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Evaluation of simple geochemical indicators of aeolian sand provenance: Late Quaternary dune fields of North America revisited

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ABSTRACT

Dune fields of Quaternary age occupy large areas of the world's arid and semiarid regions. Despite this, there has been surprisingly little work done on understanding dune sediment provenance, in part because many techniques are time-consuming, prone to operator error, experimental, highly specialized, expensive, or require sophisticated instrumentation. Provenance of dune sand using K/Rb and K/Ba values in K-feldspar in aeolian sands of the arid and semiarid regions of North America is tested here. Results indicate that K/Rb and K/Ba can distinguish different river sands that are sediment sources for dunes and dune fields themselves have distinctive K/Rb and K/Ba compositions. Over the Basin and Range and Great Plains regions of North America, the hypothesized sediment sources of dune fields are reviewed and assessed using K/Rb and K/Ba values in dune sands and in hypothesized source sediments. In some cases, the origins of dunes assessed in this manner are consistent with previous studies and in others, dune fields are found to have a more complex origin than previously thought. Use of K/Rb and K/Ba for provenance studies is a robust method that is inexpensive, rapid, and highly reproducible. It exploits one of the most common minerals found in dune sand, K-feldspar. The method avoids the problem of using simple concentrations of key elements that may be subject to interpretative bias due to changes in mineralogical maturity of Quaternary dune fields that occur over time.

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1. Introduction

Dune fields of Quaternary age occupy large areas of the world's arid and semiarid regions, largely (though not entirely) in subtropical deserts but also in rain-shadowed zones of the mid-latitudes (Wilson, 1973; Pye and Tsoar, 1990; Cooke et al., 1993; Lancaster, 1989, 1995a; Livingstone and Warren, 1996; Goudie, 2002; Warren, 2013; Lorenz and Zimbelman, 2014). Although there have been many studies of aeolian sand of Quaternary age in both arid and semiarid zones, much of the focus has been on genesis of dune forms, sedimentary structures, and chronology of dune deposition as an indicator of Quaternary paleoclimate. It is interesting that there has been much less work done on understanding dune sediment provenance, with many studies simply assuming an underlying rock or nearby sediment as the primary source or ignoring the issue altogether. Some exceptions to this include studies of the sources of late Quaternary dune sand in northwestern Mexico and the southwestern USA (Muhs et al., 2003; Kasper-Zubillaga et al., 2007; Scheidt et al., 2011), on the Arabian Peninsula (White et al., 2001; Pease and Tchakerian, 2002; Garzanti et al., 2013), in India's Thar Desert (East et al., 2015), in southwestern Africa's Namib sand sea (Garzanti et al., 2012), and in the Sinai/Negev dune fields of Egypt and Israel (Muhs et al., 2013a). Part of the reason that dune provenance studies are uncommon in aeolian geomorphology is that many of the techniques required are time-consuming and prone to operator error (point counts of heavy minerals), experimental and/or highly specialized (remote sensing techniques), expensive (some geochemical techniques), or require sophisticated instrumentation (most isotopic techniques).

Despite the challenges of determining sand provenance, the origin of sediment in a dune field is critical to understanding its evolution. Kocurek and Lancaster (1999) presented the concept of "aeolian system sediment state," which includes, within a dune field, the degree of aeolian activity vs. stability, emphasizing the components of sediment supply, sediment availability, and transport capacity of the wind. Evaluation of the first two of these components requires identification of the sediment source or sources. In a recent review of North American dune fields of late Quaternary age, Halfen et al. (2016) emphasized the importance of sediment supply and sediment availability (as a result of drought episodes) as controls on dune field activity.

Presented here is an exploration and evaluation of the potential

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for using a simple geochemical method in assessing dune field origins. Specifically, the composition of one of the most common minerals found in dune fields, K-feldspar, is tested for utility in provenance studies using K/Rb and K/Ba values. These geochemical parameters, as indices of K-feldspar composition, are used to assess the origins (sediment sources) of previously studied dune fields of late Quaternary age in the arid portions of the Basin and Range and semiarid parts of the Great Plains provinces of North America (Figs. 1–3).

2. The problem of changing mineralogy in dune fields

In a number of previous studies of the origin of North American dune fields, simple comparisons of concentrations of major or trace elements have been made between aeolian sands and candidate source sediments, as proxies for mineralogy (Muhs et al., 1995, 1997a, 1997b, 2000, 2003; Winspear and Pye, 1996; Arbogast and Muhs, 2000; Wolfe et al., 2000; Muhs and Holliday, 2001; Zimbelman and Williams, 2002). The problem with this approach is that dune fields are not static entities from a mineralogical point of view. During periods of stability with a vegetation cover, if climatic conditions are favorable, unstable minerals in dune sands, such as carbonates and feldspars, can be lost through chemical weathering and pedogenesis. During a subsequent period of activity, sands that previously lost easily weathered minerals during a period of stability can then be reworked by the wind, mixing feldspar- and carbonate-poor sands into feldspar- and carbonate-rich sands. More importantly for arid and semiarid regions, during periods of dune activity, sand-sized particles of weaker minerals can be reduced to silt sizes through abrasion and ballistic impacts (Marsland and Woodruff, 1937; Kuenen, 1960; Dutta et al., 1993; Cornwall et al., 2015). As a result, the newly formed silt-sized particles can be removed entirely from the dune field by aeolian transport in suspension, usually leaving behind sand relatively enriched in quartz, because quartz is more resistant to mechanical breakdown. This can lead to what is called a mineralogically mature dune field. Mineralogical maturity is a compositional state of a clastic sedimentary body wherein there is a dominance of quartz and an absence or minority of less-resistant particles such as feldspars, carbonates, gypsum, or soft lithic fragments. Sandstones

Fig. 1. Map of North America showing physiographic provinces. Dashed boxes outline the Basin and Range and adjacent provinces, where desert dunes were studied (Fig. 2), and the Great Plains, where semiarid dunes were studied (Fig. 3).