Quaternary Geochronology 4 (2009) 363–373

Contents lists available at ScienceDirect

Quaternary Geochronology

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

Research Paper

Dating of Late Pleistocene terrace deposits of the River Rhine using Uranium series and luminescence methods: Potential and limitations

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ARTICLE INFO

Article history:
Received 31 March 2008
Received in revised form
27 March 2009
Accepted 2 April 2009
Available online 11 April 2009

Keywords:
U series dating
Optical dating
Fluvial deposits
River Rhine
Pleistocene
Meteoric cement

ABSTRACT

Uranium-series dating of pedogenic carbonate crusts from fluvial gravels is tested using Optically Stimulated Luminescence (OSL) ages as references. OSL dating yielded ages of 30–15 ka and 13–11 ka, which correlate with the cold periods of the Last Glacial Maximum and the Younger Dryas. These ages are internally coherent and consistent with the geological background and are thus regarded as reliable. Most of the U/Th results scatter widely in the $^{230}Th/^{232}Th$ vs. $^{234}U/^{232}Th$ isochron diagram, making regression unrealistic. Semiquantitative age estimates from the data were found to be mostly older than the OSL ages and the geological context. It is suggested that a heterogeneous initial ^{230}Th input, not relatable to a detrital component, is responsible for the observed discrepancies. This input may be due to bacterial activities and Th transport on organic colloids. It appears necessary to avoid samples where bacteria could have contributed to carbonate precipitation. Further, the relative importance of this problem decreases with sample age, so that U/Th dating of sinters is expected to be more reliable in the >100 ka age range.

1. Introduction

Fluvial deposits are important archives reflecting the response of drainage networks to past environmental and sea-level changes (e.g., Blum and Törnqvist, 2000; Houben, 2003). This is, for example, demonstrated by the change from highly depositional fluvial environments of braided river systems to more erosional dominated meandering flow patterns. Additionally, in areas of local to regional uplift the vertical difference between the surface of the present-day river and raised fluvial terraces can be used to reconstruct the uplift rate of an area (Bonnet et al., 1998; Nivière and Marquis, 2000; Houtgast et al., 2002). In both cases outlined above, the age of the investigated fluvial deposits is of crucial importance to either correlate the local findings with a global scale of climate change or for quantifying uplift rates.

Until recently, the dating of fluvial sediments has been problematic. The only way would have been radiocarbon dating of organic material found in the fluvial deposits. While this may be straightforward for many Holocene deposits, it is only rarely possible for sediments formed during glacial periods, where organic remains are only infrequently found. Furthermore, radiocarbon dating is limited to the last 50 ka due to the half-life of the ^{14}C isotope. A relatively new method that overcomes these problems is Optically Stimulated Luminescence (OSL), which allows the direct determination of sediment deposition ages (e.g., Wallinga, 2002; Preusser et al., 2008). Most problems encountered with the method, such as the identification of incompletely bleached sediments, have been largely solved and an increasing number of studies have used OSL for establishing chronological frameworks in the past decade (e.g., Wallinga et al., 2004; Rittenour et al., 2005). However, two major problems remain with the dating of fluvial sediments. The first is related to the absence of suitable sand layers for OSL dating in some fluvial environments, especially in high fluvial energy regimes in mountainous areas and proglacial settings. The second is related to the upper dating limit of OSL. Although it should be, in principle, possible to date back to several 100 ka by OSL (e.g., Schokker et al., 2005; Rhodes et al., 2006), it is highly dependant on the radioactive dose rate in any particular setting. In sediments rich in radioactive elements, the saturation dose of the OSL signal may be reached in about 150 ka or even less. Furthermore, to confirm OSL beyond 200–300 ka, independent age control is desirable because many samples approach saturation and fitting of growth curves gets less precise: a recent study reports a systematic underestimation of quartz OSL dates in this age range

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doi:10.1016/j.quageo.2009.04.002

(Wallinga et al., 2007). Besides OSL and the recently tested approach of burial dating using cosmogenic nuclides (Häuselmann et al., 2007), age control for fluvial sediments beyond 100 ka may be possible by U/Th methodology.

U/Th is now a commonly used method for dating speleothems and corals (e.g., Spötl et al., 2002; Spötl and Mangini, 2006; Fleitmann et al., 2007; Scholz and Hoffmann, 2008). In addition, some promising pioneer studies showed that calcrete-like carbonate precipitates that formed within the gravel or soil of a fluvial terrace can be dated using U/Th (Ku et al., 1979; Radtke et al., 1988; Kelly et al., 2000; Candy et al., 2004, 2005). While these studies concern arid to semi arid areas, other types of sinter from temperate areas proved useful: Spötl and Mangini (2006) used flowstones precipitated in a fracture to constrain the deposition age of the host rock, a Quaternary breccia. Besides, the ages obtained by the authors were also used to constrain climatic conditions and glacier extension. Blisniuk and Sharp (2003) and Sharp et al. (2003) were able to give a chronologic frame to the formation of Pleistocene fluvial terraces from Tibet and Wyoming using carbonate crusts that formed within the gravel of those terraces. Blisniuk and Sharp (2003), for example, obtained ages between 16 and 233 ka with a fair error. Such results enabled these authors to quantify recent fault displacement.

U/Th methodology enables to measure the time elapsed since a carbonate precipitated. Thus, in the case of an investigation on the host rock of the carbonate, it only provides a minimal age, since there is usually no definite time relation between the formation of the host sediment and that of the precipitate, although in some cases it may be possible to assess this time gap (Sharp et al., 2003).

