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Petrology of a Neoproterozoic Alaskan-type complex from the Eastern Desert of Egypt: Implications for mantle heterogeneity

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ABSTRACT

This paper details petrological and geochemical studies of an ultramafic–mafic intrusion in the Southern Eastern Desert of Egypt. The Dahanib complex shows a concentric zonation, from dunites at the core, through chromitites, clinopyroxene-rich dunites, wehrlites, harzburgites, gabbronorites and layered gabbros, to hornblende gabbros/diorites at the rim, similar to other Alaskan-type complexes. These lithologies typically feature cumulate textures and layering. Their pyroxenes (Mg#s, 0.54–0.94) evidence Fe, Mn and Na enrichment, but Al, Cr, Mg and Ti are depleted with differentiation. Their chromian spinels have a wide range of Cr# (0.31–0.61), along with high Ti and Fe, as a result of their origin through crystal accumulation and reaction with interstitial liquids. The clinopyroxenes (Cpxs) in peridotites and gabbroic rocks, which are high in REE concentration (2–100 times chondrite), are depleted in LREE relative to HREE and are similar to Cpx crystallized from asthenospheric melts. The mineral inclusions in spinel, the chemistry of Cpx in peridotites (rich in Al, Cr, Na, Ti and ΣREE $=$ 13.7), and the melts in equilibrium with Cpx suggest that the Neoproterozoic lithosphere were partially refertilized by trace asthenospheric melts. The early magmas were possibly enriched by Mg, Cr, Ni, Ti, V and Sr, while the evolved types were rich in Fe, Mn, Na, Li, Zr, Co and REE via crystal accumulation and the interaction with interstitial liquids. The Neoproterozoic sub-arc mantle in Egypt is chemically heterogeneous and generally low in Nb, Ta, Zr and K, due to the low solubility of HFSE in slab-derived fluids and no other external addition of these elements. The large variations in lithology and chemistry, as well as the occurrence of scattered chromitite clots in the Dahanib peridotites, are related to a continuous supply of primitive magmas and/or the reaction between interstitial liquids and early cumulus crystals during multistage fractional crystallization. The Dahanib Alaskan-type rocks were fractionally crystallized from the hydrous tholeiitic-basaltic melts associated with a continuous supply of primitive magmas at the mantle–crust boundary in a sub-arc setting. Their parental melts are a mixture of the sub-arc mantle-derived melts associated with trace asthenospheric melts from the mantle diapir. The changes in lithology type, mineral composition, and chemistry between the Dahanib intrusion and the nearest intrusions can perhaps be attributed to mantle heterogeneity by several mantle plumes and to slab-derived inputs. These two causes could explain the large variety of parental magmas for Alaskan-type intrusions. There is a genetic link between the origins of ophiolites and Alaskan-type complexes because both of them originated in the sub-arc setting and both exhibit extension characteristics and subduction-zone components.

1. Introduction

Alaskan-type rocks have been recognized in different orogenic belts from the Archean to Phanerozoic ages; they are less abundant in the Archean age, such as Quetico in Canada (Pettigrew and Hattori, 2006), relative to the Phanerozoic age, i.e., the Duke Island complex (Irvine, 1974), Alaska (Himmelberg and Loney, 1995), the Alto Condoto in Colombia (Tistl, 1994), the Urals in Russia (Fershtater et al., 1997), New Zealand (Spandler et al., 2003), and Far Eastern Russia (Batanova et al., 2005). Neoproterozoic Alaskan-type complexes have only been recorded in the Southern Eastern Desert of Egypt, i.e., at Abu Hamamid (Farahat and Helmy, 2006; Hafez et al., 1991; Helmy et al., 2015), Gabbro Akarem (Helmy and El Mahallawi, 2003) and Genina Gharbia (Helmy et al., 2008, 2014). They are considered to be the roots of Neoproterozoic island arcs, and are exposed along ancient deep fracture zones (Garson and Krs, 1976). These intrusions occur as concentrically zoned complexes, and their age based on the Sm/Nd model is 963 $\pm$ 81 Ma (Helmy et al., 2014). The Genina Gharbia and Gabbro Akarem intrusions are the host of sub-economic Cu–Ni–PGE mineralization (Helmy, 2004; Helmy and Mogessie, 2001). There is controversy over the parental melts and tectonic settings of Egyptian Alaskan-type

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complexes, variously described as having been fractionated from hydrous picritic magmas (Helmy and El Mahallawi, 2003), fractionated from komatiitic melts (Dixon, 1981), or fractionated from hydrous tholeiitic magmas (Farahat and Helmy, 2006). This study confirms one of these possible parental melts of Alaskan-type rocks and their tectonic setting based on mineral chemistry.

