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LATE PLEISTOCENE AND HOLOCENE HISTORY OF THE LAKES IN THE KOLA PENINSULA, KARELIA AND THE NORTH-WESTERN PART OF THE EAST EUROPEAN PLAIN

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Abstract — The paper reviews the work on paleolimnology in parts of the FSU over the last 40 years. It presents a short review of *The History of the Lakes of the East European Plain*, one of the books of the series *The History of Lakes* published by the Institute of Lake Research of the Russian Academy of Sciences. It describes the Late Pleistocene and Holocene history of these lakes based mainly on the study of lacustrine sediments. Amongst the samples Lake Nero near Moscow which is located near the marginal zone of the last glaciation, and includes records that go back as early as 190,000 BP. The main elements of lake evolution are shown in different territories: Byelorussia; Baltic countries; Karelia; and the Kola Peninsula. Special attention is given to palaeolimnological data because its use for Holocene and Late Pleistocene palaeoclimate reconstructions. Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

In 1965 a Russian palaeolimnologist D. D. Kvasov and a group of his colleagues from the Institute for Lake Research held the First Symposium on Lake History in Leningrad. It was attended by more than a hundred palaeolimnologists from different scientific centres of the former Soviet Union and all papers presented were subsequently published (Kvasov, 1967). Symposia on lake history were then held in Minsk, Vilnius, Pietrozavodsk, Tallinn and Leningrad until 1989 and papers from these meetings were published (Kalechitz, 1967; Kvasov and Martinson, 1975; Basalikas, 1970; Martinson, 1975. Kvasov and Jakushko, 1975. Biske, 1977; Raukas and Saarse, 1983; Davydova *et al.*, 1986; Lishtvan, 1989). All of these, and associated meetings gave attention to the lacustrine sediments as a source of information for reconstructing global climatic change, temperature and humidity, time and characteristics of deglaciation and isostatic uplift rates. Close collaboration was maintained between palaeolimnologists of the Institute for Lake Research and limnologists studying contemporary lake processes in order to take into account lacustrine trophic state changes, influence of landscape modifications on lake ecosystems and the role of natural and anthropogenic factors on lake evolution. Special attention has been given to pollen and diatom analyses, radiocarbon dates and palaeomagnetic studies.

In 1985, D. D. Kvasov suggested that all the data should be published in a special series entitled "History of lakes of USSR" printed by the Academy of Sciences under the responsibility of an editorial council composed of leading specialists on palaeolimnology: Drs Kvasov, Martinson and Davydova from the Lake Research Institute, Dr Raukas from the Geological Institute of Estonia, Prof. Kabailene from Vilnius State University, Lithuania and Prof. Jakushko from the Byelorussian State University.

The first volume of this series was published by Kvasov in 1986. It contained the main ideas on the origin and evolution of the lakes, a review of publications on lake history previously published in Russia and the Baltic countries from the beginning of the 19th Century to 1986 and a detailed description of the full scope of methods used in the research: geology; geomorphology; shoreline variations; sampling techniques; mineralogy; and different methods for studying botanical and zoological remains; human impact on lakes and watersheds was also described in detail.

The second and third volumes were focused on the history of the basins during the Palaeozoic, Mesozoic, Paleogene and Neogene (geology and paleontology; Martinson and Neustrueva, 1987; Martinson, 1988). The next two volumes contain data on the history of the largest lakes of the humid (Kvasov, 1990) and arid/semiarid zones (Sevastyanov, 1991). In 1992, a book was published by the Institute for Lake Research of the Russian Academy of Sciences in St Petersburg which brought together all the data on the lake history of the European part of the former Soviet Union (Davydova, 1992). This paper is designed to provide to non-Russian Quaternary scientists a synthesis of the vast body of data obtained over the last 25 years, by several teams working in different regions of Russia, the Baltic countries and Byelorussia. For each country, we have chosen those lakes which had been most fully investigated for palynology, diatoms, sedimentology and radiocarbon dates.

METHODS AND SITES STUDIED

The same methods (Kvasov, 1986) for taking samples from the cores were used by the different teams (Kabailene, 1987): the uppermost 30–50 cm of sediment were divided into 1 cm subsamples for studying human impact. Below 50 cm, subsamples were taken every 5–10 cm, in the muddy sediments and every 5–10 (or even 20 cm) in sands or clays without any gaps in order to avoid missing changes in lake ecosystems and vegetation on the watershed. All samples were analysed for palynology and diatoms and subsamples for chemical and grain size determination were chosen according to lithological changes.

Treatment for pollen studies follow standard procedures. 800–1000 pollen grains were identified and the frequency of pollen grains per gram of sediment was calculated. For diatom studies (Davydova, 1985), dry subsamples were weighed for further calculations of diatom abundance. Samples were boiled with hydrogen peroxide, then washed in distilled water. One or several drops of suspension were then put on the cover glass. Hyrax was used as the mounting medium. On every slide, 500–1000 diatom frustules were identified on a known number of fields in order to calculate the diatom concentration per gram of original sediment. We assumed that dominant species represent more than 10% of the total flora, sub-dominants between 5 and 10%. We separate ecological groupings according to their affinities to salinity, water Ph, trophic status, habitats (planktonic, benthic etc...); we also used the geographical distribution of the species. Most are cosmopolitan, living from polar tundra to the tropics, but some are boreal (inhabiting in fresh waters of temperate zones) and some are northern-alpine (living in northern freshwater lakes and/or in oligotrophic lakes of mountainous zones).

For each country, we have chosen the lakes where pollen, diatoms, sedimentology and radiocarbon dates were fully investigated. The description covers the region from N-W to S-E of Eastern Europe (Fig. 1) in accordance with the main events of deglaciation history which began 16 ka BP in the S-E and ca. 9 ka BP in the N-W part.

RESULTS

The Kola Peninsula (Kagan *et al.*, 1992) and Karelia are situated at the marginal zone of the ancient Baltic Shield. There are more than 107,000 lakes in the Kola Peninsula and 62,000 in Karelia. The largest ones are mainly oligotrophic and the small ones are dystrophic.

Kola Peninsula and Bolshezemelskaya Tundra North to the Polar Circle

Kola Peninsula (Kagan *et al.*, 1992). All the lakes are considered to have a tectonic origin and were transformed by the glacial erosion. Five lakes investigated in this region indicate that sedimentation began as early as Boreal time.

Lake Imandra (67°30'N, 33°00'E, area 880 km^2) is one of the largest lakes of the Kola Peninsula.

Lake Kovdor (66°30'N, 33°00'E, area 0.72 km^2) has a maximum depth 25.2 m. Its depression is partly filled with glaciofluvial deposits. Radiocarbon dates from lakes Kovdor (Fig. 1, No. 2) and Imandra indicate that lacustrine sedimentation began about 9000 ^{14}C years BP (Boreal time according to pollen chronostratigraphy).

The diatom diagram of Lake Kovdor presented in Fig. 2 is derived from a core 200 cm length. The main features of evolution of Kola Peninsula lakes are closely connected with climate and vegetation changes and may be presented briefly.

(1) The Boreal period (BO) is characterized by pine and birch forests with many low shrubs. The lakes were shallow and oligotrophic with northern-alpine diatoms (*Aulacoseira alpigena, Tabellaria flocculosa, Anomoeoneis brachysira*).
(2) During the Atlantic climatic optimum (AT; 8000–5000 ^{14}C years BP), pine forests developed. The lake level increased and some planktonic alkaliphilous diatoms appeared (*Aulacoseira subarctica*).
(3) During the Sub-Boreal (SB) period (5000–3000 ^{14}C years BP) the pine forests were replaced by birch forests. When the climate became colder and dryer, the lakes became shallow with acidophilous diatoms, some of which were dystrophied.

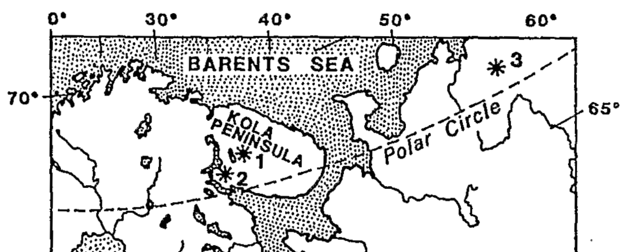

FIG. 1. Location of lakes studied in the East Europe: 1, Imandra; 2, Kovdor; 3, Mitrophan; 4, Vishnevskoye; 5, Ilmen; 6, Valday; 7, Naroch; 8, Oltush; 9, Nero.

