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Heterogeneous mantle sources feeding the volcanic activity of Mt. Karacadağ (SE Turkey)

Michele Lustrino [a,b,*], Mehmet Keskin [c], Michele Mattioli [d], Orhan Kavak [e]

[a] Dipartimento di Scienze della Terra, Università degli Studi di Roma La Sapienza, P.le A. Moro, 5, 00185 Roma, Italy
[b] CNR – Istituto di Geologia Ambientale e Georisorse (IGAG), c/o Dipartimento di Scienze della Terra, Università degli Studi di Roma La Sapienza, P.le A. Moro, 5, 00185 Roma, Italy
[c] Department of Geological Engineering, Faculty of Engineering, Istanbul University, 34320 Avcılar, Istanbul, Turkey
[d] Dipartimento di Scienze della Terra, della Vita e dell'Ambiente, Università degli Studi di Urbino 'Carlo Bo', Urbino, Italy
[e] Department of Mining Engineering, Faculty of Engineering, Dicle University, Diyarbakir, Turkey

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ABSTRACT

The volcanic activity of Mt. Karacadağ (SE Anatolia) is divided into three major stages: Siverek Stage (∼11–2.7 Ma), Karacadağ Stage (∼1.9–1.0 Ma) and Ovabağ Stage (0.4–0.01 Ma). The magmas are mildly alkaline mafic rocks, mostly basanites, hawaiites and alkali basalts. Detailed geochemical investigation indicates a continuous variation of composition with time, with the oldest products (Siverek Stage) being characterized by average lowest HFSE (Ti, Hf, Zr, Nb, Ta), $^{143}Nd/^{144}Nd$, Nb/U, Ta/Yb, Nb/Nb* and the highest ΔQ, La/Nb, Ti/Nb, Zr/Nb, Ba/Nb, Th/Ta, K/La, and the youngest products (Ovabağ Stage) at the opposite end of the trend. The overall incompatible element content of the Karacadağ volcanic rocks resembles closely average HIMU-OIB compositions, with the oldest samples deviating more strongly from typical compositions of "anorogenic" magmas.

We interpret these geochemical variations with a process of partial melting of a chemically and mineralogically heterogeneous mantle source rather than with process of variable crustal contamination at shallow depths. During the first stages of mantle melting the volumes with lowest solidus temperature (e.g., the amphibole and phlogopite-rich metasomes, particularly abundant in the Arabia mantle xenolith suite) contributed significantly to the partial melts. "Average" peridotitic matrix is involved in partial melting processes only when these metasomatic volumes start to be exhausted, producing mantle melts with geochemical composition resembling average "anorogenic" mildly alkaline sodic rocks, common in the circum-Mediterranean area.

1. Introduction

The ability to interpret the geochemical message of an igneous rock to infer the mineralogical and chemical characteristics of its source depends on the clearness of the signal. The chemical composition of oceanic basalts (MORB and OIB) is considered to reflect their mantle sources because of the presence of relatively thin crust, mostly with basaltic composition. This means that the mantle-derived partial melts that reach the surface can be modified only in minimum amounts while passing through the oceanic crust. On the other hand, the geochemical message of basaltic rocks emplaced on continental settings can be potentially obscured by the presence of much thicker crust, typically with very different chemical composition and much older than the rocks investigated. The lighter continental crustal rocks represents, indeed, a classical density barrier for relatively dense basaltic melts, forcing them to pond and, therefore, experience Assimilation and Fractional Crystallization-(AFC-) type processes. On these grounds, all the hypothetical mantle end-members proposed in the last 25 years (e.g., DMM, HIMU, EMI, EMII, EMII, PreMA, FoZo, PHeM, C, and so on) and the various models proposed to link geochemical concepts with geological entities are based on the study of oceanic basalts only (e.g., Zindler and Hart, 1986; Hart et al., 1992; Hoffmann, 2003; Stracke et al., 2005; White, 2010).

