Precambrian Research 311 (2018) 247–261

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

Preliminary detrital zircon signatures from the southern Asir terrane, Saudi Arabia: A link to Yemen or the Nubian Shield?

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ARTICLE INFO

Keywords:
Arabian-Nubian Shield
Detrital zircon
O and Hf isotopes
Crust
Mozambique Ocean

ABSTRACT

The Arabian Shield comprises early Neoproterozoic to Cambrian (~850–530 Ma) tectonostratigraphic terranes formed by the closure and accretion of juvenile volcanic arcs and back-arc basins associated with Gondwana assembly. Unlike the Nubian Shield which preserves crustal isotopic signatures, the Arabian Shield is distinctly juvenile with the exception of the Paleoproterozoic (~1800–1670 Ma) Khida subterrane in Saudi Arabia and the terranes of Yemen. This study presents the first combined zircon U-Pb, O and Hf isotope data of metavolcanic and metasedimentary rocks from southwestern most Saudi Arabia, near the Yemen border – a region thought to contain some of the oldest (> 815 Ma) lithologies in Saudi Arabia, including the Atura Formation and the Tayyah Belt. One volcaniclastic metasediment sample from the Atura Formation yields zircon U-Pb age peaks of 741, 672, 646 Ma (n = 131), $\delta^{18}O_{(V\text{-}SMOW)}$ ranging from 4.6 to 8.3‰ and ε_{Hf} (t) from +7.7 to +12.5. Two samples from the Tayyah Belt include an older metasandstone and a late intruding granitic dyke which provides a minimum age for the Tayyah Belt. The former yields two significant U-Pb peaks of 812 (n = 8) and 999 (n = 6) Ma, $\delta^{18}O$ and ε_{Hf} (t) values ranging from 4.4 to 9.6‰ and −10.1 to +12.4, respectively; the later yields a concordia age of 645.8 [±1.7] Ma (n = 29), $\delta^{18}O$ ranging from 5.7 to 6.6‰, and ε_{Hf} (t) of +5.9 to +9.6. The zircon age and juvenile Hf signatures from the Atura Formation are consistent with the synorogenic phase in the Shield. Sedimentation was likely associated with arc volcanism during the previously documented eastward phase of accretion at ~740–640 Ma and the closure of the Mozambique Ocean. In contrast, the data from the texturally more mature Tayyah Belt metasediment indicate a more distal, and more evolved crustal input at the time of sediment deposition which is unusual for the Saudi Arabian Shield. Consequently, the Tayyah metasediments are likely sourced from areas with greater continental affinity, such as the cratonic basement and/or reworked crust of the Sahara metacraton in NE Africa.

1. Introduction

The Precambrian evolution of the Arabian-Nubian Shield (ANS) is widely accepted to involve a series of isotopically juvenile tectonomagmatic phases associated with closure of the Mozambique Ocean and generation of the East African Orogen (EAO) by the amalgamation of East and West Gondwana (Stern, 1994; Stern and Johnson, 2010; Johnson et al., 2011; Fritz et al., 2013). Whole-rock Nd, Pb, Sr and O isotopes (e.g. Stoeser and Frost, 2006; Hargrove et al., 2006), and more recently Hf isotopes in zircon (e.g. Morag et al., 2011a; Robinson et al., 2014) indicate the core of the ANS is composed of Neoproterozoic juvenile oceanic crust, but outer fringes of exposed older continental crust are documented in NE Africa (Fritz et al., 2013), the Khida subterrane of the Afif composite terrane of Saudi Arabia (Whitehouse et al., 2001a), and the Abas and Al-Mahfid terranes in Yemen (Windley et al., 1996; Whitehouse et al., 1998, 2001b; Yeshanew et al., 2015). Designated as the ‘contaminated Shield’ (Stoeser and Stacey, 1988; Hargrove et al., 2006; Stoeser and Frost, 2006), ANS regions in Ethiopia (e.g., Blades et al., 2015; Yeshanew et al., 2017), southeastern Egypt (Ali et al., 2015a), Israel (Morag et al., 2011a) and isolated Saudi Arabian terranes (Robinson et al., 2017), also document crustal contamination.

