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A Multi-Proxy Analysis of two Loess-Paleosol Sequences in the Northern Harz Foreland, Germany

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ABSTRACT

Two loess-paleosol-sequences from the northern Harz foreland, Hecklingen and Zilly, have been investigated. In general, loess-paleosol-sequences represent valuable terrestrial archives of regional environmental and climatic conditions during past glacial periods. The study area is part of the northern European loess belt and was in the vicinity of the Scandinavian ice sheet during the Weichselian. Aiming towards a better understanding of the paleoenvironmental conditions during the Weichselian in an area close to the Scandinavian ice sheet, results from grain-size, geochemical (XRF, CNS), color and magnetic susceptibility measurements are combined. The findings demonstrate an increased input of aeolian material during the last glacial maximum and the last cover loess period, which is in accordance to the theory of drier and colder conditions during this time frame. Further, data reveal a strong input not only of loess but also of coarser material coming from a shorter distance during the last glacial maximum in both profiles. Material of the last glacial maximum clearly indicates a shift of wind direction towards easterly winds. In Hecklingen, an enhancement of coarser material has been observed within the recent soil and MIS 3 soil material. Since soil material that dates back to the MIS 3 is present in the profile, it can be assumed that surface processes were less intrusive during the MIS 3 and 2 than in e.g. the Lower Rhine Embayment and Saxony.

1. Introduction

Reconstructing environmental and climatic conditions of the past is crucial for understanding Earth's climate system of the past and present. For such reconstructions several types of geoarchives are available. Loess-paleosol-sequences (LPS) often represent the best accessible archive in terrestrial environments (e.g. Fischer et al., 2012; Fitzsimmons et al., 2012). Despite numerous attempts to define the term “loess”, no universally accepted definition exists. This results and causes a various use of the term “loess” and loess-like sediments at the same time (see e.g. Pécsi and Richter, 1996; Smalley et al., 2011; Sprafke and Obreht, 2015). Here, loess is defined as an aeolian, homogeneous, predominately silt-sized, calcareous and yellowish loose sediment, which covers around 10% of the land surface on Earth (e.g. Muhs, 2007; Thome, 1998; Pécsi, 1990). As some people before and after him, Smalley (1966) defined four criteria that have to be fulfilled in order to result in a formation of LPS: (1) source material is required, (2) wind is needed to transport the material, (3) a trap where loess can accumulates has to be present, and (4) an adequate amount of time for the accumulation and post-depositional modification processes needs to be given. Usually loess accumulates in dry and cold environments. Soils develop on loess during warmer and moister periods. Due to changes of climatic and environmental conditions a series of loess and paleosols accumulates and develops, forming LPS. In comparison to deep-sea sediment and ice cores, LPS represent important archives of continental conditions, also close to archeological findings (Assallay et al., 1998; Frechen et al., 2003; Pye, 1996; Pye, 1987; Smalley, 1995; Wright, 2001; Kels and Schirmer, 2010).

The forty years of German separation complicated research on LPS in the northern Harz foreland. As a consequence, only small isolated investigations have been done in the northern Harz foreland mostly during the 1960s and 1970s from both former German states with a dissimilar range of methods applied, in comparison to intensively studied areas, like the Lower Rhine Embayment (e.g. Remy, 1960; Brunnacker, 1967; Paas, 1968; Schirmer, 2000; Kels, 2007; Fischer, 2010). Additionally, the region is close to the northern loess boundary, which restricts the research area to the north. Most research done in the northern Harz foreland focused on this transition zone, where Weichselian silt- and sand-sized aeolian sediments both occur (Poser, 1951). Investigations at the northern loess boundary have been done by e.g. Gehrt (1994), Gehrt and Hagedorn (1996) and Brosche and Walther (1978). Contributions from further east concerning the loess boundary are given by e.g. Schmidt (1971), Altermann and Fiedler (1975), Billwitz and Haase (1964), Göbeler (1966), Haase et al. (1970), Neumeister (1971) and Schmidt (1971). A number of isolated studies have been done in the

