Late Pleistocene-Holocene paleolimnology of three north-western Russian lakes

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Late Pleistocene-Holocene paleolimnology of three northwestern Russian lakes

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Abstract

The vegetation history and development of three different types of lakes, lakes Valday, Kubenskoye and Vishnevskoye (northwest of the East European Plain) were reconstructed using paleolimnological techniques. Watershed vegetation demonstrates a close connection with climate fluctuations: gradual expansion of the southern broad-leaved trees to the north during the Holocene with the maximum extent during the climate optimum (8000–5000 BP); and their subsequent retreat afterwards; followed by the extension of spruce during the cold and dry Subboreal time; and dominance of pine-spruce-birch forests in the Subatlantic time. The Late Pleistocene and Holocene climate changes resulted in lake-level fluctuations and other ecosystem changes. Valday Lake was formed ca. 12,500 BP as an oligotrophic, deep water basin. The lake level decreased during the dry Boreal, then increased again during the humid Atlantic period. The large shallow Kubenskoye Lake was formerly a part of an ice margin lake, which was then separated (ca. 13,000 BP) and developed into the Sukhona Basin with an outflow to the northwest. During the Atlantic, the outflow direction changed to the east. As a result, the ancient Sukhona Lake disappeared and Kubenskoye Lake formed in its modern size and shape. Vishnevskoye Lake, on the Karelian Isthmus, was formed at the beginning of the Preboreal after the disappearance of the Baltic Ice Lake. It was flooded by waters of the Boreal Ancylus transgression of the Baltic Basin and had become a small eutrophic lake by the time.

Introduction

Paleolimnological studies of northwestern Russian lakes provide the possibility to investigate the history of the lakes and to reconstruct the climate fluctuations during the Late Pleistocene and the Holocene. This problem has been the focus of several paleolimnological studies (e.g. Kvasov, 1975; Gey et al., 1978; Davydova & Kurochkina, 1981; Davydova & Raukas, 1986b; Subetto et al., 1991; Davydova et al., 1996a). Paleogeographical data have been described in detail and generalised in a special volume (Davydova et al., 1992). Some data were published in English (Davydova & Servant-Vildary, 1996) and all stages of deglaciation of the East European Plain and the borders of glacial lakes have been published in English by Kvasov (1979). The records from studied lakes and supporting documentation have been included in the Former Soviet Union lake-level data base (Tarasov et al., 1994, 1996). In this paper, paleolimnological data from lakes Valday, Kubenskoye and Vishnevskoye have been used to reconstruct the climate fluctuations of the Late Pleistocene and the Holocene. The lakes of the northwestern part of the Russian Plain (Figure 1) were formed after the retreat of the last ice cover 16,000 BP and the disappearance of large ice margin lakes (Kvasov, 1975, 1979).

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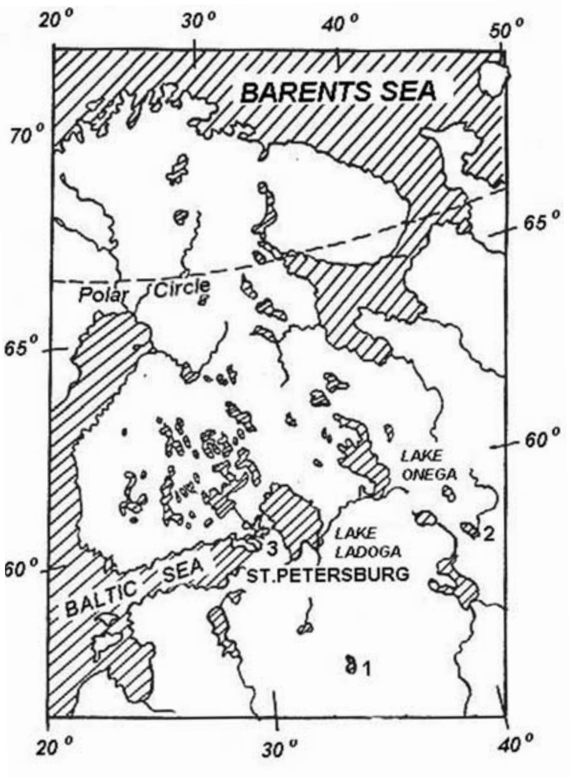

Figure 1. Location map of the study lakes: 1 – Lake Valday; 2 – Lake Kubenskoye; 3 – Lake Vishnevskoye.

Methods

Field and laboratory

Sediment cores were obtained with a rod-piston corer at the central part of the lakes during winter seasons from the ice cover. Cores were extruded and described in the field, placed in plastic bags and transported to the Institute of Limnology where they were stored at 4 °C, and subsampled into 2.5–10 cm thick sections without any gaps in order to avoid missing changes in lake ecosystems and vegetation. Lake silty gyttja and homogenous clays were subsampled into 2.5–5 cm sections, while the basal laminated clays and alterations of sand and gravel were subsampled into 10 cm thick sections because of the difference in sedimentation rates during the Post- and Late Glacial times.

The laboratory treatment of sediment samples consisted of determination of grain size, water content, loss-on-ignition, and chemical composition (N, P, C).

Treatment for pollen followed standard techniques. 800–1000 pollen grains were identified per sample and the frequency of pollen grains per gram of sediment was calculated (Kvasov et al., 1986). For Lake Vishnevskoye, the regressive analysis of pollen and spores spectra in sediments was applied by Adamenko (1995) to calculate climate fluctuations (temperature and humidity changes) during the Mid and Late Holocene.

For diatom studies the following method was used for calculation of diatom abundance per g of dry sediment (Davydova, 1985). Five g of air dried sediment (d) was treated with H_2O_2 to destroy organic matter, washed in distilled water and centrifuged with heavy liquid (CdI+KI, cadmium iodine + kalium iodine) of 2.6 g specific gravity. The liquid containing diatoms was separated, centrifuged twice with distilled water (b), 0.02–0.04 ml of stirring liquid (e), put on the cover glass (areas 18 × 18 mm) (c), and mounted in Hyrax. Five hundred diatom frustules were identified on several microscope fields (f). The number of frustules (a) per 1 g of sediment was calculated by:

$$a = 500 \bullet b \bullet c \bullet d^{-1} \bullet e^{-1} \bullet f^{-1} \qquad (1)$$

Diatom species representing more than 10% of the total count in a sample are defined as dominants and those with frequencies between 5–10 % as subdominants. The diatom abundances are recorded as thousands or millions of frustules per g of the dry sediment (Figures 3, 5 & 8). In our opinion the diatom assemblages are represented better in such a way, especially for sediments where concentrations are low.

The chronology of sediment cores was established by pollen, and is in a good agreement with the regional scheme for the northwest of the European part of Russia (Khotinsky, 1977). The pollen and diatom results are plotted in diagrams, which have been constructed with the TILIA and TILIA GRAPH2 programs (Grimm, 1991).

