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Single zircon Hf–O isotope constraints on the origin of A-type granites from the Jabal Al-Hassir ring complex, Saudi Arabia

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ABSTRACT

The Jabal Al-Hassir ring complex in the southern Arabian Shield is an alkaline granite complex comprising an inner core of biotite granite that outwardly becomes a porphyritic sodic-calcic amphibole (ferrobarroisite–katophorite) granite. A combined study of mineral chemistry and single zircon Hf–O zircon isotope analyses was carried out to infer the magma sources of the Neoproterozoic post-collisional A-type granitoids in Saudi Arabia. The granitic rocks show high positive initial εHf(t) values of +7.0 to +10.3 and δ^{18}O values of +5.8‰ to +7.4‰ that are consistent with melting of a juvenile crustal protolith that was formed during the Neoproterozoic assembly of the Arabian-Nubian Shield (ANS). Crustal-model ages (Hf-t_{NC}) of 0.71–0.94 Ga indicate minor contribution from an older continental crust in the formation of the Jabal Al-Hassir granitic rocks (crystallization age = 620 ± 3 Ma), but any such component is likely to be Neoproterozoic in age. Temperature and oxygen fugacity (fO_2) estimates suggested that the Jabal Al-Hassir A-type granite magma was generated at high temperature (820–1050 °C) and low fO_2. Geochemical characteristics (e.g., low fO_2), geochronological data, and Hf and O isotope compositions, indicate that the magmas of the Neoproterozoic A-type granites of the Jabal Al-Hassir ring complex were likely generated by crustal partial melting of a juvenile Neoproterozoic lower crustal tholeiitic rocks, following collision between East and West Gondwana in the final stages of the evolution of the Arabian Shield.

1. Introduction

The Arabian Shield is a part of a larger geological ensemble, the Arabian-Nubian Shield (ANS), which covers parts of Egypt, Eritrea, Ethiopia, Saudi Arabia, Somalia, Sudan and Yemen (2200 km NS × 1200 km EW). The ANS (Fig. 1a) is a Neoproterozoic accretionary orogen comprising various tectonostratigraphic terranes, younger sedimentary and volcanic assemblages, and late- to post-tectonic plutons and batholiths (Stern, 1994; Stern and Johnson, 2010; Johnson et al., 2011). Crustal evolution began as intra-oceanic arc systems at ~870 Ma ago and was established by ~620 Ma ago when convergence between east and west Gondwana fragments closed the Mozambique Ocean (Kröner, 1985; Stern, 1994; Johnson, 1998; Jacobs and Thomas, 2004). The arcs collided to form large composite terranes (Fig. 1b), which are today separated by ophiolite-decorated sutures. These composite terranes and older continental fragments of Eastern Gondwana (Stern et al., 2004), perhaps another continental fragment Azania (Collins and Pisarevsky, 2005), and what is now known as the Saharan Metacraton (Abdelsalam et al., 2002) amalgamated to form the East African Orogen (EAO, Stern, 1994). Collision was most intense in the southern EAO, also known as the Mozambique Belt (Meert, 2003), where deformation and igneous activity continued into early Paleozoic time. Finally, orogenic collapse and peneplanation culminated in complete cratonization of the ANS by the end of Ediacaran time (Johnson et al., 2011).

Cryogenian-Ediacaran Arabian Shield magmatism evolved from arc-related tholeiite and calc-alkaline tonalite–trondhjemite–granodiorite (TTG) assemblages, to collisional calc-alkaline TTG and granite assemblages, to post-collisional within-plate A-type granites that formed in an extensional tectonic setting during orogenic collapse (Stern and Hedge, 1985; Beyth et al., 1994; Moghazi et al., 1998; Moussa et al., 2008; Johnson et al., 2011). The transition in tectonic style from compression to extension occurred at ~600 Ma

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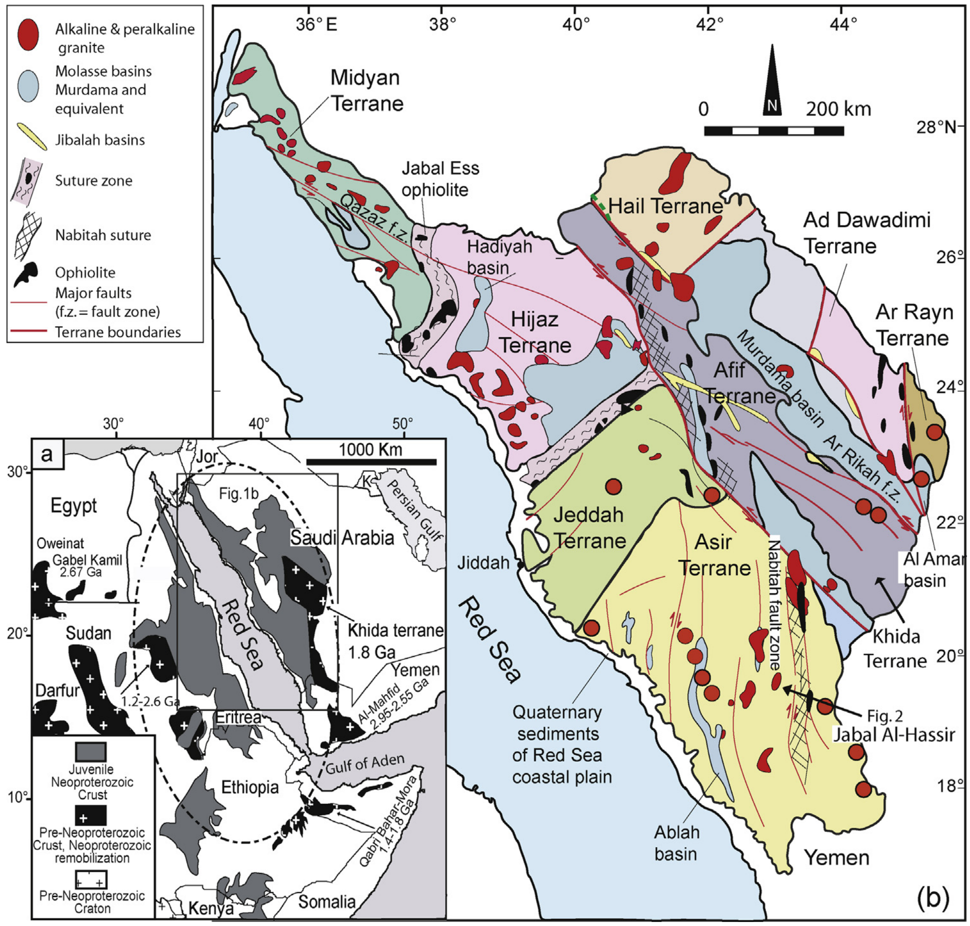

