Aeolian Research 18 (2015) 1–9

Contents lists available at ScienceDirect

Aeolian Research

journal homepage: www.elsevier.com/locate/aeolia

Provenance fluctuations of aeolian deposits on the Chinese Loess Plateau since the Miocene

Long Ma[a,b], Youbin Sun[a,*], Ryuji Tada[c], Yan Yan[a,b], Hongyun Chen[d], Min Lin[e], Kana Nagashima[f]

[a] *State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710075, China*
[b] *University of Chinese Academy of Sciences, Beijing 100049, China*
[c] *Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, 7-3-1 Hongo, Tokyo 113-0033, Japan*
[d] *Research Center for Loess and Global Changes, Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences, Shijiazhuang 050803, China*
[e] *Radiometrology Center, China Institute of Atomic Energy, Beijing 102413, China*
[f] *Research and Development Center for Global Change, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2-15 Natsushima-cho, Yokosuka 237-0061, Japan*

ARTICLE INFO

Article history:
Received 13 February 2015
Revised 8 May 2015
Accepted 8 May 2015
Available online 2 June 2015

Keywords:
Chinese Loess Plateau
Aeolian deposits
Quartz
ESR signal intensity
Crystallinity index
Provenance change

ABSTRACT

The evolution of the provenance of aeolian deposits on the Chinese Loess Plateau (CLP) is closely linked to changes in source aridity and dust transport dynamics. Although previous studies have revealed that the provenance of Chinese aeolian deposits may have fluctuated on tectonic timescales, the exact timing and cause of the provenance shifts remain poorly constrained due to limitations of the isotopic and mineralogical tracers used. Here we report the results of electron spin resonance (ESR) signal intensity and crystallinity index (CI) of fine-grained (<16 μm) quartz isolated from two aeolian sequences on the CLP, in order to address tectonic-scale shifts in dust provenance over the last ~23.5 Ma. The ESR–CI results spanning the interval ~7–5 Ma for two aeolian sequences are comparable, implying a broadly similar provenance of dust deposits over the entire CLP. The ESR–CI values are lower after ~7 Ma than before ~9.5 Ma, indicating that a significant provenance shift occurred during ~9.5–7 Ma. Comparison of the ESR–CI results for fine-grained quartz in desert surface samples and for the loess and Red Clay sequences indicates that the provenance shift may have been caused by increased dust input from the Mongolian Gobi and western China (i.e., the Taklimakan desert) since the late Miocene. The combination of our results with regional tectonic evidence and global climate record suggests that tectonically-driven climate changes in the dust sources may have played a dominant role in driving the late Miocene provenance shift.

1. Introduction

Dust materials from arid and semi-arid areas in central Asia are transported by the Westerlies and/or the East Asian Winter Monsoon and are deposited downwind in a proximal location, forming the immense Chinese Loess Plateau (CLP) (e.g., Liu, 1985; An et al., 2001; Guo et al., 2002). Since the aridification of the central Asian interior was affected by global cooling and/or the progressive uplift of the Tibetan Plateau, aeolian deposits on the CLP have been investigated intensively as a unique continental archive in order to decipher monsoonal climate changes, Asian inland aridification, and regional tectonic activities (e.g., An et al., 2001; Guo et al., 2002; Ding et al., 2005; Sun and An, 2005). Most of the paleoclimatic interpretations of the proxies generated from the aeolian deposits were based on the hypothesis of a stable dust provenance since the Miocene (Jahn et al., 2001; Chen and Li, 2011). However, both isotopic evidence and modeling results reveal that the dust sources may have shifted significantly in response to regional tectonic events and global climate changes (Li et al., 2011; Chen and Li, 2011, 2013; Shi et al., 2011; Liu and Dong, 2013) Therefore, investigation of fluctuations in the provenance of aeolian deposits on the CLP could potentially provide valuable insights into possible tectonic-climate links.

