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Loess geochemistry and Cenozoic paleoenvironments

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Abstract
Loess-soil sequences are among the best terrestrial records of paleoenvironments. Those in northern China provide a 22 million-year (Ma) geological history of the Asian deserts (dust sources), winter monsoon (dust carrier) and summer monsoon (moisture carrier) winds, and the regional vegetation. Loess geochemistry represents one of the most dynamic research fields in loess-based Paleoclimatology. Some of the most frequent approaches are reviewed here with emphasis to the loess deposits in China.

Keywords: loess geochemistry, Cenozoic climate, paleosol, monsoon

1. Introduction

Loess is terrestrial eolian dust deposits covering ~10% of the land surface (Liu, 1985). The formation of loess fundamentally requires: (1) a sustained source of dust with poor vegetation, (2) adequate winds to transport the dust, and (3) a suitable accumulation site (positive, relatively flat and tectonically stable topography). Loess deposits usually contain numerous paleosols interbedded with loess layers within the band of Earth's orbital changes (Guo et al., 2002). The formation of these soils requires, in addition, a circulation as moisture-carrier (Guo et al., 2008).

All of these factors have left their imprints in the loess deposits. Consequently, loess-soil sequences are regarded as one of the best terrestrial records of paleoenvironments. World's longest loess records locate in the Loess Plateau in northern China. They include the well-known Quaternary (0-2.6 Ma) loess-soil sequences (Liu, 1985; Ding et al., 2001a), the eolian Red Clay (2.6-8.0 Ma) in the eastern Loess Plateau (Ding et al., 2001b), and the Mio-Pliocene loess-soil sequences in the western Loess Plateau (22-3.5 Ma) (Guo et al., 2002; Hao and Guo, 2004). Their combination provides a near continuous terrestrial record of climates for the past 22 Ma.

Geochemical approaches represent one of the most dynamic domains in loess-based Paleoclimatology. This short report aims at introducing some of the main achievements in the study of loess geochemistry with special emphasis to the loess records in China.

2. Chemical composition of loess

The chemical compositions of the Pleistocene loess from different continents have mostly been determined (e.g. Liu et al., 1993; Gallet et al., 1996; 1998; Jahn et al., 2001). Compilation of worldwide data shows a remarkable similarity of elemental geochemistry (Fig. 1), with the dominance of SiO_2, Al_2O_3, Fe_2O_3 and K_2O. Recent data from the Miocene (Guo et al., 2002; Liang et al., 2009) and Pliocene loess (Ding et al., 2001a; Guo et al., 2001) show similar features.

The major and trace elemental compositions of all the loess are encompassed between shales and sandstones, two principle clastic sedimentary end-members. They essentially resemble the average composition of upper continental crust (UCC) (Taylor et al., 1985).

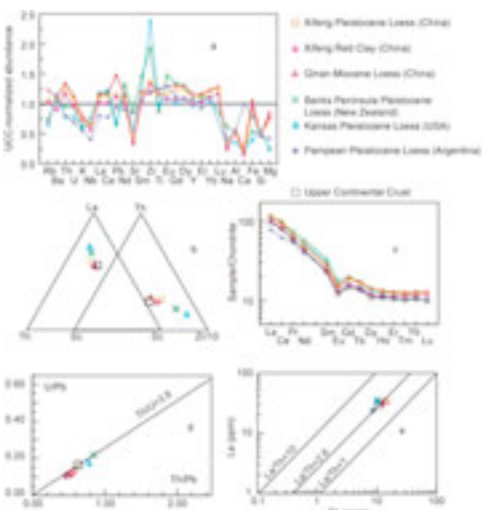

Figure 1
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The REE (Rare-earth elements) patterns of different loess (Fig. 1) are hardly distinguishable, with enriched LREE and relatively flat HREE profiles, a restrict range of $(La/Yb)_N$ ratio (7-10) and a negative Eu anormaly. Eu/Eu* ratio varies between 0.53 to 0.67 for European loess, 0.74-0.83 for the loess in Argentina (Gallet et al., 1998), and 0.6-0.7 for the loess in China (Liang et al., 2009). They have nearly a constant La/Th ratio close to 2.8 despite the location and age differences.

The basic geochemical composition of loess, therefore, remarkably resembles the average composition of UCC, indicating that most of the loess materials were derived from well-mixed sedimentary protoliths, which had undergone numerous upper-crustal recycling processes. These reinforce an earlier conclusion (Taylor et al., 1983) that the average chemical composition of UCC might be obtained from eolian deposits, and suggest that the Neogene loess in China can provide equally good proxies for UCC.

