Geochemistry of Adakitic Volcanism in Central Iran

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Abstract

Volcanic and Subvolcanic andesitic to rhyodacitic lava flows and domes with northwest-southeast trend in Yazd and Isfahan provinces are parts of the Tertiary to Plio-Quaternary Urumieh-Dokhtar Magmatic Arc (UDMA). In the dacitic to rhyodacitic subvolcanic rocks, plagioclase, amphibole, biotite and quartz are the most general phenocrysts that set in glassy to felsity groundmass. Plagioclase crystals in these rocks are mostly oligoclase to andesine (An_{19-49}) compositions. Biotite and calcic amphiboles with magnesiohornblende-magnesiohastingsite and tschermakite compositions are abundant ferromagnesian minerals in the subvolcanic rocks. Geochemical datas show that these calc-alkaline subvolvanic rocks share high-silica adakitic composition affinities with the high Na2O/K2O (>1 wt. %), Al2O3 (>15 wt. %) and Sr/Y (most >70) and La/Yb (>35) ratios, and low Yb (<1.8 ppm) and Y (<18 ppm) contents, no significant Eu anomalies, and concave-upward shapes of chondrite-normalized heavy rare-earth element (HREE) patterns. These rocks are characterized by depletion in high field strength elements (HFSE) and enrichment in large ion lithophile elements (LILE) that all display the typical of subduction-related calc-alkaline magmas. In chondrite-normalized patterns, the light rare-earth elements (LREE) are enriched in comparison to those of the HREE.

Introduction

The volcanic rocks in the northwest and southeast of Isfahan and west-southwest of Yazd provinces are belong to Urumieh-Dokhtar magmatic arc (UDMA), which forms a classical subduction-related magmatic arc along the active margin of the Iranian plate (Alavi 1994, 2004). This is a part of Zagros orogene, which is the result of the opening, closure and subduction of the Neo-Tethys oceanic floor beneath the Iranian plate and consists from northeast to southwest, of three parallel tectonic subdivisions: (1) the Urumieh- Dokhtar Magmatic arc or Central Iranian volcano-plutonic belt; (2) the Sanandaj-Sirjan Zone; and (3) the Zagros Simply Folded-thrust Belt. The UDMA contains of Eocene to Quaternary magmatic rocks (Berberian and Berberian 1981; Mohajjel et al. 2003) with an Andean type magmatic arc characteristic (Alavi 1994; Mohajjel et al. 2003). The magmatic activity in the UDMA began in the Eocene and continued up to the Quaternary. Maximum magmatic activities in UMDA belong to Eocene age (Ghasemi and Talbot 2005). It seems that collision between Iranian and Arabian plates has occurred in the Oligocene–late Miocene, and the active subduction between them has been ended, but magmatic activity did not stop (Berberian and Berberian 1981; Ghasemi and Talbot 2005). The main mechanism of post-collision magmatic activity is a controversial matter. Four mechanisms suggested for the collision magmatism are proposed: (1) the slab break off (2) the melting of normal asthenosphere by adiabatic decompression resulting from extension, (3) the continental collision and thickening of the lithosphere, (4) the delamination of mantle lithosphere (Pearce et al. 1990; Molinaro et al. 2005; Ghasemi and Talbot 2005). In active continental margins, heterogeneous lower crust or upper lithspheric mantle can be melted and their melts are rich in large ion lithophile elements (LILE), light rare earth elements (LREE) and depleted from high field strength elements (HFSE) than asthenospheric melts. In the investigated area the Pliocene–Quaternary volcanic rocks have calc-alkaline compositions with adakite characteristics. Adakites are commonly considered to be subduction-related but they are also reported from other tectonic settings (Rosu et al. 2004). In this paper, the Pliocene–Quaternary volcanic rocks in the Yazd and Isfahan areas, nearly in the middle of the UDMA are investigated and interpreted as adakite.

Geological setting

The Plio-Quaternary calc-alkaline volcanic rocks are located in the northwest and southeast of Isfahan and west-southwest of Yazd provinces. In the classification of the structural units of Iran, this area is a part of Central Iranian magmatic arc (UDMA). The older rocks in the studied area are Paleozoic sedimentary units and Post Jurassic Shir-Kuh granitoid that are overlain unconformably by the Cretaceous sandstones and conglomerates. The Mesozoic sedimentary rocks, composed mainly of sandstone and limestone, are overlain by the Eocene volcano- sedimentary rocks. The youngest unit in studied area are red sedimentary sequence (Upper Red Formation) of Miocene age (Stöcklin and Nabavi 1973; Emami 1981) and Quaternary alluvial deposits. The studied volcanic rocks crossed the Upper Red Formation and consist of lava flows and domes with compositions ranging from andesite and rhyodacite. Based on stratigraphic grounds; they erupted during the Pliocene to Quaternary.

