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Geochemistry and petrogenesis of Kolah-Ghazi granitoids of Iran: Insights into the Jurassic Sanandaj-Sirjan magmatic arc

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ABSTRACT

Kolah-Ghazi granitoid (KGG), situated in the southern part of the Sanandaj–Sirjan Zone (SNSZ), Iran, is a peraluminous, high K calc-alkaline, cordierite-bearing S-type body that is mainly composed of monzogranite, granodorite and syenogranite. Zircon U–Pb ages indicate that the crystallization of the main body occurred from 175 Ma to 167 Ma. Two kinds of xenoliths are found in KKG rocks: (i) xenoliths of partially melted pelites including cordierite xenocrysts and aluminoslicates, and (ii) mafic microgranular enclaves that reflect the input of mantle-derived mafic magmas. Field observations and geochemical data of KGG rocks are consistent with their derivation from a multiple sources including melts of metasediments and mantle-derived melts. We infer that these magmas originated by the anatexis of a metasedimentary source (mixture of metapelite and metagreywacke) in the mid- to lower-crust under low water-vapor pressures (0.5-1 Kbar) and temperature of ~800 °C. KGG is the product of biotite incongruent melting of this metasedimentary source. S-type granites are commonly thought to be produced in continent-continent collision tectonic environment. However, trace element discrimination diagrams show that S-type KGG rocks formed in an arc-related environment. The roll-back of Neo- Tethyan subducting slab accompanying oblique subduction in Late Triassic to Early Jurassic time induced trench rollback, back arc basin opening and filling with turbidite flysch and molasse- type siliciclastic sediments of the Shemshak Group on the overriding plate. Further changes in the subducting slab to flat subduction in Middle Jurassic time, the time of peak magmatism in the SNSZ, led to thickening and high temperature-low pressure metamorphism of the backarc turbidite deposits and consequent anatexis of the metasedimentary source to produce the KGG S- type rocks along with several other I-type granitoids in the SNSZ.

1. Introduction

The Iranian sector of the Alpine-Himalayan orogenic belt is a complex assemblage of several aggregated and welded continental blocks with different stratigraphic and tectonic histories separated by narrow belts of Late Cretaceous ophiolites such as Nain-Baft, Nayriz and Sabzevar (Aghanabati, 2004; Ghazi et al., 2004; Berberian and King, 1981). Middle Mesozoic to late Cenozoic magmatic rocks were generated during Neo-Tethyan subduction beneath the Iranian blocks (Verdel et al., 2011). There are two NW-SE trending magmatic belts parallel to the Neo-Tethyan suture zone in Iran; 1) the Sanandaj–Sirjan zone (SNSZ) which is dominated by Jurassic–Cretaceous granitic plutons and minor volcanic rocks (Azizi and Moinevaziri, 2009) and 2) the Urumieh–Dokhtar Magmatic Belt (UDMB), of Late Cretaceous to Quaternary age (Berberian and King, 1981).

The SNSZ is a key tectonic element and is located close to the northeastern margin of the Zagros orogen (Mohajjel et al., 2003). Lithological and structural evidence indicates that the SNSZ experienced different geodynamic settings during its evolution by rifting from the Zagros basin with basic magmatism in Paleozoic time (i.e. opening of the Neo-Tethyan Ocean; Berberian and King, 1981) to an Andean type margin in Jurassic time (Alirezaei and Hassanzadeh, 2012; Alavi, 1994; Sheikholeslami et al., 2008; Fazlnia et al., 2009; Mohajjel et al., 2003). This was succeeded by formation of Late Cretaceous ophiolites of the Inner and Outer Zagros ophiolite belts

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(Shafaii Moghadam and Stern, 2015). These ophiolite belts mark the SNSZ from Central Iran (Berberian and King, 1981; Mohajjel and Fergusson, 2000; Mohajjel et al., 2003; Davoudzadeh and Schmidt, 1984; Shafaii Moghadam et al., 2009). The subduction of Neo-Tethyan is considered to have been responsible for extensive arc magmatism from Early Jurassic to Cenozoic in the SNSZ (Mesozoic arc) and UDMB (Tertiary arc) (Alavi, 1994; Berberian and King, 1981; Omrani et al., 2008; Verdel et al., 2011; Aghazadeh and Mogaddam, 2010; Baharifar, 2004; Ghasemi and Talbot, 2006; Mohajjel et al., 2003; Chiou et al., 2013).

