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VEGETATION AND CLIMATE CHANGES AT THE EEMIAN/WEICHSELIAN TRANSITION: NEW PALYNOLOGICAL DATA FROM CENTRAL RUSSIAN PLAIN

Olga K. BORISOVA[1]

Abstract. Palynological analysis of core Butovka obtained from the Protva River basin 80 km south-west of Moscow (55º10’N, 36º25’E) provides a record of vegetation and climate change in the central Russian Plain spanning the Last Interglacial and the beginning of the following glacial epoch. Pollen profiles of the Mikulino (Eemian) Interglaciation in the Central Russian Plain show a distinctive pattern of the vegetation changes, reflecting an increase in temperatures towards the optimum phase of the interglaciation followed by a gradual cooling. Rapid climatic deterioration, manifesting an onset of the Valdai (Weichselian) Glaciation, took place after a slower cooling accompanied by increasing humidity of climate during the post-optimum part of the Mikulino Interglaciation. The interglacial/glacial transition had a complex structure, being marked by a sequence of secondary climatic oscillations of varying magnitude. A decreasing role of mesophilic plants and an increase in abundance and diversity of the xerophytes and plants growing at present in the regions with highly continental climate in the Butovka pollen record suggests that during the Early Valdai the climate grew both more continental and arid. With this tendency at the background, two intervals of climatic amelioration can be distinguished. Both of them are marked by the development of the open forest communities similar to the contemporary northern taiga of West Siberia. The latter of the two warm intervals had a larger magnitude of temperature changes than the first one, as indicated by a greater landscape role of dark-coniferous trees (*Picea* + *Abies* + *Pinus sibirica*). Based on its stratigraphic position and inferred features of climate and vegetation, the latter of the two warm intervals identified in the Butovka pollen profile can be correlated with the Upper Volga Interstade in the Russian Plain, or the Brőrup Interstade in West Europe. We can also tentatively correlate it with warm DO event 23 as reflected in the oxygen isotope record from the Northern Greenland deep ice-core (NorthGRIP Members, 2004). A slighter and shorter warming within the first cold stage of the Early Valdai probably had an interphasial rank and corresponded to a shorter DO event 24 in the NorthGRIP oxygen-isotope curve.

Key words: palynology, the Eemian/Weichselian transition, Central Russian Plain.

INTRODUCTION

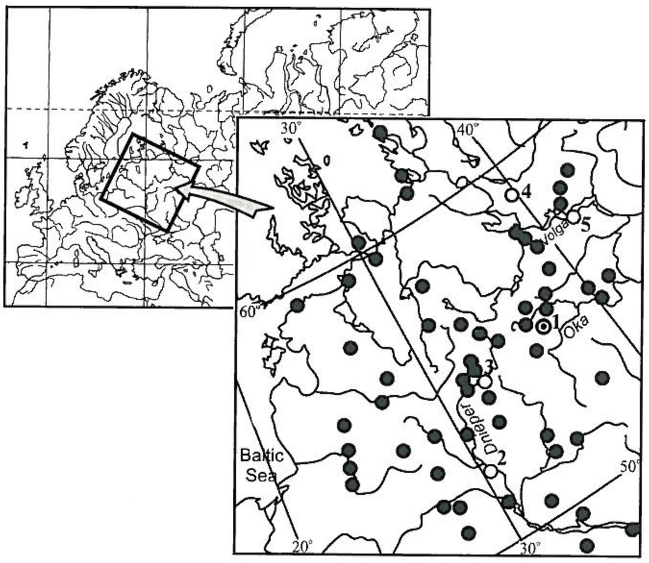
Since 1950's more than 20 sections of the Eemian (Mikulino) Interglacial deposits were discovered and studied palynologically in the central region of the Russian Plain (Fig. 1). In some of these sections interglacial deposits are directly overlain by lacustrine sediments of the Early Weichselian (Early Valdai) glacial epoch (e.g. Ples — Grichuk and Grichuk, 1959; Mikulino — Grichuk, 1961). During the initial part of the glaciation secondary climatic oscillations can be traced against the background of general cooling. Nevertheless, pollen studies were mainly focused on the interglacial epoch *s. str.*, remaining rather schematic for the “glacial” parts of the sequences. Recently studied Butovka section situated in the Borovsk region 80 km south-west of Moscow (55º10’N, 36º25’E) provides new detail palynological data on the vegetation history and climate changes at the transition from the Mikulino interglaciation to the Early Valdai glacial epoch.

[1] Laboratory of Evolutionary Geography, Institute of Geography, Russian Academy of Science, Staromonetny 29, 119017 Moscow, Russia; e-mail: olga@yas.geogr.msu.su

STUDY AREA

The study site is situated in the drainage basin of the Protva River (a large tributary of the Oka River, Volga basin), on the southeastern slope of the Smolensk-Moscow Upland, in the boundary zone of the Moscow Stage of the Dnieper Glaciation (an analogue of the Warta Stage of the Saale Glaciation in West Europe; Fig. 1). The landscape represents an undulating glacial accumulative plain, substantially changed by fluvial processes. Broad valleys (1 to 2.5 km wide) formed by glacial melt water runoff during the Moscow glacial stage dissect the watersheds, being only partly inherited by present-day river net (Rychagov, Antonov, eds., 1996).

Climate of the region is temperate with mean January temperature –10.3°C, and average July temperature 17.5°C. The climate is relatively humid, mean annual precipitation being app. 600 mm. About 2/3 of this amount occur within the frostless period. The snow cover persists on an average for 4.5 months. The region belongs to the southern taiga zone, the sub-zone of mixed broad-leaved-coniferous (mainly oak-spruce) forest. Meadows occupy about 10% of the area.