Results and discussion

Late glacial development of lakes of the northwestern part of Russia

The evolution of lakes of the northwest started after the last deglaciation ca. 16,000–10,000 BP. Nearly all the lakes are relics of the great ice-dammed water basins. The most ancient lakes of the northwest can be found along the border of the last Valday (Weichselian) glaciation.

As an example of lake evolution at the southern part of the study region, the formation and evolution of

Lake Valday has been described in detail. This lake was flooded by waters of the large Privalday Lake during the Veps Stage (ca. 15,000 BP). These events have been described earlier by Kvasov (1979).

Lake Valday

Lake Valday (57 ° 59′ N, 33 ° 16′ E, 192 m a.s.l) is located at the Valday Highland (Figure 1), the main watershed of the Russian Plain. It was formed ca. 12,500 BP (Kvasov, 1975) at the time of dead ice melting in a kettle-hole surrounded by moraine ridges and hills. A sediment core of 7 m long was obtained from a water depth of 6.5 m. The core lithology is rather complicated, and is described as follows:

0.00–0.13 m – dark grey silty clayey calcareous gyttja
0.13–0.28 m – dark grey silty clayey gyttja
0.28–3.00 m – brown silt-clayey gyttja with rare plant remains and a mixture of sand
3.00–5.00 m – dark brownish-grey calcareous clay with sand interlayers (4.21–4.22, 4.24–4.25, 4.42–4.44 m)
5.00–6.98 m – horizon of alteration of sand and clay
6.98–7.00 m – coarse sand and gravel

Pollen

According to the pollen stratigraphy (Figure 2), 7 pollen zones were identified. The pollen stratigraphy corresponds to climate changes from the Mid Dryas up to the Subatlantic. There is a hiatus in sedimentation between the Preboreal (PB, ca. 9,500 BP) and the Atlantic time (AT, ca. 7,000 BP).

The sequence 6.60–7.00 m would represent the Mid Dryas time (DR2, 12,000–11,800 BP). It is characterised by typical periglacial pollen spectra. The assemblages indicate that the region was covered by dry tundra-steppe communities dominated by *Betula nana* and *B. fruticosa* (40–78%), *Artemisia* (to 37%) and Chenopodiaceae (to 35%).

The Alleröd (AL, 11,800–11,000 BP; 4.40–6.60 m) is characterised by the development of forest vegetation. Spruce forests (*Picea* to 58%), with the addition of pine (*Pinus*, to 50%), were dominant. There were extensive grasslands with tundra-steppe communities.

The Younger Dryas (DR3, 11,000–10,200 BP; 3.60–4.40 m) is marked by the prevalence of nonarboreal pollen (6–34%) and spores (30–64.4%). The main difference between DR3 and DR2 is the dominance of *Artemisia* and Bryales during the Younger Dryas interval. Dry tundra-steppe vegetation was widely spread.

According to the pollen data, the Pleistocene-Holocene boundary is at the depth 3.60 m. Arboreal pollen, along with *Betula* (to 62%) and *Pinus* (to 50%), became dominant and was the most numerous in the Preboreal interval (PB, 10,200–9,300 BP). The vegetation was characterised by mixed birch-pine forests.

There is a main hiatus in sedimentation at 300 cm, which is marked by a sharp change in lithology from the Preboreal clay to the Atlantic gyttja. Typical Boreal pollen assemblages and pollen from the beginning of the Atlantic are not represented in the core. Sediments of the Atlantic optimum in the Holocene are represented by brown gyttja (2.10–2.30 m). The Atlantic time (AT, 6,300–5,000 BP) is characterised by maximum concentration of deciduous broad-leaf tree pollen (up to 18%): *Quercus*, *Ulmus*, *Tilia* and *Corylus* pollen. These spectra show that the region was covered by mixed forests, and indicate that the climate was warm and humid during the Atlantic period.

The boundary between the Atlantic and the beginning of the Subboreal (SB, 5,000–2,500 BP) is set at 2.10 m, where the broad-leaf pollen decreases and *Picea* pollen becomes abundant. These changes reflect cooling and increased dryness of the climate during the Subboreal.

The Subatlantic period (SA, 2,500 BP up to present) commences at 80 cm with a decrease of *Picea* pollen and a gradual increase of nonarboreal pollen (up to 20%). There was an extension of birch-pine forests (*Betula* pollen increases to 46% and *Pinus* pollen up to 40%), suggesting that deforestation took place in this region. Cereal pollen appears in the upper part of this sediment interval.

Diatoms

The sedimentary record of diatom assemblages (Figure 3) suggests that Lake Valday has remained an oligotrophic, clear-water lake for most of its history. The end of the Pleistocene epoch is characterised by the dominance of planktonic diatoms, especially *Aulacoseira islandica* (O. Mull.) Simonsen. Diatoms were not abundant (up to 50,000 frustules per g of sediment). The lake level was likely high at that time. The sharp change in lithology and in diatom assemblages at the transition zone from clay to gyttja at 3.00 m depth is consistent with a sedimentary hiatus. We interpret this hiatus as reflecting a major shallowing and drying out of the littoral zone, where the core has been obtained, during the Boreal and the beginning of the Atlantic.

