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The petrogenesis of calc-alkaline granites from the Elat massif, Northern Arabian–Nubian shield

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ABSTRACT

The petrogenesis of calc-alkaline granitic rocks from the northern part of the Arabian–Nubian shield (ANS) was studied by analyzing the mineralogy, petrography, major and trace element compositions and $^{87}Sr/^{86}Sr$ isotope ratios in suites of late Proterozoic granitoides, diorites and mafic xenoliths from Elat massif. The granites and mafic xenoliths lie on linear correlations in the major element variation diagrams and in the Rb–Sr isotope (isochron) diagram, where they yield an isochron age of 621 ± 12 Ma and initial ratio of $^{87}Sr/^{86}Sr = 0.7034 \pm 2$. Our interpretation is that the two groups are cogenetic and that the isochron indicates the formation age of mafic to granitic magmas. Several petrogenetic models were examined to explain this genetic relation. We conclude that the chemical and isotopic data are best satisfied by crustal anatexis – partial melting model. The calc-alkaline granitic magmas (such as those comprising the Elat granitic plutons) are produced by partial melting of hydrous mafic crustal rocks. Non-modal batch melting of an amphibolitic source (formed earlier above a subduction zone) could produce the suite of calc-alkaline felsic magmas, leaving a residual mafic rocks that were later trapped as xenoliths. We assume that the mafic mineral assemblage represented by the most mafic xenolith was in equilibrium with Elat granite. A melting model of a hydrous amphibolitic crustal source predicts REE patterns similar to Elat granite. The initial $^{87}Sr/^{86}Sr$ ratio of the Elat calc-alkaline granites and mafic xenoliths is consistent with the anticipated value of the juvenile magmas (~0.7034), indicating that the parental basaltic magmas that formed the amphibolitic source were derived from an enriched-mantle reservoir.

1. Introduction

The average composition of the upper continental crust is granodioritic, reflecting the important role that calc-alkaline granitic magmas take in the construction of the crust, besides the subduction related basaltic–andesitic magmas (Taylor and McLennan, 1991). Yet, the petrogenetic conditions and geodynamic relation of the calc-alkaline granites are still open issues and surprisingly limited number of geochemical–petrological works were devoted to understanding the mechanism and geodynamic environment of production and emplacement of these magmas (e.g. Wyllie et al., 1976; Wyllie, 1984; Chappell et al., 1987; Borg and Clynne, 1998; Farahat et al., 2007, 2011; Avigad and Gvirtzman, 2009; Smithies et al., 2011). Unresolved issues include the composition and location of the sources of the calc-alkaline magmas, the sources of heat that are required for the melting, the mechanism of fractionation that forms the calc-alkaline series (e.g. from gabbro, diorite, tonalite to granodiorite and granite), the mechanism of emplacement of vast amounts of granitic plutons and their place in the chronology of events during the formation of juvenile segments of continental crust.

This work focuses on the petrogenesis of late Proterozoic calc-alkaline granites and related mafic rocks from the Elat massif located at the northern tip of the exposed Arabian–Nubian shield (ANS). The ANS was formed during the late Proterozoic Pan African events comprising magmatic and metamorphic terrains that, in part, represent juvenile additions to the continental crust [see comprehensive reviews of the genesis and history of the ANS in Bentor (1985) and Stern (2004)]. The main idea that stands in the background of this work is to examine the geochemical relationship between the mafic and felsic members of the Elat calc-alkaline series assuming that they are petrogenetically related and thus their "related" geochemical properties can be of use to establish their sources and petrogenesis.

2. Geological background

The Elat massif was uplifted during the late Neogene-Quaternary providing excellent fresh exposures of the late

