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Late Glacial erosion and pedogenesis dynamics: Evidence from high-resolution lacustrine archives and paleosols in south Bohemia (Czech Republic)

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ABSTRACT

Sediments from three paleolakes and two paleosol horizons in south Bohemia, Czech Republic, provide evidence of climate change and landscape evolution in central-eastern Europe on millennial to centennial timescales over the Late Glacial (~16–11.5 ky). Based on a combination of geochemical, sedimentological and geophysical proxy indicators, along with the pollen record and soil micromorphology, we propose a relationship between vegetation cover, soil development, and erosional processes. Four major and two minor environmental stages, identified in all investigated paleo-lakes, were broadly correlated with the Late Glacial climatostratigraphy. Short-term (decadal to centennial) climatic deteriorations between the Bølling and Allerød, and within the Allerød, have been correlated with the Older Dryas and the Intra-Allerød Cold Period (IACP) respectively. B horizons of two (gleyic) podzols discovered under aeolian sand dunes in the lake catchments were dated to the Allerød interstadial and were parallelized with Usselo soils – pedostratigraphical marker horizons of west- and northern-central Europe. The upper parts of these soils have signs of colluvial processes. According to the radiocarbon dating, the erosion occurred at 13,155 ± 150 cal. yr BP and can be associated with the IACP event, which is marked by a significant input of allogenic material into the lake basins. We attribute the significant increase in the iron and consequent phosphorus content in the lake sediments during the Allerød to the podzolization that occurred with the humid interstadial conditions.

1. Introduction

As demonstrated by numerous paleoenvironmental studies worldwide, changes in climate regimes associated with the Late Glacial (LG) period (~16–11.5 ky ago) caused deep ecosystem conversions and evoked distinct interactions within and between the different components of terrestrial environments (Roberts, 2014).

Although most research has demonstrated the effects of the LG climatic oscillations on the biological components of the environment (Firbas, 1949; Watts, 1979; Ammann and Lotter, 1989; Ammann et al., 1993; Goslar et al., 1993; Hoek, 1997), significant insight into the LG climatic and, consequently landscape, dynamics can also be gained by the study of the associated erosion and pedogenesis dynamics. These processes are directly connected with climatic changes: the more favourable climatic conditions would usually favour pedogenesis, greater soil-binding by the denser vegetation, and the limiting of surface erosion, while cooling conditions tend immediately to cause surface instability, limited chemical weathering, increased erosion, and reinforced aeolian activity (Engstrom and Wright, 1984).

Some studies have shown that lacustrine sediments are able to record physical erosion, weathering, and soil development (Bakke et al., 2010; Mckay and Kaufman, 2009; Rosqvist and Schuber, 2003; Simonneau et al., 2014).

In a Pan-European context, the most straightforward evidence on the LG climatic oscillations (including the minor cooling episodes such as the Older Dryas or Intra-Allerød Cold Period) has come from the

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North-Atlantic (NA) region; further into the European sub-continent, namely into central-eastern Europe (hereafter CEE), the impact of these short-term climatic episodes has as yet been poorly documented. This could be due to: (1) geographical position, since the N and NW Europe is supposedly more heavily influenced by the hydroclimatic changes in the NA; and/or (2) the relative scarcity of suitable CEE sedimentary archives, such that would cover the complete period of the LG in sufficient resolution, compared to N and NW Europe. Consequently, many questions related to particular episodes in paleoenvironmental history remain virtually unclear throughout the territory of the Czech Republic, situated as it is in an important transition zone between the macro-climatic settings of the Atlantic and European continent. Such unanswered questions include those relating to the spatiotemporal variation of the timing of LG climatic changes and their impact on terrestrial ecosystems.

The investigation of Lake Švarcenberk in South Bohemia (Czech Republic) has already proved to be one of the most valuable archives for this period of interest in the entire CEE (Hošek et al., 2014). With a sediment thickness of over 10 m, from which 4–5 m cover just the LG period, this site provides the most complete and detailed record of the last 16 ky in the European interior. Though a wide range of paleoecological information has already been obtained from this site (Pokorný and Jankovská, 2000; Pokorný, 2002; Hošek et al., 2014), some crucial questions remain unclear. These include the interplay between terrestrial and lake ecosystems, and the wide-scale landscape evolution during the Last Termination.

To fill in some of those gaps, we hereafter report on some high-resolution lacustrine records discovered recently in in two other individually-closed paleolakes and the LG interstadial paleosol horizons that represent the former catchment surfaces.

Our aim has been to obtain evidence for the environmental changes surrounding the LG in high temporal resolution, with particular focus on how the rapid climatic shifts had affected pedogenesis, erosion, and weathering. To address these questions, we have applied geochemical, sedimentological, rock-magnetic and micromorphological methods to both the lacustrine sequences and paleosol horizons. Because of the crucial role of vegetation cover in erosion-weathering processes, we compared the geochemical data with the pollen record, currently available from Lake Švarcenberk (Pokorný, 2002, Hošek et al., 2014).

