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Comparison between luminescence and radiocarbon dating of late Quaternary loess from the Ili Basin in Central Asia

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A B S T R A C T

Dust depositions are critical archives for understanding interior aridification and westerly climatic changes in Central Asia. Accurate and reliable dating of loess is very important for interpreting and correlating environmental records. There remains a disparity between luminescence ages and radiocarbon dating of late Quaternary loess from the Ili Basin in Central Asia. In this study, we establish a closely spaced quartz optically stimulated luminescence (OSL) chronology for the 20.5-m-thick Nilka loess section in the Ili Basin. Based on OSL ages, two intervals of higher mass accumulation rate occurred at 49–43 ka and 24–14 ka. We further compare these OSL ages with 23 accelerator mass spectrometry (AMS) ^{14}C ages of bulk organic matter. The results indicate that the OSL and radiocarbon ages agree well for ages younger than ca. 25 ^{14}C cal ka BP. However, beyond 30 cal ka BP, there is no consistent increase in AMS ^{14}C age with depth, while the OSL ages continue to increase. These differences confirm the observation that the AMS ^{14}C ages obtained using conventional acid–base–acid (ABA) pretreatment are severely underestimated in other terrestrial deposits in Central Asia, which could be due to 2–4% modern carbon contamination. However, OSL dating is applicable for constructing an accurate chronology beyond 30 cal ka BP. We suggest caution when interpreting paleoenvironmental changes based on radiocarbon ages older than 25 cal ka BP.

1. Introduction

In Central Asia, loess deposits mantle the pediments of high mountains, such as the Tian Shan, Kunlun, Altai, Alai, and Hindu Kush Mountains, the terraces of alluvial plains and the margins of deserts. Loess deposits are important terrestrial archives of past environmental and climate conditions, such as interior aridification, dust sources for the Northern Hemisphere, and past global changes (Chlachula, 2003; Ding et al., 2002; Dodonov, 1991; Fang et al., 2002). Loess is also one of the few geologic deposits that contain primary information of past atmospheric circulation patterns and westerly wind regimes in Central Asia, which provides an interregional palaeoclimatic comparison along a west–east transect across the entire Eurasian loess belt (Feng et al., 2011; Machalett et al., 2008; Song et al., 2010; Ye et al., 2000; Yu and Lai, 2014). Deciphering such information requires the establishment of accurate and reliable chronologies for loess deposits at multiple sites.

The loess sediments in the Ili Basin, which is a main loess distribution area in Central Asia, have been widely investigated in recent years (Chen et al., 2012; Jia et al., 2012; Liu et al., 2012; Song, 2012; Song et al., 2014, 2010, 2008; Zhang et al., 2013). However, the dating reliability of these deposits is largely debated. Some studies have suggested that optical stimulated luminescence (OSL) ages agree well with observed loess-palaeosol sequences in which ages increase from top to bottom in the section (Song et al., 2012). However, others have suggested that most OSL and/or ^{14}C ages are underestimated, possibly due to pedoturbation during pedogenesis (Yang et al., 2014), sample contamination (Song et al., 2012), or anomalous fading (Youn et al., 2014). Disparities exist between loess deposition ages determined using luminescence and ^{14}C

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dating (E. et al., 2012; Feng et al., 2011; Shi, 2005; Song et al., 2012; Yang et al., 2014; Ye, 2001). Feng et al. (2011) compared accelerator mass spectrometer (AMS) ^{14}C ages with thermoluminescence (TL) and fine-grained (4–11 μm) quartz OSL ages from the Zeketai loess section (see Fig. 1 for site location) and found that the TL/OSL ages were much older than AMS ^{14}C ages. They considered that the loess TL/OSL signals were not completely zeroed when loess was deposited primarily by deflation from local riverbeds, which favoured the AMS ^{14}C ages obtained from snails. E et al. (2012) conducted an OSL study using coarse silt (38–63 μm) quartz on the same section and argued that OSL dating is applicable, suggesting that the previous AMS ^{14}C ages on snail shells had been underestimated because of some taxa incorporating ^{14}C-deficient carbon during shell formation. Song et al. (2012) also compared AMS ^{14}C ages and post-infrared (IR) OSL ages from a polymineral fine-grained fraction from the Zhaosu loess section (see Fig. 1 site location) in the southern Ili Basin and found that the OSL ages were approximately in agreement with the observed stratigraphy, while AMS ^{14}C ages were much younger than the OSL and assumed stratigraphical ages. Recently, Yang et al. (2014) attempted to evaluate the potential of sand-sized (63–100 μm) quartz OSL dating in the Nilka loess section in the eastern Ili Basin. They found that these samples yielded high overdispersion values for equivalent dose distributions and that age reversals had occurred. They inferred that pedoturbation may be far more dominant in the Ili Basin than other loess sequences in Asia. In the current study, we present an OSL and radiocarbon age comparison on the Nilka loess section.