The Neoproterozoic ophiolites (690–890 Ma) and associated ultramafic–mafic intrusions in the Eastern Desert of Egypt are a part of the Arabian–Nubian Shield (El-Gaby et al., 1990; Stern et al., 2004). There are several types of ultramafic–mafic rocks in the Southern Eastern Desert including ophiolitic mafic–ultramafic rocks (e.g., Abu Dahr; Khedr and Arai, 2016; Ahmed, 2013), a post-orogenic layered mafic–ultramafic intrusion (e.g., Motaghairat; Abdel Halim et al., 2016), and Alaskan-type ultramafic–mafic rocks. The Alaskan-type complexes and layered intrusions sometimes have similar lithology, but the former shows concentrically zoned intrusions with ultramafic rocks in the center and mafic rocks at the rim of zonation. The Motaghairat intrusion consists of layered rocks from the base (e.g., lherzolites) to the top (e.g., anorthosites) (Abdel Halim et al., 2016) without zonation. Dixon (1981) stated that the Gebel Dahanib also is a layered mafic–ultramafic sill formed from dunites at the base to anorthosites at the top. This study presents evidence for the Alaskan-type nature of the Gebel Dahanib intrusion based on field relations, texture, and mineral chemistry.

One of the most important ultramafic–mafic intrusions in the Southern Eastern Desert of Egypt is the Dahanib intrusion, which is located NE–SW along a major fracture zone ~50 km south-east of Genina Gharbia (Helmy et al., 2008). The concentrically-zoned Dahanib intrusion shows small-scale (3–10 cm width) layering, a cumulate texture and a gradational contact against country rocks, similar to Alaskan-type complexes from the Eastern Desert and elsewhere. The Dahanib complex is characterized by a complete outcropping sequence from ultramafic rocks (cumulate dunites, chromitites) in the center of the zoned intrusion, through wehrlites and harzburgites, to mafic rocks at the edge; it is associated not only with island-arc assemblages but also with Abu Dahr ophiolitic ultramafic–mafic rocks. The Dahanib complex is the nearest one to Genina Gharbia (Helmy et al., 2008), and then to the Abu Hamamid Alaskan-type complexes (Farahat and Helmy, 2006). The Dahanib differs from neighboring intrusions in some lithology types/volume%, mineral composition and/or modal%, and chemistry. These differences in lithology and chemistry are possibly related to Neoproterozoic mantle heterogeneity by several mantle plumes and slab-derived inputs.

This paper describes in detail the mineralogy, petrology, and geochemistry of the Neoproterozoic Alaskan-type complex in the Southern Eastern Desert of Egypt. The aim of the study is to compare the variations in lithology, texture, and chemical composition of the Dahanib complex with the nearest Alaskan-type complexes and to elucidate the variations of their parental melts as a result of mantle heterogeneity and/or different inputs from the subducted slab. This study provides a distinctive opportunity to know the tectonic setting and origin of the Dahanib complex, and to understand the Neoproterozoic mantle heterogeneity and mantle metasomatism under the Arabian Nubian Shield.

2. Geological setting

The Red Sea Mountains in the Eastern Desert of Egypt (Fig. 1) are a part of the Arabian–Nubian Shield that covers large areas in NE Africa. They consist of ophiolitic rocks, island-arc assemblages, granitoid rocks, metasediments, and gneiss, with a few intrusive ultramafic–mafic rocks. Ultramafic–mafic complexes are limited in the Eastern Desert of Egypt and are concentrated mainly in the southern part, i.e., Motaghairat (Abdel Halim et al., 2016), Gabbro Akarem, Abu Hamamid, Genina Gharbia, and the study area (Gebel Dahanib; Fig. 1). The mapped area is composed mainly of Pan-African tectogenetic ultramafic–mafic intrusions (Shutt Batholith) around Wadi Shutt (El-Gaby et al., 1990). These late Proterozoic intrusions consist of serpentinized plagioclase/clinopyroxene-rich peridotites, hornblende gabbronorites, and hornblende gabbros/diorites associated with island-arc metavolcanic rocks (Fig. 1). They were intruded by late to post tectonic granitoids (e.g., tonalites, diorites) (Fig. 1).