Last, but not least, this study has highlighted some challenges for paleoenvironmental reconstruction from the geochemistry and rock-magnetism of non-laminated lacustrine sequences.

2. Regional setting

The study area is situated in South Bohemia, the Czech Republic, in the north-eastern margin of the Třeboň Mega-basin (Fig. 1). This Mega basin is filled mostly by Cretaceous clastic sediments consisting of sandstones, conglomerates and mudstones. Cretaceous sediments are partially covered by Middle and Late Miocene fluvio-lacustrine clayey sands filling the NNE-SSW graben.

During the Last Glacial Maximum (c. 24–22 ky BP) the study area was located ~110 km north of the Alpine piedmont glaciers and ~ 420 km from the southern edge of the North European continental Ice Sheet. Quaternary periglacial sediments include Pleistocene colluvial loamy sands, fluvial sandy gravels and the Holocene floodplain of the Lužnice River. Along this axial river, numerous aeolian sand dunes formed during the Younger Dryas (Pokorný and Růžičková, 2000). The sand dunes were formed, according to their morphology, by north-westerly winds. The source material originated both from fluvial sand and unconsolidated Cretaceous sandy bedrock. Because of its altitudinal position (420 m asl) and flat landscape, the loess cover has not been preserved in the Třeboň Mega-basin. Nevertheless, remnants of loess-like sediments can be found in the NW neighbourhood of this vast area.

Due to the nature of the geological substratum of this Mega basin, local soils are deficient in calcium carbonate. Currently, most soils are leached and show a tendency towards podzolization. The soils are thus mostly acidic (pH down to 3.3).

The study area is located in the temperate transitional climatic zone between west oceanic and east continental climatic settings. The present climate is controlled by prevailing westerly air masses, already significantly reduced in moisture by their passage across central Europe. Present mean annual precipitation is 627 mm and mean annual temperature is 7.8 °C (at the town of Třeboň; 30-year observation sequence).

Nineteen depressions filled by lacustrine sediments were recently discovered in the study area (Fig. 1, for details see Hošek et al., 2013; Hošek et al., 2016), most of them covered by artificial fishponds of Medieval and Modern foundation. These basins vary in size (several tens up to several hundreds of metres in diameter), and in the depth of their post-glacial infilling (2–12 m); nevertheless, they share several common features such as their location on Miocene sedimentary bedrock, elongated shape, and the presence of tectonic faults that often run along their major axis. Although research on the origin of the lake basins is still in progress, we assume that these basins are the result of the complex of thermokarst processes (formation and collapse of alases/pingos and surface degradation of the permafrost) that occurred during the periglacial conditions of the late LGM. Another explanation which should be taken into account is that their origin is connected with short-distance neotectonic horizontal movements (pull-apart basins). The local geological settings of these study lakes and the bathymetry of the lake basins are shown in Figs. 1 and 2.

The stratigraphy of the infilling of all the basins under investigation is very similar, and the time-successive changes in sediment character are highly contrasting, reflecting well the changes in environmental conditions during the millennia of sedimentation.

3. Material and methods

This paper is based on data obtained from the three most-intensively investigated lakes: Velký Tisý – 'VT' (49°02′58.01″N; 14°43′39.60″E), Švarcenberk – 'SV' (49°08′42.01″N; 14°42′45.22″E) and Lake Veselí – 'VS' (49° 10′14.67″N; 14°40′36.06″E). All of them were closed in terms of their hydrology and with relatively small catchments (4–6 km^2).

Reference cores VTC and VSC were taken in the summer seasons of 2014 and 2015 with a pneumatic hammer-operated piston corer (tube 50 mm in diameter). The SVC core from the central part of the SV lake was taken already in 2000 (Pokorný, 2002). After a visual description of the cores, these were subsampled continuously with intervals of 2.5 cm (core VTC) and 1 cm (VSC). In the case of Lake Švarcenberk, we used archived samples from the central core (SV), sampled with 4 cm intervals.

Although the study area has been severely influenced by agricultural management over the last centuries, we were able to discover Late Glacial paleosols within two (from the total of three) investigated catchments (Fig. 1), and the erosional surfaces associated with them, preserved under thick aeolian sand dune deposits. These sections were dug manually and the soils subsampled continuously for micromorphological, geochemical and rock-magnetic investigations.

3.1. Chronology and depth-age modelling

The chronology of the VTC core is based on seven radiocarbon ages determined on terrestrial plant macroremains (2 samples) and 5 bulk sediment samples (due to the general scarcity of macroremains). From the VSC core, two samples of terrestrial plants and one bulk sediment sample were used for dating. In the case of the SVC core, we used the already published radiocarbon measurements (Pokorný, 2002; Hošek et al., 2014).

From the soil buried under the Vlkovský přesyp sand dune (VLK), two charcoal samples were taken for radiocarbon dating, and one radiocarbon date (also obtained from a charcoal sample) used from a previous investigation of the site (Pokorný, 2002) (Table 1). Samples were