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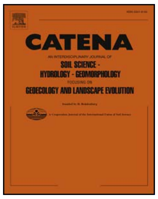

Chronostratigraphic interpretation of intermediate layer formation cycles based on OSL-dates from intercalated slope wash sediments

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ARTICLE INFO

Keywords:
Cover beds
Periglacial layer concept
Numerical dating
Pleistocene
Critical zone
Paleoenvironment

ABSTRACT

Stratified periglacial sediments extensively cover the slopes of central European low mountain areas. Periglacial cover beds and loess-like sediments as most abundant strata influence many near-surface processes, forming an important component of the Earth's critical zone.

The present study focusses on the analysis of a complex sequence of periglacial slope deposits with multiple intermediate layers and intercalated slope wash sediments in order to determine and date periods of intermediate layer formation.

Since luminescence dating often provides inconsistent data for cover beds, there is need to reconsider the numerical dating strategy. This study hence places stronger emphasis on numerical dating of interbedded, sufficiently bleached slope wash sediments. The gained OSL-ages are more reliable and consistent and thus, provide a temporal framework for relative dating of intermediate layer formation cycles. In combination with paleosol relics the numerical ages allowed a chronostratigraphic interpretation of Late Pleistocene paleoenvironmental dynamics and slope evolution.

Our findings not only prove multiple phases of intermediate layer formation in the study area during the last glacial period but also enabled the correlation of single intermediate layers with specific time spans, including Early and Middle Weichselian as well as the Late Glacial. Remnants of the Eemian soil in the studied sequence even indicate a Saalian age for the lowermost intermediate layer.

The present study shows that luminescence dating of intercalated slope wash deposits instead of cover beds is a promising numerical dating strategy for the chronostratigraphic interpretation of cover bed sequences. The findings further illustrate that complex, fanned out periglacial sediment sequences form despite their scarcity important paleoenvironmental archives for Late Pleistocene periglacial landscape dynamics in central European low mountain areas.

1. Introduction

Stratified Pleistocene sediments characterize the slopes of central European low mountain areas with periglacial cover beds and loess as most abundant strata. The stratified periglacial sediment cover influences many near-surface processes such as pedogenesis, soil properties or surface erosion (cf. Kleber, 1992; Lorz, 2008; Lorz et al., 2013; Phillips and Lorz, 2008), slope hydrology (cf. Chifflard et al., 2008; Kleber and Schellenberger, 1998; Kleber et al., 1998; Moldenhauer et al., 2013), and even slope stability (cf. Damm et al., 2013; Döhler and Menke, 2016; Terhorst et al., 2009) in low mountain areas. As pointed out by Kleber and Terhorst (2013) or Völkel et al. (2011) cover beds therefore form a basic component of the "Earth's critical zone" (cf. Brantley et al., 2007; Lin, 2009). Pleistocene periglacial slope deposits furthermore represent valuable paleoenvironmental archives (e.g. Kleber, 2014; Semmel, 1993, 1996).

1.1. *The periglacial layer concept*

In Germany, periglacial cover beds were first systematically investigated by Schilling and Wiefel (1962) and Semmel (1968). The latter distinguished three main sedimentological units in cover bed sequences: the basal, intermediate, and upper layer. The original periglacial layer concept includes two typical cover bed successions:

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https://doi.org/10.1016/j.catena.2017.11.003
Received 31 October 2016; Received in revised form 30 October 2017; Accepted 1 November 2017

bipartite sequences with upper layer on top of basal layer and tripartite sequences with an interbedded intermediate layer (Semmel, 1968, 2005). Numerous descriptions of cover bed sequences which deviate from this model (e.g. Bauer, 1995; Frank et al., 2011; Kleber, 1992; Kleber and Stingl, 2000; Kösel, 1996; Rohdenburg, 1965; Terhorst et al., 2009; Zöller and Nehring, 2002) led to constant supplementation of the periglacial layer concept in order to enhance its applicability (e.g. Sauer, 2002; Scholten, 2003; Semmel and Terhorst, 2010; Völkel, 1995).

Periglacial cover beds formed during Pleistocene in the summerly active layer over permafrost or deep seasonal frost (e.g. Benedict, 1976; Lewkowicz and Clarke, 1998; Matsuoka and Hirakawa, 2000; Shiklomanov and Nelson, 2013; Van Vliet-Lanoë, 2008) and gelifluction is regarded as main formation process. While eolian deposition of loess represents another periglacial key process, slope wash and cryoturbation are considered to be of secondary importance for cover bed formation (e.g. Adhoc-AG Boden, 2005; Kleber et al., 2013a; Semmel, 1968; Semmel and Terhorst, 2010).

While basal layers are composed of autochtonous weathering debris of underground rocks, intermediate and upper layers contain a supplementary allochtonous, eolian loess component (cf. Semmel, 1968, 2005; Semmel and Terhorst, 2010). Due to variable proportions of autochtonous and allochtonous material, the three cover bed units differ in grain size distribution and clast content (e.g. Kleber et al., 2013b; Sauer, 2004; Semmel, 1968; Semmel and Terhorst, 2010) as well as in physical and geo-technical properties (e.g. Terhorst et al., 2009; Damm and Terhorst, 2010). Abrupt changes of these characteristics cause disconformities at layer boundaries, which help to distinguish between cover beds (Kleber et al., 2013b; Leopold and Kleber, 2013; Semmel, 1968; Semmel and Terhorst, 2010).

The German periglacial layer concept has become a widely accepted approach, which is applied by geomorphologists and soil scientists in Germany and other European countries, e.g. Poland (e.g. Kacperzak and Derkowski, 2007; Waroszewski et al., 2015). In the following we give a brief overview on main characteristics of intermediate layers, which represent the main object of research in this study. For basal and upper layers see the anthology by Kleber and Terhorst (2013).