3. Geochemical tracing of dust provenance and wind trajectory

Dust materials may be produced by eolian abrasion in the deserts and by glacial grinding of bedrocks (Liu, 1985). Eolian deflation of fine-grained materials may occur in large river-beds and on continental shelves during glacial periods, leading to the loess deposits on river terraces and in coastal regions. Despite of the general geochemical similarity to UCC (Fig. 1), loess of different origins are usually distinguishable through specific geochemical parameters.

The loess of different ages in northern China are characterized by slight TiO_2 positive and Na_2O, CaO negative anomalies and slightly lower Sr content compared to UCC (Fig. 1). These are attributable to their desert origin: the inland deserts in Asia were formed as early as 22 Ma ago (Guo et al., 2002), such that the materials would have experienced many cycles involving processes of sedimentary differentiation with moderate chemical weathering.

Another distinct feature of the loess in China is the higher Cs, lower Zr and Hf concentrations (Liang et al., 2009). They are explainable by the grain-size sorting during the transportation and can be regarded as another indication of the long trajectory of dust from the remote deserts in the Asian interior. These sorting processes are minimized for loess with closer sources.

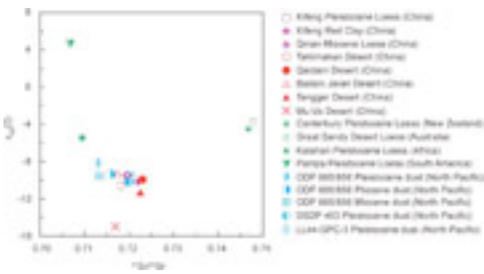

Figure 2
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Isotope tracers (e.g. Sr, Nd and Os) are particularly sensitive in the determination of dust provenance. Loess from different sources have clearly distinct isotope signatures (Fig. 2). $\varepsilon_{Nd}(0)$ values for the Pleistocene, Pliocene and Miocene loess in China average -10.0, -10.1 and -9.5, respectively, indicating roughly similar sources and dust trajectories (Fig. 2). This is also supported by their narrower range of Eu/Eu* ratio between 0.6 and 0.7 (Liang et al., 2009). $^{87}Sr/^{86}Sr$ ratio averages 0.719874, 0.722026 and 0.719579 for the Pleistocene, Pliocene and Miocene samples, respectively. Their slight differences of $^{87}Sr/^{86}Sr$ are due to the coarser/finer textures of the Quaternary/Neogene loess. Isotope data from the main deserts in northern China (Fig. 2) suggest that the Taklimakan, Qaidam, Badain Jaran and Tengger deserts would have constantly been the main sources of the loess deposits in the Loess Plateau over the past 22 Ma.

These geochemical tracers confirm the onsets of the inland deserts (as dust sources) and monsoon-dominated climate (with the winter monsoon as dust carrier) in Asia by the early Miocene due to the uplift of the Himalayan-Tibetan complex and changes in the land-sea distribution pattern (Guo et al., 2008). Asian deserts have also been the main sources of the dust deposited in the North Pacific since the early Miocene (Ziegler et al., 2007), as is confirmed by the isotope data (Fig. 2). Some dust components, such as iron, may have significantly affected the concentration of atmospheric CO_2 and global climate through modulating marine bio-productivity (Jickells et al., 2005).

4. Loess geochemistry and paleoclimate proxies

Geochemical parameters are widely used as climate proxies in loess-based Paleoclimatology to document: (1) the conditions of dust sources; (2) the strength of dust-carrying winds; and (3) climates and vegetations in the depositional regions. In the case of the loess in China, these include the drying history of the Asian interior, the strengths of the Asian winter (dust carrier) and summer (moisture carrier) monsoons, and vegetation changes in the Loess Plateau.

Dust flux is positively correlative with the source aridity (Rea et al., 1998; Guo et al., 2004), but hardly measurable due to post-depositional modifications (e.g. pedogenesis and compaction). The flux of Al_2O_3 (An et al., 2001) and Be isotopes (Shen et al., 1992; Graham et al., 2001) were used to quantify the changes in dust flux. Some other elements, such as Fe_2O_3, have also the potential to document the long-term changes of dust flux because of their resistance to post-depositional weathering and the relatively small variability over time.