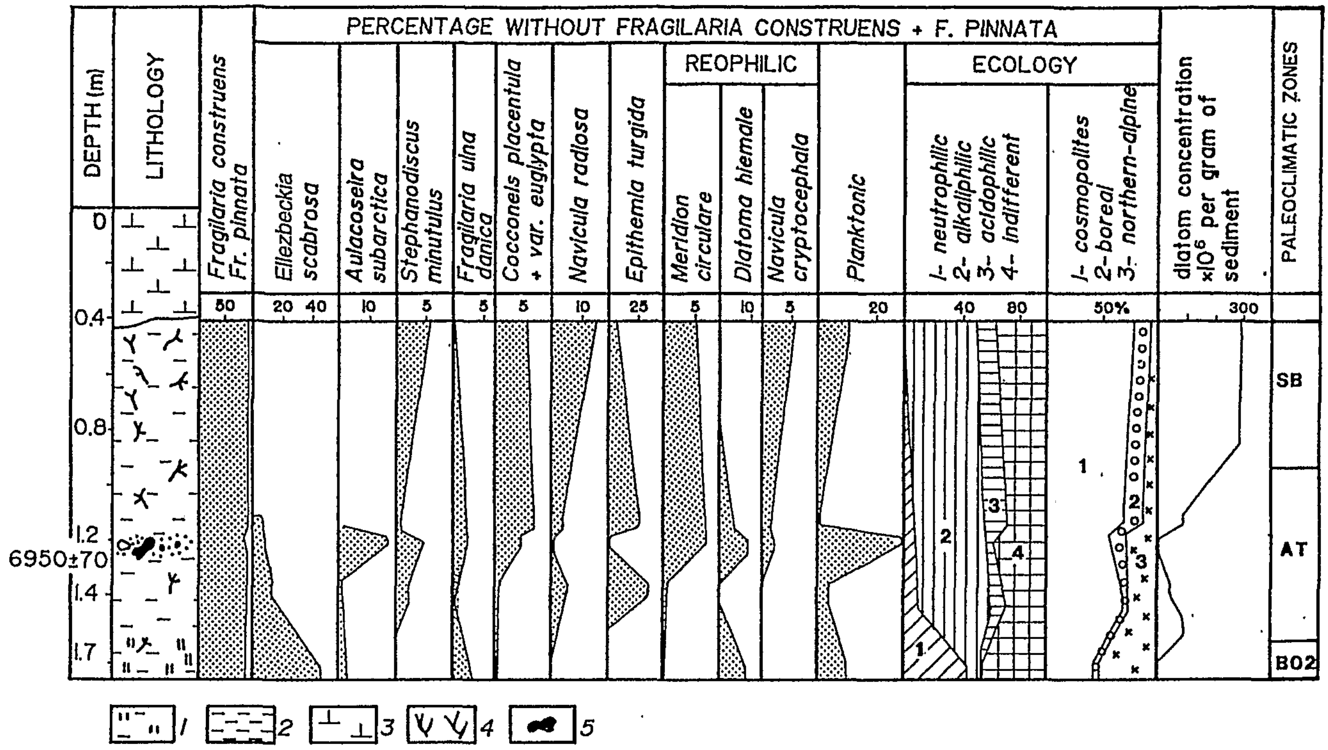

FIG. 2. Lake Kovdor (Kola Peninsula). Diatoms (Kagan *et al.*, 1992). 1, gyttia; 2, diatomite; 3, peat; 4, plant remains; 5, wood.

(4) During the Sub-Atlantic (SA), birch was replaced by tundra vegetation. The cold and humid climate of the last 2500 ^{14}C years BP resulted to the extension of tundra vegetation with shrub forms of birch and willow and northern-alpine diatoms. The frequency of acidophilous diatoms (*Tabellaria flocculosa*) increases in the uppermost sediment.

(5) During the second half of the 20th Century, the dystrophic process was accelerated by human impact as a consequence of building the metal smelting factory in the NW part of the region.

The north-eastern part of Europe, Bolshezemelskaya Tundra (Davydova *et al.*, 1992, 1994) lies adjacent to the Polar Circle. Here *Lake Mitrophan* (Fig. 1, No. 3) of the Pechora river basin has been studied (67°50'N, 59°00'E, 116.8 m a.s.l.). A core of 3.6 m length was obtained from a water depth of 5 m although the maximum depth of the lake is 20 m.

(1) Lake sedimentation started in this lake ca. 9000 ^{14}C years BP as a result of melting permafrost (Fig. 3). According to the pollen data (Fig. 4), pine and birch forests with many shrubs occupied the watershed, non arboreal pollen ratio reached 40–60%. The lake was deep, cold and oligotrophic, dominated by planktonic *Stephanodiscus rotula* and littoral *Fragilaria construens* var. *venter* and *Gyrosigma attenuatum* (Fig. 5).

(2) Sapropel sedimentation is recorded at the beginning of the climatic optimum. At this time, organic matter content was high (45–55% L.O.I.). Birch and spruce forests dominated the woodland vegetation. Diatom concentrations were high and planktonic diatoms (*Aulacoseira granulata, A. islandica*) indicate high water level. The middle of the climatic optimum was characterized by drier conditions with the development of pine forests together with spruce and birch and highest concentrations of diatoms. The diatom communities include both planktonic and benthic species (*Aulacoseira granulata, A. islandica, Fragilaria brevistriata, F. heidenii*). The lake was eutrophic. At the end of the climatic optimum, the vegetation is dominated by birch forests with an admixture of spruce, and the lake remained eutrophic (*Cyclostephanos dubius*).

(3) The coolness and dryness of the climate which started ca. 5000 ^{14}C BP (Sub-Boreal time) led to a decrease in forest vegetation and an increase in the relative importance of pine. Organic matter content diminished to 10–15% L.O.I., the frequency of planktonic *Aulacoseira islandica* and *A. granulata* decreased rapidly at the beginning and at the end of this period, and the northern alpine *Aulacoseira alpigena* became one of the dominant species.

(4) Further change to a cold and humid environment in the Sub-Atlantic caused the extension of tundra vegetation, *Betula nana* expanded along with *Artemisia* and *Chenopodiaceae* species. *Pinus* survived along the rivers. Organic matter content was the lowest (<5% L.O.I). The cooling started at about 2000 ^{14}C years BP and was characterized by a very low diatom content.

Karelia

Karelia is the easternmost area of the Fennoscandian crystalline shield (Ekman, 1992). Lakes cover more than

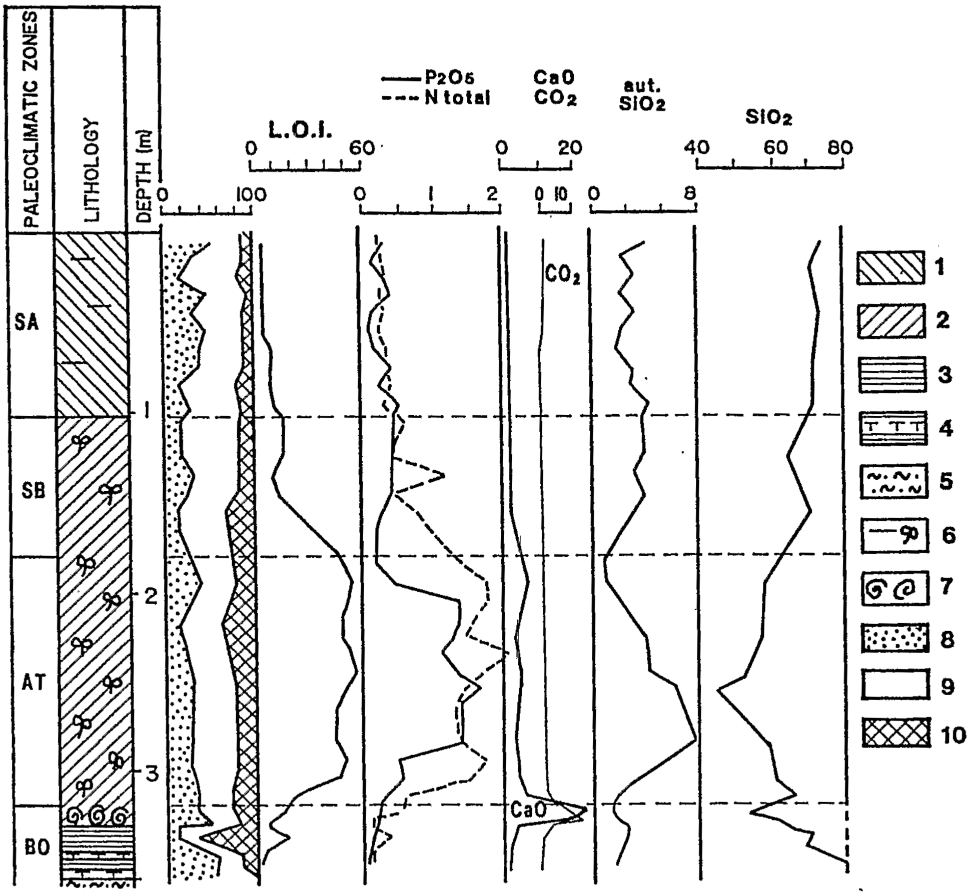

FIG. 3. Lake Mitrophan (NE of the East European Plain). Granulometry and chemical data (in percentage; adapted from D. Subetto in Davydova *et al.*, 1992). 1, greenish mud; 2, brownish mud; 3, grey clay; 4, peat with clay; 5, clay with sand; 6, plant remains; 7, mollusk shells; 8, sand; 9, silt; 10, lutite.

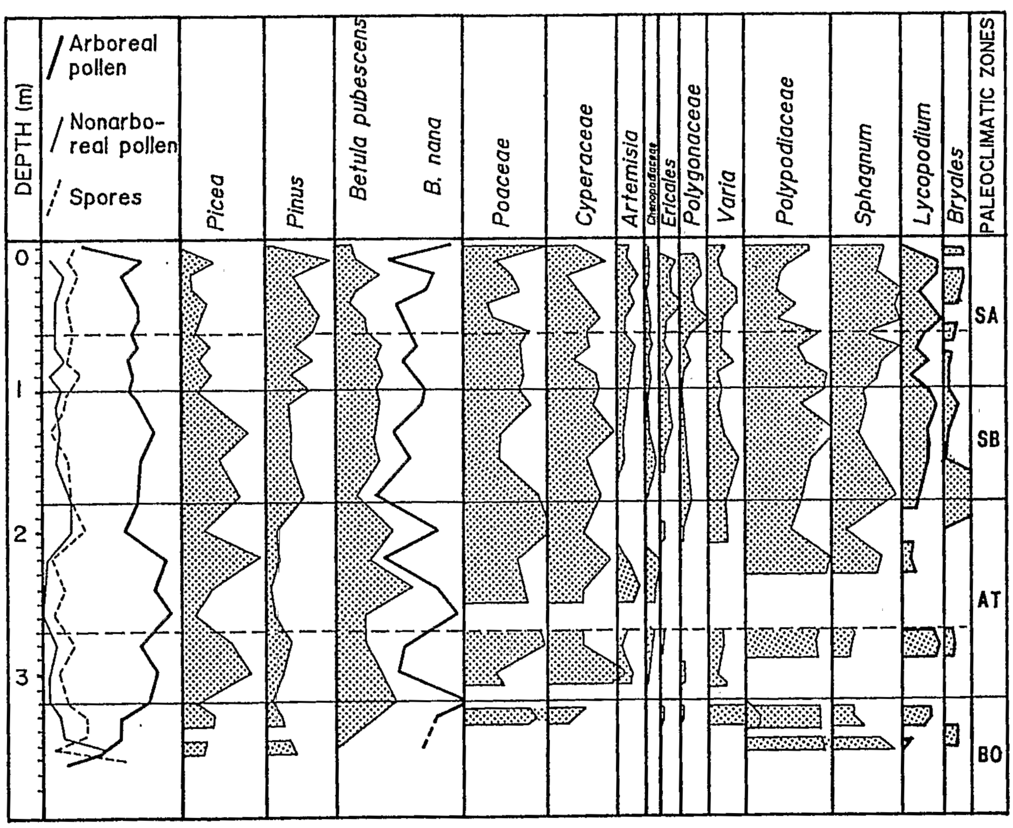

FIG. 4. Lake Mitrophan, Pollen diagram (adapted from I. Delusina in Davydova *et al.*, 1992).

