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Zircon U–Pb geochronology and Nd isotope systematics of the Abas terrane, Yemen: Implications for Neoproterozoic crust reworking events

Fitsum G. Yeshanew[a,b,*], Victoria Pease[a], Martin J. Whitehouse[a,b], Salah Al-Khirbash[c]

[a] Department of Geological Sciences, Stockholm University, SE-106 91 Stockholm, Sweden
[b] Department of Geosciences, Swedish Museum of Natural History, Box 50007, SE104 05 Stockholm, Sweden
[c] Sultan Qaboos University, Al Khoudh 123, Muscat, Oman

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ABSTRACT

High-spatial-resolution secondary-ion mass spectrometry (SIMS) U–Pb zircon ages, whole-rock Nd isotopic and geochemical data are reported for granites and granitic gneisses from a traverse across the Abas terrane, Yemen, a part of the Precambrian basement of southern Arabian Peninsula. SIMS U–Pb dating identifies two magmatic episodes, the first at c. 790–725 Ma represented by granitic gneisses, the second clearly post-tectonic at c. 625–590 Ma. The oldest sample in the post-tectonic group is slightly deformed while younger samples are undeformed indicating that penetrative deformation ceased at c. 625 Ma in the Abas region. Whole-rock $_{Nd}(t)$ values between −11 and +0.8, Nd model ages of 1.70–1.13 Ga indicate a significant contribution of evolved continental material in the genesis of the Abas granitoids, unlike most of the juvenile Arabian-Nubian Shield (ANS), although there are few inherited zircons. Secular variation in $\varepsilon_{Nd}(t)$ reflects a change in magma source with increasing juvenile magma and diminishing crustal input during post-tectonic (625–590 Ma) magmatism. The combination of subduction zone chemistry, absence of older rocks, paucity of inherited zircons, evolved Nd isotopic signatures and the I-type characteristics of the samples suggest that assimilation occurred at depth.

1. Introduction

The Arabian-Nubian Shield (ANS) is an extensive region of Precambrian basement exposed in the eastern Arabian Peninsula (Saudi Arabia, Jordan and northwest Yemen) and northeast Africa (Fig. 1). The shield covers more than 6×10^6 km^2 (Stein and Goldstein, 1996; Kusky et al., 2003) and represents one of the largest tracts of juvenile Neoproterozoic continental crust on Earth. The ANS evolved as the northern sector of the East African Orogen (EAO) (Stern, 1994) and is a collage of mostly juvenile oceanic island arc terranes that were accreted during the amalgamation of the Gondwana supercontinent (Stern, 1994, 2002; Bentor, 1985; Johnson and Woldehaimanot, 2003; Kusky et al., 2003; Meert, 2003; Stoeser and Frost, 2006; Johnson et al., 2011). Although the ANS is predominantly comprised of Neoproterozoic juvenile crust, several geochronological and tracer radiogenic isotopic studies have identified pre-Neoproterozoic crustal components within the shield and along its periphery, including the Khida terrane of Saudi Arabia and the outlying Abas and Al-Mahfid gneissic terranes in Yemen (Stacey and Hedge, 1984; Sultan et al., 1990; Kröner et al., 1992; Windley et al., 1996; Whitehouse et al., 1998, 2001b; Stoeser et al., 2001; Hargrove et al., 2006; Stoeser and Frost, 2006; Be'eri-Shlevin et al., 2009a; K.A. Ali et al., 2009; Stern et al., 2012).

The Precambrian basement rocks of Yemen, exposed over approximately 105,000 km^2, lie to the southeast of the Arabian shield, occupying a transitional area between the dominantly juvenile ANS to the north and the Mozambique Belt (MB) to the south, the latter a high-grade, mostly gneissic terrane of Mesoproterozoic to Archean age (Kröner and Stern, 2004). While the roughly NE–SW to N–S trend of the terrane boundaries in Yemen and absence of exposure along strike to the north (Fig. 2; Windley et al., 1996) precludes direct correlation with terranes in the Arabian Shield, the Yemen terranes provide the only available constraint on the nature of the basement directly to the east of the Arabian Shield in the Arabian peninsula. Together with more distant eastern Arabian basement outliers in Oman (Mercolli et al., 2006; Rantakokko et al., 2014), they provide important constraints for understanding the timing and amalgamation history within the East African

* Corresponding author at: Department of Geosciences, Swedish Museum of Natural History, Box 50007, SE104 05 Stockholm, Sweden. Tel.: +46 8 51955102; fax: +46 8 51955102.
E-mail address: Fitsum.Girum@nrm.se (F.G. Yeshanew).

