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Petrochemistry and genesis of olivine basalts from small monogenetic parasitic cones of Bazman stratovolcano, Makran arc, southeastern Iran

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ABSTRACT

Small monogenetic Quaternary parasitic cones around Bazman stratovolcano, located at the western edge of the Makran arc, southeastern Iran, erupted low-Ti subalkaline olivine basalts with MgO (3.8–8.6 wt.%) and Al_2O_3 (16.5–18.6 wt.%). Positive correlation of decreasing MgO, Ni and Cr indicates that formation of low MgO basalts involved limited crystal–liquid fractionation of olivine and clinopyroxene, the common phenocrysts. The basalts have variable $^{87}Sr/^{86}Sr$ (0.704177–0.705139) and $^{143}Nd/^{144}Nd$ (0.512689–0.512830) ratios, within the range of OIB-like intra-plate alkaline basalts erupted in eastern Iran north of the Makran arc. This, and the lack of correlation between Sr content and Sr–isotopic ratio, suggest that upper crustal contamination was not significant in their formation, consistent with the relatively thin crust (≤40 km) in the area. Enrichment of large-ion-lithophile elements (LILE) relative to light rare-earth-elements (LREE; Ba/La = 9–25), and depletions in Nb relatively to LILE (Ba/Nb = 12–35; La/Nb = 0.8–2.1), are similar in most cases to other convergent plate boundary arc basalts, suggesting that the Bazman basalts formed by melting of subcontinental mantle modified by dehydration of subducted Oman Sea oceanic lithosphere. Pb isotopic ratios of the basalts define a linear trend above the Northern Hemisphere Line, consistent with their derivation from mantle contaminated by Pb derived from subducted sediment. Trace element contents and ratios (La_N = 10–25; Yb_N = 3–6; $(La/Yb)_N$ = 3–8) suggest that these basalts formed as a result of low (~10%) degrees of partial melting of subarc mantle modified only moderately by subducted components. Relatively low Ba/Nb<15, La/Nb<1.5 and Ba/La<15 ratios for some basalts confirm only limited contamination of the source of these samples, consistent with observations in other arcs that parasitic cones tap sources less affected by slab-derived fluids than the larger stratovolcanoes they surround. Comparison with Taftan volcano in southeastern Iran and Koh-e-Sultan in Pakistan, both further to the east along the Makran arc, indicate regional west-to-east geochemical variations, including increasing K_2O, LILE, LREE, La/Yb, Ba/La and $^{87}Sr/^{86}Sr$. These changes result from an along-strike increase in both input of slab-derived fluids relative to the volume of mantle below the arc and decreasing degree of subarc mantle melting to the east. This is due to a reduction in the volume of subarc mantle below the eastern part of the Makran arc resulting from a combination of both increasing crustal thickness and decreasing angle of subduction to the east.

1. Introduction

Quaternary volcanic activity, generated by a complex combination of geodynamic and petrogenetic processes associated with the evolution of the Alpine–Himalayan collision belt, has occurred in a broad area running from west-to-east though Turkey, Iran and into Pakistan. This volcanic activity has produced both andesitic stratovolcanoes, such as Ararat in Turkey (Kheirkhah et al., 2009; Pearce et al., 1990) and Damavand in Iran (Davidson et al., 2004; Liotard et al., 2008), as well as fields of basaltic cones and plateau lavas. In eastern Iran, the area of Quaternary magmatic activity extends over a south-to-north distance of 900 km, from the Makran arc in the south (Fig. 1A; Farhoudi and Karig, 1977) to north of the northern margin of the Lut microcontinental block (Saadat, 2010; Saadat et al., 2010). The Makran volcanic arc, which consists of the Bazman (Salkhi, 1997) and Taftan (Biabangard and Moradian, 2008) stratovolcanoes in southeastern Iran, and the Koh-e-Sultan volcano in southwestern Pakistan (Nicholson et al., 2010), is produced by plate convergence involving the subduction of Oman Sea oceanic lithosphere beneath the Eurasian continent (Fig. 1A; Farhoudi and Karig, 1977). This relatively short volcanic arc segment is one of the simpler of the many different magmatically active sections of the Alpine–Himalayan collision belt, but only very limited geochemical information is available for these volcanoes. Bazman volcano, in addition to having erupted intermediate and silicic magmas, is surrounded by an extensive field of small mafic monogenetic Quaternary cones and associated lava flows (Fig. 1B). This paper presents petrochemical data for and discusses

