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Origin of I- and A-type granitoids from the Eastern Desert of Egypt: Implications for crustal growth in the northern Arabian–Nubian Shield

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Abstract

I- and A-type granitoid rocks, emplaced during pre- and post-collision stages, respectively, of the Neoproterozoic Pan-African Orogeny, are widely distributed in the Eastern Desert of Egypt, constituting ~60% of the basement outcrop. Petrological and geochemical data are presented for a selection of the two groups, the I-type, El Bula tonalite–granodiorite suite, and the A-type, Lômân alkali granites, with the aim of discussing their origin and geotectonic implications. The El Bula (EB) rocks have geochemical characteristics of medium-K calc-alkaline, metaluminous to mildly peraluminous, granitoids formed in an island-arc environment. The Lômân (LM) granites display midalkaline, metaluminous, post-orogenic, A-type characteristics. With respect to the EB granitoids, the LM granites contain lower Al_2O_3, Fe_2O_3, MgO, MnO, CaO, TiO_2, Sr, Ba, and V, but higher Na_2O, K_2O, Nb, Zr, Th, and Rb. The I-type granitoids were presumably formed by high degrees of partial melting (~40%) of a mafic (amphibolitic), lower crustal source, whereas the A-type granites are derived from a tonalitic, middle crustal source, followed by some crystal fractionation. Such high degrees of partial melting attest to the large areal distribution of these rocks and require broad thermal anomalies, likely related to significant geodynamic features of the Arabian–Nubian Shield (ANS) evolution. We propose petrogenetic models involving an upwelling of hot asthenospheric mantle, due to oblique convergence during the pre-collision stage, and following a lithospheric delamination during the post-collision stage. Such asthenosphere uprise could account for the high crustal growth rate of the ANS.

Keywords: I- and A-type granites; Noeproterozoic; Geotectonics; Arabian–Nubian Shield; Egypt

1. Introduction

Understanding the origin of the granitoid rocks has important implications for the continental crust growth in general and for the Arabian–Nubian Shield (ANS) in particular. The Neoproterozoic ANS, extending over large areas in NE Africa and Arabia, was formed during the Pan-African Orogeny (900–550 Ma; Stern, 1994), which is considered as one of the most intensive episodes of continental crust formation in the Earth's history (Stein and Hofmann, 1994). The ANS was exposed as a result of rifting along the Red Sea. Lateral crustal growth through arc accretion has been proposed as the main mechanism for the evolution of the ANS (El Gaby et al., 1988; Kröner et al., 1994; Stern, 1994). Granitoids constitute about 60% of the basement outcrops in the Eastern Desert of Egypt, Saudi Arabia and Sudan while, further south in Ethiopia and Kenya, they decrease to ~30% of the total outcrop.

The ANS consists of dismembered ophiolite suites, meta-volcanosedimentary assemblages, metagabbro–diorite complexes and calc-alkaline granitoids formed during the pre-collision, i.e., arc, stage, ~870–650 Ma ago (Stern, 1994). A metamorphic event between 650 and 620 Ma has

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been considered to represent the collision stage during which Neoproterozoic arc terranes were accreted to the East Saharan Craton. Weakly deformed granodiorites (665–614 Ma) predominantly intruded during this stage (Stern and Hedge, 1985; Greiling et al., 1994). The Pan-African orogenic event in Egypt ended at about 615 Ma, and subsequent crustal uplifting and extensional collapse occurred within the 610–550 Ma time span (Stern, 1994; Greiling et al., 1994). This post-collision stage was characterized by the emplacement of large masses of mafic to felsic, K-rich, Dokhan volcanics (610–560 Ma) and shallow level A-type granites (610–550 Ma) (Stern and Hedge, 1985; Beyth et al., 1994).

