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Instability of climate and vegetation dynamics in Central and Eastern Europe during the final stage of the Last Interglacial (Eemian, Mikulino) and Early Glaciation

Tatjana Boettger[a,*], Elena Yu. Novenko[b], Andrej A. Velichko[b], Olga K. Borisova[b], Konstantin V. Kremenetski[b,c], Stefan Knetsch[a,d], Frank W. Junge[d]

[a] UFZ, Centre for Environmental Research Leipzig-Halle – UFZ, Department of Isotope Hydrology, D-06120 Halle, Germany
[b] Institute of Geography, Russian Academy of Sciences, Laboratory of Evolutionary Geography, 109017 Moscow, Russia
[c] University of California, Department of Geography, 1255 Bunche Hall, Los Angeles, CA 90095 1524, USA
[d] Saxon Academy of Sciences in Leipzig, Research Group "Pollutants Dynamics in Catchment Area", D-04107 Leipzig, Germany

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ABSTRACT

In terrestrial records from Central and Eastern Europe the end of the Last Interglacial seems to be characterized by evident climatic and environmental instabilities recorded by geochemical and vegetation indicators. The transition (MIS 5e/5d) from the Last Interglacial (Eemian, Mikulino) to the Early Last Glacial (Early Weichselian, Early Valdai) is marked by at least two warming events as observed in geochemical data on the lake sediment profiles of Central (Gröbern, Neumark–Nord, Klinge) and of Eastern Europe (Ples). Results of palynological studies of all these sequences indicate simultaneously a strong increase of environmental oscillations during the very end of the Last Interglacial and the beginning of the Last Glaciation. This paper discusses possible correlations of these events between regions in Central and Eastern Europe. The pronounced climate and environment instability during the interglacial/glacial transition could be consistent with the assumption that it is about a natural phenomenon, characteristic for transitional stages. Taking into consideration that currently observed "human-induced" global warming coincides with the natural trend to cooling, the study of such transitional stages is important for understanding the underlying processes of the climate changes.

1. Introduction

The time intervals of global large-scale transitions between glacial and interglacial epochs are characterized by instable stages throughout Quaternary climate course. During such warm-cold transitions an increase of mid- and small-scale climate variations can be expected.

As an investigation of a large-scale change from a cold to warm epoch, the well-studied climatic transition from the Late Weichselian to the Holocene is of particular importance. With the duration of only a few millennia the very fast termination of the glacial interval (Late Weichselian) was marked by several well-known Late Glacial phases: Meiendorf – Oldest Dryas – Bølling – Older Dryas – Allerød – Younger Dryas (e.g. Firbas, 1949; Iversen, 1954; Hughen et al., 1996). This time interval is discussed more specifically in numerous multiproxy studies of European lake sediment sections (e.g. Eicher et al., 1981; Boettger et al., 1998; Scharf et al., 2005). Also, the transition from the Late Saalian (MIS 6) glacial epoch to the Last Interglacial (Eemian; MIS 5e) shows comparable to those in the termination of Late Glacial climatic fluctuations in North-west Europe (e.g. Seidenkrantz and Knudsen, 1994) and in continental regions of Western (e.g. Jung et al., 1972) and Eastern Europe (e.g. Mamakova, 1989; Zelikson, 1995; Novenko et al., 2005), possibly caused by changing in the oceanic and atmospheric circulation with temporary weakening of oceanic heat flux (Fronval and Jansen, 1996).

For the Holocene, a long term cooling trend with several, partly with major disruptions of civilization (Mayewski et al., 2004) coincided with significant climatic fluctuations has been observed in Eurasia since the Atlantic Holocene climatic optimum about 7500–5000 BP (e.g. Burroughs, 2001; Seppä et al., 2008; Giraudi, 2009). Each of the subsequent Holocene warm phases, the Subboreal warming at ca. 5000–3000 BP and the Medieval Climate Optimum at ca. 1100–800 BP, was less pronounced than the earlier

* Corresponding author at: Helmholtz Centre for Environmental Research – UFZ, Department of Isotope Hydrology, Theodor-Lieser-Strasse 4, D-06120 Halle, Saxonia-Anhalt, Germany. Tel.: +49 345 558 5227; fax: +49 435 558 5449.
E-mail address: tatjana.boettger@ufz.de (T. Boettger).

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one (Khotinski, 1977; MacDonald et al., 2000; Velichko et al., 2004). Reconstructions of ocean circulation and climate variability from marine sediments and GISP2 $\delta^{18}O$ data reflect a cooling trend with several fluctuations through the mid and late Holocene for the North Atlantic region (e.g. Knudsen et al., 2004; Jiang et al., 2007).

