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Geochemistry and *P–T–t* evolution of the Abu-Barqa Metamorphic Suite, SW Jordan, and implications for the tectonics of the northern Arabian–Nubian Shield

Ghaleb H. Jarrar[a,*], Thomas Theye[b], Najel Yaseen[a], Martin Whitehouse[c], Victoria Pease[d], Cees Passchier[e]

[a] Geology Department, The University of Jordan, P.O.Box 13633, 11942 Amman, Jordan
[b] Institut für Mineralogie und Kristallchemie, Universität Stuttgart, Azenbergstr. 18, D-70174 Stuttgart, Germany
[c] Swedish Museum of Natural History, Box 50007, SE-104 05 Stockholm, Sweden
[d] Department of Geological Sciences, Stockholm University, SE-106 91 Stockholm, Sweden
[e] Institute of Geological Sciences, Johannes-Gutenberg University, Mainz, Germany

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ABSTRACT

The Abu Barqa Metamorphic Suite (ABMS) represents the oldest part of the Arabian–Nubian Shield in southern Jordan. It comprises tonalitic gneiss, metasediments including schist and paragneiss, and granitic gneiss, intruded by later granitic bodies. Geochemically, the majority of the schist samples have shale and Fe-shale protoliths, while the paragneisses represent metagreywacke. Tectonic discrimination diagrams indicate that the protolith of the ABMS was deposited at an active continental margin/island arc setting.

U–Pb zircon (SIMS) ages from metamorphic and igneous rocks of the ABMS indicate that it evolved between ~800 and ~610 Ma. A tonalitic gneiss has a crystallization age of 787 ± 3 Ma. Detrital zircon from the metasediment has a range of concordant ages from 680 to 860 Ma. The entire metamorphic complex was intruded by calc-alkaline granitoids (~615–610 Ma) and quartz diorite dated (~600 Ma).

Field and petrographic investigations of ABMS metasediment elucidate the development of three metamorphic zones, from north to south: (1) andalusite–staurolite (andalusite + staurolite + biotite + muscovite + plagioclase ± garnet + quartz ± chlorite + fibrolitic sillimanite + accessories), (2) garnetsillimanite (sillimanite + garnet + biotite + plagioclase + quartz + K-feldspar + cordierite (pinitized) ± rutile ± ilmenite), and (3) cordierite–sillimanite (sillimanite + biotite + plagioclase + cordierite + hercynite + quartz + accessories).

The maximum metamorphic conditions (M1) were attained in the garnet–sillimanite zone (5–6 kbar, ~700 °C), while peak conditions of ~3.2 kbar and 540 °C were obtained for the andalusite–staurolite zone (using both forward-pseudosection modeling and inverse-modeling with multi-equilibrium approach). Compositional isopleth calculations of small relics of garnet yield about 3.5 kbar and 600 °C for the sillimanite–cordierite zone. These values are in agreement with results obtained by TWQ inverse modeling. The M1 event most probably occurred around ~625 and was followed by a decompressional thermal phase (M2) contemporaneous with post-tectonic granitoid emplacement at ~615–610 Ma; and lastly went through a retrograde cooling phase (M3) accompanying uplift of the whole complex to the surface at ~605 Ma.

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1. Introduction

The East African Orogen (EAO) is one of the largest orogenic belts on Earth. It was the consequence of the final collision of proto-East and West Gondwana during late Neoproterozoic–early Paleozoic time between 750 and 620 Ma (Meert, 2003). It extends over 6000 km, from the Arabian–Nubian Shield (ANS) in the north, along the East African margin (the Mozambique belt) into East Antarctica (e.g. Stern, 1994). The evolution of the EAO started with the breakup of Rodinia and the formation of the Mozambique Ocean at about 900 Ma B.P and ended by the Greater Gondwana breakup at c. 550 Ma (Stern, 1994). The ANS represents one of the largest exposures of Neoproterozoic juvenile continental crust on Earth that has been formed as a result of plate tectonic processes. It is generally regarded as a collage of juvenile volcanic arc terrains and associated ophiolite remnants, which were amalgamated during the

* Corresponding author. Tel.: +962 777461617.
E-mail address: jarrargh@ju.edu.jo (G.H. Jarrar).

