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Rare earth elements of the Altar Desert dune and coastal sands, Northwestern Mexico

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Abstract

Twenty-one surficial sand samples from the Altar Desert coastal and desert dune systems were analysed for rare earth elements (REE) content. This was done to observe the provenance signatures for four strategic dune localities near the Colorado River Delta, the El Pinacate dune fields, and the beaches of the north of the Gulf of California in the state of Sonora, Mexico. Our goals are to show which mechanisms (i.e., aeolian, marine) exert more influence on the composition of the Altar Desert dune sands. This study also shows the usefulness of REE spatial distribution to determine the relative mobility of the sand. Some sand samples from the dune systems in San Luis Río Colorado (SLRC), Golfo de Santa Clara (GSC), and Puerto Peñasco (PP) displayed dissimilar REE concentrations with respect to the rest of the sand samples from the same sites. These differences can be related to short aeolian transport distance in the sands with high REE concentrations and long aeolian transport distance in the sands with low REE concentrations. Besides, high REE concentration in the sands might be due to their closeness to the Colorado River Delta sediments and to recycled sands derived from granitic rocks. In contrast, all the sand samples from the El Pinacate (EP) site have similar REE concentration values, suggesting that the El Pinacate dune sands are influenced by more selective aeolian processes and less diverse heavy mineral content. The Altar Desert dune sands are derived from granitic sources eroded by the Colorado River. Our results also indicate that the Altar Desert dune sands are low in heavy mineral content (with the exception of Fe and Ti bearing minerals) and enriched in carbonates with phosphates (especially at the PP site) yielding poor correlations between REE and major element concentrations. The REE geographical distribution values in the Altar Desert dune sands indicate that light and heavy REE concentration values are related to aeolian transport, maturity of the sands, their low weathering rates, proximity of the source rocks, and the biogenic debris input from beach sands into the dune.

Keywords: Desert dunes; Coastal dunes; Rare earth elements (REE); Dune sands; Sonora; Mexico

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1. Introduction

Rare earth elements (REE) are used for sedimentary provenance studies due to their immobility during weathering, transport, and sedimentation (McLennan, 1989; Honda et al., 2004). The processes of transport, sedimentation, weathering, erosion, physical mechanisms (aeolian, marine, fluvial), sedimentary sorting, and diagenesis play a role in the distribution of REE in ancient and modern sediments (McLennan, 1989). Some REE determinations have been performed in outcrops of sedimentary rocks (Taylor and McLennan, 1981; Andersen and Samson, 1995; Cullers et al., 1997; Alexander et al., 2000; Hurowitz, 2001), as well as in beach and dune sands, and loess (Taylor et al., 1983; Carranza-Edwards et al., 2001; Solís-Limón, 2003; Honda et al., 2004). These studies have focused their attention on regional variations and provenance signatures of REE for different tectonic settings. However, no geochemical study of REE for provenance determination of the Altar Desert, NW Mexico, has been reported yet. This work deals with REE determinations for desert and coastal dune sands to establish the provenance of the desert and coastal dune sands. We performed REE analyses in samples from the San Luis Río Colorado (SLRC), El Pinacate (EP), Golfo de Santa Clara (GSC), and Puerto Peñasco (PP) dune sands (Fig. 1). These localities lie within four strategic dune fields: close to a Delta system (Colorado River) (SLRC), on the coast (GSC, PP), and close to a volcanic field (EP).

Our goals are to understand which mechanisms (i.e., aeolian, marine) dominate the composition of the Altar Desert dune sands and to show how the geographical distribution of REE can be used to observe the mobility of the sands. Our approach is based on REE chemistry and some major and trace elements of the dune sands. We compare our present data with previous studies on REE chemistry in granitic rocks and dune sands, as well as playa sediments in South Africa, China, and India (Compton et al., 2003; Honda et al., 2004; Roy and Smykatz-Kloss, 2005), which can be used as reference to observe the gains/losses of REE in the Altar Desert dune sands.

2. Study area

The area is located in the state of Sonora, NW Mexico (31° 32° 25′ N; 113° 85′ 115° W) (Fig. 1A).

The major geologic units are composed of volcanic, metamorphic, plutonic, and sedimentary units (Fig. 1A).

The area has a dry climate with an average temperature of 24 °C during the sampling month (i.e., November) and an annual precipitation of 250 mm.

The long-shore currents of the Upper Gulf of California during the fall-winter season come from the southeast and are originated by the effect of tides, winds, density gradients, and geostrophy (Lavin and Badan-Dangon, 1997; Marinone and Lavin, 1997) (Fig. 1B). Onshore winds come from the north, northwest, and southwest. Offshore winds come from the southeast. Onshore winds occur 40–60% of the time in 1 month with velocities between 2 and 4 m s^{-1}. Offshore winds occur 20% in 1 month with velocities between 4 and 6 m s^{-1} (Pérez-Villegas, 1990) (Fig. 1B). According to Lancaster (1989), northwesterly and southeasterly winds generate 25–30% of the annual potential sand transport. From northwest to southeast, across the sand sea, the proportion of northerly winds decreases whilst the percentage of winds from southerly directions increases. Muhs et al. (2003) has also shown that northwesterly winds, close to the US–Mexican border, have a resultant annual drift potential of 50–150 vector units (terminology of Fryberger and Dean, 1979), inducing dune migration into the Altar Desert in Mexico. Vector units are represented by a sand rose that expresses graphically both the amount of potential sand drift and its directional variability. (Fryberger and Dean, 1979).

Tides in the area are up to ~10 m amplitude (Thompson, 1968; Cupul, 1994).

Linear, star, and crescentic dune types constitute the major dune fields in the area (Blount and Lancaster, 1990).

The Colorado River water annual flow seawards is almost negligible due to human intervention over its drainage as a result of dam constructions (Carriquiry et al., 2001). In contrast, the Sonoyta River in the south flows intermittently throughout the southern part of the valley and discharges into the Gulf of California (Fig. 1A).

3. Materials and methods

Surface sand samples were collected from the uppermost centimeter of the dune crest and flank. Approximately 40 g of sands were placed in plastic bags and subsampled for grain size analysis using a Laser Particle Size Analyser (Model Coulter LS230) (Kasper-Zubillaga and Carranza-Edwards, 2005) and REE determination. Bulk composition of the sands was determined by point counting of total quartz, total feldspar, and total rock fragments using a polarized microscope (Kasper-Zubillaga et al., accepted for publication).

For the REE analysis, 0.1 g of dried sample (mesh 200) was digested with a strong acid. Acid digestion was carried out in Teflon vessels using a mixture of 4 ml $HClO_4$ and 10 ml HF. The mixture was heated until dryness. The residue was dissolved in distilled water and transferred to a volumetric flask.