

Petrology And Geochemistry Of The Dioritic And Granodioritic-Granitic Magma, GQorveh Granitoid Complex (GGC), Sanandaj-Sirjan Zone, Western Iran

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Abstract

The Qorveh Granitoid Complex (QGC), western Iran, was emplaced in a Sanandaj-Sirjan Zone (SSZ) convergent setting which resulted from subduction of Neo-Tethyan oceanic crust below Central Iran. This investigation examines the geochemistry of the QGC. In the metaluminous Eocene–Oligocene I-type calc-alkaline Qorveh Granitoid Complex, three main units have been identified based on field observations, mineralogical and geochemical characteristics. Mafic intrusions consist of diorites, followed by felsic units that include granodiorites and granites. The diorites are characterized by SiO₂ contents 48-54 wt %, low abundances of incompatible elements (Ba, Nb, La and Th) relative to enriched mantle, but consistent with values for average middle crust. In addition, they have Al₂O₃/(MgO+FeOT) ratios from 0.98 to 1.54 and molar CaO/(MgO+FeOT) ratios from 0.59 to 0.71 and were probably derived from a mafic crustal source. The geochemical features combined with the high volume of the granitoid rocks are inconsistent with an origin via differentiation of mantle-derived basaltic parent magma and assimilation. The granodioritic and the granitic rocks show moderate values of molar Al₂O₃/(MgO+FeOT) and molar CaO/(MgO+FeOT) suggesting an origin involving dehydration melting of a metagreywacke source. Geochemical data on REEs, Y, Rb and Sr in the latter units indicate that amphibole and plagioclase were the major fractionating phases during magma segregation.

Key words: *granitoid complex, felsic magma, mafic crust, metagreywacke, Sanandaj-Sirjan Zone, Iran.*

Introduction

The problem of the variations in lithology of granitoid batholiths has attracted the interest of researchers for many years, [1-3]. Petrologists consider three possible origins to explain the genesis of granitoids: a crustal origin, a mantle-derived origin, and mixed origin that involves both crustal and mantle derived components [4].

Because crustal and mantle-derived materials have distinct chemical signatures, the resulting granitoids can be distinguished by their compositional features. Some petrologists still consider that most granitoids only derive from the continental crust, therefore, the diversity of granitoid rocks then would result from the various sources that can be melted in the continental crust to form granitic magmas [2-3]. Basaltic magmas provide the heat required for the partial melting of various source rocks, such as amphibolites, either by diffusive or advective heating.

Numerous intrusive rocks of various size intrude the Sanandaj-Sirjan Zone (SSZ) [5]. They show large range of variation in rock types, but are dominated by granodiorite-granite with minor amount of mafic bodies. This paper focuses on petrology and geochemistry of the dioritic and granodioritic-granitic plutons Qorveh Granitoid Complex (GGC), the Sanandaj-

Sirjan Zone, western Iran, as a major plutonic complex in the region. The QGC is a typical I-type granitoid. The present paper describes the field relationships, petrography and whole-rock geochemistry of different lithotypes within the QGC; these data are then used for the interpretation of the magma sources and magma-generation processes for various rocks within the complex.

Field Relationships And Petrography

The QGC is an elliptical pluton and is a multi-intrusion structure, containing several rock types.

The main magmatic units are diorites, granodiorites, and granites [6-7] (Fig.1). The observed contact relationships indicate that the QGC may have an origin similar to that of Big Timber stock. The QGC intruded regionally metamorphosed rocks at 38–40 Ma [10].

Diorite unit: The dioritic unit occurs as stocks or small masses within the granodiorite.

These rocks consist mainly of plagioclase (45–55%), hornblende (15–20%), quartz (10–15%), alkali-feldspar (3–5%) and biotite (1–8%), with accessory apatite, zircon and opaque minerals. The grain size is largely invariable, showing textures ranging from fine-grained to porphyritic. Plagioclase occurs as zoned euhedral to subhedral laths that are sometimes altered to sericite, clinozoisite, epidote and calcite. Hornblende occurs as green euhedral to subhedral laths, 0.2–1.5 mm in length. Quartz and alkali-feldspar occur interstitially.