Hollow circles indicate sections with Eemian/Early Weichselian transition:
1 — Butovka;
2 — Borkhov Rov, palynologist L.V. Kurierova (Chebotareva, Makarycheva, 1982);
3 — Mikulino, palynologist Sun Xiangjun (Grichuk, 1961);
4 — Domanovo, palynologist L. A. Gaigerova (Vigdorchik *et al.*, 1970);
5 — Ples, palynologists: M. P. Grichuk and V. P. Grichuk (1959).

Fig. 1. Map of Eemian (Mikulino) sites in central Russian Plain and adjacent areas

FIELD AND LABORATORY METHODS

A sediment core 920 cm long was collected from the interior part of a raised bog using the hand-operated corer. The core included 110 cm of sandy clay, 190 cm of clayey gyttja and peat deposits, and 440 cm thickness of low-organic lake clay overlain by 180 cm of *Sphagnum* peat. The core was sub-sampled for pollen analysis at 10 cm intervals. Samples were processed using the pollen extraction technique of Grichuk (1940), with separation in heavy liquid (cadmium iodine). 500–600 pollen grains and spores per sample were counted in the organic sediments, 250–300 grains — in clayey sediments with low pollen contents. Relative frequency of pollen was calculated based upon the total terrestrial pollen and spores sum (Fig. 2). In addition, pollen diagrams based on tree pollen sum (TPS) (Fig. 3) and non-arboreal pollen (NAP) sum (Fig. 4) were compiled, following the way of separate calculations for the main components of pollen spectra traditionally used in Russian literature. This approach was applied to facilitate the comparison with earlier published pollen sequences, as well as to trace changes in the composition of the woodlands and open plant communities. To calculate pollen concentrations, Lycopodium tablets (Stockmarr, 1971) were added to each sample. All diagrams were compiled using Tilia and TiliaGraph programs (Grimm, 1990). The pollen sequence has been divided into 12 local pollen assemblage zones (LPAZ) on the basis of changes in the composition of pollen and spores, aided by results of a constrained cluster analysis (CONISS; Grimm, 1987).

PALYNOLOGICAL STUDY OF THE BUTOVKA SECTION: RESULTS AND DISCUSSION

LPAZ 1 (790–920 cm) — clayey sand (unit 1)

Among arboreal pollen (AP), that of Pinus sylvestris is abundant, Picea and Betula alba are prominent (Fig. 3). Rare pollen of Abies is registered. Of the shrubs, Betula humilis is the most important. In sub-zone 1a (815–920 cm), Betula nana reaches 10% of TPS. Pollen of Alnaster fruticosus, a cryophile shrub, widespread within the permafrost area, is also found in sub-zone 1a. Spores of another typical cryophyte, Lycopodium pungens, are registered in the same horizon. Artemisia dominates the NAP group. Pollen of Helianthemum — a typical heliophyte — indicates a wide spread of open landscapes. Low concentrations of pollen and spores in sub-zone 1a imply both low pollen productivity of plants and a rapid accumulation of the clayey sand. Pollen assemblage in sub-zone 1a points to a periglacial-type vegetation, combining features of forest tundra and forest steppe with scattered birch copses in protected habitats. Spruce occurred in places with richer and more humid soil. Herbaceous communities included cold dry Poaceae–Artemisia steppe, as well as meadows with some tundra elements. In sub-zone 1b (790–815 cm), AP makes up 80% of spectra, spruce reaching almost 50% of TPS. Rare pollen of Siberian tree species, Abies and Larix, occur here. Among NAP, Artemisia and Poaceae are predominant. A sharp increase in pollen concen-