A provenance investigation involves two essential aspects: the spatial characteristics of dust detritus originating from different geological settings and the temporal fluctuations of dust provenance on different timescales. Since provenance tracers may be influenced by complex processes, such as recycling and pre- and post-depositional modification, recent works have integrated multiple tracers with an emphasis on results of single grains (e.g., zircon, heavy minerals) to address the provenance issue (e.g.,

---

* Corresponding author.
E-mail address: sunyb@ieecas.cn (Y. Sun).

http://dx.doi.org/10.1016/j.aeolia.2015.05.002
1875-9637/

Stevens et al., 2010; Chen and Li, 2011; Pullen et al., 2011; Nie et al., 2012; Che and Li, 2013; von Eynatten and Dunkl, 2012; Nie and Peng, 2014; Yan et al., 2014, 2015). These tracers including Sr–Nd isotopes (Sun, 2002, 2005; Chen et al., 2007; Chen and Li, 2013), U–Pb ages of detrital zircon (Stevens et al., 2010; Pullen et al., 2011; Xiao et al., 2012; Che and Li, 2013), ESR signal intensity and crystallinity index (Sun et al., 2007, 2008, 2013), and the $\delta^{18}O$ of quartz grains (Hou et al., 2003; Yan et al., 2014) have been investigated systematically in order to constrain temporal changes in provenance of aeolian deposits on the CLP.

Previous studies indicated that the arid and semi-arid areas of interior Asia, including the Taklimakan Desert in western China, the Badain Juran Desert and Tengger Desert in northern China, and the Gobi Desert in southern Mongolia, were three major sources of Asian dust (Sun et al., 2001; Zhang et al., 2003; Chen et al., 2007), whereas the dominant primary areas of dust production are the mountains surrounding these deserts (Sun, 2002; Sun et al., 2007; Isozaki et al., 2008; Chen and Li, 2013). For example, the Taklimakan Desert is influenced by detrital materials from the Tianshan Mountains to the north, by the Kunlun Mountains to the southwest, and the Altun Mountains to the southeast (Derbyshire et al., 1998; Sun, 2002; Sun et al., 2007; Isozaki et al., 2008). Alluvial fans developed along the Hexi Corridor, northern Qilian Mountains, and southern Gobi Altai Mountains supplied detrital materials to the Badain Juran, Tengger Desert and southern Mongolian Gobi (Sun et al., 2007; Isozaki et al., 2008). Therefore, the northeastern Tibetan Plateau and the central Asian Orogen as well as the Taklimakan Desert in western China have been considered to be the proto-sources of Asian dust and thus of the aeolian deposits on the CLP and in the North Pacific Ocean (Isozaki et al., 2008; Li et al., 2011; Chen and Li, 2013; Nie et al., 2014; Yan et al., 2014).

Provenance fluctuations of dust deposits on land and in the ocean have been investigated on glacial–interglacial to tectonic timescales (Sun, 2005; Sun et al., 2008; Xiao et al., 2012; Che and Li, 2013; Nie et al., 2014; Yan et al., 2014). Sr–Nd isotopic and geochemical results indicate that the provenance of aeolian deposits was relatively stable at glacial–interglacial timescales (Jahn et al., 2001; Wang et al., 2007). Recently, the application of two single-grain techniques focusing on coarse-grained minerals revealed no apparent provenance shift on the CLP between glacial and interglacial periods (Che and Li, 2013; Nie and Peng, 2014). However, the ESR signal intensity and crystallinity index (CI) of fine-grained quartz revealed that the provenance of fine dust on the CLP and in the Japan Sea varied at glacial-interglacial timescales (Nagashima et al., 2007, 2013; Sun et al., 2008). Different conclusions regarding dust provenance variations are likely due to the different tracers and/or grain-size fractions used in previous work. A combination of these tracers would potentially enable a better understanding of changes in dust provenance on glacial–interglacial timescales (Yan et al., 2014).

At tectonic timescales, analysis of Sr–Nd–Pb isotopes revealed that dust provenances probably shifted at around 7–8 Ma and ~2.6 Ma (Sun, 2005; Sun and Zhu, 2010; Li et al., 2011; Chen and Li, 2011; Che and Li, 2013). A similar provenance shift at 2.6 Ma has been confirmed by analysis of quartz oxygen isotope ratios (Hou et al., 2003). The zircon U–Pb ages in Chinese loess and Red Clay deposits reveal that the provenance shifted from a proximal source in late Miocene to the Taklimakan Desert in the middle Pliocene and to a mixed sources during the Quaternary (Nie et al., 2014). However, even though Sr–Nd isotopes have extended provenance studies back to 22 Ma, the exact timing of provenance change of the aeolian deposits prior to the Pliocene cannot be clearly resolved due to the low sampling resolution and chronological uncertainties (Chen and Li, 2013). Therefore, it is important to investigate tectonic-scale provenance changes at a relatively higher stratigraphic resolution and with robust chronological control.