Intermediate layers occur in tripartite cover bed sequences between basal and upper layer. They are more restricted and often occur on lee-slopes and in former depressions of the paleotopography (e.g. Adhoc-AG Boden, 2005; Kösel, 1996; Semmel, 1968, 2005; Semmel and Terhorst, 2010). In addition to autochtonous weathering debris intermediate layers comprise considerable but varying allochtonous loess loam contents (e.g. Ad-hoc AG Boden, 2005; Friedrich, 1996; Sauer, 2004; Semmel, 1968, 1998), while the eolian material may have been incorporated during or after intermediate layer formation (e.g. Fried, 1984) or due to reworking of older loess-bearing sediments (e.g. Kleber et al., 2013b; Sauer, 2002; Zöller and Nehring, 2002). Intermediate layers are polygenetic sediments (Terhorst and Felix-Henningsen, 2010) with a complex formation history, which occasionally inherited the allochtonous sediment component entirely from older periglacial slope deposits (c.f. Hülle and Kleber, 2013) or paleosols (e.g. Bibus, 1985; Büdel, 1959; Kleber, 1998, 2004; Müller and Thiemeyer, 2012; Terhorst and Felix-Henningsen, 2010).

1.2. Periglacial cover beds in highly loess-influenced upland regions

Due to enhanced eolian loess input during Pleistocene the marginal areas of central European uplands represent transitional zones between the lower loess areas in the adjoining forelands, basins and valleys and the more elevated central parts of low mountain regions. Here, the loess component in slope deposits is enhanced and tripartite cover bed sequences with intermediate layers are more widespread. Occasionally intermediate layers occur with distinguishable sub-layers (cf. Kleber, 2004; Kösel, 1996; Sauer, 2002), particularly in former accumulation areas related to paleotopography (e.g. Kösel, 1996; Rohdenburg, 1968; Semmel, 1996). Complex periglacial sediment successions with alternating gelifluction layers, loess or loess-like deposits, and slope wash sediments form important paleoenvironmental archives and thus, grant valuable insight in Late Pleistocene landscape dynamics (Kleber, 2014).

1.3. Dating of cover beds and the age of intermediate layers

First of all, periglacial cover beds form lithological units (e.g. Fried, 1984; Semmel, 1968; Stahr, 1979) which do not necessarily represent certain time spans (e.g. Adhoc-AG Boden, 2005; Hülle and Kleber, 2013). Late Pleistocene cover bed formation depended on many factors, such as slope inclination and aspect, sediment availability and input, as well as vegetation cover (cf. Kleber et al., 2013b; Sauer, 2002). As a consequence, the age of cover beds, particularly of basal and intermediate layers, may thus vary regionally or even locally (e.g. Fiedler and Hunger, 1970; Fried, 1984; Stahr, 1979). The loess-loam content led to the idea that intermediate layers formed under cold and dry climate conditions (cf. Kleber, 1992; Völkel et al., 2002), probably during Upper Weichselian (Hülle et al., 2009; Mailänder and Veit, 2001; Völkel and Mahr, 1997). Loess admixture did, however, not necessarily take place during but before intermediate layer formation (Sauer, 2002, see also Kösel, 1996; Rohdenburg, 1965) and since the same material is probably reworked several times, intermediate layers do not represent a certain type of paleoenvironment (cf. Sauer, 2002; Zöller and Nehring, 2002).

Each cover bed in a periglacial layer sequence represents a last, final stage of translocation (Zöller and Nehring, 2002) but the time of deposition and the actual age of the deposited material may differ widely, hence causing numerical dating problems. Particularly the application of luminescence dating is difficult due to incomplete bleaching of grains, inheritance of older sediment or post-depositional mixing, which cause age over- or underestimations (cf. Fuchs and Lang, 2009; Huber, 2014; Hülle and Kleber, 2013). OSL-dates for cover beds show more or less pronounced age variations (Table 1), a transfer of results from one region to another remains difficult, and attempts to deduce universal ages for cover beds seem unrewarding (e.g. Hülle and Kleber, 2013; Stahr, 1979).

OSL-dates for intermediate layers show wide age ranges and numerical dates often coincide with OSL-ages of basal or upper layers (Table 1). Völkel and Mahr (1997), for example, dated intermediate

Table 1
List of numerical datings (IRSL) available for periglacial cover beds. ^{1} multi aliquot additive dose, ^{2} single aliquot regeneration.

Study	Study area	Dating method	Dated material	Numerical dating results for periglacial cover beds in ka		
				Upper layers	Intermediate layers	Basal layers
Völkel and Mahr (1997)	Bavarian Forest, Germany	MAAD^1-IRSL	Polymineral fine-grain	3.0 ± 0.7 to 18.3 ± 3.9	6.0 ± 1.3 to 25.5 ± 2.6	–
Hülle et al. (2009)	Taunus Mountains, Germany	SAR^2-IRSL	Quartz	10.2 ± 1.1 to 12.4 ± 1.2	19 to 23	< 43 to 195
Huber (2014)	Bavarian Forest, Germany	SAR^2-IRSL	Quartz, feldspar	7 to 10, 20 to 30	23.5 ± 1.5 to > 95 ± 5	–
Veit et al. (2014)	Alpine Foreland, Switzerland	SAR^2-IRSL	Quartz, feldspar	7 to 10	–	–
Frank et al. (2011)	Vienna Forest, Austria	SAR^2-IRSL	Feldspar, reworked loess	–	< 25.4 ± 4.8	–
Homolova et al. (2012)	Lake Neusiedel region, Austria	SAR^2-IRSL	Feldspar, reworked loess	–	< 23.1 ± 1.4	–