Quaternary Science Reviews 131 (2016) 179–192

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Geochemical and geomorphological evidence for the provenance of aeolian deposits in the Badain Jaran Desert, northwestern China

Fangen Hu [a, b], Xiaoping Yang [a, *]

[a] Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, P.O. Box 9825, Beijing 100029, China

[b] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 2 August 2015
Received in revised form
23 October 2015
Accepted 26 October 2015
Available online 19 November 2015

Keywords:
Surface process
Desert
Geochemistry
Trace and rare earth elements
Sediment source
Tibetan Plateau
Mongolia
China

ABSTRACT

Identifying provenance of aeolian deposits in the mid-latitude deserts of Asia is essential for understanding formation and changes of Earth surface processes due to palaeoclimatic fluctuations. While some earlier studies focused on the interpretation of palaeoenvironments on the basis of aeolian deposits mainly in the desert margins and inter-dune lacustrine sediments, research on provenance of desert sands in the vast Asian mid-latitude deserts is still rare. In this paper, we present new geochemical data which provide insight to the provenance of dune sands in the Badain Jaran Desert, northwestern China, an important part of this desert belt. We sampled aeolian and lacustrine sediments in various parts of the Badain Jaran Desert, and examined their major, trace and rare earth elements (REE) in bulk samples, coarse and fine fractions, respectively. In addition, we took and analyzed samples from a rarely known dune field with red sands, northeast of the Badain Jaran. Our results show that the sands from the Badain Jaran Desert are generally different from those in the red sand dune field in terms of REE pattern and geochemical characteristics, suggesting different sediment origins. Geochemical composition of the aeolian sand samples indicates these sediments should be mainly derived from mixed source rocks of granite, granitoids and granodiorite. Comparing the immobile trace elements and REE ratios of the samples from the Badain Jaran Desert, red sand dune field with rocks of granite, granitoids in their potential source areas, we conclude that: (1) The aeolian deposits in the Badain Jaran Desert are predominantly derived from the Qilian Mountains, northeastern Tibetan Plateau initially via fluvial processes; (2) The Altay Mountains and Mongolian Gobi are the ultimate source areas for the red sand dune field; (3) The Altai Mountains and Mongolian Gobi in the northwest, that could produce massive amounts of materials via intensive deflation and alluvial process, are additional sand sources of the Badain Jaran Desert although their contribution is of secondary significance. As the Badain Jaran Desert acts as sediment sinks of sediments from the Qilian Mountains of northeastern Tibetan Plateau via fluvial processes, it is likely that zircon grains of loess on the Chinese Loess Plateau with age distributions similar to those of the northern Tibetan Plateau could be derived from the Badain Jaran Desert, as the wind data suggest.

1. Introduction

Aeolian deposits, especially in arid and semiarid desert regions, are significant component of the Earth's surface sediment systems (Thomas and Wiggs, 2008). That provides a large proportion of global dust production. Dust has significant impact on the Earth system referring to radiative balance, hydrological and biogeochemical cycles, climate states (Arimoto, 2001; Hara et al., 2006; Maher et al., 2010). Many works have determined the main source regions of dust through satellites, remotely sensed data, numerical modeling and geochemistry tracing (Honda et al., 2004; Yang et al., 2007; Goudie, 2009; Skonieczny et al., 2011; Scheuvens et al., 2013). Sediment provenance of those main source regions of dust (arid and semiarid desert) is actually much less known, though

* Corresponding author.
E-mail address: xpyang@mail.igcas.ac.cn (X. Yang).

http://dx.doi.org/10.1016/j.quascirev.2015.10.039

that is important for deciphering the response of surface processes to tectonic and climatic changes, and for understanding operation of the Earth system (Molnar, 2004; Che and Li, 2013; Stevens et al., 2013).

As to the field of paleoenvironmental reconstruction in dryland areas which occupy ca. 36% of the land surface of the globe (Williams, 2014), aeolian deposits such as sand dune, are unique geomorphological and palaeoclimatic proxy (Thomas and Burrough, 2012; Yang et al., 2013, 2015; Williams, 2014), especially with the development and application of OSL dating (Munyikwa, 2005; Lancaster, 2008; Singhvi and Porat, 2008; Chase, 2009; Yang et al., 2011). The conventional view interpreted clusters of ages from aeolian sand sequence as indicating periods of extensive dune activity and dry climate (Preusser et al., 2002; Mason et al., 2009). An alternative view is that dune accumulation is likely to record the cessation of periods of more intense aeolian activity, moreover, the non-accumulating dunes actually represent the periods of dune stabilization and humid climate (Chase and Thomas, 2006; Chase, 2009; Chase and Brewer, 2009). Studies revealed that changes in sand supply or source will lead to a direct opposite interpretation of sand accumulation (Williams, 2015), particularly for fluvial-aeolian systems (Cohen et al., 2010). Thus, identifying the sand provenance is of great importance to correctly interpret the palaeoenvironmental indication of sandy sequences.

Compared with deserts in other parts of the world, the mid-latitude deserts of Asia are much more diverse in terms of landscape types and formation processes. For example, active and stable dunes occupy as much as 45% of the deserts of northern China, the eastern portion of the Asian mid-latitude desert belt. In contrast, aeolian sands cover only less than 1% of the arid zone in the Americans (Yang and Goudie, 2007). Among all deserts in China, the Badain Jaran Desert is known particularly for the occurrence of the tallest dunes on Earth (Yang et al., 2011a; Dong et al., 2013). However, the provenance of the sands making the Badain Jaran Desert is still not well understood due to lack of detailed and systematic research. Much earlier effort has been focused on the environmental and climatic changes recorded by the aeolian and lacustrine deposits in the desert and its margins (Yang et al., 2003, 2010, 2011; Gao et al., 2006; Guo et al., 2014; Wang et al., 2015).

