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Provenance of the heavy mineral-enriched alluvial deposits at the west coast of the Red Sea. Implications for evolution of Arabian–Nubian crust

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ABSTRACT

Here we present the LA-ICP-MS U–Pb ages and Hf isotopic record of detrital zircons from the active alluvial fans at the west coast of the Red Sea. The Ras Manazal alluvial fan (primarily composed of zircon, magnetite with some rutile, ilmenite and monazite) yielded a relatively restricted age population ranges from 765 to 666 Ma. These ages and present-day drainage pattern is consistent that the sediments are primarily derived from erosion of nearby subduction related granitoids in the immediate west (i.e., not more than 50 km from the Red Sea coast) of the fan. In contrast, approximately 160 km south, at the Egypt–Sudan border, the Wadi Diit fan is relatively more enriched in ilmenite and REE-bearing phases (e.g., thorite, monazite, xenotime, garnet, etc.) and yielded five zircon age populations of (1) 824–733 Ma, (2) 730–705 Ma, (3) 646–608 Ma, (4) 516–500 Ma, and (5) 134–114 Ma. The age populations 1–3 if coupled with the present-day drainage pattern can be related to the earlier subduction related and later post collision granitoids in the southern part of the South Eastern Desert and Gebeit terrane of northern Sudan. Sparse Early Cretaceous zircons (134–114 Ma) are derived from the Mesozoic volcanic suits in the source region. However, the age group 516–500 Ma is enigmatic. Wadi Diit zircons are primarily derived from granitoids in the broad S–N directed Hamisana Shear Zone and its subordinate SW to NE directed Onib-Sol-Hamed Suture Zone. These shear zones provided pathways for the present-day drainage system for sediment transportation to the Wadi Diit and adjacent coastal region. We infer that the ca. 500 Ma late-stage magmatic zircons represent a hitherto unknown magmatic event, possibly related to the shear heating associated with the crustal scale shear zones. This implies that the shear zones in the South Eastern Desert and northern Sudan remained thermally active as late as ~500 Ma. The time resolved hafnium composition (εHf (t)) of both fans varies from +3.5 to +13.5. Our new U–Pb ages and Hf isotopic composition suggests that the detrital zircons were derived from the Neoproterozoic juvenile crust. This is consistent with the Neoproterozoic juvenile igneous and metamorphic rocks in the Eastern Desert and northern Sudan.

1. Introduction

The combined U–Pb and Hf isotopic record of detrital zircons provides insight regarding source region history of parental magma with which the zircon was in equilibrium at the time of crystallization. In the last two decades numerous studies have been devoted to the isotopic record of detrital zircons to establish detailed crustal evolution models (e.g., Griffin et al., 2006; Belousova et al., 2010; Kuznetsov et al., 2010; Matteini et al., 2010 and references therein) and sedimentary provenance interpretations (e.g., Koglin et al., 2010; Clements et al., 2012 and references therein).

The Eastern Desert of Egypt is a part of the Neoproterozoic Arabian–Nubian Shield formed between 900 and 550 Ma by accretion of several mainly intra-oceanic arcs along ophiolitic sutures (Kröner, 1985; Stoeser and Camp, 1985; Vail, 1985; Johnson, 1998, 2014; Stern and Johnson, 2010; Ali et al., 2009, 2010a,b, 2012a; Johnson et al., 2011; Fritz et al., 2013) (Fig. 1). One of the longstanding controversies in this region is the origin of lower–middle crust beneath the Eastern Desert of Egypt forming the western part of the Arabian–Nubian Shield. Structurally lower granitoid gneisses exhumed in the form of gneiss domes in the Eastern Desert are suggested to have a component of the older, pre-Neoproterozoic crust that is pre-Pan-African basement (e.g., El-Gaby et al., 1984, 1988; Khudier et al., 2008). Many other workers suggested that the Arabian–Nubian crust is juvenile and exclusively Neoproterozoic in age formed in an intra-oceanic arc setting within

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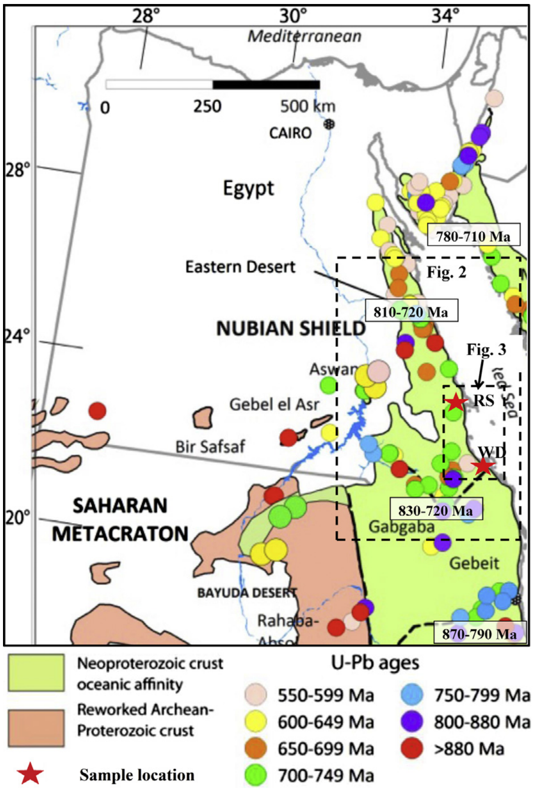

Fig. 1. The age range based on U–Pb single and multi-grain zircon dating on plutonic and volcanic rocks of Eastern Desert and northern Sudan (compiled by Johnson, 2014 and references therein). The ages given in rectangles are protolith ages (after Johnson et al., 2011 and references therein).

the Mozambique Ocean, or along one or more magmatic arcs along the western margin of the Mozambique Ocean prior to the final collision of East and West Gondwana about 630 Ma (e.g., Greiling et al., 1984, 1988, 1994; Kröner et al., 1987; Stern, 1994; Liégeois and Stern, 2010; Ali et al., 2012a,b).

