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Research paper

Pollen based quantitative climate reconstructions from the Middle Pleistocene sequences in Łuków and Zdany (E Poland): Species and modern analogues based approach

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ABSTRACT

The aim of the study was to estimate the range of climate variability during the Ferdynandovian climatostratigraphic unit (MIS 13–15). The studied pollen sequences encompass two interglacials (Ferdynandovian I and II — F I and F II), the glaciation separating them (F I/II), the late glacial of the Sanian I (= Elsterian 1) and the early glacial of the Sanian II (= Elsterian 2) and are correlated with the Cromerian Complex in Western Europe. The modern analogue technique and plant indicator taxa method are applied to two high resolution pollen records (Zdany and Łuków-3a) from E Poland to infer total annual precipitation, mean annual temperature and temperatures of the warmest and the coldest months. The results of the two methods create a coherent picture of climate changes.
The succession starts with steppe–tundra and boreal forests, reflecting a cool, late glacial continental climate and develops into widespread *Ulmus* and *Quercus* dominated communities, followed by *Corylus* expansion in warm (at least 18 °C in July), oceanic conditions (~800–900 mm annual precipitation) during the first interglacial optimum (F I). The cold, continental climate of the glaciation (F I/II) with annual precipitation of ~420 mm and mean January temperature less than −12 °C separated the two interglacials. The second interglacial (F II) characterized by *Carpinus* dominated forests was found to be warm (mean July temperature up to 19 °C) but slightly less oceanic, which is consistent with the scarcity of indicators of a warm and humid climate. Principal components analysis (PCA) confirmed the distinctive climatic features of the two interglacials and showed that the cooling F I/II has palynological characteristics similar to the stadial/interstadial changes within the Sanian I and Sanian II glaciations.

1. Introduction

Proxy based quantitative reconstructions of past climates are an important source of information for studies of palaeo-environments and of independent data for comparison and validation of GCM (General Circulation Model) palaeo-climate simulations (Edwards et al., 2007; Schmidt, 2010). Pollen, as one of most abundant palaeoecological proxies, is often used for climate reconstructions. Quantitative pollen based climate reconstructions of the last interglacial are numerous (Velichko, 1984; Tarasov et al., 1999b; Peyron et al., 2000; Seppä et al., 2004; Neumann et al., 2007; Brewer et al., 2008; Salonen et al., 2011). Most of them use transfer functions to establish the relationship between climate variables and pollen assemblages or their taxonomic composition. The indicator-taxa approach was first developed by Iversen (1944) and later applied by other researchers (see examples in Kühl et al., 2002). The pollen assemblages approach is widely applied today and several freeware programmes such as PPPbase by Guiot and Goeury (1996) and Polygon by Nakagawa (2002) designed for pollen-based quantitative climate reconstructions by the modern analogue technique are available on the internet.

The approach has been successfully applied to fossil pollen of the last climatic cycle or older (Guiot, 1990, 1993; Peyron et al., 1998; Tarasov et al., 1999a, 2009; Nakagawa et al., 2002) and the published climate reconstructions demonstrate the possibility of applying the methodology to Pleistocene sequences (Cheddadi et al., 1998; Tarasov et al., 2005; Brewer et al., 2008).

Pollen-based climate reconstructions using the modern analogue approach were developed by Guiot et al. (1989), Cheddadi et al. (1998) and Brewer et al. (2008) for the Eemian interglacial in Europe. Kühl and Litt (2007) used a method based on probability density functions for pollen-based climate reconstructions and reconstructed January and July mean temperatures throughout the Holsteinian interglacial at two Central European sites.