Fig. 1. (a) Map of the Arabian-Nubian Shield (dashed ellipsoid) (Modified from Stern et al., 2006), showing the location of the study areas and regions where pre-Neoproterozoic crust is found. Ages for pre-Neoproterozoic crustal tracts are from Whitehouse et al. (1998), Sultan et al. (1994), Agar et al. (1992), Kröner and Sassi (1996), and Stern et al. (1994). (b) Simplified map of the Arabian Shield, showing major tectonostratigraphic terranes, ophiolite belts, sutures and fault zones, and post-accretionary basins, modified after Nehlig et al. (2002), Johnson and Woldehaimanot (2003), Stern and Johnson (2010). The distribution of the alkaline/peralkaline granites in the Arabian Shield is from Stoeser (1986).

(Stern and Hedge, 1985; Beyth et al., 1994; Garfunkel, 1999), manifested by the emplacement of A-type alkaline to peralkaline granitic intrusions in association with dike swarms and volcanic rocks extruded in molasse-type basins (Eyal et al., 2004, 2010; Johnson et al., 2011). However, U–Pb dating of northern ANS in Sinai and southern Israel indicated that the post-collision calc-alkaline and within-plate alkaline magamtism formed at c. 635–590 Ma and 608–580 Ma, respectively (Be'eri-Shlevin et al., 2009b). The first pulse of the post-collision calc-alkaline rocks are deformed to undeformed, thus deformation ceased by c. 630 Ma (Be'eri-Shlevin et al., 2009b). Moreover, minor felsic intrusions in southern Israel are dated as early as c. 630 Ma (Be'eri-Shlevin et al., 2009b), indicating that the transition from collision to post-collision may have started at ~630 Ma. Johnson et al. (2011) suggested that the ANS post-tectonic A-type granites were emplaced in the ANS as early as the middle Cryogenian (e.g., Hamra and Bishah plutons, ~686 Ma and ~678 Ma), although the first major pulse of alkali magmatism occurred between 630 and 620 Ma, with the emplacement of plutons in the southern (Asir terrane) and northern (Afif and Midyan terranes) ANS. These granites marked the onset of highly fractionated intraplate, post-tectonic magmatism and the transition from convergent to extensional tectonics that characterized the remaining ANS history.

Today, is generally accepted that most of the Arabian Shield consists of juvenile crust. However, geochronology and Pb, Nd, Sr, Hf isotopic data (e.g., Fleck and Hadley, 1982; Stacey and Hedge, 1984; Stoeser et al., 2001; Whitehouse et al., 1998, 2001; Stoeser and Frost, 2006; Hargrove et al., 2006a,b; Be'eri-Shlevin et al., 2009a, 2010; Ali et al., 2010a,b, 2013; Morag et al., 2011, 2012) indicate that parts of Arabian-Nubian Shield in Saudi Arabia (Khida terrane), Yemen, and Egypt (Eastern Desert and Sinai) (Fig. 1a) incorporated Paleoproterozoic (1000–2500 Ma) to Archean (>2500 Ma) continental crust. Crust of similar age is also exposed in the Saharan Metacraton at the western margin of the Halfa terrane (Abdelsalam et al., 2002) and Bayuda Desert (Küster et al., 2008) in Sudan (Fig. 1). More direct evidence for pre-Neoproterozoic inheritance in the Arabian-Nubian Shield juvenile crust comes from Sinai (Egypt), where a 594 ± 8 Ma post-tectonic granite is "contaminated" with xenocrystic zircon with a maximum age of ~1789 Ma (Ali et al., 2009a,b).

In this report, we present new Hf–O isotopic data on single zircons for the evolution of source reservoirs of the late Neoproterozoic A-type granitic rocks of the post-collisional Jabal Al-Hassir ring complex in the Arabian Shield (Fig. 1b). In addition, the investigated ring complex is characterized by juvenile Sr isotopic compositions (Moufti et al., 2013) and thus enable us to investigate how Hf and O isotopic compositions vary in comparison with Sr whole-rock isotopic compositions of the host igneous rocks.

2. Geological setting

Ring complexes and single-ring structures are common in the Arabian Shield (Roobol and White, 1985). These structures occur in linear arrays (Fig. 1b), and most of them, especially the granitic