Lake Valday

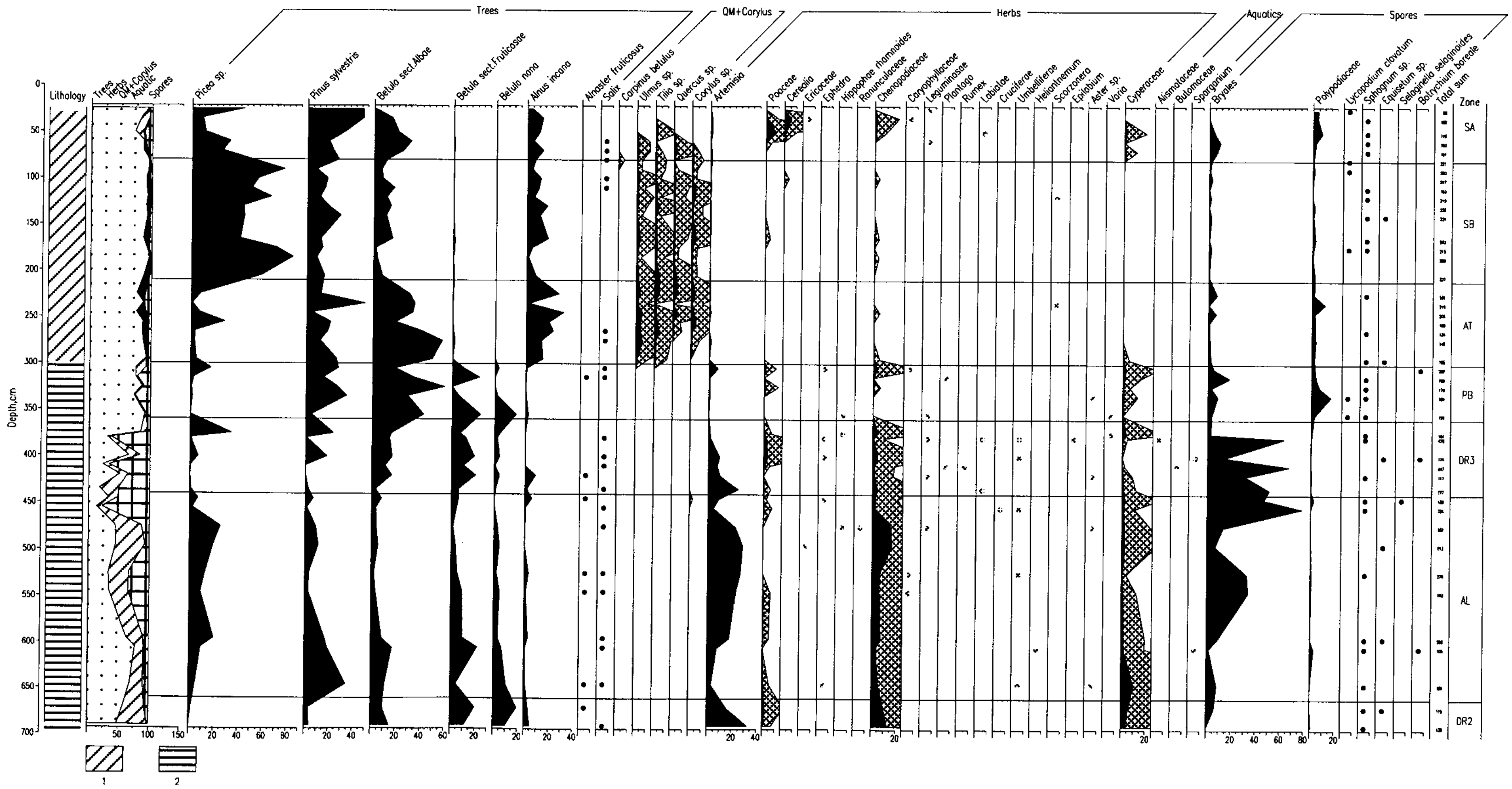

Figure 2. Pollen and spores in Lake Valday sediments: 1 – gyttja; 2 – clay; AP – arboreal pollen; NAP – non arboreal pollen; QM – Quercetum mixtum.

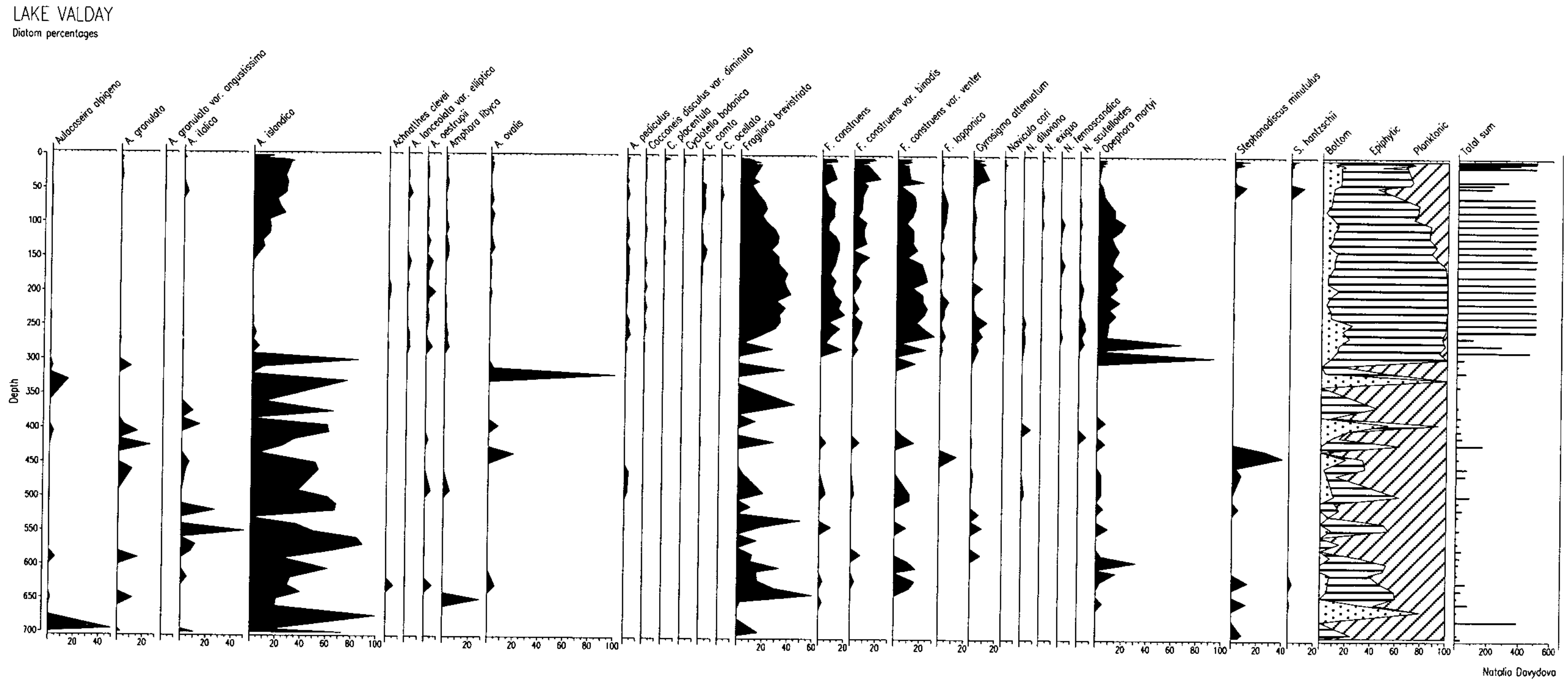

Figure 3. Diatoms in Lake Valday sediments.

The basal part of the gyttja (2.10–3.00 m) was deposited during the Atlantic and contains up to 8,000 diatoms per gram. Epiphytic diatoms, especially *Fragilaria* species, prevail (up to 90%), which is consistent with shallow-water conditions.

In the Subboreal sediments, the concentration of diatoms increases to 14×10^6 per g, which suggests an increase in diatom productivity. Epiphytic species, such as *Fragilaria brevistriata* Grunow, *F. construens* var. *venter* (Ehr.) Grunow, and *Opephora martyi* Herib., continue to dominate.

There is an increase in the abundance of planktonic diatoms up to 50% in the Subatlantic time, and *Aulacoseira islandica* is again the dominant species. The increase in planktonic diatoms abundance suggests an increase in lake level at this time. Diatom concentrations increased to 28×10^6 per g, which occurred concurrently with the Little Ice Age.