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assembly of Gondwana (Bentor, 1985; Johnson et al., 2004; Meert, 2003; Stern, 1994, 2002; Stoeser and Frost, 2006).

This juvenile crust was generated at primitive arc and back-arc systems in the Mozambique ocean from c. 870–630 Ma. Recent reports of calc-alkaline magmatic activity at 1.03–1.02–Ga (Be'eri-Shlevin et al., 2012) in the Saal volcano-sedimentary metamorphic complex (Sinai, Egypt; Fig. 1A) suggest that the ANS crustal growth may have started before 870 Ma. Furthermore, Küster et al. (2008) has documented crustal events in excess of 870 Ma from the SW margins of the ANS in the Bayuda region of central Sudan.

Ocean spreading in the Mozambique Ocean continued until about 750 Ma (Stern, 1994) and collision of the arc related fragments occurred from 630 to 600 Ma. Continued convergence and tectonic escape lasted until c. 550 Ma (Stern, 1994).

During East African Orogeny, the ANS experienced polyphase deformation and metamorphism, ranging from greenschist to upper amphibolite facies conditions. This was accompanied and followed by widespread plutonic and subordinate volcanic activity. The ANS exposures in Jordan comprise igneous, sedimentary and metamorphic rocks that were exclusively formed between 550 and 800 Ma (e.g. Bender, 1974; Jarrar et al., 2003, 2004, 2008).

The main metamorphic event that gave rise to the Abu-Barqa Metamorphic Suite (ABMS) has been dated at 750–800 Ma (Jarrar et al., 1983; Jarrar, 1985). Detailed petrographic investigation was conducted by Jarrar (1979, 1985) and Abdullah (1989). Farhat (1979) published a *P*–*T* estimation of the metamorphic conditions at Wadi Abu-Barqa, Central Wadi Araba, for the mineral paragenesis: sillimanite + plagioclase ± K-feldspar ± cordierite of 730 °C and 5.8 kbar. This study combines a larger set of bulk and detailed mineral chemistry with new geochronological data, and performs new thermobarometric modeling to better constrain the tectonic evolution of the ABMS.

2. Geologic setting

The Neoproterozoic crystalline basement of south Jordan comprises the northernmost extremity of the ANS. It covers an area of about 1400 km^2 and outcrops east, northeast and north of Aqaba, extending discontinuously as far as the southern shore of the Dead Sea (Fig. 1). It is dominated by 625–580 Ma calc-alkaline and alkali feldspar granitoids (Jarrar et al., 1983, 2003, 2008; Moshtaha, 2011) that intrude the metamorphic complexes. These complexes occur sporadically and form small outcrops, including the ABMS, along Central Wadi Araba and also in the area of Ain Al Hashim, (the Janub Metamorphic Complex) about 30 km ESE of Aqaba (Fig. 1A). This basement divides into two major lithostratigraphic domains separated by a regional Late Neoproterozoic unconformity (~610 Ma, Jarrar et al., 2008): (i) the older Aqaba Complex and (ii) the younger Araba Complex (Ibrahim and McCourt, 1995).

The ABMS forms several almost EW trending belts that outcrop in the area of central Wadi Araba, and extends from c. 45 to 85 km north of the Gulf of Aqaba (Fig. 1). The ABMS includes the oldest (~800 Ma) rocks dated in the Neoproterozoic ANS basement rocks in south Jordan (Jarrar et al., 1983). The ABMS has been metamorphosed to upper amphibolite facies at 5.8 kbar and 730 °C (Farhat, 1979).

3. Field relationships

The major exposures of the ABMS occur in Wadi Huwar, Wadi um Saiyala, Wadi Abu-Barqa, and Wadi Rahma, but are discontinuous between Abu Barqa and Wadi Rahma (Fig. 1).