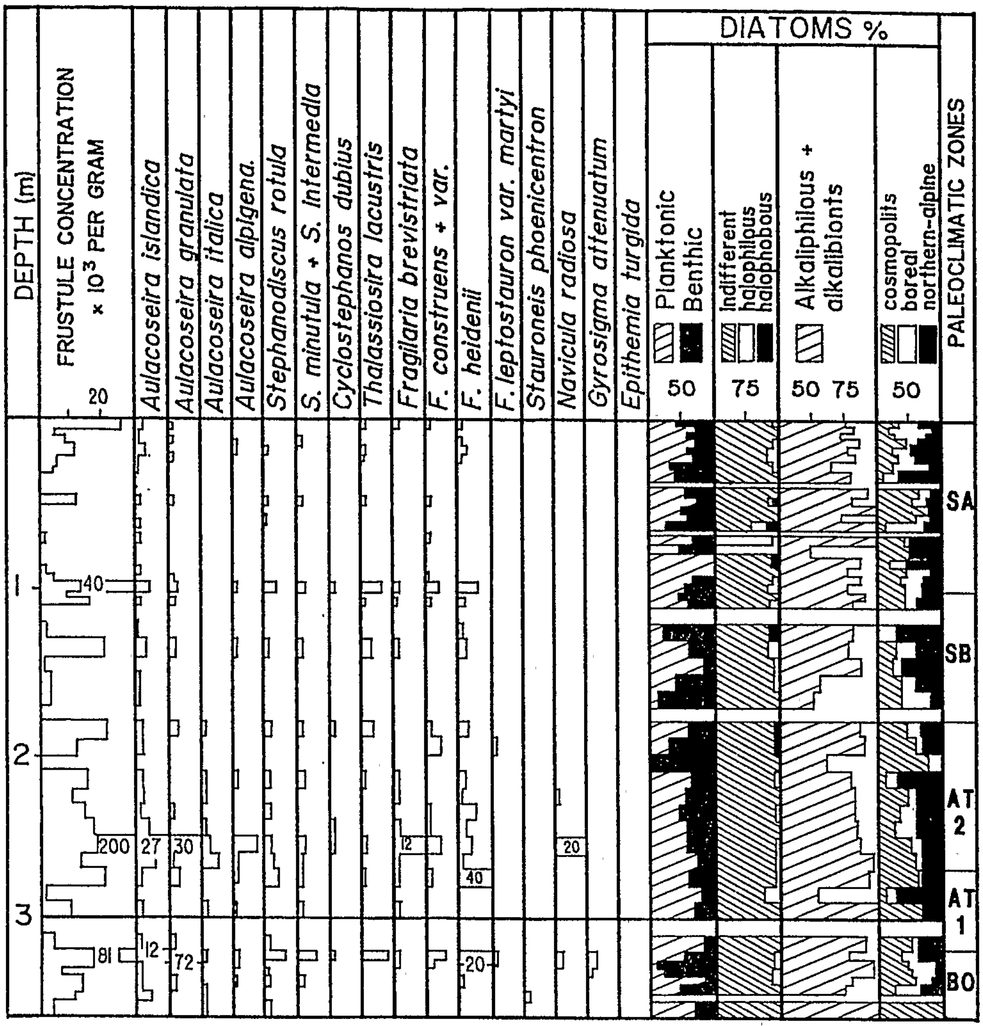

FIG. 5. Lake Mitrophan, Diatoms (Davydova *et al.*, 1992).

19% of Karelian territory. Several cores have been made from these lakes by Quaternary geologists of the Geological Institute of Karelia, and there are nearly a hundred radiocarbon dates of the lowest parts of the lacustrine sediments (Ekman *et al.*, 1988). Using this information it has been possible to date the formation of the lakes (Fig. 6). The earliest, excluding the greatest ones Lakes Ladoga and Onega, — originated at the south-eastern part of the region about ca. 12,000 ^{14}C years BP, following deglaciation.

In Central Karelia, many lakes originated during the Alleröd chronozone (11,800–11,200 ^{14}C years BP). However, climatic coolness and dryness stopped burried ice melting. Melting process was re-established and lakes developed again between 10,800 and 10,400 ^{14}C years BP. During the Pre-Boreal and the beginning of Boreal (10,200–9200 ^{14}C years BP), many small basins were formed as a result of final melt of dead-ice and permafrost. At the time of the climatic optimum (8000–5000 ^{14}C years BP), large peat bogs began to form and extend across the small lakes.

On the Karelian Isthmus (Arslanov *et al.*, 1992b) between the Baltic sea and Lake Ladoga, there are nearly 700 lakes. Many have been studied in order to investigate the drainage of the area between the Baltic and Ladoga depressions, following deglaciation. The highly eutrophic *Lake Vishnewskoye* (60°30'N, 29°30'E) 29°31'E, area 10.5 km², maximum depth 3 m,

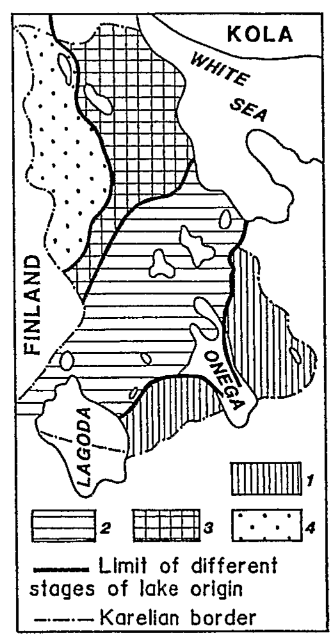

FIG. 6. The time of formation of Karelian lakes (Ekman, 1992). 1, <11,800 ^{14}C years BP; 2, from 11,800 to 11,200 ^{14}C years BP; 3, from 10,800 to 10,400 BP; 4, from 10,200 to 9200 ^{14}C years BP.

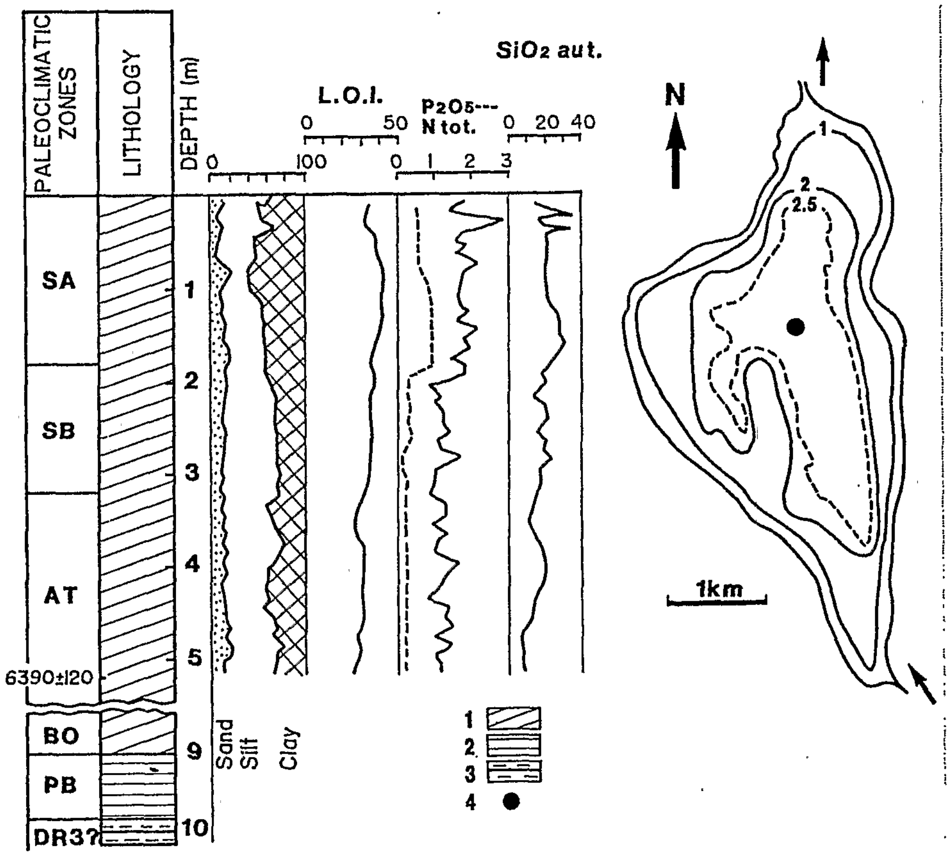

FIG. 7. Lake Vishnevskoye (Karelian Isthmus). Bathymetry and location of the core. Granulometry and chemical data in percentage (adapted from D. Subetto in Arslanov *et al.*, 1992). 1, mud; 2, clay; 3, varved clay; 4, location of the core.

altitude 15 m a.s.l.), is described here (Fig. 1, No. 4). This lake is located in the lowermost part of the Karelian Isthmus. A sediment core of 985 cm was obtained from a water depth of 2 m (Fig. 7). Radiocarbon dates on sediments at a depth of 500 cm showed an age of 6390±120 ^{14}C years BP (LU-917).