On the other hand, there are only a few well-studied sections, which document the change from warm (Interglacial) to cold (Early Glacial) stages with very high-resolution. The time correlation of oscillations in the marine environment reported for the termination of the Last Interglacial (MIS 5e/5d; Late Eemian/Early Weichselian) remains difficult (e.g. Seidenkrantz and Knudsen, 1997; Hearty et al., 2007). Numerous studies of terrestrial profiles confirm relatively stable climate in the course of the Last Interglacial in Central and Eastern Europe with a gradual temperature decrease with time after the climatic optimum was reached (e.g. Boettger et al., 2000; Kukla et al., 2002; Borisova et al., 2007). Some studies (e.g. Boettger et al., 2000; Sirocko et al., 2005; Borisova et al., 2007; Novenko et al., 2008a) document climate fluctuations during the transition from the Late Interglacial (Eemian) to the Late Glacial (Early Weichselian). For this transition in the region of Central Europe the standard sequence of Gröbern in Germany allows a high-resolution study of the full Last Interglacial and of the undisturbed Last Glacial inception with its known stadial/interstadial series Herning–Amersfoort/Brørup–Schalkholz–Odderade (Eissmann, 1990, 2002; Wansa and Wimmer, 1990). The stable isotope data from this limnic sequence indicate a pronounced warming phase towards the very end of the Eemian, just before the transition to the glacial epoch (Boettger et al., 2000), which could be classified as a first sign of increasing instability of the climatic system within the transition from Eemian to Weichselian (MIS 5e/5d). The results from the Greenland ice core presented by the North Greenland Ice Core Project members (2004) "reveals a hitherto unrecognised warm period initiated by an abrupt climate warming about 115 000 years ago towards the end of the Last Interglacial, before glacial conditions were fully developed".

The detailed analyses of the MIS 5e/5d transition period are important because the orbital changes today are similar to those which occurred at the end of the Last Interglacial stage (Kukla and Gavin, 1992; cited in Kukla et al., 2002). Furthermore, the Vostok ice core deuterium records (Petit et al., 1999) show the similarity of air temperature trends during the Last and Present Interglacials. Certainly the MIS 5e/5d transition cannot be viewed as a direct analogue of current climate developments. On the other hand, recently observed global warming proceeding under strong anthropogenic impact on the atmosphere could either reinforce or disguise the natural trends. The situation at the very end of the Last Interglacial (Eemian for Central and Mikulino for Eastern Europe) could be carefully compared to the currently observable "global warming" and therefore represents a rather fascinating and important object for studies of warm/cold terminations without human climatic influences.

The main objective of this investigation is to contribute to a better understanding of climatic variability during the termination of the Last Interglacial and the inception of the Last Glacial period in its spatial and temporal distribution by means of geochemical and palynological studies of selected European sections. This research was a part of the German DEKLIM project completed in 2006 (grant number 01LD0041) and was partly presented in Boettger et al. (2007) as a first report. The study gives a further systematization of all findings concerning the Last Interglacial/Glacial transition with an enlarged interpretation of the observed rise in climate and landscape oscillations as general features for warm/cold transition periods.

2. Studied area and methods

Results are presented of geochemical and palynological investigations on three lake sediment profiles in Central and one profile in Eastern Europe (Fig. 1), that represent the Last Interglaciation (Eemian/Mikulino) and the early part of the Last Glacial epoch (Weichselian/Valdai) respectively in Germany and in north-central Russia. In Germany there are high-resolution key sections at Gröbern (Wansa and Wimmer, 1990) and Neumark–Nord (Eissmann, 2002) in Saxony-Anhalt and the standard profile Klinge in Lusatia (Striegler, 1986; Velichko et al., 2005; Hermsdorf and Strahl, 2008; Novenko et al., 2008a). In Eastern Europe there is a well-known key section Ples from the Upper Volga region (Borisova et al., 2007). The sample resolution for all investigated profiles is approximately multidecadal to multicentennial.

2.1. Litho- and biostratigraphy

All sediment sequences discussed in this paper were deposited continuously on the top of the youngest moraines of Saalian glaciation (MIS 6) or (for the Russian profile) atop the till of the Dnieper (Moscow stage) glaciation. Their stratigraphic position clearly indicates sediments of the Last Interglacial. This is the basis for a spatial comparison of climate dynamic during the transition from the Last Interglacial (Eemian, Mikulino) to the Last Glacial (Early Weichselian, Early Valdai) attempted in this study.

Correlation of pollen data for all profiles in this paper is based on the widely accepted biostratigraphical sequence by Menke and Tynni (1984), and that of Grichuk (1961) for Western and Central and Eastern Europe respectively. The main phases (pollen assemblage zones, PAZ) in the evolution of vegetation in Central and Eastern Europe are similar (Velichko et al., 2005). The period under consideration includes the so called "*Pinus* phase", the last biostratigraphical pollen assemblage zone of the Eemian (PAZ E7), and the first biozone (PAZ WFI) of the Herning stadial of the Early Weichselian cold stage.

2.2. Isotope analyses

2.2.1. Bulk carbonate

Individual samples were manually cleaned from shells, roots and stones, ground, dried and sieved. The carbonate content was determined as inorganic carbon fraction with a Coulomat 550 PC made by Ströhlein (Ples, Neumark–Nord) or calculated from the CO_2 volume evolved from the reaction with H_3PO_4 (Gröbern). The stable isotopic composition of carbonates was measured with a Delta S Finnigan MAT mass spectrometer using the standard phosphoric acid method (McCrea, 1950; Junge and Böttger, 1994; Boettger et al., 1998).