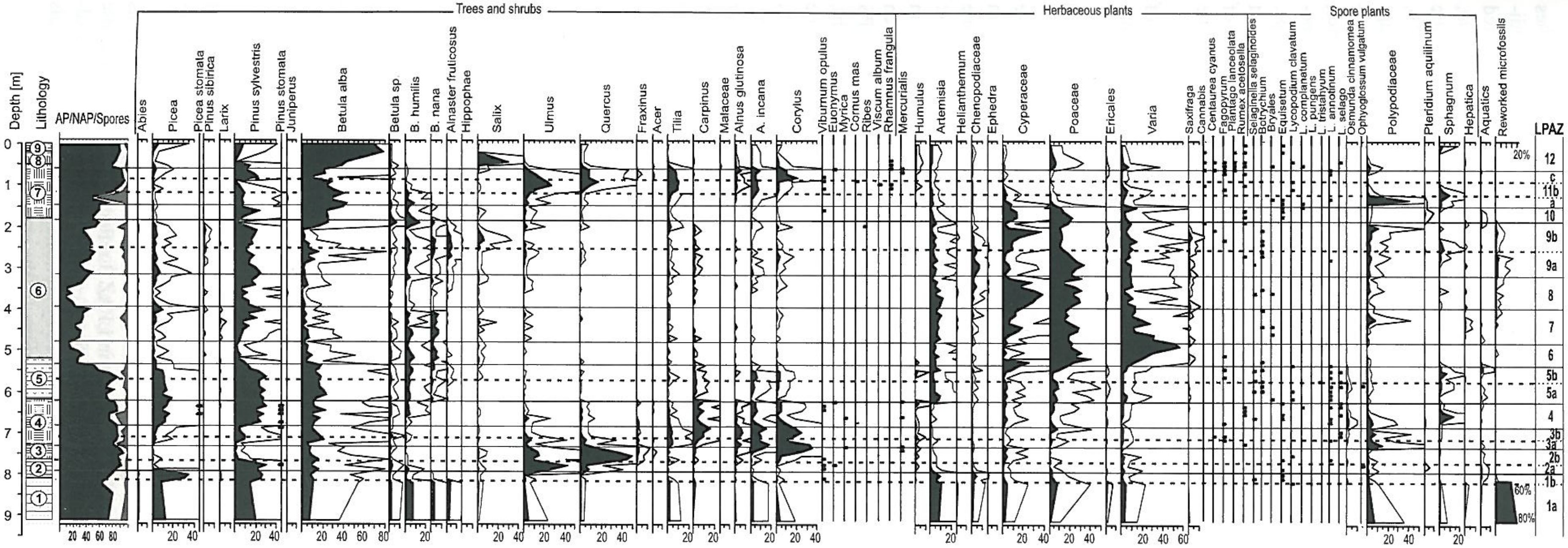
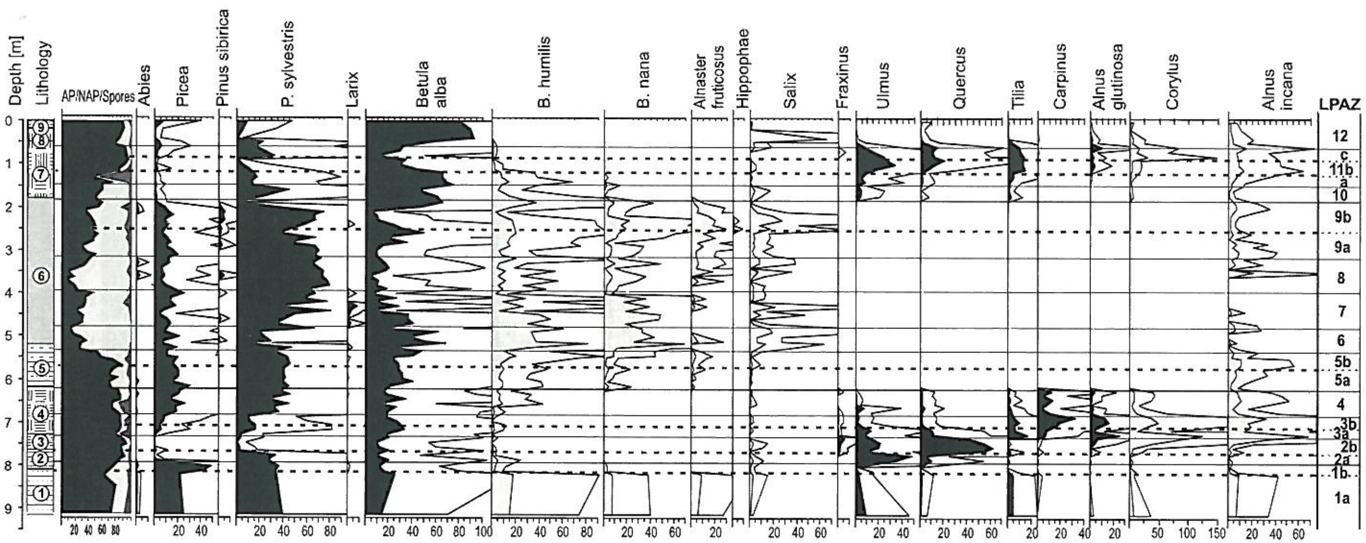


Fig. 2. Pollen diagram for Butovka — AP+NAP+Spores = 100% (for explanations see Fig. 3)



① lithological units:
unit 1 – clayey sand with rare gravel up to 2 cm,
unit 2 – dark brown clayey gyttja;
unit 3 – light brown compressed peat;
unit 4 – dark brown peat slime;
unit 5 – grey-brown lake clay with high content of plant detritus;
unit 6 – light-grey lake clay;
unit 7 – dark brown well decomposed peat;
unit 8 – brown peat with *Sphagnum* remains;
unit 9 – light brown loose *Sphagnum* peat saturated with water.

Fig. 3. Composition of arboreal pollen in the Butovka section — tree pollen sum = 100%

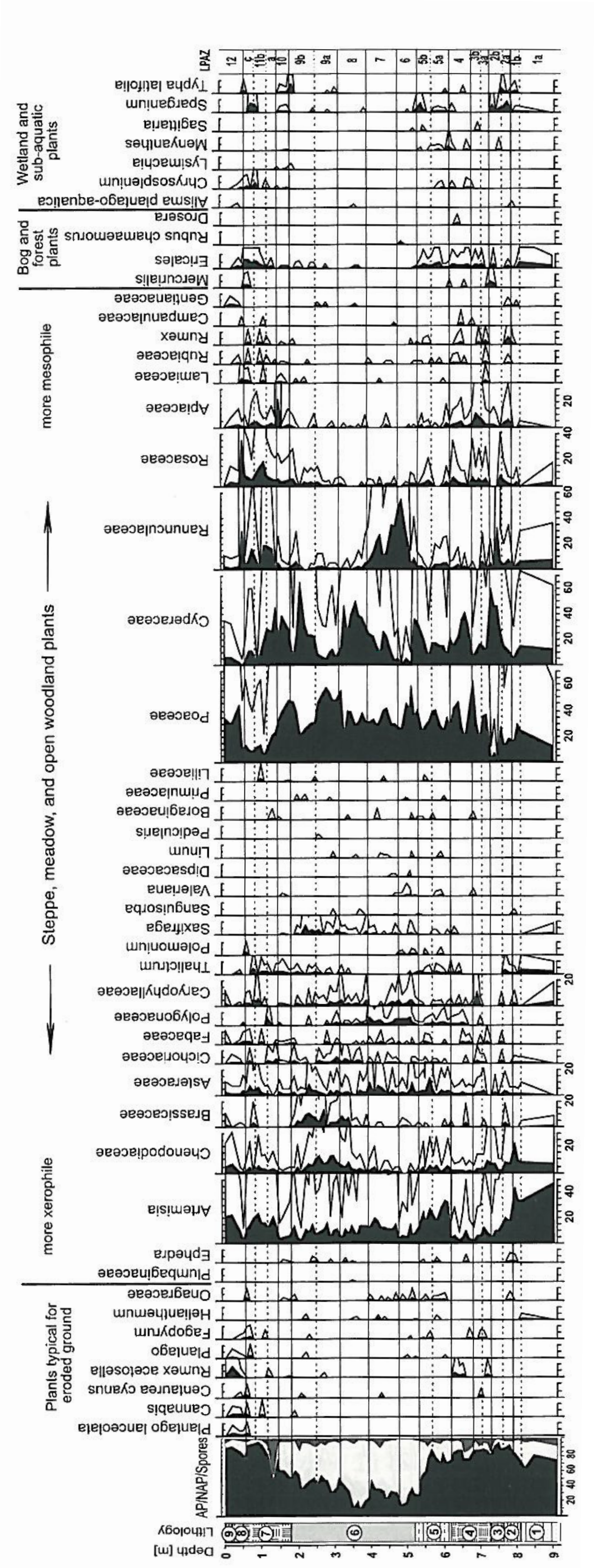


Fig. 4. Composition of non-arboreal pollen in the Butovka section — NAP = 100% (for explanations see Fig. 3)