(1) Lacustrine sedimentation started in Younger Dryas time (DR3) when the Northern Karelian Isthmus Lowland was submerged beneath the "Baltic Glacial Lake". Freshwater oligotrophic planktonic diatoms (*Aulacoseira islandica, Cyclotella radiosa*) mixed with a few eutrophic diatoms (*Aulacoseira granulata, A. ambigua, Cyclostephanos dubius*) were found in the varved clays of this basin (Fig. 8).

(2) After the regression of the Baltic Glacial Lake in the Pre-Boreal, the territory around the lake was invaded by birch forest.

(3) Improvement of the climate of the Boreal led to the extension and dominance of pine forests. This coincided with the existence of the Ancylus Lake which spread over the Baltic and Ladoga depressions and covered the lowest parts of the Karelian Isthmus. After the regression of the Ancylus Lake, the Vishnevskoye Lake again became isolated.

(4) During the Atlantic climatic optimum, the surrounding territories were covered with mixed forests of birch, alder, pine, spruce, lime, oak and hazel trees. The lake became eutrophic, diatom concentration was low and planktonic alkaliphilous diatoms were dominant (*Aulacoseira ambigua, A. granulata, Cyclostephanos dubius*). This time the lake was separated from the Baltic Littorina Sea and progressively became more shallow.

(5) The coolness and dryness of the Sub-Boreal climate caused the dominance of spruce and pine with a decrease of broad-leaved trees (oak, lime, hazel) and the increase of littoral diatoms such as *Fragilaria leptostauron* var. *martyi*. The next phase of lake evolution was due to the Ladoga transgression, caused by isostatic uplift of the Baltic Shield. At this time the lake depression was nearly filled with sediments, which is the reason why the increase of water depth is not accompanied by a marked increase of planktonic diatoms. Eutrophic conditions continued to increase in the lake. Organic matter content in sediments was high (24.4% to 31.7% L.O.I). Sub-Boreal cold climate caused only the decrease of the amount of alkaliphilous diatoms.

(6) The next step in lake evolution is connected with the improvement of climate at about 2500 ^{14}C years BP at the beginning of Sub-Atlantic, when pine and birch forests spread in the watershed. Organic content reached its maximum (41.7% L.O.I.) along with phosphorous, nitrogen, silica and diatom concentration. The lake was isolated from the Ladoga system and water depth was not greater than 5–6 m. The lake became highly eutrophied. Planktonic alkaliphilous diatoms (*Aulacoseira ambigua, A. granulata*) were dominant.

(7) As a result of the decrease of the Lake Ladoga level the lake became close to its modern shape and size. The climatic deterioration of the Little Ice Age,

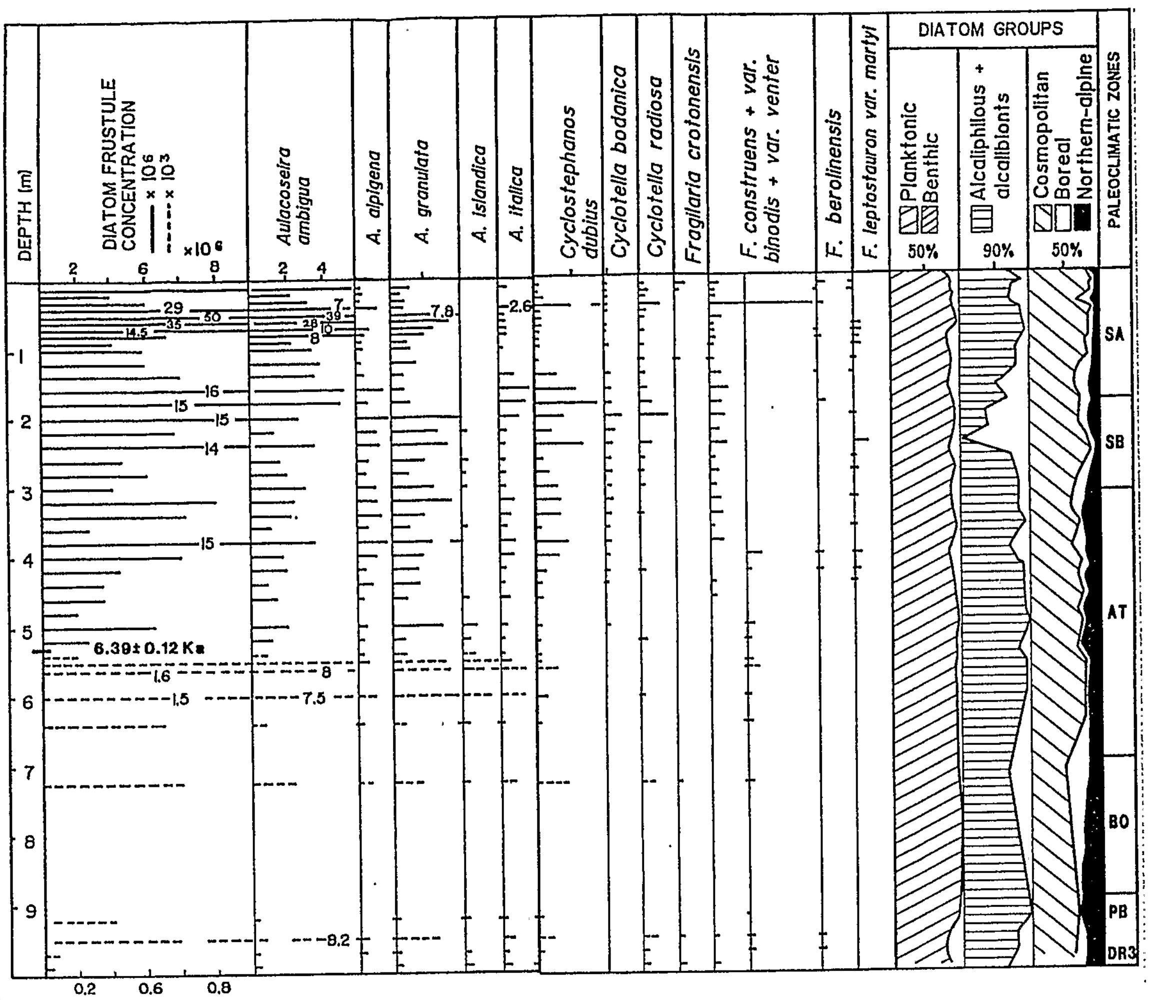

FIG. 8. Lake Vishnevskoye. Diatoms (adapted from N. N. Davydova in Arslanov *et al.*, 1992b).

stimulated the development of some littoral diatoms (*Fragilaria* spp.) and caused the increase of sediment influx, but these changes were minimal.

(8) The uppermost layers of lacustrine mud shows evidence for human impact. At the middle of the 20th Century the lake became polluted by the nutrient enrichment following the establishment of a cattle farm on its shore. *Fragilaria berolinensis* appeared in its phytoplankton and surface sediments.

South from the Karelian Isthmus, *Lake Ilmen* (Davydova *et al.*, 1992) is located 400 km south from Lake Vishnevskoye (59°15'N, 33°06'E); altitude 18 m a.s.l.; area 1200 km^2, maximum depth 4.5 m). It is one of the largest shallow eutrophic lakes of the East European Plain. At present, the lake collects the river waters of a large territory and drains to Lake Ladoga via the Volkhow river. Its catchment area is 67,200 km^2 and occupies the lowland region underlain by glaciofluvial and glaciolacustrine deposits up to altitude of 10 to 100 m. Bedrock is Devonian limestone. Initially, the lake formed marginally, and it contains substantial thickness of laminated clays (Fig. 9). Cores indicate that the thickness of postglacial lake sediments is not more than ca. 6–7 m. The sediment core used for the paleoenvironmental analyses was obtained at a water depth 5 m from the central part of the lake, in the zone of lacustrine mud sedimentation. Sands replace muds in the near-shore part

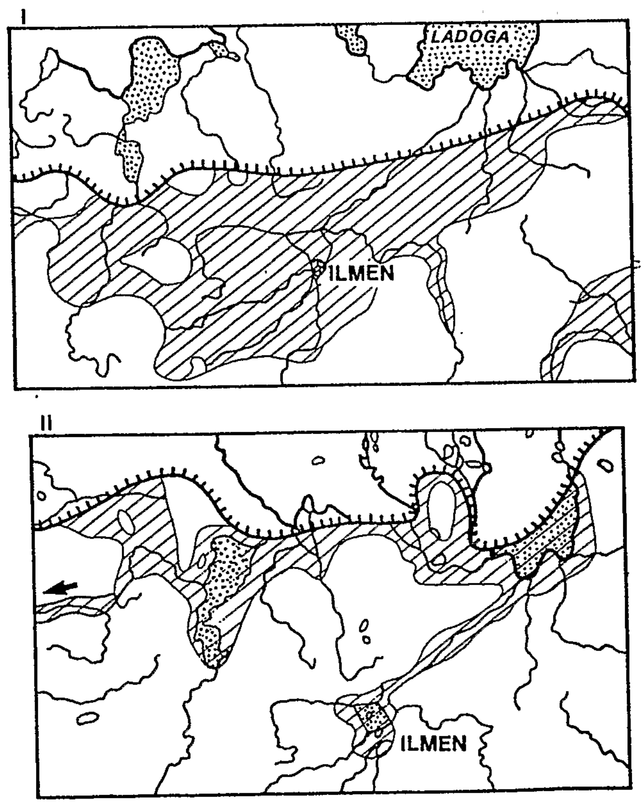

FIG. 9. Valday Ice Margin Lake of the East European Plain (adapted from Kvasov, 1975). I, 13,000 BP; II, 12,000 BP.

of the lake. The core was 656 cm length and contained greyish-brown silty mud (0–482 cm) and brownish homogeneous clay (482–656 cm). Geochronological division was made on the palynological and chemical data.