2.2.2. Organic matter

After decarbonization with dilute HCl (1:1; 20 °C), the samples were analyzed for total organic carbon content (TOC) and isotope composition (Boettger et al., 1993; Junge and Boettger, 1994). Carbon and nitrogen content was determined with element analysers CHN-Euro (Fa. EuroVector) or 1108 Fa. FISON (Carlo Erba). The precision of the carbon and nitrogen content analysis was $<0.05\%$. Isotopic analyses of carbon was determinated with a EuroVector 3000 elemental analyzer (HEKAtech, Wegberg, Germany) coupled to an IRMS-DELTA plus XP (ThermoFinnigan, Bremen, Germany).

The isotopic results are represented by use of the conventional notation with respect to the VPDB standard. The overall precision error of the replicate samples analyses is less than 0.1‰ for $\delta^{13}C$ and 0.2‰ for $\delta^{18}O$.

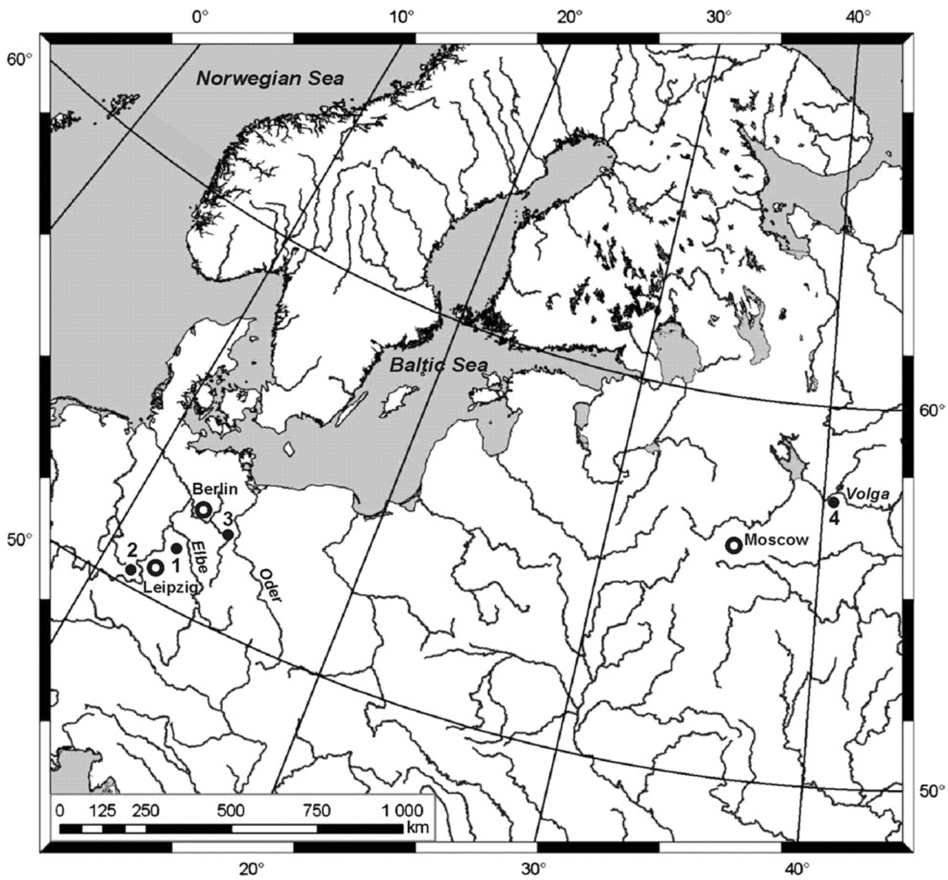

Fig. 1. Locations of investigated limnic profiles in Central and Eastern Europe: 1 – Gröbern, 2 – Neumark–Nord, 3 – Klinge, 4 – Ples.

2.3. Pollen analyses

For Neumark–Nord, Klinge, and Ples, the samples were processed for pollen analysis using the pollen extraction procedure developed by Grichuk (1940): the treatment included separation by heavy liquid (cadmium iodine) with the net weight of 2.2 g/cm^3. A minimum of 500 pollen grains and spores per sample was counted. Relative frequency of pollen was calculated based upon the total terrestrial pollen sum, arboreal pollen (AP) plus non-arboreal pollen (NAP). The pollen results of Gröbern are cited according to published papers (Litt et al., 1996; Kühl et al., 2007).

3. Results and discussion

The climate signal from isotope data of lake sediments is often blurred by a high variability of local, often interactive environmental conditions during the transition time. That includes fluctuations of the water level caused (for instance) by changes in a lake surface evaporation rate and in local inflow–outflow conditions as well as solifluction or rearrangement processes in a drainage basin. The overall effect is that it is difficult to extract climatic interpretation from the data of many investigated limnic profiles. As an example of global transitions from cold to warm, temperature effects in isotope data of several investigated Late Glacial profiles in Central Europe (e.g. Boettger et al., 1998, 2004) are often overlaid by strong oscillations in air humidity, instable hydrological conditions in the lakes accompanied by an influx of meltwater from rapidly receding Weichselian ice sheet. On the other hand, as expected, isotope data are good indicators of temperature variations during the global transitions from warm to cold. Pollen records with their own advantages (e.g. possibility of vegetation and climatic reconstruction) and disadvantages (e.g. slow or insufficient response of plant cover to climate changes) can reflect both climatic (temperature, moisture supply) and environmental changes (fires, wind falls, insect invasions). Therefore, geochemical and palynological methods represent independent tools in paleoreconstruction. There are indications for climatic fluctuations during the transition from the Last Interglacial to the Early Glacial as well in the termination of the Last Interglacial (Eemian, Mikulino) as in the first stadial of Last Glaciation (Early Weichselian, Early Valdai) in the limnic profiles in Central and in Eastern Europe.

