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Research paper

Dating of lower terrace sediments from the Middle Rhine area, Germany

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Abstract

Modern and known-age Pleistocene fluvial sediments were investigated by optical dating of quartz to test the suitability of the approach for dating deposits from the deeply incised Middle Rhine Valley. Samples from modern flood sediments revealed skewed distributions indicating different residual levels of equivalent dose (D_e) within the different aliquots. Nevertheless, a substantial number of aliquots from the modern deposits reflect D_e values close to zero. For the Pleistocene samples, optical ages are in general consistent with age control given by the presence of the Laacher See Tephra and radiocarbon dating. However, some samples overestimate the known age by a few thousand years when using the arithmetic mean. This is apparently explained by including aliquots in the determination of mean D_e where the optical signal was incompletely bleached at deposition. The most difficult issue in this context is identifying a suitable approach that can distinguish between the variability of D_e due to partial bleaching and microdosimetry. However, even when considering these limitations it appears that optical dating will by a quite suitable method to date Pleistocene sediments from such a complex fluvial environment, especially when focusing on a precision scale beyond a few thousand years.

Keywords: Optical dating; Quartz; Fluvial deposits; Partial bleaching; River Rhine; Germany

1. Introduction

The River Rhine together with its tributaries represents one of the largest drainage systems in central Europe and it is unique among other fluvial systems due to its specific geographical setting. The headwaters of the River Rhine are located within the Swiss Alps, which were repeatedly glaciated during the Quaternary, and during most of its course the stream follows the European Cenozoic Rift System. As a consequence, deposits of the Rhine record both changes in climatic conditions as well as tectonic movements. The area under consideration here, the Middle Rhine Valley, is located within the uplifting Rhenish Massif (Fig. 1) and it represents an outstanding example of an antecedent valley in central Europe. A well-developed flight of Tertiary and Quaternary terraces reflects both changes in uplift rates and environmental conditions. Although the terrace sequences have been investigated for more than a century, the absolute age of most terrace members is still inadequately known.

Previous experience from the Rhine-Meuse delta indicates that optically stimulated luminescence (OSL) dating of quartz is a suitable method for dating fluvial sediment as old as at least 200 ka (e.g. Wallinga et al., 2004). However, quartz grains from the Middle Rhine Area may have distinctly different luminescence properties compared to those from the Rhine-Meuse delta due to a pronounced local input source from Devonian bedrock of the Rhenish Massif. In the present study modern fluvial sediments and deposits from the younger and older Lower Terrace from Goldene Meile near Bad Breisig (Fig. 1) were investigated using the single-aliquot regenerative-dose (SAR) approach applied to quartz. The age of both terrace members is rather well known due to the presence of independently dated Laacher See Tephra on top and within the terrace sediment, respectively. The present report is seen as a case study on dating fluvial sediments from a deeply incised antecedent valley.

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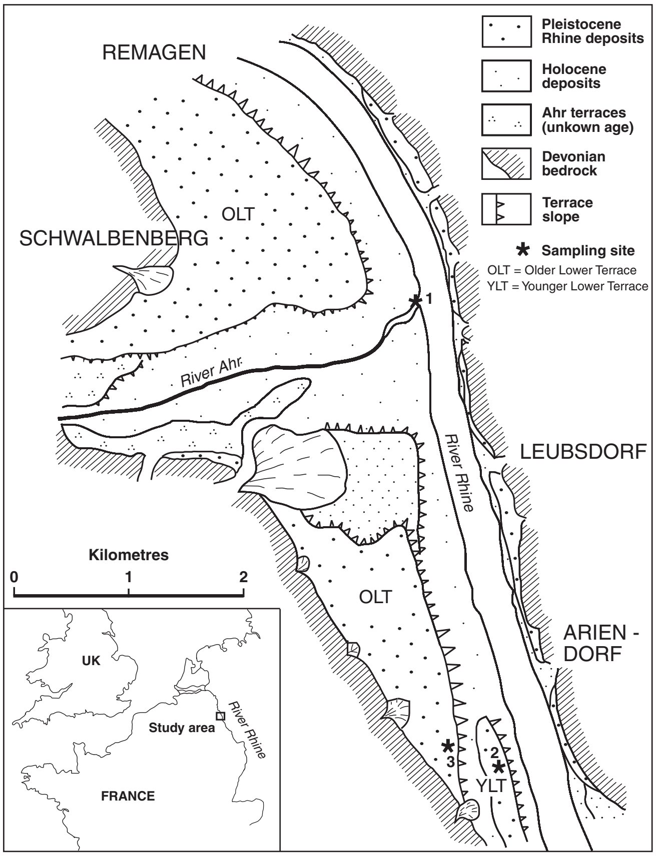

Fig. 1. Map of Goldene Meile in the Middle Rhine area with location of sampled sites (redrawn after Schirmer, 1990). The inset shows the position of the Middle Rhine Area within central Europe. Sampling sites: 1 = modern sediments, 2 = younger lower terrace, 3 = older younger terrace.

