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Geochemistry, petrogenesis and radioactive mineralization of two coeval Neoproterozoic post-collisional calc-alkaline and alkaline granitoid suites from Sinai, Arabian Nubian Shield

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ABSTRACT

The Younger Granites of Yahmid-Um Adawi area, located in the southeastern part of Sinai Peninsula, comprise two coeval Late Neoproterozoic post-collisional alkaline (hypersolvous alkali-feldspar granites; 608–580 Ma) and calc-alkaline (transsolvous monzo- and syenogranites; 635–590 Ma) suites. The calc-alkaline suite granitoids are magnesian and peraluminous to metaluminous, whereas the alkaline ones are magnesian to ferroan alkaline to slightly metaluminous. Both granitoid suites exhibit many of the typical geochemical features of A-type granites such as enrichment in Nb (> 20 ppm), Zr (> 250 ppm), Zn (> 100 ppm) and Ce (> 100 ppm) and high 10000*Ga/Al_2O_3 ratios (> 2.6) and Zr + Nb + Y + Ce (> 350 ppm). Accessory mineral saturation thermometers demonstrated former crystallization of apatite at high temperatures prior to zircon and monazite separation from the magma for both granitoid suites. The mild zircon saturation temperatures of the studied Younger Granites (around 800 °C) imply low-temperature crustal fusion and incomplete melting of the largely refractory zircon. The two Younger Granite suites were semi-synchronously evolved during the post-collisional stage of the Arabian-Nubian Shield subsequent to the collision between the juvenile shield crust and the older pre-Neoproterozoic continental blocks of west Gondwana. Their parental magmas has been generated by melting of crustal source rocks with minor involvement from mantle, which might participated chiefly as a source of heat necessary for fusion of the crustal precursor. Extensive *in-situ* gamma-ray spectrometry revealed anomalously high radioactivity of some Younger Granite exposures along Wadi Um Adawi (eU; 388–746 ppm and eTh; 1857–2527 ppm) and pegmatitic pockets pertaining to the calc-alkaline suite (equivalent U and Th; 212–252 ppm and 750–1757 ppm, respectively). The radioactivity of the syngenetic pegmatites arises from the primary radioactive minerals uranothorite and thorite together with the U- and/or Th-bearing minerals zircon, columbite, samarskite and monazite. The anomalously high radioactivity of some Younger Granite exposures in Wadi Um Adawi stem from their appreciable enclosure of the epigenetic uranium minerals metatorbenite and uranophane.

1. Introduction

The exposed Precambrian basement of Sinai (ca. 14,000 km^2) constitutes the northwestern segment of the Arabian-Nubian Shield (ANS). The ANS is a Neoproterozoic (900–550 Ma) juvenile crust evolved by amalgamation of oceanic and continental arc complexes all through the closure of the Mozambique Ocean and collision of the continental blocks of West and East Gondwana (Stern, 1994, 2002; Stoeser and Frost, 2006; Vaughan and Pankhurst, 2008; Johnson et al., 2011; Cox et al., 2012; Eyal et al., 2014; Ali et al., 2016). Subsequent to this prolonged stage of compressive tectonics and subduction-related magmatism, a transitory stage of post-orogenic magmatism has affected the Arabian–Nubian Shield crust. During this stage, a significant volume of High-K calc-alkaline and alkaline granitic crust was formed synchronous and subsequent to the collision but preceding the initiation of the ANS crustal extension (Be'eri-Shlevin et al., 2009a; El-Bialy, 2010; Eyal et al., 2010; Johnson et al., 2011; Ali et al., 2013; Azer, 2013; El-Bialy and Omar, 2015).

Compared to other juvenile continental crusts, the ANS is typified by a considerable emplacement of granitic plutons. In Sinai, granitoids are more prevalent than any other region of the ANS, comprising nearly 70% of the outcropping shield basement (Bentor, 1985). The granitoids

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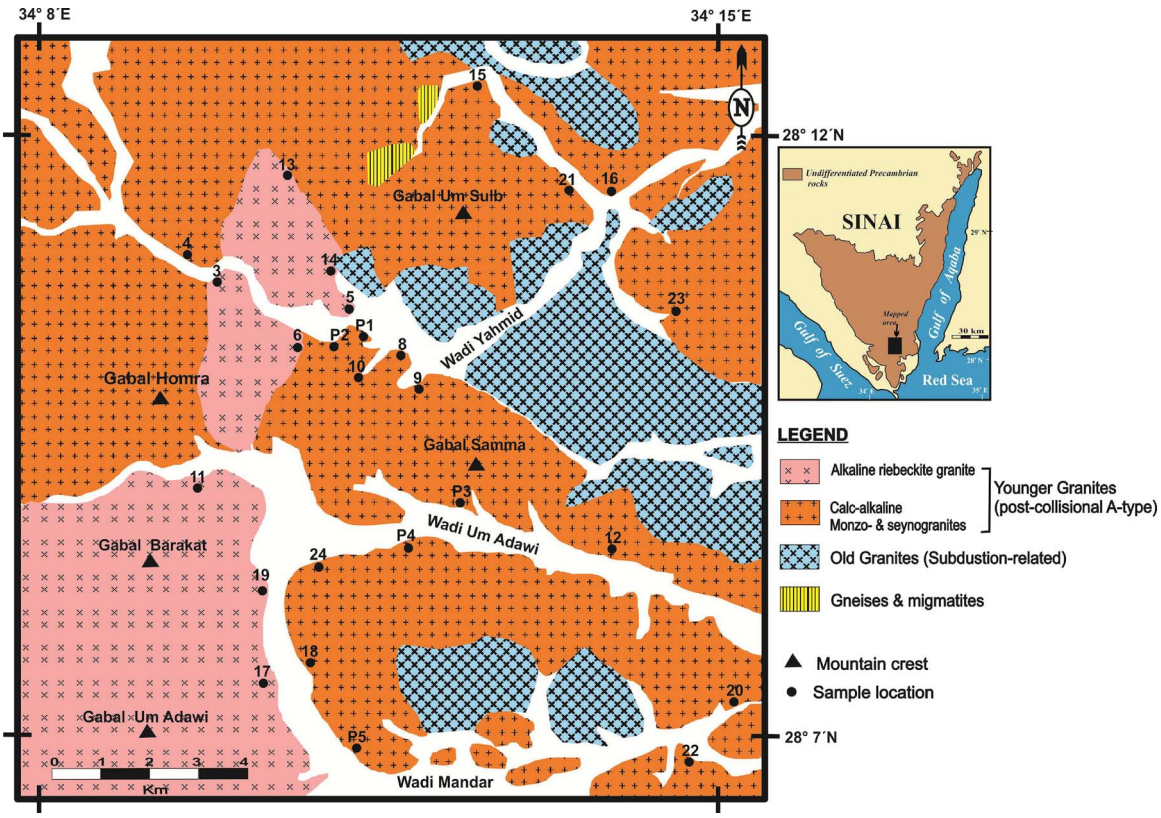