trations points to a rapid climate amelioration: *Picea reaches* 80–90 thousand grains/cm^3, indicating an increase in humidity (Fig. 5 A). A corresponding raise of water table is indicated by appearance of thelmatophytes: *Typha latifolia*, *Alisma*, and *Sparganium*. Pollen of relatively thermophile aquatic plants (*Nymphaea* and *Nuphar*) appears in sub-zone 1b. The warming has not yet reached the modern level, as suggested by the finds of spores of *Selaginella selaginoides*. Pollen of typical xerophytes, relatively indifferent to cold winter, such as *Ephedra* and *Kochia scoparia*, indicate that the periglacial communities were still preserved in the landscape. Presumably, a rapid afforestation of the area brought about a decrease in the erosional activity, as the frequencies of re-worked Palaeozoic and Mesozoic microfossils in sub-zone 1b are much lower than at the base of the core (Fig. 2).

On the whole, LPAZ 1 corresponds to the final stage of the Moscow Glaciation and transition to the Mikulino Interglacial epoch.

LPAZ 2 (730–790 cm) — dark brown clayey gyttja (unit 2) and the lower peat layer (unit 3)

Aquatic plants and thelmatophytes are especially diverse in sub-zone 2a, indicating that sedimentation took place in a shallow warm lake. With further warming the lake became filled in and overgrown, and a rich fen was formed in its place: in sub-zone 2b NAP is dominated by Cyperaceae. AP in LPAZ 2 reaches 95% of spectra due to a sharp rise in pollen contents of the broad-leaved trees: *Ulmus* (up to 40% of TPS in sub-zone 2a) and *Quercus* (up to 60% in sub-zone 2b). These species penetrated the forests of birch and Scots pine (*Pinus sylvestris*) and rapidly replaced them. In sub-zone 2b, *Tilia*, *Fraxinus*, *Acer*, and finally *Carpinus betulus* appear. Pollen concentrations of the broad-leaved trees in this layer exceed 500 thousand grains/cm^3. Relatively thermophile shrubs (*Corylus avellana*, *Viburnum*, *Euonymus*) occurred in the undergrowth and on the forest edge. Pollen of species growing on damp ground (*Alnus incana* and *Salix*) is increasingly important in LPAZ 2.

LPAZ 3 (680–730 cm) — brown peat (unit 4)

AP contents decrease to 80–85% mainly due to an increase in Polypodiaceae spores (up to 13% of spectra). *Osmunda cinnamomea* is registered in this layer. An increase in *Carpinus* (up to 40% of TPS in sub-zone 3b) and *Tilia* pollen contents at the boundary between LPAZ 2 and 3 is accompanied by a sharp decline of *Ulmus* and *Quercus*, as well as by the rise of *Betula alba*, *Pinus*, and *Picea* pollen curves. These drastic changes reflect restructuring of the forest communities and opening of the forest canopy favourable for the spread of shrubs. Pollen contents of *Corylus avellana* reach here 125% with respect to TPS (Fig. 3). Broad-leaved forests dominated by *Carpinus* reached then the greatest species diversity, containing 3 species of *Ulmus*, 2 species of *Quercus*, 2 species of *Tilia*, *Acer*, and *Fraxinus*. In sub-zone 3b pollen concentrations of the broad-leaved trees reach their maximum for the entire sequence: over 10^6 grains/cm^3. Pollen curve of Alnus glutinosa, forming swamped forests on the waterlogged soil, rises in this zone. Pollen spectra in LPAZ 3 reflect an expansion of dense mixed broad-leaved forest, succeeded by coniferous-broad-leaved forest dominated by hornbeam. This phase corresponds to the maximum warming for the entire sequence.