Granodiorite unit: The granodiorite occurs as an elliptical pluton. Based on modal mineralogy, the rock varies in composition between granodiorite, tonalite and Qtz-Hbl monzonite.

These rocks are herein collectively referred to as the granodioritic unit. In general, these rocks are medium to coarse-grained with granular texture and the following simple mineralogy: plagioclase (30–38%), green hornblende (20–25%), alkali-feldspar (15–20%) and quartz (10–25%). Accessory minerals include apatite, sphene, allanite, zircon and Fe–Ti oxides.

Granite unit: The widespread granite unit occurs as a large, NW elongated pluton through the southern part of the study area. Rock types include monzogranites, granites, alkaligranites and minor quartz-syenites. Rocks within the granite unit are generally medium- to coarse-grained, showing granular to porphyritic textures. The unit contains plagioclase, K-feldspar and quartz, with lesser apatite, allanite, sphene, magnetite and zircon and small amounts of biotite ± hornblende. The monzogranites exhibit granophyric textures. Large crystals of quartz and feldspar show deformation features such as undulatory extinction and kinking.

K-feldspar occurs as phenocrysts or large anhedral patches, as both orthoclase and microcline.

Geochemistry

Sampling And Analytical Methods

Nineteen fresh samples from different units were selected for geochemical analyses. Whole-rock

major and trace element analyses were performed by X-ray fluorescence and ICP-MS techniques in the GeoAnalytical Laboratory of Washington State University (USA). Detection limits range from 0.01 to 0.1 wt%, and 0.1 to 10 ppm for major and trace elements, respectively. Total iron is expressed as FeO_T. Data processing was by means of the program Minpet [11]. Major and trace element compositions of the analyzed rocks are given in Table 1.

Major Elements

The samples span a range of SiO₂ from about 48 to 76 wt%, including the diorites, granodiorites and granites (Table 1). They plot in the calc-alkaline field on an AFM diagram and all samples have Al₂O₃/(Na₂O+K₂O) values > 1, and Al₂O₃/(Na₂O+K₂O+CaO) values < 1 plotting as a cluster in the metaluminous field [7].

The results of representative rock analyses are plotted on Harker variation diagrams (Fig. 2). Samples from each unit show poorly defined trends. Major elements show no compositional overlap between different units; the overall trends suggest that the granodioritic and granitic rocks are co-magmatic, whereas the dioritic rocks appear to have originated from a different source or different magmatic processes.

Trace Elements

As was observed for the major elements, the felsic units show linear trends and the diorites define a distinct group, clearly shown by their high Ni, Cr, Th, U concentrations suggesting a different source or magmatic process for this unit compared to the felsic rocks. The various rock units are best distinguished on a Rb vs. Sr diagram (. Notably, rocks of the QGC form a continuous trend from high-Sr/low-Rb values (diorites) to low-Sr/high-Rb values (granites) via intermediate values for the granodiorites. In a Ba vs. Sr/Nd diagram, dioritic samples show low-Ba/high-Sr/Nd ratios, whereas all other units are characterized by high-Ba/low-Sr/Nd [6-7].

Chondrite-normalized multi-element variation diagrams are shown in Figure 3. Samples from the felsic units show depletion in Nb, Ti and Ta and enrichment in large ion lithophile elements (LILEs) (Ba, K, Rb and Th). The patterns show a systematic decrease in normalized abundances from LILE (Ba, Rb, K and Th) to HFSEs (Y, Ti and Yb).

Chondrite-normalized rare earth element (REE) patterns are shown in Figure 4. All of the samples show light rare earth element (LREE) enrichment relative to heavy REE. The patterns have concave-upward shapes that are most pronounced in the granodioritic and granitic samples. There is systematic increase in (La/Yb)_N from the diorites via the granodiorites to the granites, and negative Eu anomalies are most pronounced in the felsic units. The mafic unit shows less fractionated REE patterns [(La/Yb)_N = 4–8] and decreasing HREEs with increasing negative Eu anomalies (Eu/Eu* = 0.85–1.03), while the felsic units are characterized by strongly fractionated and relatively flat HREE patterns [(La/Yb)_N = 6–18] with moderate to strongly negative Eu anomalies (Eu/Eu* = 0.44–0.95).