3.1. Gröbern (N 51°42′12″, E 12°26′56″)

The complete undisturbed Eemian/Early Weichselian high-resolution limnic sequence revealed in Gröbern (Wansa and Wimmer, 1990) with its multitude of isotope-geochemical (Boettger et al., 2000), palynological (Litt et al., 1996) and faunal (Walkling and Coope, 1996) findings is one of the best studied Last Interglacial sequences of Germany. This sequence is represented in the lower part by an unlaminated silt of Late Saalian age, followed by sediments of the Eemian (up to 4 m thick) characterized by alternating stratification of finely laminated lime and coarse or fine detrital muds. The Eemian part of the section is followed by approx. 7 m of Early Weichselian sediments: those of the Herning stadial (the first cold stage after Eemian), the first “forest” interstadial Brörup, overlaid by the sediments of the Rederstall stadial, the Odderade interstadial and partly of the Schalkholz stadial with coarse clay muds within the stadials and organogenic sediments (calciferous muds, coarse and fine detrital muds, peat) in the interstadials (Wansa and Wimmer, 1990).

Comprehensive results of isotope-geochemical studies of the complete high-resolution sequence at Gröbern are discussed in Boettger et al. (2000). For Fig. 2, content and $\delta^{18}O$ curves of carbonate are the most representative proxies for the variation of temperature and content and $\delta^{13}C$ values of the organic sediment fraction are indicators for the intensity of submerged organic matter production depending on the temperature of lake water. In the Late Interglacial (Eemian) and in the Early Late Glacial stages (Early Weichselian) of this profile, close correlation was observed between the curves recording the carbonate level and its $\delta^{18}O$ values, and the content and $\delta^{13}C$ values of total organic carbon in the sediment. At the very end of the Eemian (PAZ E7) and just before the complete change to glacial conditions, a brief phase of warming is recognized from all geochemical indicators. This is indicated by the coordinate increase of contents and stable isotope values of both lake carbonate and the organic sediment fraction (Fig. 2). This warming followed a continuous temperature decrease in the second part of the Eemian in the *Pinus–Picea–Abies* phase (PAZ E6). Its amplitude was not on the scale of the Late Interglacial climatic optimum, but was instead comparable with the conditions found in the first Early Weichselian interstadial (Boettger et al., 2000).

There are obvious signs of shorter climatic amelioration within the Herning (first Weichselian stadial, PAZ WFI), which can be recognised from both a new occurrence of limnic carbonate production and in increased $\delta^{18}O$ values of carbonate. This warming event was relatively weak: the $\delta^{13}C$ values of organic sediment fraction show a non-detectable increase during this period.

The palynological evidence for these climatic fluctuations had not been clearly recognised for Gröbern, possibly because the pollen analysis for the Late Eemian and Early Weichselian were made with multicentennial resolution (Litt et al., 1996; Kühl et al., 2007) and some short events may have been overlooked. Additionally, the stable isotope fractionation of both chemically precipitated and biogenic autochthonous carbonates in the lake is immediately reflective of changes in summer temperature. In contrast, the reaction of vegetation development to short-term warming phases proceeds much slower. Thus, a shorter duration of the vegetation period at the beginning of the Eemian/Early Weichselian (MIS 5e/5d) transition, or a slower or insufficient reaction of the vegetation to short-term warming phases could possibly be the cause for insufficient plant growth in spite of the warming. On the other hand, Kühl et al. (2007) report a general shift towards more continental conditions with a decrease in T_{July} by 3 °C, $T_{January}$ by 15 °C and P_{annual} by 200 mm during the transition from the Eemian to the Herning stadial. In comparison to a strong temperature drop during the termination Eemian/Early Weichselian (MIS 5e/5d) reconstructed for winter, the declining trend in summer temperature is not so dramatic.

3.2. Neumark–Nord (N 51°19′14″, E 11°52′40″)

The Last Interglacial (Eemian) section Neumark–Nord (Eissmann 2002) is situated in the Geiseltal opencast lignite mine near the town of Merseburg west of Leipzig (Fig. 1). The interglacial sequence consists of coarse clay with very few molluscs in its lower part above the Saalian till and organic and calcareous silts in the middle part of the sequence. The profile is completed with a rearrangement zone in the upper part of the section between the local