Fig. 1. Geological map of the Wadi Um Adawi-Wadi Yahmed area, Sinai (modified after El-El-Bialy and Streak, 2009). The inset figure on the left is a map of the Sinai Peninsula showing the regional extent of the Neoproterozoic basement rocks and the location of the mapped area.

of the ANS include two distinctive groups: (1) Older Granites (820–620 Ma) comprising calc-alkaline I-type granitoid rocks (quartz diorite- granodiorite) that were evolved in orogenic volcanic arc settings (Hussein et al., 1982; Stern and Hedge, 1985; Hassan and Hashad, 1990; Stern, 1994; Moussa et al., 2008) and (2) Younger Granites (610–590 Ma) comprising highly fractionated calc-alkaline and alkaline A-type granites, and are believed to be emplaced throughout the post-collisional phase of the shield evolution (Hassan and Hashad, 1990; Beyth et al., 1994; Moussa et al., 2008; Ali et al., 2009; Eyal et al., 2010).

With regard to natural radioactivity, granitoids display high concentrations of U and Th relative to the exceedingly low contents observed in other crustal and mantle rocks. Thorium and uranium contents in granitoid rocks are intimately linked to their mineral compositions. They occur primarily in accessory minerals, the commonest of which are uraninite, thorite, pyrochlore monazite, allanite, xenotime, zircon, titanite, apatite, and Fe-Ti oxides (Pagel, 1982).

The mainstream of radioactive occurrences in the ANS rocks of Egypt is found in the post-collisional Younger Granites as well as their associated pegmatites (Hussein and Sayyah, 1992; Ibrahim et al., 2000; Ali et al., 2008; Raslan, 2009; Raslan et al., 2010; El Feky et al., 2011; Raslan and El-Feky, 2012; Abu El-Leil et al., 2015). Radioactive Younger Granite pegmatites have been identified in many localities, both in the Eastern Desert of Egypt and Sinai (Ali et al., 2008; Esmail and Moharem, 2009; Raslan et al., 2010; Ragab, 2011; El Gharbawy and Maadawy, 2012; Elnahas, 2012).

In this paper, we present the results of comprehensive field and petrographic studies and new whole-rock geochemical data for the Younger Granites of Wadi Yahmed- Wadi Um Adaw area, Sinai, in order to elucidate their petrogenesis and tectonic setting. Also, characterization of the associated radioactive mineralization is attained through gamma-ray spectrometry, chemical and mineralogical investigations.

2. Geological setting

The Yahmid-Um Adawi area, located in the southeastern part of Sinai Peninsula, is a mountainous rugged terrain consisting mainly of granitoid rocks, with minor much older metamorphosed basement units (Fig. 1). The exposed granitoids in this area have been differentiated into two rock unites; the Older Granites and Younger Granites (El-Bialy, 2004). The Younger Granites (YG), the target of this study, are further distinguished into two coeval Late Neoproterozoic post-collisional alkaline and calc-alkaline granitoid suites (608–580 Ma; 635–590 Ma, respectively) (Ali et al., 2009; Eyal et al., 2010).

Alkaline Younger Granites are exposed as an oval mass transected by Wadi Yahmid and also as a substantial part of the high mountainous Um Adawi pluton (1740 MASL) at the most southwestern corner of the mapped area (Fig. 1). They intrude the calc-alkaline granitoids at Wadi Yahmid with sharp contact, as well as sending numerous offshoots and apophyses (5–20 cm wide), that can be followed for a distance of several tens of meters, into them. At some mutual contacts, these granitoids display well-developed fine-grained chilled margins (×10 cm wide). The alkaline granitoids are medium to coarse-grained granular alkali-feldspar granites, of light gray to nearly white color in fresh samples that vary from leucocratic with scarce small amphiboles and/or biotite to relatively mafic with stout prismatic amphibole crystals.

The calc-alkaline Younger Granites are volumetrically the main rock unit outcropped in the study area. The landscape of these granitoids is much gentler, often forming moderately elevated mounts with gentle slopes covered by their rubbles. Contrary to the alkaline granites, they are transected by frequent quartz veins and dikes of variable composition and trends. These rocks are fine to coarse grained granular monzo- and syenogranites that display different shades of pink and red and mottled appearance due to interstitial mafics. However, porphyritic variety, with pink K-feldspar megacrysts, is not uncommon. Biotite is the sole mafic mineral and its relative abundance can differentiate them