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Origin of hydrous alkali feldspar-silica intergrowth in spherulites from intra-plate A_2-type rhyolites at the Jabal Shama, Saudi Arabia

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ABSTRACT

Miocene rhyolites (19.2 ± 0.9 Ma) at the Jabal Shama in western Saudi Arabia represent an example of rift-related silicic volcanism that took place during the formation of the Red Sea. They mostly consist of tuffaceous varieties with distinct flow banding, and pea-sized spherulites, obsidian and perlitized rhyolite tuffs. Although they have the geochemical signature of A_2-type rhyolites, these silicic rocks are not typically alkaline but alkali-calcic to calc-alkaline. They developed in a within-plate regime and possibly derived from a recycled mafic subducted slab in depleted sub-continental mantle beneath the western Arabian plate. The Jabal Shama rhyolites are younger in age than their Miocene counterparts in Yemen and Ethiopia. The Jabal Shama spherulites consist of hydrous alkali feldspar-silica radial intergrowths with an occasional brown glass nucleus. Carbonate- and glass-free spherulites give up to 4.45 wt% L.O.I. The hydrous nature of these silicates and the absence of magnetite in the spherulites is a strong indication of oxidizing conditions. The spherulites contain hydrous feldspars with up to ~6 wt% H_2O, and they develop by diffusion and devitrification of glass in the rhyolite tuff at ~800 °C. Owing to higher undercooling due to supersaturation, the radial hydrous phases within spherulites might grow faster and led to coagulation. The polygonal contacts between spherulites and the ~120° dihedral angle suggest solid-state modification and recrystallization as the process of devitrification proceeds as low as ~300 °C. The sum of FeO + MgO is positively correlated with total alkalies along with magnetite oxidation in the matrix to Fe-oxyhydroxides, and to the incorporation of OH^- into silicates within the spehrulites themselves. Structural H_2O in glass of the Jabal Shama perlite (obsidian) is considerable (~9–12 wt%) with 3.72–5.6 wt% L.O.I. of the whole-rock. The presence of deleterious silica impurities would lower the ore grade due to poor expansion. Zeolitization of the rhyolite tuff was limited or incomplete in comparison with that of Pliocene-Pleistocene rift-related mafic volcanics in the western Arabian plate.

1. Introduction

Silicic magmatism and tectonics are subject of extensive studies by several workers during the last 4-5 decades, in which geodynamic models are presented, and models for genesis of silicic magma generation are suggested (Christiansen, 2001; Bryan et al., 2008; Ferrari et al., 2009). In this context, silicic volcanic rocks spread widely in several parts of the world where extensional tectonics dominate, and most of them occurred during the Cenozoic including the rift of the Red Sea. Similar rift systems are known worldwide, and two models for the generation of silicic magmas are suggested based on combined geochemical, stable isotope ratios and geophysical evidence. The first model suggests that rhyolite forms by partial melting of the crust (Albrecht and Goldstein, 2000; Bryan et al., 2002). In the contrast, a second model suggests rhyolite formation by differentiation of basaltic magmas from mantle sources (Cameron and Hanson, 1982; Wark, 1991; Smith et al., 1996). Some intra-plate volcanism in the world is bimodal, for example the Cenozoic Yellowstone Plateau volcanic fields of Wymong in the USA (Christiansen, 2001). This is not the case in the rift of the Red Sea where rhyolites are old (Miocene) and basalts are much younger (Pliocene to recent), and the volcanic do not represent a genetically unified evolution, which is the case in the Afar triangle (Ukstins Peate et al., 2002) but not in Saudi Arabia (Bakhsh,

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2015). Nevertheless, some younger (Quaternary to Recent) intermediate to rarely silicic volcanic are present in Saudi Arabia (e.g. Camp and Roobol, 1989; Moufti et al., 2012).

Intra-plate volcanism occurs in areas remote from plate-boundaries, and their evolution may involve mantle plumes and magma derivation from partial melting of metasomatized ancient oceanic slabs in the asthenosphere (Johnson, 1989; Smith, 2003; Lee and Grand, 2012; Liu and Stegman, 2012). The largest Cenozoic intra-plate volcanic fields (Harrats) in the world are represented by the rift-related volcanic rocks in the south Red Sea Afro-Arabian junction, and they cover an area of 89,670 km^2 in western Saudi Arabia where Quaternary-Tertiary volcanism has been documented (Coleman et al., 1977, 1983; Bohannon, 1989; Brown et al., 1989; Abdel Wahab et al., 2014). They are dominated by continental flood basalts (>90% of the total volume) and they continued to erupt until the Recent (Moufti et al., 2010, 2012 and 2013a) including the Al-Madinah 641 AD historic eruption (Camp et al., 1987; Moufti, 2013b) and the most recent Al 'Ays-Lunayyir activities in 2009 (Koulakov et al., 2014). In the neighborhood of the Arabian Peninsula, flood volcanism began prior to 30.9 Ma in Ethiopia and may predate initiation of similar magmatic activity in Yemen by ~0.2–2 Ma. Rhyolitic volcanism in Ethiopia commenced at 30.2 Ma, contemporaneous with the first rhyolitic ignimbrite unit in Yemen at ~30 Ma. (Ukstins Peate et al., 2002). According to the same workers, a transition from pre-to syn-rift volcanism (~26-25 Ma) was triggered by the separation of Africa and Arabia, followed by a second magmatic event 10.6–3.2 Ma ago in the Arabian plate. The formation of Harrats coincides with older fracture trends in the Precambrian basement, and they were activated by extensional stresses during the spreading stages of the Red Sea (El-Akhal, 2004). Heterogeneity of the lithospheric mantle has been documented beneath the Harrats (Weinstein et al., 2006). Lithospheric rifting in the Miocene resulted from partial melting of mantle materials from different sources at two levels. An ascending deeper garnet-facies melt mixed with a shallower spinel-facies melt, and the final products are basalt-dominated volcanic fields (Shaw et al., 2007). Some recent studies documented the contribution of ancient mafic slabs in the generation of rift-related magmas, for example in Saudi Arabia (Moufti et al., 2013a,b; Surour and Moufti, 2013) and in China (Li et al., 2015).

