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Petrology of the Motaghairat mafic–ultramafic complex, Eastern Desert, Egypt: A high-Mg post-collisional extension-related layered intrusion

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ABSTRACT

The geodynamic settings of the Precambrian mafic–ultramafic complexes in the Eastern Desert of Egypt have important bearing on understanding the geotectonic evolution of the Arabian Nubian Shield. We present a detailed petrological study on a layered mafic–ultramafic intrusion that is located at the contact between the Precambrian continental crust and the Miocene Red Sea oceanic crust. The Motaghairat layered intrusion consists of basal lherzolite, orthopyroxenite, troctolite, olivine gabbro and anorthosite on the top. Variations in modal mineralogy and mineral chemistry along with the chemical composition of these units suggest their derivation from a common high-Mg tholeiitic parent melt through fractional crystallization processes. The parental magma was derived from a metasomatised mantle source. The primitive mantle-normalized patterns of the calculated melts exhibit enrichment in U relative to Th and Ba relative LREE which indicate that the enriched lithospheric mantle source was metasomatised by fluids derived from a subducted oceanic crust rather than by a sediment melt. Geological and petrological evidences suggest that the layered Motaghairat intrusion was emplaced during post-orogenic extension following subduction break-off and lithospheric delamination after the collision between the amalgamated island arc terranes and the Saharan Metacraton. The heat source required to melt the metasomatised lithospheric mantle was derived from the upwelling of hot asthenosphere after the subduction-break-off.

1. Introduction

Mantle-derived mafic–ultramafic magmas form in various tectonic settings and provide valuable information on plate tectonic processes and on Earth's evolution. In each setting, the geochemical criteria of magma offer hints on the chemical history of the source. Magmas generated in mid ocean ridges (MOR) form ophiolites and usually reflect previous partial melting events of the source. Those form in arc settings form concentrically zoned intrusions and reflect the subducted slab contribution to the source. Based on the distance from the magmatic arc, magmas generated in the backarc reflect variable input from the subducted slab (Pearce and Stern, 2006; Helmy et al., 2015). Ophiolitic successions are encountered along suture zones in orogenic belts as remnants of fossil oceanic lithosphere (Dilek and Furnes, 2011; Kakar et al., 2014). Alaskan-type mafic–ultramafic intrusions form along major structures (e.g. the Urals) and represent uplifted fragments of the deep levels of island arcs (Batanova et al., 2005; Helmy et al., 2014). Layered mafic–ultramafic intrusions are commonly exposed in cratons as well as orogenic belts as post-collision phases related to later extensional events (Seo et al., 2013) and are commonly attributed to mantle plume events (Pirajno, 2004; Mao et al., 2008). Indentifying the nature and geologic setting of mafic–ultramafic complexes is, therefore, crucial for the understanding of tectonic evolution of orogenic belts. In addition, the mafic–ultramafic intrusions are potential for chromitite and magmatic Ni–Cu-(PGE) sulfide deposits (e.g. Tistl, 1994; Helmy, 2004, 2005).

Mafic–ultramafic rocks are widespread in the Nubian Shield; field and geochemical data suggest that they were formed in various geologic settings. They comprise mantle and basal crustal

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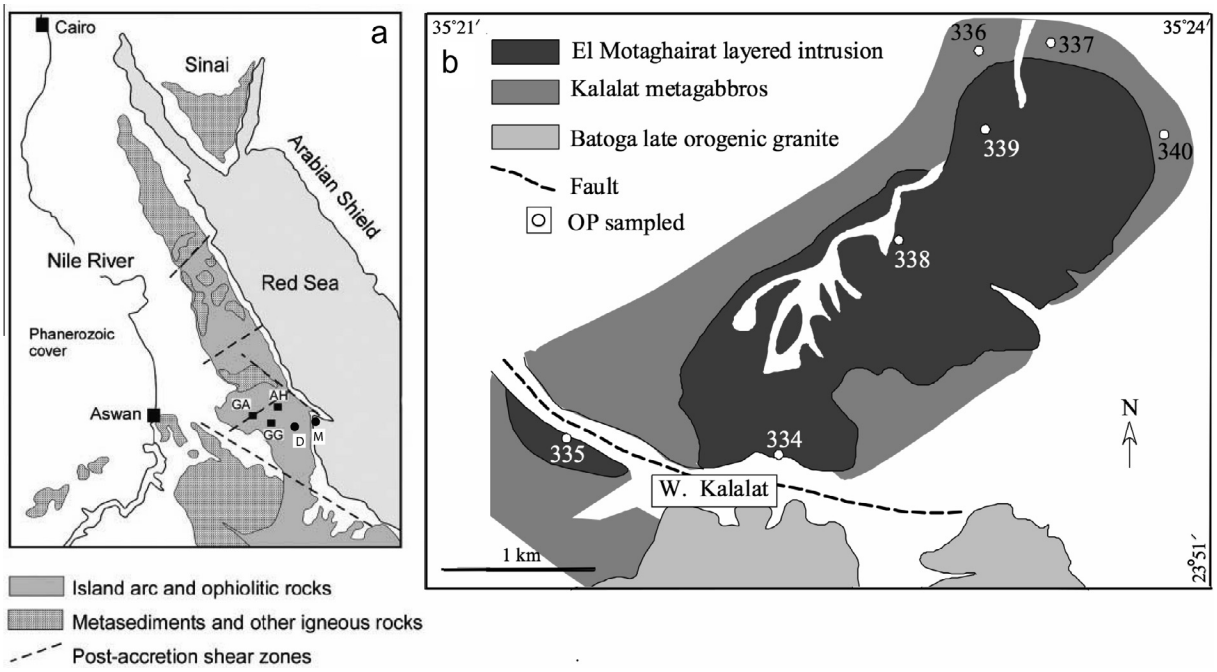