The ABMS comprises paragneisses, tonalitic gneisses, metapelites, and granitic gneisses (Jarrar, 1985) and is intruded by Turban granite (610–615 Ma, Jarrar, 1985), Mureihil diorite (598 Ma, discordia by Jarrar, 1985 recalculated), and the Huwar two mica granite (612 Ma, this study). The ABMS and the intruding granitoids are overlain by the Safi Group with angular unconformity (Fig. 2). Both the ABMS and the Safi Group are overlain by the Lower Cambrian bedded arkosic sandstones of the Salib Formation (Amireh et al., 2008).

The metasediments in the four Wadis occur in the form of E–W trending, steeply dipping, belts that are invaded by parallel intrusions of the post-orogenic Turban granite (Fig. 3A), Rahma granite (Fig. 1B) and the Huwar two mica granite. The Turban granite is whitish-gray colored to locally reddish with abundant orthoclase phenocrysts. This granite is rich in biotite streaks (Fig. 3B) implying partial assimilation of the metasediments. The S_1 schistosity represents the dominant regional penetrative foliation in the metapelites with an approximately E–W trend that dips steeply to the north or to the south, and with a gently dipping lineation (Figs. 2 and 3C).

Schists occur in two varieties: one dark and fine-grained, the other silver-gray and medium to coarse-grained. The two occur in an alternating sequence (Fig. 3D) reflecting the original sedimentary layering (S_0). The former is rich in quartz and relatively poor in biotite and aluminosilicates; while the latter is enriched in biotite and porphyroblasts of garnet, staurolite, andalusite, and sillimanite. This is a consequence of the mineralogical composition of the protolith.

The paragneiss is coarse-grained, white gray colored, and consist mainly of biotite, plagioclase, and quartz with subordinate amounts of sillimanite and garnet in Wadi Abu Barqa and cordierite, sillimanite in Wadi Rahma. Furthermore, typical agmatite and stromatic migmatite structures are common in Wadi Abu-Barqa (Fig. 3E). The melanosome consists of up to 50% biotite enclosing augen of polycrystalline aggregate of andesine plagioclase (Fig. 3F). The leucosome in stromatic migmatite is rimmed by massive streaks of biotite (Fig. 3E).

Metapelite and paragneiss contain isoclinally folded intrusive granitic veins, a strong approximately EW-trending main foliation and a stretching lineation in which sillimanite is stable. This fabric was formed during peak metamorphic conditions (M1). The orientation of the foliation is variable but mostly steep, and deformation may have been close to constrictional at least part of the time. There are no good shear sense indicators because of the constrictional fabric. The high grade fabric (M1) is overprinted by open folding with horizontal axes and axial planes. This fabric indicates a component of vertical shortening, and the geometry of the folds suggests that deformation took place at a decreased metamorphic condition (M2).

The different types of porphyroblasts are distinguishable in the field. Silver white sillimanite porphyroblasts, up to 3 cm long, are widespread in Wadi Abu Barqa (Fig. 3G). Garnet is mostly euhedral (Fig. 3H) and can reach up to 10 mm in size in Wadi Um Saiyala. Cordierite occurs in the sillimanite zone in Wadi Abu-Barqa but has almost been totally transformed to pinite and frequently mantles garnet prophyroblasts. Staurolite is dull brown with a resinous luster and ranges in size from minute grains up to 5 mm. Andalusite is lenticular, dark-gray colored and up to 4 cm in length (Fig. 3I). Both staurolite and andalusite are restricted to Wadi Huwar.

The tonalitic gneiss is coarse-grained, gray-colored, homogeneous and has a consistent steep dip due south (Fig. 2). The occasional change in dip direction in the metapelite, to the contrary, is mostly attributed to the foliation parallel emplacement of the Turban granites.

The granitic gneiss is also coarse-grained and homogenous, but reddish gray colored. The constrictional fabric dips steeply to the north (Fig. 2) and is seen Wadi Barraq (Figs. 2 and 3J). The fabric is often focused around enclaves of biotite amphibole schist due to competency contrast. Deformation fabric formed during upper greenschist to lower amphibolite facies metamorphic conditions.

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