Excluding magmas produced after partial melting of a supra-subduction mantle wedge, continental basalts can, however, still be used to infer the composition of their mantle sources. The presence of mantle xenoliths associated with alkali sodic basaltic rocks is evidence for rapid magma ascent to the surface. However, rapid and turbulent ascent may also produce a sort of crustal contamination by digesting small amounts of crustal lithologies (e.g., Rutter, 1987).

* Corresponding author at: Dipartimento di Scienze della Terra, Università degli Studi di Roma La Sapienza, P.le A. Moro, 5, 00185 Roma, Italy. Tel.: +39 06 49914158; fax: +39 06 4454729.
E-mail address: michele.lustrino@uniroma1.it (M. Lustrino).

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The Karacadağ volcano (also known as Karacalıdağ) in south-eastern Anatolia offers a unique opportunity to investigate the potential effects of crustal contamination. Its activity lasted from ~11 Ma to ~0.1 Ma, during which a huge amount of magmas erupted to the surface (covering an area of ~10,000 km^2; Lustrino et al., 2010), rendering the Karacadağ volcano the largest shield volcano of the Circum-Mediterranean Anorogenic Cenozoic Igneous Province (Lustrino and Wilson, 2007).

The only accessible paper dedicated to the petrology of Karacadağ volcano (other papers dealing with this volcano are written in Turkish) is Lustrino et al. (2010), in which detailed geochemical, Sr–Nd isotopic and K/Ar age data on the oldest Karacadağ volcanics (older than 2.6 Ma) have been reported. The lavas of the Karacadağ are characterized by a spread of geochemical and Sr–Nd isotopic compositions that can be potentially explained by two main petrogenetic processes. The first process involves a "pure" mantle melt that is later modified by interaction with crustal lithologies at relatively shallow depths. The second process involves the partial melting of a heterogeneous shallow mantle, whose first products showed anomalous geochemical signatures, while the last products reflect the composition of the high-melting portion of more refractory mantle.

Below we report a detailed petrographic investigation and the large number of major and trace element data mostly on the younger volcanic activity (<2.6 Ma) that, combined with the results of a companion paper (Lustrino et al., 2010), show the geochemical variation with time of the Karacadağ lavas. The aim of this paper is to provide data on the youngest lavas, and to test whether the geochemical variations are related to partial melting of heterogeneous mantle or to the effects of crustal contamination.

2. Geological setting

The Karacadağ volcano (Fig. 1a) sits on the Arabian foreland (i.e., the Arabian autochthon), which comprises a stratigraphic sequence of primarily shelf sediments, deposited on an Atlantic-type continental margin. This sequence ranges from Early Paleozoic to Miocene and rests unconformably on a basement, presumed to be Precambrian in age (Hall, 1976; Yılmaz, 1993; Yiğitbaş et al., 1993). The Arabian platform has been subjected to two main tectonic events: major ophiolite obduction during the Late Cretaceous (Şengör and Yılmaz, 1981) and continental collision between the Eurasian and Arabian plates during the Cenozoic after the closure of the southern branch of the Tethys Ocean (Şengör and Kidd, 1979; Yılmaz, 1993; Westaway, 2003). The latter resulted in the formation of a complex suture zone adjacent to the Arabian foreland, extending as a ~2500 km-long, curved and south-vergent fold-and-thrust belt, known as the Bitlis–Zagros Belt and a large plateau (~400 km wide; ~90,000 km^2) in the north with an average elevation around 2 km, known as the Eastern Anatolian–Iranian high plateau (Şengör and Kidd, 1979; Dewey et al., 1986). The collision was accompanied by the tectonic escape of the Anatolian crustal block to the west-southwest along two major strike-slip fault zones, the North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (Fig. 1a; Şengör and Yılmaz, 1981; Şengör et al., 1985; Bozkurt, 2001; Gürsoy et al., 2009).

Geophysical studies have revealed that the Eastern Anatolian–Iranian high plateau had a slightly thickened crust (~40–50 km) and a considerably reduced lithospheric lid (~0–30 km thick lithospheric mantle; e.g., Al-Lazki et al., 2003; Şengör et al., 2003, 2008; Angus et al., 2006).

