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Damped fluctuations in Chinese loess grain size

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[1] The sediment record of the loess-paleosol sequence in the Chinese Loess Plateau reveals a strong relationship between grain size fluctuations and glacial-interglacial cycles documented by marine oxygen isotope variations. However, on tectonic time scales, differences between the loess-paleosol grain size record and the marine oxygen isotope record can be identified. Analytical results from the Baishui, Jingchuan and Lingtai sections show that the grain size of eolian loess, superimposed on a coarsening trend, has two abrupt shifts at about 2.55 and 1.25 Ma, which are followed by significantly damped fluctuations in grain size. This is different from the global oxygen isotope record which demonstrates higher amplitude variations since the late Pliocene-early Pleistocene and lacks analogs of the abrupt shifts. We propose that the progressive uplift of the Tibetan plateau may have forced the regional environmental system across two thresholds at the late Pliocene-early Pleistocene and the middle Pleistocene, respectively, inducing two pulses of climatic and environmental changes over north-western China which are superimposed on the global cooling trend and orbital climate changes. *INDEX TERMS:* 3344 Meteorology and Atmospheric Dynamics: Paleoclimatology; 9320 Information Related to Geographic Region: Asia; 9604 Information Related to Geologic Time: Cenozoic; *KEYWORDS:* Loess-paleosol, Grain size, East Asian winter monsoon, Uplift of the Tibetan Plateau. **Citation:** Xiong, S. F., Z. L. Ding, W. Y. Jiang, S. L. Yang, and T. S. Liu, Damped fluctuations in Chinese loess grain size, *Geophys. Res. Lett.*, *30*(19), 2007, doi:10.1029/2003GL018187, 2003.

1. Introduction

[2] Uplift of the Tibetan plateau has had significant impacts on atmospheric circulation and detritus supply over the East and South Asia, and the increased weathering which accompanied the uplift would have drawn down atmospheric CO_2 and teleconnected the climatic effects of regional uplift the global climate [*Ruddiman and Kutzbach*, 1989; *Raymo and Ruddiman*, 1992; *Ruddiman et al.*, 1997]. However, the limited and sometimes contradictory conclusions from tectonic and geomorphology studies do not satisfactorily constrain the timing and nature (e.g., the rates, magnitude and duration) of the uplift of the Tibetan plateau [e.g., *Harrison et al.*, 1998] and the climatic effects of the uplift, especially for the period of the late-Pliocene and Pleistocene, is largely unknown [e.g., *Fort*, 1996]. The loess-paleosol deposits from the Chinese Loess Plateau provide an important archive of the evolution of atmospheric circulation, variations in detritus supply, and the expansions and retreats of Gobi and deserts over north-western China. Thus, they provide a regional record of the late-Pliocene and Pleistocene uplift of the Tibetan plateau and general global cooling [*Liu et al.*, 1985; *An et al.*, 2001; *Ding et al.*, 2002]. It is certain that changes in source areas and deposition of the loess were linked to the uplift of the Tibetan plateau, the aridity of the interior of central Asia, global cooling and variations in the global ice volume. However, uncertainty remains about how these processes have influenced the deposition of the loess and how this subsequently affects inferred variations in the East Asian monsoon circulation derived from these records. Further investigation is warranted and should be focused on evidence that can be used to differentiate signals of regional processes from those of global extent, with which one could obtain a better understanding of interactions between the climate systems over East Asia and the timing/effects of uplift of the Tibetan plateau.

[3] Here we re-examine and compare the grain size data from well-correlated sections at Lingtai [*Ding et al.*, 1998, 1999a], Jingchuan [*Yang et al.*, 2000; *Xiong et al.*, 2001] and Baishui [*Xiong et al.*, 2002, 2003] from the central Loess Plateau. We find that two abrupt shifts of grain size occurred around 2.55 and 1.25 Ma, and each shift was subsequently followed by increasingly damped amplitudes of fluctuations. This is different from the global oxygen isotope record which trends towards higher amplitude variations since the late Pliocene-early Pleistocene, suggesting a two-pulse regional forcing, probably related to the uplift of the Tibetan plateau.

