript was revised by Helle Kukk (Tallinn). I am indebted to Prof. Anto Raukas (Tallinn) for critical remarks concerning the manuscript. I wish to express my sincere thanks to all these persons.

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УДК 55I.794:55I.8:556.55/474.2/

ОБ ИЗМЕНЕНИИ УРОВНЯ ВОДЫ В МАЛЫХ ОЗЕРАХ ЭСТОНИИ

Л.А. Саарсе

Резюме

На основе микро- и макрофоссильного анализа, по составу донных отложений и фрагментам террас заключается, что наиболее высокий уровень в изученных озерах придерживался в середине пребореала, во второй половине атлантического, в середине суббореального и в начале и середине субатлантического климатических периодов. Тенденция понижения уровня воды наблюдалась в начале и конце пребореала, раннем бореале и атлантики и в начале суббореала. Отмеченные тенденции не уловимые во всех озерах. Например, в позднем бореале в озерах Южной Эстонии наблюдался низкий, а в озерах острова Сааремаа высокий уровень воды.

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ON THE EFFECT OF HUMAN ECONOMIC ACTIVITIES ON ESTONIAN LAKE ECOSYSTEMS

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As a result of impetuous scientific and technical progress, intensification of agricultural and industrial production and rapid growth of the population the nature is being subjected to an ever growing human impact. It is especially distinctly revealed in the development of inner water bodies. Estonia is a highly developed agro-industrial republic where the lake ecosystems have experienced the effect of man's economic activities since long.

The Estonian territory has been inhabited for over 9000 years. The first inhabitants came here about 9500 years B.P. The remains of the oldest settlement have been found at Pulli (9575±115 B.P.) within the lower reaches of the Pärnu River near the town of Sindi. These were tribes of hunters and fishers who left no remarkable traces on the landscape development in a sparsely populated territory. Although in Estonia the beginning of primitive land tillage dates back to the Late Stone Age, it was of negligible influence on the nature. The interrelations between the nature and man changed substantially at the beginning of the Bronze Age, about 1500 years B.C., when land cultivation gained in importance alongside of hunting and fishing. It seems to be just the period that the pollen of weeds and cultivated plants buried in lake and bog deposits originate from. Occasional pollen grains and lots of various tools embedded in lake deposits are evidently related to earlier periods. Lake deposits near Kunda have proved especially rich in the tools of ancient man which have yielded the age of 8500 years (Jaanits et al., 1982).

Land cultivation began to dominate in the life of ancient man at the beginning of the Early Iron Age about 600 years B.C. Since that man has inflicted incurable wounds on the nature. This is revealed everywhere, but first of all in the devastation of forests which brought about intensification of soil erosion and eolian processes, etc. By 1887 the woodedness of the former Estonian province had decreased to 19.8% (in the Estonian SSR in 1977 it amounted to 37.9%, in 1986 - 40.1%).

Early evidence of draining lake shores and swamps by means of ditches dates from 14th-15th centuries. For supplying Tallinn with water a 4km-long channel was built from Lake Ülemiste (from the start of the former Härjapea River) to Viru Gate already in 1345. Another channel, 1.5 km in length, connected the town with the sea (Veering, 1986).

Large-scale drainage performed in the republic in the recent decade with regard to dry and droughty years, has brought about a considerable decrease of the water table in lakes and flow depletion in small rivers and springs with drying up here and there within the low water period. During the last five years about 30,000-40,000 ha of agricultural land and 15,000-20,000 ha of forests have been improved annually. By 1983 about one million ha of land had been drained (Aruja, 1983). At the present time the rate of land improvement has slowed down; during 1981-1985 only 88,700 ha of land underwent drainage. To avoid damage caused by drought, springs, river channels, ponds and shallow reservoirs serving simultaneously as storage units for sprinkling and two-sided regulation of water regime, are backed up by retention dams. During 1981-1985 about 2,100 ha of irrigational lands was taken into use. A large-scale construction of dams and regulators with spills and drops concurrently promotes water aeration and surface-water self-purification. In the republic the water table of 300 lakes (out of 1500) is regulatable. About 150 water reservoirs, making up 1.5% of the Estonian territory have been founded (Aruja, 1983).

A large variety of waste waters, detergents, and biogenic compounds of agricultural origin, including toxic substances, find their way from the catchment area into Estonian lakes due to the growth of population and expansion of industrial and agricultural enterprises. Major hog-raising factories produce great amounts of liquid manure whose proper utilization is still a problem. So far it is not possible to dispense with an aerial spraying of fertilizers on snow-bound fields and to give up field fertilization in winter

conditions, though up to 80% of biogenic substances are known to be washed off in spring into water bodies, thereby causing their pollution and eutrophication.

In Estonian lakes the acidity of water is abruptly rising and water quality worsening. It leads to the decline or complete disappearance of the populations of valuable commercial fish. At the present time the vast majority of Estonian lakes are highly eutrophicated or have entered the final stage of overgrowing.

Typological analysis carried out by A. Mäemets (1977) indicate that most of the Estonian lakes (36.6%) are either dyseutrophic or eutrophic (36.4%). The former represent the final stage of lake development, while the latter together with alkalitrophic and dystrophic lakes belong to its middle stage. Thus, at present about 37% of the republic's lakes with regard to their stage of evolution have become old, whereas nearly 50% have reached the middle age. In view of the above, purposeful renovation of old lakes has begun, since the construction of artificial lakes, meeting all the requirements, would be much more expensive than conservation of natural lakes.

Protection of waters against depletion, pollution and anthropogenic eutrophication is performed by restricting the land drainage and taking into use two-sided regulation of the water regime;of great importance are the construction of more efficient waste-water purification installations (about 900 of them are in operation now), removal of sapropels from lake basins for agricultural a.o. purposes, raising of water level in some lakes, planting of special forests for water conservation purposes, introduction of complete or partial prohibition regime.

The renovation of lakes has become a topical problem which calls for urgent but scientifically grounded and economically reasonable solution. In view of this, traditional study methods and research trends should be critically reviewed and new ones introduced. On the one hand the scientific research has to consider the claims of national economy, however, on the other hand, favourable ecological conditions for living organisms, and primarily for man, must be ensured. Thus, the above problem concerns not only the expedient use of natural resources, but it is also of great social and economical importance. Therefore its solution assumes the collaboration of experts in different specialities (e.g. biologists, geologists, economists, sociologists) and statesmen as well.

The removal of sapropels filling up lake basins, is often the only way to protect lakes from overgrowing. Thus, the renovation of lakes is closely related with the utilization of sapropels. In Estonian lakes the reserves of sapropels are estimated at 2.5-3 milliard cubic metres. In the Soviet Union sapropels are acknowledged as mineral resources with all the related claims, including economical profitability. Although since long sapropels are known to have curative properties, and they may be also used as organic fertilizers and supplementary feed for livestock, in production of building materials (sapropel concrete), and in several other branches of national economy (Järvemudade kasutamisest, 1984; Нейштадт, 1982; a.o.) their production is still being considered unprofitable. So far little attention has been paid to the elaboration of the technique to be applied to producing of sapropels.

We are of opinion that narrow material interest of single institutions in drawing out scoopshoveling sapropels from lakes for one or another purpose, cannot serve as a basis for evaluating the total effect obtained through the utilization of sapropels in national economy. Especially while speaking about the effect derived from the reclamation of environment, replenishment of pure water reserves, qualitative and quantitative improvement of commercial fish stock, not speaking about the active protection of the environment, as a whole. In view of this, while renovating inner water bodies sapropels cannot be regarded purely as useful mineral resources, which usage in national economy must compensate for all the expenses related to their production, but as a by-product, which is to be utilized (Паап и др., 1985).

In the geological past Estonia was considerably richer in lakes, e.g. in the Early Holocene their number reached 5000, of which only one third has preserved to our days. Therefore, in principle, all the lakes, as an inseparable and the most picturesque part of landscapes deserve protection and maintaining. However, it is unthinkable, and therefore special care should be afforded to the most

valuable of them (Mäemets, 1977):

1) Lakes of rare and unique origin, e.g. Lake Kaali in a meteoritic crater on Saaremaa Island;

2) Lakes rich in fish, e.g. Lake Saadjärv;

3) Lakes abundant with river crayfish; which have (e.g. Lake Karujärv on Saaremaa Island) become now rather uncommon within the republic;

4) Especially picturesque lakes or groups of lakes, e.g. Lake Pühajärv;

5) Lakes posessing rare ecosystems, particularly oligotrophic, semidystrophic, and alkalitrophic ones;

6) Lakes with a sluggish flowage and those without outflow, in particular;

7) Lakes rich in rare plant and animal species;

8) Lakes whose research history is fairly long, which makes them of special value for future comparative investigations;

9) Drinking water storages.

Landscape sanctuaries and preserves have been set up and hydrological preservations have been planned to ensure a possibility for coming generations to live in a world of naturally pure waters. Only bathing in merely fixed places is allowed in lakes under complete conservation. Protection of the lakes under complete conservation covers the catchment area as well, where amelioration, non-selective cutting, chemical fertilization and liming are prohibited within the range of 5 km. Changing of the water level and introduction of new taxa in the lakes mentioned above are prohibited.

While speaking about the protection and conservation of lakes, we mustn´t forget about lake sediments either, since the latter store valuable information about the past geological events, environmental and human history, including the development of land cultivation. Quite frequently lakes are related with ancient settlements (Kunda, Narva, etc.), and therefore these recent lakes or deposits of palaeolakes must be taken under the state protection as archaeological monuments. Some lake basins, e.g. those containing annually laminated deposits should be protected as natural objects.

In view of the above, the strategy of the utilization and conservation of lakes varies. The value of each lake should be estimated jointly by limnologists, geologists and archaeologists in order to determine the sphere of its utilization and the degree of its protection.

According to economic estimates, water deficiency in Estonia increases annually by 5 per cent. Many reserves are available to increase fish yield in inland water bodies. Recreative resources of lakes are not sufficiently used. Therefore, a wide spectrum of scientists, including geographers, biologists, geologists, medical men, hydrotechnicians, chemists and so on, are engaged in studying the lakes of the republic. Their work is coordinated by the Republican Council of the Coordination of the Research of the Baltic Sea and Inland Waters and the Problem Commission of Anthropogenic Eutrophication of Inland Waters under the Presidium of the Academy of Sciences of the Estonian S.S.R. Joint efforts of scientists and public opinion promote conservation of our lakes for future generations and increase their recreative and economic potential.

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О ВЛИЯНИИ ХОЗЯЙСТВЕННОЙ ДЕЯТЕЛЬНОСТИ ЧЕЛОВЕКА НА ОЗЕРНЫЕ ЭКОСИСТЕМЫ ЭСТОНИИ

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Резюме

Человек заселяет территорию Эстонии свыше 9 000 лет, но перелом во взаимоотношениях человека и природы произошел здесь в конце каменного и начале бронзового века,около 2500-1500 лет до н.э., когда скотоводство и земледелие,по данным археологии, начали наряду с охотой и рыболовством играть все большую роль в жизни общества. Примерно с этого времени в озерно-болотных отложениях обнаруживаются первые проблематичные находки пыльцы культурных растений и сорняков, а более достоверные - с начала субатлантического времени. Наиболее ранние следы непосредственного воздействия человека на озерные экосистемы /напр. свидетельства об убыстрении эвтрофикации по данным изучения кладоцер/ также относится к началу субатлантического климатического периода.

Первые сведения об осушительных работах на берегах озер и в болотах с заложением систем осушительных канав относятся к 14-15 векам. К настоящему времени уровень воды урегулирован примерно у 700 озер из имеющихся 1500 и создано более 150 водохранилищ, на которые приходится около 1,5% территории республики. Начаты работы по оздоровлению озер с утилизацией сапропелей. Кроме созданных ландшафтных заповедников и заказников запланировано учредить специальные гидрологические заповедники и заказники. Многие озера и их группы уже сейчас находятся под государственной охраной.

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PALAEOGEOGRAPHICAL STAGES IN THE DEVELOPMENT OF LATGALE UPLAND LAKES

L. Sergeeva, V. Khomutova, I. Trifonova

In the region of Latgale Upland a group of lakes has been studied by the investigators of the Institute of **Lake Research** Acad.Sci. USSR. Within the frames of complex limnological investigations much attention was given to palaeolimnology of lakes Vorkalu, Sleinovas, Rogaizhu, Dlinnoye Snidzinjas, Becheru (Яковлева et al. 1981; Давыдова, 1983; **Сергеева**, 1983; Хомутова, 1983; **Яковлева**, 1983).

The present paper deals with the recent palaeolimnological data obtained through the study of Lake Rudushskoye. Lake Rudushskoye is situated in the central part of the Latgale Upland. It lies in the main moraine zone coinciding with the region of maximal glacial accumulation (**Серебрянный, Чукленкова**, 1973). The lake has a small catchment area (1.35 sq.km), with its hummocky relief being composed of till and occupied by agricultural land. The total area of the lake is 0.061 sq.km, maximum depth 8 m, average depth 4.2 m. Modern bottom sediments are represented chiefly by organomineral silts with organic matter content accounting for 19-21% (in dry weight of sediments). Littoral zone is very narrow and covered by sandy deposits. Silts are of brownish-black and black colouring. Calcium carbonate has accumulated only in the form of biogenous shelly material in the sublittoral zone (10-40% $CaCO_3$). Silty sediments are practically free of carbonate ($<10\%$ $CaCO_3$).