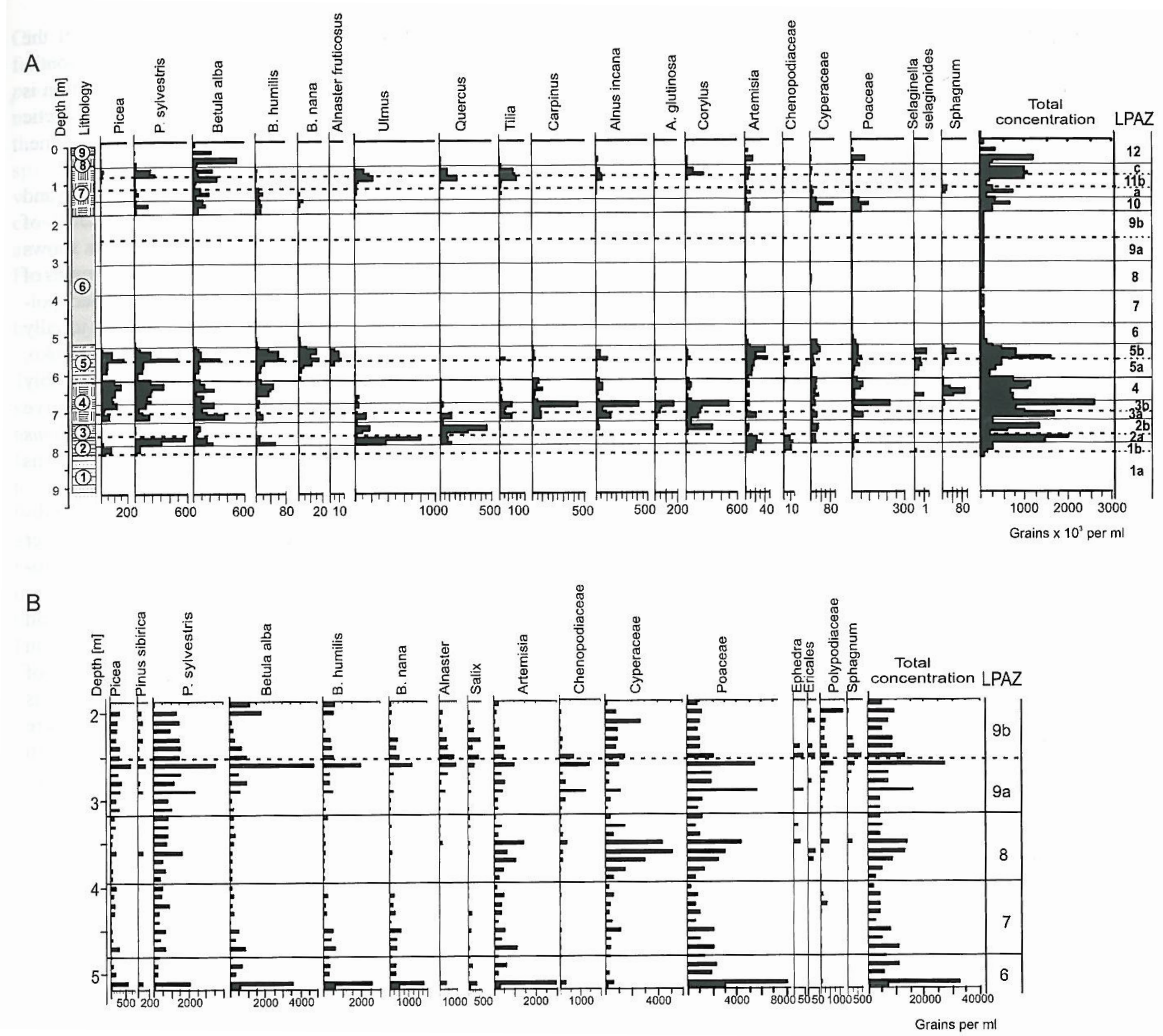


Fig. 5. Concentrations of pollen and spores of selected taxa in Butovka section: A — in the entire profile, B — in the Early Weichselian (Early Valdai) part of the sequence (for explanations see Fig. 3)

LPAZ 4 (620–680 cm) — brown peat (unit 4)

Substantial changes occur within the AP group: the decline of the broad-leaved trees, *Alnus glutinosa*, and *Betula alba*, is accompanied by rise of Scots pine and spruce up to 45 and 30%, respectively. Concentrations of Picea pollen reach $2x10^5$ grains/cm^3, those of *Pinus* — $3x10^5$ grains/cm^3. Along with pollen, stomata of *Picea* and *Pinus* are found in LPAZ 4. Rare pollen grains of *Abies* and *Larix* are registered. NAP content (mainly that of Poaceae) increases from 10 to 20% of the spectra. Pollen of herbs — inhabitants of wet meadows is both diverse and abundant. *Sphagnum* curve rises, and pollen of *Drosera* — a typical plant of peat mires — is found in the layer with the highest content of *Sphagnum* spores. Spores of Osmunda, taiga species of club-mosses (*Lycopodium selago*, *L. annotinum*), and *Pteridium aquilinum*, inhabitants of pine and other light forests, occur frequently. These changes indicate an expansion of dark coniferous and pine forests with participation of broad-leaved trees and birch, reflecting a gradual cooling and increasing humidity of climate. The positive shift in the water balance once again brought about formation of a lake in place of the peat mire.

A distinct succession of forest communities, reflected in LPAZ 2–4 of the Butovka profile, as well as composition of the flora during the warmest (optimum) phase, proves that this sequence belongs to the Mikulino Interglaciation. On the basis of extensive material collected by many authors, V.P Grichuk (1961) worked out the stratigraphic scheme of the Mikulino Interglaciation on the Russian Plain. The climatic optimum of the interglaciation coincides with maximum of *Carpinus* (LPAZ 3 in Butovka section). The absence of direct correlation between heat and moisture supply during the interglacial epoch has long been established by palaeobotanists (Grichuk, 1960), who noted the displacement of the maximum of moisture supply to the second half of the interglaciation. As a result, an interglacial epoch was divided into two stages: an early warm and dry, thermoxerotic stage, and a later (post-optimum) warm and humid, thermohygrotic stage (Grichuk, 1960). The peculiarities of these stages are well differentiated on the Butovka pollen diagram, where sub-zone 3b and zone 4 correspond to the later, thermohygrotic stage of the Mikulino Interglaciation. Thermoxerotic and thermohygrotic stages can be traced within different interglaciations, being their characteristic feature (Velichko *et al*., 1991).

LPAZ 5 (530–620 cm) — grey-brown lake clay with high content of plant detritus (unit 5)

AP decreases from 80 to 60%, *Pinus* (40–50%), *Betula* (up to 40%), and *Picea* (20%) being the main forest-forming trees. Pollen curve of *Betula humilis* rises; *B. nana* and *Alnaster* re-appear in the spectra. Presence of these cryophile shrubs suggests that pollen of the broad-leaved trees in this layer is re-deposited from the underlying sediments. The broad-leaved trees are also incompatible with *Botrychium boreale* and *Selaginella selaginoides*, registered in zone 5. In sub-zone 5a pollen concentrations of the broad-leaved species are 50–80 times lower than in zone 4, while those of pine and spruce decrease only 2–5-fold.