Łuków and Zdany pollen sequences belong to unique long records of vegetation and climate changes in the older part of the Middle Pleistocene of Eastern Europe. Both of them encompass two warm

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periods of interglacial rank and cold units of a glacial character. Pollen succession correlates with interglacials III and IV of the Cromerian Complex in Western Europe (Rzechowski, 1996; Lindner et al., 2004; Winter, 2006; Ber et al., 2007) or alternatively with interglacials II and III of the Cromerian Complex (Zagwijn, 1996a). The so called "bi-partite Ferdynandovian sequence" in the most recent stratigraphic division of Poland has been related to oxygen isotope stages 13–15 (Lindner et al., 2004; Ber et al., 2007) and probably covers a time span of ca. 140 kyr, ~480–620 kyr BP (Cohen and Gibbard, 2011). Zdany and Łuków-3a profiles have the best resolution among the Ferdynandovian profiles from Poland. The pollen sequences correlate well with several successions of the same age in Eastern Europe (Rylova and Savchenko, 2005; Kalnina et al., 2013). The correlation was presented in Pidek and Małek (2010), except for the last paper which was published in 2012. Vegetation history and climate conditions have been reconstructed based on pollen spectra of both profiles applying the traditional approach of climate indicator taxa (Zdany profile in Pidek, 2000, 2003; Łuków-3a profile in Pidek and Małek, 2010; Pidek, submitted for publication).

High numbers of pollen samples in the profiles provide a good resolution record for palaeobotanical and climate reconstructions, offering a unique chance to study different aspects of palaeoecology and palaeoclimate over several interglacial–glacial cycles. The present paper focuses on quantitatively reconstructing the dynamics of climatic conditions of interglacials and glacials, distinguishing several oscillations of stadial/interstadial rank during the Middle Pleistocene. Although the modern analogue based reconstruction of Middle Pleistocene climate must be regarded as a very tentative one, its relation to the existing climate reconstructions of two younger Pleistocene interglacials: Holsteinian/Mazovian and Eemian offers new insights into similarities and differences between these warm periods in terms of oceanic and continental air mass circulation.

2. Study area

The study sites are situated in E Poland in the Southern Podlasie Lowland, which is part of the Central European Lowland belt. The region is located in the peripheral part of the East European platform. Quaternary deposits are underlain by Oligocene glauconitic–quartzitic sands, Miocene sands and clays with brown coal and Pliocene clays, sands and silts. The Quaternary deposits in the South Podlasie region form a continuous cover of rather variable thickness (40–115 m) defined by bedrock relief. Within them numerous palaeolake basins occur which are filled with organogenic sediments from different interglacials: Eemian, Mazovian (=Holsteinian) and Ferdynandovian (=Cromerian). They have been discussed by, among others, Żarski et al. (2005), Nitychoruk et al. (2006), and Małek and Pidek (2007). Both the examined palaeobasins (Zdany and Łuków) are situated within end moraines of the Warthe Glaciation and its recession stages (Zdany) or next to them (Łuków) (Terpiłowski, 2001).

The fossil profile at Łuków (51°55′58″ N and 22°26′09″ E), known from studies by Rühle (1969) and Sobolewska (1969), was drilled again for the needs of the Łuków sheet of the Detailed Geological Map of Poland, scale 1:50,000 (Małek and Buczek, 2006). The site is located in the region of Łuków Plain — the mesoregion belonging to the South Podlasie lowland (acc. to Kondracki, 2001). The coring was marked as Łuków-3a. Lacustrine deposits (10.10 m thick) occur at a depth of 24.30–34.40 m and consist of silts, gyttja, peat and overlying silts with fine-grained sands. The lacustrine deposits are covered by fluvio-periglacial deposits from the Sanian II (=Elsterian 2) Glaciation and Odranian (=Drenthe) Glaciation (Małek and Buczek, 2006).

The fossil profile at Zdany (52°8′16″ N and 22°24′32″ E) was drilled for the needs of the Siedlce Południe sheet of the Detailed Geological Map of Poland, scale 1:50,000 (Małek, 2004). Lacustrine deposits occur at a depth of 28.90–37.70 m and are covered by a 15.6 m thick till of the Sanian II (=Elsterian 2) Glaciation and fluvio-periglacial sands (Małek, 2004). The site is located 19 km to the north of Łuków-3a in the Siedlce Plateau region in the South Podlasie lowland.