The column was taken at a depth of 5.5 m. Total thickness of sediments is 610 cm. The section reveals the following layers from bottom upwards (Fig. 1):

fine gray sand ....6.10 - 6.05 m
peaty silt (mud) with wood fragments ....6.05 - 5.98 m
fine sand rich in plant detritus ....5.98 - 5.93 m

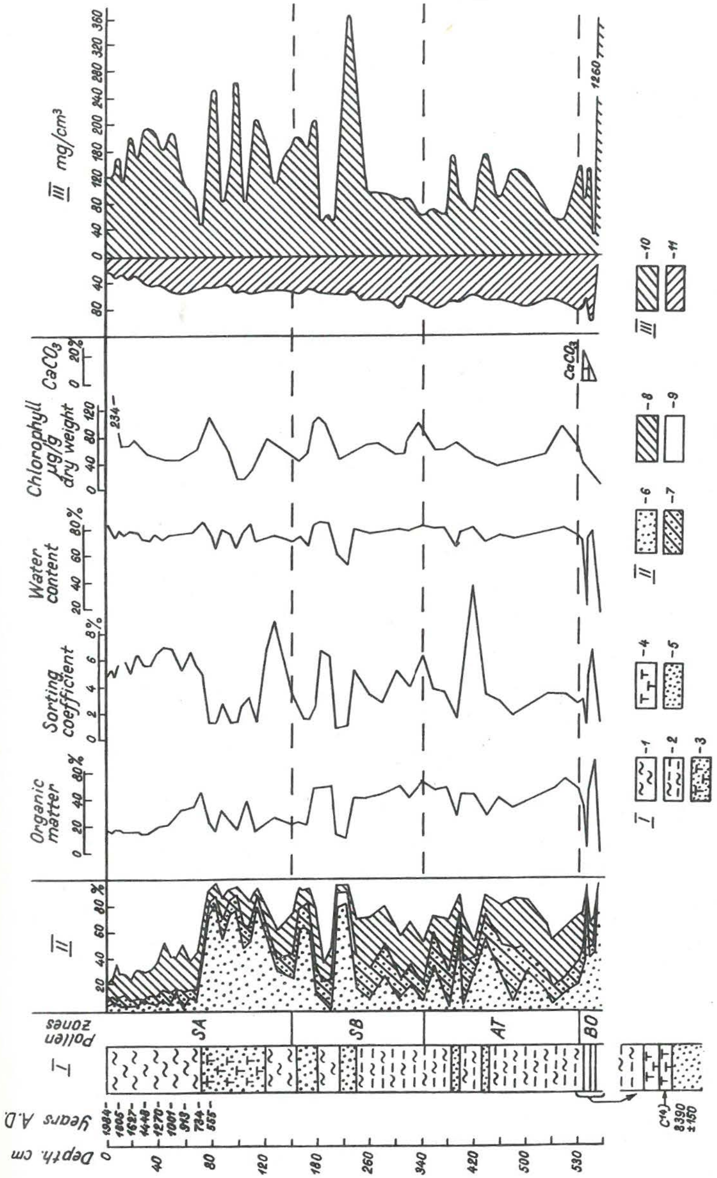

Fig. 1. Lithological composition of Lake Rudushkoye deposits. Legend: I - Lithology (1-organo-mineral silt; 2-organo-mineral silt with organic detritus; 3-sand with abundant inclusions of detritus; 4-peaty silt, 5-sand. II - Grain-size composition of mineral part of deposits (fractions, mm: 6 - 1.0-0.1; 7 - 0.1-0.05; 8 - 0.05-0.01; 9 - <0.01). III - Absolute mass of organic and mineral components, mg/cm^3: 10 - mineral components; 11 - organic components.

laminated organo-mineral brown silt (mud) composed of sandy laminae of various thickness, with unevenly distributed plant remnants of different origin (macrophytes, wood pieces, leaves) .... 5.93 - 1.20 m

fine sand with woody remnants and gravel .... 1.20 - 0.75 m

dark-brown silt (mud) with black sticklers comprising plant remnants .... 0.75 - 0.30 m

dark-brown silt (mud) passing into black, silt (mud) .... 0.30 - 0.00 m

Palaeogeographic stages of lake development are discussed on the basis of the results of palynological analysis, ^{14}C dating, lithological and geochemical analysis (graine-size, absolute masses of principal components of sediments, derivatographic, chemical analysis of the concentrations of biogen elements). Spore-and-pollen diagram is presented in Fig. 2, the indices of the above characteristics are shown in Fig. 1. According to floristic composition 7 palynozones are distinquished in the spore-and-pollen diagram. On the whole the diagram holds information on the development of vegetation in the study area for the Holocene period since Boreal(BO).

According to palynological evidence the lake sediments are dated in the following way: 610-580 cm (BO); 580-340 (AT); 340-140 (SB); 140-0 (SA). Holocene stages are differentiated according to (Нейштадт, 1957), the limits of chronozones according to N.A. Khotinsky (Хотинский,1977). On differentiating the sediments as a key horizon served the Holocene Atlantic optimum. In pollen spectra broad-leaved species accounted for 35% of the total amount of arborecent pollen. As a rule, the pollen of elm, lime and oak is represented.

By means of radiocarbon method Kh. A. Arslanov has dated a semple of peat from the depth of 6.05-5.98 m: 8390± 150 (ЛУ-1713). Thus, both radiocarbon and palynologic evidence refer the formation of Lake Rudushskoye to the Late-Boreal. Mineral sandy sediments covering the bottom of the basin are of terrigenous origin as is evidenced by dry unit weight of these sediments (1.28 g/cm^3) and extremely

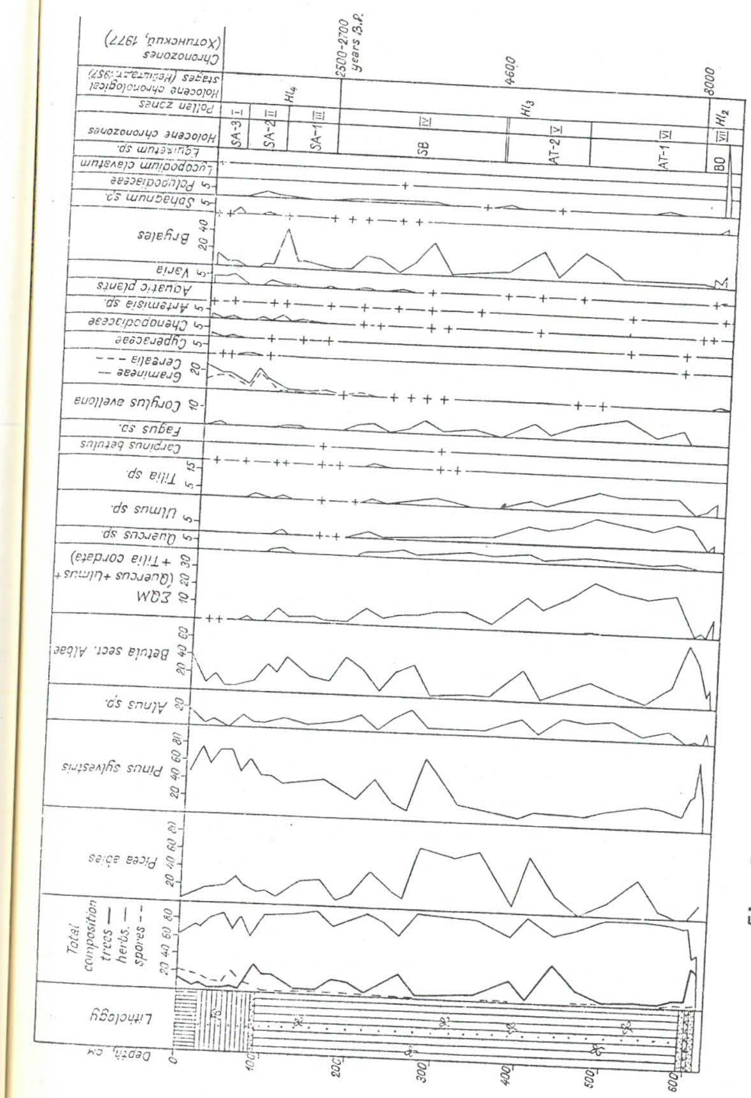

Fig. 2. Pollen-and-spore diagram of Lake Rudushkoye deposits.

low content of organic matter (1.57%). The Boreal stage of lake development is characterized by extremely unstable hydrodynamical regime. The filling of the basin with water and accumulation of lake sediments started with the formation of the peat horizon under the conditions of shallow water and poor flowage regime. This is proved by fine aleuritic composition of sediments and their poor sorting (S_0 - 7.3). The role of terrigenous material is insignificant in sediment composition, the content of organic components is 2.4 times as much as that of mineral ones. A thin layer of fine silts (3 cm) (S_0 - 5.1) enriched by carbonate matter ($CaCO_3$ - 20.2%) and lying on peaty stratum was formed under similar conditions. Towards the end of the Boreal the flowage of shallow Lake Rudushskoye increases significantly because the sandy sediments overlying a carbonate horizon are well sorted (S_0 - 1.3). The share of terrigenous components increases sharply in sediment composition (0.86 mg/cm^3) whereas that of organic components decreases (0.058 mg/cm^3).

At the beginning of Atlantic period the lake regime stabilizes. Sharp decrease in the share of carbonate and terrigenous components and increase in organogeneous components in fine silts testifies to water level rise in the lake. The process of carbonate accumulation ceases, the contribution of organogenic components of sediments increases. It is greatly due to warm and humid climate of Atlantic period. At the background of general favourable hydrodynamic regime and high level of lake trophy at this stage of Holocene it may be distinguished between three phases with a certain decrease in lake level as is revealed in the composition of bottom sediments (well-sorted sandy and coarse silt beds). In these horizons the absolute mass of terrigeneous components increases (Fig. 1).

In the Subboreal Lake Rudushskoye passed a number of transgressive-regressive phases in its development. The sediment profile reveals two prominent sandy layers characterized by high absolute mass values of terrigeneous components. These sediments are well sorted (S_0 - 1.3-1.8). It shows that they were formed under shallow-water conditions due to repeated redeposition of sediments. The presence of these sandy horizons evidences about regressive stages of lake development.

At the beginning of the Subatlantic the lake level rose again (layer at the depth of 120-140 cm) which is shown by fine-silt composition of poorly sorted sediments characterized by low content of mineral components. The composition of sediments at the depth of 120-70 cm proves the recurrent lowering of water level in the lake. Sandy sediments accumulated during this period are well sorted (S_0 - 1.4-2.8) and show an increase in absolute masses of terrigeneous components. The phase of high water level begins from the middle of Subatlantic period. Sandy sediments give place to poorly sorted (S_0 - 5-7) aleuritic-pelitic (60-30 cm) and pelitic silts (30-0 cm).

On the whole, the transgressive-regressive rhythm in the evolution of Lake Rudushskoye correspond to those of Latgale Upland lakes in Latvia and to Lithuanian lakes (Яковлева, 1983; Гарункштис, 1975).

The level of productive processes in the water body changed in accordance with the alteration of climatic conditions. We have traced it by means of two indices - absolute masses of organogenous components and the content of chlorophyll derivates.

It is known that the utilization of plant pigments as the index of lake primary production in the last depends mainly upon their preservation in the bottom sediments. Analogous run of distribution curves of chlorophyllderivates and organic matter concentration points to good preservation of residual chlorophyll in sediments of the lake investigated. On this basis we may suppose that its content during postglacial time corresponds to the ancient levels of primary production.

The analysis of the distribution curve of chlorophyllderivates in the column permits to distinguish between 4 stages characterizing the alteration of lake productivity (Fig. 1).

The first stage is characterized by increase in the lake's productivity at the beginning of Atlantic period when the input of mineral matter from the catchment area reduced. The second stage marks a rather long-term trophic equilibrium with environment (AT and SB). The concept of trophic equilibrium has been described by other investigators (Hutchinson, 1969; Adams, Duthie, 1976) as well. At the background of definite constancy of the values of residual chlorophyll pigments and organic matter content some fluctuations are still revealed. They correlate with earlier described rhythmic fluctuations of lake hydrologic regime. Low concentrations of components coincide with regressive phases, the higher ones with transgressive phases.

The third stage coincides with the period of human impact on the lake (the 8-10th centuries). The intensification of terrigeneous (mineral) material input from the catchment area in this period is characterized by low lake productivity.

The fourth stage associates with a sharp increase of water trophy in the 19-20th centuries, the content of chlorophyll reaches its maximum (100-234 mg/g). This stage is characterized by decreasing input of mineral component from the catchment area, reinforcement of diagenetic processes due to the increase in silting of depression and change of its morphometric indices. Sharp decrease of P/C, P/Fe at this stage points to the expansion of geochemical phosphorus mobility, which becomes again available for the lake ecosystem.