(1) In Younger Dryas time (DR3) homogeneous clays (Fig. 10) occupied the lowest part of the core where there was 80% non arboreal pollen, mainly *Betula* sect. Fruticosae and *B. nana* (to 38%), *Artemisia* spp. (to 28%) and Chenopodiaceae (to 41%). The diatom content is low (29×10^3 per gram) and planktonic diatoms predominate (*Aulacoseira granulata, Thalassiosira lacustris, Stephanodiscus minutulus*). Birch shrubs were prevalent along the shores. Organic matter content is not more than 5%. The lake was meso-oligotrophic.

(2) The sediments of Preboreal time (480–560 cm) contain arboreal pollen-pine (10–38%), birch (12–40%) and alder (12–38%), non arboreal pollen decreases. The organic matter content is still low (L.O.I. not more than 5%). During the Preboreal the littoral diatoms (*Fragilaria brevistriata, F. heidenii*) become more numerous (to 50%). But the diatom concentration was still low (10×10^3 per gram).

(3) Improvement of climate in the Holocene caused the appearance of shallow water diatoms (*Fragilaria brevistriata, F. heidenii*) and macrophyte communities. The basal boundary of the Boreal (380–480 cm) is extremely clear because of the disappearance of herbs and bushes from pollen spectra, and the dominance of pine pollen (64%). At the end of Boreal, spruce pollen (ca. 38%) and the organic matter content increased (L.O.I. ca. 4%). The character of sedimentation changes from homogeneous clays to mud. The diatom concentration increased to 100×10^3 per gram. The dominance of planktonic *Aulacoseira granulata* and littoral *Fragilaria* show that the lake was mesotrophic with macrophytes occupying shallow nearshore waters.

(4) At the beginning of the climatic optimum (AT; 260–380 cm) broad-leaved woodland including lime, elm and oak appeared (22–25%), organic matter content increased (~10%) and planktonic mesotrophic diatoms became dominant (*Aulacoseira granulata, A. ambigua, Stephanodiscus rotula, Fragilaria crotonensis, F. capucina, Asterionella formosa*). Diatom concentration was especially high at the beginning of the Atlantic (200×10^3). The lake ecosystem was in a

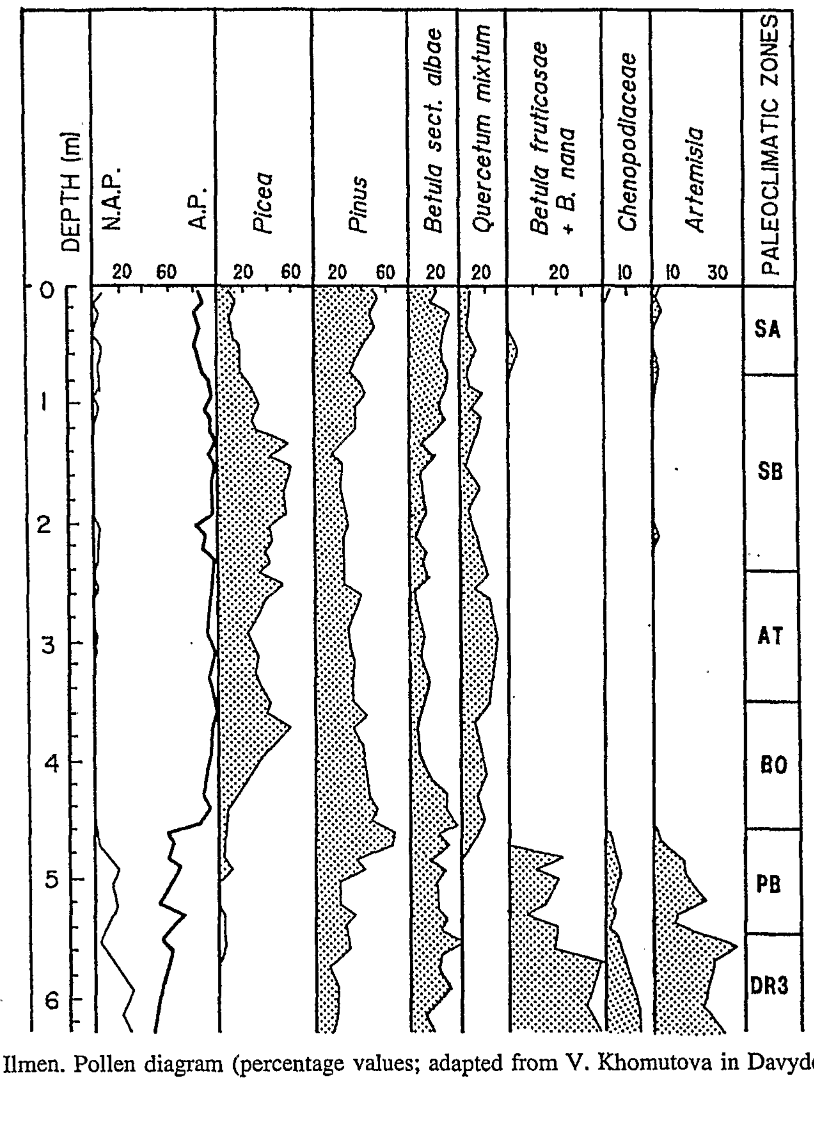

FIG. 10. Lake Ilmen. Pollen diagram (percentage values; adapted from V. Khomutova in Davydova *et al.*, 1992).

highly productive eutrophic state. The lake level was also rather high.

(5) The cooling of climate (SB) caused the replacement of broad-leaved forests by spruce (30–58%) and pine (10–22%) forests. The lake became shallow and mesotrophic and *Aulacoseira granulata* and *A. islandica* diatoms prevailed.

(6) The humidity of the Sub-Atlantic (SA; 0–120 cm) caused an increase of pine (*Pinus* pollen is 28–50%) and birch (*Betula* 14–32%) forests and a simultaneous decrease of spruce (*Picea* 10–32%). This period was characterized by a dominance of northern-alpine planktonic diatoms (*Aulacoseira islandica, A. alpigena*). This trend continued into the Little Ice Age (ca. 700–300 BP). The diatom concentration was also low (1.2 instead of 300×10^3 per gram).

(7) At present, grassland and meadows exist around the lake as well as fields, and cereal pollen has appeared in the spectra as a result of agriculture.

Lake Valday (Arslanov *et al.*, 1992; 58 00'N, 33 16'E), area 30 km^2, maximum depth 60 m, altitude 192,5 m a.s.l. is situated at the Valday Highland in the end-moraine landscape of the last glaciation (Fig. 1, No. 6). Sedimentation processes started at the beginning of deglaciation, which occurs in this region at little more than 16,000 ^{14}C years BP. The lowest lacustrine deposits are laminated clays with sands formed during the Lateglacial climatic improvement. The sediment core (length 7 m) was taken at the depth of 6.5 m in the shallower part of the lake.

(1) The Older Dryas is characterized by a tundra vegetation. The sediments that accumulated during the Older Dryas are dominated by N.A.P. (Fig. 11), diatoms were sparse (1×10^3 per gram) and belong to a cold type (*Aulacoseira islandica*).

(2) During the Alleröd chronozone, pine and spruce forests developed. The lake became shallower and epiphytic diatoms appeared (*Fragilaria brevistriata, F. construens* var. *venter*).

(3) The Younger Dryas period was characterized by the prevalence of *Artemisia* and shrub birch. The lake was oligotrophic and shallow with a macrophyte zone. Some species, typical of more high trophic state, such as *Aulacoseira granulata*, appeared among

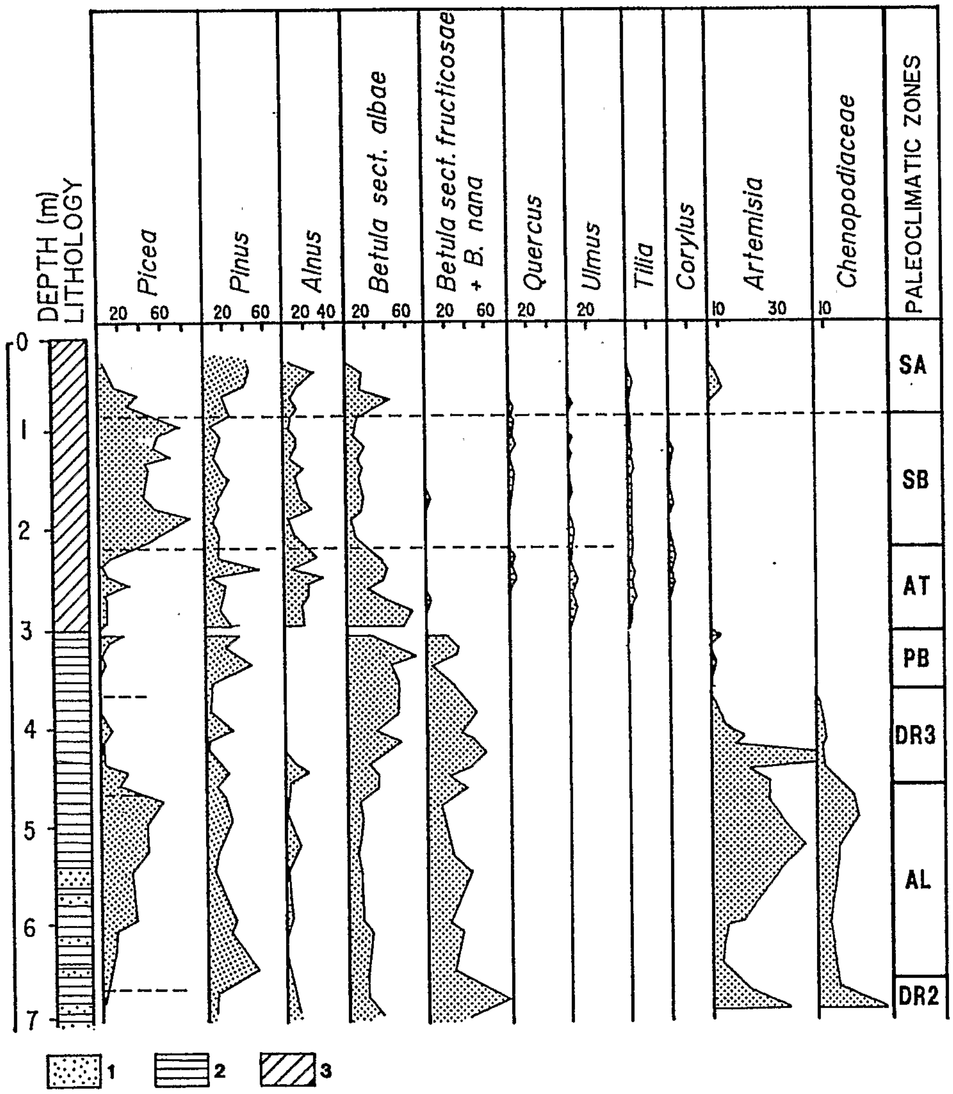

FIG. 11. Lake Valday. Pollen diagram (percentage values; adapted from V. Khomutova in Arslanov *et al.*, 1992). 1, sand; 2, gyttia; 3, sapropel.

the subdominants. Thus, during the Lateglacial time the Lake Valday was a deep oligotrophic basin.

