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Loess accumulation in the Tian Shan piedmont: Implications for palaeoenvironmental change in arid Central Asia

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ABSTRACT

Whilst correlations have been made between the loess of Europe and China, deposits in Central Asia have remained largely overlooked by scientific investigation. The nature of the relationship between loess accumulation and palaeoclimate at the core of the Eurasian loess belt is particularly poorly understood.

Here we reconstruct palaeoenvironmental change in Central Asia over the last 40 ky based on data from the Remizovka loess profile, in the northern foothills of the Tian Shan in southern Kazakhstan. Our interpretations are based on synthesis of chronostratigraphic, colour and magnetic susceptibility data, supported by chronostratigraphies from two additional sites nearby, Maibulak and Valikhanova. All three sites record substantially increased loess accumulation during late MIS 3 into the global last glacial maximum (gLGM). At Remizovka, increased loess flux occurred in two pulses at c. 38-25 ka and 22-18 ka, with the intervening period involving incipient pedogenesis. At Maibulak, two loess pulses at c. 40-30 ka and c. 28-22 ka are separated by a weakly developed paleosol which may date to the same time as pedogenesis at Remizovka. There is additional possible periglacial influence at Maibulak from c. 40–33.5 ka. At Valikhanova, there is some age overlap between paleosol and loess samples, but overall loess accumulation appears to have increased at c. 42-35 ka, c. 30 ka and the gLGM, with pedogenesis occurring >40 ka and c. 32 ka. At all three sites, Holocene loess accumulation is minimal; this period is characterised by pedogenesis.

The chronostratigraphic variability between our sites highlights a need to interrogate climate-driven models for loess formation in piedmont environments. We interpret our data in the context of regional palaeoenvironmental archives to indicate that loess accumulation increased coeval with MIS 3 glacial advance in the Tian Shan, which was facilitated by northward expansion of the Asian monsoon and associated increase in precipitation. We hypothesise that increased ice volume impeded teleconnections with the temperate zone westerlies to the north; these were compressed against the piedmont resulting in increased wind strength and facilitating increased loess flux. Peak loess accumulation during the gLGM occurred under colder, drier climatic conditions, with reduced but sustained glacial ice volume and persistent influence of the westerlies in the arid Central Asian piedmont loess belt. In the absence of more widespread, reliably dated palaeoenvironmental records from the region, our data become of critical importance for understanding past environmental conditions in Central Asia, relative to elsewhere in Eurasia and globally.

1. Introduction

The Eurasian loess steppe extends more or less continuously from eastern Europe to China. At its core lies Central Asia, at the

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sensitive climatic transition zone between Asian monsoon influence from the south (Dettman et al., 2001), the mid-latitude westerlies (Vandenberghe et al., 2006), and the polar front from the north (Machalett et al., 2008) (Fig. 1a). In spite of its key position in the northern hemispheric climate circulation systems, the past environmental history of Central Asia remains limited, due in part to its political history and relative logistical inaccessibility.

The most valuable palaeoenvironmental archive in this region is its widespread, thick loess deposits. As is the case for the eastern (Markovic et al., 2011; Marković et al., 2015) and western (Guo et al., 2002) extremes of the Eurasian loess steppe, Central Asian loess also appears to have accreted almost continuously over at least the last million years (Ding et al., 2002). The prevailing wisdom correlates increased loess accumulation with cold glacial phases, and pedogenesis with milder interglacial periods (Fitzsimmons et al., 2012; Liu and Chang, 1964; Sun et al., 2006; among others). During milder periods and reduced dust accumulation, such as interglacials and the less extreme interstadials, pedogenesis alters these deposits, leading to the formation of loess-paleosol sequences.

The hypothesis for climate-driven stratigraphic sequences in loess is linked with a genetic model for loess generation based on glacial grinding of rocks as the major source of fine-grained sediment for loess entrainment (Smalley, 1995), often with rivers as major conduits to the lowland plateaux where the thickest deposits are found (Smalley et al., 2009; Stevens et al., 2013b). Researchers concede that the situation for loess generation and deposition in Central Asia may be still more complex due to the close juxtaposition between glaciated high mountains with arid deserts in the basins to the north which act as sediment sinks, and with the piedmont (foothills) in between on which the loess accumulates, transported primarily via westerly or northerly winds (Smalley, 1995; Smalley et al., 2006, 2009; Machalett et al., 2008). In the absence of reliable or absolute chronologies for Central Asian loess, correlations between profiles in this region with those elsewhere in Eurasia are often made on the assumption that flux increases during glacials and stabilizes during interglacial phases (Ding et al., 2002; Vandenberghe et al., 2006; Machalett et al., 2008).