In this study, fluvial deposits of the River Rhine located on the Swiss–German border between the confluence with the River Aare and the city of Basel are investigated. This part of the river is usually referred to as the Hochrhein (i.e., Preusser, 2008). From east to west, the river follows the border between the crystalline massif of the Black Forest to the north and the sedimentary rocks of the Jura Mountains to the south. At the city of Basel, the River Rhine changes its course and follows the Cenozoic Upper Rhine Graben structure to the north (Fig. 1). The most important part of the Hochrhein's drainage area and its most important sediment source are the Cenozoic molasse midlands and the Alps of Switzerland. The terrace sediments are mainly composed of gravel, with a large proportion of sand matrix and rarely some finer, sandy material. Typical braided river sedimentary structures such as cross-stratifications, imbricated pebbles, sand lenses, open-framework layers, confluence scour fills and erosive structures are frequently found (Siegenthaler and Huggenberger, 1993; Huggenberger and Regli, 2006).

In the present study we investigated sediments of the so-called Lower Terrace ("Niederterrasse"), which is usually attributed to the last glaciation of the Alps. However, the Lower Terrace does not represent a single level, but can be subdivided into several sublevels that were most likely formed by subsequent erosion of the main terrace body (Wittmann, 1961; Kock et al., submitted for publication). Sediments attributed to the Lower Terrace and deposited in close proximity to the former ice margin have been dated by Preusser et al. (2007) in the most eastern part of the Hochrhein area. These authors report three radiocarbon ages of $18{,}240 \pm 130$ ^{14}C yr BP, $21{,}510 \pm 510$ ^{14}C yr BP and $22{,}190 \pm 190$ ^{14}C yr BP for bone fragments found in the gravel, which reflect corrected radiocarbon ages of ca. 22–27 ka. Four single-aliquot quartz OSL ages determined for sand layers from the same gravel pit confirm the correlation of this deposition with the last glaciation of the Alpine Foreland (i.e., Preusser, 2004). However, multiple-aliquot feldspar dating of Hochrhein Lower Terrace sediments presented by Frechen et al. (2004) resulted in ages significantly higher than 30 ka. These authors speculated that no deposition of gravel took place in the Hochrhein area during the Last Glacial Maximum, which is in contrast to common assumptions and especially the findings reported by Preusser et al. (2007).

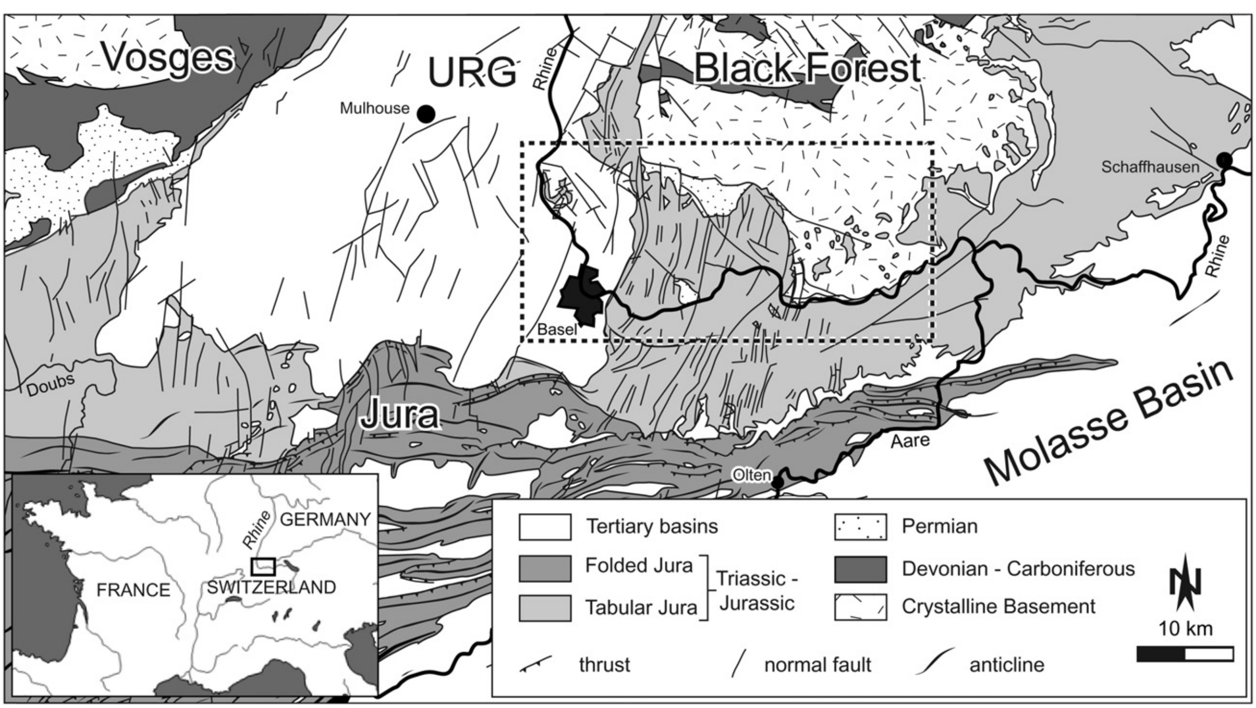

Fig. 1. Tectonic map of northern Switzerland, with the neighbouring parts of France and Germany. The dashed box indicates the study area. In this area, the main geological features are the Folded and Tabular Jura (mainly limestone), the Black Forest massif (mainly crystalline) and the Upper Rhine Graben (URG, mainly detrital sediments). The Rhine and Aare rivers (thick black lines) represent the main drainage system of Switzerland, including all the northern Alps.