2. Materials

[4] Baishui (35°24′10″N, 106°56′43″E), Jingchuan (35°17′30″N, 107°22′05″E), and Lingtai (35°00′33″N, 107°30′33″E) are located in the northwest part of the central Loess Plateau and comprise a southeast-northwest transect [Figure 1, *Xiong et al.*, 2002]. Previous magneto-stratigraphic studies have concluded that the base of the red clay in the Jingchuan and Lingtai were deposited at about 8 Ma [*Yang et al.*, 2000] and 7 Ma [*Ding et al.*, 1998], respectively. The base of the red clay in the Baishui section can be placed at about 6.2 Ma by magnetic susceptibility correlation [*Xiong et al.*, 2002].

[5] This study is primarily based on the re-examination and comparison of previous published grain size and magnetic susceptibility data of the loess-paleosol sequence from the Baishui [*Xiong et al.*, 2002, 2003], Jingchuan [*Yang et al.*, 2000; *Xiong et al.*, 2001] and Lingtai [*Ding et al.*, 1998, 1999a] sections. In these studies, the measurements of magnetic susceptibility were conducted with a Bartington MS2 susceptibility meter for air-dried samples, and the grain size distribution was determined with a Sald-

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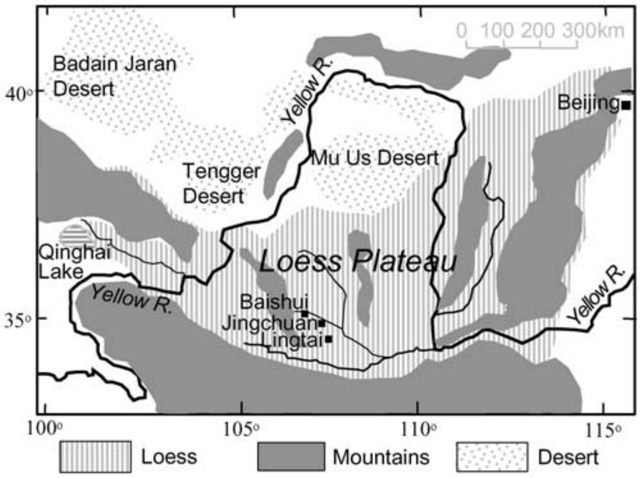

Figure 1. Map of the Chinese Loess Plateau and adjacent regions showing locations of the Lingtai, Jingchuan and Baishui sections.

3001 diffraction particle analyzer after the carbonate-free samples had been ultrasonically treated in a 20% $(NaPO_3)_6$ solution [*Xiong et al.*, 2002, 2003; *Yang et al.*, 2000; *Ding et al.*, 1999a].

[6] The age model was based on the magnetic reversal stratigraphy for the Jingchuan [*Yang et al.*, 2000] and Lingtai [*Ding et al.*, 1998] sections using the *Cande and Kent* [1995] timescale with linear interpolation between the age control points. The age control of the Baishui section was assigned by correlating the magnetic susceptibility record with the Jingchuan section [*Xiong et al.*, 2003].

3. Results

[7] The results of this study indicate that for all the three sections, superimposed on an overall coarsening and amplitude-increasing trend, two grain-size events (extreme coarse-grained horizons) occurred at L33 and L15, and each was followed by gradually damped fluctuations in grain size (Figure 2). The coarsening trend seems beginning from the base of the loess-paleosol (even older, not shown), and the amplitude-increasing trend is especially apparent above L9 (Figure 2). Although complicated with the coarsening trend, the damped fluctuations in grain size are still clear in the sections. For example, the median grain size (Md) of L15 for the Baishui section is about 33 μm, decreasing to about 27 μm for L9 and 20 μm for L1. The Md of L33 (∼25 μm) in the Baishui section is also significantly larger than that for L16 (about 15 μm). Based on magnetostratigraphy [*Yang et al.*, 2000; *Ding et al.*, 1998] and the time scale of *Ding et al.* [2002], the timing of these two events is estimated as around 2.55 Ma and 1.25 Ma, respectively.