2. Study area and sampling

The Ili Basin is a valley in the Tian Shan Mountains in Central Asia. The basin is far from oceanic influences and has a temperate, semiarid, continental climate that is dominated by mid-latitude westerlies throughout the year. It is an ideal region for studying palaeoclimatic changes in the context of westerlies. The winter climate in this region is primarily controlled by the intensity and position of the Siberia High and is also influenced by the northern branch of the mid-latitude westerlies. The summer climate is partially affected by the Indian low-pressure cell when the southern branch of the westerlies shifts northward (Hu, 2004; Li, 1991). The mean annual precipitation is between 200 mm and 500 mm on the plains, but can reach 1000 mm in mountainous areas (Hu, 2004; Song et al., 2014). Depending on the orientation and location of the terrain, the mean annual temperature varies from 2.6 to 10.4 °C. The surface soils are a sierozem (aridosols) with desert steppe vegetation distributed over a broad region (Hu, 2004). *Artemisia* and *Chenopodiaceae* typically dominate the modern surface and sediment pollen spectra in the region (Li et al., 2011).

To the west of the Ili Basin are the vast Central Asian Gobi Deserts, such as the Saryesik-Atyrau Desert and the Taukum Desert (Fig. 1), representing the probable source of dust for late Quaternary loess deposits to the east. The distribution of the Ili loess is clearly controlled by topographic and geomorphic conditions, occurring mainly on river terraces, low uplands, the piedmont, and the margins of deserts. The thicknesses range from several metres to two hundred metres. The loess sections exposed in the Ili Basin have mainly accumulated since the last interglacial period (Song et al., 2014).

The Nilka section (83.25°E, 43.76°N, 1253 m a.s.l.) was located on the second terrace of the Kashi River, which is a branch of the Ili River, in the eastern Ili Basin (Fig. 1). This loess section was recently excavated by local residents for making bricks. The loess sequence is 20.5 m thick, largely homogeneous in appearance, and rests on fluvial sand and gravels. Twenty-two OSL samples were obtained by hammering steel tubes (20 cm long tubes with a diameter of 4 cm) into the freshly cleaned surface of the excavated wall. Twenty-three bulk samples were also collected for AMS ^{14}C dating.

3. Methods

3.1. OSL dating

3.1.1. Sample preparation

All sample preparation was conducted under subdued red light and followed the procedures outlined by Lai (2010). The outer 3–4 cm of sediment in each tube was removed; the middle portion was used for further processing, which involved pretreatment with 10% HCl (to remove carbonate), 38% H_2O_2 (to remove organic matter), and wet sieving to obtain the 38–63 μm grain fraction. The 38–63 μm fractions were etched with 35% hydrofluorosilicic acid (H_2SiF_6) for 2–3 weeks to dissolve feldspars and subsequently treated with 10% HCl to remove acid-soluble fluoride precipitates (Lai, 2010; Lai et al., 2007a; Roberts et al., 2010). It is important to ensure that the feldspar contamination is efficiently removed to avoid age underestimation (Lai and Bruckner, 2008; Roberts, 2007).

Fig. 1. Loess distribution and locations of loess sections in the Ili Basin and vicinity (modified from Song et al., 2014). Loess sections: 1 Bishkek (Youn et al., 2014); 2 Remisowka (Machalett et al., 2006), 3 Zhaosu (Song et al., 2012), 4 Talede (Shi, 2005), 5 Zeketai (Ye, 2001; Shi, 2005; Feng et al., 2011; E et al., 2012), and 6 Nilka (this study).