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Geology, geochemistry and petrogenesis of post-collisional adakitic intrusions and related dikes in the Khoynarood area, NW Iran

Hossein Mahmoudi Nia[a], Saeid Baghban[a], Vartan Simmonds[b,*]

[a] Earth Sciences Department, Faculty of Natural Sciences, University of Tabriz, 5166616471, Tabriz, Iran
[b] Research Institute for Fundamental Sciences, University of Tabriz, 5166616471, Tabriz, Iran

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ABSTRACT

The Khoynarood area is located in the northwest of Iran, lying at the northwestern end of the Urumieh–Dokhtar volcano-plutonic belt and being part of the Qaradagh–South Armenia domain. The main intrusive rocks outcropped in the area have compositions ranging from monzonite–quartz monzonite, through granodiorite, to diorite–hornblende diorite, accompanied by several dikes of diorite–quartz diorite and hornblende diorite compositions, which were geochemically studied in order to provide further data and evidence for the geodynamic setting of the region. The SiO_2, Al_2O_3 and MgO contents of these rocks are about 58.32–68.12%, 14.13–18.65% and 0.68–4.27%, respectively. They are characterized by the K_2O/Na_2O ratio of 0.26–0.58, $Fe_2O_3 + MnO + MgO + TiO_2$ content about 4.27–13.13%, low Y (8–17 ppm) and HREE (e.g., 1–2 ppm Yb) and high Sr contents (750–1330 ppm), as well as high ratios of Ba/La (13.51–50.96), $(La/Yb)_N$ (7–22), Sr/Y (57.56–166.25), Rb/La (1.13–2.96) and La/Yb (10–33.63), which may testify to the adakitic nature of these intrusions. Their chemical composition corresponds to high-silica adakites, displaying enrichments of LREEs and LILEs and preferential depletion of HFSEs, (e.g., Ti, Ta and Nb). The REE differentiation pattern and the low HREE and Y contents might be resulted from the presence of garnet and amphibole in the solid residue of the source rock, while the high Sr content and the negative anomalies of Ti, Ta and Nb may indicate the absence of plagioclase and presence of Fe and Ti oxides in it. As a general scenario, it may be concluded that the adakitic rocks in the Khoynarood were most likely resulted from detachment of the subducting Neo-Tethyan eclogitic slab after subduction cessation between Arabian and Central Iranian plates during the upper Cretaceous–early Cenozoic and partial melting of the detached slab, followed by interactions with metasomatized mantle wedge peridotite and contamination with continental crust.

1. Introduction

Adakites are silica-rich magmatic rocks with high Sr/Y and La/Yb ratios, which are commonly found in different tectonic settings, such as subduction and continental collision zones (Defant and Drummond, 1990; Guo et al., 2007). Adakites are distinguished from boninites by LREE enrichment (La/Yb >40), high Sr content (>400 ppm), high Sr/Y and low $^{87}Sr/^{86}Sr$ ratios, and low radiogenic and non-radiogenic Pb concentrations (Defant and Drummond, 1990; Grove et al., 2005). Adakites were initially believed to be related to the convergent plate margins formed through the melting of hot and young oceanic crusts (<25 Ma; Kay, 1978; Defant and Drummond, 1990; Green and Harry, 1999). However, other genetic models have also been proposed for adakites, including partial melting of mantle wedge materials (e.g., Castillo et al., 1999; Robin et al., 2009) or thickened and/or delaminated garnet-bearing mafic lower crust, underplating of basaltic magmas under a thick continental crust (e.g., Atherton and Petford, 1993; Barnes et al., 1996), high-pressure fractionation (involving garnet) of a hydrous basaltic magma (e.g., Prouteau and Scaillet, 2003; Macpherson et al., 2006) and mixing of basaltic magmas with felsic melts derived from continental crust in both arc and non-arc tectonic settings (Guo et al., 2007). Adakitic rocks are also reported from young island arcs, as well as post-collisional regions (e.g., Jahangiri, 2007 and Simmonds, 2013 from NW Iran). Owing to their particular and characteristic composition, adakites can reflect their source condition and tectonic setting.