Grain-size of eolian sediments is indicative of the strength of dust carrying-winds, i.e. the westerly winds for the dust in North Pacific (Rea et al., 1998), and the Asian winter monsoon for the loess in China. However, grain-size of bulk samples were usually affected by post-depositional pedogenesis and weathering. SiO_2/Al_2O_3

molecular ratios were proven to be a sensitive proxy of the Asian winter monsoon for both Quaternary and Neogene loess in China (Guo et al., 2004), as SiO_2 and Al_2O_3 are stable under semi-arid conditions while quartz (SiO_2) is much more abundant in coarser dust fractions. Some other components, of which the concentrations are dependent of grain-size, were also used to reflect the strength of the winter monsoon (Liu et al., 1995).

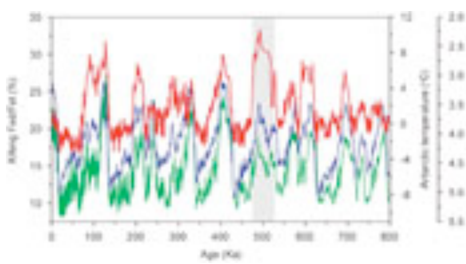

Figure 3
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Chemical weathering in the monsoon zones mainly depends upon summer precipitation and temperature. Accordingly, chemical weathering indexes (e.g. Fed/FeT, CIW, Rb/Sr) are widely used to reflect the changes of the Asian summer monsoon (Guo et al., 1996; 2000; Chen et al., 1999; Ding et al., 2001b). These new proxies have documented a series of monsoon features that had not been reflected by magnetic susceptibility, an index that was widely used as a proxy of the summer monsoon. They brought some key insights for understanding the monsoon dynamics. For example, chemical weathering in the loess of China shows an overall declining trend (Liang et al., 2009) from the early Miocene to the Pleistocene, indicating a gradually weakened summer monsoon. This trend is broadly consistent with the late Cenozoic global cooling, suggesting that global temperature is an important forcing of the long-term monsoon changes. Also, correlation of the loess weathering history in China with the ice and marine records (Fig. 3) revealed a strong asymmetry of climates between the Northern and Southern Hemispheres ~500 ka ago that exercised a strong impact on the monsoon circulations and ocean conditions (Guo et al., 2009).

The loess deposits in China contain several hundred of paleosols (Guo et al., 2002). Carbon isotopes of soil carbonates and organic matter are reliable indicators of the proportions of C3 and C4 plant biomass as the C3 and C4 photosynthetic pathways fractionate carbon isotopes to different degrees. Data from the loess in China (e.g. An et al., 2005; Ding and Yang, 2000) yielded a faire history about the Neogene expansions of C4 grasslands in northern China, which significantly differs from that south to the Himalayan-Tibetan complex (Cerling et al., 1997).

In the regions with pure C3 vegetation, carbon isotopes are indicative of paleo-rainfall (Hatte et al., 2001). Oxygen isotopes of the authigenic carbonates in loess may reflect the changes in temperature, evaporation and rainwater sources (Ding and Yang, 2000; Li et al., 2007).

5. Summary and perspectives

This report summarizes some of the most frequent applications of Geochemistry in the study of loess. There are many other promising insights with regards to the loess geochemistry and Cenozoic environments. For example, geochemical methods may offer the means of resolving loess ages beyond the range of radiocarbon and luminescence dating (Oches and McCoy, 1995). Carbon isotopes of some molecular components in loess may bear more accurate information of paleo-vegetation (Xie et al., 2004). Elemental carbon in loess likely reflects the history of natural fires (Zhou et al., 2007). Hydrogen and nitrogen isotopes in loess may provide new environmental signals (Liu and Wang, 2008). Some of these results are still contentious, but it is rightly this kind of debates that add charms to the loess geochemistry field. In particular, there is a strong need to develop more accurate geochemical proxies and geochemical models for loess-based Paleoclimotology towards quantifying environmental parameters and climate dynamics.

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References

An Z.S., Huang Y., Liu W.G., Guo Z.T., Clemens S., Li L., Prell W., Ning Y.F., Cai Y.J., Zhou W.J., Lin B.H., Zhang Q.L., Cao Y.N., Qiang X.K., Chang H. and Wu, Z.K. (2005) Multiple expansions of C4 plant biomass in East Asia since 7 Ma coupled with strengthened monsoon circulation. *Geology* **33**, 705-708.