2. Geological setting

Sediments of both terraces, older Lower Terrace and younger Lower Terrace, represent braided river deposits formed during times of much colder climatic condition than present (Fig. 2). The gravel fraction of the sediment is mainly build up by quartzitic sandstones and quartz pebbles originating for the Rhenish Massif. Most coarse sediment originating directly from the Alps is already stored in the Upper Rhine Graben much further to the south. In the sand fraction, heavy mineral associations indicate some input of alpine material by the presence of metamorphic minerals (Boenigk, 1982). However, most of the sand fraction is dominated by quartz, which most likely originates from omni-present outcrops of Devonian sandstones in the Rhenish Massif. Input of sediment into the glacial Rhine braided river system was most probably dominated by influx from medium to small-scale tributaries (rivers such as Mosel and Lahn, for example) or directly from the slopes. As a consequence, most quartz underwent only few bleaching/dosing cycles and may show poor luminescence properties such as low OSL intensity and large changes in sensitivity. Such poor OSL properties are recently reported for quartz with similar short sedimentary histories as found in the foreland of the Swiss and New Zealand Alps, for example (Klasen et al., 2006; Preusser et al., 2006). Short distant transport may also be responsible for incomplete bleaching of the OSL signal prior to deposition.

To investigate the properties of local material, we sampled modern sandy high-flood sediments (samples BBG 16–18) of the River Ahr at its confluence with the Rhine, a few kilometres north of the site where the Pleistocene sediments have been sampled (Fig. 1). The River Ahr is a small stream with its headwaters about 50 km to the west of the Rhine Valley and the river is deeply cut into the Devonian bedrock. Hence, the sampled site at the mouth of this river is probably a suitable equivalent for lateral input into the Rhine system during glacial times (short and rapid transport).

The deposits of the older Lower Terrace (BBG 1, 13, 14, 19) pre-date the eruption of the Laacher See Volcano as indicated by the presence of tephra within fine-grained sediments on top of the terrace deposits (Fig. 2). According to varve chronology, the eruption of the volcano occurred about 12,900 years ago (Litt et al., 2003) and this age has been confirmed by OSL dating of dune sands (Radtke et al., 2001). Since the older Lower Terrace was formed during pronounced cold climatic conditions, it is attributed to the period prior to the warming of the Late Glacial (prior to ca. 14,500 years ago) (Schirmer, 1990; Litt et al., 2003). Considering formation of the older Lower Terrace during full-glacial conditions, its most likely age is about 20,000 years. The fine-grained sediments on top of the terrace (BBG 2–6) are attributed to the warming during the Late Glacial (starting ca. 14,500 years ago) and especially the Allerød warm period (13,400–12,700 years ago). The fine-grained sediments are interpreted to represent overbank deposits, which contain at Bad Breisig a remarkable association of Latest Palaeolithic finds (Waldmann et al., 2001). The River Rhine apparently shifted to a meandering river system and was eroding into its own sediments during this period. The age of the overbank deposits is well established by the presence of a layer of slightly reworked Laacher See Tephra in the upper part of the alluvial sequence (Fig. 2). Three radiocarbon ages available from the archaeological findings just below the Laacher See Tephra indicate an age of about 12,800 cal. yr BP (Baales et al., 2001) and are consistent with the varve age of the eruption considering the uncertainties of radiocarbon dating and calibration. The age of the younger Lower Terrace (BBG 7–12, 20) is deduced from the presence of reworked Laacher See Tephra within the sediment, which indicates that the younger Lower Terrace post-dates the time of eruption. Since the formation of the terrace sediment is interpreted to have occurred under relatively cold climatic conditions, it is usually assumed to have formed during the climatic recession of the Younger Dryas Chron (ca. 12,700–11,600 years ago).