Discussion

a) Genesis of the dioritic unit

Several mineralogical and geochemical characteristics such as the presence of hornblende, (primary) sphene and magnetite as well as ASI < 1, high content of CaO, Na₂O and Sr can be used to infer the I-type affinity [6] of the studied diorites. Chemical characteristics of the diorites suggest an origin involving partial melting of mafic crustal material. The low concentration of incompatible elements (e.g. La, Ba, Nb and Th) rule out the possibility that these rocks were produced by melting of enriched lithospheric mantle. Furthermore, the amount of some trace elements including Ba (100–600 ppm), Th (1–7 ppm), La (10–30 ppm) and Nb (7–19 ppm) (Table 1) is lower than observed in diorites derived from the enriched

mantle, but rather consistent with average values of the middle crust (Ba: 400–700 ppm, Th: 6–8 ppm, La: 17–36 ppm and Nb: 6–11 ppm, [13]. Thus, it seems likely that the investigated diorites were derived from a mafic lower crustal source. Several experiments [e.g. [14]; cited in [15] have shown that melting of amphibolite under anhydrous conditions and at relatively low temperatures (880–800 °C) leads to the formation of mafic magma. [16]; cited in [17] documented that basic magmas can supply much of the heat required for the melting of basement rocks. However, this depends on the volume of the mafic melt. The $\text{Al}_2\text{O}_3/(\text{MgO} + \text{FeO}_T)$ and $\text{CaO}/(\text{MgO} + \text{FeO}_T)$ ratios obtained for the diorites vary from 0.98 to 1.54 and from 0.59 to 0.71, respectively (Table 1). As is evident from Figure 5, these rocks most likely were derived from partial melting of metabasaltic and/or metatonalitic sources. On this basis, we conclude that the dioritic magmas were probably derived from a mafic crustal source.

b) Genesis of the granodioritic and granitic units

Figure 2 demonstrates that both the granodioritic and granitic rocks show little internal compositional variation, and there is almost no compositional overlap between them. In addition, both rock types are characterized by low concentrations of transitional elements (Ni, Cr and V). It is therefore unlikely that the voluminous felsic magmas were generated by the differentiation and assimilation of a mantle-derived basaltic parent magma.

The compositional diversity of crustal magmas arises from melting of different source compositions and variations in melting conditions, including H_2O content, pressure, temperature, and oxygen fugacity [18-19]. Compositional differences that result from the partial melting of different source rocks such as amphibolites, under variable melting conditions may be characterized in terms of their molar oxide ratios such as $\text{K}_2\text{O}/\text{Na}_2\text{O}$, $\text{Al}_2\text{O}_3/(\text{MgO} + \text{FeO}_T)$ and $\text{CaO}/(\text{MgO} + \text{FeO}_T)$. For example, the $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios obtained for the granodiorites and granites in the present study range from 0.1–0.8 to 0.4–0.8, and their average $\text{Al}_2\text{O}_3/(\text{MgO} + \text{FeO}_T)$ and $\text{CaO}/(\text{MgO} + \text{FeO}_T)$ ratios are 6.5 and 1.47, respectively (Table 1). As evident from Figure 9, these rocks were most likely derived from metagreywackes. A significant contribution from metapelitic and meta-igneous felsic magmas can be excluded given that the granodiorites and granites display high molar $\text{CaO}/(\text{MgO} + \text{FeO}_T)$ and low molar $\text{Al}_2\text{O}_3/(\text{MgO} + \text{FeO}_T)$ ratios (Fig. 5).

The granodiorites and granites are characterized by a general decrease in normalized abundances of elements from Rb to Y (or Yb) (Fig. 3) and concave-upward REE patterns (Fig. 4). This suggests that the amphibole-out boundary was not crossed during partial melting, leaving amphibole as a major restite phase. Compared with the granites, the granodiorites show higher Sr/Nd and Sr concentrations and smaller negative Eu/Eu* anomalies, suggesting a relatively small amount of plagioclase fractionation in the latter.