Furthermore, while there is general agreement regarding loess as a homogeneous, silty sediment primarily deposited by wind (Pécsi, 1990), precise models for its accumulation across the world remain poorly defined. The origins of fine-grained aeolian silt clearly depend on geographic context (Nemecz et al., 2000) but can include glacial grinding of rocks (Smalley, 1995), weathering due to tectonic activity (Smalley and Derbyshire, 1990; Smalley, 1995), particle abrasion in upwind deserts (Smalley and Vita Finzi, 1968;

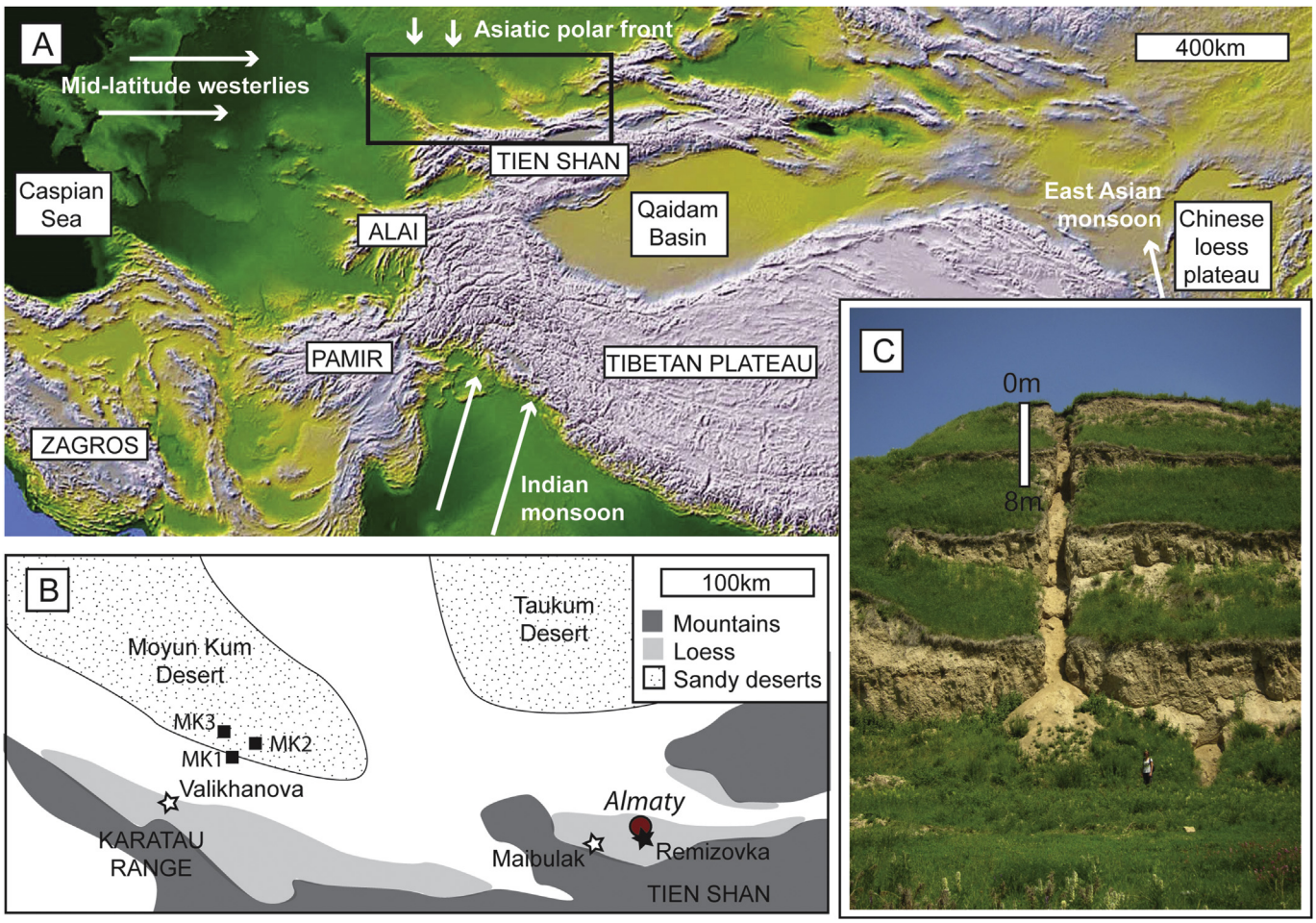

Fig. 1. A. Shuttle Radar Topography Mission (SRTM) topographic map of Central Asia showing mountain ranges and major climate influences on the region. The Tian Shan loess piedmont area of interest to this study is highlighted by a black outline and is shown in more detail in (B). B. Location of the three loess sites discussed in this paper relative to the Tian Shan and Karatau mountains, loess distribution and sandy deserts (Machalett et al., 2008 and own cartography). The Remizovka site is situated on the southern periphery of Almaty city in southern Kazakhstan. The three sand dune sites in the Moyun Kum Desert (MK) sampled for XRD mineralogy are also shown. C. Photograph of the upper section of the Remizovka loess profile, looking northeast. The uppermost 8 m investigated in this study are indicated by the vertical scale.

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