Natural rhythm of sedimentation processes in Subatlantic was greatly disturbed by human impact on the catchment area.

As is known the sedimentation of terrigeneous material reflects the degree of the development of erosional processes in the catchment area. The results of lithological-geochemical analysis of Subatlantic sediments of Lake Rudushskoye shows that important changes have taken place in sediment composition since the second half of Subatlantic period. They correlate neither with climatic changes nor with the state of lake at that time. As a result of these changes three-four-fold increase of terrigeneous component and decrease of percentage concentrations of organic matter in sediments took place. The initial stage of radical changes in sediment composition coincides with empirical limit of Cerealea pollen curve dated as the 8-10th centuries. Undoubtedly, the increased input of terrigeneous material into the lake has been caused by activation of erosional presesses due to human disturbances of landscapes (plowing, forest fell, etc.).

The results obtained through the studies on the composition of bottom sediments of Lake Rudushskoye and, first of all, of such important indices as the mineral and organic matter content agree

with the data of pollen-and-spore analysis aimed at determining the initial stages and development of human influence in retrospective aspect.

In the Holocene the essential changes in vegetation cover occured also in its last stage, i.e. in Subatlantic period, especially during the last 800-1000 years. The empirical limit of Cerealia pollen and accompanying weeds is distinct on pollen-and-spore diagram. This boundary is closely related to the development of agriculture. The second important anthropogenic boundary is distinguished at chronological level approximately 200 years ago. It is recorded on the diagram by the culmination of birch, willow and cultural Gramineae pollen owing to native forest fell and plowing of theterritory.

Thus the detailed complex palaeolimnologic investigation of natural sedimentation processes serves as a basis for the elucidation of human impact.

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УДК 551.8:551.807:551.57

ПАЛЕОГЕОГРАФИЧЕСКИЕ ЭТАПЫ РАЗВИТИЯ ОЗЕР ЛАТГАЛЬСКОЙ ВОЗВЫШЕННОСТИ

Л.В. Сергеева, В.И. Хомутова, И.С. Трифонова

Резюме

Эволюция озер Латгальской возвышенности /Восточная Латвия/ в голоцене рассматривается на примере типичного для данного района озера Рудушское. Комплексом аналитических методов/ литолого-геохимический, палинологический, радиометрический и др. / изучена грунтовая колонка мощностью 6,1 м. По результатам палинологического изучения и ^{14}C датирования установлено, что озеро возникло в бореальный период, примерно 8 500 лет назад. Озеро испытывало ряд трансгрессивно-регрессивных фаз, связанных с изменениями климатических условий, что нашло отражение в особенностях вещественного состава осадков. В соответствии с изменениями природных условий менялся и уровень продукционных процессов в водоеме, который прослежен авторами с помощью двух показателей - абсолютных масс органогенных компонентов и содержаний дериватов хлорофилла. На фоне изученных закономерностей естественно-природной ритмики осадконакопления выявлены ее нарушения под влиянием антропогенного фактора.

Академия наук СССР,
Институт озероведения

ON FORMATION OF SEDIMENTS AND DIATOMS AND POLLEN COMPLEXES IN THE LAKES OF THE LITHUANIAN NATIONAL PARK

M. Kabailiene, J. Tamošaitis, F. Martinkeniene, B. Vaićviliene

The Lithuanian National Park is situated in the NE part of Lithuania. It has an area of about 300 sq.km., of which 15% is taken up by lakes. Woodlands cover 78% of the territory, i.e. the woodiness of the area is thrice as much as the average for Lithuania. Pine forests (83%) prevail, birch and spruce woods make up 8.7 and 5.2%, correspondingly.

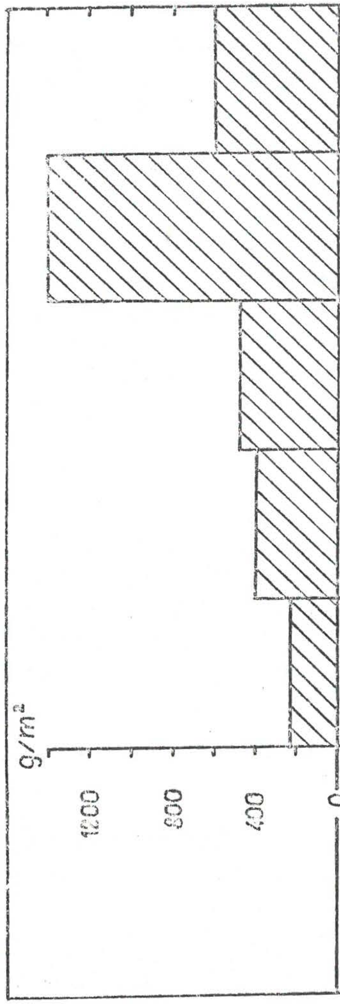
For several years the principal lakes in the National Park have been subjected to complex studies. This paper deals with the recent data obtained through the analysis of pollen, diatoms and composition of sediments accumulated in five lakes within the year of 1980. The sedimentation rates obtained are also presented. Studies were carried out on lakes of different type.

Of the lakes studied, the largest is Lake Dringis (7.21 sq.km), its average depth being 8.4 m, and the maximal one - 24 m. Its catchment area is rather woody (45.2%).

The lakes Pakasas and Utenis are of the same size and depth, but they differ in woodiness of their catchments. Forests around Lake Pakasas occupy only 9% of the catchment area (with the agricultural lands prevailing), whereas the environs of Lake Utenis are rather rich in forests (42.7%). Both lakes, being several times smaller than Lake Dringis, are similar in depth and have rather large catchment areas.

Lake Šakarvai is not large (0.78 sq.km), but the deepest of all the lakes studied: maximum depth - 40 m, average - 16.5 m, with a high flowage and large catchment area.

The smallest and the shallowest of the lakes studied is Lake Gruodiskis (0.24 sq.km). It has an outlet and small catchment area covered with forests (67%) (Fig.1).



LAKES		GRUODIŠKIS	ŠAKARVAI	DRINGIS	PAKASAS	UTENIS
CHARACTERISTIC OF CATCHMENT	AREA, KM²	1,1	495,3	147,5	96,9	117,8
	WOODEDNESS,%	67,0	31,8	45,2	9,1	42,7
	BOGGEDAREA,%	5,0	9,9	8,5	11,5	10,1
	AREA OF LAKE,%	22,5	8,4	6,3	8,6	2,4
RELATIVE BASIN		4,0	629,9	20,4	62,4	58,9
AREA OF LAKE, KM²		0,24	0,78	7,21	4,55	2,0
MAXIMAL DEPTH,M		10,4	40,0	24,0	17,0	21,0
AVERAGE DEPTH,M		5,2	16,6	8,4	7,3	8,5

Fig. 1. Annual quantities of settled material in the lakes of the Lithuanian National Park within the year of 1980.

In order to determine the sedimentation rate and take sediment samples for the analyses of pollen, diatoms and chemical composition, sediment traps of original construction have been fixed on the bottom in the deepest points of the lakes. They have been examined four times a year in each lake. Thus, it became possible to periodize the data on accumulation of sediments, abundance and composition of pollen and diatom algae deposited, like this: winter (January - March), spring (April - June), summer (July - August) and autumn (September - December). Such studies allowed to determine the abundance of pollen grains and frustules of diatoms settled on a certain area within a certain time (quantities of pollen and diatoms settled on 1 m^2 per second and per day were determined by the method proposed by M. Kabailiene (Кабайлене, 1985).

In the target lakes the highest rate of sediments accumulation was registered during summer and autumn periods: 1.23-4.31 and 0.59-6.61 g/m^2 per day, correspondingly. In winter, under ice conditions, deposits are also being accumulated in all the lakes, but in small quantities (0.064-0.62 g/m^2 per day).

Sedimentation rates vary with lakes. The lowest was recorded in the small, shallow Lake Gruodiškis fed prevailingly by ground water (0.064-1.23 g/m^2 per day). Organic material in its sediments makes up 65.9-81.3%, and its amount is directly proportional to the intensity of sedimentation. The amount of inorganic material, rather small and slightly fluctuating in the course of years, indicates that the contribution of slope erosion to sedimentation is not significant and that the autochthonous material is a principal factor of sediment formation.

In a deep lake of Šakarvai fed by water from other lakes the sedimentation is also slow (0.58-1.76 g/m^2 per day). The amount of organic material is not large (16.9-25.2%) here, but the content of calcium carbonate (33.4-49.1%) and inorganic particles (25.7-47.4%) is rather high. In this case, a part of material coming from the catchment area is accumulated in the lakes serving as feeders for Lake Šakarvai. Oxygen is abundant, and therefore autochthonous material is being oxidized (Fig.1).

The lakes Dringis, Pakasas and Utenis are mainly being fed by surface water. The catchments of these lakes are intensively used for agricultural purposes. Sedimentation rate is considerably higher here (up to 6.61 g/m^2 per day) than in the above-mentioned lakes, and sediments are rather rich in inorganic particulate material and calcium carbonate (Кабайлене и др., 1983).

The highest sedimentation rate of diatoms (up to 165,000 frustules/m^2 per sec) was found in the running-water lakes of Pakasas, Utenis and Dringis, fed mainly by surface water, i.e. in the lakes with highest amount of delivered nutrients necessary for the development of diatoms. The lowest sedimentation rate of diatoms (3-603 frustules/m^2 per sec) was registered in Lake Gruodiškis fed mainly by groundwater. Accumulation of diatoms proceeds at the highest rate during the summer period (603 and 47,900 frustules/m^2 per sec in Gruodiškis and Utenis, correspondingly), whereas in the open lake of Pakasas (having a catchment area with a widely developed agriculture), it was most intensive in autumn.

The overwhelming majority of diatoms belongs to the freshwater, either oligohalobic or indifferent species. In summer, there is an increase in abundance (especially in the lakes of Dringis, Utenis, Šakarvai) of halophilous species (Cyclotella operculata, Fragilaria crotonensis, Fragilaria primata, Epithemia sorex), probably, due to their preference to the water with slightly increased mineralization. These changes in the composition of diatoms occur as a response to the human economic activities, and are connected with the growing input of inorganic material into the lake. During the same period, the abundance of boreal species characteristic of the water basins of middle latitudes increases as well. Halophobes are found in small quantities, being a bit more abundant (2-3%) in the sediments of winter period (under ice conditions) in the lakes of Gruodiškis and Šakarvai, where Tabellaria fenestrata, Tabellaria flocculosa, Neidium iridis etc. have been found (Fig.2).

Since the studies were performed on the sediments from the deepest sites of the lakes, the planktonic species proved most abundant, and only in the shallow lake of Gruodiškis benthic diatoms prevailed with rather large quantities of epiphytes. The diatoms abounded in

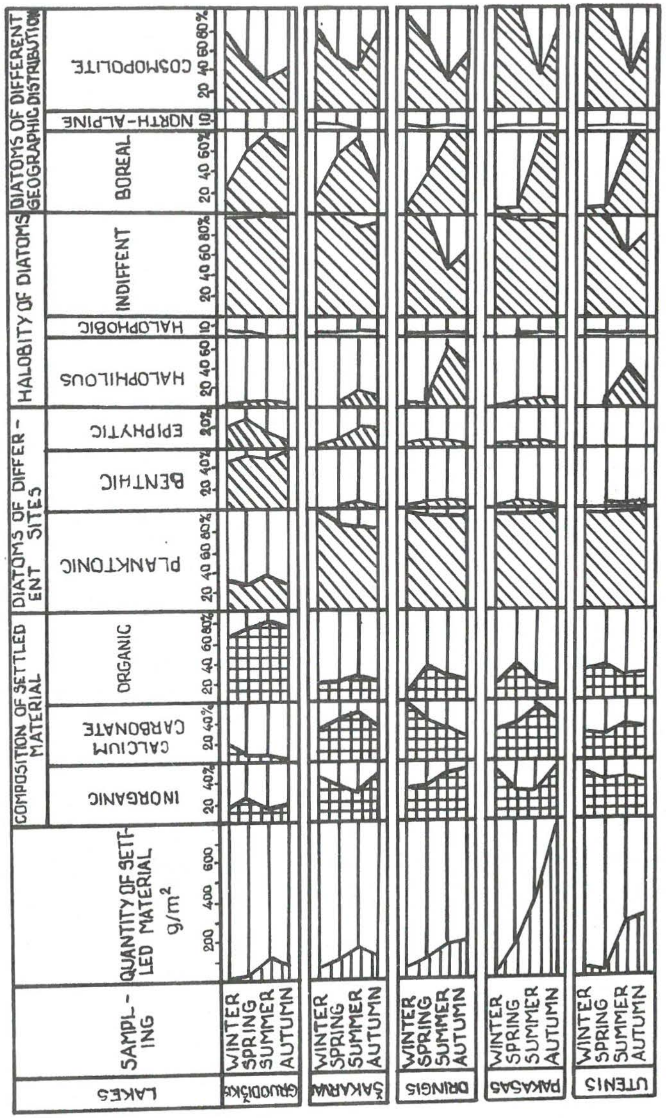


Fig. 2. Sedimentation rate, composition of settled material and diatoms in the lakes of the Lithuanian National Park within the year of 1980.

the sediments of Lake Šakarvai, which is a deep lake with intensive drainage. This favours the transport of frustules of littoral species (including the epiphytes settled on the bottom in the shallow near-shore zone) to the deep zone.

