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Asian Monsoon variation over the late Neogene–early Quaternary recorded by Anisotropy of Magnetic Susceptibility (AMS) from Chinese loess

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ABSTRACT

This paper discusses the Anisotropy of Magnetic Susceptibility (AMS) records during late Neogene to early Quaternary from the Lantian loess section near the southern margin of the Chinese Loess Plateau. The AMS results for this site are shown to reflect variations in the direction of the paleomonsoon. The Lantian loess sediments are largely aeolian in origin, but also include a thin layer that exhibits secondary aqueous depositional features. The major ellipsoid axis AMS orientations in the loess samples indicate a pervasive Northwest–Southeast directional component since the late Neogene. Since that time, the W–E component gradually overtakes the N–S component, which may explain the trend toward increased aridity during that time. Finally, a local heavy rainfall event seemingly occurred in the Lantian region about 2.6 Ma, which may have been responsible for the aqueous redeposition of sediments observed in L_{33} layer in this study.

1. Introduction

The loess–paleosol sequences of Chinese Loess Plateau which spans a broad region of central China provide continuous terrestrial archives of the climate changes for the past 2.6 Ma (Liu and Ding, 1998; An, 2000; Zhu et al., 2007a). Further studies have confirmed that the paleoclimatic signals that were recorded by the climatic proxies from Chinese loess (e.g., magnetic susceptibility and grain size) can be well correlated to the marine oxygen isotope records (Kukla, 1987; An et al., 2001; Ding et al., 2002). Chinese loess has become one of the most important tools in studying paleoclimatic changes, along with the marine sediments and polar ice cores.

Anisotropy of Magnetic Susceptibility (AMS) is a fundamental physical characteristic of sediments that is caused by the ordered arrangement of magnetic particles (Hrouda, 1982; Rochette et al., 1992). AMS is a sensitive indicator of the magnetic fabric of sediments, perpetrated by wind. Consequently, paleowind directions can be investigated with AMS in sediments deposited over time (Zhang et al., 2010). In recent years, several studies using AMS to trace paleowind directions have been reported (e.g., Wang, 1998; Lagroix and Banerjee, 2002, 2004; Zhu et al., 2004; Huang and Sun, 2005; Zhu et al., 2007b; Zhang et al., 2010; Ge et al., 2014). Most of these studies showed that the AMS of the sediments can exhibit a discernible directivity (Wang, 1998; Lagroix and Banerjee, 2002, 2004; Zhu et al., 2004; Huang and Sun, 2005; Zhang et al., 2010; Ge et al., 2014), except for an AMS study from Chinese loess formed in the late Neogene–early Quaternary (Zhu et al., 2007b). To further examine the possibility of using AMS for paleomonsoon-direction reconstructions, we have investigated 1500 samples with high temporal resolution from the Lantian loess, deposited during the late Neogene–early Quaternary.

2. General setting

The Lantian (Duanjiapo) loess section (about 34.2°N, 109.2°E, Fig. 1) is located on the east slope of Bailuyuan loess tableland,

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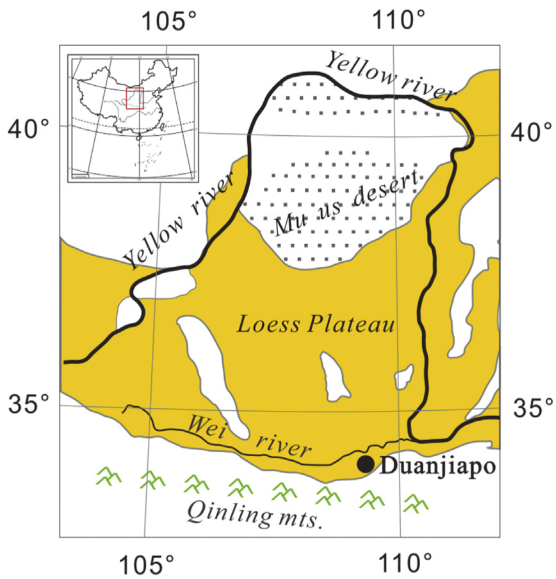

Fig. 1. Location of Duanjiapo section, Lantian, China.

which is in the southern part of the Chinese Loess Plateau. At present, this region is basically controlled by the Asian Monsoon climate, with a mean annual precipitation of ~615 mm and a mean annual temperature of ~13 °C. Winters are relatively cold and dry under the influence of the East Asian winter monsoon, while summers are relatively warm and humid under the influence of the East Asian summer monsoon. The loess–palaeosol sequence in this region is ~132 m thick and is underlain by ~62 m of the Pliocene Red Clay deposits. The stratigraphic division of the sampled loess sequence is shown in Fig. 2a.