Due to the stable physical and chemical properties of quartz (Xiao et al., 1995), ESR signal intensity and CI, which reflect respectively the formation age and temperature of the host rocks (Murata and Norman, 1976; Toyoda and Naruse, 2002), have been measured intensively in order to trace the provenance of aeolian dust deposits on the CLP and in the Japan Sea (Nagashima et al., 2007, 2011, 2013; Sun et al., 2007, 2008, 2013). Previous studies have confirmed that ESR and CI of quartz can effectively distinguish dust provenance. Here we extend the application of ESR–CI measurements on fine-grained quartz (<16 μm) to two aeolian sequences at Zhuanglang (Miocene to early Pliocene Red Clay deposits) and Lingtai (late Miocene-Pliocene Red Clay deposits and Quaternary loess-paleosol sequences) on the CLP. Accumulation of Red Clay at the Zhuanglang and Lingtai sites overlaps during the interval 7–5 Ma, and combining the quartz ESR–CI results from these two sites should provide a robust evaluation of dust provenance fluctuations since the Miocene. Tectonic and climatic impacts on dust provenance were further addressed by comparing changes in provenance with thermo-chronological data and with the global climate record.

2. Materials and methods

The CLP is divided into two parts by the Liupan Mountains (Fig. 1): the western CLP, including thick Mio-Pliocene Red Clay formation overlain by Quaternary loess deposits (Guo et al., 2002; Hao and Guo, 2004, 2007; Qiang et al., 2011); and the central CLP, consisting of aeolian deposits accumulated continuously since the late Miocene (Sun et al., 1998a,b; Ding et al., 1998). The present study reports results from aeolian sediments of the Lingtai section (LT, 35°04′N, 107°39′E) and the Zhuanglang core (ZL, 35°13′N, 106°05′E) (Fig. 1). These two sites are located in the central and western CLP, respectively. The LT section comprises 120 m thickness of the Red Clay Formation accumulated during the late Miocene and Pliocene (~7.2–2.6 Ma) and ~170 m thickness of the Quaternary loess-paleosol sequence (Sun et al., 1998a; Ding et al., 1998). Based on the pedostratigraphy of the LT section, representative samples were selected for each loess (L1–L33) and paleosol (S0–S32) layer, while Red Clay samples were selected at a 2-m interval (Fig. 2A). The ZL Red Clay was accumulated from ~24.6 to 4.8 Ma, with a thickness of ~654 m (Qiang et al., 2011; Fig. 2B). Based on the magnetostratigraphy, samples were chosen at a ~0.2 Ma resolution from 23.5 to 5.0 Ma. A total of 127 and 77 samples were selected from the LT section and the ZL core, respectively, for grain-size separation and analyses of ESR signal intensity and crystallinity index (CI).

Since fine-grained dust can be easily transported by the low-level winter monsoon or the high-level westerly jet both to the proximal CLP and to the distant ocean (e.g., the Japan Sea, North Pacific) (Nagashima et al., 2007, 2011, 2013; Pettke et al., 2002), only the <16 μm fraction was separated from bulk samples, using the pipette method, for the ESR and CI measurements. In accordance with previous analytical approaches (Sun et al., 2007, 2008), the extracted fine-grained fraction was pretreated to remove organic matter, carbonate and Fe/Mn oxides prior to measurements of ESR signal intensity and CI. The CI of quartz was measured using an X'Pert Pro MPD powder X-ray diffractometer at the Institute of Earth Environment, Chinese Academy of Sciences. Each sample was measured 6 times. The measurement conditions were as follows: irradiated source of Cu Kα with a voltage at 40 kV and 40 mA, scanning range of 66°–69° (2θ), scanning speed of 0.0176° s^{-1}, and step size of 24.765 s. The CI was calculated using the following equation