The first stage of subduction-related magmatism in Iran was during Jurassic time with peak activity at ~165 Ma, as evidenced by the presence of widespread volcanic and intrusive massifs that range in age from 199 to 144 Ma in the SNSZ (Chiou et al., 2013). Jurassic arc igneous activity is best preserved in the SNSZ. The main Jurassic intrusive bodies in the SNSZ include Azna (Moazzen et al., 2004; Sepahi and Athari, 2006), Aligudarz (Bagherian and Khakzad, 2001), Saqqez (Sepahi and Athari, 2006), Golpayegan (Davoudian et al., 2007) Hamadan (Sepahi, 1999) Kolah-Ghazi (Noghreyan and Tabatabaei-Manesh, 1995; Khalili and Khalili, 2002), Borujerd and Astaneh (Masoudi, 1997; Ahmadi Khalaji et al., 2007) (Fig. 1b).

The Kolah-Ghazi granitoid (KGG) and other SNSZ intrusions are associated with nearby Shahr-e-Kord high pressure metabasites, amphibolites and eclogites with mid-ocean ridge (MORB)-like compositions attributed to exhumed remnants of Neo-Tethyan oceanic lithosphere (Davoudian et al., 2006, 2007). These together with the proximity of the KGG to the Nain-Baft ophiolitic belt and the geochemical or geochronological similarity of the KGG to several other arc-related I-type granitoids in the SNSZ, make it important to better understand the KGG and what it tells us about SNSZ geodynamic evolution. Despite its significance, the age, geochemistry and geodynamics of the KGG remain poorly understood. Thus, a detailed study of this intrusion provides a unique opportunity to better understand Jurassic subduction and arc magmatism processes that took place beneath SW Eurasia. In this study, we present a detailed account of the field relations, rock types, mineral chemistry, whole-rock geochemistry, and SIMS zircon U-Pb dating of the KGG for the first time and use these data to determine the petrogenesis, source region and tectonic setting in the framework of Jurassic arc magmatism along the northern margins of Neo-Tethyan in the SNSZ.

2. Geological setting and field relationship

The SNSZ can be subdivided into two parts: (1) the southern part, deformed and metamorphosed in Middle to Late Triassic time; and (2) the northwestern part, deformed in Late Cretaceous time, which contains many intrusive felsic rocks of mainly Late Cretaceous–Paleocene age (Eftekharnejad, 1981; Rachidnejad-Omran, 2002; Ghasemi and Talbot, 2006; Shafaii Moghadam and Stern, 2011). The southern SNSZ is subdivided transversally into two separate parts with different tectonic histories: (i) Esfahan–Sirjan region in the north consisting of Paleozoic, Mesozoic, and Cenozoic sedimentary rocks with typical Central Iranian stratigraphies; and (ii) southwestern part (Shahrekord–Dehsard Terrane), which is an intensely faulted zone consisting of high to low grade metamorphic rocks and metasedimentary strata with intercalations of intermediate and basic volcanic rocks (Arfania and Shahriari, 2009).