An Z.S., Kutzbach J.E., Prell W.L. and Porter S. C. (2001) Evolution of Asian monsoons and phased uplift of the Himalaya-Tibetan plateau since Late Miocene times. *Nature* **411**, 62-66.

Basile I., Grousset F.E., Revel M., Petit J.R., Biscaye P.E. and Barkov N.I. (1998) Patagonian origin of glacial dust deposited in East Antarctica (Vostok and Dome C) during glacial stages 2, 4 and 6. *Earth and Planetary Science Letters* **146**, 573-589.

Cerling T.E., Harris J.M., macFadden B.J., Leakey M.G., Quade J., Eisenmann V. and Ehleringer J.R. (1997) Global vegetation change through the Miocene/Pliocene boundary. *Nature* **389**, 153-158.

Chen J., An Z.S. and Head J. (1999) Variation of Rb/Sr ratios in the loess-paleosol sequences of central China during the last 130,000 years and their implications for monsoon paleoclimatology. *Quaternary Research* **51**, 215-219.

Chen J., Li G., Yang J., Rao W., Lu H., Balsam W., Sun Y. and Ji J. (2007) Nd and Sr isotopic characteristics of Chinese deserts: Implications for the provenances of Asian dust. *Geochimica et Cosmochimica Acta* **71**, 3904-3914.

Ding Z.L., Yang S.L., Sun J.M. and Liu T.S. (2001a) Iron geochemistry of loess and red clay deposits in the Chinese Loess Plateau and implications for long-term Asian monsoon evolution in the last 7.0 Ma. *Earth and Planetary Science Letters* **185**, 99-109.

Ding Z.L., Sun J.M., Yang S.L. and Liu T.S. (2001b) Geochemistry of the Pliocene red clay formation in the Chinese Loess Plateau and implications for its origin, source provenance and aleoclimate change. *Geochimica et Cosmochimica Acta* **65**, 901-913.

Ding Z.L. and Yang S.L. (2000) C3/C4 vegetation evolution over the last 7.0 Myr in the Chinese Loess Plateau: evidence from pedogenic carbonate d13C. *Palaeogeography, Palaeoclimatology, Palaeoecology* **160**, 291-299.

Gallet S., Jahn B.-m. and Torii M. (1996) Geochemical characterization of the Luochuan loess-paleosol sequence, China, and paleoclimatic implications. *Chemical Geology* **133**, 67-88.

Gallet S., Jahn B.-m., Van Vliet Lanoe B., Dia A. and Rossello E. (1998) Loess geochemistry and its implications for particle origin and composition of the upper continental crust. *Earth and Planetary Science Letters* **156**, 157- I77.

Graham I., Ditchburn R. and Whitehead N. (2001) Be isotope analysis of a 0-500ka loess-paleosol sequence from Rangitatau East, New Zealand. *Quaternary International* **76/77**, 29-42.

Grousset F.E., Biscaye P.E., Revel M., Petit J.R., Pye K., Joussaume S. And Jouzel J. (1992) Antarctic (Dome C) ice-core dust at 18 k.y. B.P.: Isotopic constraints on origins. *Earth and Planetary Science Letters* **111**, 182-1750.

Guo Z.T., Liu T.S., Guiot J., Wu N.Q., Lu H.Y., Han J.M., Liu J.Q. and Gu Z.Y. (1996) High frequency pulses of East Asian monsoon climate in the last two glaciations: Link with the North Atlantic. *Climate Dynamics* **12**, 701-709.

Guo Z.T., Berger A., Yin Q.Z. and Qin L. (2009) Strong asymmetry of hemispheric climates during MIS-13 inferred from correlating China loess and Antarctica ice records. *Clim. Past*. **5**, 21-31.

Guo Z.T., Biscaye P., Wei L.Y., Chen X.H., Peng S.Z. and Liu T.S. (2000) Summer monsoon variations over the last 1.2 Ma from the weathering of loess-soil sequences in China. *Geophysical Research Letters* **27**, 1751-1754.

Guo Z.T., Ruddiman W.F., Hao Q.Z., Wu H.B., Qiao Y.S., Zhu R.X., Peng S.Z., Wei J.J., Yuan B.Y. and Liu T.S. (2002) Onset of Asian desertification by 22 Myr ago inferred from loess deposits in China. *Nature* **416**, 159-163.

Guo Z.T., Peng S.Z., Hao Q.Z., Biscaye P.E. and Liu T.S. (2001) Origin of the Miocene-Pliocene red-earth formation at Xifeng in Northern China and implications for paleoenvironments. *Palaeogeography, Palaeoclimatology, Palaeoecology* **170**, 11-26.