3. Sampling and test methods

To insure sample quality, large blocks unaffected by weathering were continuously sampled in the field. The hand-cut blocks of ~15 cm in width and ~20–30 cm in height were oriented in situ using a magnetic compass. After the blocks were air dried in the laboratory, both the powder sample and the cube sample (2 cm × 2 cm × 2 cm) were collected at 2 cm interval from the blocks. Geomagnetic azimuth was marked on every cube. A total of 750 powder samples and 750 cube samples at 2 cm interval were collected.

The magnetic susceptibility of the powder samples (10 g standard) were measured using a Bartington MS2 Double-frequency Magnetism Measurement Instrument, located at the Xi'an Accelerator Mass Spectrometry Center (Fig. 2b). The AMS of the cubed samples were measured using a Kappa Bridge MFK1A multi-frequency magnetic susceptibility instrument in the paleomagnetic laboratory, Institute of Earth Environment of CAS. Each sample was rotated and measured along three orthogonal planes, and the AMS ellipsoid was then calculated by the least-squares method (Zhu et al., 2004; Zhang et al., 2010). The anisotropy parameters that we obtained (Fig. 2c–g, where c is the mass magnetic susceptibility χ converted from measured volume susceptibility κ_m) was calculated using software, following the method of Jelinek (1981).

Magnetic hysteresis loops, isothermal remanent magnetization (IRM) acquisition curves and back-field curves were determined for 14 samples from different layers of the section using a Model 3900 vibrating sample magnetometer (Princeton Measurements Corporation VSM3900, sensitivity: 0.5×10^{-9} Am^2) in the paleomagnetic laboratory, Institute of Earth Environment of CAS. Every powdered raw sample of ~0.2 g was firstly used to determine the hysteresis loops (maximum field: 1500 mT, step increment: 12 mT, averaging time: 100 ms). Saturation magnetization (M_s), saturation remanence (M_{rs}) and coercive force (B_c) were determined after correction for the paramagnetic contribution identified from the slope of loop at high fields. Subsequently, an isothermal remanent magnetization (IRM) was imparted from 0 to 1500 mT (step increment: 10 mT, averaging time: 1000 ms) and followed by demagnetization in stepwise backfield (0 to −1500 mT, step increment: −10 mT, averaging time: 1000 ms) to obtain the coercivity of remanence (B_{cr}).

4. Results and discussion

4.1. Magnetic mineralogy

IRM acquisition curves of representative samples from the loess and red clay sediments follow similar trajectories that reflect their similar characteristics in magnetic mineralogy (Fig. 3). All IRM acquisition curves undergo a major increase below 300 mT, which is consistent with the dominant contribution of low-coercivity magnetite and maghemite to the magnetic mineralogy. All the samples in Fig. 3 are saturated below 1000 mT except the sample at 830 cm (Fig. 3c) which is saturated at 1300 mT. The curves increase slightly above 300 mT, implying the presence of high-coercivity hematite. The IRM demagnetization curves (Fig. 3a, b, d, e, f) demonstrate that the reversed field applied to the $IRM_{1500\ mT}$ can demagnetize the remanence when reaching 40 mT, supporting the dominance of low-coercivity magnetite. The sample at 830 cm required 50 mT to demagnetize remanence (Fig. 3c), which is in agreement with the presence of hematite as suggested previously.

Fig. 4 shows magnetic hysteresis loops for representative samples from loess and red clay. All of the samples display a significant paramagnetic contribution (not shown in Fig. 4). After correction for the paramagnetic contribution, the hysteresis loop for the sample at 830 cm almost closes at 500 mT (Fig. 4c), which reveals the existence of a high-coercivity hematite component in addition to the low-coercivity magnetite and maghemite component. The other samples show hysteresis loops that close below 500 mT, such as samples at depths of 316 cm, 600 cm, 1000 cm, 1158 cm and 1430 cm (Fig. 4a, b, d, e, f). In these samples, the dominant magnetic mineral components are low-coercivity magnetite and maghemite. In summary, the magnetic mineralogy of the Lantian loess-red clay sequence is dominated by low-coercivity magnetite and maghemite, high-coercivity hematite co-exists in the samples as a minor component.

4.2. Timescale

Sun et al. (2006) have published a robust timescale for Chinese loess through an orbital tuning method. For this study, the Lantian sedimentary sequence timescale was derived by correlating our magnetic susceptibility curve with that of Sun et al. (2006).

We selected control points to constrain the time frame of the Lantian section. The control points are mainly located in transition layers between loess and paleosol or loess and red clay, so that each time interval shares a roughly constant sedimentation rate under the same climatic conditions. By assuming that the sedimentation rate of each time interval is constant, a continuous age model can be calculated. The timescale is shown in Fig. 5.

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