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A hybrid composite dike suite from the northern Arabian Nubian Shield, southwest Jordan: Implications for magma mixing and partial melting of granite by mafic magma

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ABSTRACT

The Arabian Nubian Shield is an exemplary juvenile continental crust of Neoproterozoic age (1000–542 Ma). The post-collisional rift-related stage (~610 to 542 Ma) of its formation is characterized among others by the intrusion of several generations of simple and composite dikes.

This study documents a suite of hybrid composite dikes and a natural example of partial melting of granite by a mafic magma from the northernmost extremity of Arabian Nubian Shield in southwest Jordan. The petrogenesis of this suite is discussed on the basis of field, petrographic, geochemical, and Rb/Sr isotopic data. These dikes give spectacular examples of the interaction between basaltic magma and the granitic basement. This interaction ranges from brecciation, partial melting of the host alkali feldspar granite to complete assimilation of the granitic material. Field structures range from intrusive breccia (angular partially melted granitic fragments in a mafic groundmass) to the formation of hybrid composite dikes that are up to 14 m in thickness.

The rims of these dikes are trachyandesite (latite) with alkali feldspar ovoids (up to 1 cm in diameter); while the central cores are trachydacite to dacite and again with alkali feldspar ovoids and xenoliths from the dike rims.

The granitic xenoliths in the intrusive breccia have been subjected to at least 33% partial melting.

A seven-point Rb/Sr isochron from one of these composite dikes yields an age of 561 ± 33 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70326 ± 0.0003 (2σ) and MSWD of 0.62.

Geochemical modeling using major, trace, rare earth elements and isotopes suggests the generation of the hybrid composite dike suite through the assimilation of 30% to 60% granitic crustal material by a basaltic magma, while the latter was undergoing fractional crystallization at different levels in the continental crust.

1. Introduction

Magma mingling and mixing are widely known and accepted mechanisms for the diversification of igneous rocks (e.g., Sparks and Marshall, 1986). A great deal of work has been done to explain the field, petrological, and geochemical features caused by these processes. Magma mixing and interaction between contemporaneous magmas range from simple complete and homogenous mechanical mixing of two magmas through the production of heterogeneous daughter magma to diffusive exchange between the two melts (Baxter and Feely, 2002). Although it is well accepted that hybrid rocks represent different levels of interaction between mafic and felsic magmas, the conditions and mechanisms of this interaction are still controversial (Slaby and Martin, 2008).

While the field, petrographic, and geochemical evidence for incorporation of crustal material into a mafic magma is beyond debate, the mechanism of this incorporation is still less well understood (Glazner, 2007). Possible mechanisms according to Glazner (op.cit) comprise: 1) magma mixing, where a homogenous magma is formed that contains crystals from both end-members and in this case the term hybridization applies; 2) selective assimilation (extraction of a melt phase from a solid rock); 3) bulk assimilation (dissolution of solid crustal rocks in magma); and 4) disaggregation (xenoliths disaggregate into constituent minerals without dissolution).

When mafic magma is intermingled with felsic magma, high proportions (typically >50%) of the former are required for mixing to take place (Sparks and Marshall, 1986).

Evidence for magma mixing can quite often be recognized during field observation, in particular when contrasting compositions interact. This also has supporting evidence from geochemical and isotopic data (e.g., linear trends on Harker variation diagrams; Brueseke and Hart, 2008).

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Equally important is understanding the role of mafic magmatism in the generation of rocks of intermediate composition (those with SiO_2 between 52 and 64 wt.%). The generation of these magmas in intracontinental setting, where bimodal magmatism generally dominates, has been attributed to a complex combination of fractional crystallization (FC) and assimilation fractional crystallization (AFC) processes (Grove et al., 1988; Brueseke and Hart, 2008 and references therein).

Simultaneous fractional crystallization and crustal assimilation (FCA) are recognized in almost all mantle-derived magmas emplaced in the crust of the Earth (Tegner et al., 2005). This fractional crystallization takes place either at the base of the continental crust and/or at different crustal levels and could have supplemented the necessary heat for assimilation of granite. Rate of assimilation is normally expressed as the ratio of the rate of mass assimilated to the rate of mass crystallized (DePaolo, 1981).

Numerous studies have reported melting of crustal rocks by basic intrusions (Hersum et al., 2007 and references therein).

