Gondwana Research 25 (2014) 1570–1598

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

SIMS zircon U–Pb and mica K–Ar geochronology, and Sr–Nd isotope geochemistry of Neoproterozoic granitoids and their bearing on the evolution of the north Eastern Desert, Egypt

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ARTICLE INFO

Article history:
Received 20 November 2012
Received in revised form 23 May 2013
Accepted 1 June 2013
Available online 1 July 2013

Handling Editor: A.S. Collins

Keywords:
Post-collision magmatism
Sr–Nd isotopes
NED
Lithospheric mantle
Delamination

ABSTRACT

Granitic rocks are commonly used as means to study chemical evolution of continental crust, particularly, their isotopic compositions, which reflect the relative contributions of mantle and crustal components in their genesis. New SIMS and K–Ar geochronology, isotope, geochemical, and mineral chemistry data are presented for the granitoid rocks located in and around Gabal Dara in the Northern Eastern Desert of Egypt. The granitoid suite comprises quartz diorites, Muscovite (Mus) trondhjemites, and granodiorites intruded by biotite-hornblende (BH) granites and alkali feldspar (AF) granites. Mus trondhjemite, granodiorite and BH granite exhibit I-type calc alkaline affinities. Mus trondhjemite and granodiorite show medium-K calc-alkaline and metaluminous/mildy peraluminous affinities, whereas BH granites have high-K calc-alkaline and metaluminous character. Concordant $^{206}Pb/^{238}U$ weighted mean ages together with geochemical peculiarities suggest that Mus trondhjemites (741 Ma) followed by granodiorites (720 Ma) are genetically unrelated, and formed in subduction-related regime by partial melting of lower oceanic crust together with a significant proportion of mantle melt. The genesis of Mus trondhjemites is correlated with the main event in the evolution of the Eastern Desert, called "~750 Ma crust forming event".

The field and geochemical criteria together with age data assign the high-K calc-alkaline BH granites (608–590 Ma) and alkaline AF granites (600–592 Ma) as post-collisional granites. The differences in geochemical traits, e.g. high-K calc-alkaline versus alkaline/peralkaline affinities respectively, suggest that BH granites and AF granites are genetically unrelated. The age overlap indicating coeval generation of calc-alkaline and alkaline melts, which in turn suggests that magma genesis was controlled by local composition of the source. The high-K calc-alkaline BH granites are most likely generated from lithospheric mantle melt which have been hybridized by crustal melts produced by underplating process. AF granites exhibit enrichment in K_2O, Rb, Nb, Y, and Th, and depletion in Al_2O_3, TiO_2, MgO, CaO, FeO, P_2O_5, Sr, and Ba as well as alkaline/peralkaline affinity. These geochemical criteria combined with the moderately fractionated rare earth elements pattern ($La_N/Yb_N = 9–14$) suggest that AF granite magma might have been generated by partial melting of Arabian–Nubian Shield (ANS) arc crust in response of upwelling of hot asthenospheric mantle melts, which became in direct contact with lower ANS continental crust material due to delamination. Furthermore, a minor role of crystal fractionation of plagioclase, amphibole, biotite, zircon, and titanomagnetite in the evolution of AF granites is also suggested. The low initial $^{87}Sr/^{86}Sr$ ratios (0.7033–0.7037) and positive $\varepsilon_{Nd}(T)$ values (+2.32 to +4.71) clearly reflect a significant involvement of depleted mantle source in the generation of the post-collision granites and a juvenile nature for the ANS.

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http://dx.doi.org/10.1016/j.gr.2013.06.006

1. Introduction

Eastern Desert of Egypt experienced successive major tectonic events during the Late Neoproterozoic Pan-African orogeny (PAO) including subduction, accretion, and extension (rifting) processes together with an intervening collisional event (Stern, 1994). This event yielded widely distributed granitoids, as an outstanding feature of the late development of the PAO, especially in its northern part, which is the Arabian–Nubian Shield (ANS). The ANS consists dominantly of juvenile crust formed through accretion of intra-oceanic arcs ± oceanic plateaus during 880 to 630 Ma (Stern et al., 2010). During the collisional stage of the Pan-African Orogen (PAO), huge volume of granitic rocks intruded into the pre-existed juvenile crust. Another prominent felsic igneous activity occurred in the post collisional-extension stage (~600 Ma; Kröner et al., 1987; Harris et al., 1993; Stein and Goldstein, 1996). Granitic rocks in the PAO form ~50% of the basement in the Northern Eastern Desert (NED) of Egypt and southern Sinai, which comprises the extreme northwestern tip of the ANS and which is the location of the Jabal Dara area presented here (Fig. 1). The Eastern Desert basement represents a typical example of an accretion to collisional orogen, with tectonic evolution from an oceanic lithosphere, through accretions of intra-oceanic island arcs to a continental crust formed by continental collision. Ages of the plutons in the Eastern Desert basement gradually become younger toward the north, an area which is occupied by unmetamorphosed volcanic successions of Dokhan Volcanics and volcanoclastics molasse sediments of the Hammamat Group, both intruded by granitoids and associated dykes (Stern and Gottfried, 1986). The episode that created Dokhan Volcanics and Hammamat Group is much younger than that of the emplacement of the older (syn- to late-orogenic) but it is intervened or slightly earlier than the younger (post-collision) granites' time (Breitkreuz et al., 2010; Eliwa et al., 2010).

