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Carbonatite crystallization and alteration in the Tarr carbonatite–albitite complex, Sinai Peninsula, Egypt

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ABSTRACT

Carbonate dykes occurring in the Arabian-Nubian Shield (ANS) are clearly intrusive in origin and carbonatites according to the IUGS classification, yet previous investigations refer to them as "intrusive carbonates", due mainly to their low Sr, Ba, Nb, Y, Th and rare earth element (REE) contents. The Tarr carbonatite albitite complex (TCA) in SE Sinai, Egypt contains a series of small (<1.2 km^2) albitite intrusions surrounded by small veins and dykes of carbonatite, which occur predominantly in a narrow zone of brecciation surrounding the intrusions. Fennitic alteration surrounding TCA has been reported but there is little consensus on the extent and origin of this alteration. Fennitic alteration surrounding the TCA carbonatites is not abundant. Alteration is dominated by precipitation of carbonates in the breccia zone surrounding the albitite intrusion with associated actinolite, chlorite, sericite and epidote. Geochemical compositions are consistent with addition of carbonates and associated secondary minerals because the altered rocks contain higher CaO, MgO, Fe_2O_3 and MnO and lower SiO_2, Al_2O_3, Na_2O and K_2O compared to their less altered rocks. Fluid inclusion investigations show that the carbonatite magma contained a high-salinity H_2O–CO_2–NaCl–$CaCl_2$ fluid, although the lack of fennitic alteration implies that this fluid was not abundant. The crystallization conditions of the carbonatite dykes and carbonatite matrix in the breccia zones have been constrained using Zr-in-rutile thermometry and fluid inclusion microthermometry. Crystallization of the carbonatite in the dykes and in the breccia zone occurred between 565 ± 38 °C and 420–480 °C, respectively and at 0.75–1.3 kbar, which corresponds to a depth of 2.8–4.9 km. Rutile hosted within the carbonatite crystallized earlier at high temperature and the carbonate matrix crystallized later after cooling. Immiscible fluid from carbonatite magma would have altered the surrounding country rocks at lower temperature (between 400 °C and 150 °C deduced from the fluid inclusion thermometry) after the intrusion of the carbonatite melt.

1. Introduction

The migration of carbonate-rich solutions was common during deformation and metamorphism of the Arabian-Nubian Shield (ANS), forming veins and dykes, and causing diffuse and pervasive carbonation of a wide range of basement rocks (Stern and Gwinn, 1990). The carbonate dykes are clearly intrusive, contain more than 50% carbonate minerals and thus classify as carbonatites according to the International Union of Geological Sciences (IUGS) classification (Le Maitre et al., 2002), yet much of the literature describing intrusive carbonates in the ANS refer to them as "intrusive carbonates" rather than carbonatites, due mainly to their low Sr, Ba, Nb, Y, Th and rare earth element (REE) contents compared to "classic" carbonatites (Bogoch et al., 1986; Stern and Gwinn, 1990; Blasy et al., 2001; Azer et al., 2010). The association between carbonatites and REE-enrichment is well known; carbonatite rocks currently represent one of world's major rare earth element (REE) resources (Hornig-Kjarsgaard, 1998). Some previous studies have suggested that carbonatites should contain Sr, REE and Ba in excess of 700, 500 and 250 ppm, respectively (Le Bas, 1981; Samoilov, 1991). However, carbonatites with low trace element contents are not uncommon particularly those with a magnesian, dolomite-rich affinity (e.g. Andersen, 1986; Harmer et al., 1998; Hornig-Kjarsgaard, 1998; Halama et al., 2005; Brady and Moore, 2012). The low trace element concentrations in these rocks is an

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interesting feature that may aid interpretation of their origin and emplacement conditions (Brady and Moore, 2012).

Global compilations of the diversity and abundance of silicate rocks associated with carbonatites, show a common spatial association with a specific suite of alkaline silicate rocks including nephenlinites, ijolites, phonolites, lamprophyres, trachytes and syenites, but also that at 24% of localities carbonatites were found to occur with no associated igneous silicate rocks (Woolley and Kjarsgaard, 2008). The relationship between carbonatite and associated silicate rocks, should they occur, is key to understanding the petrogenesis of carbonate complexes (Moore et al., 2009). Another characteristic feature of carbonatite complexes is the occurrence of fennitic alteration; alkali metasomatism associated with alkali-silicate and carbonatite igneous activity (Le Bas, 2008). The nature of fennitization associated with carbonatite complexes is highly variable and in many cases the exact relationship between the fennitic alteration, the alkali silicate and carbonatite magmatism is unclear (Heinrich, 1985; Le Bas, 2008).

The Tarr carbonatite albitite complex (TCA) in SE Sinai, Egypt is the only carbonatite in ANS occurring with an associated alkaline igneous intrusion. Most other ANS carbonatites are reported to occur as veins or dykes intruding calc-alkaline metavolcanic rocks (Stern, 1981). TCA contains a series of small (<1.2 km^2) albitite intrusions surrounded by small veins and dykes of carbonatite which occur predominantly in a narrow zone of brecciation surrounding the intrusions (Shimron, 1975; Bogoch et al., 1984; Blasy et al., 2001; Azer et al., 2010). Although a number of different origins for the carbonatite have been proposed including remobilized carbonate sediments and carbonate produced by metamorphism of serpentinites, stable and radiogenic isotope analyses indicate a mantle source for the TCA carbonatite (Bogoch et al., 1986; Azer et al., 2010). Fennitic alteration has been reported but there is little consensus on the origin of this alteration (Shimron, 1975; Bogoch et al., 1987). Shimron (1975) reports a zone of fennitization up to a few hundred meters wide occurring outside the breccia zone that surrounds the albitite, whereas Bogoch et al. (1987) propose that the albitite body itself is the result of fennitization from a carbonatite that lost its alkalinity during crystallization and cooling. The nature of fennitic alteration at TCA, the conditions under which it occurred and the relationship between this alteration and the albitite and carbonatite are not well known.