Although exposed pre-Neoproterozoic crust is limited in the ANS, the ‘contaminated Shield’ remains an important, but enigmatic aspect in relation to pre-ANS rifting, Neoproterozoic (~850–620 Ma) Mozambique Ocean closure and the EAO. Whether the origin of this apparent crustal component is subducted reworked crustal material, cratonic basement or simply a different mantle source (Stoeser and Frost, 2006) is not easily resolved. Stern et al. (2010) highlight that only ~5% of dated ANS zircons are > 880 Ma and these form 4 distinct populations interpreted to be xenocrystic zircons from the mantle

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https://doi.org/10.1016/j.precamres.2018.04.017
Received 29 June 2017; Received in revised form 12 April 2018; Accepted 16 April 2018
Available online 17 April 2018
0301-9268/

incorporated into the juvenile ANS crust. These zircon populations are Tonian-Stenian (0.9–1.15 Ga), late Paleoproterozoic (1.7–2.1 Ga), Paleoproterozoic–Neoarchean (2.4–2.8 Ga) and early Archean (> 3.2 Ga), and with the exception of the ~1800–1670 Ma Khida subterrane, potential source regions are not exposed in the Saudi Arabian part of the ANS. The xenocrystic scenario is certainly plausible for ANS magmatism both prior to and associated with the EAO, but the origin of detrital zircons with crustal signatures found within similar age ANS metasedimentary units remains more elusive. South of the ANS, multiple pre-Neoproterozoic zircon populations (as seen in the northern EAO; Stern et al., 2010) and two different source regions (possibly either side of the EAO) have been indentified in Madagascan metasediments associated with Mozambique Ocean basin deposition (Collins et al., 2003). The associated suture zone adjoining the Dharwar Craton, India and the Congo/Tanzania/Bangweulu Craton is interpreted to be a relict of subducted Mozambique Ocean crust, which in other regions of Madagascar is constrained to ~850 –700 Ma (SHRIMP U-Pb in zircons from metabasaltic rocks; Jöns and Schenk, 2008). Metasedimentary units hosted in similar suture zone environments of the Arabian Shield could potentially be used to constrain the source region of sediments in the Mozambique Ocean basin and its associated closure in the northern EAO.

This study presents the first combined zircon U-Pb, O and Hf isotope data from some of the oldest (> 815 Ma) metavolcanic and metasedimentary rocks present in southwestern Saudi Arabia. This combination of isotopic data is used to characterise the source region of the detrital and igneous samples of the Atura Formation and the Tayyah Belt in the southern Asir terrane. These data suggest that the younger synorogenic Atura Formation is locally derived from juvenile crust, whereas the older Tayyah Belt has a significant crustal recycling fingerprint suggestive of derivation from areas with more continental affinity, such as those of NE Africa outside the ANS. These outcomes provide important constrains on the highly debated extent of ANS continental affinity and timing of the northern EAO associated with East and West Gondwana amalgamation.

2. Geological setting and sample description

The Arabian Shield is widely accepted to have formed by the closure and accretion of juvenile volcanic arcs and back-arc basins in which eight distinct terranes separated by five ophiolite-bearing suture zones have been isotopically and geochronologically identified (Stoeser and Camp, 1985; Stoeser and Frost, 2006; Stern et al. 2010; Johnson et al., 2011). This study focuses on the southern Asir terrane of the Arabian Shield (Fig. 1a), which is segmented into a fanning array of NE-SW and N-S trending tectonic belts known as the Makkah, Arafat, Lith, Bidah, Ablah, Tayyah, Khadra, Malahah and Tathlith Belts (Greenwood et al., 1982). Although the majority of these belts are fault bound and have similar structural characteristics (steeply dipping fault boundaries, shallow plunging folds, lineations indicating several phases of movement, younger sediment deposition in tectonic rifts and half grabens), they are quite diverse in compositional and depositional facies, and metamorphic grade (Greenwood et al., 1982). There is also a general trend of older belt ages (> 800 Ma) west of the Tayyah-Khadra Belt boundary, which to date document juvenile, island-arc affinity (Fig. 1a; Greenwood et al., 1982; Stein, 2003; Stoeser and Frost, 2006; Johnson et al., 2011). Eastward accretion between ~740 and 640 Ma of the oceanic tholeiite, bimodal arc volcanism and associated pre-collision volcanosedimentary basins within these tectonic belts, gave rise to syncollisional magmatism and basin deposition. This is well illustrated by the Late Tonian and Cryogenian age gneissic and metavolcanic/sedimentary units within the Tayyah-Khadra-Malahah Belts, which collectively form the southern portion of the Nabitah Orogenic Belt (Fig. 1b). The tectonic significance of this N-S trending orogenic belt (often referred to as the Nabitah Suture) is discussed in Johnson et al. (2011), Flowerdew et al. (2013) and more recently in Robinson et al. (2017). The cessation of accretion across the belt is not synchronous and in the southern Nabitah Belt is marked by the appearance of post-orogenic A-type granites (Johnson, 2006; Johnson et al., 2011). According to Robinson et al. (2014), accretion associated with the Nabitah Belt ceased at ~636 Ma when the Al Hafoor Igneous Suite intruded the Tathlith terrane and the ~630 Ma Kawr, ~618 Ma Ibn Hashbal and ~616 Ma Wadbah Igneous Suites intruded the southern Tayyah/Khadra Belts (Fig. 1b).