Lake Kubenskoye

Lake Kubenskoye (59 ° 42′ N, 39 ° 30′ E, 110 m a.s.l.) is located in the central part of the Kubeno-Sukhona Lowland at the north of the Russian Plain (Figure 1). It is one of the large shallow lakes (area 417 km^2, maximum width 10 km, maximum length 54 km, maximum depth 4.5 m, average depth 2.9 m) of the Vologda region. The lake is bounded to the east by the accumulative formations of the maximum stage of the Valday (Würm) glaciation (ca. 20,000 BP) in this region (Arslanov et al., 1970), and to the south by accumulative formations of the Moscow (Riss) glaciation. The catchment area of the lake (14,440 km^2) is formed by Permian sedimentary rocks covered by a thick layer of Quaternary deposits. During the Luga stage of the deglaciation (ca. 13,000 BP), Lake Kubenskoye was part of the large ancient Lake Sukhona, formed during the ice retreat from the lowland ca. 17,000–16,000 BP (Kvasov, 1979). A sediment core of 3.3 m length was obtained at 4 m water depth and contained:

0.0–1.0 m – brownish silt-clay gyttja with a sandy layer at the depth 0.4–0.45 m
1.0–1.5 m – grey homogenous clay with hydrotroilite ($FeS*nH_2O$) inclusions
1.5–3.15 m – brown laminated clay
3.15–3.3 m – brown laminated clay with mollusc shells

Pollen

According to the pollen stratigraphy (Figure 4), seven sediment zones were identified. They correspond to climate changes from the Alleröd (AL, ca. 11,300–11,000 BP) up to the Subatlantic interval (SA, from ca. 2,500 BP up to present). Alleröd sediments (2.90–3.30 cm) are characterised by the dominance of spruce (*Picea abies*, 45%) and pine (*Pinus silvestris*, 25%) pollen. The nonarboreal pollen is represented by *Artemisia* (45%), Chenopodiaceae (20–40%) and Cyperaceae (5–20%). Bryales (90–95%) are the main dominants among spores. The region was covered by coniferous forests with extensive grassland tundra-steppe communities. These data are in good agreement with the pollen and radiocarbon data obtained in sediments of Puchka sequence and other nearby surroundings (Kolesnikova & Khomutova, 1971).

The Younger Dryas sediments (DR3, 11,000–10,200 BP; 1.30–2.90 m) are marked by the prevalence of nonarboreal pollen, especially *Artemisia* (up to 60%), Chenopodiaceae (up to 40%), Cyperaceae (up to 20%). *Betula nana* and *B.* sect. *fruticosae* (both up to 65%) pollen dominates in the arboreal group. Dry tundra-steppe vegetation was wide spread. The presence of *Ephedra* pollen further indicates the dryness of the climate at this time.

According to the pollen data, the Pleistocene-Holocene boundary is at the depth of 1.3 m. Arboreal pollen are numerous (up to 65%) in the Preboreal sediments (PB, 10,200–9,500 BP; 0.80–1.30 m), with spruce and pine pollen dominant. Cyperaceae (up to 45%) and Gramineae (up to 50%) pollen are the most characteristic species in the nonarboreal pollen, although *Artemisia* (up to 45%) is also common. Mixed pine-spruce forests and grasslands were wide-spread and demonstrated climate improvement at the beginning of the Holocene.

The Boreal sediments (BO, 9,500–8,000 BP; 0.60–0.80 m) contained mainly arboreal pollen of pine (up to 55%), spruce (up to 20%) and birch (up to 40%). Single pollen grains of broad-leaf trees (*Ulmus*, *Tilia*, *Quercus*, *Corylus*) pollen were found. This assemblage suggests that mixed coniferous-birch forests with pioneering broad-leaf trees were wide-spread during the Boreal interval.

Sediments of the Atlantic optimum of the Holocene (AT, 8,000–5,000 BP; 0.45–0.60 m) are characterised by concentrations of broad-leaf pollen up to 4%, dominance of coniferous spruce (up to 20%) and pine (up to 60%), and the presence of birch (up to 50%) pollen. Mixed coniferous and deciduous forests covered nearly 90% of the territory. The climate was warm and humid.

The boundary between the Atlantic and Subboreal sediments (SB, 5,000–2,500 BP; 0.20–0.45 m) is set

