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Dust deposition and climate in the Carpathian Basin over an independently dated last glacial–interglacial cycle

Thomas Stevens[a,*], Slobodan B. Marković[b], Michael Zech[c,d], Ulrich Hambach[c], Pal Sümegi[e]

[a] Centre for Quaternary Research, Department of Geography, Royal Holloway, University of London, Egham, Surrey TW20 0EX, UK
[b] Chair of Physical Geography, University of Novi Sad, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia
[c] Chair of Geomorphology, University of Bayreuth, Universitätsstr. 30, D-95440 Bayreuth, Germany
[d] Soil Physics Department, University of Bayreuth, Universitätsstr. 30, D-95440 Bayreuth, Germany
[e] Department of Geology and Paleontology, University of Szeged, Egyetem u. 2-6, H-6722 Szeged, Hungary

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ABSTRACT

Loess in the Carpathian Basin is some of the thickest and most complete in Europe. Located in the Vojvodina region of the southern Carpathian Basin the Crvenka loess-palaeosol section appears to preserve a detailed climate proxy archive of the last glacial–interglacial cycle. Central to the interpretation of the site is a detailed and independent age model. Here, the results of detailed optically stimulated luminescence (OSL) dating and elevated temperature post-IR infrared stimulated luminescence (post-IR IRSL) dating are presented. Quartz OSL ages appear accurate to about 50–60 ka, where $2D_0$ values are reached, while elevated temperature post-IR IRSL yields more accurate ages below this. In line with recent results, the latter signal appears to show negligible fading rates. Two age models are developed that combine (a) OSL and post-IR IRSL ages and (b) OSL ages and 'expected' ages from tying unit boundaries to the marine record. If the luminescence model is regarded as accurate, differences between this and the OSL/marine age model raise questions over the accuracy of the latter, as well as the processes controlling the zeroing of luminescence dates. The luminescence based age model is then used to derive the first fully independent reconstruction of climate proxies and accumulation rates from Carpathian loess. Such reconstructions can be used to compare to other independent records without assumptions inherent in correlation-based approaches. The findings demonstrate how variable accumulation rate is at the site, and compared to other independently dated Carpathian loess records. Average values vary north–south but are of similar order throughout the basin. Accumulation rate was highest during the later part of the last glacial, but variation on millennial timescales does not always match shifts in grain-size, suggesting diverse and complex influences. Environmental reconstructions using grain-size and magnetic susceptibility show that no one atmospheric system or air mass can explain the changes in the Carpathian Basin and that millennial-scale variability can only intermittently be tied to North Atlantic Heinrich events. Expanded ice sheets during the peak last glacial, combined with other atmospheric teleconnections, may have served to develop a strong anticyclone in the region. It was likely windier during earlier parts of the last glacial, but Atlantic and Mediterranean moisture was probably less abundant than during more humid interglacials.

1. Introduction

The Carpathian (Pannonian) Basin comprises a series of sedimentary depocentres active since the Miocene (Royden et al., 1983). The area currently lies at the border between Atlantic, Continental and Mediterranean climate zones and consequently small changes in the relative influence of associated atmospheric systems will have significant impacts on the region's climate (Ducić and Radovanović, 2005). During the Quaternary, extensive deposits of windblown dust have accumulated as loess over large areas of the region. These deposits reach their thickest and most complete in the Vojvodina region of Northern Serbia, where sequences extend to the Middle and potentially Early Quaternary (Marković et al., 2008, submitted for publication). The relatively high accumulation rates of the Late Quaternary loess sequences in particular, mean that they form some of the most detailed archives of environmental and sedimentological change in Europe (Frechen et al., 2003; Marković et al., 2005).

* Corresponding author.
E-mail address: thomas.stevens@rhul.ac.uk (T. Stevens).

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The loess records can be compared to other detailed records from the region, as well as tied to the extensive loess deposits of the Chinese Loess Plateau (Stevens et al., 2007a) and Central Asia (Machalett et al., 2008) in order to build a continental-wide picture of environmental change over the Late Quaternary. Further, understanding the rate of accumulation of Carpathian Basin loess may provide insight into the dynamics of source regions. The sources of Serbian and other Carpathian loess are debated, with various hypotheses suggesting: (1) Alpine/Eurasian ice sheet sources (Smalley and Leach, 1978; for Croatian loess only Újvári et al., 2010); (2) reworking of Pliocene–Pleistocene Pannonian deposits (Smith et al., 1991); (3) fluvial movement of sediment by major rivers after erosion in montane regions, particularly the Moravian massif and Carpathian Mountains (Smalley and Leach, 1978; Buggle et al., 2008; Smalley et al., 2009; Újvári et al., 2010) and; (4) fine silt blown in from Saharan sources (Stuut et al., 2009). If accumulation can be constrained, it may be possible to ascribe changes to shifts in source activity, for example ice sheet fluctuations, and atmospheric dust loadings. This is of great significance as dust aerosols directly affect the radiative forcing of climate (Tegen et al., 1996) and when deposited in the oceans, affect productivity and uptake of CO_2 (Martin, 1990). However, dust loadings remain relatively uncertain for Pleistocene Europe, largely because of the scarcity of stable plateau depocentres and the effects of localised river sources (Frechen et al., 2003) and it has recently been suggested that previous estimates of aeolian activity in the basin are likely underestimated (Újvári et al., 2010).