Large igneous provinces (LIPs) include voluminous bodies of volcanic and plutonic rocks that have evolved every ~20 Ma since the Archean (Ernst and Buchan, 2001). Some workers reduced this frequency to ~10 Ma (Coffin and Eldholm, 2001; Prokoph et al., 2004) based of the records of the last 250 Ma. Large-volume eruptions (>10^3 km^3) are dominated by continental flood basalts with lesser massive rhyolite, tuffs, domes and plugs (Chenet et al., 2009; White et al., 2009). According to Thordarson et al. (2009), large-volume silicic eruptions, in contrast to continental flood basalts, are not exclusive to LIPs and are not restricted to discrete eruptive episodes such as LIP events throughout Earth history. Large-volume silicic volcanic eruptions can be generated in a variety of tectonic settings including active continental margins (rifted or back-arc), extensional belts and intra-plate to rifted continental environments (Bryan et al., 2010). Red Sea rifting since the Oligo-Miocene time caused large-volume silicic eruptions (>1000 km^3) in the Afro-Arabian region (Mason et al., 2004). The Tertiary silicic volcanism in southwest Saudi Arabia is less voluminous and represents the youngest phase of silicic volcanism in the southern Red Sea region (~19–21 Ma; Gettings and Stoeser, 1981), compared with larger eruptions in Eritrea, Ethiopia and Yemen that formed ~29.5 Ma ago (Ukstins Peate et al., 2003, 2005 and 2008). On the other hand, Tertiary continental flood basalts form large volcanic fields (Harrats) that extends from Yemen in the south to Lebanon, Syria and Jordan in the north (Fig. 1). The basaltic eruptions are either monogenetic or polygenetic and consist of about 960 pyroclastic cones with single and multiple aligned vents (Camp and Roobol, 1989; Moufti et al., 2012; Murcia et al., 2014; Runge et al., 2014).

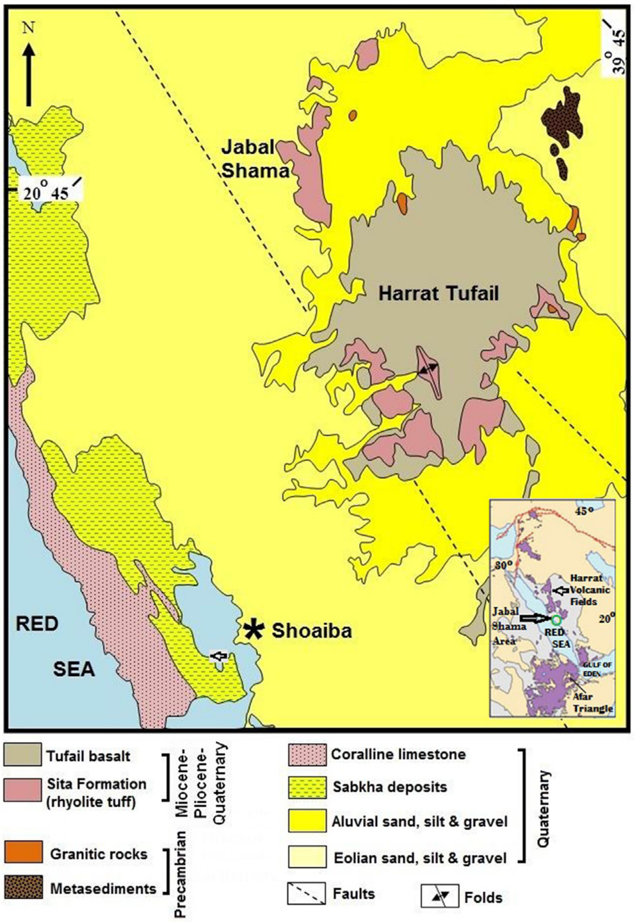

Fig. 1. Geological map of the Jabal Shama area (Pallister, 1986b). Inset map shows the distribution of the Tertiary-Quaternary Harrat volcanic fields and location of the Jabal Shama area.

The present work presents the first detailed mineralogical and geochemical information about the rhyolitic rocks at the Jabal Shama, which is adjacent to the Harrat Tufail (Fig. 2). Recently, work by Abdel Motelib et al. (2014) provided the stratigraphic sequence at the Jabal Shama-Harrat Tufail but lacks any mineralogic and geochemical data of that sequence. The present work provides petrographic and geochemical classification of the felsic rocks. Also, the present work discusses silicic magma generation in terms of partial melting and/or fractional crystallization. In addition, a special attention is paid to the modification of alkali feldspar composition, apparent in destabilized spherulites in aqueous depositional basins. The possible trajectories of mineralogical and geochemical variations due to formation of zeolitized rhyolite, perlite and obsidians are also considered. The Jabal Shama rhyolitic rocks represent a unique example of felsic lavas erupted in a rift-related basin. Formation of spherulites merits detailed studies because they document events of degassing and tells about some geochemical fingerprints of viscous silicic magma at plate margins.

2. Methodology

Major and trace element analyses of the studied volcanic rocks were performed at the ACME Analytical Laboratories Ltd., Canada.