Journal of Asian Earth Sciences 166 (2018) 80–88

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Full length article

Binary sources of Chinese loess as revealed by trace and REE element ratios

Wenfang Zhang[a,b], Jian-xin Zhao[c], Jun Chen[b], Junfeng Ji[b], Lianwen Liu[b,*]

[a] State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[b] Ministry of Education Key Laboratory of Surficial Geochemistry, School of Earth Sciences and Engineering, Nanjing University, Nanjing 210023, China
[c] Radiogenic Isotope Facility, School of Earth and Environmental Sciences, The University of Queensland, St, Brisbane 4072, Australia

A R T I C L E I N F O

Keywords:
Chinese loess
Deserts
Trace and rare earth elements
Source
Upper continental crust

A B S T R A C T

Chinese loess is generally accepted to be one of the most important archives for establishing the average geochemical compositions of the upper continental crust (UCC), assuming numerous upper crustal recycling processes. However, the effect of such recycling processes on elemental fractionation has still not been systemically and quantitatively assessed. This study investigates the trace and rare earth elements (REE) of the < 75 µm and < 5 µm silicate fractions of ten deserts and sandy lands in northern China, and of Chinese loess, to evaluate the effect of grain size on element ratios. Our results indicated that REE- and some trace elements (Y, Ta and Nb)-related ratios have the negligible effect of grain size, and can therefore be regarded as size-independent proxies to trace the source of eolian deposits. The principal component analysis (PCA) of these size-independent ratios was conducted for the deserts and loess samples. The PCA results reveal that Chinese loess was ultimately derived from the materials eroded from two tectonic settings, *i.e.* the northern Tibetan Plateau (NTP) and the Central Asian Orogenic Belt (CAO). We propose that the UCC component of Chinese loess can not only be ascribed to numerous upper crustal recycling processes, but also to the thorough mixing of materials from different tectonic settings.

1. Introduction

Chinese loess is widely accepted as a reliable archive for estimating the mean elemental contents of the UCC, a fact which can be attributed to the remarkable homogeneity of loess materials sourced from large deserts and sandy lands in the Asian interior after experiencing numerous upper crustal recycling processes (Gallet et al., 1996; Jahn et al., 2001; Taylor et al., 1983). These deserts and sandy lands are distributed over a wide area, and mainly include the Gurbantunggut, Ulan Buh, Hobq, Mu Us, Taklimakan, the Qaidam Basin, Badain Jaran, Tengger and Gobi deserts (Fig. 1). It has been indicated that the Chinese Loess Plateau (CLP) received eolian dust from these deserts *via* near surface East Asian Winter Monsoon and/or low-altitude Westerly atmospheric circulations (Che and Li, 2013; Chen and Li, 2011; Chen et al., 2007; Nie et al., 2014). The long-distance transportation of eolian dust on the CLP from these remote deserts would preferentially remove fine particles and leave behind relatively coarse residue in the deserts and sandy lands, leading to grain size-induced changes in mineral assemblages and elemental contents both in the deserts and sandy lands, and in any loess deposits. For example, the Chinese loess is rich in SiO_2 as a result of preferential enrichment of quartz during transportation and sedimentary recycling processes (Rudnick and Gao, 2014). The anomalously high Zr and Hf concentrations of loess (Taylor et al., 1983) are mainly due to the greater abundance of heavy mineral zircon through size sorting (Liu, 1985). Thus, understanding the effect of grain size on the concentrations of particular elements in deserts and sandy lands and loess deposits during the size sorting process is crucial to constraining more accurately the average elemental contents of the UCC using Chinese loess.

