A mineral tracer toward high-resolution dust provenance on the Chinese Loess Plateau: SEM, TEM, and sulfur isotopes of sulfate inclusions in biotite

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ABSTRACT

The most important terrestrial archive of the Quaternary climate is the Chinese Loess Plateau (CLP) distributed over a vast region peripheral to the deserts of Inner Asia. Numerous paleoclimatic studies have examined magnetic, chemical, and isotopic proxies from deep loess-paleosol sections. However, the highly uniform mineralogy of the CLP has made it difficult to track the provenance, transportation, and deposition of dust particles. Here, we report that the micrometer-scale mineralogical heterogeneity of the loess particles has a significant potential in determining high-resolution loess provenance. Scanning and transmission electron microscopy of the Chinese loess reveals that biotite particles commonly have microinclusions of Ba-Sr sulfates displacing the micaceous layers along cleavages. Chemical compositions varied widely from barite to celestine within the same biotite grain. The Ba-rich sulfates precipitated first, followed by an overgrowth of Sr-rich sulfates. The frequency of sulfate-bearing biotite varied greatly over several loess sections, implying a specific source and sedimentation process. Their abundance on the western CLP and sulfur isotopic composition support their derivation from porous sedimentary sequences reacted with hypersaline solutions, e.g., arkosic sandstone, probably located west of the CLP covering the Qilian Mountains, Qaidam Basin, and surrounding mountains of the Tibetan-Qinghai Plateau. The sulfate-bearing biotite is the first microscopic mineral tracer in the CLP, provoking further search for other microscopic heterogeneities of the Chinese loess and their equivalents in the source regions.

Keywords: Barite, biotite, celestine, loess, provenance

INTRODUCTION

The Chinese Loess Plateau (CLP) has recorded global climate change throughout the entire span of the Quaternary period. Numerous proxies have been successfully used to extract climatic signals from the thick loess and paleosol sequences. These proxies have included magnetic susceptibility (Heller and Liu 1982; Liu et al. 1988; Kukla and An 1989; An et al. 1991), isotopes (Heller et al. 1993; Gu et al. 1996; Yang et al. 2000), chemical composition (Ding et al. 2001; Yang et al. 2006), grain size (Xiao et al. 1995; Yang and Ding 2008), micromorphology (Kemp et al. 2001), and clay mineralogy (Gylesjö and Arnold 2006). Compared with the well-established long-term variation in climatic proxies, much uncertainty still exists in the regional sedimentology of the Chinese loess. Further refinements are required to clarify the source lithology, the fine silt production mechanism, transportation routes, and depositional processes (Smalley 1995; Derbyshire et al. 1998; Smith et al. 2002; Sun 2002, 2005; Sun et al. 2008; Maher et al. 2009). For such clarification, we need to find new tracers that indicate distinctive source lithology and deposition along specific migration tracks.

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The loess has been generally regarded as a mixture of silt particles showing largely uniform mineralogy and geochemistry within the same stratigraphic unit across the CLP (Eden et al. 1994; Jahn et al. 2001). The mineralogical study of the last glacial Malan loess along 350 km transects from the north to the south of the CLP (Eden et al. 1994) showed that the mineralogy of the coarse silt, fine silt, and clay fractions is generally uniform across the Loess Plateau although the contents of heavy minerals decreased in the coarse silt fraction southward, with a slight increase in mica content in the clay fraction. The only significant variation noted was a decrease in particle size with increasing distance from the desert margin, i.e., from sandy to clayey loess and corresponding variation in mineral and chemical compositions (Liu et al. 1988; Eden et al. 1994). Strontium and Nd isotope and rare earth element (REE) compositions of the CLP loess have been studied to obtain information about the dust source, suggesting the same dust source and storm trajectories for the last 0.8 Ma (Gallet et al. 1996), uniform REE patterns and restricted Nd isotopic compositions from a distant and homogeneous source region (Jahn et al. 2001), the major change of source materials in dust provenance around 2.58 Ma (Sun 2005), the major dust sources including alluvial deposits around the Gobi Altay Mountains, the Hangayn Mountains, and