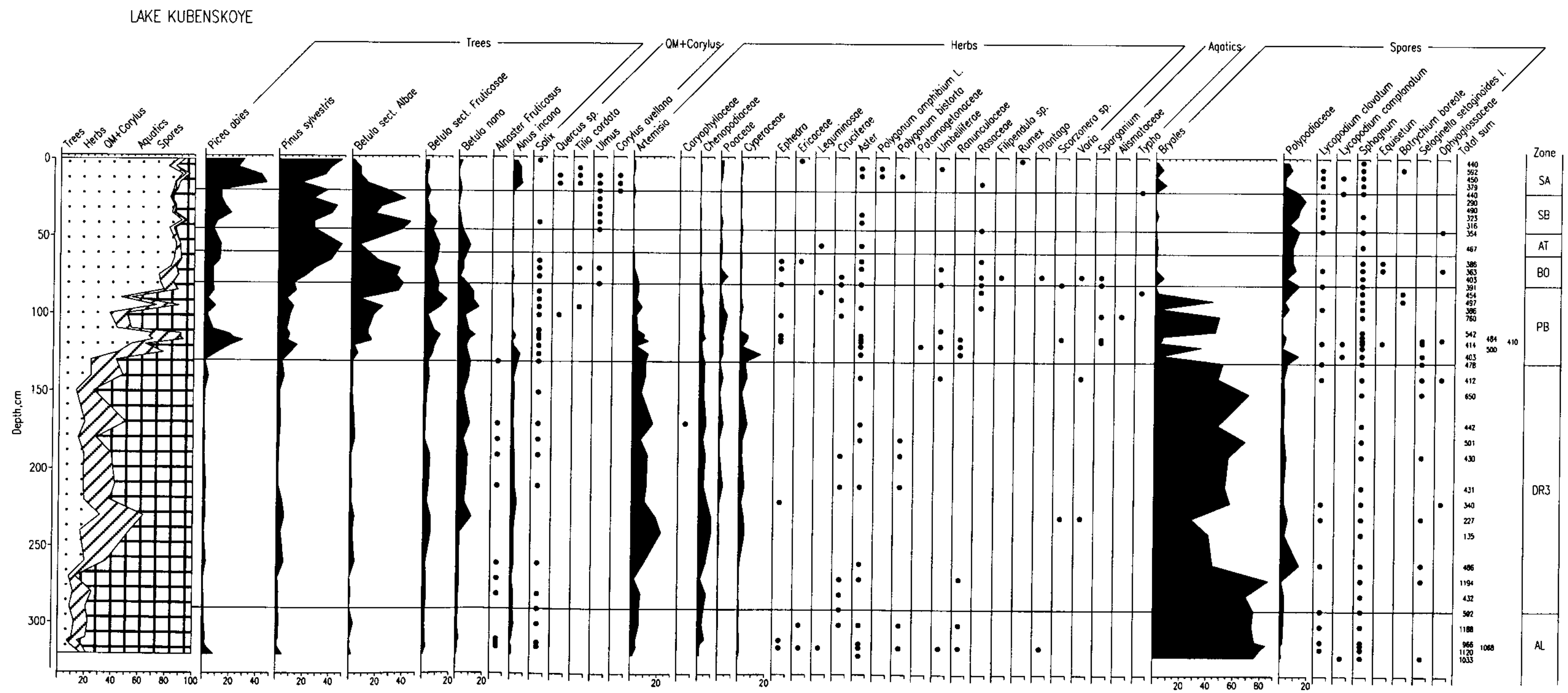

Figure 4. Pollen and spores in Lake Kubenskoye sediments.

at 0.45 m with an increase of spruce pollen (up to 60%). During the Subboreal epoch, spruce forests dominated with a mixture of pine, birch and alder. Some broad-leaf trees still survived along the river valleys. This assemblage suggests increasing cold.

Subatlantic sediments (SA, ca. 2,500 BP to present; 0.00–0.20 m) are characterized by *Pinus* (up to 50%) and *Picea* pollen (up to 32%). This assemblage indicates the expansion of pine-spruce forests, suggesting that the climate became warmer.

Diatoms

Diatoms are rare (up to 243,000 frustules per g) in late-glacial sediments (1.50–3.30 m, Figure 5). Epiphytic *Fragilaria* are dominants (from 70–100%). *Aulacoseira ambigua* (Grun.) Sim. and *A. granulata* (Ehr.) Sim., planktonic diatoms of mesotrophic waters, were present. The lake was most likely shallow and mesotrophic. At the beginning of the Holocene (PB, 0.80–1.50 m), the amount of diatoms in the sediments rapidly increases to 22.5×10^6 per g. Epiphytic *Fragilaria* are dominants as before. This assemblage may correspond with climate warming at this time. During the Preboreal interval there is a change from grey clay sedimentation to brownish silt-clay gyttja. This demonstrates the increase of organic matter content and total lake productivity linked with the improvement of the climate.

During the next chronozones of the Holocene, there is an overall decrease in the sedimentation rate. The diatom assemblages in the Boreal period (BO, 0.60–0.80 m) are the same as in the Preboreal, with *Fragilaria* species as the main dominants.

There is an increase in diatom concentration up to 34×10^6 per g and a change in diatom assemblages in the Atlantic period (0.45–0.60 m). The planktonic species *Aulacoseira ambigua* and *A. granulata* increase in abundance up to 45%. This suggests that the lake was deeper and more productive. The high humidity of the Atlantic period likely caused an increase in water level in the ancient Kubeno-Sukhona Lake and, as a result, a new outflow (the Sukhona River) to the northeast was formed and the lake level rapidly decreased (Gey et al., 1978). Diatom assemblages did not change markedly during the Subboreal-Subatlantic time: the lake continued to be shallow and mesotrophic. There is a rapid increase of diatom concentration in the uppermost 5 cm. The dominants, especially planktonic *Aulacoseira ambigua*, *A. granulata* and epiphytic *Opephora martyi*, also increases (Figure 5). This increase corresponds to the higher-nutrient concentrations in lakes as a result of human impacts.

Lake Vishnevskoye

Vishnevskoye Lake (60 ° 30′ N, 29 ° 31′ E; 15 m a.s.l.) is a small (surface area 10.5 km^2), shallow (average depth – 2 m, maximum depth – 3.5 m), flat-bottomed, hypereutrophic lake located on the abrasive-accumulative limno-glacial plain to the north of the Central Highland of the Karelian Isthmus (Figure 1). The Karelian Isthmus is situated between the Baltic Sea and Lake Ladoga. The high and terraced slopes of the lake basin are formed by glacial and limno-glacial sediments. A sediment core of 9.85 m long was obtained from a water depth of 2 m and consists of:

0.0–7.0 m – green-brownish organic gyttja
7.0–9.7 m – grey homogeneous clays
9.7–9.85 m – grey varved clays

Chemical composition of the sediments are represented in Figure 6. Loss-on-ignition of organic gyttja increases from 24.4 to 41.7%. Total phosphorus (P_2O_5) varies between 0.07–0.93%, total nitrogen varies between 0.75–2.94% and biogenic silica (SiO_2 aut.) varies between 5.7–36.4% (Arslanov et al., 1992b).

Pollen

The pollen stratigraphy is in accordance with the bulk radiocarbon date of 6,390 ± 120 BP (LU-917) obtained from a sediment depth of 5.0 m. According to the pollen data, 3 pollen zones were identified (Figure 7) between 0.0–5.2 m of the organic gyttja (Davydova et al., 1992).

Atlantic sediments (AT, ca. 8,000–5000 BP, 3.2–5.2 m) are characterised by a prevalence of arboreal pollen (up to 98%), where pine (*Pinus silvestris*) is the main dominant (up to 80%). Other tree pollen is less abundant: *Picea abies* up to 28%, *Betula* sect. *albae* up to 12% and broad leaf pollen up to 12%. These spectra show that the region was covered by mixed forests, and indicate that the climate was warm and humid during the Atlantic period. The climate inferences from the pollen and spore data confirm that the temperature increased by more than 1 °C and humidity was ca. 50 mm higher than at the present (Adamenko, 1995).

The overlying unit (1.8–3.2 m) was identified as Subboreal (SB; 5,000–2,500 BP). The pollen assemblages show an increase of *Picea* pollen up to 44% and *Pinus* up to 50%, and a decrease of broad-leaf tree