Guo Z.T., Peng S.Z., Hao Q.Z., Biscaye P.E., An Z.S. and Liu T.S. (2004) Late Miocene-Pliocene development of Asian aridification as recorded in the Red-Earth Formation in northern China. *Global and Planetary Change* **41**, 135-145.

Guo Z.T., Sun B., Zhang Z.S., Peng S.Z., Xiao G.Q., Ge J.Y., Hao Q.Z., Qiao Y.S., Liang M.Y., Liu J.F., Yin Q.Z. and Wei J.J. (2008) A major reorganization of Asian climate by the early Miocene. *Clim. Past*. **4**, 153-174.

Hao Q.Z. and Guo Z.T. (2004) Magnetostratigraphy of a late Miocene-Pliocene loess-soil sequence in the western Loess Plateau in China. *Geophysical Research Letters* **31**, L09209, doi: 10.1029/2003GL019392.

Hatte C., Antoine P., Fontugne M., Lang A., Rousseau D.D. and Zoller L. (2001) $\delta^{13}C$ of loess organic matter as a potential proxy for paleoprecipitation. *Quaternary Research* **55**, 33-38.

Jahn B.M., Gallet S. and Han J. (2001) Geochemistry of the Xining, Xifeng and Jixian sections, Loess Plateau of China: eolian dust provenance and paleosol evolution during the last 140 ka. *Chemical Geology* **178**, 71-94.

Jickells T.D., An Z.S., Andersen K.K., Baker A.R., Bergametti G., Brooks N., Cao J.J., Boyd P.W., Duce R.A., Hunter K.A., Kawahata H., Kubilay N., laRoche J., Liss P.S., Mahowald N., Prospero J.M., Ridgwell A.J., Tegen I. and Torres R. (2005) Global iron connections between desert dust, ocean biogeochemistry, and climate. *Science* **308**, 67-71.

Jouzel J., Masson-Delmotte V., Cattani O., Dreyfus G., Falourd S., Hoffmann G., Minster B., Nouet J., Barnola J.M., Chappellaz J., Fischer H., Gallet J.C., Johnsen S., Leuenberger M., Loulergue L., Luethi D., Oerter H., Parrenin F., Raisbeck G., Raynaud D., Schilt A., Schwander J., Selmo E., Souchez R., Spahni R., Stauffer B., Steffensen J.P., Stenni B., Stocker T.F., Tison J.L., Werner M. and Wolff E.W. (2007) Orbital and millennial Antarctic climate variability over the past 800,00 years. *Science* **317**, 793-796.
Li G., Sheng X., Chen J., Yang J. and Chen Y. (2007) Oxygen-isotope record of paleorainwater in authigenic carbonates of Chinese loess-paleosol sequences and its paleoclimatic significance. *Palaeogeography, Palaeoclimatology, Palaeoecology* **245**, 551-559.
Liang M.Y., Guo Z.T., Kahmann A.J. and Oldfield F. (2009) Geochemical characteristics of the Miocene eolian deposits in China: Their provenance and climate implications. *Geochemistry Geophysics Geosystems* **10**, Q04004, doi:10.1029/2008GC002331.
Lisiecki L.E. and Raymo M.E. (2005) A Plicene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records. *Paleoceanography* **20**, PA1003, doi: 10.1029/2004PA001071.
Liu C.Q., Masuda A., Okada A., Yabuki S., Zhang J. and Fan Z.L. (1993) A geochemical study of loess and desert sand in northern China: Implications for continental crust weathering and composition. *Chemical Geology* **106**, 359-374.
Liu W.G. and Yang H. (2008) Multiple controls for the variability of hydrogen isotopic compositions in higher plant n-alkanes from modern ecosystems. *Global Change Biology* **14**, 2166-2177.
Liu T.S. (1985) Loess and the Environment (in Chinese with English abstract). China Ocean Press, Beijing.
Liu T.S., Guo Z.T., Liu J.Q., Han J.M., Ding Z.L., Gu Z.Y. and Wu N.Q. (1995) Variations of eastern Asian monsoon over the past 140,000 years. *Bulletin de la Societe Geologique de France* **166**, 221-229.
Nakai S., Halliday A.N. and Rea D.K. (1993) Provenance of dust in the Pacific Ocean. *Earth and Planetary Science Letters* **119**, 143-157.
Oches E. and McCoy W. (1995) Amino acid geochronology applied to the correlation and dating of central European loess deposits. *Quaternary Science Reviews* **14**, 767-782.
Pettke T., Halliday A.N., Hall C.M. and Rea D.K. (2000) Dust production and deposition in Asia and the north Pacific Ocean over the past 12 Myr. *Earth and Planetary Science Letters* **178**, 397-413.
Rea D.K., Snoeckx H. and Joseph L.H. (1998) Late Cenozoic eolian deposition in the North Pacific: Asian drying, Tibetan uplift, and cooling of the northern hemisphere. *Paleoceanography* **13**, 215-224.
Shen C.D., Beer J., Liu T.S., Oeschger H., Bonani G., Suter M. and Wolfli W. (1992) 10Be in Chinese loess. *Earth and Planetary Science Letters* **109**, 169-177.
Taylor S.R. and McLennan S. (1985) *The Continental Crust: Its Composition and Evolution*. Blackwell, Oxford.
Taylor S.R., McLennan S.M. and McCulloch M.T. (1983) Geochemistry of loess, continental crustal composition and crustal model ages. *Geochimica et Cosmochimica Acta* **47**, 1897-1905.
Xie S., Guo J., Huang J., Chen F., Wang H. and Farrimond P. (2004) Restricted utility of $\delta^{13}C$ of bulk organic matter as a record of paleovegetation in some loess-paleosol sequences in the Chinese Loess Plateau. *Quaternary Research* **62**, 86-93.
Zhou B., Shen C.D., Sun W.D., Zheng H.B., Yang Y., Sun Y.B. and An Z.S. (2007) Elemental carbon record of paleofire history on the Chinese Loess Plateau during the last 420 ka and its response to environmental and climate changes. *Palaeogeography, Palaeoclimatology, Palaeoecology* **252**, 617-625
Ziegler C.L., Murray R.W., Hovan S.A. and Rea D.K. (2007) Resolving eolian, volcanogenic, and authigenic components in pelagic sediment from the Pacific Ocean. *Earth and Planeary Science Letters* **254**, 416-432.

