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Provenance and recycling of Arabian desert sand

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ABSTRACT

This study seeks to determine the ultimate origin of aeolian sand in Arabian deserts by high-resolution petrographic and heavy-mineral techniques combined with zircon U–Pb geochronology. Point-counting is used here as the sole method by which unbiased volume percentages of heavy minerals can be obtained. A comprehensive analysis of river and *wadi* sands from the Red Sea to the Bitlis-Zagros orogen allowed us to characterize all potential sediment sources, and thus to quantitatively constrain provenance of Arabian dune fields. Two main types of aeolian sand can be distinguished. Quartzose sands with very poor heavy-mineral suites including zircon occupy most of the region comprising the Great Nafud and Rub' al-Khali Sand Seas, and are largely recycled from thick Lower Palaeozoic quartzarenites with very minor first-cycle contributions from Precambrian basement, Mesozoic carbonate rocks, or Neogene basalts. Instead, carbonaticlastic sands with richer lithic and heavy-mineral populations characterize coastal dunes bordering the Arabian Gulf from the Jafurah Sand Sea of Saudi Arabia to the United Arab Emirates. The similarity with detritus carried by the axial Tigris–Euphrates system and by transverse rivers draining carbonate rocks of the Zagros indicates that Arabian coastal dunes largely consist of far-travelled sand, deposited on the exposed floor of the Gulf during Pleistocene lowstands and blown inland by dominant Shamal northerly winds. A dataset of detrital zircon U–Pb ages measured on twelve dune samples and two Lower Palaeozoic sandstones yielded fourteen identical age spectra. The age distributions all show a major Neoproterozoic peak corresponding to the Pan-African magmatic and tectonic events by which the Arabian Shield was assembled, with minor late Palaeoproterozoic and Neoarchean peaks. A similar U–Pb signature characterizes also Jafurah dune sands, suggesting that zircons are dominantly derived from interior Arabia, possibly deflated from the Wadi al-Batin fossil alluvial fan or even from Mesozoic sandstones of the Arabian margin accreted to the Cenozoic Zagros orogen. Due to extensive recycling and the fact that zircon is so resistant to weathering and erosion, the U–Pb age signatures are much less powerful a tracer of sedimentary provenance than framework petrography and heavy minerals. Actualistic provenance studies of dune fields at subcontinental scale shed light on the generation and homogenization of aeolian sand, and allow us to trace complex pathways of multistep sediment transport, thus providing crucial independent information for accurate palaeogeographic and palaeoclimatic reconstructions.

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> "*In the deserts of Arabia there is no rhythm to the seasons, but empty wastes where only the changing temperature marks the passage of the years. It is a bitter, desiccated land which knows nothing of gentleness or ease…*"
> Wilfred Thesiger, Arabian sands

1. Introduction

Continental desert interiors of arid tropical belts are commonly blanketed by vast dune fields. The origin of such sand seas and their evolution in space and time are faithfully recorded in the innumerable detrital grains of which they are composed, but deciphering these immense archives of geological information is not straightforward. Sediment-dispersal paths are variable and complex, because transport by wind is not controlled directly by gravity, and thus varies repeatedly in relation to both seasonal and longer-term climate changes. The pronounced and frequent climatic and eustatic oscillations during the Pleistocene, in particular, have profoundly influenced aeolian transport and dune dynamics (Teller et al., 2000; Preusser et al., 2002; Stokes and Bray, 2005). The ultimate origin of sand grains is not easily determined also because many of them may be recycled from older sandstones (Dott, 2003). The information they contain may thus result from multiple events that punctuated their polycyclic histories. On the other hand, the sensitivity of desert sands to environmental change provides us with a formidable means to reconstruct the profound modifications undergone by the surface of our planet during the Quaternary (Glennie, 1998).

The diverse methods adopted to investigate the origin of desert sand range from detrital mineralogy and geochronology to satellite imagery (White et al., 2001; Howari et al., 2007), but if used singularly they may provide only partial or even misleading results. Much firmer provenance assessments can be achieved by an integrated approach based on a variety of independent provenance tools, allowing us to quantitatively determine the relative incidence of different potential sediment sources (Garzanti et al., 2012a). Application of petrographic and heavy-mineral techniques is particularly fruitful in the case of dune sands, because their composition directly reflects parent lithologies and primary provenance signals. In modern deserts, in fact, chemical weathering is irrelevant and physical effects are limited to winnowing of platy micas and selective mechanical destruction of fragile sedimentary and metasedimentary rock fragments, whereas most detrital components become efficiently rounded but resist high-energy aerial impacts even if protracted for a million years (Vermeesch et al., 2010). Because many of the world's sand seas monotonously consist of monocrystalline quartz with zircon as one of the few accessory minerals (Muhs, 2004), zircon geochronology appears to represent one of the few available methods to trace the ultimate provenance of desert sand (Pell et al., 1997; Dickinson and Gehrels, 2009).

Arabia, covering a vast area evolved from Pan-African assembly in the Neoproterozoic to progressive fragmentation in the Permian and Jurassic, eventually followed by collision with Eurasia and separation from Africa in the Neogene, provides an unexcelled natural laboratory to study dune fields with such integrated techniques. Desert conditions grant minor soil development and negligible modifications of natural systems by man. Scarce rainfall hampers fluvial transport, whereas seasonal wind regimes and lack of vegetation favour massive aeolian sand drift. Detailed petrographic and mineralogical data on desert, *wadi* and beach sand from Saudi Arabia, coupled with information obtained in neighbouring regions (Garzanti et al., 2001, 2002, 2003; Garzanti and Andò, 2007a), have allowed us to follow changes in modern sand composition all across the Arabian peninsula, from the Red Sea to the Arabian (Persian) Gulf (Fig. 1). Previous studies on the mineralogy of Arabian sands include Ahmed et al. (1998), Nasir et al. (1999), El-Sayed (1999, 2000), and Radies et al. (2004).

The principal aims of this article are: a) to provide a detailed description of framework petrography, heavy-mineral assemblages and zircon U–Pb age spectra in Arabian dune fields, specifically including the Nafud, Dahna, and Jafurah Sand Seas; b) to compositionally characterize all potential sources of aeolian sediments, from the Red Sea rift-shoulder to the Gulf foreland basin; c) to demonstrate the efficacy of integrated provenance studies to unravel complex pathways of sediment dispersal in desert settings; d) to stress the importance of long-distance multistep sediment transport during Late Pleistocene lowstands. The knowledge of diagnostic signatures of detritus derived from contrasting geodynamic settings allows us to relate the mineralogy of modern dune sands to the recent evolution of wide source areas, and thus to better understand how aeolian sand seas accumulate and evolve in response to climate change.