(4) At the beginning of the Holocene birch and pine forests spread across the lake watershed, and mud was deposited. Two *Aulacoseira* and some shallow water *Fragilaria* diatoms dominated in the sediments.

(5) During the Boreal, dead ice melted finally from the catchment and the topography of the territory was changed due to an increase in the depth of the basin and a decrease in water level. The shallower parts of the lake show a break in sedimentation.

(6) During the warm and humid climate of the Atlantic period, the water level again increased. The radiocarbon age of the sediments just under the mud zone was 7810±150 ^{14}C years BP (LU-2287). Littoral diatoms prevailed (*Fragilaria brevistriata, F. construens* var. *binodis, F. leptostauron* var. *martyi*) and mixed forests of birch, pine, elm, lime and oak were widespread.

(7) The climatic dryness of the Sub-Boreal resulted in an abundance of shallow water diatom communities, with *Fragilaria leptostauron* var. *martyi, Fragilaria* sp. and other littoral species. Diatom content reached very high values (15×10^6 per gram). Spruce forests predominated.

(8) The Sub-Atlantic shows the replacement of spruce forests by pine and birch and planktonic forms began to predominate (*Aulacoseira islandica*).

(9) In the Russian Plain, the 'Little Ice Age' is indicated by a decrease of diatom abundance (4.4×10^6 per gram) especially in sediments of the colder 16–18th Centuries. The uppermost layers show mesosaprobic conditions (*Stephanodiscus hantzschii*). Human impact is significant due to the presence of Valday Town and many sanatoria on the lake shore.

Baltic Countries

The lake history of the Baltic countries (Kabailene *et al.*, 1992) has been studied by Lithuanian, Latvian and Estonian colleagues and the palaeoclimatic evolution is based on many cores and radiocarbon dates from lacustrine sediments found in more than a hundred lakes. These lakes are characterized by a low organic matter content. Sedimentation started as early as the Bölling chronozone, and up to 38.5 m thickness of Lateglacial and Holocene deposits have been recorded.

(1) Pollen spectra attributed to Bölling and Older Dryas exist at the base of sediments from many lakes in Lithuania and Southern Latvia. These sediments are characterized by abundance of *Artemisia*, Chenopodiaceae, *Betula nana, Hippophae rhamnoides*. Diatoms indicate shallow and oligotrophic conditions with a dominance of *Cyclotella radiosa, Ellerbeckia arenaria, Fragilaria brevistriata, Gyrosigma attenuatum*. The deglaciation process and the history of the Late Pleistocene environmental changes in the Baltic territory are still a subject of controversy. One version suggests that Estonia was still glaciated at this time (Kabailene *et al.*, 1992). Another version suggests that Estonia was already ice free in the Bölling (Davydova and Raukas, 1986; Kabailene and Raukas, 1987; Saarse *et al.*, 1988; Raukas and Hyvarinen, 1992).

(2) During the Alleröd chronozone, the dead ice melted and the landscape was colonized by birch and pine forests. Lacustrine sedimentation started as the result of thermokarst process. The thickness of the Alleröd lacustrine deposits varies from 0.05 to 3.8 m.

(3) During the Younger Dryas, tundra vegetation again became widespread. The lakes were shallow and the melting of permafrost was arrested. The presence of *Aulacoseira italica, Cyclotella radiosa* and *Stephanodiscus rotula* indicated that during the second part of this period, the lakes became deeper.

(4) Improvement of climate during the early Holocene is associated with the development of birch and pine forest and an increase of organic matter and calcareous sediments. The thickness of Preboreal lake deposits is $\leq$0.2 m. The lake was shallow.

(5) During the Boreal, the climate of Baltic countries was warm and dry. The last dead ice melted. Some lakes experienced an increase of depth and some small lakes filled with sediments to become bog and wetlands. At the second half of the Boreal, broadleaf forest started to spread over the territory. Oak, lime, elm, alder and hazel forests became dominant during the climatic optimum. Sapropel sedimentation started in the lakes with a general increase in lake depth. The lakes became mesotrophic or even eutrophic with *Aulacoseira italica, Cyclotella krammeri* being dominant.

(6) During the Sub-Boreal, pine and spruce were dominant. Many shallow lakes were transformed into peat bogs, the deepest lakes became shallower. Littoral diatoms are typical of this period (*Epithemia turgida, E. adnata, Cocconeis placentula, Fragilaria ulna*).

(7) With the onset of the Sub-Atlantic, mixed oak forest was replaced by spruce and during the "Little Ice Age" lakes became oligotrophic with the appearance and even dominance of planktonic oligotrophic species *Aulacoseira islandica* in some cases.

(8) Currently forest decline and the extension of agriculture characterize the region. Lakes have become eutrophic and some of them characterized by a dominance of *Cyclostephanos dubius* are even hypertrophic.

Byelorussia

Byelorussia is a region upon the Russian platform south of the Baltic countries with more than 10,000 lakes (Jakushko *et al.*, 1992a). They are situated from 80 to 346 m a.s.l., covering an area of 1500 km^2. Nearly 300 lakes have been cored and studied by scientists of the Laboratory for Lake Research of the Byelorussian University.

Lake Naroch (540 5'NN, 260 45'E, 195 m a. s.l., area 80 km^2) is the largest in Byelorussia. It is situated in the

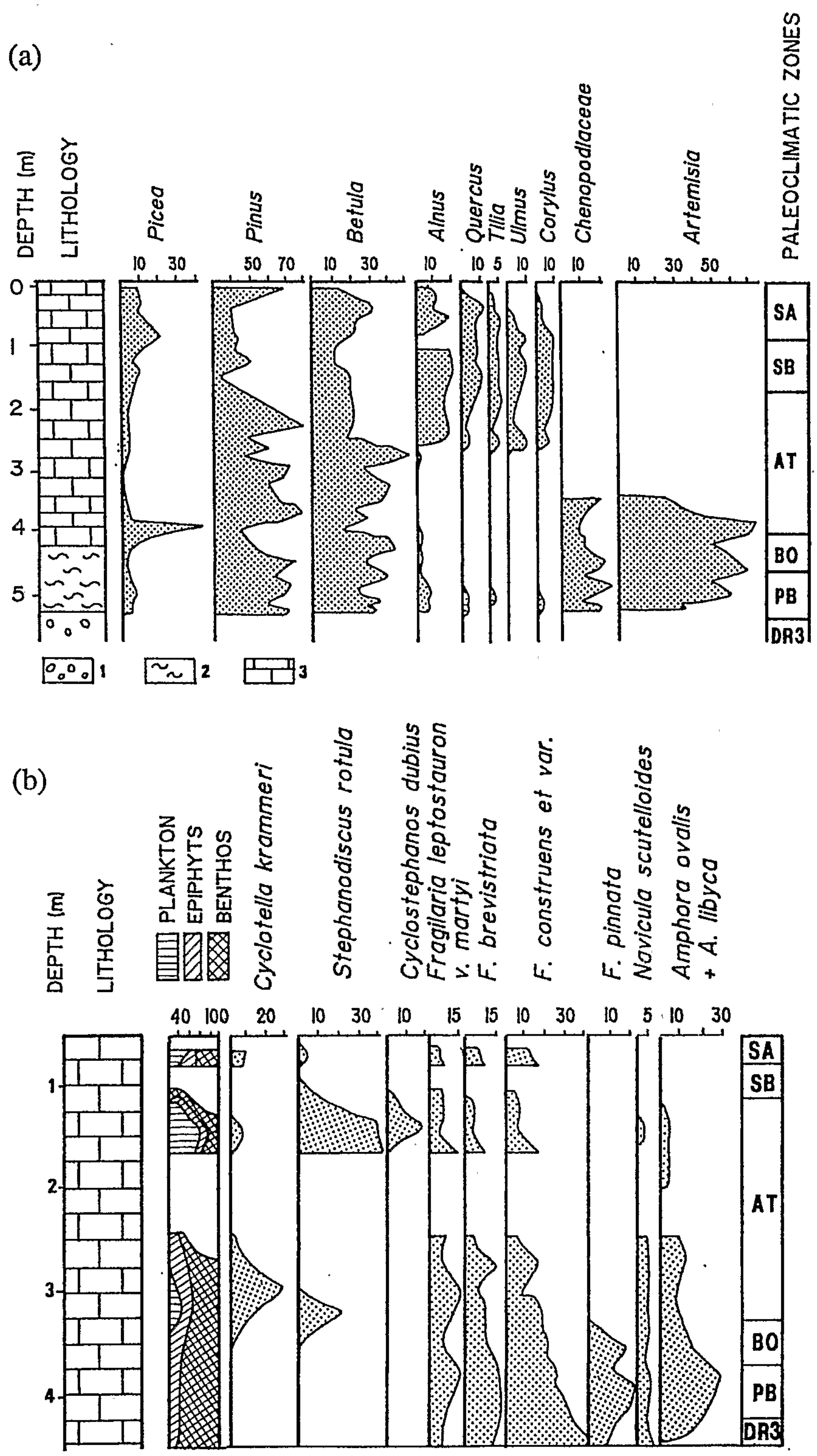

FIG. 12. Lake Naroch (Byelorussia). (a) Pollen, (b) diatoms (adapted from N. Makhnach and G. Khursevich in Jakushko *et al.*, 1992a). 1, sand; 2, sapropel with macrophytes; 3, calcareous sapropel.

end-moraine belt of the last glaciation. A sediment core (length 5.2 m) was obtained at a depth of 3.3 m, and contains Lateglacial and Holocene sediment (Fig. 12) as indicated by radiocarbon dates 10,710±70 ^{14}C years BP (TLN-653) at the depth of 4.4–4.6 m and 13,110±70 ^{14}C BP (TLN-654) at the depth 4.9–5 m.

