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Late Pleistocene and Holocene landscape formation in a gully catchment area in Northern Hesse, Germany

Susanne Döhler [a,*], Bodo Damm [a], Birgit Terhorst [b], Christine Thiel [c,d,e], Manfred Frechen [e]

[a] ISPA, University of Vechta, Driverstraße 22, 49364 Vechta, Germany
[b] Institute of Geography and Geology, University of Würzburg, Am Hubland, 97047 Würzburg, Germany
[c] Center for Nuclear Technologies, Technical University of Denmark (DTU), Risø Campus, Frederiksborgvej 399, 4000 Roskilde, Denmark
[d] Nordic Laboratory for Luminescence Dating, Department of Geoscience, Aarhus University, Risø Campus, Frederiksborgvej 399, 4000 Roskilde, Denmark
[e] Leibniz Institute for Applied Geophysics, Section, S3: Geochronology and Isotope Hydrology, Stilleweg 2, 30655 Hannover, Germany

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ABSTRACT

Permanent gully channels under forest are common geomorphological features in Central European low mountain areas. In the Rehgraben/Fuchslöchergraben gully catchment in Northern Hesse, Germany the Late Pleistocene landscape formation is reconstructed based on periglacial cover beds. In addition, the Holocene landscape development and soil erosion history are investigated using anthropogenic soil sediments and alluvial fan sediments. Until now, a combination of these approaches has not been applied to a gully catchment to this extent. The distribution of the different Quaternary sediments enables the differentiation between Pleistocene and Holocene landforms. Radiocarbon and optically stimulated luminescence dating are applied to add numerical data to the relative ages of the sediments and landforms.

The gully channels are oriented along Pleistocene depressions that are built up of periglacial cover beds and intercalated reworked loess. As the gully channels cut through the periglacial cover beds, especially the upper layer, the gully system is of Holocene age. At least two phases of gully erosion are identified in the alluvial fan sediments. The initial gully erosion is dated to the time span between the Late Bronze Age and Roman Times. A second gully erosion phase is dated to the 14th century and may be correlated to the severe precipitation events during this time. Gully erosion started during the Younger Holocene and is connected to human settlement and land use activity. The intense human impact hampers the application of the concept of periglacial cover beds to reconstruct landscape formation and limits it to areas where the periglacial upper layer is still preserved.

1. Introduction

In Central European low mountain areas landforms are often characterized by geomorphological features which result from gully erosion. Gully erosion is defined as a linear soil erosion process caused by concentrated runoff on non-vegetated surfaces leading to the removal of soil material and the formation of erosion channels (Soil Science Society of America, 2008) during or shortly after heavy precipitation events (Poesen, 1993). The detachment of soil material and its transportation is mainly controlled by runoff intensity (Poesen, 1993) and vegetation cover. Therefore, it is directly affected by climatic conditions and land use change (Poesen et al., 2003; Valentin et al., 2005). Before the onset of anthropogenic land use soils were protected from soil erosion by a dense vegetation cover (e.g. Bork, 1985; Bork et al., 1998; Dotterweich, 2008; Dreibrodt et al., 2010) and high infiltration capacities of forest soils, which prevented surface runoff (Valentin et al., 2005; Dreibrodt et al., 2010). Intensive soil formation proceeded in a phase of geomorphodynamic and geoecological stability before any human impact on landscape development. Pedogenesis was interrupted and the phase of geomorphodynamic stability ended abruptly as a consequence of human land use activity, starting during the Early Neolithic (Rohdenburg, 1971). Land use was particularly intense in loess regions; therefore, loess landscapes are affected by linear soil erosion in particular due to their sedimentological features (Bork, 1983, 1985; Lang and Bork, 2006).

* Corresponding author.
E-mail address: susanne.doehler@uni-vechta.de (S. Döhler).

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Gully erosion is a highly dynamic process that commonly proceeds in a cycle of incision and infilling, with the gully repeatedly forming in the same position (Poesen et al., 2003; Poesen, 2011). Ephemeral gullies may be filled with sediment shortly after their incision (Poesen, 1993; Soil Science Society of America, 2008). Typical (or classical) gullies are more deeply incised and are, therefore, more persistent in the landscape; they are called permanent gullies (Poesen et al., 2003; Valentin et al., 2005; Soil Science Society of America, 2008). Afforestation occasionally disrupted the formation cycle of both infilled and permanent gullies by protecting the first from re-incision and the latter from infilling (e.g. Valentin et al., 2005). Many studies from the past decades have shown that the erosion channels developed in historical times under different climate and/or land use conditions (Valentin et al., 2005). At present, permanent gully erosion is a rare phenomenon in Central Europe (Poesen et al., 2003; Valentin et al., 2005). Verstraeten et al. (2009) state that the importance of both climate change and vegetation cover on soil erosion may be variable and that often the impact of these factors on soil erosion cannot be defined clearly.