Appendix – Figure 1

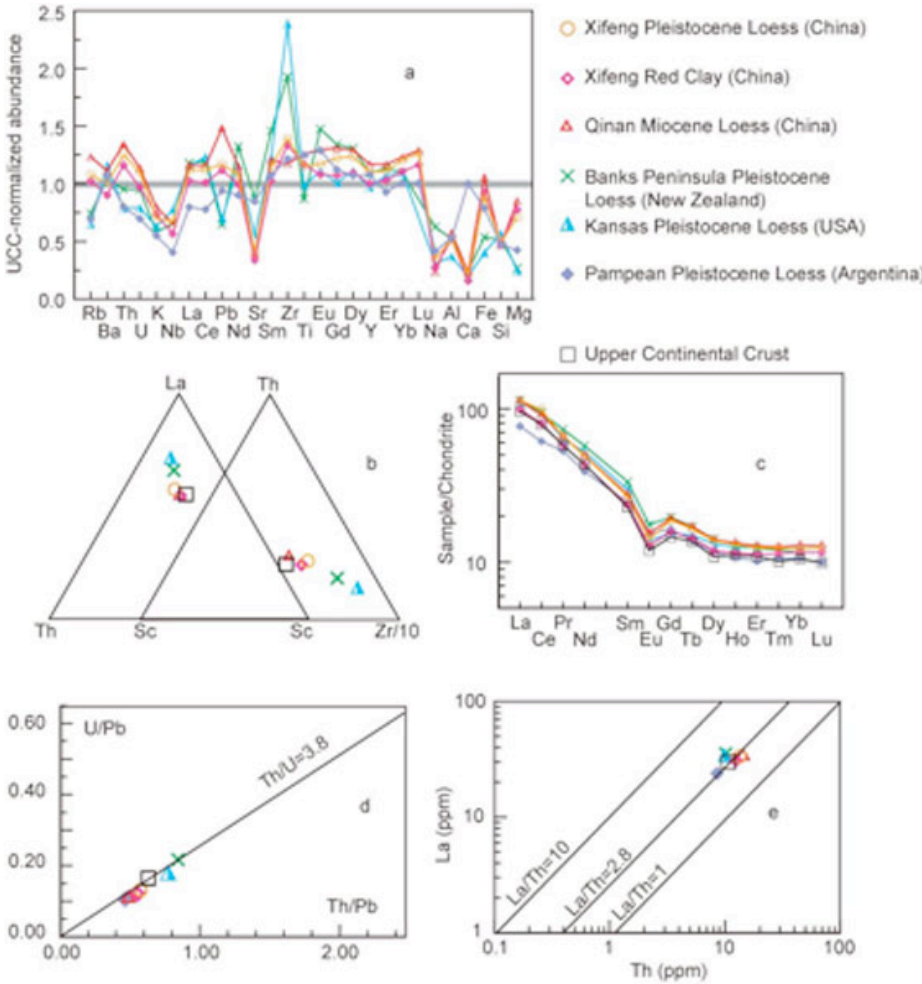

Figure 1. Elemental compositions of loess from different locations and ages. a. UCC-normalized abundances. b. La-Th-Sc and Th-Sc-Zr/10 discrimination diagrams. c. Chondrite-normalized REE distribution patterns. d. U/Pb versus Th/Pb ratios. e. La versus Th diagram. The Banks Peninsula (average of 5 samples) and Kansas (average of 3 samples) Pleistocene loess data are from Taylor et al. (1983). Data for the Pampean (average of 6 samples) Pleistocene loess are from Gallet et al. (1998). Data for the Xifeng Pleistocene loess (average of 6 samples), the Xifeng Pliocene Red Clay (average of 4 samples) and the Qinan Miocene (average of 7 samples) loess are from Liang et al. (2009). UCC data are from Taylor and McLennan (1985).