Artemisia contents in LPAZ 5 reach 30% of NAP. Pollen of light-demanding and cold-tolerant plants (*Helianthemum*, *Polemonium coeruleum*, *Thalictrum*, *Linum*), as well as of the plants growing on eroded and sandy ground (*Ephedra*, *Saxifraga*, *Plantago*, Onagraceae) appears in the spectra. These changes suggest a decline of forests, including both their opening, and diminishing forested area. Presence of *Pteridium aquilinum* and *Lycopodium tristachyum* (species of light coniferous and open mixed forest), of *Juniperus* and other shrubs confirm this conclusion. Open boreal coniferous and birch forests with abundant shrub thickets spread over the area under climatic conditions, colder than the present. Changes in AP contents and pollen concentrations imply that the earlier part of the interval (sub-zone 5a) was slightly colder than its later part. LPAZ 5 corresponds to the transition from the Mikulino interglaciation to the Early Valdai glaciation (zone M8 according to Grichuk, 1961).

LPAZ 6 (475–530 cm) — the basal part of the light-grey lake clay (unit 6)

AP contents decrease to 15%. TPS is dominated by *Betula alba* (over 60%), while pine curve drops below 30%, and spruce remains as low as at the top of LPAZ 5. Concentrations of tree pollen are low (Fig. 5 B). Pollen curves of mesophilic and cold-tolerant shrubs (*Betula humilis*, *B. nana*, *Alnaster*, and *Salix*) form distinctive peaks. Shrub and dwarf birch reach their maximum values for the entire section, their pollen concentrations being relatively high compare to other intervals within the layer of low-organic clay (Fig. 5 B). Poaceae and Ranunculaceae families, including mainly mesophilic plants, dominate NAP group. As in sub-zone 5b, pollen of the cold-tolerant and heliophile plants (*Polemonium coeruleum*, *Thalictrum*, *Linum*, *Valeriana*, *Sanguisorba*) often occurs. Inhabitants of the disturbed, sandy, and rocky soil (*Fagopyrum*, *Saxifraga*, *Polygonum bistorta/viviparum*, Onagraceae) are also typical for LPAZ 6. A gradual cooling reflected in LPAZ 5 continued during the initial stage of the Valdai glacial epoch. Vegetation became similar to the southern (shrub) tundra, or birch forest tundra. This assumption is confirmed by presence of *Rubus chamaemorus*, a hypoarctic species, equally common on both sides of the northern tree line.

LPAZ 7 (395–475 cm) — lake clay (unit 6)

AP contents increase up to 40–45% of terrestrial pollen and spores. *Pinus sylvestris* curve rises from app. 40 to 60% of the TPS at the top of the zone, while *Betula alba* shows a marked decline. *Larix* pollen is registered in most samples of the zone. Comparison between the composition of recent pollen spectra and that of the vegetation shows that *Larix* is usually strongly underrepresented in the pollen spectra (Pyavchenko, 1966). Therefore, constant presence of larch pollen probably indicates a spread of larch open forest. Spruce pollen curve forms a small but distinct peak in LPAZ 7. Pollen of *Pinus sibirica* is scarce. Of the cryophile shrubs, *B. nana* remains the most abundant, while *B. humilis* retreats gradually.

Changes in the AP composition compare to LPAZ 6 indicate an increase in the continentality of climate, with warmer and possibly drier summer. Warmer summer caused development of larch and spruce open woodlands, similar to the modern forest tundra of West Siberia, with widespread thickets of dwarf birch. Scots pine probably occurred in warmer places with sandy soil. According to the studies of recent pollen spectra (Pyavchenko, 1966), *Pinus sylvestris* is usually strongly over-represented in the forest tundra, where the actual landscape role of pine woodlands is very low. In spite of its high relative frequencies in this zone, concentrations of pine pollen remain as low as in LPAZ 6 (Fig. 5 B). Increasing role of *Artemisia* (up to 20% of NAP) and Chenopodiaceae, presence of plants, growing on barren or eroded ground (*Centaurea cyanus*, Onagraceae, and Hepaticae), and of typical xerophytes (*Eurotia ceratoides*), and heliophytes (*Helianthemum* supsp.) also indicate slightly warmer and drier summer conditions. Along with the shrub thickets, open vegetation was then represented by meadows with periglacial steppe elements. Places with higher ground moisture were occupied by mires and wet meadows. Such a complex pattern of plant communities was characteristic for glacial epochs of the Late Pleistocene (Grichuk, 1969; Borisova, 1994). It has only partial and incomplete analogues in the present-day "interglacial" vegetation.

LPAZ 8 (315–395 cm) — lake clay (unit 6)

AP contents drop to app. 10% — their minimum value for the entire profile. Tree pollen is represented almost exclusively by *Pinus sylvestris* — a prolific pollen-producing plant with pollen most easily transported by wind. Tree pollen concentrations, including that of Scots pine, are very low (Fig. 5 B). Pollen percentages of cold-tolerant mesophilic shrubs, calculated with respect to the TPS, are also low. Only pollen values of *Alnaster fruticosus*, a species characteristic to the regions with severe continental climate and spread of permafrost, slowly increase in LPAZ 8. Rare pollen grains of *Abies* and *Pinus sibirica* — also species with predominantly Siberian present-day ranges — are registered in this zone.

Among herbaceous plants, Poaceae, Cyperaceae, and *Artemisia* are predominant, all of them forming peaks in pollen concentrations, accompanied by a smaller increase in

Chenopodiaceae (Fig. 5 B). Spores of typical cryophytes found in this layer (*Botrychium boreale*, *Lycopodium pungens*, *Selaginella selaginoides*) are indicative of cold climate. The landscape became almost entirely forestless, with the vegetation of the periglacial tundra type, with only sparse groups of spruce and birch trees. Open vegetation with discontinuous ground cover promoted erosion processes, as indicated by increasing amount of the reworked ancient microfossils in the sediments, as well as by finds of Hepaticae spores (Fig. 2).

