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Origin of the Sinai–Negev erg, Egypt and Israel: mineralogical and geochemical evidence for the importance of the Nile and sea level history

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ABSTRACT

The Sinai–Negev erg occupies an area of 13,000 km^2 in the deserts of Egypt and Israel. Aeolian sand of this erg has been proposed to be derived from the Nile Delta, but empirical data supporting this view are lacking. An alternative source sediment is sand from the large Wadi El Arish drainage system in central and northern Sinai. Mineralogy of the Negev and Sinai dunes shows that they are high in quartz, with much smaller amounts of K-feldspar and plagioclase. Both Nile Delta sands and Sinai wadi sands, upstream of the dunes, also have high amounts of quartz relative to K-feldspar and plagioclase. However, Sinai wadi sands have abundant calcite, whereas Nile Delta sands have little or no calcite. Overall, the mineralogical data suggest that the dunes are derived dominantly from the Nile Delta, with Sinai wadi sands being a minor contributor. Geochemical data that proxy for both the light mineral fraction ($SiO_2/10–Al_2O_3 + Na_2O + K_2O–CaO$) and heavy mineral fraction ($Fe_2O_3–MgO–TiO_2$) also indicate a dominant Nile Delta source for the dunes. Thus, we report here the first empirical evidence that the Sinai–Negev dunes are derived dominantly from the Nile Delta. Linkage of the Sinai–Negev erg to the Nile Delta as a source is consistent with the distribution of OSL ages of Negev dunes in recent studies. Stratigraphic studies show that during the Last Glacial period, when dune incursions in the Sinai–Negev erg began, what is now the Nile Delta area was characterized by a broad, sandy, minimally vegetated plain, with seasonally dry anastomosing channels. Such conditions were ideal for providing a ready source of sand for aeolian transport under what were probably much stronger glacial-age winds. With the post-glacial rise in sea level, the Nile River began to aggrade. Post-glacial sedimentation has been dominated by fine-grained silts and clays. Thus, sea level, along with favorable climatic conditions, emerges as a major influence on the timing of dune activity in the Sinai–Negev erg, through its control on the supply of sand from the Nile Delta. The mineralogy of the Sinai–Negev dunes is also consistent with a proposed hypothesis that these sediments are an important source of loess in Israel.

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1. Introduction

Many of the world's largest ergs, or aeolian sand seas, are found over a vast area of the subtropical zones of the Sahara Desert of Africa and the Arabian Peninsula, with a total dunefield area well in excess of 3 million km^2 (Pye and Tsoar, 2009). Dunefields over this region have tremendous importance for paleoclimate studies, as the presence of dunes indicates strong winds or low precipitation (<100 mm) either at present or in the past, as well as an availability of source sediments and lack of stabilizing vegetation in the source area. Furthermore, the orientation of inactive dunes gives important clues for paleowind directions in the past. Thus, dune geomorphology constitutes one of the most robust, direct records of past atmospheric circulation, aridity, wind strength and paleohydrology.

The advent of optically stimulated luminescence (OSL) dating (see review in Singhvi and Porat, 2008) has revolutionized paleoclimatic studies of dunes, as the only requirement is the presence of quartz, which is rarely an issue with aeolian sand. Recent studies of the dunefields in the Sahara, the Sinai–Negev erg, and the Arabian Peninsula, with good OSL geochronology, have yielded important paleoclimatic information in Mauritania (Lancaster et al., 2002),

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Egypt and Sudan (Bubenzer et al., 2007), Israel (Roskin et al., 2011a, 2011b) and Arabia (Goudie et al., 2000; Preusser et al., 2002, 2005; Atkinson et al., 2011, 2012), as well as regional syntheses (Swezy, 2001; Glennie and Singhvi, 2002; Lancaster, 2007, 2008; Singhvi and Porat, 2008). One conclusion common to these studies is that dunes over a wide region were very active during the Last Glacial Maximum (LGM), but dune activity diminished at the close of the Last Glacial period, a concept articulated earlier by Sarnthein (1978). During the post-LGM period and in the late Holocene, dune activity resumed in many of these regions.

More than one forcing mechanism is possible for the shift from intense Last Glacial and post-glacial dune activity followed by early-to mid-Holocene dune stability in the Sahara and Arabian Peninsula. Increased moisture at the beginning of the Holocene could have been supplied by insolation-forced northward migration of the intertropical convergence zone, or ITCZ (Bernhardt et al., 2012). This has been referred to as the African Humid Period (~15 ka–5.5 ka) and is well established as a period of diminished dust accumulation in the early-to mid-Holocene, based on studies of marine cores off Africa in both the Atlantic (DeMenocal et al., 2000) and the Mediterranean (Hamann et al., 2008, 2009). During such a humid period, sand supplies to dunes in some parts of the region may have been cut off by the growth of Holocene lakes in basins that previously provided sediment (ultimately from fluvial sources) to active dunes (Lancaster, 2008). In coastal regions, such as the southern part of the Wahiba Sand Sea of Oman, sea level history may have played a role in diminishing sand supply by post-glacial sea level rise (Radies et al., 2004; Preusser et al., 2005). Whether sediment supplies to feed actively migrating dunes are a function of climate in the source area, regional hydrology, or sea level fluctuations requires identification of the source sediment of the dunefield, but few studies in the Sahara Desert or Arabian Peninsula have been undertaken to determine provenance of dune sands.