The granitoids that dominate the Neoproterozoic basement complex in south Jordan (Fig. 1) are cross-cut by several generations of dikes of variable composition from mafic to felsic (e.g., Jarrar et al., 2004). The youngest generation of these dikes dated by K–Ar at about 545 Ma has a basaltic composition and was produced by 5% partial melting of a metasomatized phlogopite-bearing lherzolite (Jarrar, 2001). Jarrar (op.cit.) demonstrated that this dike suite is highly fractionated and concluded that the intra-suite geochemical features are explicable by 64% fractional crystallization of olivine, pyroxene, plagioclase and titanomagnetite and possibly other accessories like apatite at a later stage. Another important field aspect of this generation of dikes is that it cuts all other Neoproterozoic magmatic rocks in south Jordan, and it is almost the only dike phase that cuts the final intrusive magmatic phase of reddish A-type granites (~600–585 Ma; Moshtaha, 2011) in the northern Arabian–Nubian Shield

Several dikes belonging to this generation and outcropping in the area of Quweira (Fig. 1), show evidence of partial melting of the granitic crust, which resulted in the formation of intrusive breccia (basaltic material with angular pieces of partially melted granite of variable sizes); while other dikes exhibit magma mixing and hybridization that gave rise to typically composite hybrid dikes with latite rims and dacite and trachydacite cores.

In this paper an attempt is made to quantify the assimilation and magma mixing in the formation of hybrid composite dikes. It should give an excellent example of how mantle-derived magmas interact and incorporate the continental crust during their ascent to the surface; and how partial melting of granite xenoliths in a basaltic

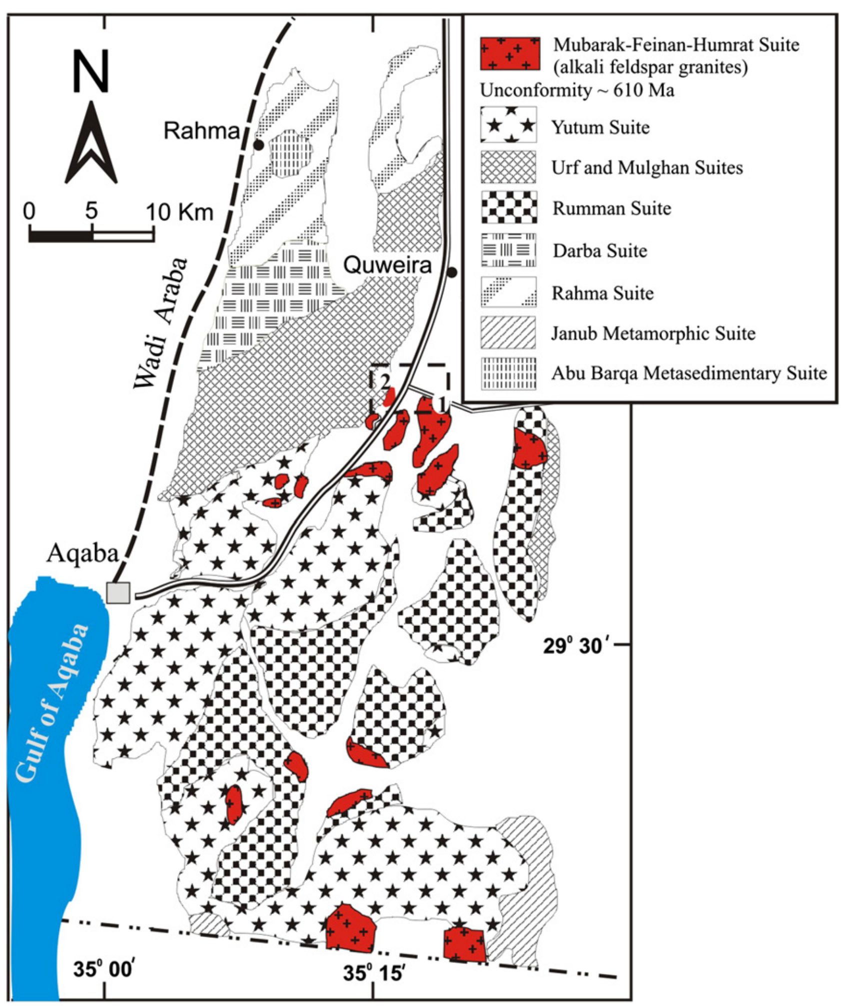

Fig. 1. A simplified geologic map of the Neoproterozoic in southwest Jordan showing the location of the area of study. After Ibrahim and McCourt, 1995.