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The MIS 3/2 transition in a new loess profile at Krems-Wachtberg East – A multi-methodological approach

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ABSTRACT

Local to regional paleoenvironmental reactions to past climate changes are preserved in loess-paleosol sequences (LPS). In order to extract this information we used a multi-methodological approach in the Upper Paleolithic site of Krems-Wachtberg East in Lower Austria. Detailed field studies and high-resolution geochemical, colorimetric, and granulometric analyses help to understand the interplay between soil formation, loess accumulation, and surface processes. In comparison to the main profile/excavation of Krems-Wachtberg 2005–2015 it can be stated that OSL- and ^{14}C-ages as well as the (archeological) stratigraphy of both profiles are comparable. However, pedogenic features are more evident at Krems-Wachtberg East. The new investigations show that well-established weathering indices do not clearly trace interstadial soil formation in the studied profile. Apart from this fact, single specific elements like Fe and Mg react more sensitive to initial pedogenic processes. Weak pedogenesis can further be evidenced by quantitative spectrophotometric results. The latter is also capable of refining and supporting the stratigraphy/pedology based on field analyses. As a general rule, next to loess also initial soil horizons of the MIS 3 are remarkably rich in primary carbonates indicating that soil formation took place in an alkaline environment. Due to the fact that hydrolysis of feldspars could not clearly be detected by the application of pedochemical indices, soil formation was probably limited to the oxidation of iron bearing minerals and weak carbonate leaching. These phases of favorable climatic conditions in terms of pedogenesis were terminated by increasing dust input towards the onset of MIS 2. The eolian deposits are overprinted during reducing conditions in soils and/or modified by colluvial processes. Altogether, weak pedogenesis can be reliably detected using a multi-methodological approach which leads to enhanced paleoenvironmental interpretations. The OSL-ages put the profile in a range of ~41 to 30 ka. We present a tentative correlation of the studied loess profile to the record of the North Greenland Ice Core Project (NGRIP) for the part of the profile where OSL and ^{14}C complement each other.

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1. Introduction

Loess-paleosol sequences (LPS) are widespread terrestrial archives and contain information on Quaternary paleoenvironments. Records that formed within the last glacial period are increasingly correlated to the paleoclimatic archives of the Greenland ice cores (Antoine et al., 2009, 2013; Grootes and Stuiver, 1997; Hambach, 2010; Hambach et al., 2008; Moine et al., 2017; NGRIP members, 2004; Nigst et al., 2014; Schirmer, 2012). In particular, the transition from the milder marine isotope stage (MIS) 3 to the cold MIS 2 before the last glacial maximum (LGM) is of major interest for the

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investigation of past climate change and the response of geosystems (Heiri et al., 2014; Spötl et al., 2006). In this context, for Central Europe, there is an ongoing discussion about the chronological position of paleosol formations related to the mentioned time span. For instance, the Lohne soil (Germany/Upper Austria) and its correlatives like e.g. Stillfried B (Lower Austria) or PK1 (Czech Republic) (Antoine et al., 2009; Fuchs et al., 2012; Kadereit et al., 2013; Sauer et al., 2016; Terhorst et al., 2011) represent the last significant period of terrestrial soil formation during the Middle Pleniglacial, before the onset of the Upper Pleniglacial.

LPS are complex records for past dust sedimentation, pedogenesis, and frost dynamics. Furthermore, they repeatedly evidence erosion and reworking processes and therefore, can prove geomorphodynamic activity as well (Sprafke, 2016). It is most relevant that several sites also contain archeological findings of Paleolithic hunter-gatherer cultures, specifically during the MIS 3/2 transition (Händel et al., 2009a; Ranov, 1995). Increasing interest in past climate oscillations and environmental conditions during the arrival of anatomically modern humans, led to intense research activities in LPS. Developments in loess research are closely connected to methodological advances in dating techniques as for instance, in OSL procedures. In the timeframe of the MIS 3/2 transition the combination of radiocarbon ages (e.g. from charcoal of archeological horizons) and OSL provides the possibility of chronological control and refinement (Heiri et al., 2014).

The study area is located to the southeast of the Bohemian Massif, where numerous LPS of varying ages and temporal resolutions are present. Several sequences, e.g. Krems-Wachtberg, Stratzing, or Willendorf cover the transitional period of MIS 3/2 and contain archeological findings. However, expected soil formations related to a milder climate and stable environmental conditions are not yet proved for the study area. Significant interstadial paleosols like Stillfried B/the Lohne soil seem to be absent (Haesaerts et al., 2007; Händel et al., 2009b; Terhorst et al., 2014; Thiel et al., 2011). Discussions on this phenomenon have previously been arguing for high dust accumulation rates, active local slope processes, and low weathering intensity (Terhorst et al., 2015). Qualitative detection of incipient pedogenic processes through field analyses is possible, but their quantitative proof by laboratory data is lacking for the LPS in the study region (Terhorst et al., 2014).