The Red Sea coast in the Eastern Desert is accumulating the alluvial deposits by active erosion and transportation through the present-day drainage system during recent flash flooding. Several alluvial deposits enriched in REE bearing minerals have been identified in the coastal strip between Ras Banas in the north and at the Egypt–Sudan border in the south (Ibrahim et al., 2009). Accumulations of heavy minerals have been observed along Red Sea beaches at Ras Manazal, Khudaa, Shalateen, Wadi Diit, and along the coastal stretches between these locations. The morphology and positions of the alluvial fans with respect to the coast line indicate that the sediments derived nearly exclusively from the interior drainage areas, with marginal input from a longshore sediment transport. Therefore, it seems less likely that the alluvial fans have significant contribution from other parts of the Red Sea coast by longshore currents. The denudation and erosion of the Eastern Desert have been investigated using apatite fission track dating (e.g., Omar and Steckler, 1995; Bojar et al., 2001; Abbate et al., 2002; Balestrieri et al., 2009). This dating indicates that the Arabian–Nubian Shield underwent uplift in two stages, an early uplift stage in the Oligocene (±35 Ma) and a later major uplift period in the Miocene (20–25 Ma). During these uplifts of the flanks of the rift zone, sediments might have transported to the coastal areas of the Red Sea. However, if there were such early coastal deposits, they have since been eroded, submerged in the Red Sea or deeply buried (Moawad, 2013). Therefore, our samples do not belong to these ancient Oligocene to Miocene coastal sediments, but instead represent the top 1 m of the active alluvial fans transported by present-day drainage system through recent flash flooding periods.

In this paper we report “in-situ” U–Pb ages and time resolved Hf isotopic composition of detrital zircons from the two alluvial fans in the South Eastern Desert along the west coast of Red Sea which have been recording the sediment accumulation arguably from proximal and distant sources from Eastern Desert and northern Sudan. Our data not only provide additional constraints regarding evolution of the Arabian–Nubian Shield in the Eastern Desert of Egypt but also test the provenance of mineralogically and geochemically distinct black sands alluvial deposits along the west coast of Red Sea. The determination of the provenance of these sands has significant implications for the economic development emphasizing the sources of REE-enriched deposits.

2. Geological setting

2.1. Eastern Desert of Egypt

The Eastern Desert of Egypt is primarily characterized as Neoproterozoic crust of the Arabian–Nubian Shield formed during the accretion stage-2 between 760–650 Ma of East African Orogeny and is separated from Gebiet and Gabgaba terranes in the south formed during the accretion stage-1 between 890–710 Ma (Fritz et al., 2013 and references therein, Fig. 1). The Neoproterozoic crust is traditionally divided into two groups (Greiling et al., 1994), (1) the structurally lower, so-called infrastructure group (El-Gaby et al., 1984) composed of granitoid orthogneisses and migmatites exposed in the domal structures in Meatiq, Sibai, Shalul and Hafafit gneiss complexes from north to south in the Central and Southern Eastern Desert and (2) surrounding Neoproterozoic ophiolite complexes, island arc-related low grade (green schist facies) metavolcanic and metasedimentary assemblages, referred as the suprastructure group (Fig. 2). The infra- and suprastructures are separated by the Eastern Desert Shear Zone (EDSZ; Andresen et al., 2010). Further to the west, these Neoproterozoic rocks are bordered by the pre-Neoproterozoic Sahara metacratonic crust, however this transition is poorly understood (e.g., Abdelsalam et al., 2002, Figs. 1 and 2).

The granitoids of Eastern Desert of Egypt are generally subdivided into two groups, “Older and Younger” granites (e.g., El Ramly and Akaad, 1960). The calc–alkaline to alkaline older granites are typically deformed and have variable composition from quartz diorite to tonalite/trondhjemite and quartz monzonite. Tectonically, the older granites are interpreted as synorogenic, subduction related and emplaced at convergent plate boundaries. Geochronological data suggest that these rocks were emplaced between 880 and 610 Ma (Johnson, 2014 and references therein). The Younger alkaline to peralkaline or metaluminous granites are post collisional, undeformed and shallowly emplaced. These rocks are characterized as within-plate A-type granites (Kröner et al., 1994; Bregar et al., 2002; Shalaby et al., 2005; Moussa et al., 2008; Andresen et al., 2009; Pease et al., 2010; Lundmark et al., 2012). Mineralogically, older subduction related granites in the Eastern Desert are interpreted as magnetite series granites (e.g., Botros and Wetait, 1997; El-Gaby et al., 1988; Hussein et al., 1982) while later post collision granites are suggested to be ilmenite series granites (e.g., Hussein et al., 1982). Volcano-sedimentary rocks are also present primarily in the Eastern Desert and northern Sudan (e.g., Kröner et al., 1987). The Dokhan volcanics and Hammamat Group crops out in post amalgamation basins of Eastern Desert. Both units are of variable thicknesses with a maximum of 1300 m and 7000 m, respectively (e.g., Eliwa et al., 2006; Abd El-Wahed, 2010).