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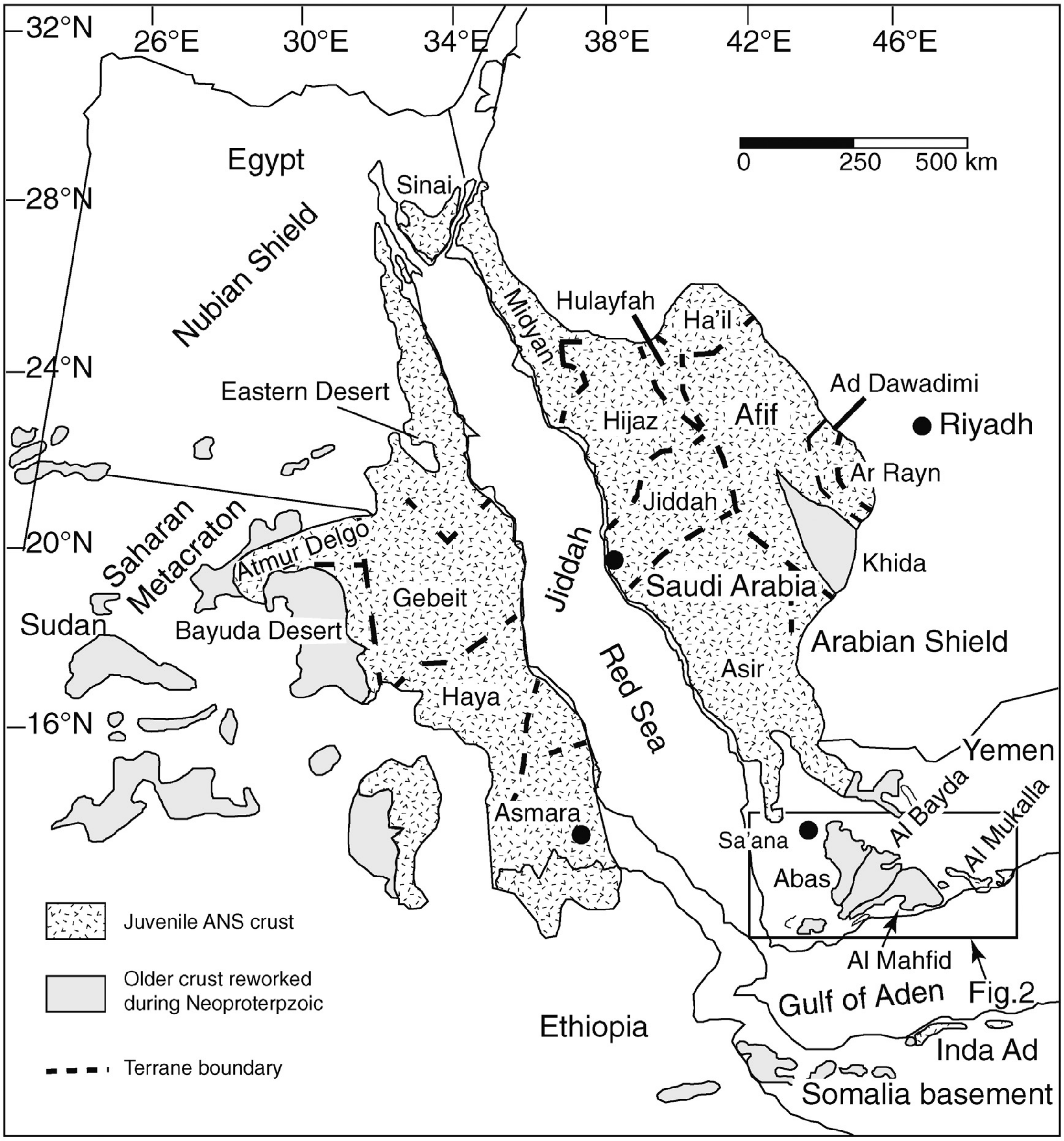

Fig. 1. Simplified geological map of the Arabian-Nubian Shield (after Johnson and Woldehaimanot, 2003; Stern et al., 2010). The Yemen Precambrian basement is indicated by rectangle (designated as Fig. 2).

Orogen (EAO) of northern Gondwana (Stern, 1994; Whitehouse et al., 2001a). A particularly intriguing feature of the Abas terrane in Yemen, arising from the earlier studies of Windley et al. (1996) and Whitehouse et al. (1998), is the appearance of evolved initial Nd isotopic signatures indicating the involvement of pre-Neoproterozoic continental crust in their petrogenesis despite the absence of older zircon cores or known older rocks in the region. This contrasts with the long and polyphase history of the Al Mahfid terrane to the east and raises the questions: (1) How is such a crustal component introduced into the parental melts (e.g. by intrusion into pre-existing old crust or transport of sediments to the melt emplacement region)? (2) Why are no old zircons indicative of this crustal material preserved (e.g. zircon dissolution in high-T melts or simply an absence of zircon if the old Nd signature comes from pelagic or fine-grained sediments)?

In this study, samples were collected from a traverse across the northernmost exposures of the Abas terrane and part of the neighboring Al-Bayda island arc terrane (Fig. 3). These samples represent a more diverse range of rock types than were investigated in earlier studies (Windley et al., 1996; Whitehouse et al., 1998), and include granitic gneisses that are likely to correlate with the arc-formation stage of the ANS, as well as post-tectonic granites. We present new secondary ion mass spectrometer (SIMS) U–Pb zircon geochronology, whole rock Sm–Nd isotopes, and geochemical data from these samples. The results are used to constrain the time of magmatism and crustal evolution in the Abas terrane, evaluate the extent to which older continental material is involved during this crustal growth, and to refine models of crustal evolution for the region.

2. Background geology and sampling

The Precambrian basement of Yemen comprises alternating gneissic terranes (Abas and Al-Mahfid) and Neoproterozoic volcanic arcs (Al-Bayda and Al-Mukalla) (Windley et al., 1996), which were amalgamated to form an arc-gneiss collage during Pan-African orogeny (Whitehouse et al., 2001a). The polyphase gneisses