Geomorphology 276 (2017) 71–85

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Timing of early Quaternary gravel accumulation in the Swiss Alpine Foreland

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ARTICLE INFO

Article history:
Received 15 December 2015
Received in revised form 27 September 2016
Accepted 9 October 2016
Available online 11 October 2016

Keywords:
Cosmogenic
^{10}Be
Depth-profile dating
Deckenschotter
Pleistocene

ABSTRACT

Deckenschotter ('Cover Gravels') are proximal glaciofluvial gravels located in the northern Alpine Foreland mainly beyond the extent of the Last Glacial Maximum. They cover Tertiary Molasse or Mesozoic bedrock with an erosional unconformity. In Switzerland, Deckenschotter are referred to as Höhere (Higher) and Tiefere (Lower) Deckenschotter based on their topographical positions with a significant phase of incision that separates these two units. For this study, we performed sedimentological analyses to identify the provenance, transport mechanisms and depositional environment of these gravels. In addition, we established the chronology of the Höhere Deckenschotter gravels at Stadlerberg using cosmogenic ^{10}Be depth-profile dating technique. The inherited ^{10}Be concentration then allowed estimation of a catchment-wide palaeo-denudation rate. The results from clast fabric investigations indicate that braided rivers within a glaciofluvial environment transported these sediments to the study site mainly as bedload. In addition, the petrographic composition of the deposits shows that a large portion of the gravels was derived through erosional recycling of Miocene Molasse conglomerates. Some material was additionally sourced in the northern Central Alps. We then conclude that gravel accumulation in the Swiss Alpine Foreland was completed at 1.9 ± 0.2 Ma. This age, however, represents a minimum age and the oldest ^{10}Be depth-profile age ever obtained for a geological unit. Furthermore, a palaeo-denudation rate of c. 0.3–0.4 mm/a was estimated for the catchment of Stadlerberg gravels. Finally, elevation differences between the bedrock underlying the Höhere Deckenschotter and the modern base level imply a long-term regional incision rate of c. 0.12 mm/a.

1. Introduction

In 1909, Penck and Brückner differentiated four Quaternary morphostratigraphic units at sites in the south German Alpine Foreland based on different levels of former outwash plains. At these sites, the higher elevation Deckenschotter units are attributed to the Günz glaciation, lower Deckenschotter units to the Mindel glaciation, Hochterrasse (HT; Higher Terrace) to the Riss glaciation and Niederterrasse (NT; Lower Terrace) to the Würm glaciation. It is important to know that the older sediments are situated at higher elevation while the altitudes of the younger ones are lower. For a long time, the Quaternary stratigraphy of Switzerland was correlated to that of southern Germany (Penck and Brückner, 1909). Based on results of decades of research, a refined stratigraphy was proposed for the northern Swiss Alpine Foreland, which reveals that glaciers advanced at least 13 times into the foreland during the Quaternary (Schlüchter, 1986; Graf, 2009a). These include the four to eight Deckenschotter glaciations during the early Pleistocene (Graf, 1993, 2009b), at least five glaciations during the middle Pleistocene (Graf, 2009a) and two glaciations during the late Pleistocene including the Last Glacial Maximum (Schlüchter and Müller-Dick, 1996; Keller and Krayss, 2010; Preusser et al., 2011).

1.1. Deckenschotter in Switzerland

In Switzerland, the Deckenschotter units have been divided into Höhere Deckenschotter (HDS; Higher Cover Gravels) and Tiefere Deckenschotter (TDS; Lower Cover Gravels) (Du Pasquier, 1891; Frei, 1912). The stratigraphic relationship of HDS and TDS to the original location in southern Germany is not established yet. Deckenschotter deposits have been mapped as laterally discontinuous isolated relicts on plateaus found between the Jura Mountains in the west and Lake Constance in the east; some outcrops occur even further westward, along the River Rhine (Du Pasquier, 1891; Frei, 1912; Graf, 1993, 2009a; Keller and Krayss, 2010; Preusser et al., 2011) (Fig. 1). Deckenschotter lie unconformably on Tertiary Molasse or Mesozoic carbonate bedrock.

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http://dx.doi.org/10.1016/j.geomorph.2016.10.016