Species composition of dominant diatoms differs with lakes. Diatoms are subjected to the especially strong influence of water entering the lake and bringing in the substances necessary for their life. There are different dominants of Navicula (N. radiosa, N. subtilissima, N. cryptocephala) and Cymbella (C. affines, C. ehrenbergii, C. naviculiformis) in the sediments of Lake Gruodiškis. Most of the planktonic species belong to Cyclotella comta. Some dominants are common for the lakes of Pakasas, Utenis and Dringis. However, there are differences as well. For example, in Lake Pakasas the representatives of the genus Aulacosira are of the utmost importance, whereas Fragilaria crotonensis prevails in Lake Utenis. The sediments of Lake Dringis are dominated by Fragilaria crotonensis (up to 40-60%), there are many frustules of Cyclotella operculata, whereas Aulacosira italica appears in rather small numbers. The sediments of Lake Šakarvai are dominated by representatives of Stephanodiscus (about 50% of the total quantity) (Fig.2).

A close relationship was found between the abundance of diatoms and the sedimentation rate. The increase in the abundance of diatom frustules in sediments is related to the higher rate of sedimentation.

The results of diatom analysis indicate, that under the similar physical and geographical conditions differences in the composition of dominant diatoms are rather common in coeval sediments in the lakes of different type. They also show that the abundance of diatom frustules increases with an increase in the inflow of surface water. On the basis of these data, it can be assumed that strata with increased numbers of diatom frustules (in the section of Holocene lake deposits) correlate with more humid climatic periods. Such an assumption is well supported by the data obtained through the research on diatoms in Holocene deposits of Lithuania's lakes.

The maximum quantities of pollen in the target lakes were found in spring and summer sediments. For the majority of the lakes, pollen sedimentation was higher in spring than in summer, e.g., in Lake Gruodiškis 53,500 pollen grains were settled on 1 m^2 per day in spring, in autumn - 29,500. For Lake Pakasas, the corresponding values were 206,500 and 82,900. For the largest lake - Lake Dringis, on the contrary, pollen sedimentation in summer was slightly higher than in spring: 65,300 and 49,700 pollen grains on 1 m^2 per day, correspondingly. Here, due to a considerable mixing of water in spring, the delivered pollen settled with some delay.

During the year, tree pollen grains (40-89%) prevailed in all the lakes with a dominance of birch pollen in spring and pine pollen in other seasons of the year. The spectra of pollen settled in summer and autumn were found to have the maximum resemblance to pollen spectra of forests growing in the catchment area. During these seasons, the pine pollen was prevailing (40-70%), followed by birch (15-35%), alder (5-20%), fir (5-10%) and broad-leaved species (2-4%). The response to phenological phenomena, i.e. the sequence of blooming, is better displayed by the pollen spectra of spring sediments.

Slightly increased quantities of pollen of broad-leaved tree species and hazel were found in the sediments of Lake Pakasas. The pollen of cultured cereals appeared in larger quantities than in the other lakes.

The largest quantities of herb pollen were settled in summer, i.e. during the intensive blooming of herbaceous plants, and most of the spores were found in the spring sediments. The pollen of ground plants prevailed among herbs, and representatives of Bryales dominated among spores.

The sedimentation rates of pollen in winter (under ice conditions) have been also estimated. At this time, the largest quantities of pollen were settled in Lake Šakarvai (with intensive drainage) and in the largest study lake - Lake Dringis (6800 and 4671 pollen grains on 1 m^2 per day, correspondingly). The smallest quantities (224 pollen grains on 1 m^2 per day) were registered in the small and shallow lake of Gruodiškis. The maximum quantity of pollen of some species of the year was found in the winter sediments of several lakes: oak (up to 3-4%), elm (up to 3-4%), there were rather large quantities

of pollen of pine, birch, alder, but little spruce pollen. Large quantities of herb pollen were also found in the winter sediments of all the lakes. In winter, herb pollen abundance was higher than in spring, and in some cases, higher than in summer. For instance, under ice conditions, the winter sediments of Lake Dringis had the maximum quantity of pollen of Rumex and Polygonaceae, whereas those of the lakes of Utenis and Šakarvai were dominated by Gramineae pollen (Fig.2).

Sedimentation of pollen in winter, under ice conditions, indicates the complexity of this process in the lakes. The obtained data indicate that a part of pollen brought into a lake does not settle immediately on the bottom. The resuspension of settled pollen grains from the bottom of the littoral under the influence of waves and currents is also possible.

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R E F E R E N Ć E S

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УДК 551.8:551.79

О ФОРМИРОВАНИИ ОСАДКОВ, ДИАТОМОВЫХ И ПЫЛЬЦЕВЫХ КОМПЛЕКСОВ В ОЗЕРАХ ЛИТОВСКОГО НАЦИОНАЛЬНОГО ПАРКА

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Резюме

Изучение скорости осадконакопления, состава осадков, диатомовых водорослей и пыльцы в пяти разнотипных озерах Литовского национального парка в течение года показало:

1. Скорость осадконакопления в разных озерах различная. Самый низкий темп осадконакопления был установлен в небольшом, неглубоком, питаемом в основном подземными водами озере, наиболее интенсивно осадки накоплялись в озерах, питаемых поверхностными водами, имеющими мало облесенные водосборы.

2. Общее количество диатомовых водорослей наиболее высокое в сильно проточных, питаемых в основном поверхностными водами озерах. Видовой состав доминирующих диатомовых водорослей в разных озерах различный.

3. Максимальное количество пыльцы оседает весной, во время цветения деревьев. В весенних осадках преобладает пыльца березы, а в другое времена года - сосны. Пыльца продолжает оседить зимой в подледных условиях. Полученные данные свидетельствуют о сложности процесса седиментации в озерах.

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SEDIMENTATION PROCESSES AND RATES OF SEDIMENT ACCUMULATION IN THE LAKES OF DIFFERENT TYPE

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The character and rates of sedimentation processes in the lakes are determined by both quality and quantity of the supplied material and lakes morphometry (Гарункштис, 1975; Россолимо, 1949). Formation of bottom deposits is caused by a variety of factors such as those related to the catchment (area, physical and geographical conditions), lake basin (morphologic-morphometric features), which the material dissolved or suspended is being supplied from by the surface (river, overland flow) and ground-water run-off, as well as climatic and meteorologic factors (air temperature, precipitation, wind regime) causing the delivery of dissolved and suspended material in a form of aerosols. In the lake itself, the processes of sediment accumulation are influenced by morphologic-morphometric traits (area, shape, depth), physical properties of water masses and chemical composition of water, aquatic plants and fauna being the cause of mechanical, chemical and biological sedimentation. According to their impact on sedimentation processes, they can be divided into active and passive factors, the former taking part directly in the formation of bottom deposits, e.g. the surface and ground-water run-off, wind, precipitation, aquatic plants and fauna, the latter being embodied in the physical-geographical conditions of the catchment, morphologic-morphometric traits of the basins, etc.

The material can be delivered into the lake from the catchment by water run-off, atmospheric dust and precipitation in a suspended and dissolved form; thereafter, suspended material is being settled on the bottom, whereas dissolved material becomes to participate in the material and energy circulation in the water body, and only subsequently, its certain part enters the bottom deposits.

Physical and geographical conditions of the catchments are considered as the principal factor determining the hydrochemical regime of the lakes, their biological production and, hence, their evolution and biolimnological types. The limnological typology, in its turn, is based on a certain set of indicators and different processes of sediment formation (Россолимо, 1977). Oligotrophic lakes are characterized by a low nutrients supply. Therefore, a characteristic feature of oligotrophic-limnic ecosystems is a low value of positive balance of production-destruction processes, i.e. a slight excess in formation of new organic material over its destruction and, hence, its rather modest accumulation in the water body.

A characteristic feature of eutrophic lakes, rich in nutrients (P and N, prevailingly) is the rapid growth of autotrophic hydrobionts causing the mass development of planktonic algae and, hence, an increased production of organic material. The abundance of organic material and its accumulation in bottom deposits is typical of these lakes (e.g. lakes Duobelis, Lavysas).

Mesotrophic limnic ecosystems are related to the transitional stage of lake development with the organic material accumulating in bottom deposits. To this group belongs a vast majority of target lakes, e.g. lakes Akmena, Galve, Kriaunelis, Dusia, Baltas Kauknoris, Totorishkes).

The formation of dystrophic limnic ecosystems is closely related with the impact of bog water poor in assimilable phosphorus and nitrogen, and, therefore, they provide unfavourable ecological conditions for the development of autotrophic hydrobionts (Lake Esherinis).

For the investigation of recent rates of sedimentation in the lakes of different type the sedimentometers (sediment traps) of original design were used. They were settled on the bottom of lakes in characteristic places (usually at the maximum depth). The sediment trap consists of a plastic cylinder (70 cm high, 10 cm in diameter) attached to the triangular duraluminium support (its side being 60 cm long and 50 cm high). A small rein-steel rope covered with plastic insulation is tied up to the central upright of support. Floats tied up to the end of the steel rope are usually lowered to the horizon of 3-5 m below the water surface (during the anchoring in summer). Sediment traps were installed and examined every month at the same time. After the sedimentometer was taken ashore, water samples for the

analyses were collected with a rubber tube. Material was analyzed in the laboratory for the content of dry material, loss on ignition and ash content, as well as $CaCO_3$, organic carbon, total nitrogen, P_2O_5. Sedimentation value is expressed as the quantity of dry material in grams per 1 m^2 (g/m^2), and chemical composition of sediments is estimated in per cents on dry material. From 1972 to 1985 the recent sedimentation has been already studied in more than 20 lakes in the Lithuanian SSR. For each lake the research covers a period from 1 to 4 years.

The target lakes are situated in different landscapes of the SE Lithuania. Catchments of lakes Akmena, Galve, Ilgis (Trakai District), Kriaunelis (Rokishkis District), Galstas, Shlavantas (Lazdijai District), etc., are located in the zone of marginal morainic uplands. Lakes Baltas Kauknoris, Duobelis (Lazdijai District), Lavysas (Varena District), Totorishkes (Trakai District), Gruodishkis (Ignalina District) lie on an aqueoglacial plain of the last glaciation; lakes Dringis and Shakarvai (Ignalina District) occupy a part of the landscapes of mixed type, whereas Lake Esherinis lies in a large mire area. Lakes Baltas Kauknoris, Duobelis, Ilgis, Pakasas, Kriaunelis and Shakarvai are located in groove-like depressions or in their segments; lakes Gruodishkis and Lavysas are related with the areas of cryogenic subsidences; lakes Akmena, Galve, Totorishkes occupy the basins of complex origin. The target lakes differ in the size of their catchment areas, their physical and geographical conditions, economic value, water surface areas and morphometric indices.

Catchments of lakes Baltas Kauknoris, Duobelis, Lavysas, Gruodishkis are almost entirely covered with forests and long-fallow lands. Highly wooded are the catchments of lakes Dringis and Shakarvai. The catchments of the most lakes studied (e.g. lakes Akmena, Galve, Ilgis, Pakasas, Totorishkes) are dominated by agricultural mainly arable lands. Besides, the town Trakai is situated at lakes Galve and Totorishkes. The target lakes represent a recent sedimentation pattern of water bodies being fed by ground, river, lake and atmospheric water; differences are observed in the degree of water exchange and in the extent of changes due to human impact in their catchments (Table 1).

Table 1

The main characteristics of lakes and their catchments

Lakes	Area, km^2		Depth, m		Feeding	Flowage	Utilization of catchment
	of catch-ment	of lake	maxi-mum	ave-rage			
Akmena	29.4	2.76	30.2	11.2	ground-water	lake with outlet	farming lands
Baltas Kauknoris	3.6	0.20	40.0	12.0	- " -	- " -	forest landscape
Dringis	147.5	7.24	24.0	8.4	river and ground-water	open lake	50% forest
Gruodishkis	1.1	0.24	10.4	5.2	ground water	lake with outlet	forest landscape
Kriaunelis	158.0	0.31	7.9	4.6	river water	open lake with high flowage	50% farming lands
Totorishkiu	18.2	0.76	20.0	10.1	ground-water	lake with outlet	farming lands and town Trakai

Depending on physical and geographical conditions and intensity of human impact, the catchments of the lakes are of direct influence on the formation of hydrodynamical regime and the development of sedimentation processes. Drainage lakes in the National Park of the Lithuanian SSR are supplied by the river run-off with suspended material with its amount ranging from 0.6 to 26.2 t/year/km^2 from different catchments. The supply with dissolved inorganic material from the catchments by lake tributaries is fluctuating from 22.2 to 140.9 t/year/km^2, that for inorganic phosphorus, inorganic nitrogen and organic carbon is 0.002-0.053, 0.02-0.67 and 0.06-6.0 t/year/km^2, correspondingly (Василяускене и др., 1984). Lakes formed in deep basins with steep slopes or slopes occupied by arable lands receive large quantities of terrigenous material (from 15 to 28 t/ha) due to the influence of sheet and rill erosion.