Appendix – Figure 2

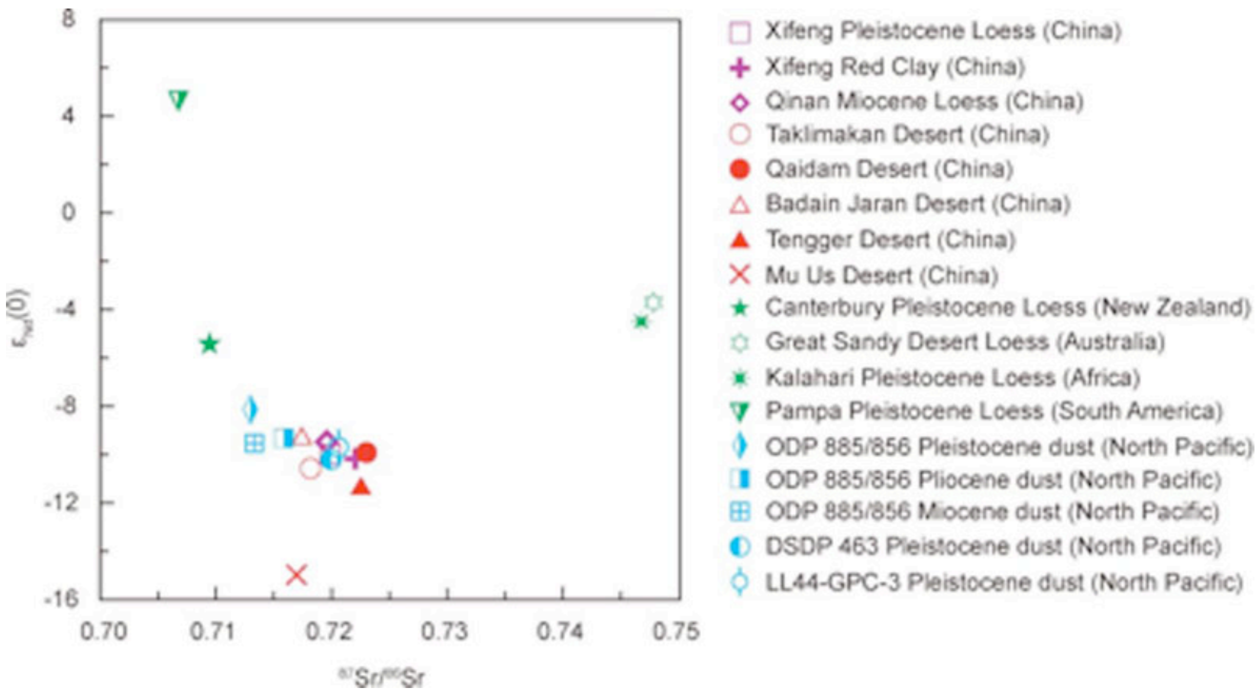

Figure 2. Isotopic signatures of loess/dust from different locations and ages. Data for the Xifeng Pleistocene loess (average of 5 samples), the Xifeng Pliocene Red Clay (average of 5 samples) and the Qinan Miocene loess (average of 5 samples) are from this study. Data for Taklimakan (average of 9 samples), Qaidam (average of 7 samples), Badain Jaran (average of 11 samples), Tengger (average of 5 samples) and Mu Us (average of 10 samples) deserts in China are from (Chen et al., 2007). Data for Canterbury (1 sample), Great Sandy Desert (average of 2 samples), Kalahari (average of 2 samples) and Pampa (average of 3 samples) Pleistocene loess are from Basile et al (1998). Date for the Pleistocene (average of 4 samples), Pliocene (average of 7 samples) and Miocene (average of 9 samples) at the ODP site 885/886 are from Pettke et al (2000). Data for DSDP 463 (1 sample) and LL44-GPC-3 (1 sample) sites are from Nakai et al (1993).

