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Paleoenvironmental changes recorded in a luminescence dated loess/paleosol sequence from the Tianshan Mountains, arid central Asia, since the Penultimate Glaciation

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ABSTRACT

Mid-latitude arid central Asia (ACA) is one of the driest regions in the world and is a key source area of global atmospheric dust. Loess records of paleoclimatic changes in ACA are complex and interpretations are problematic due primarily to the lack of robust chronologies. Quartz OSL and K-feldspar pIRIR dating methods were employed to date 8 quartz and 30 K-feldspar samples from a 30 m loess sequence (BYH10 section) on the northern slope of the Tianshan Mountains, central ACA, northwest China. The reliability of quartz and K-feldspar ages was monitored by internal checks of luminescence characteristics and by comparison of the quartz and K-feldspar ages. The section lithology, proxy indexes of grain size and magnetic susceptibility, and the high resolution OSL chronology together indicate: (1) Quartz OSL dating can be used to date ACA loess samples less than 40 ka, while K-feldspar pIRIR dating is reliable for loess samples at least as old as ∼150 ka from ACA; (2) Aeolian loess began to be deposited on the northern slope of Tianshan Mountains beginning at least ∼145 ka ago, and was deposited primarily during the penultimate and last glaciation periods; (3) Rapid loess deposition occurred during MIS 6, MIS 4 to early-mid MIS 3, and MIS 2, but little or no loess deposition occurred during MIS 5, MIS 3a and MIS 1; (4) This loess depositional sequence is comparable to previously published stalagmite growth records in the region on glacial-interglacial cycles. Rapid dust deposition and lack of stalagmite growth during glacials, and lack of loess deposition and stalagmite growth during interglacials, indicate a climatic pattern of wet-warm (interglacial) and dry-cold (glacial) climatic regimes on orbital cycles in ACA; (5) Variation in the loess deposition rates in ACA was much larger than in the central loess plateau during the last glaciation; (6) Depositional hiatuses of >50 kyr occur in ACA loess sequences, and high resolution chronologies are needed when reconstructing past climatic changes.

1. Introduction

Mid-latitude East Asia consists of East Asian summer monsoon (EASM) dominated humid regions, and Westerlies dominated arid central Asia (ACA) (Dando, 2005; Wang and Ding, 2008). The ACA is one of the driest regions in the world, with sparse water resources and fragile ecosystems (Qin et al., 2005; Narisma et al., 2007), it extends from western Kazakhstan to eastern Mongolia, and is one of the major source areas for global atmospheric dust (Prospero et al., 2002). Episodes of paleoclimatic change on suborbital and orbital timescales in ACA have been extensively explored. Lacustrine records (Chen et al., 2008), peat sediments (Hong et al., 2014), and sand (Long et al., 2014) and loess–paleosol sequences (G.Q. Li et al., 2015) in the region suggest that moisture changes in ACA during the Holocene are characterized by a dry early Holocene and an increasingly humid mid-late Holocene, contrasting with a mid-Holocene moisture maximum in the EASM region (e.g., Central loess plateau (CLP), Stevens et al., 2008; Lu et al., 2013). This climatic asynchronism has been attributed to variations in Westerlies strength on orbital and suborbital timescales. Climate simulation models suggests that increasing intensity in the Westerlies resulted from an increasing insolation latitude gradient, and that a negative trend of Arctic Oscillation (AO) or North Atlantic

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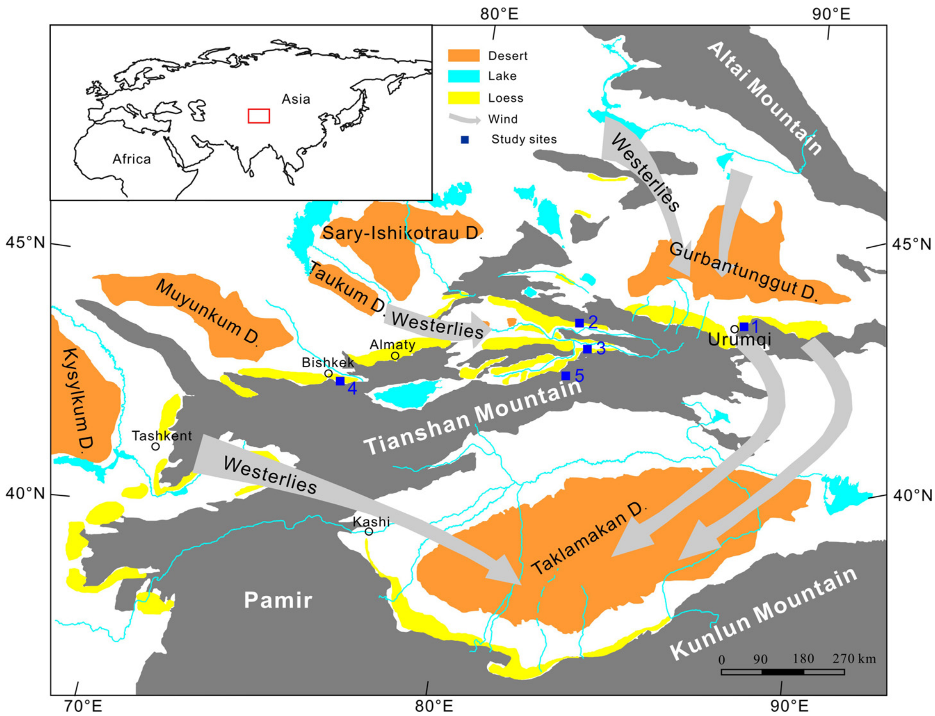