Lakes fed by groundwater, especially from catchments with sandy-gravel deposits, receive large amounts of hydrocarbonate and calcium ions promoting under favourable conditions the processes of chemical sedimentation, i.e. deposition and accumulation of calcium carbonate (lakes Baltas Kauknoris, Gruodishkis) (Тамошайтис, Мартинкенене , 1976; Тамошайтис и др., 1981; Тамошайтис и др., 1984).

A number of lakes is characterized by increased photosynthetic activities of organic matter producents, i.e. phytoplankton and macrophytes. The research carried out in the lakes of the National Park has shown that during vegetation period the biomass of phytoplankton in naturally eutrophicated Lake Gruodishkis fluctuated from 0.7 to 2.5 g/m^2, for lakes Shakarvai and Dringis subjected to remarkable human impact these values were 0.3-5.7 and 0.6-15.3 g/m^2, correspondingly. The accumulation of organic matter shows a good correlation with the growth of phytoplankton (Тамошайтис и др., 1983).

In the annual course of sedimentation one can distinguish between two sharply differing periods: ice-free period with increased sedimentation and ice-covered period of low sedimentation (Lawacz, 1969; Россолимо, 1949; Тамошайтис, Мартинкенене, 1976). They depend on the energy supplied to the catchment and water body, i.e. solar radiation,and changes both in heat stock of water mass and in trends

Table 2

Amounts of deposited material in the lakes

Years	Lakes											
	Gruodishkis 1978		B.Kauknoris 1972		Akmena 1976		Totorishkiu 1976		Dringis 1978		Kriaunelis 1972	
Months	g/m^2	%	g/m^2	%	g/m^2	%	g/m^2	%	g/m^2	%	g/m^2	%
January	1.1	0.4	12.1	5.0	13.7	3.3	7.7	1.3	18.7	2,7	20.9	1.4
February	0.9	0.3	3.5	1.5	10.3	2.5	4.5	0.7	19.7	2.9	48.8	3.3
March	1.6	0.6	5.8	2.4	7.2	1.7	7.8	1.3	2.3	0.3	68.0	4.6
April	6.4	2.3	23.4	9.7	22.2	5.4	46.5	7.7	46.6	6.8	216.1	14.7
May	18.5	6.6	32.6	13.5	48.5	11.7	49.3	8.2	109.0	15.9	151.9	10.4
June	26.6	9.5	26.2	10.8	36.6	8.9	49.6	8.2	77.0	11.2	33.3	2.3
July	32.0	11.4	28.2	11.7	54.0	13.2	71.7	11.9	70.6	10.2	53.3	3.6
August	76.4	27.2	17.3	7.1	20.3	4.9	32.5	5.4	53.4	7.8	129.9	8.9
September	37.8	13.4	13.4	5.5	72.6	17.5	48.3	8.0	51.4	7.5	243.5	16.6
October	29.0	10.3	**26.9**	11.1	80.9	19.5	98.7	16.4	102.5	14.9	263.2	18.0
November	46.0	16.4	35.7	14.7	18.8	4.5	90.6	15.0	81.0	11.8	161.5	11.0
December	5.2	**1.9**	17.2	7.1	28.8	6.9	94.6	15.7	54.1	7.9	75.0	5.1
	281	100	242.3	100	413.9	100	602.1	100	686.3	100	1465.4	100

and intensities of production-destruction processes. Detailed studies on annual sedimentation course allowed us to differentiate between four cycles in majority of lakes: winter minimum, spring maximum, summer minimum and autumn maximum. The cyclic character of the annual sedimentation course depends on the seasonal rhythms of general natural phenomena and processes occurring in the catchments and limnic ecosystems.

In shallow lakes winter minimum of sedimentation is observed from December to March, and, in deep lakes, from January to March. The shallow lakes of Lithuania become covered with ice at the beginning of December, and the deep ones in the second half of December. The share of material deposited during winter minimum makes up from 1 to 10% of the total annual amount. Low sedimentation rates are characteristic of the open or low-drainage lakes fed mainly by groundwater e.g. lakes Gruodishkis, Duobelis and Lavysas (3.6, 4.2 and 13.5 g/m^2, correspondingly). Rather high rates are characteristic of the drainage lakes, e.g. lakes Utenis, Pakasas, Kriaunelis (46.9, 51.2 and 137.7 g/m^2, correspondingly). In the majority of target lakes the smallest quantities of sediments are formed in February and, occasionally, in January or March. In most cases the material deposited during winter minimum is characterized by a high content of inorganic material (67.0-79.0%) (Мартинкенене, Тамошайтис, 1977; Тамошайтис, Мартинкенене, 1976; 1979/.

Spring maximum of sedimentation is very intensive and it lasts two months. The amount of material deposited during spring maximum makes up from 10 to 50% of the total annual amount. The maximum rate of sedimentation (368.0 and 156.6-182.7 g/m^2) is characteristic of the lakes with high water flowage (e.g. lakes Kriaunelis and Dringis, correspondingly). As the principal source for sedimentation serves the material supplied into the lake during spring flood by overland flow and river run-off, accumulated on the ice surface during winter period and formed by abrasion of shores and shallows. In the lakes fed by groundwater and having overgrown basin slopes only a slight increase in sedimentation was observed in spring (Lake Gruodishkis 26.7 g/m^2).

Bottom deposits of shallow open lakes (e.g. Lake Gruodishkis) and low-drainage lakes (e.g. Lake Duobelis) are characterized by a low content of inorganic (7.9-13.3%) and increased content of organic (55.4-64.4%) matter. Inorganic material dominates in the composition of bottom deposits in deep drainage lakes (e.g. in lakes Shakarvai and Kriaunelis 43.2 and 61.5%, correspondingly) (Мартинкенене, Тамошайтис, 1977; Тамошайтис, Мартинкенене, 1976; 1979).

Sedimentation rates decrease during the summer cycle of sedimentation in the majority of lakes in the Lithuanian SSR, as compared to the spring cycle. Summer minimum of sedimentation usually lasts three months (June-August). However, for several lakes, as can be judged by the amount of sedimentary material, the summer minimum is sometimes observed in September, too. As the main source for accumulating sediments, especially for the lakes with summer maximum of sedimentation, serves autochtonous material - the planktonic organisms. The processes of chemogenous sedimentation are of consequence as well. The quantity of material deposited during a cycle varies from 71.7 (Lake B. Kauknoris) to 216.5 g/m^2 (Lake Kriaunelis), this makes up from 15 to 30% of the annual amount (Тамошайтис, Мартинкенене, 1976, 1979). On the contrary, for the shallow open lakes (Lake Gruodishkis) and low-drainage lakes (Lake Duobelis) as well as for those fed by the other lakes (Lake Shakarvai) the annual maximum of sedimentation occurs during the summer cycle. Deposits settled there are characterized by the highest amount of organic material (70.3-77.3%) (Тамошайтис и др., 1984). Despite the intensive biological processes occurring during the summer cycle, deposits accumulating in the drainage lakes and those fed by groundwater are prevailed by inorganic material (49-64%).

For the majority of lakes, the autumn cycle represents the second peak of sedimentation in the annual course (Мартинкенене, Тамошайтис, 1977; Тамошайтис, Мартинкенене, 1976). Depending on meteorological conditions (air temperature) and lake depth, this cycle lasts for three (September-November) or four months (September-December). As mentioned above, shallow lakes get often covered with ice at the beginning of December. During the autumn cycle, sedimen-

tation rate fluctuates from 76 (Lake Gruodishkis) to 668 g/m^2 (Lake Kriaunelis). The greatest amount of sedimentary material is characteristic of drainage lakes fed by river water and those with their catchments intensively affected by human activities (Тамошайтис и др., 1981). Sediments in the lakes of various types differ in chemical composition; shallow open and low-drainage lakes are rich in organic matter, whereas in deep lakes, either high-drainage ones, the content of inorganic material has increased (29.8-64.2%).

Total annual sedimentation rates show great differences, being 109 g/m^2 in the dystrophic lakes fed by bog water (Lake Esherinis), 200-300 g/m^2 in the lakes having forested slopes and being fed by groundwater (lakes B. Kauknoris, Ilgis), 300-800 g/m^2 in the lakes situated in the areas of intensive agricultural activities, and more than 800 g/m^2 in the lakes fed intensively by the river run-off.

The studies on chemical composition of bottom deposits have shown that in the lakes fed by groundwater in the wooded landscape the formation of recent bottom deposits depends mainly on chemical and biological sedimentation. For the lakes with a low content of HCO_3^- (50-100 mg/l) the mean annual sedimentation of $CaCO_3$ makes up 50 g/m^2 at the maximum depth (Lake Gruodishkis), whereas that for the lakes with a high content of HCO_3^- (160-250 mg/l) is 80-100 g/m^2 (Lake B. Kauknoris), i.e. 20 and 40% of the total annual amount, correspondingly. In some months, the share of organic matter in Lake Gruodishkis reaches 56.2-96.1% (Тамошайтис и др., 1981, 1984).

For the lakes fed by groundwater in the areas of developed agriculture, the formation of recent sediments depends mainly on mechanical and biological sedimentation. For the lakes at the town Trakai (lakes Akmena, Galve, Totorishkes), the share of inorganic (except CaO) and organic matter makes up 37.0-38.8% and 26.7-42.3%, correspondingly. Besides, in Lake Totorishkes, the chemogenous sedimentation is also very active; the share of $CaCO_3$ accounts for 35.5% (Мартинкенене, Тамошайтис, 1977).

As for the lakes fed by river water in the agricultural areas, recent sediments are mainly formed by mechanical sedimentation with inorganic matter accounting for 63.8-79.0% (Lake Kriaunelis).

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ПРОЦЕССЫ СЕДИМЕНТАЦИИ И СКОРОСТЬ ОСАДКОНАКОПЛЕНИЯ В РАЗНОТИПНЫХ ОЗЕРАХ

Ю.С. Тамошайтис

Резюме

Рассматриваются основные факторы, участвующие при формировании донных отложений озер. Они по своему воздействию на седиментационные процессы разделяются на активные и пассивные. Дана оценка физико-географических условий на формирование донных осадков речным стоком, поверхностным смывом и воздействием грунтовых вод. В годовом ходе седиментации выделены два резко отличающиеся периода: свободный ото льда - повышенной седиментации и подледный - с низкой седиментацией и 4 цикла: зимний минимум, весенний максимум, летний минимум и осенний максимум. Каждый цикл

характеризуется неодинаковым количеством осадочного материала и различным химическим составом формирующихся донных осадков. Представлены общегодовые темпы седиментации в разнотипных озерах в зависимости от воздействия водосбора /антропогенного преобразования ландшафтов и характера питания/ и морфометрии озер.

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PALAEOLIMNOLOGICAL CHANGES IN THE BYELORUSSIAN TERRITORY DURING THE LATE-GLACIAL AND THE HOLOCENE

O. Jakushko

Byelorussia is situated in the western part of the East-European Plain. Here proceed the limits of the last two glaciations (Fig. 1) marked by regular distribution of the main types of relief and lake-river network. Wide distribution of lakes both in the northern and southern parts of the republic serves as a distinctive palaeolimnological characteristics.

In northern Byelorussia lakes lie within the limits of the last (Valdai) glaciation. In Byelorussian Polesye water bodies are situated in the south; they are not related to the glacial formations. Abundant material (more than 400 sequences has been obtained through the drilling of sediments of modern lakes. Drilling and common analyses were performed by the Laboratory of Limnology of the Byelorussian State University named after V.I. Lenin by different investigators.

Long-term field and analytical works testify to a young age of lakes on the territory of Byelorussia (the Holocene or the late-glacial); they also reveal considerable differences in the evolution of lakes in the northern and southern parts of the republic.