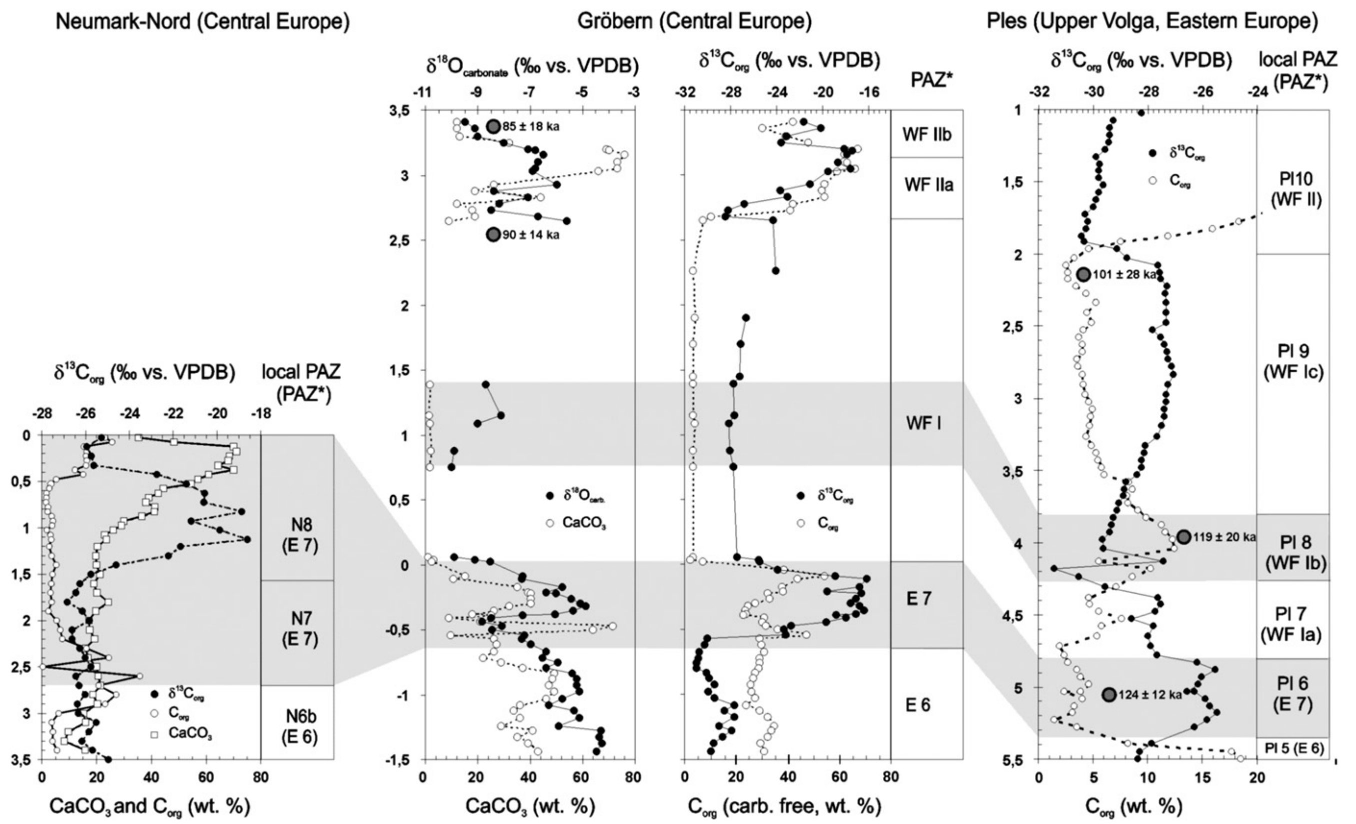

Fig. 2. General geochemical remarks in Central (Neumark-Nord, Gröbern) and Eastern Europe (Ples) Eemian/Early Weichselian profiles (PAZ*: after Menke and Tynni, 1984; IR-OSL data: according to Degering and Krbetschek, 2007 and Krbetschek, personal communication).

pollen assemblage zone (LPAZ) N6b and the lower part of LPAZ N7, corresponding to the upper part of biozone E6 and the beginning of biozone E7 of Menke and Tynni (1984). These are followed by a compact layer of calcareous mud in the uppermost part of LPAZ N7 and N8 corresponding to the PAZ E7 (Fig. 2). C/N atomic ratios of about 10–16 throughout the entire period indicate stable limnic bioproductivity. The detailed results of geochemical and palynological investigations for the Neumark–Nord interglacial profile with a total thickness of approximately 10 m are described by Boettger et al. (2007). According to the geochemical data, the end of the interglacial in the upper part of biozone E7 is characterized by an increasing carbonate content, which is revealed by a very high abundance of molluscs. Additionally, the organic matter content increases. Both factors indicate an eutrophication of a paleolake. The strong spread of molluscs together with a renewed increase of lake productivity towards the very end of the Eemian can be associated with the brief warming phase found in the Gröbern profile in PAZ E7 (Boettger et al., 2000).

The palynological records (Fig. 3) clearly show an increase of magnitude of change in vegetation cover at the termination of the Eemian during the transition from the interglacial to glacial time. The PAZ E7 can be correlated to LPAZ N7 and N8 in the Neumark–Nord section. The beginning of LPAZ N7 is dominated by *Pinus* pollen. Then at the end of LPAZ N7 pine and spruce-pine forest with a small participation of oak, ash and elm became predominant. In zone N8 the percentage of *Betula* increases and at some levels the amount of birch pollen significantly exceeds that of pine. An increase in the *Betula* percentage is accompanied by the rise in non-arboreal pollen: *Artemisia* and *Chenopodiaceae* (Boettger et al., 2007). Comparable findings were also described by earlier investigations of the Neumark–Nord profile (Litt, 1994). A pronounced increase of fluctuations in arboreal vegetation during the final stage of the Last Interglacial in LPAZ N8 is observed. Pollen data indicate at least two stages of degradation of coniferous forest vegetation, while birch woodlands became widespread. Together with geochemical data, these can be interpreted as an indicator of increased climatic instability caused by short warming events during the very end of the Last Interglacial (Eemian).

