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A comparison of heavy mineral assemblage between the loess and the Red Clay sequences on the Chinese Loess Plateau

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ABSTRACT

QEMSCAN-based (Quantitative Evaluation of Minerals by Scanning Electron Microscopy) heavy mineral analysis has recently been demonstrated an efficient way to allow a rapid extraction of provenance information from sediments. However, one key issue to correctly obtain a provenance signal using this technique is to clearly separate effects of diagenetic alteration on heavy minerals in sediments, especially in fine-grained loess. Here we compare heavy mineral assemblages of bottom Quaternary loess (L33) and upper Pliocene Red Clay of three sites on the Chinese Loess Plateau (CLP). Two sites (Chaona and Luochuan) with similar modern climate conditions show similar heavy mineral assemblages but contain much less of the unstable heavy mineral amphibole than the drier Xifeng site. This result provides strong evidence supporting that climate-caused diagenesis is an important factor controlling heavy mineral assemblages of fine-grained loess. However, heavy mineral assemblages are similar for loess and paleosol layers deposited after 0.5 Ma on the Chinese Loess Plateau regardless of climate differences, suggesting that time is also a factor controlling heavy mineral assemblages of loess and Red Clay. Our high resolution sampling of the upper Miocene-Pliocene Chaona Red Clay sequence reveals similar heavy mineral compositions with a minor amphibole content, different from the drier Xifeng site results of the same age. This result indicates that the monsoonal climate pattern might have been maintained since the late Miocene. Furthermore, it indicates that the heavy mineral method is promising in tracing provenance for sites northwest of the Xifeng site on the Loess Plateau.

1. Introduction

Aeolian sediments cover one tenth of the Earth terrestrial surface and are encoded with important information of past atmospheric circulation pattern and inland terrestrial aridification (Liu, 1985; Kukla and An, 1989; An et al., 1991; Ding et al., 1998; Heller and Evans, 1998; Guo et al., 2000; Lu et al., 2004; Hao et al., 2008; Li and Song, 2011). The aeolian sediments on the Chinese Loess Plateau (CLP) record paleoclimatic information since at least the late Miocene (Qiang et al., 2001; Guo et al., 2002) and, thus, have been the focus of the paleoclimatic society during the past decades. Many methods have been used to trace the provenance of the Quaternary loess and the underlying Red Clay sequences on the Chinese Loess Plateau, and some potential sources have also been proposed (Sun, 2002, 2005, 2008; Chen et al., 2007; Sun and Zhu, 2010; Stevens et al., 2010, 2013; Pullen et al., 2011; Che and Li, 2013; Nie et al., 2013b, 2014b; Nie and Peng, 2014a). But because of the inherent complexities of provenance analysis (Nie et al., 2012), no concensus has been reached about provenance history of the Loess Plateau, nor its exact source regions (Maher et al., 2009; Schettler et al., 2009; Yang et al., 2009; Zhu and Yang, 2009; Nie and Peng, 2014a). The single-grain zircon U–Pb geochronology method is considered an effective source tracing method (Dickinson and Gehrels, 2008; Xiao et al., 2012; Stevens et al., 2013; Che and Li, 2013; Nie et al., 2014b), but dating enough zircons to allow quantitative comparison of age distribution pattern based on this method requires ∼1000 analyses per sample (Pullen et al., 2014), which is both time consuming and expensive.

Heavy mineral analysis is another promising single grain provenance technique, but as with zircon U–Pb dating, counting heavy minerals is time consuming as well (Garzanti and Andò, 2007b; Najman et al., 2009; Nie et al., 2012). Fortunately, QEMSCAN-based (Quantitative Evaluation of Minerals by Scanning Electron Microscopy) heavy mineral analysis can overcome this

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disadvantage, since it is capable of quickly recognizing thousands of heavy minerals, allowing quantitative comparison of heavy mineral assemblages (Knappett et al., 2011). Thus, this technique has great potential in provenance analysis because statistical robustness of quantitative provenance analysis requires large sample populations (Pullen et al., 2014). However, different from the zircon U–Pb geochronology technique, some heavy minerals are easy to get destroyed after deposition by diagenesis (Morton and Hallsworth, 1999; Garzanti and Andò, 2007a; Nie et al., 2012; Andò et al., 2012). Without separating alteration effects after deposition, provenance analysis based on this technique can be flawed. Prior preliminary studies (Nie et al., 2013b) proposed that climate is an important factor that can significantly change the original heavy mineral composition for the loess and Red Clay sequences on the CLP. Here, we present more convincing evidence supporting this hypothesis by comparing heavy mineral assemblages of loess and Red Clay layers deposited synchronously from three sites: Luochuan, Chaona and Xifeng (Fig. 1). The modern climate conditions are similar for Luochuan and Chaona, both of which are wetter and warmer than Xifeng. If climate is a key factor controlling heavy mineral assemblage for loess and Red Clay, Xifeng should have more unstable heavy minerals than Luochuan and Chaona and the latter two sites should have similar heavy mineral assemblage with lower unstable heavy mineral content.