Within the boundaries of Byelorussian lake district the lake basins were formed mainly by the glacier and its melt waters. The retreat of the ice cover was accompanied by long-term halts, known as stages. The maximal distribution of the glacier (the lake stage) corresponds to the Brandenburg stage; Sventsjan stage - to the Frankfurt stage, and the northernmost, Braslav stage - to the Pomerian stage (Якушко, 1981). Each stage of the ice retreat resulted in the formation of a specific glacial geomorphological complex composed of marginal uplands, till and outwash plains and lake basins. The relief of till plains and elevations (Sventsjan, Braslav, Ushachko-Lepelsk) is dismembered by numerous closed depressions, occu-

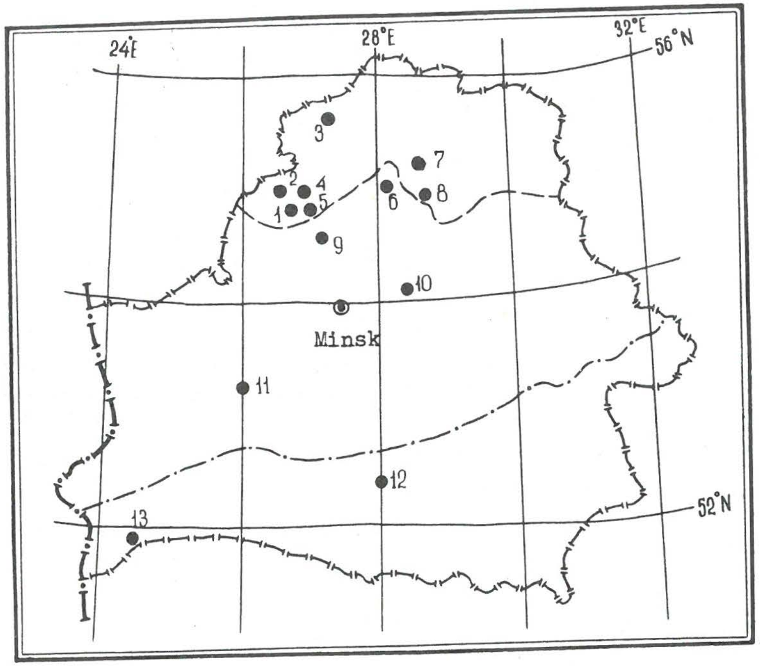

Fig. 1. Investigated lakes: 1 - Naroch, 2 - Glubelka, 3 - Poteh, 4 - Batorino, 5 - Myastro, 6 - Meszuszol, 7 - Isno, 8 - Bobritsa, 9 - Kobuzi Mire, 10 - Sudoble, 11 - Koldychevskoe, 12 - Chervonoye, 13 - Mokhno.
Broken line indicates the maximum boundary of the Poozerskoye (Valdai) glaciation, broken-dotted line - Sosz (Moscow) glaciation.

pied by lakes and bogs, often with adjoining kame fields and esker ridges.

The formation of periglacial basins, connected with the stages of Valdaian glacier retreat was caused by damming up of melt water by a more ancient end moraine in the south or by the glacier margin in the north. The retreat of the glacier in the Sventsjan stage was followed by the formation of Narotchano-Vileisk, Verkhne-Berezinsk, Lutchesk and several other shallower periglacial lakes, with their water level reaching 200 m a.s.l. At the highest lake level moraine

uplands looked like large islands, with their shores being subjected to intensive abrasion. Within the boundaries of Byelorussia the main runoff from periglacial lakes of the Sventsjan stage was directed to the south towards big rivers, such as the Dniepr, Beresina and Niemen. The direction of the efflux was predetermined by the system of water gaps, the latter being often distinctly marked in the relief as narrow troughs with paludified bottoms. In other cases the runoff was parallel to the margin of the glacier. The speed of the stream decreased and marginal (glaciosubsequent) valleys were formed. Their formation showed that the territory had a general tilt to the northwest.

As a result of the retreat of the ice margin to the limits of the Braslav stage (17,000-16,000 B.P.), several water bodies, such as the lakes Disnensky, Polotsky, Surazhsky a.o. located at a lower hypsometric level in comparison with the previous ones, were formed to the south of the margin. At the maximum stage of evolution the level of Lake Disnensky-Polotsky reached 155-160 m a.s.l. It was just at these heights where the abrasional coasts preserved. During the northernmost stages of the glacial retreat (beyond the boundaries of Byelorussia) the absolute heights of periglacial lakes continued to decrease, as if following the glacier up to the Baltic Sea.

Taking the maximum level of periglacial water bodies of the Braslav stage equal to about 155 m one should assume that lake waters penetrated periodically into till plains and uplands. The latter emerged from the fresh-water "sea" like insulated rocks. That brief period of maximum flooding when morainic material occurred in frozen state, has left behind a thin layer of sandy silt and clay deposits, which form a peculiar accumulative plane composed of vast flat areas representing the transitional zone between the highest peaks of the elevations and the basins of modern lakes. Temporal water covers and slow streams couldn't cut into the ice-bounded till and thaw the ice buried in the basins (Fig. 2).

The runoff from the lakes of the Braslav stage to the south was limited by its high watershed. Nevertheless, the movement of the water in this direction was evident in the district between the Dniepr and the Dvina rivers from Lake Surazh; the water flew along the an-

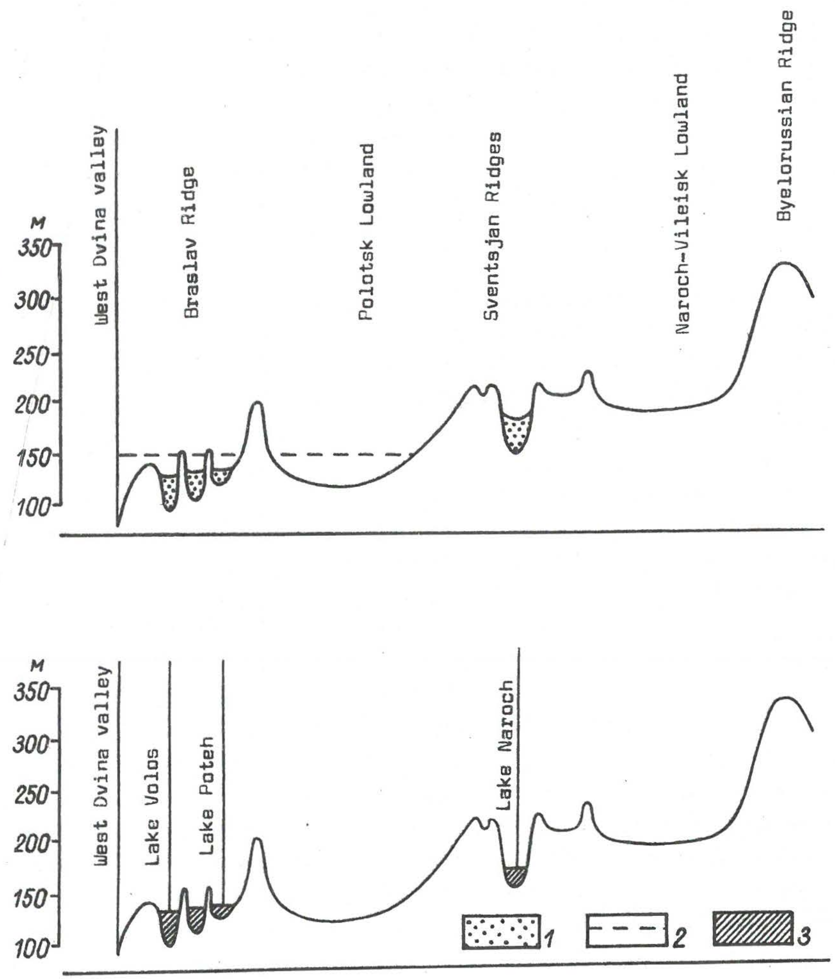

Fig. 2. Hypsometric profile of the western part of Byelorussian Lake District. Legend: 1 - buried ice, 2 - periglacial water-level, 3 - contemporary lakes.

cient Ulla and Usveika valleys, through the basin of Lake Selava to the system of the Dniepr River. An intensive runoff from the periglacial lakes of the Braslav stage is connected with the formation of the Zapadnaya (West) Dvina River water-gap which crosses the Baltic morainic ridge between Kraslava and Daugavpils. Simultaneously with the Zapadnaya Dvina cutting in, the period of the most extensive flooding of the territory was over, the waters rushed from the uplands due to natural inclination to the north-west. Numerous deep hollows, formed by melt-water runoff look nowadays like dry valleys "hanging" over contemporary lakes. If these lakes existed at that time they should have inevitably been drained, because of their higher hypsometric position in comparison with that of Lake Disnensko-Polotsk situated to the south of them.

Serving as the basis of the stream erosion and accumulation of river load, the periglacial water bodies have piled up thick layers of clastogenic sediments, derived from abrasional and solifluctional material, coming from the surrounding uplands. The character of sediments witnesses about very cold periglacial conditions of sedimentation. In the water bodies of the Sventsjan stage prevail sandy and sandy-silt sediments, whereas those related to the Braslav stage and being deeper and older, are dominated by varved clays and clayey sediments.

The retreat of the glacier margin to the north-west, and sharp reduction of water feeding resulted in sinking of the level of periglacial water bodies. In the middle of the late-glacial (Older Dryas, Alleröd) they were transformed into flat-concave lowlands with rare shallow-water lakes of residual type. In the current geomorphological complex of Byelorussian lake district, modern lakes are situated generally within moraine uplands and till plains forming thus a higher level in comparison with the periglacial ones. Several types of contemporary lake basins may be distinguished. The largest lakes (lakes Narotch, Drivjaty, Mjadel, Osvey) are situated in the dammed basins, being assymetrical and rather shallow. They lie in the proximal part of the marginal zone or between moraine ridges. Subglacial basins are widely spread in marginal parts of glacial complex. Not large in area, they are remarkable for their depths (40-50 m) and were formed by glacial exaration and erosion of subglacial streams (e.g. lakes Dolgoe, Bolduk, Soro, Ginkovo, Vetchelje and others). They are elongated in the direction of glacier movement.

Small lakes in evorsional basins are deep. Their formation is due to melt water, falling from the height (e.g. lakes Rudakovo, Svetloe, Voronets, Zhenno). In many cases evorsional hollows form the deepest parts in the basins of other types of lakes (Якушко,1971).

The formation of complicated glacial basins is related to the processes of erosion, thermokarst and evorsion evoked by the relief surface inversion, while the glacier moves along uneven surface. Numerous crevasses appearing in that case, contribute to the accumulation of loose material and further formation of eskers and kames. Monolithic ice segments, subjected to melting turned into the lake pools. Such basins are characterized by complicated shoreline and variable shape (e.g. lakes Nespish, Otolovo, Krivoe, Nedrovo).

The basins of thermokarst origin are spread not only in the glacial but also in the periglacial zone of geomorphological complex; they are related to the melting of ice blocks buried in frozen bedrock or degradation of permafrost. In the last case they are small and shallow.

The study of the basins of modern lakes has revealed a discrepancy. On the one hand they were formed comparatively long ago, in the epoch of the glacier's activity, while, on the other hand, they seem to be outwardly juvenile and well preserved in relief; they are still considerably deep, with small thickness of mineral deposits, and they have undergone only slight transformation due to modern geomorphological processes, etc. Preservation of lakes on morainic heights and till plains is marked by weak development of the valley network and considerable deepening of the lake bottoms which occupy deep hollows even in watersheds. The above peculiarity allows to suppose that in the epoch of the glacier melting and maximum inundation of the territory the basins of modern lakes were filled with the masses of ice and frozen deposits, i.e. they were in "preserved" state. Only during the general climatic amelioration at the end of the late-glacial and in the early Holocene the first lakes appeared in the basins recovered from ice. Only comparatively late

sinking of basins in glacial relief can account for the good preservation of lake basins.

Thus, on the territory of Byelorussia the beginning of the late-glacial (15,000-13,000 B.P.) was characterized by cold arctic and subarctic conditions. Drainage of periglacial water bodies and lack of lakes on the heights corresponds to the "lakeless" period of the late-glacial.

The warm stage of the Alleröd affected the course of palaeolimnological processes, as a whole. The warming up of rocks and deposits resulted in considerable reduction of frozen soils, partial melting of buried ice and appearance of shallow cold lakes with high hypsometric level in glacial thermokarst hollows. The development of solifluction processes contributed to remarkable input of loose material into lake basins. This material together with the products of abrasion gave rise to lake sediments. High ground water level under warm climatic conditions accounted for the development of chemical weathering and input of dissoluble mineral substances to the primary oligotrophic water bodies. As a result, not only typical clastogenic sediments were found in some lakes, but also sediments with remarkable concentration of chemogenic component on account of calcium carbonate (carbonate clays in Lake Narotch). A thin peat layer found in some stratigraphical sequences, dates back to the Alleröd in dammed lakes and to Preboreal in glaciogenic gorges (L. Krivoe 10280± 110 years). Its formation may be related to the time when the basins got free from ice and the peat layer, formed on the surface of frozen soils,sank to the bottom of lake basin. Peat, overlain by sapropel on the bottom of lake basins, testifies also to the arid climate of the late-glacial and sharp reduction of the number of lakes (Fig. 3).

Considerable input of terrigenous and chemical material as well as weak competition between thermophilous species of flora and fauna favoured the development of life in young shallow oligotrophic lakes. It accounts for the outbreak of diatomaceous flora at the end of the late-glacial (Alleröd). 180 and 216 taxa of diatoms were found in the deposits of that age in L. Narotch and L. Glubelka, correspondingly (Якушко, 1975).