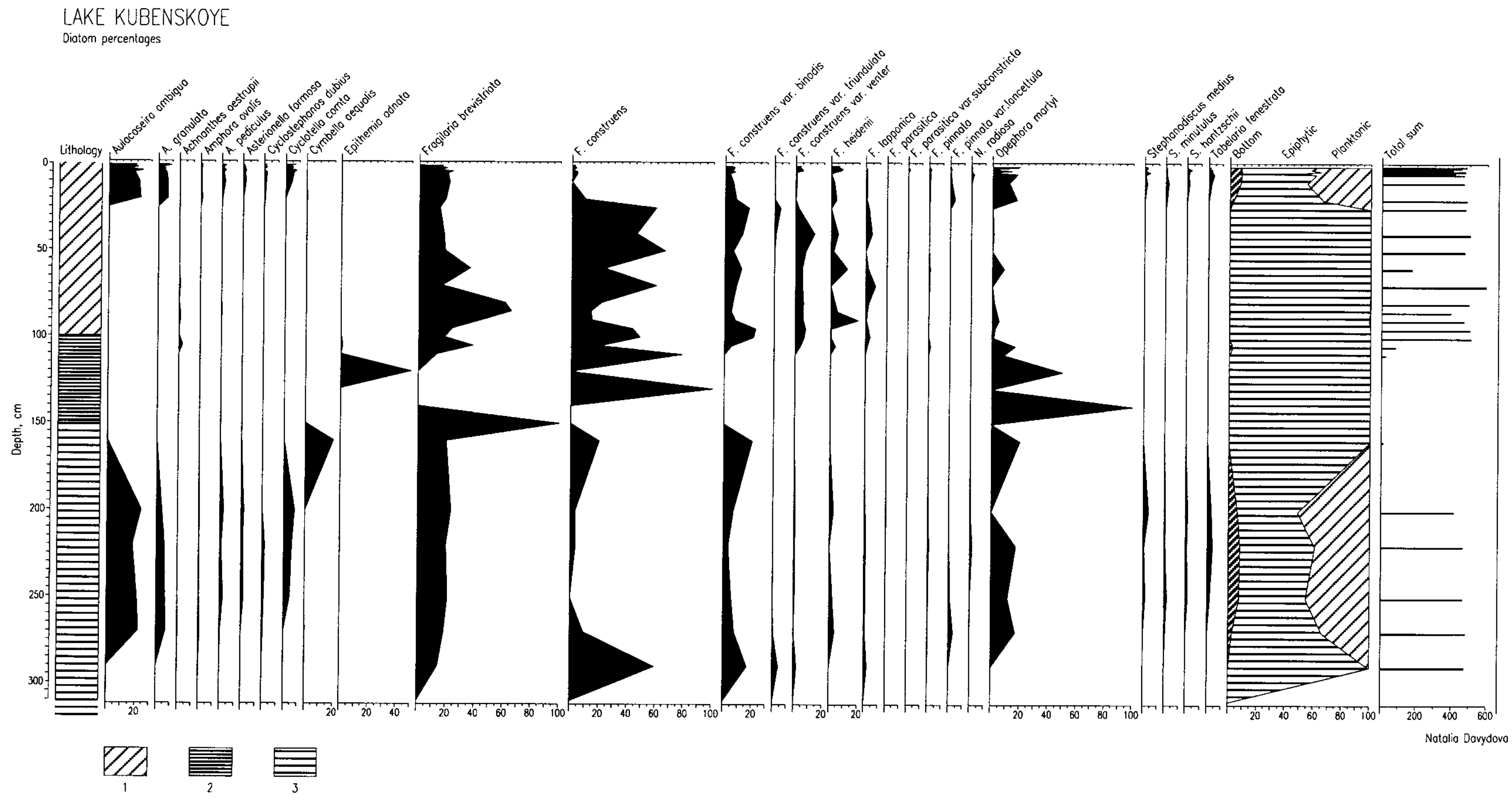

Figure 5. Diatoms in Lake Kubenskoye sediments: 1 – gyttja; 2 – homogenous clay; 3 – varved clay.

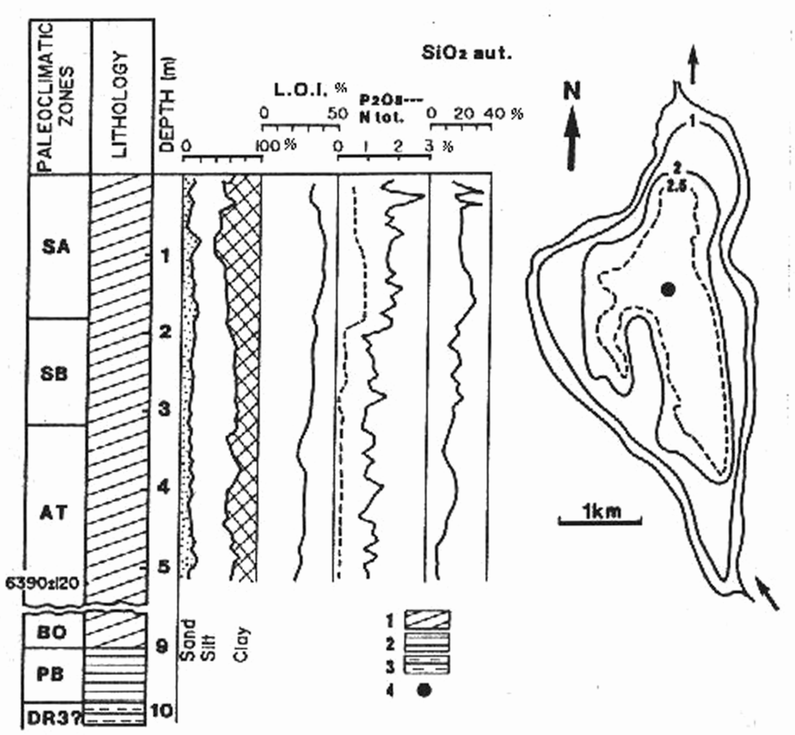

Figure 6. Lake Vishnevskoye sediments: 1 – gyttja; 2 – homogenous clay; 3 – varved clay; 4 – sampling site. The map is a bathymetric contour map with contours in meters.

pollen (to 5%). It indicates a development of spruce-pine forests along the watershed of the lake. These changes reflect cooling during the Subboreal.

According to Adamenko (1995), there were two coolings during the Subboreal when January temperatures were 3 °C lower than at present time, and annual precipitation was 100 mm higher.

The uppermost layer of sediments (0.0–1.8 m), deposited during the Subatlantic (SA, 2,500 BP onwards), is characterised by the dominance of *Pinus* (up to 85%) and *Betula* (up to 25%), with some *Picea* (up to 22%) and *Alnus* (up to 18 %). This assemblage indicates the expansion of pine-birch forests, suggesting that the climate became warmer at this time.

According to the calculations of Adamenko (1995), based on vegetation reconstructions, the climate fluctuations were not very distinct during the SA. It is possible that these pollen assemblages were related to increasing human impacts and formation of new types of landscapes along the lake watershed.

Diatoms

Glacial-lacustrine sedimentation took place during the Younger Dryas (DR3, 9.85–9.70 m) when the northern lowland of the Karelian Isthmus was submerged beneath the Baltic Ice Lake. Freshwater, oligotrophic, planktonic diatoms (*Aulacoseira islandica*, *Cyclotella radiosa* Grun.) are mixed with a few eutrophic diatoms (*Aulacoseira granulata*, *A. ambigua*, *Cyclostephanos dubius* (Fricke) Round), were found in the varved clays of this basin (Figure 8). Diatom frustule concentration was not more than 400,000 per g.

In the Preboreal (PB, 10,200–9,500 BP; 9.0–9.7 m) there was an increase in diatom concentration to 2×10^{-6} per g. Planktonic diatoms dominated as before. Lacustrine sedimentation started at this time and homogeneous clays were deposited.