3. Material and methods

3.1. Pollen analysis

The samples for pollen analysis were treated according to standard palynological procedures used in the analysis of lacustrine sediments — with HCl, KOH, HF and Erdtman's acetolysis. Pollen spectra were counted on at least two slides 18×18 mm. In Zdany, 94 pollen samples were analysed, in Łuków-3a — 161 samples. The minimum terrestrial pollen count was 500 per sample, but in the samples representing interglacials over 1000 pollen grains were counted. Three plant functional types were distinguished: boreal trees and shrubs (BTS), temperate trees and shrubs (TTS) and herbs and dwarf shrubs (HDS). BTS includes *Betula*, *Pinus*, *Picea*, *Salix*, *Juniperus* and *Larix*. We assume that here *Larix* is probably Siberian larch (*Larix sibirica*) and not the more temperate *Larix decidua*, as larch pollen appears explicitly in cold units along with boreal trees (e.g. *Pinus*, *Betula* and *Picea*). Temperate trees and shrubs included: *Abies*, *Acer*, *Carpinus*, *Corylus*, *Fraxinus excelsior*, *Hedera*, *Quercus*, *Tilia*, *Ulmus*, *Taxus*, *Frangula alnus* and *Alnus*. The last taxon is most probably represented by *Alnus glutinosa*, which is a tree of temperate climate as the pollen curve of *Alnus* attains maximum values simultaneously with thermophilous trees (*Quercus*, *Ulmus*). It is possible that in more boreal climate conditions, *Alnus* pollen may be represented by *A. incana* or even *A. viridis*. Herbs and dwarf shrubs were represented by *Artemisia*, Chenopodiaceae, Cyperaceae, Poaceae, Ericaceae and *Ephedra*. The percentage pollen diagrams (Figs. 2, 3) of selected taxa (represented by values >1%) were constructed using TILIA and TGView software (Grimm, 2007).

3.2. Numerical analysis

The local pollen assemblage zones (LPAZs) were determined using binary splitting by the sum-of-squares method implemented in the psimpoll 4.10 programme (Bennett, 1994) based on pollen taxa presented in diagrams. The significance of statistically determined zones was tested by comparison with the broken-stick model described by Bennett (1996). Numerical zonation was correlated with the climatostratigraphical units distinguished by Lindner et al. (2004). The determined LPAZs correspond well to zones distinguished visually based on traditional criteria, presented among others by West (1970), Berglund and Ralska-Jasiewiczowa (1986), and Janczyk-Kopikowa (1987). Complete pollen diagrams of investigated sequences are presented by Pidek (2003, submitted for publication).

Additional zonation using a 50% threshold limit of *Pinus* pollen as a marker of pine woodland development was adopted to distinguish late and early interglacial/glacial units and interstadials (Figs. 2, 3). The threshold was defined based on published data on modern and fossil pollen spectra, reflecting the presence of pine forest (see Lisytsyna et al., 2012 and discussion therein) and represents the upper limit of values presented by Lisytsyna et al. (2012). This value is consistent with earlier findings of Hicks (2001) in Finland and undoubtedly reflects the existence of boreal pine communities. Determining of the occurrence of pine dominated communities on the basis of long pollen sequences representing glacial/interglacial cycles within the Pleistocene may be useful in terms of climate interpretations as the distribution limit of pine in Scandinavia is delimited by the mean July temperature of 12 °C (Zagwijn, 1989).

Ordinations by detrended correspondence analysis (DCA) and principal component analysis (PCA) were done based on a united dataset including all samples from both investigated sequences and terrestrial pollen taxa exceeding 1%, using CANOCO 4 for ordination and CANODRAW 3.0 (ter Braak and Smilauer, 1998) for plotting.