(1) During the end of the Pleistocene time (DR1, BØ, DR2), vegetation that has been dominated by *Artemisia, Cyperaceae, Hippophae, Ephedra, Betula nana, Salix* and *Alnus*, is replaced by pine, birch and spruce forests. The lake sediments are calcareous (10% $CaCO_3$) and contain no diatoms.

(2) During the Younger Dryas, pine and birch forests were replaced by tundra vegetation. The lake was shallow and oligotrophic, dominated by *Fragilaria brevistriata* and *F. construens* et var. Some northern-alpine species (*Cyclotella antiqua, Achnanthes flexella, Cymbella ancyli*) were also found.

(3) At the beginning of the Holocene, pine and birch forests became more extensive. The lakes were shallow and littoral *Fragilaria*, (*F. construens*, *F. brevistriata*, *F. pinnata*, *Fragilaria leptostauron* var. *martyi*) or epiphytic diatoms (*Amphora ovalis*) predominated.
(4) The Atlantic climatic optimum was characterized by the presence of alder, oak, lime, elm and hazel, and mixed forests develop with pine and birch predominant. Lake depth increased and *Stephanodiscus rotula* and *Cyclotella krammeri* were the most numerous, although diatoms were absent from the middle of the climatic optimum. Diatoms reappeared at the end of the warm and humid epoch, when the lake was eutrophic with a high productivity of phytoplankton (*Stephanodiscus rotula* and *Cyclostephanos dubius*).
(5) Sediments of the next dry Sub-Boreal period do not contain any diatoms which is typical of calcareous lake sediments of Byelorussia and the adjoining territories of Poland. This is due to dissolution during diagenesis.
(6) During Sub-Atlantic, planktonic diatoms (*Aulacoseira italica*, *A. granulata*, *Cyclotella krammeri*) with some littoral species reappeared. The lake was mesotrophic at this stage. Vegetation around the lake shows the increasing influence of human impacts with deforestation and the appearance of plants connected with human activity.

The study of lake deposits of Byelorussia showed that during the Lateglacial and at the beginning of the Holocene, Byelorussian lakes were oligotrophic. In Atlantic and Sub-Boreal times, they changed and became mesotrophic and later eutrophic. The lake level increased up to the Atlantic period. It decreased in dry and cold Sub-Boreal and increased again in Sub-Atlantic.

THE CENTRAL REGION OF THE EAST EUROPEAN PLAIN

The Central region (Aleshinskaya *et al.*, 1992) around Moscow is of particular interest because it contains the oldest lakes of Eastern Europe. These lakes originated at the end of Moscow (Saale) glaciation, survived during the Mikulino interglacial period, Valday (Weichselian) glaciation, and the Holocene; some still exist. Such old lakes were situated near the ice margin during the last glaciation. One of them is located north of Moscow, near the small town Dimitrov, on the Klinsko-Dimitrovky ridge. This is known as ancient Tatishchevskoye lake (Semenenko *et al.*, 1981). According to ^{14}C dates, there is a gap in sedimentation between 19 and 13,000 BP which is attributed to a complete freezing of the lake during the coldest part of the Last Glaciation. This phenomenon is common in the present day for lakes of Yakutia, and occurs during long and extremely cold winters when the temperature drops to –55°C.

Lake Nero (50 08'N, 39 28'E; Figs 13 and 14) has an altitude of 95 m, area 51.7 km^2 and a maximum depth of 4 m.

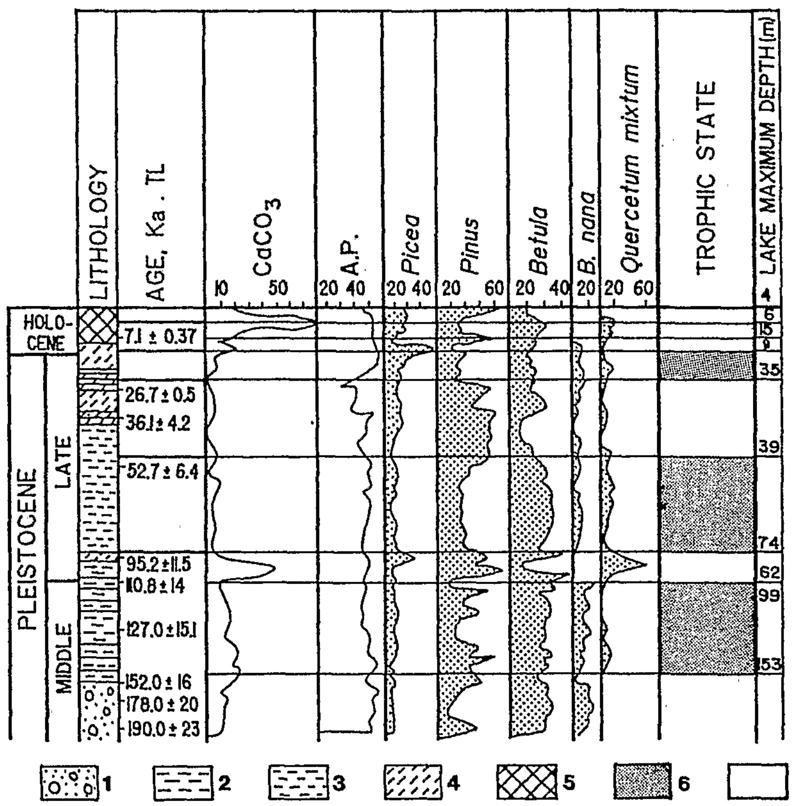

FIG. 13. Lake Nero (Moskow District). Pleistocene palaeolimnology (adapted from Z. V. Aleshinskaya, V. S. Gunova and O. N. Leflat, 1992). 1, boulders and gravels; 2, sandy clay; 3, varved clay; 4, sapropel; 5, clay; 6, trophic state white-eutrophy, black-oligotrophy; 7, maximum lake levels (inferred from terrace altitudes).

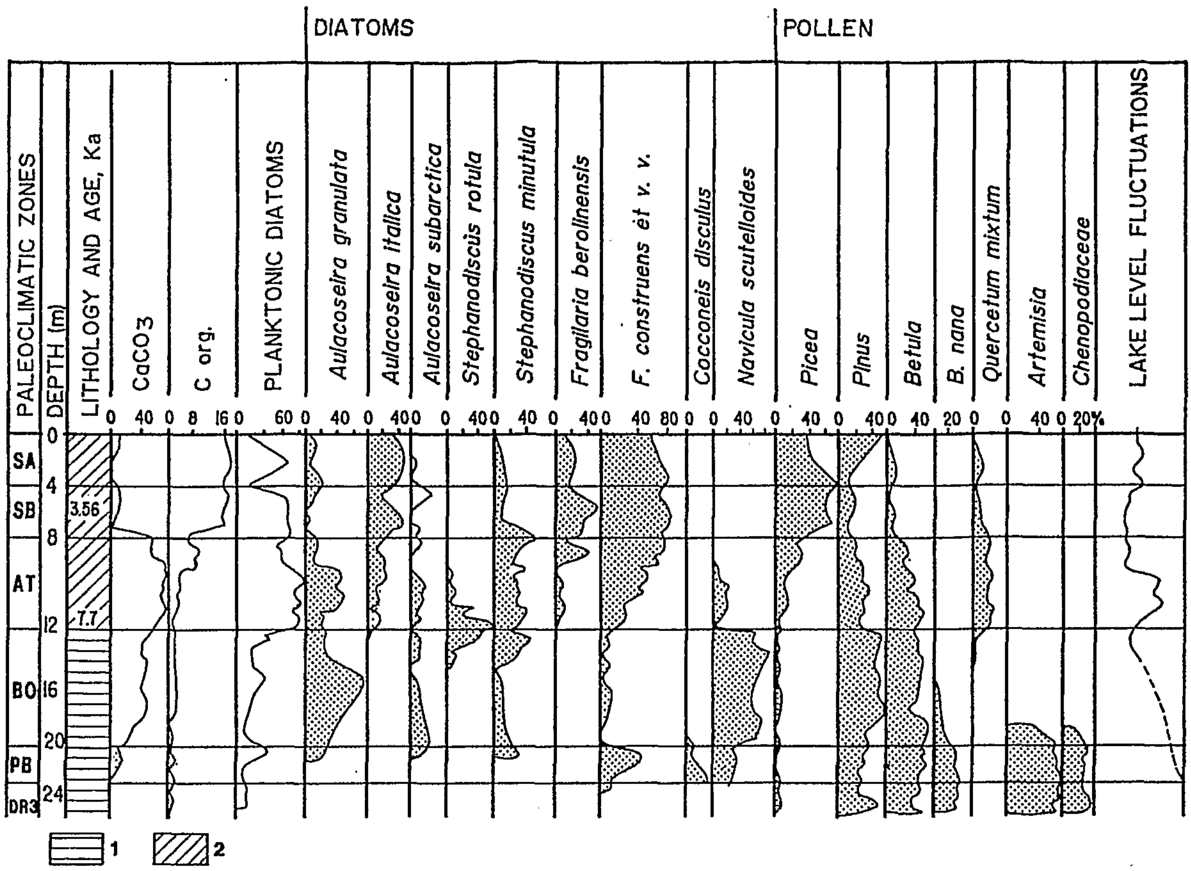

FIG. 14. Lake Nero. Holocene deposits and palaeolimnology (adapted from Z. V. Aleshinskaya, V. S. Gunova and O.N. Leflat, 1992). 1, clay; 2, mud.