[8] Other important aspects can be further accessed with the comparison of grain size data from these sections. First, it seems that the two coarse-grained events are not a consequence of a gradual change in grain size, and there is no precursor for these events (Figure 2). Second, the grain size change at the lower boundaries of L33 and L15 is abrupt (Figures 3 and 4), implying an abrupt shift in environments and in atmospheric circulation. Third, the average Md of L33 and L15 exhibits a coarsening gradient towards north/northwest (from Lingtai to Baishui) (Figures 3 and 4), similar to those of Malan loess [*Liu et al.*, 1985].

4. Discussion and Conclusions

[9] Extremely coarse (and thick) horizons of L33 and L15 in Chinese loess-paleosol sequences have been noticed in previous studies [e.g., *Liu et al.*, 1985; *Kukla*, 1987] and linked to tectonic uplift of mountains in Asia [e.g., *Kukla and Cilek*, 1996; *Xiao and An*, 1999; *Xiong et al.*, 2001]. However, the lacking of sustained effect of mountain uplift in the loess grain size record has challenged the tectonic explanation [*Ding et al.*, 2002]. The new observation is that the damped oscillations in grain size following the two extremely coarse loess horizons hint at an important forcing

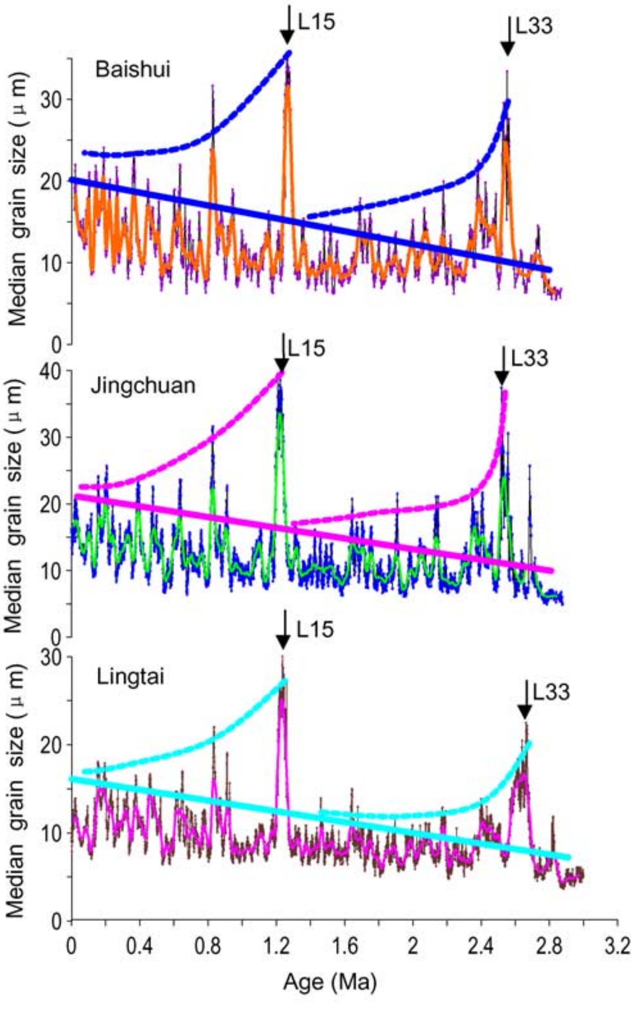

Figure 2. Correlation of the grain size variations and the 25-point running means of the data of loess-paleosol sequences at the Baishui, Jingchuan and Lingtai sections (Data of Jingchuan and Lingtai sections are from *Yang et al.* [2000] and *Ding et al.* [1999a], respectively). The extreme coarse loess horizons L15 and L33 are indicated with an arrow. The dotted lines represent the damped fluctuations in grain size for the loess horizons from L33 and L15, respectively. The heavy lines indicate the coarsening and amplitude-increasing trend.