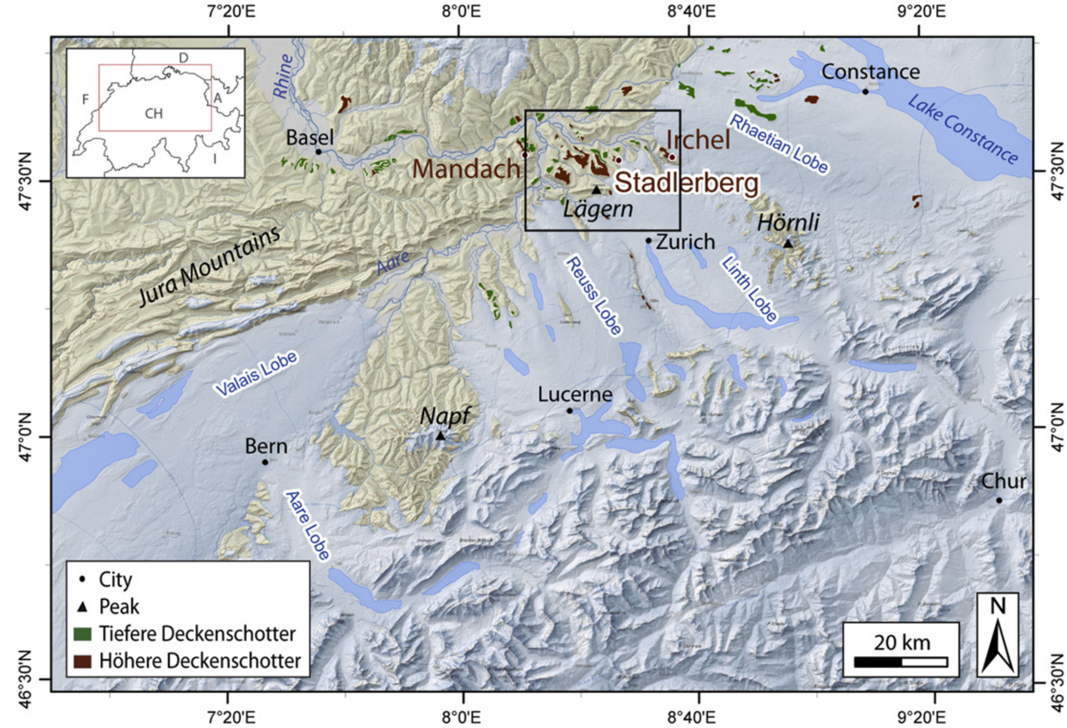

Fig. 1. Extension of the Valais, Aare, Reuss, Linth and Rhaetian Lobes during the Last Glacial Maximum (from Bini et al., 2009); location of the study site Stadlerberg and distribution of the Deckenschotter in the northern Alpine Foreland (©Federal Office of Topography, swisstopo, CH-3084 Wabern). The black square marks the outline of Fig. 2A.

The gravel base of the HDS lies approximately between 400 m above sea level (a.s.l.) in the west and 700 m a.s.l. in the east, whereas TDS deposits are found at lower altitudes ranging from 350 m a.s.l. near Basel to 600 m a.s.l. near Constance (Du Pasquier, 1891; Frei, 1912; Graf, 1993; Keller and Krayss, 2010). The difference in elevation suggests that the two Deckenschotter units are separated from each other by a period of significant incision (Graf, 1993, 2009a, 2009b). Sediments recognised at the various outcrops were interpreted as proximal glaciofluvial gravels with local intercalations of till and overbank fines (Frei, 1912; Suter, 1939; Graf, 1993; Bitterli et al., 2000). These glaciofluvial deposits have been considered to represent braided river sediments, where gravels accumulated in broad channels when the ice released large volumes of coarse sediments that accumulated in close proximity, downstream of the snout of glaciers (Graf, 1993). In addition, these sediments have been interpreted to mark the major drainage network of the northern Swiss foreland during the early Pleistocene (Liniger, 1967; Graf, 1993; Hofmann, 1996; Petit et al., 1996; Kuhlemann and Rahn, 2013). In the period between HDS and TDS deposition, an incision of approximately 80–100 m into formerly deposited gravels and 30–110 m into bedrock are observed. Even deeper bedrock incision was observed after TDS deposition with erosional depths ranging between 140 and 260 m (Graf, 1993; Kuhlemann and Rahn, 2013).

The timing of Deckenschotter accumulations is poorly understood compared to the late Quaternary glaciations (Preusser et al., 2011 and references therein; Heuberger et al., 2014; Ivy-Ochs, 2015). Deckenschotter deposits are thought to be the oldest Quaternary units in the northern Swiss Alpine Foreland known so far. Palaeomagnetic studies were performed at some sites of the Höhere Deckenschotter in Switzerland (see Graf, 1993 for further details). Based on these results, the deposition of the oldest HDS occurred during a period of normal polarity, prior to the Brunhes Chron because some samples showed a normal magnetization with values that do not coincide with the direction of today's magnetic field (Graf, 1993; Bolliger et al., 1996). Thus, the minimum age for their accumulation would have been the Normal Jaramillo event during the Matuyama Reversed Chron (0.915–1.010 Ma; Spell and McDougall, 1992). In the topmost HDS deposits at Irchel, a mammalian faunal assemblage was assigned to Mammal Neogene Zone 17 (MN 17: 1.8–2.5 Ma) (Bolliger et al., 1996). Recently, the stratigraphically youngest HDS deposits near Mandach (Fig. 1) were dated with cosmogenic ^{10}Be depth-profile dating to 1.02 ± 0.1 Ma (Akçar et al., 2014). Accordingly, more detailed chronological investigations are needed to improve our understanding.

A first absolute age was obtained by Häuselmann et al. (2007a) who applied burial dating techniques to Deckenschotter deposits at their type locality in southern Germany (Penck and Brückner, 1909). These authors proposed burial ages of $2.35^{+1.08}_{-0.88}$ Ma for HDS sediments at Böhener Feld and $0.68^{+0.23}_{-0.24}$ Ma for TDS deposits at Bad Grönenbach.

1.2. Goals of this study

Although Deckenschotter deposits in Switzerland have been extensively studied for their lithostratigraphic position, relatively little quantitative information has been published on the chronology of these archives and on the paleo-denudation rate recorded by them. This paper focuses on the Higher Deckenschotter deposits at Stadlerberg (canton Zurich, northern Switzerland) (Figs. 1, 2). The fabric and petrographic composition of the deposits are studied to identify the provenance of the sediments and to interpret the transport mechanisms and depositional environment. This information then allows inference to be made about the distance to the ice margin at that time. In order to contribute to the understanding of Quaternary landscape evolution in the foreland, it is of high importance to reconstruct the chronostratigraphy of the Swiss Deckenschotter. We use both ^{10}Be depth-profile and ^{10}Be and ^{26}Al isochron burial dating techniques to determine the age when these sediments were deposited. In addition, we estimate a catchment-averaged denudation rate from the inherited ^{10}Be concentration preserved in these deposits. Finally, based on the reconstructed chronology, we report a post-depositional incision rate into bedrock. In conclusion, the overall goal is to provide, for the first time,