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Late Glacial/Early Holocene slope deposits on the Swiss Plateau: Genesis and palaeo-environment

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ABSTRACT

On the Swiss Plateau, glacial and glaciofluvial sediments deposited during MIS 2 are widespread. They are generally overlain by younger sediments of different origin, mainly related to periglacial and slope wash processes. Depending on their genesis and composition, 3 types of slope deposits can be distinguished, which are classified as units 1, 2a and 2b. Unit 1 is characterized by its wide spatial occurrence and a constant thickness of 40–60 cm, high silt contents, and a sharp lithological discontinuity to the lying sediments, generally forming the parent material for the Ah- and Al-horizons of the Luvisols. Unit 2 represents erosion rills, filled up with loess loam and some gravel (< 5%) due to slope wash. Locally, periglacial deformations led to cryoturbatic structures in these sediments, which is used to differentiate between unit 2a (no indications for periglacial activities) and unit 2b (with cryoturbations).

Based on stratigraphic assumptions, the formation of unit 1 has been tentatively attributed to the Younger Dryas. Optical Stimulated Luminescence and radiocarbon dating of unit 2 indicate morphodynamic activity during the Early Holocene up to 7.5 ka, suggesting an open landscape. This scenario is in conflict with the established notion that reforestation in Middle Europe took place during the Bölling-Alleröd warm period. In order to explain this apparent contradiction for the Younger Dryas to Early Holocene environment, we suggest a continental climate with dry summers and drought stress on the vegetation, in combination with very cold winters and deep soil frost at the Pleistocene/Holocene transition, caused by the orbital precession maximum. After 7.5 ka, with the spread of oceanic woodland and reduced seasonal contrasts, the landscape stabilized and soils developed.

1. Introduction

The existence of Late Pleistocene periglacial slope deposits in Central Europe and their importance as soil parent material is widely accepted. In Germany, a differentiation into three periglacial layers, called “Basal Layer”, “Middle Layer” and “Upper Layer (UL)”, is known. A detailed research history and characterization of these deposits has been published by Semmel and Terhorst (2010) and Kleber and Terhorst (2013). Yet, there remain controversies related to their chronology and the palaeoecological conditions of their formation.

The widespread UL has first been described as having formed under periglacial conditions during the Younger Dryas (12.7–11.6 cal ka BP; e.g. Semmel, 1964, 2002; Frühauf, 1996). It is assumed to be the last period with periglacial activity at the end of the Würmian. The age estimate of the UL is based on the presence of heavy minerals associated to the Laacher See Tephra (LST), an eruption which occurred during the Alleröd, ca. 12.9 cal ka BP (Brauer et al., 1999; Schmincke, 2006). Additionally, Horn and Semmel (1985) found evidence of UL below peat from the Preboreal. The assumption of widespread solifluction and cryoturbation, in connection to permafrost during the Younger Dryas, is in contrast to the known vegetation history, indicating reforestation in Middle Europe as early as during the Bölling-Alleröd and the existence of birch and pine forests. Völkel and Leopold (2001) describe the existence of the UL below peat from the Bölling-Alleröd, therefore assuming a pre-Bölling age of the UL, which would fit better to known palaeoclimate and palaeoenvironmental reconstructions based on pollen records. Nonetheless, this age estimate has been rejected by Semmel and Terhorst (2010). In the German northern alpine foreland, in the area of the former Rhine Glacier, the UL has been described and mapped in detail by Kösel (Kösel, 1992, 1994, 1996, 2014; Kösel and

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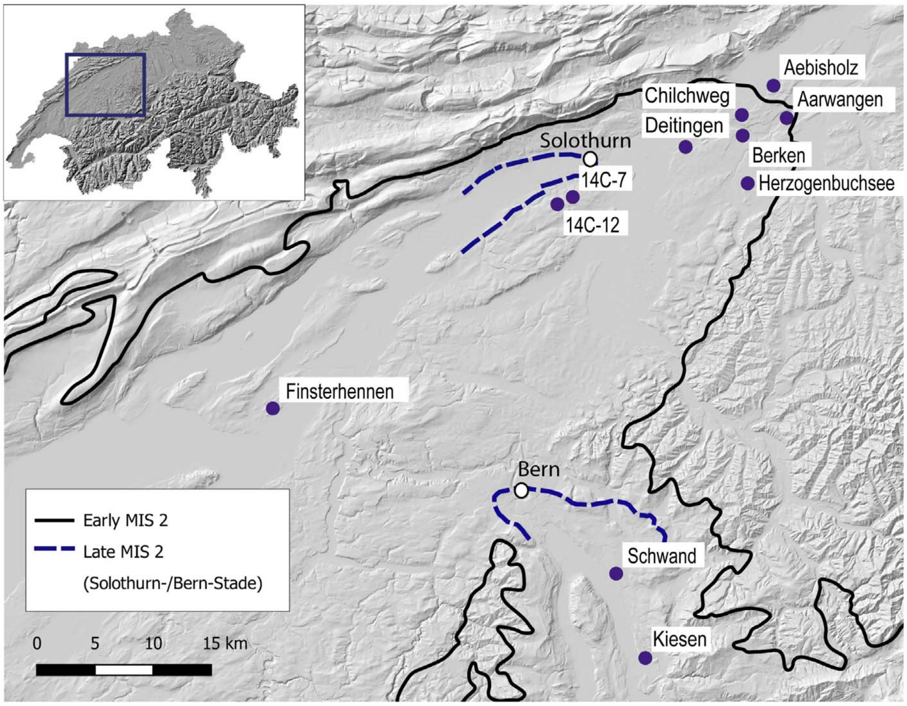