Granitoid rocks in the Eastern Desert of Egypt have long been classified as syn- to late-orogenic granitoids (Older granitoids) and post-orogenic to anorogenic granites (Younger granites) (Hume, 1935; El-Ramly and Akaad, 1960; El Gaby, 1975; Akaad and Noweir, 1980). The older granitoids range from quartz diorite to rare true granite (predominantly muscovite trondhjemite, tonalite, and granodiorite). These are I-type, subduction-related plutons, with ages between 870 and 614 Ma using Rb–Sr and U–Pb methods (Stern and Hedge, 1985; Hassan and Hashad, 1990; Kröner et al., 1994; Stern, 1994). Younger granites are mainly monzogranites, syenogranites, and alkali-feldspar granites, I-type (partly subduction-related) but mainly alkaline to peralkaline A-type plutons, formed between 610 and 550 Ma based on the Rb–Sr and U–Pb dating (Stern and Hedge, 1985; Hassan and Hashad, 1990; Beyth et al., 1994), and developed during extension. Anyhow, some granitoid rocks in the Dara area and to the north around G. Gharib have been dated; Abdel-Rahman and Doig (1987) reported whole rock Rb–Sr ages for gabbro-diorite-tonalite (881 Ma), granodiorite–adamellite–leucogranite (552 Ma) and Mus trondhjemites (516 Ma) in the Ras Gharib segment. Stern and Hedge (1985) reported a Rb–Sr model age of 596 Ma for G. Dara granites.

There is a consensus that the older granitoids and early younger granites were related to subduction at active-continental margin (Abdel-Rahman, 1990), but the circumstance of emplacement of the younger granites is still controversial, whether their formation was related to subduction, collision, transtension, or rifting. To examine and place new constraints on the petrogenesis and tectonomagmatic evolution of both older and younger granites, the Dara granitoids were selected. The granitoids in the Dara area are an excellent example and of particular interest since they contain various plutons composed largely of syn- to late-tectonic granitoids of diorite, Mus trondhjemites, and granodiorite intruded by biotite-hornblende (BH) granite and alkali-feldspar (AF) granite. Also the suspect range of previous ages is one of the reasons to do precise dating. To address this problem of the origin of the Egyptian granitoids, we present new mica K–Ar and SIMS zircon U–Pb ages, geochemistry (whole-rock major, trace, and rare earth elements), Sr–Nd isotope composition, petrological characteristics, and microprobe mineral data from granitoid rocks of the Dara area. SIMS U–Pb data have implications for the existence (or absence) of pre-Neoproterozoic crust within the basement of the Eastern Desert. We discuss the petrogenesis of the Dara granitoids in a regional geodynamic context.

2. Geological setting

Dara area is located in the Northern portion of the Eastern Desert, which together with Southern Sinai constitutes the extreme northwestern part of the ANS. The Eastern Desert (Fig. 1b) has been subdivided into three distinctive basement terranes (Stern and Hedge, 1985): North Eastern Desert (NED), Central Eastern Desert (CED) and South Eastern Desert (SED). Ophiolites and gneissic rocks are common in the SED, the metasediments, metavolcanics and serpentinites of oceanic affinities, while granites, gneisses, and volcanosedimentary successions of continental affinities are more voluminous in the NED (Stern and Hedge, 1985).

The Dara area collectively constitutes one of the largest exposures of granitoid rocks in the NED, which is traversed by abundant individual dykes and dyke swarms of various compositions, trends, and ages. The Neoproterozoic basement of the study area, located between latitudes 27° 48′ to 28º 00′ N, and longitudes 32° 50′ to 33° 05′ E (Fig. 1), comprises, from old to young, metavolcanics, quartz diorites, muscovite (Mus) trondhjemites (termed following Abdel-Rahman and Doig, 1987), granodiorites, Dokhan Volcanics, Hammamat sediments, biotite-hornblende granites (BH granites), alkali feldspar granites (AF granites), and dykes. Together, Gabal (G.) Dara and G. Um Suwasi (north of the mapped area) form a NNW/SSE elongated, medium to high mountainous, granitic pluton terrane with maximum dimensions of ≈30 km N/S and 6 km E/W. Francis (1972) mapped G. Dara as composed mainly of Gattarian pink biotite granite with pink white muscovite–biotite granodiorite, Dokhan Volcanics/Hammamat sediments and biotite-hornblende granodiorite. El-Mansi et al. (2004) classified G. Dara granites as syenogranites and considered them to be formed by anatexis of pre-existed crustal material in the late-collision stage. The area is mainly traversed by many faults of different directions, N–S, NW–SE, NE–SW, and E–W.

Metavolcanics are the oldest rock unit in the basement complex of the investigated area. To the northwest, partly to the middle, and in the south of the Dara area, the metavolcanics have been intruded by a series of granitoid rocks including quartz diorites, granodiorites, and finally by AF granites with sharp contacts partially obscured by a thick cover of rock debris.

Quartz-diorites are hard, massive, dark gray, and medium- to coarse-grained rocks exhibiting spheroidal weathering, and variably extents of deformation, shearing and gneissosity. These rocks are mainly exposed in the middle of the mapped area with few outcrops in association with metavolcanics in the northwest. Quartz diorites are of low to medium-lying relief, most probably due to extensive erosion over long periods. They are unconformably overlain by Dokhan Volcanics and by Hammamat sediments (Fig. 2a), and are intruded by granodiorites with sharp contact to the south of G. Dara.

Mus trondhjemites form pale gray huge complexes in the central Dara area and extend as scattered low-lying hills to the west. They are located along and at the crossing of N–S and E–W directed faults. They are medium- to coarse-grained, massive leucocratic whitish rocks with (very) coarse muscovite flakes. They are intruded by BH and AF granites with sharp intrusive contacts, by quartz-diorites along gradational intrusive contact, and are unconformably overlain by volcanosedimentary successions. They are commonly dissected by a series of felsic, intermediate and alkaline dykes of different trends and variable thickness (Fig. 2b).

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