3.3. Klinge (N 51°47′31″, E 14°32′23″)

The interglacial limnic section Klinge is exposed in the open cast lignite mine Jänschwalde near the town of Cottbus (Fig. 1). This sequence is developed in a kettle depression on Saalian till and has in its interglacial part a thickness of about 5 m. The investigated profile includes sediments from the Late Saalian (silty and calcareous muds) and the complete Eemian Interglacial (a complex of different muds, liver muds, silty muds and peat layers). Above this is a unit of peat and clay with increasing clay content. The uppermost horizon of this profile is represented by a pure peat layer (Novenko et al., 2008a,b).

Klinge is one of the best studied Eemian and Early Weichselian key lacustrine sequences in the Lower Lusatia region. Several authors have studied the lithology, macrofossil assemblages and faunal remains of this section (e.g. Nehring, 1895; Striegler, 1986; Cepek et al., 1994). The paleobotanical investigations of this section were carried out by Erd (1960), Kühner et al. (1989), Strahl (2004) and Velichko et al. (2005).

A high-resolution detailed pollen analysis of the sequence situated ca. 2 km further north was performed recently by Novenko et al. (2008a). Due to the better exposure, this profile is more suitable to characterize the very end of Eemian and the first phase of the Weichselian epoch. From this palynological data set of the Klinge profile, the last stage of the Last Interglacial, LPAZ 11 corresponding to biozone E7 according to the scheme of Menke and Tynni (1984), was characterized by noticeable changes in the plant

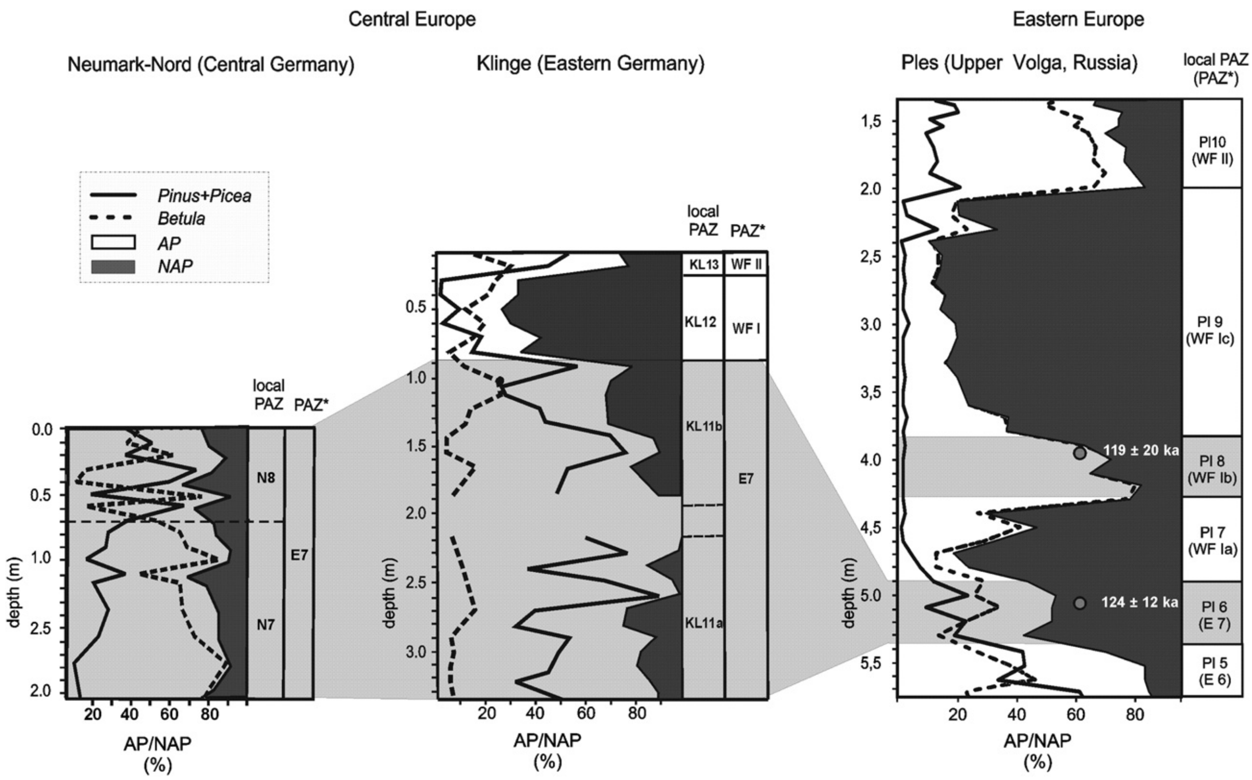

Fig. 3. General vegetation remarks in Central (Neumark–Nord, Klinge) and Eastern Europe (Ples) Eemian/Early Weichselian profiles (PAZ*: after Menke and Tynni, 1984; IR-OSL data: according to Degering and Krbetschek, 2007 and Krbetschek, personal communication).

cover (Fig. 3). This zone is divided into two parts (11a and 11b) by a horizon with a high amount of reworked tertiary microfossils. The beginning of LPAZ 11a was marked by pine and birch forests with an admixture of spruce. The role of broad-leaved trees fell substantially. In the upper part of the LPAZ 11b the role of forest communities in the plant cover decreased, and birch woodlands with dry meadow became widespread. At the end of this stage, pine forest reappeared in the territory.