The effect of size sorting on elemental contents has been studied on Asian dust in previous work, principally based on the relative mobility of elements during the recycling and sedimentary processes (Ferrat et al., 2011; Hao et al., 2010; Honda et al., 2004; Yang et al., 2006). It has been proven that some trace elements and REEs do not easily experience fractionation during chemical weathering and transportation process, and could therefore be potentially better indicators of the sources and depositional processes of eolian sediments (Ding et al., 2001; Gallet et al., 1998). Element ratios, rather than individual concentrations, are frequently used when distinguishing different eolian dust sources, because element ratios have the potential to eliminate the dilution effects of some certain minerals, such as zircon and quartz, which dominate abundances of Zr, Hf and SiO_2, and thus allow a

* Corresponding author at: Ministry of Education Key Laboratory of Surficial Geochemistry, School of Earth Sciences and Engineering, Nanjing University, Nanjing 210023, China.
E-mail address: liulw@nju.edu.cn (L. Liu).

https://doi.org/10.1016/j.jseaes.2018.07.017
Received 8 August 2017; Received in revised form 12 July 2018; Accepted 13 July 2018
1367-9120/

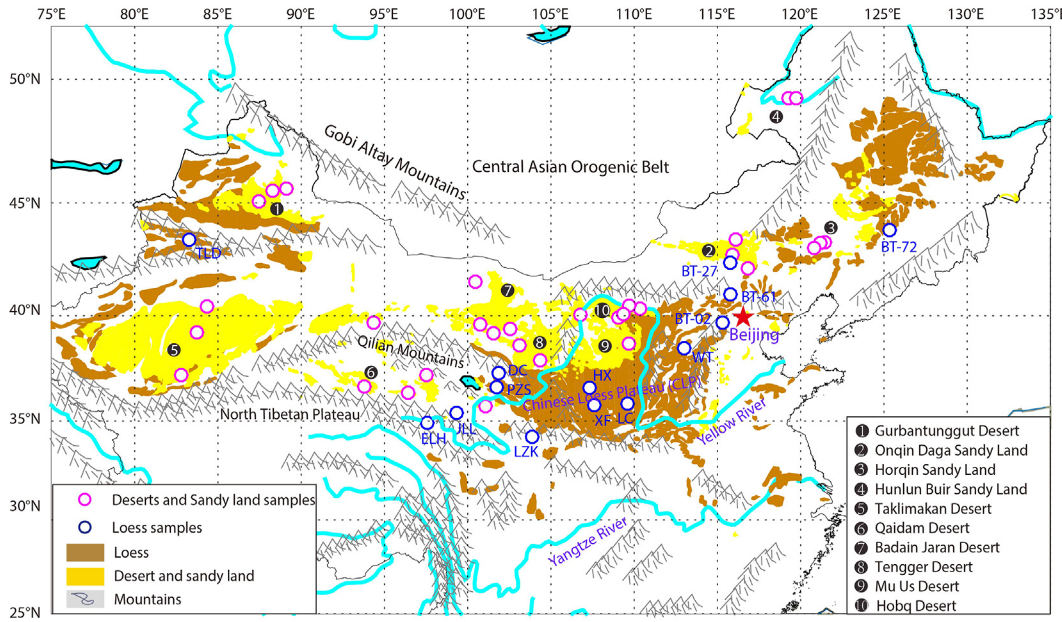

Fig. 1. Locations of sampling sites in the named northern Chinese deserts and sandy lands and on the CLP.

delineation of the different trends observable in REE and trace element patterns (Ferrat et al., 2011). REE-normalized patterns, Chondrite-normalized Eu anomalies ($\delta Eu = Eu_N/(Sm_N * Gd_N)^{1/2}$, where the subscript 'N' indicates the Chondrite normalized values, same hereinafter), La/Th, Y/Nb, Zr/Hf, Hf/Nb, Zr/Nb and La-Th-Sc triangle diagrams are usually used to distinguish different dust sources (Ferrat et al., 2011; Gallet et al., 1996; Hao et al., 2010; Hu and Yang, 2016). However, trace elements and REEs have been mostly investigated for some Chinese deserts and loess samples (Ding et al., 2001; Ferrat et al., 2011; Gallet et al., 1996, 1998; Hu and Yang, 2016; Liang et al., 2009). A systematic investigation of the effect of grain size on the element ratios of Chinese loess deposits and the potential source deserts and sandy lands in northern China has not yet been conducted, impeding our understanding of any Chinese loess particles typical of the UCC.