2. Luminescence dating of loess records

A significant obstacle to the extraction of dust accumulation rates and the secure correlation of loess sequences across the continent is the difficulties in dating loess deposits. Many studies rely on correlating climate proxy records from loess to the marine record (Martinson et al., 1987; Thompson and Goldstein, 2006), in the absence of a secure radiometric chronology (Roberts, 2008). One technique that has the potential to greatly improve the independent chronology of loess sequences is luminescence dating (Aitken, 1998; Wintle and Murray, 2006). Thermoluminescence (TL) techniques were originally applied to loess deposits (Wintle, 1987; Singhvi et al., 1989), although recent developments in the use of optically stimulated luminescence (OSL) protocols have superseded the use of standard TL dating of loess (Aitken, 1998), and it is likely that many pre-existing TL ages are inaccurate (Roberts, 2008). OSL dating measures the last time that dosimeter minerals (typically quartz) were exposed to light (Aitken, 1998). Exposure to ionising radiation causes electrons to accumulate in metastable traps in the crystal structure. When stimulated with laboratory induced or natural light these electrons recombine with centres, some of which radiate light. The light signal given off is proportional to total trapped electrons, which in turn is dependent on total radiation dose received (palaeodose), the latter being a function of the rate of dosing and the time since last daylight exposure. Through laboratory calibration of aliquot responses to administered radiation doses, an estimate of the palaeodose can be obtained (termed equivalent dose).

While more accurate than TL for dating loess, standard single aliquot regenerative (SAR) quartz based OSL protocols are limited to c. 50 ka in loess deposits, beyond which significant underestimations are consistently seen (Buylaert et al., 2007; Roberts, 2008). To circumvent this, Infrared Stimulated Luminescence (IRSL) SAR dating of mixed mineral assemblage aliquots (dominated by K-feldspar) has been used extensively in European loess deposits (Novothny et al., 2002, 2009; Marković et al., 2007; Bokhorst et al., 2008; Fuchs et al., 2008; Bokhorst, 2009; Schmidt et al., 2010), although seldom in Chinese deposits, where other quartz signals with higher saturation levels have been used (Wang et al., 2006a; Stevens et al., 2009). However, while saturation of the IRSL signal growth curve with dose occurs a higher doses than in quartz OSL (c. 2000 Gy), 'low temperature' IRSL methods rely on significant corrections for apparent anomalous signal loss (anomalous fading; Aitken, 1985; Spooner, 1994). These are only properly applicable to younger samples where the natural signal is lying in the linear part of the luminescence growth curve (Huntley and Lamothe, 2001).

While further fading corrections have been proposed (Kars et al., 2008) that may be applicable to non-linear parts of the IRSL growth curve, recent empirical work has uncovered an IRSL signal for K-feldspar that exhibits negligible fading (Thomsen et al., 2008; Buylaert et al., 2009; Murray et al., 2009; Thiel et al., in press). Laboratory fading rates for IRSL measurements performed at 225 °C (detected in the blue part of the spectrum) following an initial IRSL measurement at 50 °C (detected in the blue part of the spectrum) have been shown to be much lower than the conventional 'low temperature' IRSL signal at 50 °C (Thomsen et al., 2008). Buylaert et al. (2009) further demonstrated that this 'post-IR IRSL' signal had fading rates lower by a factor of two for coarse-grained K-feldspar, and that resulting ages agreed with independent control. It has also been demonstrated that the higher the preheat temperature, the lower the fading rate is likely to be (Murray et al., 2009; Thiel et al., in press) and that the IRSL trap lies above 320 °C (Murray et al., 2009). In light of this, Thiel et al. (in press) successfully used a post-IR IRSL protocol involving a 320 °C preheat, initial IRSL at 50 °C and final post-IR IRSL at 290 °C on 4–11 μm polymineral aliquots of Austrian loess. A natural post-IR IRSL at 290 °C signal close to or at saturation was found, suggesting negligible fading, while laboratory calculated rates of 1–1.5% per decade are lower than those measured with the IRSL signal at 50 °C and in light of the sample shown to be in saturation, may be a laboratory artefact. Fading uncorrected ages were therefore deemed the most appropriate. While quartz OSL dating can still be considered the 'method of choice' for deposits younger than c. 50 ka due to relatively high residual doses in bleaching experiments in the post-IR IRSL technique, the latter now appears a viable alternative for testing on many samples beyond that age.

In this study a combination of quartz OSL and post-IR IRSL methods will be used to develop a detailed independent Last Interglacial–glacial chronology for the Crvenka loess-palaeosol sequence in the southern Carpathian Basin in the Vojvodina region of Serbia (Fig. 1). Being independent of orbital tuning, this chronology will be used to calculate independent loess accumulation rates and provide an independent timescale for climate proxy records. Accumulation rates will be used to investigate the dynamics of sediment sources and potential environmental influences. They will be compared to accumulation rates derived from other independently dated Carpathian Basin loess sequences. Further, the independently dated climate records will be compared to other regional and hemispheric climate records that will allow insight into the dynamics of climate change over various regions.

3. Study site

The study site (Crvenka; 45° 39.750′N, 19° 28.774′E, 108 m a.s.l.) lies in the central Carpathian Basin (Fig. 1) and is situated in a brickyard exposure on the southwestern edge of the Bačka Loess Plateau (Fig. 2). One profile comprising four sections was sampled and Fig. 3 shows the detailed stratigraphy with normalised (by mean) low frequency magnetic susceptibility measurements. Broad stratigraphy, grain-size and magnetic susceptibility have previously been published by Marković et al. (2008) with new dating results and a detailed stratigraphic log presented here. The profile (just