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Crustal evolution and metamorphism in east-central Eritrea, south-east Arabian-Nubian Shield

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Abstract

The crust of the Arabian-Nubian Shield (ANS) was formed in oceanic settings in the Mozambique Ocean during the Neoproterozoic (c. 0.9–0.6 Ga). Convergence started to coalesce island arcs, closed the ocean, and continental collision followed (<c. 0.7 Ga). The investigated rocks of east-central Eritrea occupy a southeasterly position in the ANS. Mafic and felsic rocks from both the greenschist facies Bizen and amphibolite facies Ghedem sub-domains are calc-alkaline to tholeiitic with typical arc geochemical characteristics. The Nd and Sr isotopic composition of five felsic, mafic and metasedimentary gneisses from the Ghedem sub-domain are all highly juvenile (ε_{Nd} at 800 Ma: +4.9 to +7.2, and $^{87}Sr/^{86}Sr$: 0.7027–7054). SIMS geochronology of two amphibolite-facies orthogneiss samples yielded ages of magmatically zoned zircon at 795 ± 14 and 818 ± 9 Ma. A few cores, indicating the presence of relatively older crust, yielded ages of maximum c. 890 Ma, and no metamorphic rims were observed. TIMS geochronology on monazite from an orthogneiss and a kyanite schist from the Ghedem sub-domain yielded 593 ± 5 and 587 ± 2.5 Ma, respectively, while rutile from the latter gave 565 ± 7 Ma. Metamorphic conditions in garnet-bearing kyanite schists from the Ghedem and Barka sub-domains in eastern and western Eritrea, respectively, were estimated using garnet–biotite–plagioclase–kyanite–quartz thermobarometry. Peak metamorphic conditions for the Ghedem sample was c. 700 °C and 8 kbar and for the Barka sample c. 600 °C and 9 kbar. The geochemistry and Nd–Sr isotopes of the east-central Eritrean rocks confirm a juvenile oceanic arc origin for the crust in this region, allowing only very small contributions from older crust. The c. 800 Ma igneous ages are typical for juvenile Eritrean and ANS crust. The peak amphibolite facies metamorphic conditions were reached during continental collision between east and west Gondwana, at c. 590 Ma in this area, while the c. 565 Ma rutile age represents cooling and exhumation through c. 400 °C and 3–4 kbar after collision.

Keywords: Arabian-Nubian Shield; Eritrea; Geochronology; Metamorphism; Juvenile; Arc magmatism

1. Introduction

The rocks of the Arabian-Nubian Shield (ANS) are essentially juvenile in character, derived from mantle sources and produced new continental crust during the Neoproterozoic (e.g., Kröner et al., 1991; Pallister et al., 1988; Reischmann and Kröner, 1994; Teklay, 1997; Tadesse et al., 2000). This new crust formed in oceanic island arc settings in the Mozambique Ocean that lay in between the Archaean and Palaeoproterozoic cratons of East and West Gondwana (Stern, 1994; Johnson and Woldehaimanot, 2003). Plume-related oceanic plateau magmatism was also important during the early stages of crust formation in the ANS (Stein and Goldstein, 1996; Stein, 2003). The cratonic crust thus provided little input into the juvenile ANS rocks. A collage of juvenile crustal blocks welded together along sutures decorated with ophiolites (Berhe, 1990). Continental collision was active in the interval between 750 and 650 Ma, followed by crustal shortening and escape tectonics until ca. 550 Ma (Stern,

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1994). During the collision of East and West Gondwana, a strong reworking with high-grade metamorphism and magma formation affected both the ANS and the adjoining Palaeoproterozoic and Archaean cratons east and west of the juvenile shield, and along the Mozambique Belt to the south, now constituting the East African Orogen (e.g., Stacey and Agar, 1985; Kröner et al., 1987, 1997; Harms et al., 1990; Muhongo, 1994; Kröner and Sassi, 1995; Abdelsalam and Stern, 1996; Al-Saleh et al., 1998; Whitehouse et al., 1998; Sommer et al., 2003). This has obscured the limits between old and juvenile terranes in the region, and delimiting the extent of the juvenile crust still remains a challenge.

Towards contributing to the solution of this problem and in order to understand better the crustal character in the southeastern part of the ANS, we have conducted additional relatively detailed studies on the geochemical and isotopic characters, present new U–Pb ages on zircons and monazites and mineral *P*–*T* data on high-grade rocks from eastern-central Eritrea. The results give evidence that the high-grade rocks have similar ages of formation as the low-grade rocks in this part of the shield.