Pedogenic processes like decalcification, oxidation, reduction or humification lead to color changes within the pedosphere. In loess sediments, the most important minerals are quartz, feldspars, clay minerals, and carbonates. In addition to these mainly white/colorless components, fine limonite is responsible for the typical pale yellowish appearance of loess (Pécsi, 1990). Spectrophotometry is an inexpensive and valuable tool to reliably measure high resolution color variations in LPS and detect slight paleoecological variations during the formation of LPS (Buggle et al., 2014; Sprafke, 2016; Sprafke et al., 2013; Zeeden et al., 2016).

A further parameter suitable for high-resolution analyses is grain-size distribution (GSD). The texture of unaltered loess reveals insights into the sedimentation dynamics related to different paleoenvironmental and −climatic conditions (Újvári et al., 2016; Vandenberghe, 2013). In areas which were morphologically active during the Pleistocene (periglacial slope dynamics), GSD of loess can be altered by syn- and postsedimentary processes (Neugebauer-Maresch, 1993; Sprafke et al., 2013; Terhorst et al., 2014). Pedogenesis in loess leads to a fractionation of grain-sizes after the eolian accumulation of the parent material. This is mainly reflected by an enrichment of particles belonging to the clay fraction due to clay neo-formation. Laser granulometry is a state of the art method to measure the GSD of loess fast, reliably, and reproducibly (Schulte and Lehmkuhl, in press).

Geochemical parameters require a thorough interpretation that reflects both, changes in sedimentological and pedogenic processes. In general, the use of weathering indices based on the process of hydrolysis is common in loess research to describe pedogenesis (a.o. Buggle et al., 2011; Schatz et al., 2015). In this context, certain elements are stable, dissolved and/or reprecipitated according to their ionic charge, ionic radius, and the physio-chemical setting of the paleoenvironment (e.g. redoximorphic conditions, pH-value). The widely applied indices incorporating Na and Al, such as the chemical index of alteration (CIA), or the chemical proxy of alteration (CPA), mainly describe the hydrolysis of plagioclases. Several studies were able to trace weathering on the base of these proxies, mainly on glacial/interglacial cycles, using XRF-measurements (Buggle et al., 2008; Raczyk et al., 2015; Smykatz-Kloss, 2003; Újvári et al., 2014).

The present study is a high-resolution multiproxy approach to the late MIS 3/early MIS 2 LPS at Krems-Wachtberg East, which is situated in close proximity to the well-known Middle Upper Paleolithic site of Krems-Wachtberg excavated in the years 2005 to 2015 (Einwögerer et al., 2006; Händel et al., 2014). Based on thorough field analysis that assessed the geomorphological context and the general forming processes of the studied LPS we use our comprehensive dataset consisting of spectrophotometric, laser granulometric, and XRF pedochemical measurements for detailed interpretations of the genesis of weak paleosols. A chronological frame consisting of luminescence ages in combination with radiocarbon ages supports the pedosedimentary studies.

2. Study area

The area to the west of the city of Krems is characterized by the river Danube, which cuts into the crystalline bedrock of the Bohemian Massif and formed the steep Wachau valley. Krems is located at the exit of this topographic bottleneck where the Wachau opens into the Tullnerfeld basin. The river Krems has its source northwest of Krems and joins the Danube close to the city (Fig. 1A). The regional geology is mainly determined by metamorphic rock of the Variscan units: to the north of Krems the bedrock is composed of amphibolite, paragneiss, and shist, whereas to the south it consists of granulites (Matura, 2006). Loess is mainly preserved on Pleistocene fluvial terraces (Fink, 1956).

The present climate of Lower Austria is characterized by an annual average temperature between 10 and 11 °C. The annual precipitation is spatially variable (Fig. 1B). Relative to the moist Westerlies, Krems is situated at the leeward side of the Bohemian Massif, which causes the area to be comparatively dry (500–550 mm). Although the rainfall maximum is in June and July (ZAMG, 2002), the hydrological balance can temporarily reach negative values during this time of the year (Harlfinger, 1999). High evaporation rates are the reason for low moisture rates in soils and the low winter precipitation is not capable of balancing this deficit. In comparison, the area to the southwest beyond the foothills of the Bohemian Massif is more influenced by moist Atlantic air masses (annual precipitation > 700 mm). To the east, precipitation follows a general trend towards even more continental conditions (Fig. 1B). The present soil distribution also reflects this trend in case loess forms the parent material. Thus, Cambisols developed in the region around Krems, whereas Chernozems dominate further to the east. Luvisols represent the recent soil in areas of higher moisture further to the west (BMLFUW, 2017).

The studied LPS is situated on Pleistocene fluvial terraces in the northwestern area of the confluence of the river Krems and the Danube. The term Wachtberg is designated to the lower slope of the Kuhberg mountain, which is peaking at 398 m above the Adriatic (AA). A number of important Paleolithic find spots, the Krems-

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