(1) The lake depression is bordered by the end moraines of the Moscow Glaciation of the Middle Pleistocene. The full thickness of the lake sediments in the lake depression is nearly 100 m. The basal varved clay deposits which overlie glacial sediments have a TL age of 152,000±1600 BP (MGU-KTL-104). According to the diatom assemblages, the lake was oligotrophic and was surrounded by sparse birch forests with low shrubs.

(2) During the first part of the Mikulino Interglacial the lake watershed was covered with pine forests. Deciduous trees such as alder, hazel, oak lime and elm appeared, at the climatic optimum (110,000±1400 BP, MGU-KTL-117). Diatoms are not preserved in the sediments of this alkaline, eutrophic lake, but are found from the succeeding colder phase. The lake was shallow, but remained eutrophic. *Aulacoseira granulata, A. italica, Fragilaria pinnata, Navicula radiosa, Amphora ovalis* were the most abundant diatoms. During the final stage of the interglacial, spruce forests initially replaced by pine were then replaced by birch with increasing areas of shrubs (95,200+1150 BP, HGV-KTL-116). Northern alpine diatoms appeared in the lake (*Achnanthes oestrupii, A. calcar, Cocconeis disculus and C. diminuta*), but planktonic species were absent because of the coldness of the climate.

(3) During the Early Valday Glaciation, between 95,000±1,150 BP and 52,700±650 BP, vegetation consisted of sparse pine and birch forests with tundra shrubs. *Fragilaria leptostauron* var. *martyi* and northern *Achnanthes borealis, A. oestrupii, A. laterostrata* dominated in the shallow oligotrophic lakes. The Middle Valday was a time of climatic improvement; pine and spruce forests dominated with an admixture of oak, lime and elm. Tundra vegetation had not entirely disappeared as *Ephedra* and dry steppe elements (*Artemisia, Chenopodiaceae*) remained. At this time the lake was shallow and oligotrophic. At the maximum of the Late Valday Glaciation, the ice margin was only 200–250 km to the north of the lake. Sometimes the lake was frozen to the bottom. Tundra vegetation existed as well as rare pine and birch trees with low shrubs of *Betula nana, Salix* and herbaceous plants. The lake was shallow and oligotrophic (*Achnanthes borealis, A. oestrupii, Amphora ovalis*).

(4) Valday Lateglacial warming between 13,000 and 11,000 ^{14}C years BP is associated with the extension of spruce forests and the shallowing of the lake. During the Younger Dryas the forest area again decreased and birch became dominant. Northern alpine littoral diatoms became numerous (*Cocconeis disculus, Navicula scutelloides, Campylodiscus noricus*).

(5) At the beginning of the Holocene, the lake became oligotrophic and was surrounded by birch forests. The warming of the climate caused eutrophication with

the appearance of *Aulacoseira granulata, A. italica, Stephanodiscus rotula*. Pine and birch forests spread into the watershed.

(6) During the climatic optimum, oak, lime and elm forest included pine and birch. At that time the lake water level increased and the lake become eutrophic with *Aulacoseira granulata* dominating.

(7) At the Sub-Boreal, spruce became dominant in a mixed forest, and eutrophic conditions developed. The lake became shallower. *Fragilaria* species predominated with littoral planktonic *Aulacoseira italica* and *Fragilaria berolinensis*.

(8) During the Sub-Atlantic, the lake remained shallow and eutrophic with macrophytes and the dominance of littoral *Fragilaria* species. Pine and birch forests with admixture of lime, oak and elm characterized the woodland in the catchment.

(9) Finally, the lake ecosystem became modified by the development of the town of Rostov Velikly.

The southern part of the East European Plain

This region is known as Lowland Polesjes (Jakushko *et al.*, 1992b). It was never glaciated although it was near the ice margin with glaciofluvial sediments. Polesjes are characterized by the continuous tectonic subsidence of the basement overlying pre-Quaternary sediments. Glacier meltwater formed large lakes and the region contains many lakes to this day.

Lake Oltush (51 55'N, 24 03'N, area 1.86 km^2, maximum depth 2.2 m) in Byelorussia is one of nearly 300 lakes investigated (Fig. 1, No. 8). The mean thickness of sediment is 6 m. A peat sample at the base of the core gave a radiocarbon age of 9870±50 ^{14}C years BP (KI-3394) indicating that lacustrine sedimentation started at the beginning of the Holocene (Fig. 15).

(1) During the early Holocene the plain was submerged by a large lake. Planktonic diatoms dominate (*Aulacoseira ambigua, Tabellaria fenestrata, Asterionella formosa*) with some littoral *Fragilaria* (*F. construens* var. *venter, F. pinnata*). This lake disappeared as the ice margin retreated to the north and the deepest part was occupied by a small shallow lake with a littoral diatom flora: *Fragilaria pinnata, F. leptostauron* var. *martyi, Gyrogsima attenuatum* and different *Navicula*. Pine and birch forests spread across the surrounding territories.

(2) During the climatic optimum, mixed forests with pine, alder, lime, oak, hazel and beech developed and organic muds were deposited in the lake. The organic matter content was more than 50% (L.O.I.) with blue-green algae being dominant. Diatoms disappear nearly completely, due to dissolution in high alkaline water and only a few *Aulacoseira, Fragilaria* and *Asterionella* were preserved.

(3) Diatoms re-appeared during the Sub-Boreal with planktonic *Aulacoseira italica, A. granulata, A. ambigua* and some *Fragilaria* (*F. construens* and var. *venter*) along with the blue-green algae. The region was covered with pine and oak forest with some lime and hazel. The lake ecosystem was highly productive with an organic matter content in the order of 60–77% (L.O.I).

(4) In the last 2500 ^{14}C years BP, the situation has changed a little, with only oligotrophic *Aulacoseira islandica* and *A. alpigena* appearing in diatom communities. In the forest, pine, spruce and alder increased. The southernmost territories of the East European plain have only small lakes connected with the river valleys and deltas.

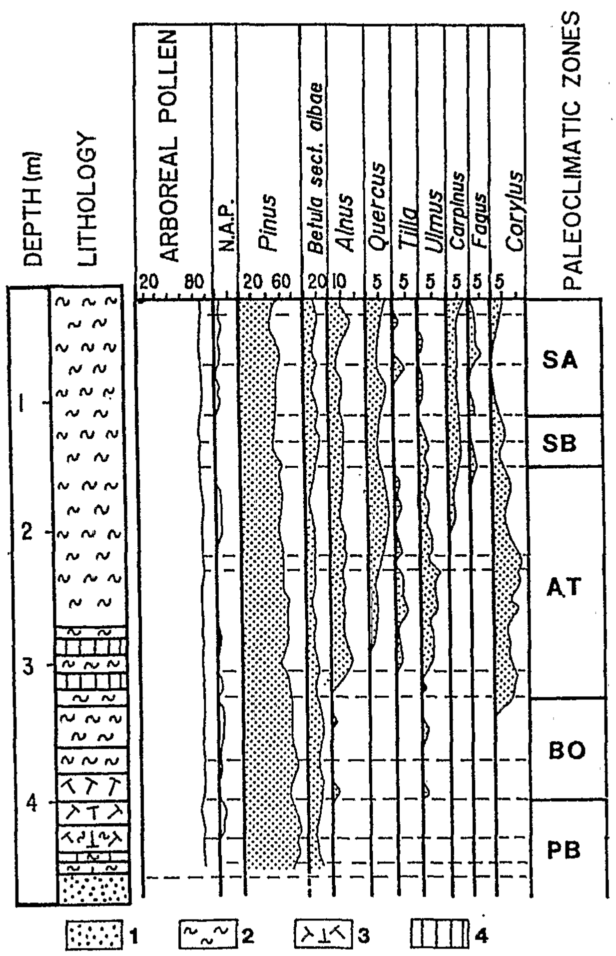

FIG. 15. Lake Oltush. Pollen diagram (adapted from J. Elovicheva and N. Kovalukh, 1992). 1, sand; 2, gyttia; 3, peat; 4, lacustrine lime.

CONCLUSION

In the northern temperate zone of Eurasia, lakes are short lived because they originated after the melting of Weichselian ice sheet.

Dryness of climate of the glacial epoch prevented the formation of lakes. Only a few ones as Lake Nero (Fig. 13) have survived throughout the Eemian interglacial, the last glaciation and exist presently.

At the beginning of Weichselian deglaciation, a large territory south to the ice margin was covered with ice marginal lakes (for example Pre-Valday lake, Fig. 9) and lake sediments in the territories of Byelorussia, Lithuania and South Karelia commence with glaciolacustrine sedimentation and continue during Bölling and Alleröd chronozones (Fig. 6)

During the Younger Dryas lakes survived in the northern part of the Baltic (Latvia, Estonia, Karelian Isthmus and in the East European plain (Ilmen Lake; Figs 8–10)

The process of the formation of lakes was intensified by the melting of permafrost at Pre-Boreal and Boreal time in all the investigated territory. Mitrophan lake in the NE (Figs 3–5) and some lakes of the Kola Peninsula (Fig. 2) originated as late as the Boreal period.

Climatic changes and lake evolution from oligotrophic to eutrophic stages of the Holocene were clearly marked by dominant diatoms.

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