Appendix – Figure 3

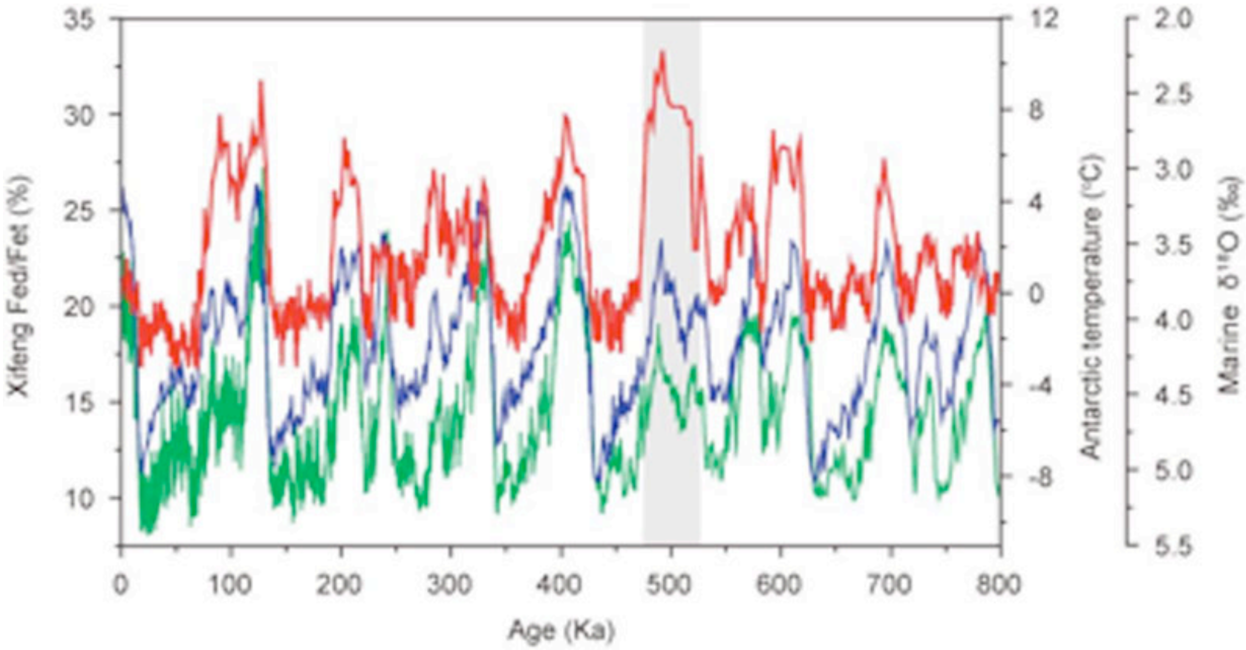

Figure 3. Correlation of loess weathering record at Xifeng in China (Guo et al., 2009) (red) with the Antarctic temperature (Jouzel et al., 2007) (green) and marine $\delta^{18}O$ records (Lisiecki and Raymo, 2005) (blue)

About the Author

Zhengtang Guo is a professor of Cenozoic Geology. He obtained a PhD in 1990 from University of Pierre & Marie Curie, France. His main research interests center on the Cenozoic paleoclimates and biogeochemistry. He was a member of the Scientific Steering Committee of Past Global Change (PAGES), co-leader of PAGES's Australasian Pole-Equator-Pole (PEP-II) international project, Vice-President of the INQUA Commission on Paleoclimates. He and his colleagues extended the loess records in China from 8 Ma to 22 Ma, and use geochemical approaches to explore climate information from loess deposits.