Earlier studies assumed that the sandy materials in the Badain Jaran should have been derived from the weathered and denuded products of the underlying Mesozoic and Cenozoic sandstones, sandy conglomerate, clastic rocks (Lou, 1962; Sun and Sun, 1964) and the extensive lacustrine sediments of dry lake beds in the west and northwest (Yang, 1991; Yan et al., 2001), and the giant alluvial fan of Heihe River (Mischke, 2005; Wünnemann et al., 2007). However, these opinions are lack of convincing evidence and have not been verified.

Geochemical fingerprinting has great potential for identifying the provenance of sediments and their transport pathways (Taylor and McLennan, 1985; McLennan, 1989; Muhs et al., 1996, 2003, 2013; Cullers and Podkovyrov, 2002; Ferrat et al., 2011; Lancaster et al., 2015), particularly the trace and rare earth elements (REE), because they are less fractionated during the weathering, transport and sedimentation (Murray, 1994; López et al., 2005; Moreno et al., 2006; Kasper-Zubillaga et al., 2007; Castillo et al., 2008). In this paper, we present our new studies about major and trace elements and REE in the sediment samples collected from various parts of the Badain Jaran Desert and from a small dune field located in its northeast side. In association with the regional geological background and wind data, these geochemical data are further applied to interpret the sources of the Badain Jaran sands which should have an important impact on the Earth's surface system via global dust cycles.

2. Geological and physiogeographical settings

The Badain Jaran Desert lies in the northwest of the Alashan Plateau in the western Inner Mongolia, China, covering an area of 49,000 km^2 (Yang et al., 2011). It is a part of the Alashan Desert region including Tengger and Wulanbuhe deserts, and surrounded by mountain ranges such as Mongolia Altay in the North, Beishan in the northwest and Qilian Mountains in the south (Fig. 1). Mongolia Altay Gobi range, the largest accretionary orogenic collage in the world (Windley et al., 2007), is known in its more extensive equivalent as the Central Asian Orogenic Belt (CAOB). The entire Gobi Corridor region is characterized by a basin and range physiography with discontinuous mountain blocks trending WNW, E-W and ENE. Thick alluvial deposits of late Miocene-Recent age are widespread throughout the region (Cunningham, 2013). Aeolian deflation is a major erosional process throughout the region that provides windblown sediments to the huge Chinese Loess Plateau (CLP) in the southeast direction since at least the late Miocene (Heller and Liu, 1984). The Beishan, situated in the southernmost Altaids (Fig. 1), is a typical accretionary orogenic belt within the Altaids, and topographic culmination is Mazong Mountain. Intrusive rocks occur widely, and are main granitic in composition (Tian et al., 2014). The Qilian Mountains is the foreland region of the Northern Tibetan Plateau (NTP), which is a long-lived accretionary orogen formed in response to the closure of an oceanic basin between the Central Qilian and North China plates in the Paleozoic (Yan et al., 2010). The bedrocks are dominated by Precambrian granitic gneisses with minor Proterozoic granitoids and migmatites (Huang et al., 2014). It crops out overlain by early Paleozoic sedimentary rocks (Harris et al., 1988).

Geologically, the Alashan Plateau is a long-term and stable uplift and denudation area and consists in some faults and basins on the southern part. The Badain Jaran Desert developed in the fault basins and its boundaries are consistent with occurrence of faults. To the north, it is bounded by the Guaizihu wetland, which merges with the Gobi and plains of Mongolia. Jurassic, Cretaceous and Tertiary lacustrine sediment, with thickness of up to 300 m, can be found on the western edge of Badain Jaran Desert (Cai, 1986). Sporadically distributed Yardangs composed of alternations of fine-grained lacustrine and aeolian sand deposits, are exposed in the interdune areas or covered by shifting dunes in Guaizihu and Gurinai (Yang, 1991; Yan et al., 2001).

Climatically, the Badain Jaran Desert, located in the marginal area of East Asian Summer Monsoon, is characterized by a strongly continental climate, with a mean annual temperature of 7.7 °C in the southern portion and 8.2 °C in the northwest (Yang et al., 2010). Mean annual precipitation decreases significantly from ~120 mm in the south to 40 mm in the north of the desert (Yang et al., 2010). The wind strength and direction are mainly controlled by the East Asian Monsoon system, presenting the alternation of southeast winds in summer and northwest winds in winter. Wind rose based on monthly records from 1983 to 2012 displays a distribution pattern dominated by northwest winds (Fig. 1), which is driven by winter monsoon blows from the Siberian High Pressure System.

3. Materials and methods

Eighteen aeolian sand samples (marked by B1-18) and eight lacustrine sediment samples (marked by L1-8) were collected from various parts of the Badain Jaran Desert (Fig. 1). Sample numbers are generally ordered from north to south, with smaller numbers marking the sediments in the north. The aeolian sand samples were collected from the surface of active dunes. Lacustrine sediments are characterized by fine grain size, flat beddings or laminations and clayey and calcareous cementations, while two samples (L1-2)