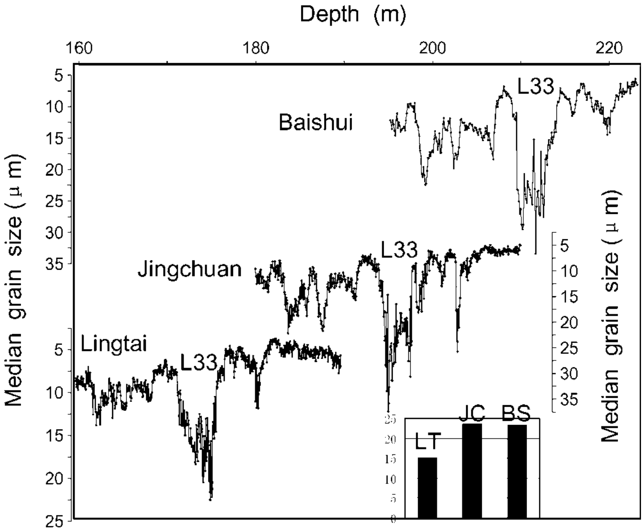

Figure 3. Comparison of the grain size variations around loess L33 from the Baishui, Jingchuan and Lingtai sections. Insect shows average Md (μm) of L33 for these three sections.

mechanism which influences the deposition of loess and variations in the East Asian monsoon circulation over tectonic time scales.

[10] Eolian grain size variations have commonly been used to monitor past wind intensity changes [e.g., *Rea*, 1994]. For the Chinese eolian loess, grain size generally varies with the alternations of the loess and paleosol deposits [*Liu et al.*, 1985]. The coarser-grained horizons are interpreted to be a response of loess deposition associated with stronger winter monsoon winds [e.g., *Ding et al.*, 1994] and/or the expansion of deserts caused by increasing aridity [*Ding et al.*, 1999b]. The extremely coarse horizons around 2.55 Ma (L33) and 1.25 Ma (L15), with a coarsening gradient towards north/northwest as Malan loess, suggest the occurrence of significantly strengthened winter monsoon winds over northwestern China. These two extreme events are followed by upward damped fluctuations in grain size which persist over long periods of time (Figure 2).

[11] To explain this feature, we may first compare the Chinese loess grain size record with the marine oxygen isotope record. The grain size of loess-paleosol sequence coarsened and increased in amplitude upward, similar to the global oxygen isotope record which shows a trend towards larger global ice volume and higher amplitude variations since the late Pliocene-early Pleistocene [e.g., *Mix et al.*, 1995]. This similarity suggests that the coarsening and amplitude-increasing trend in grain size record of the Chinese loess probably reflect the influence of global cooling on the environment and climate over East Asia. The most prominent difference between the loess grain size and marine oxygen isotope record is in that the grain size of eolian loess has two intervals of abrupt grain size shift followed by damped oscillations from 2.55 and 1.25 Ma, respectively, which lacks analogs in marine record. This difference suggests that although there are strong climatic linkages between the variations in dust transporting winds over East Asia and the global ice volume changes over orbital time scales [e.g., *Ding et al.*, 1994, 2002] and at the early stage of major northern hemisphere glaciation [*Xiong et al.*, 2003], the main mechanism that is responsible for the tectonic time scale shifts in the East Asian winter monsoon strength is unlikely related to global ice volume forcing.

[12] The Milankovitch insolation forcing caused by changes in Earth's orbital parameters (obliquity, precession and eccentricity) is also very unlikely to be an appropriate explanation for the first order variations in the loess grain size, because the orbital parameters have not shown similar tectonic scale variations [*Berger and Loutre*, 1991] with the loess record. Other factors that may be invoked to explain the climatic variations over tectonic time scales during the late Cenozoic include volcanism, opening and/or closing (Panamanian Isthmus) of gateways, and long term CO_2 variations [e.g., *Crowley and Burke*, 1998]. The gradual closure of the Panamanian Isthmus ranging from 2.5 to 3.7 Ma [*Haug and Tiedemann*, 1998] can not be used to explain the abrupt coarsening event in loess around 2.55 Ma. In addition, volcanism and long term CO_2 variations cannot satisfactorily account for the two-pulse change in loess grain size and inferred winter monsoon strength.