The Gebel Dahanib (1268 m), which represents a part of the Neoproterozoic Arabian–Nubian Shield, includes a well-preserved ultramafic–mafic intrusion (4 km in length–1.5 km in thickness) in the Southern Eastern Desert of Egypt (Fig. 1b) (Dixon, 1981). It lies ~50 km southeast of Genina Gharbia (Helmy et al., 2008, 2014), and ~80 km southeast of Abu Hamamid (Farahat and Helmy, 2006) and Gabbro Akarem (Helmy and El Mahallawi, 2003). The Dahanib complex is considered the northern extension of dismembered ophiolites in Gebel Abu Dahr (Khedr and Arai, 2013, 2016), and the northeast extension of island arc metavolcanics in Gebel Abu Husaynat (Geological map of Baranis, scale 1: 250,000, 1992) (Fig. 1a). It is a small elliptical or rounded intrusion (Fig. 1b) which is located along the major NE–SW trending fracture zones that prevail in the Southern Eastern Desert of Egypt (Farahat and Helmy, 2006; Garson and Krs, 1976). The Dahanib complex is sometimes dissected by N–S fracture lineaments (Fig. 1). Because the peridotites are mainly enveloped by gabbronorites and gabbros (Fig. 1), the Dahanib complex shows a concentric zonation with the peridotite core enveloped by gabbronorites–gabbros at the rim, similar to other Alaskan-type complexes in the Southern Eastern Desert. The Dahanib zoned complex, from center to rim, consists of dunites, chromitites, clinopyroxene-enriched dunites, wehrlites, harzburgites, gabbronorites, layered gabbros and hornblende gabbros/diorites (Fig. 1b). The gabbros sometimes cut across the center of the zoned intrusion, possibly due to tectonism (Fig. 1). Peridotites are locally cut by irregular clinopyroxene-rich veins, which are rimmed by amphiboles and/or serpentines (Fig. 2a). They are also cut by several amphibole veins, forming network channels of hydrous magmas (Fig. 2b). The thin chromitite layers are enveloped by the host peridotites. They were cumulated in the form of seams or bands simultaneously with the host dunites and wehrlites (Fig. 2c, d). They also occur as nodules or clots that are scattered in the peridotites (Fig. 2d). Some gabbros show magmatic layering (Fig. 2e, f), which is not similar to rhythmic layering but may be cryptic layering.

The immature metasediments and amphibolites, occurring as a thin rim around peridotites–gabbros, are the oldest rock units (Fig. 1b). The pre-existing metavolcanic and metasediment assemblages are intruded by magmatic mafic to ultramafic rocks, forming amphibolites at the margin of the Dahanib intrusion (Dixon, 1981). The Dahanib complex does not show tectonic contacts with the surrounding rocks; it shows gradational contacts among them, unsheared coherent margins, cumulate textures, and layering in gabbros (Fig. 2e, f), implying their magmatic rather than their tectonic emplacement. The systematic samples (40 samples) were collected from different rock units across the variation from peridotites and chromitites in the center of the zoned intrusion toward gabbros at the rim.

3. Petrography

The modal abundance or modal volume % of minerals in ultramafic–mafic rocks is based on point counting (2000 counts for 2.5×4.5 cm of slide).

Cumulate dunites and Cpx-enriched dunites (= dunitic rocks) show adcumulate textures (Fig. 3a) and the latter is rich in clinopyroxene (Cpx < 8 vol.%). They also contain a few orthopyroxene (Opx) grains (<2 vol.%). Dunites are composed of cumulus olivine and chromian spinel (<6 vol.%) with subordinate intercumulus Cpx (<3 vol.%) (Fig. 3a). The olivine occurs as subhedral equant crystals (1.5–2.0 mm), forming equigranular textures. The pyroxene crystals, 0.5–2.0 mm, occur interstitially between olivine grains; a few Opx grains are altered to fibrous amphibole crystals. Some needle-like