There was an increase in the sedimentation rate during the Boreal period (BO, 9,500–8,000 BP; 7.0–9.0 m) which reduced the diatom concentration. It is possible that these phenomena are a consequence of an increase in lake level during the Ancylus transgression of the Baltic.

During the Atlantic climatic optimum (AT, 8,000–5,000 BP; 3.2–7.0 m), the diatom content increased to 15×10^{6} per g. The lake became eutrophic and planktonic alkaliphilous diatoms were dominant (*Aulacoseira ambigua*, *A. granulata*, *Cyclostephanos dubius*). This time the lake was separated from the Baltic Litorina Sea and gradually became more shallow.

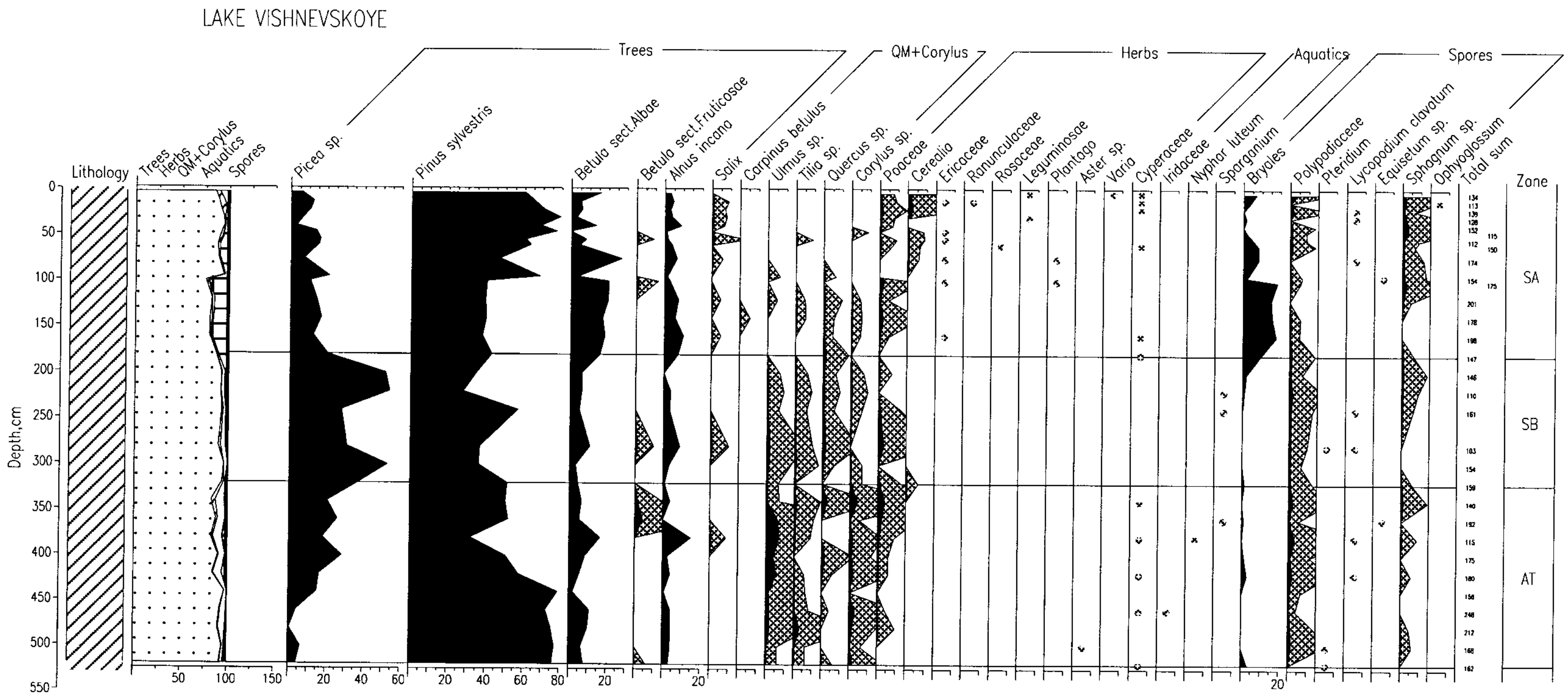

Figure 7. Pollen and spores in Lake Vishnevskoye sediments. Temperature and humidity curves based on the data from trees, grasses and spores regression analysis (Adamenko, 1995).