In the southern Shield near the Yemen border, the ~350 km N-S trending Tayyah Belt comprises some of the oldest (> 815 Ma; Johnson, 2006) volcanic and sedimentary packages inthe Arabian Shield, with the exception of the Paleoproterozoic Khida subterrane (Whitehouse et al., 2001a; Stoeser and Frost, 2006). Greenwood et al. (1982) highlighted the lithological variation between the northern part of the belt composed of basaltic and andesitic pyroclastics material, subaerially deposited welded tuffs and dioritic batholiths and the southern part of the belt dominated by submarine pillow basalts and greywacke-chert-quartzite interbeds. In addition, Greenwood et al. (1982) reported that in some areas pillow basalts overlie mature, shallow water siliclastic sediments possibly derived from the erosion of adjacent belts (e.g. Bidah) or even the African craton. The Tayyah Belt is reported to have greenschist facies metamorphism with the exception of localised upper amphibolite to granulite facies associated with gneissic and gabbroic to granitic intrusions (Greenwood et al., 1982). Two samples were collected from the Tayyah Belt (mapped as different packages in Fig. 1b): a granite dyke (SA12-6) intruding the older package (tyv) and a quartz-rich metasandstone (SA12-12) from the younger package (tya). The assumed relative ages follow the south-eastward general younging trends described in Greenwood et al. (1982).

Sample **SA12-6** is a medium-fine grained, white–grey, weakly deformed granitic dyke. Granitic textures are porphyritic to granular and petrography (Fig. 2a) reveals a quartz, alkali feldspar, plagioclase, muscovite dominant mineralogy with minor biotite, hornblende, allenite and apatite (< 5%) that define a granite composition. Quartz occurs as two crystallization phases: 1) initial medium size grains with consertal texture and undulose extinction co-existing with altered alkali feldspar and plagioclase grains that contain both inclusions of apatite and rare zircon, and 2) an anhedral interstitial phase alongside biotite, hornblende and accessory allenite and apatite (Fig. 2a). Both muscovite and biotite are overprinting stages that are very weakly aligned, and combined with undulose quartz, support low grade greenschist metamorphism documented in the southern Tayyah Belt by Greenwood et al. (1982).

Sample **SA12-12** is laminated and weakly foliated, quartz-rich metasandstone with a well-sorted (sand to fine sand size) sub-rounded matrix surrounded by patches of recrystallised quartz grains in calcite-poor cement. Petrography (Fig. 2c) reveals a quartz dominant mineralogy with minor alkali feldspar and plagioclase grains (< 5%) overprinted by weakly aligned biotite and muscovite (< 5%). Recrystallised quartz grains often display undulose extinction and the grain boundary intersections are overprinted by muscovite (Fig. 2c) which supports the low grade greenschist metamorphism recognised by Greenwood et al. (1982).

Further to the east, the Tayyah Belt is in fault contact with the younger (< 730 Ma) Khadra Belt, which is composed primarily of greenschist facies andesitic and rhyolitic flows (Greenwood et al., 1982). An abundance of volcaniclastic rocks (e.g. welded/unnwelded tuffs with interbed conglomerate and siltstone) and localised basaltic and trachytic units occur in the southern section (Greenwood et al., 1982). Within the southern Khadra Belt, close to the Yemen border, is the fault bound, Cryogenian age Atura Formation represented by sample **SA12-8** (Fig. 1b). Sample SA12-8 is a well-cemented, weakly foliated quartz-rich volcaniclastic rock. The grains are well-sorted (< sand size), sub angular, and are surrounded by a fine-grained calcite-bearing matrix. Petrography reveals quartz, alkali feldspar and