Geological, petrological, and isotopic studies indicate the presence of two distinct types of granitoid rocks within the Egyptian basement complex: an older (850–614 Ma), also referred to as grey or syn-to late-orogenic, calc-alkaline diorite to granodiorite assemblage, and a younger (610–550 Ma), post-orogenic, alkali granite, syenogranite, and monzogranite association (Hassan and Hashad, 1990; Stern and Gottfried, 1986; Beyth et al., 1994). Based on mineralogy, geochemistry, source rocks and tectonic settings these granitoids have been further classified into I- and A-types (e.g., Hussein et al., 1982; El Gaby et al., 1990; Noweir et al., 1990). Numerous studies have been concerned with the petrogenetic and geotectonic evolution of the granitoid rocks from the ANS. However, controversy still persists on several important points, in particular their source regions and the role of fractional crystallization vs. crustal anatexis (e.g., Stern and Gottfried, 1986; Beyth et al., 1994). Also, much debate exists on the syn- vs. late-orogenic geotectonic setting for the calc-alkaline granitoids on the one hand, and post-orogenic vs. anorogenic (i.e., continental-rift) tectonic setting for the younger alkali granites in the other. Here we contribute to the resolution of this controversy by examining the geochemistry and petrology of a selection of the two major groups of granitoid rocks outcropping in the Eastern Desert of Egypt; the older group from the El Bula area (EB), and the younger group from the Lômân area (LM). Special emphasis is placed on their implications for the overall evolution of this segment of the ANS continental crust.

2. Field description and petrography

The El Bula and Lômân granitic plutons are located within the central and northern parts of the Eastern Desert of Egypt, respectively, which are two of the three basement provinces defined by Stern and Hedge (1985). The central part is characterized by the occurrence of a complete succession of the Egyptian Pan-African Neoproterozoic basement complex, comprising gneisses, ophiolitic rocks, island-arc meta-volcanosedimentary association, arc metagabbro–diorite complexes, syn- to late-orogenic calc-alkaline granitoids, post-orogenic alkaline granites and the Dokhan volcanics. However, ophiolites and island-arc volcanics are of limited distribution in the northern part.

2.1. The El Bula pluton

The Neoproterozoic rocks of the El Bula area have been mapped and studied by Akaad et al. (1973), El Gaby and Habib (1982), Takla et al. (1997), El Shazly and El Sayed (2000). The exposed rocks are represented by gneisses, metavolcanics, metagabbro–diorite complexes and the investigated syn-orogenic granitoids.

El Gaby et al. (1990) considered gneisses, exposed mainly in the basement domes, as a pre-Pan-African (continental) crust basement. The gnessies, exposed in the northern and western parts of the mapped area, represent the oldest rock unit (Fig. 1b). On the other hand, the El Bula granitoid rocks are the youngest unit as they intrude both the metavolcanics and metagabbro–diorite complexes. The contact is distinctly sharp and, in places, shows variable degrees of interaction against the associated metavolcanics and metagabbro–diorite complexes. Enclaves and xenoliths of metavolcanics within the granite are found near the contact (Takla et al., 1997). On the other hand, metagabbro–diorite complexes intrude the metavolcanics along a sharp contact. Granitic apophyses and veins are found in the metagabbros.

The EB granitoids form a pluton of slightly circular shape, occupying a total area of 25 km^2. The marginal parts of the intrusion commonly show a narrow zone of foliation, a few meters wide, and occasionally enclose spheroidal mafic enclaves arranged parallel to the contact (Akaad et al., 1973). NW trending faults are the conspicuous regional structure in the area (Fig. 1b).

Petrographically, the EB granitoids vary from tonalites to granodiorites. Tonalites consists essentially of plagioclase (48–55%), quartz (35–40%), biotite and hornblende (8–10%). K-feldspar, magnetite, titanite and zircon are accessory phases. Plagioclase, (An_{18-27}) shows lamellar twinning, in places zoned and commonly partially saussuritised. Quartz occurs as either embayed large crystals exhibiting undulotary extinction or interstitial grains. Biotite is the common mafic mineral forming homogeneous small flakes partly altered to chlorite. Hornblende occurs as long prismatic crystals frequently enclosing plagioclase crystals. Some of the tonalites are devoid of K-feldspar while others contain only subordinate, slightly corroded and sericitized, microcline. With increasing abundances of K-feldspar, tonalite grades into granodiorite. The major phases are plagioclase (An_{7-14}) (55%), quartz (24%), perthitic microcline and orthoclase (14%), and biotite (7%) in decreasing order of abundances.

2.2. The Lômân pluton

The Lômân pluton forms an elongated, NW trending block, displaying, in most cases, no apparent field relation with their country rocks on the surface. However, in the extreme northern and eastern parts of the mapped area