Conclusion

The Qorveh Granitoid Complex (QGC) displays field relations and mineralogical and geochemical characteristics that are typical of calc-alkaline granitoids in the Sanandaj- Sirjan Zone, which presumably developed during subduction of the Arabian plate beneath the continental crust of the Central Iran plate. Field relationships, petrography and whole-rock geochemistry of the different rock units of the QGC indicate that the magmas that produced the dioritic, granodioritic and granitic units had intra-crustal sources. The chemical

characteristics of the felsic rocks point toward the partial melting of metagreywackes, whereas the dioritic magma was derived from a lower crustal mafic source. Further isotopic studies are necessary to better understand the nature of the protoliths.

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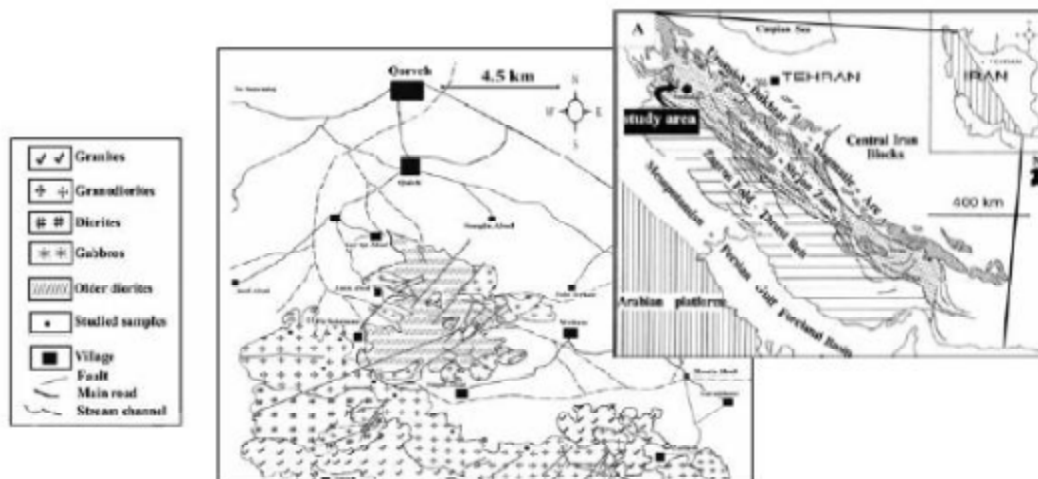


Fig. 1. Tectonic zones of the Zagros orogen in western Iran (after [8]) and simplified geological map of the Qorveh Granitoid Complex (based on [9]).

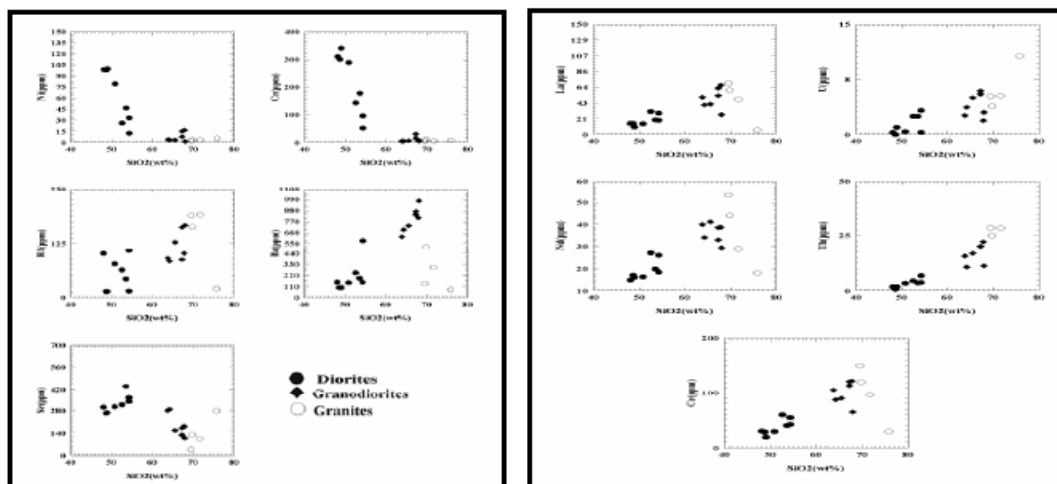


Fig. 2. Harker variation diagrams for some of major and trace elements from the QGC. Note that there is a compositional gap between the diorites and the granodiorites-granites.