The collision has been accompanied by a widespread and long-lasting volcanic activity on the Eastern Anatolian–Iranian high plateau. The volcanism commenced with the eruption of volcanic units around ~11–13 Ma displaying subduction-related geochemical characteristics (e.g., Innocenti et al., 1982; Pearce et al., 1990; Keskin et al., 1998, 2006; Keskin, 2003, 2007; Omrani et al., 2008). These volcanics were followed temporally by the eruption of more alkaline volcanics (e.g., hawaiites, alkali basalts, basanites and their evolved derivatives) as well as rarer tholeiitic basalts and basaltic andesites (e.g., Innocenti et al., 1976, 1980; Pearce et al., 1990; Alıcı et al., 2001; Alpaslan, 2007; Kurt et al., 2008), displaying anorogenic geochemical characteristics.

Contemporaneous with the block uplift of the Eastern Anatolian–Iranian high plateau, the collision also gave rise to N–S extending impactogens on the Arabian Platform. These can be interpreted as an indication of E-W extension related to N–S shortening. One of them is represented by the Akçakale Graben in the vicinity of Urfa city while the other is thought to be covered by the lavas of the Karacadağ shield volcano (Şengör and Yılmaz, 1981). It should be noted that the collision-related volcanism on the Eastern Anatolian–Iranian high plateau was partially contemporaneous with the anorogenic-type magmatism of the Karacadağ volcano on the Arabian foreland.

The Precambrian basement of the Arabian foreland is exposed near the town of Derik, SE of the Karacadağ volcano. It is represented by the Telbesmi formation consisting of an unmetamorphosed sequence of dacitic-rhyolitic lavas interlayered with pyroclastics and sandstones. The Telbesmi formation is unconformably overlain by the Cambrian Sadan, Koruk and Sosink formations respectively, composed of detrital and carbonate sediments (Bozdoğan and Erten, 1990). These, in turn, are unconformably overlain by the Cretaceous Mardin group (Turonian–Campanian; Perinçek, 1980) consisting of carbonates and then by the clay-rich Karaboğaz formation limestones. The Germav formation, spanning an age interval from Late Maastrichtian to Paleocene lies conformably over the Karaboğaz formation. The Eocene to Early Miocene Midyat formation (Perinçek, 1980), consisting principally of limestones, covers all these sedimentary formations with an angular disconformity. The Midyat formation is one of the most widespread sedimentary units, exposed SE of the volcano and in contact with the Karacadağ lavas over great distances.

3. Volcanological background

On the basis of the stratigraphic and geochronological studies (Haksal, 1981; Ercan et al., 1990; Ercan et al., 1991; Notsu et al., 1995; Lustrino et al., 2010), the Karacadağ volcanic activity may be divided into three stages (Fig. 1b). During the first stage – called the Siverek Stage – a volcanic plateau, occasionally up to 700 m thick, but with an average thickness of less than 10 m, was produced during Middle-Late Miocene–Early Pliocene times (~11 to ~2.7 Ma; Haksal, 1981; Ercan et al., 1990; Lustrino et al., 2010). The volcanic rocks of the Siverek stage account for >80% of the entire surface area of the Mt. Karacadağ volcano, (~8000 km^2). The second phase of activity – the Karacadağ Stage – developed during Pleistocene (~1.9–1.0 Ma) producing the main edifice (Fig. 1c) as well as satellite scoria and spatter cones, the number of which exceeded one hundred in the north-eastern sector during the Pleistocene (Sanver, 1968; Haksal, 1981; Ercan et al., 1991; Notsu et al., 1995; Bridgland et al., 2007; Westaway et al., 2009). The main edifice rests on the central-eastern sector of the old Siverek Stage volcanic plateau, with an elliptical shape elongated N–S (Fig. 1c). The products of the Karacadağ Stage cover less than 15% of the present-day outcrops of the Mt. Karacadağ volcano, with an area of ~1300 km^2. A third, volumetrically minor, phase of igneous activity is very recent, younger than 0.4 Ma (Ercan et al., 1991; Notsu et al., 1995; Westaway et al., 2009), possibly continuing until historical times (Şaroğlu and Emre, 1987). The products emplaced during this final stage – the Ovabağ Stage – crop out only in