The KGG lies within the Esfahan–Sirjan Block (32°20′N–51°55′E) southeast of Esfahan city along the southern extension of the Kolah-Ghazi ranges (Fig. 1). The Kolah-Ghazi range is a fault bounded, NW–SE trending anticlinorium, characterized by a belt of Jurassic to Cretaceous sedimentary rocks 50 km long and 7 km wide. The KGG crops out in three small separate exposures in the Lagoor-e-bozorg and Soroushjoon valleys along the main northern and southern faults of the Kolah-Ghazi range. The Najafabad–Kolah-Ghazi and Golpayegan faults restrict the northern and southern Kolah-Ghazi range, respectively, and are the main structural elements of the study area. These faults were active during Jurassic and Cretaceous time and their vertical movement formed large NW-SE oriented, fault- bounded basins in which Mesozoic sediment was deposited (Khosrow-Tehrani, 1970). The Jurassic succession in the Kolah-Ghazi region is dominated by shale and sandstone with interlayered fossil-bearing limestones (Zahedi, 1976). The Cretaceous sequence consists of Barremian to Coniacian basal conglomerate, sandstone, shale and limestone that unconformably overlies the KGG (Khosrow-Tehrani, 1970; Fig. 3). The presence of KGG clasts in the basal conglomerate of the overlying Cretaceous succession and contact metamorphism and hydrothermal alteration of Jurassic units testify to the KGG emplacement during Late Jurassic, before deposition of Early Cretaceous limestones.

The KGG is mainly composed of monzogranite, granodiorite and syenogranite associated with aplitic dykes and quartz-tourmaline veins (Fig. 2). It intruded the Jurassic shale, producing a narrow contact metamorphic aureole made of biotite-hornfels. Up to 10 cm oval xenoliths, both mafic microgranular enclaves (MMEs) and surmicaceous (biotite-aluminosilicate) enclaves (Fig. 3e) have been identified in KGG rocks. The surmicaceous enclaves are rounded xenoliths composed of andalusite, cordierite, spinel, sillimanite, biotite, plagioclase and quartz. The MMEs are fine-grained with biotite, plagioclase, quartz, apatite, and zircon as dominant assemblage.

3. Petrography

Detailed mapping of the KGG (Fig. 2) reveal three main rock types, hereafter referred to as granodiorite, monzogranite, and syenogranite. Monzogranite outcrops throughout the Soroushjoon valley, east and west of the Lagoor-e-bozorg and Cheshmehneyzar area. They are coarse-grained with a granular texture. Mineral assemblages include quartz (40%) alkali feldspar (30–35%), plagioclase (25–35%), biotite (5–10%) and some primary muscovite. Zircon, apatite, andalusite, sillimanite are common accessory minerals (Fig. 4f). Large phenocrysts of quartz show undulatory extinction and have inclusions of biotite, alkali feldespar, plagioclase and apatite. Plagioclase (altered to sericite) and alkali feldspar occur as euhedral to subhedral crystals with polysynthetic twins and Carlsbad twins, respectively.

Granodiorites are second in abundance after monzogranites and crop out as low high hills that intrude Jurassic shales and are unconformably overlain by Cretaceous limestones (Fig. 3a & b). These rocks show medium to coarse-grained textures with a simple mineralogy (Fig. 4d): quartz (25–30%), plagioclase (30–40%), alkali feldspar (<20%) and biotite (10–20%). Apatite, zircon, silimanite and andalusite are common accessory minerals, with some muscovite and spinel. Quartz crystals occur as anhedral isolated grains with undulatory extinction. Plagioclase forms rectangular to subhedral laths, 1–2 mm or less in length that exhibit variable amounts of sericitisation and zoning (Fig. 4e). Biotite occurs as brown flakes, 1–2 mm in length, with a preferred orientation; these are mostly altered to chlorite, cordierite and/or titanite (Fig. 4f). Evidence that cordierite in KGG formed from biotite includes the lack of zoning in cordierite crystals and the occurrence of the cordierite with biotite, spinel and aluminosilicate according to the following reaction:

$$\text{Biotite} + \text{Aluminosilicate} \rightarrow \text{Cordierite} + \text{Spinel}$$

Syenogranites are less abundant than monzogranite and granodiorite. There are several aplite veins with syenogranitic composition that are located in the western part of Lagoor-e-bozorg; these are porphyritic with a weak alteration consisting