This study systematically investigates trace elements and REE contents of ten potential deserts and sandy lands, as well as that of Chinese loess. The deserts and sandy lands samples were separated into < 75 μm and < 5 μm silicate fractions, while the loess samples were separated into bulk silicate and < 5 μm silicate fractions. The grain size effect on the element ratios for all the potential single element-to-element ratios was quantitatively examined by comparing the element ratios of the < 75 μm and < 5 μm silicate fractions within one sample. The elemental source tracers of any size-independent ratios were identified and then were used to trace the source of Chinese loess through a statistical method based on our data and the published data. Our results show that Chinese loess was derived ultimately from materials eroded from the deserts and sandy lands lying along the NTP, and from the CAO. We propose that numerous upper crustal recycling processes, as well as the mixing of materials from the region's broad tectonic settings, enable Chinese loess to be taken as typical of the UCC.

2. Materials and methodology

The sampled deserts and sandy lands and three samples of L_1LL_1 loess (HX, Huanxian; LC, Luochuan; XF, Xifeng) (formed during the last glacial maximum (LGM)) on the CLP in the Asian interior were split from the same samples used in the previous study (Chen et al., 2007). The detailed locations of these deserts and loess samples are shown in Fig. 1. In addition, another eleven loess samples formed during the LGM were also collected from large-scale areas, including the CLP (WT, Wutai; LZK, Lazikou), northeastern China (BT-72 and BT-27), the northeastern TP (JLL, Jiangluling; DC, Dongchuan; PZS, Southeast Qi'lian Mountains; and ELH, around Lake E'ling), the Ili Basin (TLD) and the city of Beijing (BT-02 and BT-61) (Fig. 1).

For all the deserts and sandy lands and loess samples, only the acid-insoluble residues (mainly are silicate fractions) were extracted by dissolving the samples in 0.5 mol/L acetic acid after the method of Chen et al. (2007). Such a pretreatment is designed in order to eliminate the effect of carbonate enrichment and dissolution on the trace and REE elemental concentrations during chemical weathering and pedogenesis. Then, the < 75 and < 5 μm fractions of the deserts and sandy lands samples were extracted. All the loess samples were treated for bulk silicate fractions and three loess samples (labeled HX, LC and XF) were also treated for < 5 μm fractions. The consideration of this particle size selection is twofold. Firstly, the particles of deserts and sandy lands are mostly very coarse and most dust particles transported by the atmosphere are mainly < 50 μm (Tsoar and Pye, 1987). In addition, it is suggested that the grain size of the particles in loess is mostly < 75 μm fraction (Ding et al., 2001). Secondly, the < 5 μm particles were used because it could be transported for a long distance and deposit in remote areas, such as north Pacific Ocean and Greenland, whose dust grains mostly have diameters < 5 μm (Biscaye et al., 1997). Thus, the extraction of < 75 μm and < 5 μm fractions could enable us to evaluate the effect of grain size sorting on the elements contents and their ratios for the dust deposits on the CLP and their potential dust sources (deserts and sandy lands). The < 75 μm silicate fractions of the deserts and sandy lands samples was extracted through a 200 mesh sieve by sieving the ultrasonically dispersed samples in pure water. The < 5 μm fractions of deserts and sandy lands samples and three loess samples (labeled HX, LC, XF) were separated according to Stokes' Law, and were then obtained by centrifuging.

About 25 mg of each extracted sample was weighed and transferred into a Teflon container. Samples were first dissolved using a mixture of 0.2 ml triple-distilled concentrated HNO_3 and 2 ml ultra-pure HF, then placed in an ultrasonic bath for 15 min. The Teflon container was sealed into a steel jacket and put into an oven at 180 °C for 48 h. The containers were opened and placed on a hotplate to evaporate to dryness. Afterwards, 1 ml HNO_3 was added and evaporates to dryness. This last step was repeated twice. Finally, 1.5 ml HNO_3 and 8.5 ml milli-Q H_2O were added to containers, and then placed on a hotplate for 12 h to allow full refluxing to make sure the sample was completely dissolved. Elemental concentrations were determined using Inductively Coupled