Fig. 1. (a) Distribution of Neoproterozoic rocks in the Eastern Desert of Egypt and location of non-ophiolitic mafic–ultramafic complexes. The Alaskan-type complexes; GG (El Genina El Gharbiya), GA (Gabbro Akarem), AH (Abu Hamamid) and high-Mg layered complexes; D (Gebel Dahanib); M (GebMotaghairat). (b) A simplified geologic map of the Motaghairat layered intrusion (modified after Elhaddad et al., 1984) with sample locations. Numbers correspond to observation points (see text for explanation).

sections of the Neoproterozoic ophiolitic complexes that occur along major suture zones trending N–S and NW–SE (Abd El-Rahman et al., 2009a, 2009b; Ahmed, 2013). Non-ophiolitic complexes comprise Alaskan-type and layered intrusions forming small elliptical bodies (Helmy and El Mahallawi, 2003; Ahmed et al., 2008; Abd El-Rahman et al., 2012a; Helmy et al., 2014, 2015). Alaskan-type complexes show a typical arc affinity and their magmas were separated from the mantle before 900 Ma (Farahat and Helmy, 2006; Helmy et al., 2014, 2015). The normal layered intrusions are komatiitic in composition (e.g. Dixon, 1981b); their age and mechanism of emplacement are poorly known. While these layered intrusions are distinct from the un-differentiated post-collisional gabbroic rocks (El-Mettwaly, 1992), their genetic relationship to the Alaskan-type complexes is not known.

In this contribution, we present the first detailed geological, mineralogical and geochemical data on one of the layered intrusions (Motaghairat intrusion). The Motaghairat intrusion (MI) is located at the transition between the cratonic Nubian Shield and the Miocene Red Sea oceanic crust (Fig. 1a). The objectives of this study are: (1) to understand the petrogenesis of the MI; (2) to predict the nature of the parent magma of this layered intrusion and evaluate its mantle source; (3) to understand the geodynamic processes under which the MI was formed.

2. Mafic–ultramafic rocks in the Nubian Shield

The Nubian Shield extends to the west of the Red Sea from the Eastern Desert of Egypt through the Sudan to Eretria. This shield is a major accretionary orogenic system formed through accretion and amalgamation of intra-oceanic island arcs and, finally, through collision with a continental margin of the Saharan Metacraton during the Neoproterozoic era (Abdelsalam and Stern, 1996; Kröner et al., 2007; Johnson et al., 2011). It is dominated by island arc volcanic and plutonic rocks, ophiolites and granitoids (Fig. 1a). There is over-whelming isotopic, trace element, and geochronological evidence that the continental crust of the Nubian Shield was juvenile and had been extracted from a depleted mantle during the Neoproterozoic Pan African orogeny (Stern and Hedge, 1985; Kröner et al., 1987; Stern and Kröner, 1993).

The mafic–ultramafic complexes represent petrologically important rock units in the northern part of the Nubian Shield; they were formed in various geologic settings. They comprise mantle and basal crustal sections of the Neoproterozoic ophiolitic complexes that occur along major suture zones trending N–S and NW–SE in the south and central Eastern Desert (Abd El-Rahman et al., 2009a, 2009b; Ahmed, 2013). Non-ophiolitic mafic–ultramafic complexes are represented by concentrically zoned (Alaskan-type) intrusions and layered intrusions occurring as small elliptical bodies along major structures (Helmy and El Mahallawi, 2003; Farahat and Helmy, 2006; Ahmed et al., 2008; Abd El-Rahman et al., 2012a). Alaskan-type complexes are known from Gabbro Akarem (Helmy and El Mahallawi, 2003), Abu Hamamid (Farahat and Helmy, 2006; Helmy et al., 2015) and Genina Gharbia (Helmy et al., 2014), they represent uplifted fragments of the deep levels of island arcs (Helmy et al., 2014). There are also the post-tectonic extensional related mafic complexes. They are younger than the ophiolitic and the Alaskan-type complexes. The age of this type is less than 640 Ma (Be'eri-Shlevin et al., 2009). These complexes are undeformed and unmetamorphosed and are almost devoid of ultramafic rocks (El-Mettwaly, 1992; Azer and El-Gharbawy, 2011). The magma type of this type varies from tholeiitic through calc-alkaline to alkaline. Be'eri-Shlevin et al. (2009) attributed such variation to coeval derivation from variable sources rather than formation in different tectonic settings. In addition to MI, few layered intrusions are known from south Eastern Desert; Dahanib (Dixon, 1981b) and Um Ginud (Ahmed, 1991). Another possible occurrence is the differentiated lherzolites of the Zabargad Island (Brueckner et al., 1995), although these rocks considered also as an asthenospheric mantle diaper intruding a Pan-African continental crust during the early stages of the Red Sea rifting (Bosch and Bruguier, 1998).