Fig. 1. Study area, showing locations of selected profiles mentioned in the text and former extents (Early MIS 2 and late MIS 2) of the Rhone-Aare Glacier system. Glacier limits are drawn after Bini et al. (2009) and own observations. At profiles Aebisholz, Aarwangen, Herzogenbuchsee, Chilchweg, Deitingen, 14C-7 and 14C-12, chronometric datings have been realized. Profiles Finsterhennen, Schwand and Kiesen are for sedimentary analysis only. For profile Berken see Fig. 3c.

Rothenhäusler, 1994), but no numerical age control is available up to now. Völkel and Mahr (2001) and Hülle et al. (2009) report Optically Stimulated Luminescence (OSL) ages of the UL reaching from Marine Isotope Stage 2 (MIS 2) to the Holocene, emphasising the role of post-depositional mixing.

In this paper we focus on the Swiss Plateau and investigate the age and genesis of slope deposits based on detailed field survey of soil profiles, analyses of physical and geochemical soil parameters and OSL dating. These results will be discussed in the palaeo-geoecological context. To avoid misunderstandings in nomenclature of the slope deposits (layer, cover bed, colluvium etc.), the neutral expression “unit” is used, here.

2. Material and methods

2.1. Study area

The study area is situated on the Swiss Plateau, where numerous soil profiles have been studied between the lake district around Finsterhennen in the west, and Solothurn-Aarwangen in the east (Fig. 1). In its basal part, the Swiss Plateau is built up of sand- and siltstones, marls and conglomerates (Nagelfluh) of the Molasse. These are widely covered by Pleistocene sediments of different origin, mainly till, glaciofluvial outwash deposits (gravel and sand), and reworked and decalcified loamy loess. The Pleistocene deposits are of different ages, due to the variable extent of the Rhone-Aare Glacier (RAG) during the Würmian period. Fig. 1 shows the situation during the assumed maximum ice advance of the Würmian glaciation. The RAG reached its maximum extent during early MIS 2 probably at ca. 27–24 ka (Ivy-Ochs et al., 2004, 2008; Preusser et al., 2007), whereas minor re-advances during the Bern- (Aare glacier) and Solothurn-Stade (Rhone glacier) occurred at ca. 19 ka (Wüthrich et al., in review; Bern- and Solothurn-Stades = BSS). The uppermost deposits (origin: periglacial, slope wash, eolian), in which most of the modern soils have developed, cover the underlying glacial and glaciofluvial sediments.

Today, the climate on the lower Swiss Plateau is characterized by annual mean temperatures of ca. 8.5–10.0 °C, with July means of ca. 18–20 °C and January means of -0.5 ± 0.7 °C. Annual precipitation amounts to ca. 1000–1200 mm (www.meteoschweiz.admin.ch; period 1981–2010).

2.2. Characterization of slope deposits

Field work comprised the investigation and sampling of soils and sediments available at gravel pits, hand coring (1–2 m Pürckhauer) and excavations. After having realized hundreds of hand- and motor corings during the last years, which allow to have a good knowledge of the spatial extent of the observed phenomena, and with some results already published (e.g. Mailänder and Veit, 2001), we selected some representative locations as indicated in Fig. 1 for further geochemical and sedimentary analysis and especially for chronometric dating. All profiles presented here are characterized by a topographic situation in a relatively flat, gently rolling landscape, build up by ground moraine and glaciofluvial plains (terraces). Slope is always $< 5°$. Soil horizons have been described according to Ad-hoc-AG Boden (2005). All geochemical analyses were realized on the fine fraction < 2 mm.

Particle size distribution was determined using a Malvern 2000 laser particle sizer connected to the Hydro 2000s module (Malvern Instruments Ltd., UK). Sub-samples (2 g) of the Ah- and Ap-horizons were pretreated with 15% H_2O_2 to remove organic matter, and sub-samples of all soil samples were dispersed (sodium hexametaphosphate and sodium carbonate) overnight on a rotational shaker (modified after DIN ISO 11277). The refraction indices of water ($n_D = 1.33$) and of the sediment ($n_S = 1.52$) were used for the optical model calculating the particle size distribution. Samples were measured three times (10 s each) in order to obtain a high reproducibility. Particles < 4 μm were classed as clay to overcome the problems occurring in the clay fraction (> 2 μm) caused by the non-sphericity of the clay particles (Konert and Vandenberghe, 1997). Soil pH was measured in 0.01 M $CaCl_2$ with a soil to solution ratio of 1:2.5, using a glass electrode (WTW 3310, and SenTix 41 electrode). Carbonate content was tested by 10% HCl in the field. Carbonate content was determined in samples showing effervescence after adding HCl by the gas-volumetric method using a Scheibler apparatus.

The classification of the different slope deposits into sedimentary units is based on field descriptions and lab analysis, as generally used in soil science (e.g. Ad-hoc-AG Boden, 2005; Schaetzel and Anderson, 2005), such as content of coarse material, silt content, lithological

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