Nie et al. (2013b) also found that the bottom Red Clay at Xifeng has similar heavy mineral assemblage as the late Quaternary loess, an observation suggesting that the CLP provenance at 7 Ma is similar to the late Quaternary. In this study, in addition to testing whether climate is a key factor that can significantly change heavy mineral composition in loess and Red Clay, we also sampled more Red Clay samples from the oldest Red Clay section (Chaona; with a bottom age of ~8.1 Ma) on the central CLP to explore spatial distribution pattern of heavy mineral composition and discuss its implications for East Asian monsoon evolution.

2. Materials and methods

The dust on the CLP was accumulated on a planation surface that formed since the Mesozoic. Cenozoic uplift of the Liupan Mountains due to the far-field effect of India–Asia collision disrupted the surface and brought the surface close to the mountains upward, creating a basement for dust to accumulate (Song et al., 2001). No dust older than 8.1 Ma is found east of the Liupan Mountains and the oldest dust sequences occur at Chaona, which should be the depositional center of the dust on the CLP (Song et al., 2000). This is due to its geographical location, which is close to the Liupan Mountains resulting in slightly elevated basement to allow dust accumulation, but not so proximal that the basement was elevated too high to make erosion dominate.

Chaona and Luochuan have similar climate conditions, with annual mean temperature of ~9 °C and annual mean precipitation of ~600 mm (Fig. 1). By contrast, Xifeng is colder and drier than these two sites with annual mean temperature and precipitation of 8.7 °C and 545 mm, respectively (Sun et al., 2006). Caoxian is located on the northwestern (NW) margin of the CLP, with annual mean temperature and precipitation of ~8.3 °C and ~275 mm, respectively (Sun et al., 2006). For Caoxian, Luochuan and Xifeng, we did not collect new samples and samples are from published data (Nie et al., 2013b; Nie and Peng, 2014a). In order to compare with these published data, we collected 11 Red Clay samples and three loess samples (L14, L16 and L33) from the Chaona section. The approximate ages of these samples (Fig. 3) are estimated based on the paleomagnetic age model of the section (Song et al., 2000).

Heavy mineral analysis was carried out at the Colorado School of Mines, using the QEMSCAN technique. The detailed operation process was described by Nie et al. (2013b) and will not be repeated again here. The number of heavy mineral grains counted in each sample ranges from 1600 to 25,000, significantly higher than the number in traditional heavy mineral analysis based on point counting, which is normally lower than 500.

3. Results

The L33 and upper Red Clay (RC-3 Ma) samples from Luochuan and Chaona have similar heavy mineral composition (Fig. 2 and Table 1), with low amphibole (~10%) and higher ZTR (Zircon + Tourmaline + Rutile) (~25%) content. These samples are different from Xifeng L33 and RC-3 Ma samples, which have high amphibole (~45%) and lower ZTR content (~10%). Epidote and amphibole are the most dominant minerals for Chaona/Luochuan and Xifeng samples, respectively.

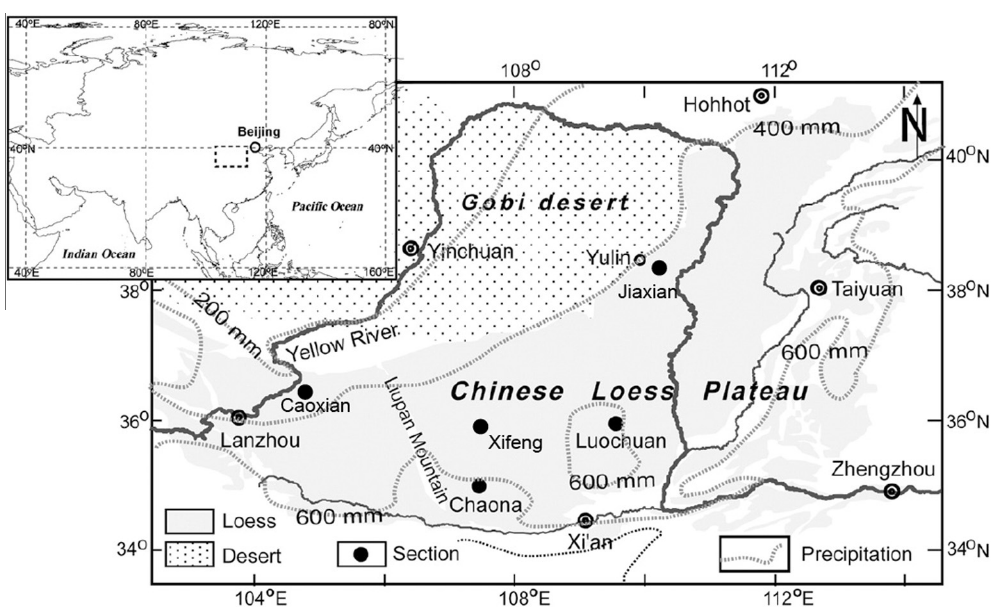

Fig. 1. Map of the study sites. Revised from Nie et al. (2013a). Dots show the sites in the study.