Martin et al. (2005) have classified adakites into 2 groups of low-silica (LSA) and high-silica (HSA). HSAs are formed through melting

* Corresponding author at: Research Institute for Fundamental Sciences, University of Tabriz, 5166616471, Tabriz, Iran.
E-mail addresses: simmonds_vartan@tabrizu.ac.ir, simmonds_vartan@yahoo.co.uk (V. Simmonds).

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of the subducted metabasaltic oceanic slab in the stability field of garnet, while LSAs are generated from partial melting of the garnet-bearing metasomatized mantle wedge. Another group of adakites is also introduced, known as continental or potassic adakites, which are resulted from various petrogenetic processes (Rapp et al., 2002; Ding et al., 2007; Gao et al., 2007; Wang et al., 2007a; Wang et al., 2007b).

In many cases, adakitic composition can indicate high-pressure melting of a mafic source, with a garnet-bearing residue left behind (leading to low HREE and Y) but no residual plagioclase (high Sr content). However, medium-pressure melting of garnet-bearing pelitic rocks also provides high La/Yb ratio which, in such cases, cannot be considered as adakitic geochemical characteristics (Moyen, 2009). Moreover, the continental crust melting and fractionation processes also lead to generation of adakitic composition (Macpherson et al., 2006).

The Khoynarood area is located 120 km north of Tabriz. This area is part of the Qaradagh mountain range and Alpine orogenic belt. Several intrusions of Oligocene age have intruded into the upper Cretaceous–Paleocene flyschoid rocks in this area. Their compositions range from monzonite–quartz monzonite through granodiorite to diorite.

According to Brunet et al. (2003), the study area is located in the South Armenia–Qaradagh zone and based on authors such as Nabavi (1976), it is part of the Alborz Azarbaidjan zone in NW Iran. It lies on the Urumieh–Dokhtar Tertiary volcano-plutonic belt (UDMA) at its NW section (Fig. 1a), neighboring the Qaradagh batholith in NW Iran and Meghri-Ordubad pluton in the southern Lesser Caucasus. This magmatic belt with 2000 km length and 50 km width was formed by the subduction of the Neo-Tethyan oceanic crust. It extends to the Lesser Caucasus and East Turkey (Lustrino et al., 2010, 2012) and contains volcanic and plutonic rocks of the Eocene and post-Eocene ages.

The time of closure and the evolution history of the Neo-Tethys Ocean in Iranian domain are still matters of controversy (Aghanabati, 2004). These uncertainties have led different authors to suggest various theories for the evolution of the Neo-Tethys basin. Authors like Berberian and King (1981), Mohajjel and Fergusson (2000), Agard et al. (2005) and Ghasemi and Talbot (2006) propose a single-stage subduction scenario for the Neo-Tethyan oceanic crust beneath Central Iran, attributing the compositional variations in UDMA rocks to the subduction angle or even the detachment of the subducting slab (slab break-off) during the Eocene and Miocene (Agard et al., 2005), whereas Amidi et al. (1984) believe that the UDMA has a post-collisional nature.

Contrastingly, Glennie (2000) advocates a double-stage subduction for the Neo-Tethys (I and II), considering the opening of two parallel ocean basins. Recent studies show that the collision between Arabian and Central Iranian blocks occurred in the early Cenozoic (Ghasemi and Talbot, 2006; Horton et al., 2008). However, based on the clastic zircon dating from the north of Central Iranian domain, Horton et al. (2008) have placed the collision date of Arabian and Central Iranian plates between middle Eocene and late Oligocene, whereas other geologists propose different dates: late-Cretaceous to early-Paleocene (Ghalamghash et al., 2009; Mazhari et al., 2009), late Paleocene (Agard et al., 2005) and middle to late-Miocene (Azizi and Moinevaziri, 2009).