The climatic reconstruction of the Klinge profile shows that the winter temperature (T_I) decreased by about 8 °C during the biozone E7. The changes in July temperature (T_{VII}) were not so dramatic (about 3 °C). However, vegetation dynamics indicate that the general cooling trend was interrupted by a short, relatively warm interval before the final transition to the Early Glacial conditions.

3.4. Ples (N 57°27′23″, E 41°32′27″)

The high-resolution Ples limnic sequence is situated in the Upper Volga region in European Russia (Fig. 1). The sequence comprises the period from the Late Saalian Glaciation (Dnieper, Moscow stage), the complete Last Interglacial (Mikulino), and the Early Last Glacial (Valdai) including its first Interstadial, the Verkhnevolzhsky (Borisova et al., 2007). The profile is about 8.5 m thick and exposed in a bank of a deep gully close to the Volga River. The lithological composition of this carbonate free profile is mainly determined by clastic sediments (silt and clay) in the cool periods and organic rich muds and peat layers in the warm stages. This Eastern European Late Pleistocene key section was sampled and investigated in detail in summer 2002. The new palynological (Borisova et al., 2007) and geochemical (Boettger et al., 2007) results show that, similar to Central Europe, instabilities in vegetation dynamics and phases of increasing lake productivity possibly caused by short warm phases occur in Eastern Europe at the interglacial/glacial transition (Figs. 2 and 3). The first fluctuation can be observed during the final part of the Last Interglacial in LPAZ Pl 6, which corresponds to biozone (PAZ) E7 in the scheme by Menke and Tynni (1984). The second is within the first Last Glacial stadial during LPAZ Pl 8 (PAZ WF Ib). Within the middle of the *Pinus–Picea–Betula* phase (LPAZ Pl 6) an increase in content of organic carbon accompanied by a decrease of $\delta^{13}C$ values occurs (Fig. 2). This can be attributed to an increase in lake productivity accompanied by a rise of ^{12}C-enriched carbon in the lake water due to the intensification of such processes as organic matter decays in the water column and on the lake bottom (Wolfe et al., 1999) during short warming events in transition to glacial conditions.

Changes in the composition of pollen spectra (Fig. 3), with a considerable increase in herb percentage and concentrations accompanied by a reduction in tree and shrub content and total pollen concentration, suggest a common degradation of forest communities during the transition from interglacial to glacial conditions. The abrupt fall of arboreal pollen content occurs at the beginning of LPAZ Pl 6, then tree and shrub percentages rise mainly due to an increase in birch and coniferous tree (*Picea, Pinus sylvestris, Pinus sibirica*) pollen. The role of forest communities in the complex plant cover increased, which can indicate a slight warming in the final part of the Eemian (*Pinus–Picea–Betula* phase). New radiofluorescence data (Degering and Krbetschek, 2007) from the Ples profile dated for this interval at approx. 124 ± 12 ka (Fig. 2).

The second pronounced warm phase appears in the LPAZ Pl 8, which corresponds to PAZ WF Ib following the biozonation of Menke and Tynni (1984), within the first Last Glacial stadial. The radiofluorescence data for this event show an age of approx. 119 ± 20 ka BP. The submersed primary production in the lake rises, which can be seen in an increase of C_{org} content, and the $\delta^{13}C$ values decrease. In this zone, pollen spectra are characterized by a noticeable increase of tree birch pollen (up to 70–85%). Other trees and shrubs are poorly represented with the exception of *Betula nana*. Pollen of herbaceous plants typical for birch communities (*Polygonum bistorta, Sanguisorba officinalis, Thalictrum, Valeriana*) occur in this interval. The presence of *Nuphar* pollen in PAZ Pl 8, registered here for the first time since the onset of the glacial epoch, indicates some warming. Therefore, birch open forest with dense undergrowth of dwarf birch replaced the tundra vegetation that occupied the region in the previous stage. Apparently, the climate amelioration, which gave an impulse to the development of birch woodlands only, was of minor magnitude and duration. *Betula alba*, being a typical 'pioneer' tree, responded quickly, while other tree species with more demanding requirements did not spread over the area. The spread of *Betula* can indicate cold-derived open environments. However, the combination of all geochemical and palynological findings points rather to a moderate increase in temperature.