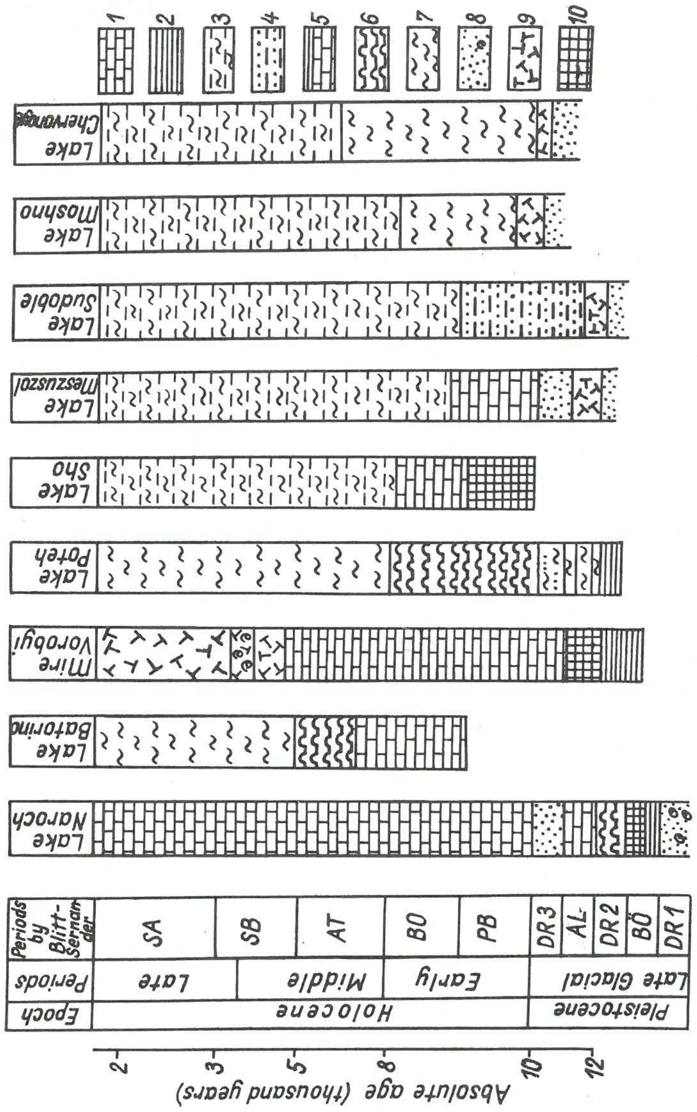

Fig. 3. Chronology of lakes in the Byelorussian Lake District. Legend: 1 - lake lime, 2 - lacustrine clay, 3 - clay ooze, 4 - sand ooze, 5 - lake marl, 6 - mixed sapropel, 7 - siliceous sapropel, 8 - sand, 9 - peat, 10 - sapropel.

Brief but considerable cooling in the Younger Dryas was reflected in stratigraphical sequences by accumulation of a thin layer of sandy deposits.

Further amelioration of the climate at the beginning of the Holocene gave rise to specific processes which became evident in the Boreal. In the northern part of Byelorussia the glaciokarstic processes and final formation of lake basins took place. As a result of this process and remarkable aridity of the climate the lake level sank, it was accompanied by simultaneous deepening of lake basins (Fig. 4). The cusp of a high erosion terrace (more than 10 m in height) was finally formed on lake slopes in the Boreal.

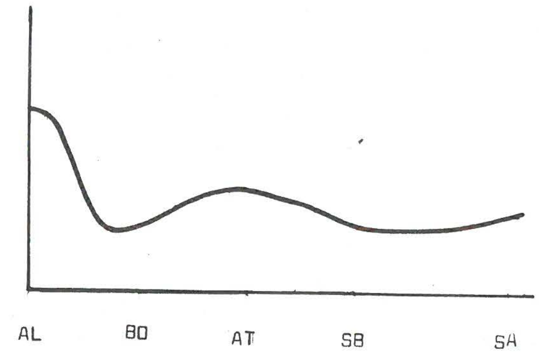

Fig. 4. The scheme of fluctuation of lake levels in Byelorussia.

The typical features of young basins of oligotrophic type appeared in the sequences of lake deposits in Preboreal-Boreal times. Preboreal time is characterized by the accumulation of terrigeneous sandy-clayey deposits, often containing carbonates of chemogenous origin. It refers to the warming of climate, melting of frozen sediments and intensification of chemical weathering. Under Boreal conditions these processes became even more intensive. Low lake level, increasing input of carbonate matter into sedimentation basins contributed to the accumulation of carbonates in the water, especially in the lakes with inconsiderable outflow. A sharp reduction of input of siliceous material was probably caused by the latter process.

The lakes formed were rather deep and warm characterized by oligotrophic and mesotrophic conditions. Oxidation under the conditions of insufficient carbonic acid saturation of water resulted in the accumulation of carbonates into sediments. The carbonate layer ($CaCO_3$ 50-80%) found in most of the profiles should be referred to the Boreal stage. In the Boreal the accumulation of carbonates was most intensive in the western part of Byelorussian lake district, where it has in places continued up to our days (lakes Narotch, Glublja, Mjadel). In the eastern part many sequences are characterized by the absence of a lake marl bed, but at corresponding depths there are sediments with higher (25%) content of $CaCO_3$. These peculiarities reflect considerable maintenance of carbonates in tills in the west of Byelorussia (20-30%). It should be pointed out that carbonate layers in lake deposits, dating from Preboreal and Boreal times, is mentioned by several authors in the Baltic Republics and Poland. At present carbonate formation is still in progress,indicating to high carbonate content in tills (Гарункштис, 1970; Wieckowski, 1966).

Boreal time is characterized by poor diatom flora in accordance with the composition of sediments and inconsiderable transportation of siliceous matter.

The Atlantic period is associated with the climatic optimum and higher humidity. In northern Byelorussia the outflow from lakes increased, and, as a result the potential output of salts concentrated in lake water increased as well. Mild climate, favourable for the development of water organisms, accelerated the process of natural eutrophication and changed the ratio of the main compounds of bottom sediments towards the increase of organic matter. In sequences of the majority of lakes under consideration the transition to the Atlantic period was marked by the appearance of siliceous sediments with high amount of organic matter. Due to intensive input of clastogenic material the number of diatom taxa increased in comparison with the Boreal flora.

In Subboreal time the climate turned gradually more arid,former

temperature regime preserved. Climatic changes caused the lowering of the ground water and lake level. At the same time river channels cut into flood-plain alluvium and formed cusps of the lower (accumulational) terrace of contemporary lakes. In spite of arid climate the amount of organic matter continued to increase in bottom sediments. Autochthonous processes connected with intensive eutrophication of water bodies and impoverishment of sediments in the catchment area with carbonates prevailed. Only in some lakes in western parts of the lake district the accumulation of carbonates is still observed in sublittoral zone. The deepest lakes which released from the ice rather late have retained oligotrophic regime, and clastogenic type of sedimentation.

The last stage of the Holocene - Subatlantic - is characterized by a certain drop of temperature and increase of humidity. Climatic alteration caused the rise of ground water level. The signs of transgression appeared in lakes, accompanied by partial flooding of littoral zone. In the shallow part of a basin underwater accumulative terrace was formed. Siliceous-rich sapropel with organic matter more than 20% was formed. Mesotrophic lakes are characterized by clayey and carbonaceous sediments. The rise in water level, increase of their flowing capacity influenced the diatom flora. In the sediments of L. Glubelka of that time 85 taxa are found, in L. Narotch -nearly 60 taxa. Simultaneously with the transgression of lakes, shallow water bodies fulfilled with sediments were subjected to intensive overgrowing and they became dystrophic.

Evolution of the lakes of Polesje has genetic differences with respect to the lakes situated in the north. However, modern investigations do not confirm the above point of view about the relict character of Polesje lakes. In investigated stratigraphic sequences of lakes in Polesje the Valdaian sediments were not found. All the sequences are of the Holocene age and they overlie thick sandy beds that testify to a "nonlake" stage in the late-glacial.

Externally stratigraphic sequences of modern lakes of Polesje resemble those of lake district, however, the conditions of sedimentation and age of sediments differ greatly. At the bottom of sequences medium-grained quartz sand is frequent. The poorly decomposed peat layer with its thickness fluctuating from 5-10 cm to 0.8 m (L. Moshno) overlies this sand. The mere lake sediments on the peat are represented by ash-rich calcareous sapropels. Upwards lies fine and coarse detritus sapropels, containing more than 30% of C_{org}. The sediments of this type are the thickest ones and complete the profiles of bottom sediments in Polesje.

The radiocarbon age of subsapropelic peat is 10,060± 120 (in L. Moshno) and 10,190± 140 years (in L. Chervony), and hence, it was formed in Preboreal time. Thus, the uppermost calcareous sapropels was formed in the Boreal and, may be, at the beginning of the Atlantic period.

The present lakes of Polesje are represented by some genetic groups. Lakes - floods, the formation of which is connected with the humidity of climate and rise of ground water level at the very end of the Boreal andin Atlantic period.It isn't excluded either that at that time the flooding was likely to have been promoted by glacioisostatic submergence of the Earth's crust. As a result,a large area of Polesje was subjected to paludification and formation of peat.In the hollows large shallow lakes were formed due to the accumulation of ground water and precipitation. These lakes were called floods, on their bottom typical lake deposits started to accumulate above the peat layers (L. Tchervonoe, L. Oltushskoje, L. Orekhovskoje) (Якушко, 1975).

Geological structure of Polesje Lowland bedding of limestone furnished favourable conditions for the development of karst processes, which became more active during paludification and flooding periods. As a result of ground water level rise small but deep lakes were formed in karst hollows. They had a kettle-like basin and relatively high mineralization of water (lakes Vulka, Lukovo, Somino, Chernoe).

The central part of Byelorussia is poor in lakes. There are shallow, rather small lake basins of suffosic-karstic (L. Svitjaz) and residual thermokarstic origin. The latter are characterized by a considerable thickness of deposits. A typical sequence of Lake Sudoble (Fig. 3) testifies to the Holocene age of the lake, and also to high intensity of the sedimentation of organogenous sapropels du-

Table

Stages of the development of the Byelorussian territory in the late-glacial and Holocene

Periods by Blitt and Sernander	Lake district			Polesye		
	Natural conditions	Lake regime	Lake sediments	Natural conditions	Lake regime	Lake sediments
1	2	3	4	5	6	7
Subatlantic	Climate similar to contemporary one. Mixed forests: pine, spruce, birch, with admixture of broad-leaved species.	Predominance of eutrophic lakes,rarely-mesotrophic	Siliceous, fine- and coarse-detritus gyttja	Climate similar to the contemporary one. Pine forests with admixture of broad-leaved,and broad-leaved forests	Eutrophic and dystrophic. Mesotrophic in karst hollows	Fine-and -coarse detritic siliceous
Subboreal	Mild arid climate. Pinus-spruce-broad-leaved forests with birch	Lake level falls.Eutrophic,rarely mesotrophic regime prevailing	Fine-and-coarse detritus sediments, siliceous and carbonate sediments rare	Mild, arid climate, pine forests with admixture of broad-leaved species and birches.	Rapid eutrophication of shallow lakes. Contin. of karst process	Fine-and coarse detritic rarely siliceous, enriched with carbonates
Atlantic	Warm,humid climate.Coniferous-broad-leaved and broad-leaved forests	High lake level.Running-water increase. Transition to eutrophic regime	Siliceous and fine detritus gyttja, rarely carbonate and mixed	Very warm and humid climate.Pine, pine-and-broad-leaved forests with birch and spruce, broad-leaved forests	Shallow lakefloods in ancient kettle-holes. Karst lakes of oligotrophic regime	Carbonate and enriched with carbonates, siliceous, detritic

1	2	3	4	5	6	7
Boreal and Prebo-real	Warm and dry climate, pine-birch forests with admixture of broad-lea-ved species	The end of thermokarst process. Pre-sent-day lake forma-tion with low level. Oligotrophic and mesotro-phic regime	Carbonate gyttja, si-licatic sediments, clayey silts en-riched with car-bonates	Warm, arid cli-mate. Mixed pine-and-birch forests with admixture of broad-leaved species. At the end of the pe-riod the humi-dity increases	The beginning of lake for-mation	Peat sedi-ments
Youn-ger Dryas	Subarctic climate. Woodland tundra com-munities	Lakes freeze for the most part of the year	Sand and carbonate sand	Climatic cool-ing	Large lakes do not exist	Alluvial and eluvial-de-luvial sedi-ments
Alle-röd	Climatic ame-lioration. Birch-pine-spruce fo-rests	Proglacial lakes are drained. Thermokarst. Young lakes of moraine uplands, shallow, oli-gotrophic	Carbonate clay, clay with orga-nic matter, peat	Remarkable amelioration of arid climate, pine forests with admixture of birches	Large lakes do not exist	Alluvial and eluvial-de-luvial sedi-ments
Older Dryas	Cold subarctic climate. Wood-land tundra communities	Proglacial wa-ter-basins di-minish in size. Lake basins on uplands are preserved by ice	Sand, clay	Cold, subarctic arid climate. Mixed pine-birch forests with patterns of woodland tundra		

ring the warm and humid climatic conditions(in the central part of Byelorussia) of the Holocene.

The basic conclusions drawn from the above are presented in the Table (pp. 197 - 198).

Byelorussian State University
named after V.I. Lenin

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УДК 551.481:551.794/476/

ПАЛЕОЛИМНОЛОГИЧЕСКИЕ ИЗМЕНЕНИЯ НА ТЕРРИТОРИИ БЕЛОРУССИИ В ПОЗДНЕЛЕДНИКОВЬЕ И ГОЛОЦЕНЕ

О.Ф. Якушко

Резюме

Рассмотрены этапы развития озер севера и юга Белоруссии в

разные этапы позднеледниковья и голоцена. На основании комплексного анализа озерных отложений установлены характер седиментации и возраст осадков на фоне общих природных закономерностей территории. Основные выводы в сжатой форме представлены в таблице.

