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Petrogenesis of A-type granites and origin of vertical zoning in the Katharina pluton, Gebel Mussa (Mt. Moses) area, Sinai, Egypt

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Abstract

The central pluton within the Neoproterozoic Katharina Ring Complex (area of Gebel Mussa, traditionally believed to be the biblical Mt. Sinai) shows a vertical compositional zoning: syenogranite makes up the bulk of the pluton and grades upwards to alkali-feldspar granites. The latters form two horizontal subzones, an albite–alkali feldspar (Ab–Afs) granite and an uppermost perthite granite. These two varieties are chemically indistinguishable. Syenogranite, as compared with alkali-feldspar granites, is richer in Ca, Sr, K, Ba and contains less SiO_2, Rb, Y, Nb and U; Eu/Eu* values are 0.22–0.33 for syenogranite and 0.08–0.02 for alkali-feldspar granites. The $\delta^{18}O$ (Qtz) is rather homogeneous throughout the pluton, 8.03–8.55‰. The $\delta^{18}O$ (Afs) values in the syenogranite are appreciably lower relative to those in the alkali–feldspar granites: 7.59–8.75‰ vs. 8.31–9.12‰. A Rb–Sr isochron ($n=9$) yields an age of 593 ± 16 Ma for the Katharina Ring Complex (granite pluton and ring dikes).

The alkali–feldspar granites were generated mainly by fractional crystallization of syenogranite magma. The model for residual melt extraction and accumulation is based on the estimated extent of crystallization (~ 50 wt.%), which approximates the rigid percolation threshold for silicic melts. The fluid-rich residual melt could be separated efficiently by its upward flow through the rigid clusters of crystal phase. Crystallization of the evolved melt started with formation of hypersolvus granite immediately under the roof. Fluid influx from the inner part of the pluton to its apical zone persisted and caused increase of P_{H2O} in the magma below the perthite granite zone. Owing to the presence of F and Ca in the melt, P_{H2O} of only slightly more than 1 kbar allows crystallization of subsolvus Ab–Afs granite. Abundance of turbid alkali feldspars and their $^{18}O/^{16}O$ enrichment suggest that crystallization of alkali-feldspar granites was followed by subsolvus fluid–rock interaction; the $\delta^{18}O$ (Fsp) values point to magmatic origin of fluids.

The stable and radiogenic isotope data [$\delta^{18}O$ (Zrn) = 5.82 ± 0.06‰, I_{Sr} = 0.7022 ± 0.0064, ε_{Nd} (T) values are +3.6 and +3.9] indicate that the granite magma was generated from a ‘juvenile’ source, which is typical of the rocks making up most of the Arabian–Nubian shield.

Keywords: A-type granite; Alkali-feldspar granite; Vertical zoning; Fractional crystallization; Oxygen and Sr–Nd isotopes

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1. Introduction

The worldwide distribution of A-type granites has been recognized more than 20 years ago (Loiselle and Wones, 1979; White and Chappell, 1983). The composition of A-type granites is diverse; they comprise syenogranite, peralkaline and alkali-feldspar granite and syenite, rapakivi granite, monzogranite and F-rich topaz granite (e.g. Collins et al., 1982; Whalen et al., 1987; Eby, 1992; Whalen et al., 1996; Patiño Douce, 1997). Therefore, along with the problem of the origin of the A-type granites (e.g. Whalen et al., 1987; Eby, 1990; Whalen et al., 1996; Wu et al., 2002; Bonin, 2004, and many others), possible genetic links between the different varieties of the A-type granites are of particular interest. In the vast crustal provinces of Central Asia and the Arabian–Nubian Shield (Bentor, 1985; Wickham et al., 1995; Litvinovsky et al., 2002; Jahn, 2004) three rock types are dominant among the A-type granites: metaluminous syenogranite, alkali-feldspar (mostly perthitic) granite and peralkaline granite. Close consanguinity of alkali-feldspar and peralkaline granites is demonstrated in many localities (e.g. Zanvilevich et al., 1995; Whalen et al., 1996; Jahn et al., 2000; Litvinovsky et al., 2002; Jahn, 2004). However, the nature of links between silicic magmas, forming alkali-feldspar granite and oligoclase bearing syenogranite, has not been resolved.