We present a re-evaluation of the mineralogy and chemical composition of the albitite, carbonatite and altered country rocks in TCA to investigate the geochemical properties of carbonatite intrusions and fennitization. We also present new fluid inclusion and thermometry data from the carbonatites in order to constrain the conditions under which the carbonatite emplacement and related fennitic alteration.

2. Geological setting

TCA occurs in the southernmost part of the Wadi Kid metamorphic core complex, one of the four main Neoproterozoic metamorphic belts in the Sinai Peninsula (Fig. 1; Blasband et al., 1997, 2000; Brooijmans et al., 2003; Fowler et al., 2010). Metamorphic grades of the Wadi Kid metasedimentary and metavolcanic rocks range from lower-greenschist to amphibolite facies with a general increase in grade towards the north (Shimron, 1980; Khalaf, 2004). TCA is hosted by the Tarr Formation, a volcano-sedimentary succession with late Proterozoic intrusive rocks that occurs in the southern parts of Wadi Kid (Khalaf, 2004). Volcanic rocks of this area include pyroclastic rocks and lavas of andesitic to rhyolitic composition of the Heib and Tarr Formations and metasedimentary rocks mostly consist of metamorphosed mudstones, sandstones, conglomerates and carbonates (Shimron, 1975). Zircon from the Heib Formation rhyolite clast defines a ^{206}Pb/^{238}U weighted mean age of 609 ± 5 Ma, which is taken to approximate the age of the Heib and Tarr Formations (Moghazi et al., 2012).

TCA occurs as a series of irregular-shaped intrusive bodies scattered over a 10 km^2 area in the SE part of Wadi Kid, with the largest body occurring in Wadi Tarr (Fig. 2). The albitite is a white to pale yellow leucocratic rock consisting of up to 90% albite with minor quartz and orthoclase, and accessory biotite, zircon, and titanite (Azer et al., 2010). Medium-grained equigranular and fine-grained porphyritic textures both occur and are interpreted to indicate hypabyssal and volcanic components of the intrusion (Azer et al., 2010). U–Pb dating of zircons from the albitite yield ages of 605 ± 13 Ma (Azer et al., 2010), similar to A-type granites in the Wadi Kid region (Be'eri-Shlevin et al., 2009; Ali et al., 2009; Moghazi et al., 2012). The country rocks immediately surrounding the albitites are dominated by pyroclastic rocks and metasedimentary rocks metamorphosed up to greenschist facies (Fig. 2). A zone of brecciation affects the albitite and the hosting volcanic rock surrounds the albitite intrusions. The carbonatites occur within the breccia zones surrounding the albitites as small dyke-like bodies commonly <1 m but up to 10 m wide in places. They are coarsely crystalline and consist dominantly of dolomite and breunnerite with minor calcite in places. The dolomite varies in grain size from <0.5 cm to >4 cm wide with the larger grains appearing as phenocrysts that are locally zoned (Azer et al., 2010). Breunnerite contains secondary Fe-oxides and cross cuts the dolomite in places. Olivine dolerite and lamprophyre dykes also occur mainly within or near the breccia zone surrounding the albitite intrusion (Shimron, 1975; Bogoch and Magaritz, 1983; Azer et al., 2010). The carbonatite intrusions commonly occur as swarms of parallel bodies but can be irregularly shaped with variable dip and orientation, and are reported to contain abundant dolomite rich ocelli (Bogoch and Magaritz, 1983).

3. Sampling

The aim of this study was to investigate the occurrence of fennitic alteration surrounding TCA and for this purpose, samples of albitite, breccia zone, intrusive carbonatites and country rocks of the intrusive body were collected along two main transects; the Northern Transect and Wadi Khashm El-Fakh. Further samples were collected from carbonatite and surrounding rocks near the quarry office (see A and B sections in Fig. 2).

The Northern transect area is actually located inside the main Tarr albitite pluton according to previous maps (A in Fig. 2). In this area the volcanic country rock is surrounded by irregularly shaped patches of albititite (Fig. 3a). The country rock comprises pyroclastic volcanic rocks and cordierite bearing metasedimentary rocks (Fig. 3a). Two patches of coarse dolerite-like rock also occur, most likely as irregularly orientated dykes although contacts with surrounding rocks were not exposed (a in Fig. 3). The contact between the albitite and the country rocks is sharp (Fig. 3b) and is characterized by a roughly 20 m wide zone of brecciation both hosted by the albitite and the volcanic country rock (Fig. 3c). Systematic sampling of the same lithology outwards from the albitite was not possible due to the variability of exposure of country rock lithologies and the irregular nature of the albitite-country rock contact (Fig. 3a).

Wadi Khashm El-Fakh (transect B in Fig. 2) displays similar features to those observed in the Northern transect. The sharp contact between the albitite and the country rock is brecciated and the country rock is variable in composition including pyroclastic rocks and metasedimentary rocks (Table 1). Coarse dolerite-like rock is also observed occurring here as thin (1 m) wide dykes distal (300 m from the albitite contact; Table 1).