

Supplemental Material

Supplemental Note 1.

Geochemical proxies of provenance of the Xishuigou Red Clay

Geochemical composition of eolian deposits, such as trace and rare earth elements (REE), constrain the dust provenance and transport pathways (Ding et al., 2001; Ferrat et al., 2011; Hu and Yang, 2016; Liang et al., 2009; Qiao et al., 2011; Sun, 2002), as they are relatively stable during weathering, transportation, and deposition processes (Muhs et al., 2008; Taylor and McLennan, 1985).

Chemically immobile major (such as Si, Al and Ti) and trace elements (such as Th, Sc, Zr, Hf and Nb) have great potential for determining the clastic source of sediments (Taylor and McLennan, 1985). The $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio has been proposed as a proxy to reflect the grain size of the original eolian particles for loess deposits on the Chinese Loess Plateau, because weathering-resistant quartz (SiO_2) which dominates the detrital component in loess tends to be enriched in the coarser fractions, whereas Al_2O_3 tends to be enriched in the finer fractions (Muhs and Bettis, 2000; Peng and Guo, 2001). Thus, with the increasing transportation distance, the $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio tends to decrease. The $\text{Al}_2\text{O}_3/\text{TiO}_2$ ratio is also regarded as an effective indicator in tracing sources of various sediments (Ahmad and Chandra, 2013; Girty et al., 1996; Young and Nesbitt, 1998), because Ti and Al are more immobile and insoluble compared with other major elements (Sugitani et al., 1996), and the $\text{Al}_2\text{O}_3/\text{TiO}_2$ ratio in sediments is distinctive for different types of source rocks (Girty et al., 1996).

REEs have also been widely used in provenance studies (McLennan et al., 1993; Muhs et al., 2008). For example, the ratio of light-REE to heavy-REE (LREE/HREE) can reflect the lithological composition of source areas and has been regarded as an effective provenance indicator in Chinese loess (Gallet et al., 1996; Sun, 2002). The fractionation of Nb from REEs can provide crucial constraints on the processes of crust-mantle differentiation and crustal growth (Barth et al., 2000), and Nb is virtually immobile, even in strongly weathered soils with total Si depletion (Kurtz et al., 2000). Hf is enriched in heavy minerals (McLennan, 1989). Thus, the Hf/Nb ratio can be applied to discriminate provenance linked to different parent rocks (Hao et al., 2010; Kahmann et al., 2008). Rb and Ba ions are often retained in clay minerals even after intense weathering, and their contents in sediments is more likely inherited from source rocks, so the Ba/Rb ratio can be used to study the provenance of eolian deposits (Gallet et al., 1996; Qiao et al., 2011).

In this study, we apply the above-mentioned major element ratios ($\text{SiO}_2/\text{Al}_2\text{O}_3$, $\text{Al}_2\text{O}_3/\text{TiO}_2$) and trace element ratios (LREE/HREE, Ba/Rb, Hf/Nb) as provenance proxies to determine the geochemical characteristics of the Xishuigou Red Clay throughout the sequence.

Supplemental Figure 1. Schematic model showing dust transport routes for the lower (51–46.5 Ma) and upper (46.5–40 Ma) Xishuigou Red Clay sequence. The red arrow represents dust transportation from the West Kunlun piedmont (distal source) via westerly winds. Purple area indicates sediments released from basement rocks of the Altun-Xorkol region, which would serve as a proximal dust source for the Red Clay sequence. Dark blue arrows show southerly

moisture blocked by uplifted mountains. Red star shows the depositional site of the studied Xishuigou Red Clay.

Supplementary Data File 1. Major (wt%) and trace element (ppm) compositions of the Xishuigou and Caihonggou Red Clay sequences.

Supplementary Data File 2. LA-ICP-MS analytical results of zircon U-Pb isotopic ratios and ages of Xishuigou Red Clay samples.

Supplementary References

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