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Geochemical evidence for the provenance of aeolian deposits in the Qaidam Basin, Tibetan Plateau

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ABSTRACT

The main purpose of this study is to analyse the material source of different grain-size components of dune sand in the Qaidam Basin. We determined the trace and rare earth element (REE) compositions and Sr-Nd isotopic compositions of the coarse (75–500 μm) and fine (< 75 μm) fractions of surface sediment samples. The comparison of the immobile trace element and REE compositions, Sr-Nd isotopic compositions and multidimensional scaling (MDS) results of the dune sands with those of different types of sediments in potential source areas revealed the following information. (1) The fine- and coarse-grained fractions of dune sands in the Qaidam Basin exhibit distinctly different elemental concentrations, elemental patterns and characteristic parameters of REE. Moreover, Sr-Nd isotopic differences also exist between different grain-size fractions of aeolian sand, which means that different grain-size fractions of these dune sands have different source areas. (2) The geochemical characteristics of the coarse particles of dune sand exhibit obvious regional heterogeneity and generally record a local origin derived from local fluvial sediments and alluvial/proluvial sediments. The coarse- and fine-grained dune sand in the southern Qaidam Basin mainly came from Kunlun Mountains, whereas the coarse- and fine-grained dune sand in the northeastern Qaidam Basin mainly came from Qilian Mountains. (3) The fine-grained fractions of sediments throughout the entire Qaidam Basin may have been affected by the input of foreign materials from the Tarim Basin.

1. Introduction

Aeolian deposits are important components of Earth's depositional systems because they create unique desert landscapes, contain important information about surface processes and have palaeoenvironmental implications (Guo et al., 2002; Thomas and Wiggs, 2008; Zhang et al., 2014). However, conflicting perspectives have been presented on the palaeoclimate significance of aeolian sequences because the process of aeolian sedimentation is controlled by the source of aeolian deposits and is influenced by climatic conditions (Williams, 2015). Therefore, tracing the source of aeolian sediments is an important component in understanding the processes that control these deposits. Provenance studies of deserts are beneficial for understanding the formation and evolution of deserts. Such research strengthens our understanding of Earth surface processes in arid areas and can help establish effective environmental governance policies for these sensitive areas (Yang et al., 2007a,b).

In recent years, geochemical methods have been widely used to assess the provenance of desert sand and loess material. In particular, rare earth elements (REEs) and Sr-Nd isotopes are often used because they are less fractionated during weathering, transport, and sedimentation (Grousset and Biscaye, 2005; Xie and Chi, 2016; Zhang et al., 2016). Major elemental and REE data suggest that coarser dune sand (> 250 μm) differs between areas of the Taklamakan Desert, whereas fine fractions (mainly silts) are more homogenized; additionally, the regional differences in coarse fractions are consistent with the fluvial and wind systems in the basin (Yang et al., 2007b). Differences in the Sr-Nd isotopic and REE compositions of different grain-size fractions of aeolian sand exist in the Erdos desert; the coarse-grained fractions (> 75 μm) mainly originated from the weathering of local parental rock, whereas the fine-grained fractions (< 75 μm) were likely affected by the input of foreign materials (Rao et al., 2008, 2011). Geochemical data indicate that the sources of the coarse (> 250 μm) and medium (180–212 μm) fractions of dune sands in the Hunshandake Sandy Land are diverse and are controlled by the local geology and geomorphology, whereas the fine-sand fractions are more homogenous, mainly due to intense mixing caused by aeolian processes; thus, these sands are likely primarily sourced from the surrounding mountains by fluvial/alluvial

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processes, rather than from remote territories (Liu and Yang, 2013). A comparison of the immobile trace elements and REE ratios of samples from the Badain Jaran Desert with those of their potential source areas revealed that the dune sands in the Badain Jaran Desert are predominantly derived from the Qilian Mountains via fluvial processes; the Altai Mountains and the Mongolian Gobi in the northwest are additional sand sources of the Badain Jaran Desert, although their contributions are of secondary significance (Hu and Yang, 2016). However, the provenance of dune sands in the Qaidam Basin still lacks detailed and systematic research.

The Qaidam Basin has experienced very strong wind erosion in the past. Yardangs in the western part of the basin cover an area of $\sim 3.88 \times 10^4\,km^2$ (Kapp et al., 2011), making the Qaidam Basin the largest yardang region in China. According to the age of the lacustrine strata and the geological profile, the erosion rate in the western part of the basin is estimated to have been > 0.12 mm/yr since the Late Pliocene (Kapp et al., 2011). The wind erosion rates in the western Qaidam Basin, based on measurements of cosmogenic ^{10}Be in exhumed Miocene sedimentary bedrock, range from 0.05 to 0.4 mm/yr, and the majority of measurements are clustered at 0.125 ± 0.05 mm/yr, which is consistent with the results of the abovementioned study (Rohrmann et al., 2013). In addition, shells in the eastern Qaidam Basin and salt crusts in the western part of the basin both have an age of ~100 ka; the basin has lacked sediment deposition since 100 ka, which is indicative of severe wind erosion (Han et al., 2014; Lai et al., 2014). Because the Qaidam Basin appears to exhibit very strong wind erosion characteristics, the following question arises: Is the homogenization of dune sands present throughout the entire basin?

To answer these questions, the geochemical analysis of dune sand in the Qaidam Basin is conducted in this study. We analyse the geochemical characteristics of the dune sand to explore its provenance through a comparative study of the dune sands in the Qaidam Basin and different types of sediments in potential source areas. Moreover, the Sr-Nd isotopic composition data of dust in adjacent areas of the Qaidam Basin are examined to discuss the provenance link between the Qaidam Basin and the Tarim Basin.