The Katharina pluton is a central granite pluton of the Neoproterozoic Katharina Ring Complex located in the southern Sinai Peninsula, Egypt. It is made up of syenogranite and alkali-feldspar granite. The two rock types are confined to different levels of the pluton and thus define its vertical zoning. In this paper, we present chemical and isotope data to constrain the likely processes responsible for the zoning of the Katharina pluton and formation of alkali-feldspar granite.

2. Geological setting

The Katharina Ring Complex is a typical Late Pan-African granitoid ring complex in the Arabian–Nubian Shield. Along with numerous A-type granite plutons, it was formed in the last stage of the Shield evolution, when a fundamental transition in tectonic style, from compressional to extensional, occurred 620–600 My ago (Gass, 1982; Stern et al., 1984; Bentor, 1985; Kröner et al., 1987; Stern, 1994; Genna et al., 2002; Meert, 2003). The Katharina Complex is situated in the high mountainous area of the Sinai Peninsula (Fig. 1). Gebel Mussa, the mountain in the central part of the Complex, is traditionally believed to be the biblical Mount Sinai. The total area of the Complex is over 400 km^2. Country rocks include a volcaniclastic suite (Rutig volcanics), a calc-alkaline plutonic series represented by diorite and various granites, and a granitic gneiss.

The formation of the Katharina Ring Complex occurred in three stages. It commenced with the extrusion of the Katharina volcanics including peralkaline ignimbrite and trachyrhyolite. Along with flows, tuffs and volcanic breccia, a number of subvolcanic bodies of peralkaline granophyre and quartz syenite porphyry were emplaced (Goor, 1982). Two ring dikes mark the second stage of the Complex formation. The larger Outer Ring Dike is about 30 km in diameter and up to 1.5 km wide. It is steeply dipping at an angle of 70–80° inward and is intruded by the Katharina pluton. The dike is built by emplacement of quartz monzonite porphyry, quartz syenite porphyry and alkali-feldspar granophyre (Fig. 1). The Inner Ring Dike is similar in composition. At present only the eastern half of the Inner Ring Dike is preserved to the south of Gebel Mussa (Fig. 1); the western half was eliminated by the intrusion of the Katharina pluton.

The emplacement of the *Katharina pluton* occurred in the third stage of development of the Complex. The pluton is roughly oval-shaped, with NE–SW orientation, and occupies an area of 210 km^2. Several small stocks that are likely projections of a larger unexposed body accompany the pluton. The pluton has a fairly flat upper surface and steeply dipping walls (Fig. 2, cross section). In the southwestern part (area of Gebel Bab) a projection of 4 by 3 km in area and 300 m high is inferred. At the northern end, the pluton intrudes the country rocks as a dike more than 1 km wide that narrows gradually over a distance of 20 km into a horse-tail splay of small dikes about 5 m wide. The contact of granites with country rocks is sharp, without evidence of metasomatic alteration. In the 40–60 m thick marginal zone below the flat roof the grain size of the granite slightly decreases and irregular patches of porphyritic varieties appear. Porphyritic varieties are characteristic of all types of granites making up the pluton. Plutonic rocks are cut by pegmatite veins of a few decimeters to few dozen meters, and narrow aplite and microgranite dikes. Not infrequently pegmatites form lenses and pockets in granite. During the Neogene the pluton was tilted about 5° to the north and its eastern part was uplifted by ~ 1 km along a major fault (Eyal and Hezkiyahu, 1980).

The granite was emplaced at shallow depth, as evidenced by fine-grained and porphyritic marginal zones, as well as by the thickness of the volcanic roof that is slightly more than 1–1.5 km (Eyal and Hezkiyahu, 1980). Judging from the size of the volcanic caldera