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Petrology of the Namib Sand Sea: Long-distance transport and compositional variability in the wind-displaced Orange Delta

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ABSTRACT

Sourced as the Nile in distant basaltic rift highlands, the Orange River is the predominant ultimate source of sand for the Namib Desert dunes, as proved independently by bulk-petrography, heavy-mineral, pyroxene-chemistry, and U/Pb zircon-age datasets. Additional local entry points of sand do exist at the edges of the desert, and were quantified by comparison with detrital modes and heavy-mineral suites of hinterland-river sediments.

After long-distance fluvial transport, Orange sand is washed by ocean waves and dragged northwards by vigorous longshore currents. Under the incessant action of southerly winds, sand is blown inland and carried farther north to accumulate in the Namib erg, a peculiar wind-dominated sediment sink displaced hundreds of kilometres away from the river mouth. And yet changes in sand mineralogy along the way are minor. After a multistep journey of cumulative 3000 km from their source in Lesotho, volcanic rock fragments and pyroxene are found in unchanged abundance as far as the northern edge of the desert. Only locally is volcanic detritus slightly depleted and minor but regular enrichment in quartz and garnet is observed, the sole potential effect of prolonged transport or recycling of Tertiary aeolianites. Selective comminution of fragile minerals is thus proved unable to substantially modify sand composition in fluvial, coastal, or aeolian settings. Mechanical processes have a much greater effect on the morphology of detrital grains, which in Namib dunes appear commonly shaped into nearly perfect spheres. Aeolian sorting concentrates denser minerals locally in placer lags, but such effects can be identified and compensated for. This study demonstrates that mechanical breakdown is unable to markedly affect provenance signatures even during long-distance and prolonged multistep transport in high-energy settings. In arid climates, where chemical processes are negligible, high-resolution bulk-petrography and heavy-mineral analyses are thus powerful techniques to quantitatively reconstruct provenance, and to trace sediment sources and dispersal paths over distances up to thousands of kilometres.

Contents

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"The river", he reminded her. "Tell me about the river", and listened avidly as she went on. "The river gathers them up, from every little pocket and crevice along its course. It picks up those that were flung into the air during the volcanic eruptions at the beginning of the continent's existence. For hundreds of million years it has been carrying the diamonds toward the coast. Those beaches are so rich in diamonds that they are the forbidden area, the Spieregebied."
Wilbur Smith, Power of the sword, p.78

1. Introduction

The Orange has been a powerful river possibly since the Jurassic (Cox, 1989). Or at least it was, until man tamed it with dams to exploit its waters for agricultural and industrial purposes. And extremely energetic has long been the microtidal South Atlantic shore where it debouches, subjected to vigorous waves and northward longshore drift fuelled by persistent southerly winds (Bluck et al., 2007). As well as an open-air diamond mine so rich that it is forbidden land (Jacob et al., 2006), the Orange Delta is thus widely recognised as a wave-dominated end-member (Spaggiari et al., 2006). But there is more. Incessantly dragged northwards by longshore currents and eventually blown inland under the long-lived wind regime, Orange Sand has been accumulating since the Miocene at least in the Namib Sand Sea, a sediment sink detached from the river mouth and displaced on land several hundreds of kilometres away (Fig. 1; Rogers, 1977; Vermeesch et al., 2010).

In such a geological setting, changes in sediment composition and grain morphology caused by multistep transport can be monitored over a cumulative distance summing up to 3000 km. Whereas abrasion and mechanical breakdown have long been established to be scarcely effective during long-distance fluvial transport by both studies of natural river systems and laboratory experiments (Russell and Taylor, 1937; Kuenen, 1959), their incidence during wind transport has been debated for a full century, and still remains controversial (Twenhofel, 1945; Goudie and Watson, 1981). Laboratory experiments have shown that aeolian abrasion is 100–1000 times more effective than fluvial abrasion (Kuenen, 1960), and the generation of quartz-rich sand through selective breakdown of feldspar by aeolian impacts has received theoretical support (Dutta et al., 1993). Studies in natural environments, however, have produced ambiguous results (Johnsson, 1993), because detrital sources are generally multiple and undetermined, and dune sand commonly consists of quartz whose rounded shape may have resulted from aeolian abrasion as well as from recycling of rounded grains from older sandstones (Garzanti et al., 2003; Muhs, 2004; Mehring and McBride, 2007).

Understanding aeolian effects is crucial to correctly interpret desert environments of the past, which is in turn essential for accurate palaeogeographic and palaeoclimatic reconstructions (Dott, 2003; Avigad et al., 2005). The peculiarity of the Namib Sand Sea, supplied from fundamentally one single entry point with a wide spectrum of detrital species including pyroxene and volcanic rock fragments, offers a unique opportunity to solve such a thorny petrological problem, provided we succeed in quantifying subsidiary detrital sources (hinterland rivers, recycled Tertiary sediments, deflation areas along the coast; Lancaster and Ollier, 1983; Besler, 1984) and local effects of wind-induced sorting.

The aims of the present study are to illustrate in detail the compositional variability of Namib dune sands through high-resolution bulk-petrography and heavy-mineral analysis, to pin-point all sediment sources and quantify their relative contributions to various parts of the erg, to evaluate wind-induced concentrations of heavy minerals, and to assess morphological and compositional changes caused by mechanical abrasion and selective breakdown of detrital grains with variable durability during aeolian transport. Quantitative provenance analysis represents an effective way to identify long-term transport paths and sediment modifications in modern deserts, and represents a key requirement for reconstructing palaeowind patterns and palaeoclimate changes during the geological evolution of such dynamic geomorphic systems.

2. The Orange River and the Namib Sand Sea

2.1. The Orange River

The Orange is one of the largest African rivers, with a drainage area of ~970,000 km^2 (Fig. 2). Sourced not far from the Indian Ocean in the Drakensberg mountains of Lesotho (maximum elevation 3482 m a.s.l.), it flows westwards for ~2200 km across an increasingly arid interior plateau towards the Atlantic Ocean (Moore et al., 2009). The catchment receives primarily summer rainfall (October to April), varying from 1200 mm/yr in relatively cold Lesotho highlands (mean temperatures −5 °C in winter and 16 °C in summer) to 40 mm/yr near the mouth (Swanevelder, 1981). Rainfall and snowmelt in Lesotho, occupying only 3% of the catchment, contributes 47% of total water flow (Makhoalibe, 1999).

This ancient drainage system, originated in the Early Jurassic as a result of ~2 km surface uplift associated with emplacement of Drakensberg lavas during rifting from Antarctica, cuts antecedently in its lowermost tract across the regional uplift formed during Lower Cretaceous rifting of the South Atlantic (Cox, 1989; Moore and Blenkinsop, 2002). The oldest basement rocks are widely exposed north of the Vaal River (Neoarchean metavolcanic Ventersdorp