2. Materials and methods

2.1. Study area and sampling

The Qaidam Basin is a giant sedimentary basin that is located in the northeastern region of the Tibetan Plateau (Fig. 1), which is the highest plateau on Earth. The basin has an area of $\sim 120{,}000\,km^2$ and is enclosed by four mountain belts: the Kunlun Mountains to the south and west, the Altyn Tagh Mountains to the northwest, the Qilian Mountains to the northeast, and the Ela Shan Mountains to the east. The interior of the basin has an average elevation of 2800 m above sea level (asl), whereas the surrounding mountains reach elevations of 4000–5000 m asl. The Qaidam Basin has been an internally drained basin since at least the Oligocene (Yin et al., 2008). The geomorphology of the basin exhibits a zonal distribution; mountains, wind erosion hills, gobi, dunes, swamps, and salt lakes occur from the edge of the basin to the center. Currently, the basin is shielded by efficient orographic barriers and characterised by a hyper-arid climate with mean annual precipitation ranging from 100 mm in the southeast to < 20 mm in the northwest and a potential mean annual evaporation of 3000–3200 mm. The westerlies are the major circulation over the basin; prevailing strong north and northwest winds occur in winter and spring, and aeolian activity mainly occur annually from March to May. Strong north and northwest winds from the Tarim Basin can pass through the low areas of the Altyn Tagh Mountains and enter the Qaidam Basin as an extremely dry foehn that moves from northwest to southeast (Halimov and Fezer, 1989; Wang et al., 2005). The wind direction becomes more northwest as the wind passes through the basin due to the influence of the basin-bounding mountain ranges in the south, which divert the wind towards the southeast (Fig. 2).

The sand dunes are mainly distributed on the southwestern and eastern margins of the Qaidam Basin (Fig. 2). In these regions, dunes have been morphologically classified as barchan dunes, barchan dune chains, linear dunes, dune network, and star dunes (Xiao et al., 2017; Zhang et al., 2017). Numerous yardangs are widely distributed in the western Qaidam Basin; these are the major source of modern dust storms in the basin and offer abundant clastics for aeolian sediments in the basin. The outcropped lacustrine sediments also offer large amounts of clastics for aeolian sediments in the basin when lakes shrink during periods of arid climate. Moreover, the rivers in the basin bring large amounts of sandy sediment to the basin, and the proluvial fans on both sides of the basin contain a large amount of loose material, which provides sufficient material for the development of sand dunes in the basin. Here, we collected 48 surface sediment samples in the Qaidam Basin, and each sample weighs 800–1000 g, including 15 aeolian sand samples, 10 fluvial sediment samples, 15 proluvial deposit samples, 7 lacustrine deposit samples, and 1 eluvial sediment sample; the sampling locations are shown in Fig. 2, sample distribution corresponds to the distribution of loose sediments in Fig. 2. Aeolian sand and proluvial deposit samples are roughly evenly distributed in the northeastern and southern regions of the basin every 50–80 km. The aeolian sand samples were collected from the surface of active dunes. Fluvial sediment samples are mainly from the main river in the basin, and we collected 1–3 samples in each river. Lacustrine deposit samples are mainly distributed in the central and western basin where lacustrine sediments are very common. Based on the watershed of the sediments and the relationship between sediments and the surrounding mountains, the 48 sediment samples were divided into five regions. The dune sands are mainly located in the northeastern, southeastern, south-central, and southwestern regions of the basin (Fig. 2).

2.2. Laboratory measurements

We collected 48 sediment samples from the Qaidam Basin to determine their trace element and REE compositions and to analyse their Sr-Nd isotopic compositions. Aeolian sand transport exhibits three distinct modes, namely, reptation, saltation, and suspension, which primarily depend on wind speed and the grain size of the available sediment. Very small particles (approximately < 75 μm) tend to travel in suspension in windy conditions; in particular, < 20 μm fractions can be transported to higher atmospheric levels, leading to long-distance transport; medium particles (approximately 75–500 μm) primarily move by saltation, which is the dominant process of sand transport and accounts for at least 75% of the total flux of blown sand; larger particles (> 500 μm) are pushed and rolled along the surface through reptation, which is driven by wind and by impacts from saltating grains (Lancaster, 1995; Lee et al., 2002; Pye, 1987). Given that different grain-size fractions of sediments can undergo different transport processes (Lancaster, 1995; Lee et al., 2002; Pye, 1987), we separated the samples into two different grain-size fractions by dry sieving to obtain a fine grain-size fraction of < 75 μm and a coarse grain-size fraction of 75–500 μm. The < 75 μm fractions are chosen for this study for the following three reasons: (1) particles of < 75 μm in size tend to travel in suspension in windy conditions, especially dust in the < 20 μm fraction, which can be transported to higher atmospheric levels, leading to long-distance transport; (2) previous studies have reported a large amount of Sr-Nd isotopic data for the < 75 μm fractions of sediments around the Qaidam Basin, which can be used for regional comparison (Chen et al., 2007; Rao et al., 2015); (3) Nd isotopic compositions are not affected by sample pre-treatments, such as grain size-based separation and acid leaching. At the same time, the variations in the Sr isotopes of the < 20 μm fraction of dust are much larger than those of the < 75 μm fraction in the same study area, because the < 2 μm particles have $^{87}Sr/^{86}Sr$ ratios that are much higher than those of the entire size range of loess, while other grain-size fractions of loess have similar Sr isotopic