Several adakitic occurrences have been reported from different parts of UDMA (Jahangiri, 2007; Omrani et al., 2008; Aghazadeh et al., 2011; Simmonds, 2013; Pang et al., 2016), along with reports of ultra-potassic and alkaline basic magmatism of the late Miocene and Plio–Quaternary age, which post-dates the adakitic occurrences (e.g., Jahangiri, 2007; Jahangiri et al., 2011; Aghazadeh et al., 2010; Shafaii Moghadam et al., 2014). In this regard, the intrusive bodies in Khoynarood were subjected to detailed geochemical studies to compare them with other studied intrusions in the region and provide additional data basis to support the geodynamic scenario proposed for the region, as investigating the different parts of UDMA can help to elucidate the uncertainties related to the subduction history of the Neo-Tethyan oceanic crust beneath the Central Iran, the fate of the subducting slab and the time of the collision.

2. Geology of the study area

An oval-shape intrusive body of monzonite–quartz monzonite composition (with relative age of Oligocene, considering the history of magmatism in the region and the age of neighboring dated intrusive bodies, as well as the cross-cutting and stratigraphic relationship with respect to the country rocks) intruded the upper Cretaceous–Paleocene flyschoids (Figs. 1 b and 2). It subsequently suffered argillic and propylitic alterations. Flyschoid sediments have been precipitated in an environment with high subsidence, probably corresponding to a pull-apart basin. They include alternations of limestone, sandy limestone, shale (containing *Globotruncana* and *Heterohelix* microfossils) and submarine tuff (with traces of *Rotalia*) (Mehrpartou et al., 1992). Due to the presence of extensional conditions during the formation of such a basin, submarine basic magmatism accompanies these sediments. Accordingly, basaltic and andesi-basaltic lavas are alternatively observed in the northern parts of the host flyschoid association which, based on microscopic studies, show hyalomicrolitic porphyritic and microlitic porphyritic textures and moderate to intense propylitic alteration. They are composed of clinopyroxene and plagioclase phenocrysts, set in a highly chloritized and epidotized, vitric and fine-grained groundmass. For the study region, such a pull-apart basin was most likely related to the dip-angle subduction of the Neo-Tethyan oceanic crust in NW Iran (e.g. Saccani et al., 2013; Hajialioghli and Moazzen, 2014), which was subsequently closed following the closure of the Neo-Tethys.

According to the field studies, a porphyritic diorite stock intruded the monzonite–quartz monzonite body within which, epithermal gold-bearing cross-cutting silicic veins have been developed. In this regard, it post-dates the porphyritic monzonite body, while it is older than the epithermal mineralization. The presence of xenoliths from monzonitic stock within the porphyritic diorite confirms the suggested sequence. There are also dioritic dikes, similar in composition to the dioritic stock, which cross-cut the monzonitic body and seem to be branched off from the dioritic stock. The porphyritic hornblende-diorite body and the related dikes in the western part of the study area also show distinct contact and cross-cutting relationship with the porphyritic diorite stock.

Granodioritic body is bright-color and has genetic relationship with the rest of the intrusive rocks in the area, being ascended from a common magma chamber and post-dating the other intrusive bodies (Fig. 1b). All these bodies and the related dikes form a multi-episode intrusive complex. They emplaced within the upper Cretaceous–Paleocene flyschoids, producing contact metamorphism in albite–epidote–hornfels facies, as well as vast hydrothermal alterations in the area, including phyllic, argillic and propylitic alterations. Due to the presence of abundant quartz in the argillic alteration zone, protruded outcrops of quartz can be found in this zone.

3. Materials and methods

Following the detailed field survey in the study area, a total of 60 rock samples were collected from the magmatic bodies to carry out petrographic and whole-rock geochemical studies. Petrographic studies were performed using an Olympus BX60 polarized light microscope at the Petrology laboratory, University of Tabriz.