Fig. 1. Map of loess distribution and loess sequences in ACA (modified from Y. Li et al., 2015). 1 is the location of the BYH10 loess section. 2 is the location of the ZKT loess section (E et al., 2012). 3 is the location of the NLK loess section (Song et al., 2015). 4 is the location of the BSK loess sequence (Youn et al., 2014). 5 is the location of the Kesang stalagmite cave (Cheng et al., 2012).

Oscillation (NAO) may have been responsible for the middle-late Holocene moisture in ACA (Jin et al., 2012). However, variations in a 500 ka speleothem δ^{18}O record from the Tianshan Mountains (Cheng et al., 2012) in central ACA correlate with speleothem δ^{18}O records in the EASM dominated zone (e.g., Sanbao Cave, Wang et al., 2008), suggesting that incursions of the EASM during high insolation intervals played an important role in changing orbital-scale hydrology of the region (Rudaya et al., 2009; Zhong et al., 2010; Li et al., 2011; Cheng et al., 2012). On the other hand, recent work indicates speleothem δ^{18}O variations in the Tianshan Mountains may result from a south–north movement of the Westerlies (Liu et al., 2015). These interpretive differences suggest that the interactions of middle-latitude Westerlies and low-latitude EASM and resulting changes in ACA paleoclimate complexity at different orbital timescales remain unclear.

Extensive, thick loess deposits are present in a wide band across the Eurasian continent, extending from northwestern Europe to ACA and East Asia (e.g., CLP) (Youn et al., 2014). The loess/paleosol sequences in the ACA, found primarily on the pediments of high mountains (Fig. 1), can potentially provide high resolution climatic change records on orbital and suborbital timescale (Ye, 2000, 2001; Feng et al., 2011; Song et al., 2015). However, the nature of loess–paleosol sequences in ACA are still poorly known due to a lack of sufficiently reliable age controls (E et al., 2012; Yang et al., 2014). In recent years, the ^{14}C dating of snails and organic materials and the OSL dating of silt and sand size quartz from loess/paleosol sequences have been used to establish chronologies. However, there remains a disparity between quartz OSL ages and the radiocarbon dating of late Quaternary loess from the Ili Basin in Central Asia (Song et al., 2015). The ^{14}C dating chronology has an obvious large offset to quartz OSL ages, making the establishment of a robust chronology a challenge (Feng et al., 2011; Song et al., 2012). For example, in the Zeketai loess–paleosol section, accelerator mass spectrometer (AMS) ^{14}C ages of bulk sediments and snails vary between ∼48 and ∼3 ka, with the majority of the loess dating to <10 ka. However, the quartz OSL ages on fine-grained (4–11 μm) quartz extracts using the simplified multiple aliquot regenerative dose (SMAR) protocol span ∼70 to ∼30 ka (Feng et al., 2011). These age estimates are generally consistent with quartz OSL ages of ∼72 to ∼14 ka on 38–63 μm quartz extracts using single aliquot regenerative-dose (SAR) protocols from the same section (E et al., 2012). It is possible the AMS ^{14}C ages on snail shells are underestimated due to recent contamination (E et al., 2012; Song et al., 2012; Pigati et al., 2013; Rakovan et al., 2013). More recently, Song et al. (2015) presented a more detailed OSL and radiocarbon age comparison with 22 OSL ages of 38–63 μm quartz and 23 AMS ^{14}C ages of bulk organic matter on the Nilka loess section at Yili Valley Basin. Results indicate that the OSL and radiocarbon ages agree well for ages younger than ∼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. They suggest that underestimation of AMS ^{14}C ages obtained using conventional acid–base–acid (ABA) pretreatment could be due to 2–4% modern carbon contamination. In addition, ^{14}C dating can only be used to date samples less than ∼50 kyr, and quartz OSL ages are generally limited to the dating of deposits younger than ∼80 kyr due to saturation of the quartz OSL signal (Buylaert et al., 2007). As a result, a robust chronology on orbital and suborbital timescale for loess in ACA is still lacking. The K-feldspar IRSL signal has a much higher saturation dose compared to the quartz OSL signal, and a new-developed K-feldspar pIRIR dating protocol, utilizing a post IR IRSL signal stimulated at 290 °C, can potentially provide an alternative way to date deposits where the quartz OSL signal is saturated (Thomsen et al., 2008; Thiel et al., 2011; Buylaert et al., 2012). Previous comparisons of K-feldspar pIRIR ages with reliable independent ages indicates that this method can be used to date samples up to 300–400 ka (Buylaert et al., 2012). This method also has been successfully applied to loess–paleosol sequences in the CLP and in NE China (Buylaert et al., 2015; Yi et al., 2015).