LPAZ 9 (180–315 cm) — upper part of the light grey lacustrine clay (unit 6)

The proportion of AP in the spectra increases to 50–60%. Tree pollen is dominated by *Pinus sylvestris* and *Betula alba* in sub-zone 9a, and only by pine in sub-zone 9b (Fig. 3). *Picea* contents rise to app. 20%. Pollen curves of shrub and dwarf birch form peaks in the middle part of LPAZ 9. The maximum contents of *Alnaster* and *Salix* pollen are characteristic for sub-zone 9b. Pollen of *Pinus sibirica* occurs in most samples in this zone along with rare pollen of *Abies* and *Larix*. *Hippophae rhamnoides*, a heliophyte, is represented in sub-zone 9b. Pollen concentrations of all arboreal species reach in LPAZ 9 their maximum values for the entire layer of lake clay (unit 6) (Fig. 5 B). Poaceae dominates NAP group in sub-zone 9a, and Cyperaceae — in sub-zone 9b. Chenopodiaceae contents reach 15% of NAP in the lower part of the zone (Fig. 4). Rare pollen of *Ephedra* is also recorded. Spores, represented mainly by Polypodiaceae and *Sphagnum*, reach 10% of the total spectrum.

Composition of pollen spectra indicates forest expansion, caused by substantial climate amelioration. The main forest types included open woodlands of birch and spruce with minor participation of Siberian pine and fir, and possibly patches of Scots pine and larch (*Larix*) woods. The vegetation was then similar to the present-day northern taiga of West Siberia, although high percentages of NAP with high relative abundance of *Artemisia* and Chenopodiaceae, and presence of cryophytes, xerophytes, and heliophytes, suggest that this warm interval had an interstadial rank. Based on changes in the pollen spectra in LPAZ 9 an earlier, thermoxerotic, and later, thermohygrotic phase can be distinguished within this interval. According to Grichuk (1969), these phases can be traced within a typical interstade, while minor warmings non-differentiated in terms of humidity of climate, such as the one reflected by LPAZ 7 in Butovka section, should be considered as "inter-phase" events.

Accumulation of low-organic lake clay (unit 6) ceased as the shallow depression was filled in with sediments. In the Early Holocene, when the climate became sufficiently warm and humid for peat formation, sedimentation at the site resumed (LPAZ 10–12).

COMPARISON TO OTHER SECTIONS INCLUDING THE EEMIAN/EARLY WEICHSELIAN TRANSITION

Second-order climatic events can be distinguished in other pollen profiles with continuous sedimentation at the transition from the last interglaciation to the full-glacial conditions of the Early Valdai. Thus, in the Mikulino type-section (Grichuk, 1961), an interstadial warming is expressed by a rise of AP contents and frequencies of *Pinus* and *Picea* within the group. In the warmest part of the interval values of *Betula nana* and *B. humilis* drop below 10% of TPS. NAP is dominated by Cyperaceae, which indicates an increase in the effective moisture. This short warm event can be correlated to the earlier warming reflected in the Butovka profile (LPAZ 7), rather than to the later longer and warmer interstade (LPAZ 9). Its stratigraphic position supports such correlation, as the zone under consideration is separated from the final zone of the Mikulino Interglaciation (M8) only by a thin layer (0.5 m) of lake clay.

South-east of Butovka, at Borkhov Rov (Fig. 1), two warm phases can be distinguished within the Early Valdai part of the pollen sequence, the first of them being both shorter in duration and smaller in the magnitude of changes (Chebotareva, Makarycheva, 1982). During the earlier warming, AP is dominated by *Pinus* pollen (over 70% of TPS). *Betula* values decrease compare to the previous cold stage from 60–80 to app. 20%. This assemblage reflects a development of open pine and birch woodland. The second, more profound warming was accompanied by greater expansion of pine woodlands, *Pinus* pollen reaching over 90% of TPS. Percentages of *Betula alba* drop below 10%; *B. humilis* and *B. nana* are scarce. *Picea* pollen is registered in this interval, and the percentages of *Lycopodium* and *Sphagnum* increase considerably, indicating an increase in effective moisture and milder climatic conditions, favourable for spruce penetration into the plant communities.

The role of spruce in the interstadial vegetation in the Butovka area was greater than in the region of Borkhov Rov, in accordance with our earlier conclusion that during both warm and cold events of the Valdai glacial epoch participation of spruce and other dark coniferous trees (*Abies*, *Pinus sibirica*) increased to the east of the Russian Plain, while that of Scots pine increased to the west (Borisova, 1994; Borisova, Faustova, 1994). The ice-wedge casts discovered in the Borkhov Rov suggest development of permafrost in the area as early as the first post-Mikulino cold stage, being in good agreement with the finds of cryophyte pollen and spores in the corresponding cold interval in Butovka (LPAZ 6) and other sections.

North-east of Butovka, in the Domanovo section (Vigdorchik *et al.*, 1970), two phases of climatic amelioration can be traced in the Early Valdai part of the pollen profile as well. The earlier warming was characterised by spread of birch woods with rare spruce trees and thickets of *Betula nana*, while the latter one featured an expansion of spruce and birch boreal forest with pine copses on lighter and warmer soil. An important role of tree birch in the vegetation throughout the glacial epoch, and especially in its warmer intervals, is due to high tolerance of this "pioneer" tree to cold climate, windstress, drought, and spring frosts. According to Huntley and Birks (1983), values of birch pollen over 25% can indicate local birch-dominated woodland, and values over 50% indicate dense birch forests. The decrease in the continentality of climate during the interstades is reflected in greater proportion of pollen of meadow herbs in the NAP group, while during cold stages NAP is dominated by *Artemisia*. A larger contribution of conifer trees into the vegetation during the second interstade can be attributed to warmer and more humid climate of this interval.