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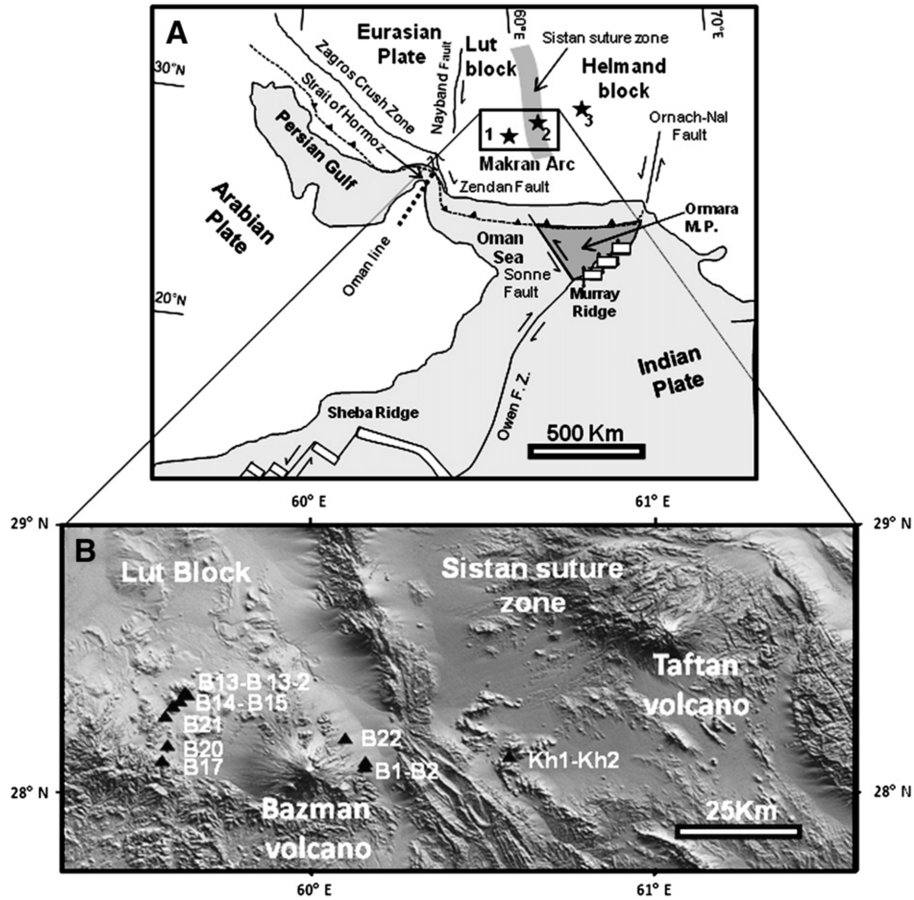

Fig. 1. A. Simplified geotectonic elements in relation to the Makran arc area modified from McCall (2002) and Musson (2009). The three stratovolcanoes that form the Makran arc include, from west-to-east, 1. Bazman; 2. Taftan; and 3. Koh-e-Sultan in Pakistan. B. Sample locations of basalts from parasitic cones around the Bazman volcano.

the genesis of the olivine basalts erupted from these monogenetic cones. These data provide constraints on the generation of magmas within the Makran arc, as well as a baseline for understanding the more complex magmatic and geodynamic processes associated with volcanic activity in other segments of the Alpine-Himalayan continental collision belt.

2. Geologic and tectonic setting

2.1. Pre-Neogene

From Late Precambrian until Late Paleozoic time, central and eastern Iran, including the Lut microcontinental block and Makran arc area (Fig. 1A), were separated from both the Eurasian and the Arabian plate by the Neo-Tethys Ocean (Dercourt and Vrielynck, 1993; Golonka et al., 1994; Sengor and Natalin, 1996). The northeastwards movement of the Arabian margin of the African–Arabian plate and the northwestward movement of India during the Cretaceous led to the narrowing of both the western and eastern parts of the Neo-Tethys Ocean (Golonka et al., 1994).

The final closure of western Neo-Tethys and collision between Arabia and central Iran took place during the Neogene (Ahmadian et al., 2009; Berberian et al., 1982; Berberian and King, 1981; Haschke et al., 2010; Shafiei et al., 2009). According to Hatzfeld and Molnar (2010), collision in the Zagros region of southwestern Iran seems to have begun sometime between the end of the Eocene (~35 Ma) and the beginning of the Miocene (~23 Ma). Ages of early foreland basin fill in the Zagros fold-thrust belt suggests that collision-related shortening was certainly underway by the late Oligocene–early Miocene (Fakhari et al., 2008; Horton et al., 2008). The Arabian platform, which had been stable since Precambrian time and lies adjacent to the Arabian shield, now plunges beneath the crust of central Iran, which has progressively become part of Eurasia (Hatzfeld and Molnar, 2010).

2.2. Neogene regional structures

The Zagros Fold-Thrust Belt, the Sanandaj–Sirjan Zone, and the Urumieh–Dokhtar magmatic arc are three major structures recognized in western and southwestern Iran related to the subduction of the western portion of Neo-Tethys oceanic crust and subsequent collision of the Arabian plate with the central Iran microplate (Alavi, 1994). To the southeast, along the eastern part of Urumieh–Dokhtar magmatic arc, the Makran area is the emerged portion of an accretionary prism resulting from the subduction of the Oman Sea oceanic lithosphere beneath southeastern Iran (Byrne et al., 1992; Kopp et al., 2000; McCall, 1997, 2002). The transition between Zagros and Makran is described as the 'Oman Line' trending N20°E (Kadinsky-Cade and Barazangi, 1982). It separates the continental crust to the west from the Oman Sea oceanic crust to the east (Fig. 1). Geologically, the boundary between the subduction of Arabian continental crust to the northwest and oceanic crust to the southeast is marked by the presence of salt domes to the northwest and their absence to the southeast, because the salt derives from old saline evaporate sediments of the continental crust (Talbot, 1998). In addition, a change in structural style from anticlines in the Zagros to synclines in the Makran arc occurs at the position of the Oman Line (McCall, 1985; Talbot, 1998). This transition also marks the boundary between a region of high seismicity located in the northwest, the Zagros domain, and the Makran arc region of relatively low seismicity