Results and discussions

Petrography

Petrographically, the studied volcanic rocks are mainly rhyodacite, dacite and andesite. These rocks are porphyritic, with fine-grained groundmasses and glass where the most abundant phenocryst phase is plagioclase. The andesite lava flows are constituted of plagioclase, pyroxene and opaque oxides, which can be accompanied by amphibole and biotite. The dacites contain abundant plagioclase, amphibole, biotite, quartz, and opaque oxides. In the rhyodacitic rocks, plagioclase, amphibole, biotite and quartz (±sanidine) are the most general phenocrysts. Some of the rocks are characterized by disequilibrium phenocrysts assemblages and textures. Disequilibrium criteria include occurrence of heterogeneous compositions of plagioclase in core and rim, sieved or dusty plagioclase, reaction rims and pseudomorphs after mafic phases on amphibole and biotite, embayed and resorbed quartz, normal, reverse and oscillatory zoning of minerals especially plagioclases.

Whole-rock data

Whole-rock geochemistry data from the studied rocks in the Isfahan and Yazd provinces show variable SiO_2 ranging between 56.27 to 69.78 wt. %, Al_2O_3 from 13.96 to 17.48 wt. %, total alkali (Na_2O+K_2O) from 5.32 to 8.25 wt. %, Fe_2O_3 from 2.18 to 7.95 wt. %, MgO from 0.79 to 2.51 wt. %, and CaO from 2.27 to 7.42 wt. %. All samples are subalkaline and plot within the andesite-dacite-rhydacite field. All of these rocks show calc-alkaline character according to the AFM diagram of Irvine and Baragar (1971). On the K_2O vs. SiO_2 (wt. %) diagram of Peccerillo and Taylor (1976), subvolcanic rocks falls completely into the calc-alkaline series, whereas some samples lie in the field of High-K calc-alkaline series. These rocks have A/CNK and A/NK molecular ratios ranging from 0.78 to 1.08 and 1.35 to 1.98, respectively.

On the Sr/Y vs. Y and chondrite-normalized La/Yb vs. Yb diagrams, the volcanic rocks, mainly plot within the adakite field. Most of the studied roks exhibit geochemical characteristics of adakite, i.e., high SiO_2 (>66.0 wt. %), Al_2O_3 (>15 wt. %), Sr/Y (most >70), La/Yb (>35), low Yb (<1.8 ppm) and Y (<18 ppm), no significant Eu anomalies, and concave-upward shapes of chondrite-normalized heavy rare-earth element (HREE) patterns (Defant and Drummond 1990; Martin *et al*. 2005; Castillo 2006). Subvolcanic rocks are poor in MgO (0.79–2.51 wt. %,), Ni (5–12 ppm, mean = 8), and Cr 7-21 ppm, mean = 14) compared with an average adakite and adakitic rocks (MgO = 2.20-1.96 wt. %, Ni = 24 ppm, and Cr = 36-46 ppm; Martin 1999). However, Sr (375–1057 ppm,) and Na_2O+CaO (6.02–12.06 wt %,) contents of the studied rocks show a similar compositional range that of an average adakite and adakitic rocks (706–280 ppm, 9.09–7.86 wt. %; Martin 1999).

On the primitive-mantle normalized spider diagram, all the volvanic rock samples show subduction-related signatures; they are enriched in large ion lithophile elements (LILE) (e.g., Ba, Rb, Sr, and K) relative to high-field strength elements (HFSE) (i.e., Nb, Ti, and Zr) and heavy rare-earth elements (HREE) (i.e., Yb and Lu). The LILE are enriched relative to those of mid-ocean-rich basalt (MORB). The volcanic rocks show a steep pattern with $(La/Yb)_n$ values ranging from 10.50 to 36.32, $(La/Lu)_n$ values ranging from 10.99 to 39.06, and $(Ce/Yb)_n$ values ranging from 8.12 to 23.69. In chondrite-normalized rare-earth element (REE) patterns, the light rare-earth elements (LREE) are variably enriched relative to those of the HREE.

Conclusion

Based on petrographical and geochemical data, the following conclusions for these Pliocene volcanic rocks might be outlined as:

1) These magmatic rocks form a calc-alkaline suite ranging in composition from andesitic to dacitic lava flows and domes with dominated by silicic composition.

2) These volcanic rocks have higher SiO_2 and Sr, lower MgO, Y and Yb contents and higher Sr/Y and La/Yb ratios than normal calc-alkaline rocks. They display similar normalized multi-element patterns with LILE and LREE enrichment and negative Nb, Ti, P without Eu anomaly.

3) These rocks are exhibiting adakite characteristics and were emplaced during the Pliocene after collision between the Iranian and Arabian plates.

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