Based on detailed stratigraphic analyses several phases of soil erosion and gullying have been reconstructed throughout Central Europe (e.g. Bork, 1985; Bork et al., 1998; Schmitt, 2003; Dotterweich, 2005; Dotterweich et al., 2012). Phases of severe gully erosion came about during the first half of the 14th and from the end of the 17th century until the first half of the 19th century. Both phases correspond to the beginning and end of the Little Ice Age, respectively, indicating a climatic impact. In addition, population density was high and the demand for arable land increased, with the consequence of woodland cover being reduced to its lowest extent in the history of Central Europe during Medieval times, leaving surfaces bare and vulnerable to soil erosion (Lang and Bork, 2006; Dotterweich, 2008; Dreibrodt et al., 2010). Numerous studies on historical gully systems in Central Europe have aimed to reconstruct Holocene landscape formation and soil erosion history in particular and have tried to identify the main controlling factors in Central Europe. Infilled or partly infilled gully systems have been studied by Bork (1983, 1985), Bork et al. (1998) and Dotterweich (2005) in Germany, and by Dotterweich et al. (2012) in Poland. Historical gully systems under forest cover have been studied by Bauer (1993), Semmel (1995), Stolz and Grunert (2006) and Stolz (2008) in Germany, by Nachtergaele et al. (2002) and Vanwalleghem et al. (2006, 2003) in Belgium, by Schmitt et al. (2006) in Poland, by Stankoviansky (2003), Papčo (2011), Stankoviansky and Ondrčka (2011), Dotterweich et al. (2013) in Slovakia, and by Gábris et al. (2003) in Hungary.

Pleistocene sediments such as periglacial cover beds and loess record the conditions of Pleistocene landscape formation and the paleotopography before the impact by human activity. Different Pleistocene sediments form the parent material for Holocene pedogenesis. Pleistocene sediments and soils hold information on the paleoenvironment and represent the surface conditions at the time of human occupation. Holocene anthropogenic sediments as well as landforms carry information on geomorphodynamic processes and the extent of landscape alteration caused by human impact; they further store information of the impact of extreme climatic events on landscape formation. Besides the formation of gully channels, soil erosion during the Holocene caused the formation of slope depressions in gully catchment areas (Bork, 1983; Bork et al., 1998) and the deposition of alluvial fans by gully erosion events (Poesen et al., 2003; Valentin et al., 2005). On upper slopes and in convex slope positions, soil erosion results in truncated soil profiles. Transported soil material was mainly deposited on slopes as anthropogenic soil sediments (e.g. Fröhlich et al., 2005) or in older linear erosion forms (e.g. Bork, 1985; Bork et al., 1998; Dotterweich, 2005, 2012).

Together, different Quaternary sediments and soils constitute important archives and serve as tool to reconstruct Quaternary landscape history. Infilled gullies and alluvial fans record single gully erosion events, incision, and accumulation periods. Permanent gully channels under forest provide less information, since soil sediments within the erosion form are absent. In this context, Pleistocene periglacial cover beds may be used to reconstruct the Late Pleistocene landscape formation in Central European low mountain areas and to distinguish between Pleistocene and Holocene sediments and landforms (Semmel, 1968, 2002a; Bibus et al., 2001). The concept of periglacial cover beds, developed by Schilling and Wiefel (1962) and Semmel (1968), has been successfully applied to reconstruct Pleistocene and Holocene landscape history in landslide areas in Austria (e.g. Terhorst et al., 2009) and Germany (e.g. Terhorst, 2007).

In general, studies on landscape formation in gully catchment areas have focused on the reconstruction of soil erosion history and on Holocene landscape dynamics. Periglacial cover beds were used to date gully channels to the Holocene (e.g. Bauer, 1993; Moldenhauer, 1995; Stolz, 2008). Until now, Quaternary sediments along gully channels have rarely been investigated. However, the distribution and degree of erosion or absence of Quaternary sediments connected to gully channels provide a very detailed view not only on soil erosion history during the Holocene but also on the Late Pleistocene landscape evolution.

The aim of this study is to reconstruct the landscape formation in a gully catchment area by analyzing the different Quaternary sediments with a focus on periglacial cover beds to study the Late Pleistocene landscape formation. In addition, gully formation is investigated with respect to Holocene soil erosion processes. The combination of both approaches has as to yet not been applied to gully catchment areas to this extent.

2. Quaternary sediments as tool to reconstruct landscape formation

2.1. Pleistocene periglacial cover beds

Periglacial processes including solifluction, cryoturbation, and eolian sedimentation led to the formation of a multi-layered sediment cover in central European low mountain areas during the last glacial period. In general, three main cover bed units formed under periglacial conditions: the basal layer, the intermediate layer, and the upper layer. Schilling and Wiefel (1962) and Semmel (1968) introduced the concept of periglacial cover beds, and at present, many terms exist for the different sediment layers. However, in this article we use the terminology suggested by Kleber (1992, 1997) and Kleber and Terhorst (2013, and articles therein).

Basal layers are widespread, cover almost all slopes of low mountain areas with an increasing thickness downslope and may consist of several sub-layers (Semmel, 1968; AG Boden, 2005). Basal layers often fill older landforms and thereby overprint and reduce the relief intensity of the paleolandscape (Semmel, 1968; Kleber and Scholten, 2013). Basal layers are composed of weathering debris of the surrounding bedrock which mainly underwent short-distance transport. An allochthonous, silty eolian component is commonly absent (Semmel, 1968; Altermann et al., 1977). Therefore, the basal layers formed before the accumulation of loess (Terhorst et al., 2009) and most likely before the Last Glacial Maximum (LGM) (Raab, 1999; Raab and Völkel, 2002); according to Hülle and Kleber (2013), this represents a minimum age.

Intermediate layers superimpose the basal layers in sheltered positions, such as slope depressions, and are related to paleodepressions (e.g. Altermann et al., 1995; AG Boden, 2005; Semmel and Terhorst, 2010). However, Kleber and Scholten (2013) and