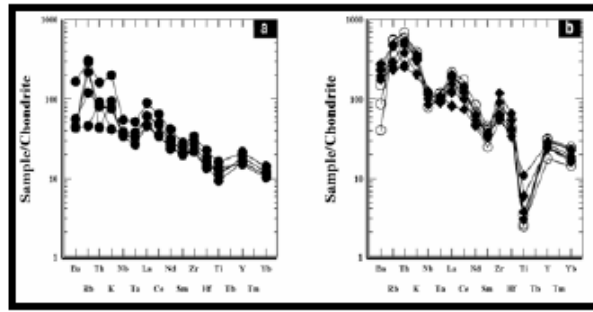


Fig.3. Chondrite-normalized multi-element variation diagrams (values given by Thompson et al., 1982; in Richard 1995) for samples from (a) diorites and (b) granites and granodiorites. Symbols are as in Fig. 2.

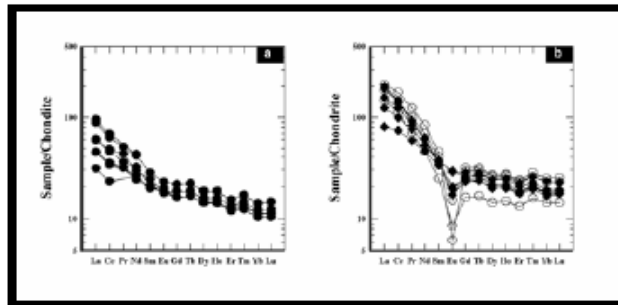


Fig. 4. Chondrite-normalized REE patterns [12] for (a) diorites(b) granites and granodiorite. Symbols are as in Fig. 2.

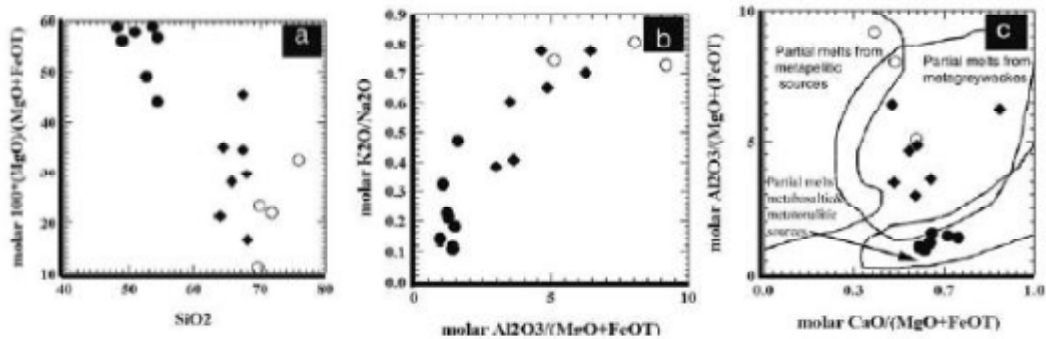


Fig. 5. Chemical compositions of different unit: (a) Mg number [Mg# = molar 100*MgO/(MgO + 0.9 FeOT)] vs. SiO₂. (b) Molar K₂O/Na₂O vs. Al₂O₃/(MgO + FeOT) (c) Molar Al₂O₃/ (MgO + FeOT) vs. molar CaO/(MgO + FeOT). Curves separating the partial melt fields are from [18-19]. The granodioritic and granitic rocks show high ratios of molar Al₂O₃/(MgO + FeOT) as expected for partial melts derived from metapelitic and metabasaltic–metatonalitic sources but similar to melts derived from metagreywackes sources. Symbols are as in Fig. 2.