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THE EVOLUTION OF MODERN LAKES IN SMOLENSK REGION

A. Kremen, E. Malyasova, V. Shkalikov

In order to compare the role and importance of natural and anthropogenic factors in the development of lake ecosystems and to evaluate the rate of eutrophication processes one should have complete knowledge both of the original state of basins before human impact and their development in time. For these purposes bottom sediments serve as an important source of information. We have investigated stratification of bottomset beds in the lakes Mutnoye, Kasplya, Zalubische, and in the mire Chistic located within the limits of the Valdai glaciation (Smolenskoye Poozerye). Analytical data on botanical composition of peat, granulometrical and geochemical evidence and pollen and spore diagrams for a number of mires, such as Gubinskoye, Vyalkovskoye and Barsuchky have been also used. The results of these complex investigations have been partly published. The present paper attempts to systematize the available palynological and other data for all the sections studied, and on this basis, to evaluate the evolution of modern lakes in Smolensk region, varying in topographic infancy.

At present in the area of Poozerye there exist nearly 90 glacial lakes (60% of all the lakes of the region) with the total area of about 60 km^2 (90% of the total area of the lakes). These lakes are characterized by different trophic state.

As compared with the Moscow glaciation region where lakes occupy 0.01-0.04% of the area, the lakes of Poozerye cover 0.4-1.0% of the territory. The peat-covered area is also larger: it makes up 5.3%, the average for the region being 2.7%. The thickness of lacustrine deposits ranges from 4 to 8 m, seldom more.

The development of Poozerye lakes is closely connected with the history of the Valdai glaciation in this territory.

From geomorphological point of view the Poozerye lakes are characterized by the occurrence of end moraines and abundant depressions which have promoted the accumulation of glacial meltwater in them. Due to the prevalence of hills the Valdai glaciation did not practically influence the change of the lakes in the Moscow glaciation region. The rivers had well-developed valleys which favoured the withdrawal of glacial meltwater. On the basis of the investigation of peat land with lake deposits (sapropel, silt, carbonate deposits) we can conclude that the territory of primary lakes in Poozerye made up 4% in the Holocene, and 1% in the Moscow glaciation region. Out of 23 types of mires which we have chosen in the north-west of the region, 14 mires were formed on the place of former lakes. These data agree with the results obtained for Byelorussia, the Baltic Republics and other neighbouring areas, where glacial lakes have often served as a "hotbed" of the peat land formation. (Конойко, 1970; Тамошайтис, 1970; Пиррус et al., 1975; Лесненко, Исаченков, 1983).

Relict lakes prevail in the Moscow glaciation region. At the same time 17 types of mires (out of 22) were formed in the place of former lakes. The majority of lakes is small, located in river valleys prevailingly. In the main, these are floodplain oxbow lakes and also small erosive basins adjacent to river valleys or river terraces. The lake basins were considerably deep, and recharged by ground-and flood waters. Lake deposits are represented by silt and sapropel with a high mineral content. The thickness of the deposits is about 6 metres. The valleys of the Sozh, Vikhra, Iput, Khmara, Voptza and other rivers are rich in former oxbow lakes with their deposits being represented mainly by calcareous gyttja. Underground water, formed in the bedrock from limestone, chalk or in Quaternary deposits rich in calcium, is of great importance in the recharge of these lakes.

On the whole, the lake deposits of the Moscow glaciation region are more mineralized. Calcareous sapropels, intensively deposited during the Atlantic period (Минкина, 1956; Салов, 1963) are more frequent.

The stratigraphic investigation of lake and lake-and-mire deposits permits us to determine the pecularities of their accumulation in the basins of the Moscow and Valdai glaciation regions.

The comparison of stratigraphic diagrams of bottomset beds in Poozerye, the northern part of Byelorussia and the Baltic Republics

shows the common trend of sediments genesis and its synchronity (Якушко, 1971; Бартош, 1963; Гарункштис, 1970; Лыокене, 1983). The Poozerye lakes have typical pollen and spore spectra.

The infilling of Poozerye lakes basins with deposits started in the late-glacial period in the Bölling interstadial (Гричук , 1961), and Alleröd (Кремень, Малясова, 1968). These deposits are a characteristic feature of primary oligotrophic basins. At the early stages of evolution (Bölling, Alleröd) clayey gyttja, sandy and argillo-silty deposits accumulated in the lakes. Alleröd deposits (Lake Mutnoye) are represented by black silicic gyttja interstratified by slightly decomposed peat.

At the beginning of the Holocene (Preboreal and Boreal times), with the gradual rise in temperature and prevalence of oligotrophic and mesotrophic regimes, silicic silt enriched by calcareous material and lakemarl with CaO making up 42% (Кремень, 1970) was deposited in the lakes.

The warm and humid climate of the Atlantic period promoted the deposition of the silicic gyttja with a higher organic content in the basins. Under the conditions of increasing humidity, at the eluvium acid stage there begins the intensive iron migration and its intense inflow into the basins. The content of Fe in Atlantic deposits reaches its peak - 14% Fe_2O_3. During that period the thickest layer of deposits accumulated (Грибовская et al., 1971).

During the Subboreal period with its relatively dry climate the process of natural eutrophication of lakes, which had begun in the Atlantic period, was in progress resulting in the accumulation of organic matter in deposits. During the period the content of CaO, MgO, Al_2O_3 and especially that of Fe_2O_3 reduced. Si, Fe and Ca served as prevalent elements. Organic matter content in Subboreal deposits reached its maximum.

During the Subatlantic period, characterized by certain fall in temperature and the rise in humidity the lake eutrophication process continued leading to further deposition of organic matter (organomineral and organic sapropels). The deposits of the period were characterized both by the reduction of SiO_2, Fe_2O_3 and Al_2O_3 contents and increase in CaO and MgO contents.

The earliest deposition in the basins of the Moscow glaciation region started in the Alleröd.

The intensity of the genesis of lake sediments varied in time. By calculations, the absolute age of the limits of climatic periods was taken according to Khotinsky (Хотинский, 1977). The average standards of deposition for different Holocene periods range from 0.7 to 1.2 mm per year (Table 1). These estimates are close to the average accumulation rate of organogenous and organomineral deposits in the lakes of Byelorussia and the Baltic Republics (Якушко, Власов, 1981; Пиррус, 1975;Яковлева, 1981).

In general, the sedimentation standards for lacustrine silt of Poozerye correspond to the Holocene climatic change. Thus, the accumulation of organic matter increases from the Preboreal and Boreal periods (Lake Mutnoye, 25-30%) to the Atlantic period, when it reaches its maximum: 75-97% (Lakes Kasplya, Zalubishche, mire Chistic. By the end of the Middle and in the Late Holocene the sedimentation rate has somewhat reduced making up 40-74% (Lakes Mutnoye, Kasplya, Zalubishche). In the mire Chistic the prevalence of organic sedimentation is obvious (92-97.5%) and mineral deposition insignificant during the Holocene. The most intensive sedimentation (1.2 mm annually) in Lake Mutnoye is connected with the lakemarl accumulation during the Preboreal (Table 1).

The process of sedimentation in the lakes, many of which turned into swamps comparatively quickly, is also worth of studying. The deposits of the mire Chistic in the marginal zone of the Valdai glacier were analysed for these purposes. The mire covers an area of 784 ha, the average depth of the peat deposit is 4.1 m. The sequence in the south-east of the peat deposit reveals: 4.15-4.20 m - sands, 3.95-4 m sapropel, higher - peat.

The pollen and spore diagram for this sequence is typical of the region. The base of the sequence is formed by sands, sandy sapropels, dated as Alleröd. The sapropel shows that the lacustrine regime existed at the beginning of Younger Dryas. In the second half of the Late Dryas the lake was overgrown with grass and it turned into a fen. At the end of the Boreal (3.25 m) eutrophic alimentation was alternated by the mixed one. In the Atlantic period the accumulation of the

Table 1

SEDIMENTATION RATES IN THE LAKES AND MIRES OF SMOLENSK REGION

Region	Lakes, mires	Periods	Absolute age (in years)	Duration (in years)	Thickness of deposits, cm	Sedimentation rate
1	2	3	4	5	6	7
		SA		2500	150	0.06
		SB	2500			
			5000	2500	165	0.066
	Lake	AT		3000	330	0.11
	Mutnoye		8000			
	(centre)	BO		1600	30	0.018
			9600			
		PB		700	80	0.12
		DR 3	10300		10	
		AL	11000	1000	20	0.02
		SA		2500	40	0.016
		SB	2500			
	Lake		5000	2500	210	0.084
	Kasplya	AT		3000	140	0.046
	(centre)		8000			
		BO		1600	70	0.043
			9600			
		SA		2500		
	Lake	SB	2500		85	0.017
	Zalubi-		5000	2500		
	shche	AT		3000	180	0.06
	(centre)		8000			

1	2	3	4	5	6	7
	Mire	SA		2500	105	0.042
	Chistic	SB				
	(South-		5000	2500	75	0.033
	west	AT		3000	155	0.051
	peri-		8000			
	phery)	BO		1600	20	0.0125
			9600			
		PB		700	30	0.71
		DR 3	10300		20	
		AL	11000	1000	15	0.01
		SA		2500	50	0.02
	Mire	SB	2500 5000	2500		0.02
	Gubin- skoye	AT		3000	100	0.02
	(centre)		8000			
		BO		1600	100	
			2600			0.05
		PB		700		
	Mire	SA		2500	100	0.04
	Barsuchky	SB	2500			
	(centre)		5000	2500	2.75	0.05
		AT		3000		0.05
			8000			
		SA		2500	75	0.03
	Mire	SB	2500			
	Vyakov-		5000	2500	225	0.04
	skoye	AT		3000		
	(centre)		8000			
		BO		1600	100	0.051
			9600			
		PB		700		
		DR 3	10300		25	0.019
		AL	11000	1000		

peat of intermediate type, characterized by a low ash content and a comparatively low decomposition degree (24-34%), was in progress. In the middle of the Atlantic (2.5 m) the bog passed over into the upper stage with the oligotrophic regime.

In the Subboreal period the accumulation of peat (Sphagnum magellanicum) characterized by a low ash content (1.4-1.6%) and a low decomposition degree continued.

The Late Holocene (the Subatlantic period) is characterized by a one-meter-thick peat layer with an exceptionally low decomposition degree and, due to the anthropogenic factor, a higher ash content in the upper layers (2.5-3.8%).

Several lakes, which formed and exist under geological and geomorphological conditions close to those of the mire Chistic, are likely to have undergone analogical development. In the middle of the Subatlantic period the human impact appeared. At present its effect has drastically grown.

The analyzed deposits and pollen and spore diagrams for the mire Vyaltzevskoye, Barsuchky, Gubinskoye of the Moscow glaciation region, which developed on the place of the lake basins of short duration show that in the Poozerye region the deposition proceeded at a similar rate.

Thus, one can conclude that the complex approach to the investigation of bottomset beds from the comparative historical point of view permits us to find out the main trends of lakes evolution and changes in the character of deposition resulting from alterating natural and anthropological factors.

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УДК 551.8+551.481.1/474.3/

ЭВОЛЮЦИЯ СОВРЕМЕННЫХ ОЗЕР СМОЛЕНСКОЙ ОБЛАСТИ

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Резюме

Даются результаты исследования разрезов донных отложений ряда озер и болот /возникших на месте существовавших озерных водоемов/ Смоленской области /зона московского и валдайского оледенений/. Освещается история развития озер в голоцене. Уделяется внимание изменениям в характере осадконакопления под влиянием антропогенного фактора.

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УДК 55I.8:556.55

II том из трехтомного сборника содержит материалы по озерам Северо-Запада Советского Союза, которые были получены по проекту № I58 Международной программы геологической корреляции. Рассматриваются методические проблемы изучения озерных отложений, эволюцию озерного осадконакопления, колебание уровня воды и вопросы палеолимнологии и палеоэкологии.

Академия наук Эстонской ССР. Институт геологии. ПАЛЕОГИДРОЛОГИЯ УМЕРЕННОЙ ЗОНЫ. Том II. Озера. На английском языке, с резюме на русском языке. Под редакцией А.В.Раукаса и Л.А.Саарсе. Художник-оформитель Х.Пузанов. Таллин, "Валгус".
Toimetaja U.Alas. Kunstiline toimetaja M. Henno. Trükkida antud 13.04.87. MB-04275. Formaat 60x84/16. Trükipaber nr. 1. Masinakiri. Ofsettrükk. Tingtrükipoognaid 12,32. Tingvärvitõmmiseid 12,56. Arvestuspoognaid 12,27. Trükiarv 500. Tellimuse nr.2543 Hind rbl.1.90. Tellitud. Kirjastus "Valgus", 200090 Tallinn, Pärnu mnt.10. Trükikoda "Pärnutrükk", 203600 Pärnu, Ringi t. 1.