Sand dunes and their histories have significance in other aspects of sedimentation history and landscape evolution. Although abrasion of sand grains and size reduction due to ballistic impacts have been recognized for a long time as a possible source of loess and finer grained dust (see reviews in Muhs and Bettis, 2003; Muhs, 2013), there has been considerable emphasis on the importance of this process in subtropical deserts in recent years (Crouvi et al., 2008, 2010, 2012; Enzel et al., 2008, 2010; Amit et al., 2011). In these latter studies, the Sinai–Negev erg is proposed to be at least a partial source of loess in Israel, downwind of the dunefield.

In this study, we examine the composition of dune sands from the Negev Desert of Israel and the Sinai Desert of adjacent Egypt, situated between the vast deserts of the Sahara and Arabia (Fig. 1). As pointed out by Tsoar et al. (2008) these two dunefields (Sinai and Negev) are geomorphically part of the same sand sea; their division into two landscape entities is due solely to the political boundary that separates them. Studies by Goring-Morris and Goldberg (1990), using archeology and radiocarbon dating, and by Enzel et al. (2010) and Roskin et al. (2011a, 2011b), using OSL geochronology, show that dunes of the Sinai–Negev erg, like other dunefields in the Sahara Desert-Arabian Peninsula region, were active during the Last Glacial period, the post-glacial period and the latest Holocene, but show little evidence of activity during the early-to mid-Holocene.

Determination of the source of sand in the Sinai–Negev erg is a major goal of our study. To the best of our knowledge, one sediment source alone has been proposed for the Sinai–Negev erg, sand from the Nile Delta. Emery and Neev (1960) inferred a Nile source for the non-carbonate component of beach sands on the Mediterranean coast of Israel and Pomerancblum (1966) reported that continental shelf sands off this coast were Nile-derived as well. Nachmias (1969) reported a Nile source for Tertiary Saqiye Group sediments found in Israel. All these studies inferred Nile origins using heavy mineral analyses. Davis et al. (2012) propose that the Nile has been a major source for aeolian sediments in Israel for the past ~2.5 million years, based on cosmogenic isotope evidence from quartz. Nevertheless, identification of the Nile as a source for the Sinai–Negev erg sands seems to have been both a working assumption and an untested hypothesis (Neev et al., 1987; Goring-Morris and Goldberg, 1990; Pye and Tsoar, 2009; Amit et al., 2011; Roskin et al., 2011b, 2012). The best argument for a Nile Delta source is the simple lack of evidence for other likely sources (Tsoar et al., 2008). Nevertheless, the lack of an alternative source does not actually prove a Nile Delta source. Further, the inference of derivation of quartz-rich dunes from what seems at first glance to be an obvious Nile Delta source is problematic. Sneh and Weissbrod (1983) report that dune sand in Sinai is composed of ~95% or more quartz, and Roskin et al. (2011b) present preliminary data showing that dunes in the Negev part of the erg are also quartz-rich. However, recent petrographic and isotopic data show that Nile River sands are, at present, derived primarily from two major tributaries in the upper part of the drainage basin, the Blue Nile and Wadi Atbara. The White Nile contributes at most ~3% (Garzanti et al., 2006; Padoan et al., 2011). Both the Blue Nile and Wadi Atbara drain rocks of the Ethiopian Plateau that are dominated by Cenozoic basalts (Pik et al., 1998), rocks that do not contain quartz. Thus, in this study, we also examine the composition of probable late Pleistocene age, dune-sand-sized sediments of the Nile Delta.

Other possible quartz-rich sources for the Sinai–Negev erg are very limited. Areas in central Sinai within the Wadi El Arish drainage basin have bedrock dominated by Cretaceous or Eocene rocks. Although these rocks are composed mostly of carbonate facies, Bartov (1990) reports that sandstone facies are also present in two of the Cretaceous units. These rocks are situated in the upper drainage basin area of Wadi El Arish (Figs. 1 and 2) and thus provide a source that is upstream and upwind of much of the Sinai–Negev erg. Farther north, in north-central Sinai, Lower Cretaceous sandstones, now part of what is called the Kurnub Group (Bartov, 1990), were formerly referred to as "Nubian Sandstone." These rocks are downwind of many of the dunes in the erg, however, so at most they constitute a potential source for only part of the erg. To test the competing hypotheses of the Nile Delta versus local rocks in Sinai for the source of the Sinai–Negev erg, we conducted studies of the mineralogy of the dune sands and these possible source sediments.

Study of the Sinai–Negev erg mineralogy also allows us to test the hypothesis that abrasion of sand-sized particles is the source for loess in Israel that is found downwind of the Sinai–Negev erg (Fig. 1). Crouvi et al. (2008, 2010, 2012), Enzel et al. (2008, 2010), and Amit et al. (2011) have emphasized the importance of this dunefield in supplying silt-sized quartz, generated by aeolian abrasion of sand-sized quartz, to loess downwind. If reduction of sand-sized quartz to silt size by aeolian abrasion has occurred, then other minerals in the Sinai–Negev erg should also be affected by this process. Experimental work by Kuenen (1960) and Dutta et al. (1993) shows that aeolian abrasion and ballistic impacts can efficiently reduce sand-sized feldspars to silt sizes. Kuenen's (1960) studies show that both sand-sized feldspars and carbonate minerals abrade to finer sized particles much more quickly than does quartz. Thus, if dune sands of the Sinai–Negev erg provide some of the particles to the loess bodies downwind of the dunefield by aeolian abrasion of quartz, they should also contribute a proportionally greater amount of feldspar and calcite, because these latter minerals are less resistant to aeolian abrasion. The evidence for this should be a dunefield whose mineralogy is measurably more quartz-rich than that of the loess found downwind.