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eastern and southeastern Harz foreland by e.g. Kunert and Altermann (1965), Ruske and Wünsche (1961, 1964, 1968), Ruske et al. (1962), Neumeister (1966) and Göbeler (1966). An overview of the research done prior to 1970, covering the loess areas of the former GDR is given by Haase et al. (1970). Attempts to broaden the knowledge of the regional loess stratigraphy in the western Harz foreland studies on several LPS were initiated by Rohdenburg and Meyer (1966), Bork and Rohdenburg (1979), Ricken (1983) and Brosche and Walther (1991). Wagner (2011) recently analyzed the spatial distribution of loess and its derivates along the Weser-Aller catchment.

The first study which aimed to cover a larger area of the northern Harz foreland crossing the former border was done by Reinecke in 2006. For about ten years now no further intense research has been done in the northern and northeastern Harz foreland. In the eastern and southeastern Harz foreland and east of Leipzig new investigations have been conducted by Mania (2003), Mania and Altermann (2001), Baumgart et al. (2013), Kreutzer et al. (2012, 2014), Meszner et al. (2011, 2013) and Zech et al. (2013). Meszner et al. (2013) introduced a composite profile of Saxony which indicates strong erosion phases causing hiatuses, having large depositional gaps, e.g. a gap between ~35–65 ka.

In general, a stratigraphical classification of the last glacial cycle in Western and Central Europe is usually based on a locally valid nomenclature. This makes cross referencing challenging (e.g. Schönhals et al., 1964; Rohdenburg and Meyer, 1966; Brunnacker, 1967; Haesaerts et al., 1981; Schirmer, 2000; Bibus, 2002; Zens et al., 2016). For the northern Harz foreland a stratigraphical classification of the LPS was last done by Reinecke (2006). He tried to integrate the stratigraphies of the northern Harz foreland into the local Late Weichselian loess stratigraphies of Rohdenburg and Meyer (1966) and Semmel (1968). However, the lack of solid LPS exceeding 2.5 m of thickness makes a precise stratigraphical classification of the LPS challenging. Except the profiles in favorable relief positions (especially subrosion depressions) only a few LPS are known exceeding 2.5 m thickness (Brosche and Walther, 1991; Reinecke, 2006). Further, the Eltville tephra as an important marker within the Weichselian loess is missing. It is widely accepted that the LPS generally can only be placed into the Late and, if present, the Middle Weichselian without further subdivision (e.g. Merkt, 1968; Haase et al., 1970; Brosche and Walther, 1991; Gehrt, 1994; Feldmann, 2002; Reinecke, 2006). The first trials of narrowing down the age range of sediments at the northern loess boundary (OSL-/TL-dating) suggest that they date to the Weichselian Late Pleniglacial until Late Glacial (Hilgers et al., 2001). Ages generated by Reinecke (2006) for LPS close to the northern margin of the Harz Mountains suggest loess sediments to be partially of Middle Weichselian age.

In this paper two LPS initially introduced by Reinecke (2006) are discussed. They have been reinvestigated by using new analytical methods. The aim of this paper is the expansion of knowledge concerning the paleoenvironmental conditions during the last glacial period in an area close to the former Scandinavian ice sheet by applying grain-size, geochemical (XRF, CNS), color and magnetic susceptibility measurements. An equivalent multi-proxy approach has not been done before in this region.

2. Regional setting

The two profiles, Hecklingen (N 51°50.451′; E 11°31.580′; 106 m asl) and Zilly (N 51°56.280′; E 10°50.643′; 182 m asl), are located in the northern and northeastern Harz foreland (see Fig. 1) which represents a transition zone between the flat North German Basin and the Harz Mountains. The Hecklingen profile is located on a relative shallow angled slope which follows a northwest direction with a slope angle of 2.3°. The profile faces towards the southeast. In Zilly the slope follows a southwest direction with an angle of around 2°. The profile faces towards the east.