In Ples section (Grichuk, Grichuk, 1959), 200 km south-east of Domanovo, an episode of substantial climate amelioration is expressed by an increase in AP percentages reflecting a rapid afforestation of the area. Birch forests with spruce occupied the area in the early part of this interval, those of larch, pine and spruce with *Pinus sibirica* spread during its late part. These forests were similar to the contemporary middle taiga in West Siberia. This part of the pollen sequence is very similar to LPAZ 9 in the Butovka section. In Ples pollen profile, a wide *Betula* zone with *Betula* pollen values reaching 95% of TPS separates the interstadial warming from the final phase of the Mikulino Interglaciation (Grichuk, Grichuk, 1959). New palynological studies of the Mikulino and Early Valdai sediments at Ples (Borisova *et al*., 2004) provided more detail information on the "birch" interval, revealing that birch woodlands occupied the area during a short warmer phase within it, both preceded and followed by spread of birch forest tundra. This small-scale warming can be tentatively correlated with the one reflected by LPAZ 7 in the Butovka pollen sequence.

Similar short-term climatic oscillations, modifying the transition from Eemian to the Weichselian Glaciation, can be seen in other sections in the East, Central and West Europe, where continuous sediment sequences of this age are studied in detail (e.g. Ionenis — Kondratene, 1965; Rederstall-I — Menke, Tynni, 1984; Gröbern — Litt, 1990), suggesting the broad geographical distribution of these events. A comparison of the AP curve from Butovka section with the oxygen-isotope curve derived from the deep ice core from northern Greenland (NorthGRIP Members, 2004) reveals a close resemblance of the two curves (Fig. 6). The main early-glacial peaks of AP in Butovka can be correlated with the warm Dansgaard-Oeshger (DO) events 24 and 23. In that case, the cold Greenland stage 26, following DO event 26 and reflecting the cooling in the end of the Eemian/Mikulino Interglaciation, corresponds to the earlier, colder part of LPAZ 5, in full agreement with our conclusion that the early part of phase M8 in the classical scheme of Mikulino (sub-zone 5a in Butovka) was slightly colder than its later part (sub-zone 5b).

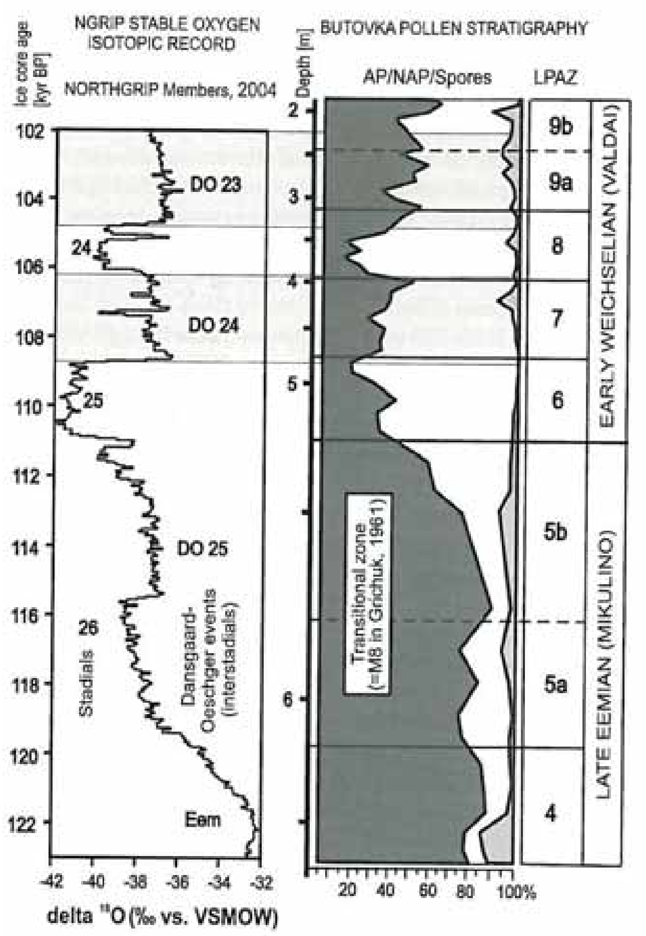


Fig. 6. Secondary climatic oscillations at the interglacial/glacial transition, as reflected in AP frequencies in Butovka, compared to the NGRIP oxygen isotopic profile (NORTHGRIP Members, 2004)

CONCLUSION

Rapid climatic deterioration, manifesting an onset of the Valdai Glaciation, took place after a slower cooling accompanied by increasing humidity of climate during the post-optimum part of the Mikulino Interglaciation. The interglacial/glacial transition had a complex structure, being marked by a sequence of secondary climatic oscillations of varying magnitude. During the part of the Early Valdai reflected in the Butovka pollen diagram, the climate grew increasingly cold and continental, as indicated by the diminishing role of mesophilic plants and an increase in abundance and diversity of xerophytes and plants growing at present in the continental interior. With this tendency at the background, two intervals of climatic amelioration can be distinguished. Both of them are marked by development of open forest communities similar to the contemporary northern taiga of West Siberia, but with certain specific "periglacial" features. The second interstadial warming in the Butovka profile had a larger magnitude of temperature changes than the first one, as indicated by a greater landscape role of dark-coniferous trees (*Picea* + *Abies* + *Pinus sibirica*). The later part of this interval was probably more humid than its early part.

Following an earlier suggestion by A.I. Moskvitin, V.P. Grichuk (1961) named the first major post-Mikulino warming the Verkhnevolzhsky (Upper Volga) Interstade, after the region where it was first distinguished. Based on its stratigraphic position and inferred features of climate and vegetation, the latter of the two warm intervals identified in the Butovka pollen profile can be provisionally correlated with the Upper Volga Interstade, and therefore with the Brőrup Interstade in West Europe. We can also tentatively correlate it with warm DO event 23 reflected in the Northern Greenland deep ice-core (NorthGRIP Members, 2004). A slighter and shorter warming within the first cold stage of the Early Valdai probably had an interphasial rank and therefore can be correlated to a shorter DO event 24 in the NorthGRIP oxygen-isotope curve.

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