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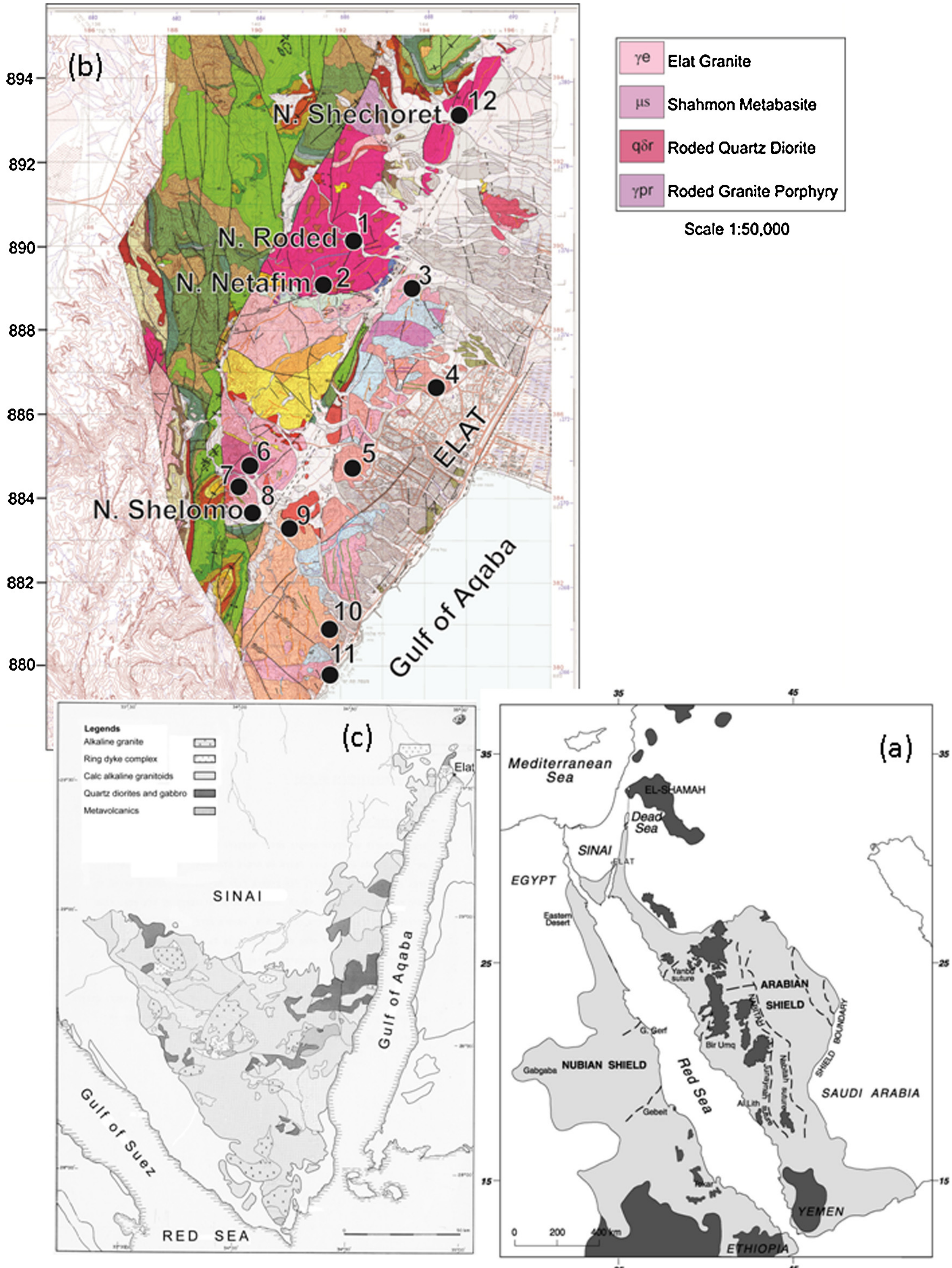

Fig. 1. (a) The exposures of the Arabian–Nubian shield (ANS) on both sides of the Red Sea; (b) geological map of the Elat massif area (Beyth et al., 2012). Sampling locations are also shown (site numbers are listed in Table 1); (c) regional geological setting of the Arabian–Nubian shield and the Sinai Peninsula – Elat area. Most of the exposed shield at the Sinai Peninsula is covered with calc-alkaline granitic plutons and diorites.

Proterozoic Arabian–Nubian shield – ANS (Fig. 1) (Garfunkel, 1980, 2000; Bentor, 1985; Eyal et al., 2004). The Elat massif exposes rocks that comprise the three last phases in the general history and stratigraphy of the ANS. Rocks from the earliest phase in the history of the ANS that comprises oceanic magmatism are exposed only in the southern parts of the shield (e.g. Bentor, 1985; Stein and Goldstein, 1996; Stern and Johnson, 2010).

The three phases exposed in the Elat area are:

Phase II: Subduction-related calc-alkaline magmas, mainly volcanics (subsequently metamorphosed to meta-volcanics) were mainly produced between $\sim$870750 Ma. Thick sequences of calc-alkaline meta-volcanics are mainly exposed in the southern parts of the ANS. In the Elat massif the phase II calc-alkaline volcanics are represented by the Elat schists that were derived from andesitic