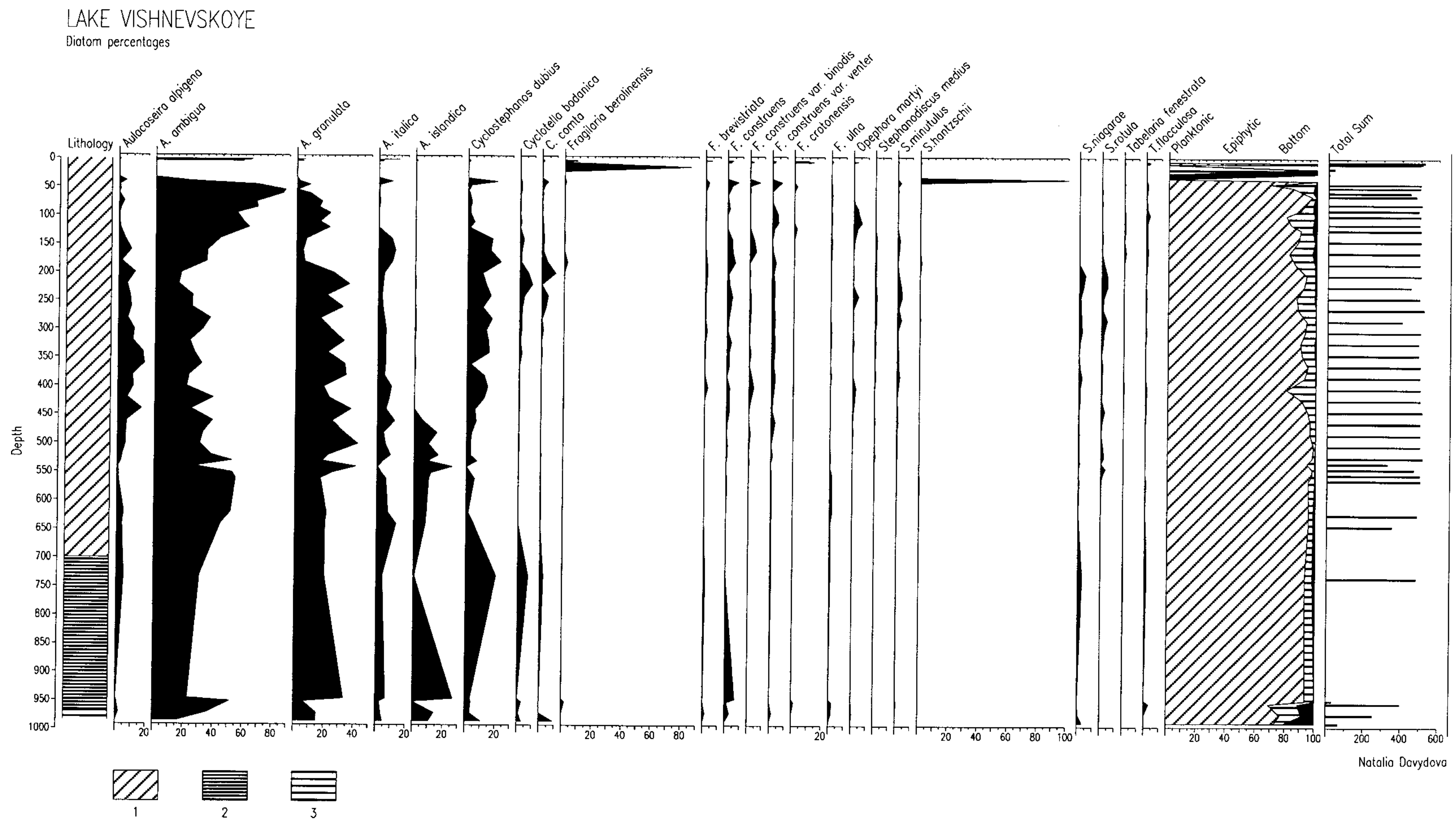

Figure 8. Diatoms in Lake Vishnevskoye sediments: 1 – gyttja; 2 – homogenous clay; 3 – varved clay.

The Subboreal climate corresponds with the increase of littoral diatoms, such as *Opephora martyi*. The next phase of the 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 explains why the increase of the water level was not accompanied by a marked increase in planktonic diatoms. A marked increase in the amount of *Aulacoseira granulata* and *Cyclostephanos dubius* corresponds with increasingly eutrophic conditions in the lake. The colder climate in the Subboreal time corresponded with a decrease in the amount of alkaliphilous diatoms in the sediments.

The next step in lake development appeared to be related with the improvement in climate at about 2,500 BP at the beginning of the Subatlantic period. The lake was isolated from Lake Ladoga and became highly eutrophic. Planktonic alkaliphilous diatoms (*Aulacoseira ambigua*, *A. granulata*) were dominant. The diatom concentration reached its maximum (to 75 $\times 10^6$ per g) in the uppermost 10 cm of the core. The lake was more probably close to its modern shape and size. The climatic deterioration of the Little Ice Age stimulated the development of some littoral diatoms (*Fragilaria* species) and caused an increase in sediment influx, but these changes were minimal. The uppermost layers of lacustrine gyttja demonstrate the increase in human impacts. At the middle of the 20th century, the lake became polluted by nutrient enrichment following the establishment of a cattle farm on the shore. *Fragilaria berolinensis* appeared in the phytoplankton and surface sediments of the lake.

Conclusions

Lakes are relatively ‘short lived’ water bodies in the northwest of the Russian Plain. They originated after the melting of the last glacial ice cover (Würm). The large territories to the south of the ice shield were covered with ice marginal lakes (Kvasov, 1979). After their disappearance, only some relic lakes survived, and the investigated lakes were among them.

Valday Lake was formed ca. 12,500 BP after the disappearance of the ancient ice-dammed Pre-Valday lake (Kvasov, 1979). This deep water lake is situated at the Valday Highland. The process of lake deepening was intensified by permafrost melting during the Preboreal. The warmer and dryer climate during the Boreal caused a decrease in lake level (by 10 m or even more), which is recorded as a hiatus in sedimentation from the shallow water sediment core. The increased precipitation during the Atlantic caused lake levels to rise again. From that time, the water level gradually increased up to the Little Ice Age, and was relatively high in both the Subboreal and Subatlantic periods. The lake was oligotrophic from the Late Pleistocene up to the middle of the 20th century, when human impacts on the lake increased productivity. Kubenskoye Lake, a large shallow mesotrophic basin, is situated in the Kubeno-Sukhona Lowland. The ancient Kubeno-Sukhona Lake, with an outflow to the northwest, was formed during the Luga stage of deglaciation (ca. 13,000 BP), and was shallow. The moist climate during the Atlantic resulted in a gradual increase in lake level, and a general change in the direction of the lake outflow to the east via the new Sukhona River, and the disappearance of the Kubeno-Sukhona Lake. Geological studies of river sand sediments along the Sukhona River (Gey et al., 1978) confirm this conclusion. Paleoecological changes in Lake Kubenskoye during the Late Pleistocene and early Holocene were related mainly to changing climate. In the Atlantic period, the main stratigraphic change was caused by the intensification of erosion processes, and, as a result of it, the lowering of the water level of the lake. During the Subboreal and Subatlantic periods there was a gradual increase of human impacts on the lake and its watershed.

Vishnevskoye Lake’s development was influenced by its position on the lowland between two great waterbodies – the Baltic and Ladoga. It had been an inland bay of the Baltic Ice Lake at the end of the Pleistocene. At the beginning of the Holocene (the Preboreal time), it had become a small shallow isolated lake. It became a deep inland bay of the Baltic again during the Boreal Ancylus transgression. So the first steps of Vishnevskoye Lake’s development were correlated with fresh water stages of the Baltic. After the Boreal period, the lake history was similar to that of Lake Ladoga. The postglacial isostatic uplift of the Baltic Shield and the Karelian Isthmus caused the isolation of Vishnevskoye Lake during the beginning of the Atlantic period. The next major event was the formation of the new outflow from the Saima Lake system to the east via the Vuoksa River, which was the main reason for the Subboreal Lake Ladoga transgression. During this period, Vishnevskoye Lake was still a separate water basin, as it is at present.

The Late glacial and Holocene histories of the three study lakes were closely related to lake-level fluctuations. The main lake-level changes took place during the Atlantic climate optimum, both for lakes in the highland and in the lowland territories of the Russian Plain.

Similar data were obtained in lakes of the Karelian Isthmus (Tarasov et al., 1994; Davydova et al., 1996; Davydova & Servant-Vildary, 1996; Subetto et al., 1999), which is situated to the north of the Russian Plain. The Atlantic period was the warmest and the most humid epoch of the Holocene at the East European Plain. Our data confirm the reconstruction of Holocene temperatures and humidity, based on the palynological data (Adamenko, 1995). The circumstances of changes in lake-level were different for the three lakes. The Valday Lake water level gradually increased. In Kubenskoye Lake the increase in lake level caused the formation of a new outflow, via the Sukhona River, directed to the east, and the disappearance of the ancient Kubeno-Sukhona Basin. The post-Atlantic history of Vishnevskoye Lake was related to tectonic processes along the Baltic Shield.

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