Some ambiguity of the spruce and pine phases is not unique to Ples. Similar vegetation dynamics have been recognised in several pollen records from the profiles of Eastern Europe. The pronounced changes in the composition of the main forest forming trees at the very end of the Last Interglacial have been registered in its stratotype on the East European Plain, the Mikulino section (Grichuk, 1961) and in a section on Valdai Hills (Novenko et al., 2008b) in Central European Russia. In the western regions of the East European Plain, Druskininkai in Lithuania is noteworthy (Kondratene, 1996). The sharp oscillations in tree pollen content begin in this profile in the *Carpinus* zone and continue during the latest warm phases. Good examples for similar fluctuations in the north-western part of the East European Plain are the Rybatskoye section (Lavrova and Grichuk, 1960) near St. Petersburg, and Domanovo, Vologda (Gei et al., 2000).

At the end of the Last Interglacial (Eemian, Mikulino), pollen and geochemical data of all investigated sequences in Central and in Eastern Europe show a gradual cooling during the interglacial/glacial transition. This can be correlated with the continuous temperature fall at approx. 120 ka BP in the NGRIP ice core from central Greenland (NGRIP members, 2004). Within this global climatic transition are clear indications for instabilities of climate and vegetation dynamics possibly caused through short warming phases towards the very end of the Last Interglacial (Eemian) in Central European profiles Gröbern, Neumark–Nord and Klinge.

Moreover, Menke and Tynni (1984) referred to environmental oscillations for profiles from north-western Germany. Strong climate fluctuations accompanied by intensive loess deposition at the "Late Eemian aridity pulse" and an abrupt cooling event exactly at the time of the Last Glacial inception at ca. 118,000 BP were also noted by Sirocko et al. (2005) and Seelos and Sirocko (2007) in records of laminated lake sediments of northern Germany, and annually laminated and varve counted maar lake sediments in the Eifel (Western Germany). Possibly, these results correspond to the worldwide observed sea level rising phases in the final stage of the Last Interglacial (MIS 5e; Hearty et al., 2007). In Eastern Europe, slight warming oscillations occurred during the very end of the Last Interglacial at profile Ples (Upper Volga region) and also were noted earlier for several other profiles in the North-west of Russian Plain and Lithuania (e.g. Grichuk, 1961; Kondratene, 1996; Novenko et al., 2008b).

Furthermore, there is clear evidence of a further warming event within the first stadial of the Last Glacial (Herning/Early Weichselian, first Early Valdai cold stage) in Central as well as in Eastern Europe in profiles suitable for the investigation of this question (Gröbern, Ples) which includes this period. The correlation of the detected climatic fluctuations between the continental limnic sequences in Central and Eastern Europe is well established: the first fluctuation definitely occurred before the beginning of the first Early Last Glacial stadial (Herning) during PAZ E7, the second within the Herning stadial during PAZ WF I. Probably, the climate of the interglacial/glacial transition was characterized by inner instability resulting in the sequence of climatic oscillations expressed against the overall trend towards cooling.

The precise correlation between the investigated limnic profiles and the results of NGRIP ice core remains under discussion. There are some problems with the correlation of DO 25 in NGRIP with terrestrial records. Johnsen et al. (2005) report the warming event DO 25 lasted some 4 ka. Such a period seems to be too long for correlation with the first warming event at the very end of the Last Interglacial (Eemian-PAZ E7, Menke and Tynni, 1984) in terrestrial records, although the exact duration of the observed warming events in lake profiles presented here remains unclear. From this point of view, comparison to the second warming event during the first Last Glacial stadial (Herning-PAZ WFI) seems to be plausible as well.

For the Last Interglacial (Eemian, Mikulino) as for the Holocene, after significant warming during the transition from the glacial to interglacial and reaching the climatic optimum, stable warm climatic conditions set in with a gradual temperature decrease with time. It appears that in Central and Eastern Europe a short warming phase at the very end of the Last Interglacial period preceded the final transition to glacial conditions. This is part of the observed increase in climatic and environmental instability during this global warm/cold transition, which appears to be at least a European phenomenon.

The observed climatic and environmental instability during the Last Interglacial/Last Glacial (MIS 5e/5d) transition could be carefully considered as a possible general natural characteristic for global warm/cold transition periods. Therefore detailed studies of these phenomena are important for evaluating and understanding the currently observed and very controversially discussed (e.g. Velichko et al., 2006; IPCC, 2007; Keenlyside et al., 2008) climatic trends and for detecting anthropogenic input to climate changes. Thus, the currently observed warming during the proceeding natural long term cooling trend since the Holocene climatic optimum, could also be at least partly a generally natural phenomenon.

4. Conclusions

In terrestrial records from Central and Eastern Europe after a gradual temperature decrease with time since reaching the climatic optimum the end of the Last Interglacial is recognized by evident climatic instabilities recorded by geochemical and vegetation indicators. The transition from the Last Interglacial (Eemian, Mikulino) to the Early Last Glacial (Early Weichselian, Early Valdai) is marked by at least two warming events observed in geochemical results and simultaneously by an increase of environmental instabilities as reconstructed from palynological data on the lake sediment profiles of Central (Gröbern, Neumark–Nord in central Germany, Klinge in eastern Germany) and Eastern Europe (Ples in Upper Volga region). The pronounced climate and environmental instability during the interglacial/glacial transition could be interpreted as a natural phenomenon. It is not only local or regional but seems to be an event on a European scale. Taking into consideration that currently observed "human-induced" global warming coincides with the natural trend to cooling, the study of such transitional stages is important for understanding the underlying processes of climate changes.

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