2. Geological setting

In E and NE Africa, terrane classification is commonly applied for any shear zone or fault-bounded rock masses no matter of genesis, age or tectono-metamorphic evolution of the rocks. The tectonics of Eritrea has been interpreted in terms of docking of several terranes (Drury and Berthe, 1993; Drury and De Souza Filho, 1998), or of only two major terranes; a high-grade and a low-grade, each with distinct distinguishing fabrics and structures (Ghebreab, 1996; Fig. 1). However, such an approach is being disputed by recent investigations (e.g., Ghebreab, 1999a; Woldehaimanot, 2000; Ghebreab et al., 2005; Tsige and Abdelsalam, 2005; Andersen, 2005). Instead, two major domains, namely the high-grade gneiss domain and low-grade metavolcano-sedimentary domain are proposed (Ghebreab et al., 2005; Fig. 1). Hence, in this study the term domain or sub-domain is preferred and referred to where appropriate.

The central highlands of Eritrea consist primarily of greenschist facies, juvenile 850–650 Ma old supracrustal and intrusive rocks (Teklay, 1997) bounded by amphibolite facies rocks in the eastern and western lowlands (Ghebreab, 1996). In the west, the Barka sinistral strike-slip shear zone separates the amphibolite facies rocks in the Barka lowlands from the tholeiitic greenschist facies of the central highlands to the immediate east of them (Fig. 1; De Souza Filho and Drury, 1998; Teklay et al., 1999). Further east, these tholeiitic rocks are truncated, and separated from calc-alkaline greenschist facies rocks, by the Adobha strike-slip shear zone that contains MORB-like dismembered ophiolites (Woldehaimanot, 2000). Metabasalts from the tholeiitic rocks display geochemical features of plume-related oceanic plateaux magmatism (Teklay et al., 1999), while the calc-alkaline rocks east of the Adobha shear zone have oceanic island-arc character with a minor plume-related signature (Teklay et al., 2002). The Barka suture zone (Kazmin, 1976) has been interpreted as a major shear zone, which separates the amphibolite and greenschist facies rocks where the western margins of the greenschist facies rocks contain imbricated wedge material (incl. MORB), that experienced subduction zone P and T of ca. 14.5 kbar and 550 °C (De Souza Filho, 1995; De Souza Filho and Drury, 1998). In eastern-central Eritrea, which is the main focus of this study, the Ghedem and Bizen sub-domains, represent high and low-grade metamorphic rocks, respectively. According to Ghebreab et al. (2005) the Ghedem sub-domain experienced post-collisional exhumation from lower (ca. 45 km deep) to upper (ca. 15 km) crustal levels in the period 593–567 Ma.

3. Methods and results

3.1. Metamorphism

Two samples of kyanite schist from Eritrean high-grade metamorphic areas, one from the west and one from the east (Fig. 1a,b), have been studied with respect to mineral paragenesis and composition in order to estimate the metamorphic conditions. A Cameca SX50 microprobe, with an acceleration voltage of 20 kV, a beam current of 15–20 nA, and a beam diameter of 1–3 μm was employed. Calibration was performed on natural minerals and synthetic compounds supplied by Cameca, and for the ZAF correction the Cameca PAP procedure was used (Pouchou and Pichoir, 1991). Representative mineral compositions are given in Table 1.

A sample of kyanite schist (E16) from the east Eritrean lowlands (Ghedem sub-domain) (Fig. 1b) contains quartz, plagioclase, garnet, kyanite, biotite, muscovite, tourmaline, ilmenite and rutile. Garnet, kyanite, muscovite, and oxides are indicated from textural relations to have formed at the expense of biotite, quartz and plagioclase. The garnet and kyanite contains numerous inclusions of mainly quartz, and few plagioclase and biotite. Garnets are subhedral to euhedral and slightly zoned. The zoning shows an increase in Mn and Fe/Mg from core to rim, but barely any change in Ca (Fig. 2a).

Thermobarometry assuming near-equilibrium between the high-Mg garnet cores and the most Fe-rich large biotites in the matrix, combining garnet–plagioclase–kyanite–quartz barometry (GASP) and Gt–Bt thermometry (using the most recent Gt–Bt thermometer of Gessmann et al., 1997, and the GASP barometer calibration of Koziol and Newton, 1988; Koziol, 1989), yield estimates of the metamorphic peak to c. 700 °C and 8 kbar (Fig. 3a). Most other Gt–Bt calibrations indicate temperatures in the range 650–750 °C. The Koziol GASP barometer indicates conditions just on the phase border between kyanite and sillimanite, depending on which plagioclase is assumed in