[13] Based on these data, some constrains for the mechanism of tectonic scale variations in the East Asian winter monsoon strength can be observed. The difference between the loess grain size and the global ice volume records suggests regional forcing is responsible for the tectonic scale variations in East Asian monsoon strength, which exerts an influence mainly on northwestern China. The loess record also suggests that changes in climate systems over northwestern China around 2.55 Ma and 1.25 Ma are abrupt, rather than gradual. The prolonged intervals of damped oscillations in loess grain size subsequent to the extremely coarse-grained events imply a long-term effect of the initial perturbation on East Asian monsoon climate system, which favors a tectonic explanation.

[14] Although there are presently no accurate records for the uplift history of the Tibetan plateau especially during the

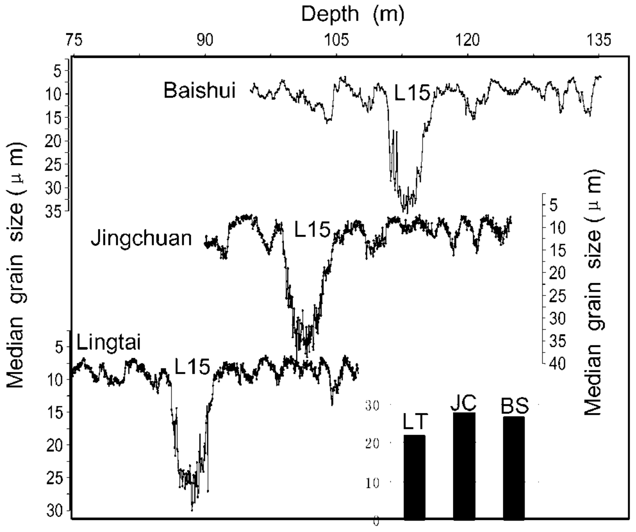

Figure 4. Comparison of the grain size variations around loess L15 from the Baishui, Jingchuan and Lingtai sections. Insect shows average Md (μm) of L15 for these three sections.

late-Pliocene and Pleistocene [e.g., *Harrison et al.*, 1998; *Fort*, 1996; *Ruddiman et al.*, 1997], the evidence outlined above seems to support an interpretation linking the uplift of the Tibetan plateau and East Asian winter monsoon variations. Given that the loess deposition on the Chinese Loess Plateau is controlled on one hand by the detritus input of the uplift terrain (northern Tibet) into deserts and on the other hand by the winter monsoon winds which could be strengthened due to the uplift of the Tibetan plateau [e.g., *Xiong et al.*, 2001], we suggest that the uplift of the northern part of the Tibetan plateau is probably the main forcing factor inducing the tectonic scale changes in loess grain size and the inferred East Asian winter monsoon variations. It is likely that at about 2.55 Ma and 1.25 Ma, the progressive uplift of the Tibetan plateau may have led some parts of the regional environmental system to cross new thresholds. This initial perturbation on the regional environmental system could have significantly changed climate regimes, probably by cooling the surface of the plateau, drying inland deserts in northwestern China, enhancing weathering and erosion of detritus materials due to steeper mountain slopes and more frequent glacial advances and retreats, and intensifying winter monsoon winds, as well as positive and/or negative links, thus resulting in two pulses of tectonic scale of environmental changes over north-western China (and such effect may be gradually damped out through time due to long term erosional lowering of elevated topography after uplift) as seen in the loess grain size record. Such a regional perturbation may have also played an important, but not yet clearly understood, part in global climate change during the late-Pliocene and Pleistocene.

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