The climate of the northern Harz foreland gradually changes from sub-oceanic to sub-continental following a west-east gradient. Whereas in the western Harz foreland the mean annual precipitation can reach over 1000 mm, it drops below 500 mm in the eastern part of the northern Harz foreland due to the rain shadow effects caused by the Harz Mountains. The eastern part of the northern Harz foreland is part of the so-called Central German Arid Region where annual precipitation can even drop below 400 mm in drier years (Döring, 2004; Fabig, 2007; Haase et al., 1970; Krauß et al., 2013; Reinecke, 2006).

With a mean annual air temperature of ca. 9 °C the northeastern Harz foreland is one of the warmer regions in Germany. Excluding areas along the Rhine and its tributaries, there are only a few places with comparable high or higher mean annual air temperatures. Longer frost periods during winter time are rather the exception, resulting in mean monthly winter temperatures above 0 °C. July and August have similar mean temperatures with 18.4 and 18.3 °C which mark the middle of summer. In combination with low annual precipitation rates, the mild temperature regime causes a negative climatic water balance at least during drier years (Döring, 2004; Krauß et al., 2013).

The dominant wind direction is west-southwest and the secondary is from the east. On average, the winter is dominated by southwesterly to west-southwesterly winds with the highest frequency of occurrence in January. In summer a westerly to northwesterly wind direction is most frequent. In April and March easterly wind patterns dominate. During the more cyclonic weather phases (January–February and June–July) the easterly wind direction is weakest (Döring, 2004).

The northern Harz foreland is part of the Subhercynian Basin, which is bordered by uplifted bedrock. To the northeast it is limited by the Flechtinger-Rosslauer block and to the southeast and south by the Halle-Hettstedter mountain ridge and the Harz Mountains. To the northwest the basin is open. Generally, the basin is covered by Mesozoic and Cenozoic sedimentary rocks, mainly of shallow marine origin. Due to block faulting and salt tectonics, the formerly horizontally bedded Mesozoic layers are anticlinal in several places and show an almost exclusively southeast-northwest strike trend. The synclines between those anticlines are commonly filled with Cretaceous sediments beneath a Quaternary cover (see Fig. 2). This causes a slightly wavy surface appearance (Haase et al., 1970; Patzelt, 2003; Razinksi et al., 2008; Reinecke, 2006; Wagenbreth and Steiner, 1990).

In the northern Harz foreland Pleistocene deposits are mainly loose sediments, which vary in thickness and composition. Those sediments are primarily fluvial terraces, some lacustrine and (peri)glacial deposits of the Saalian and Weichselian glacial cycle (Litt and Wansa, 2008). Major rivers in the northern Harz foreland are the Oker River and the Ilse River as tributaries of the Weser River. The Aue River, the Holtemme River, the Bode River, the Selke River and the Wipper River are tributaries of the Elbe River. The closest river to Hecklingen is the Bode River 2.5 km north-east of the profile. The Zilly profile is within 0.4 km south to 1 km east of the Aue River. Even though those rivers are small, they developed large alluvial fans during the Quaternary. For more details, see Reinecke (2006) and Lehmkuhl et al. (2016).

The loess-covered areas are part of the Northern European loess belt. The northern edge of the loess distribution is characterized by the occurrence of both Weichselian silt- and sand-sized aeolian sediments. Gehrt (1994) found that this transition zone cannot be understood as a result of continuous sorting as Poser (1951) suggested, but as a result of multiple aeolian sorting phases, where sediments get increasingly sandier the younger they are. To the northeast the loess distribution is restricted by the river Elbe. To the south the Northern European loess belt is limited by the Central German uplands. Here the continuous loess cover disperses into separated loess basins where loess can only be found up to elevations between 400 and 500 m asl and is only present as reworked loess. The Weichselian loess of the northern and eastern Harz foreland surrounds the Harz Mountains in a 40 to 50 km wide belt (see Fig. 1). Generally, the thickness of the loess cover rarely exceeds 2.5 m. However, in unique settings (e.g. subrosion depressions) the thickness can reach several meters (Haase et al., 1970; Reinecke, 2006).

Recent soils developed on the loess cover are chernozems and regosols. In flood plains fluvisols are present, mainly derivatives of former