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Geochemistry And Petrology Of Granophyric Granite Veins Penetrated In The Igneous Intrusive Complex In South Of Qorveh Area, West Iran

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Abstract: Qorveh area (west Iran) belongs to the Sanandaj-Sirjan zone. Igneous activity resulted from subduction of Neo-Tethys beneath Iran microplate during Mesozoic and Cenozoic produced several intrusive and extrusive rocks throughout Sanandaj-Sirjan zone that convoluted intrusive complex in south of the study area is one of them. This complex is generally comprised of diorite, gabbro, monzonite, quartz-monzonite and quartz-monzodiorite. Several garnophyric granite veins penetrated into the diorite and gabbro in the complex. These granite veins are metaluminous (A/CNK=0.66-0.9), alkalic and have I-type and A-type granitiod geochemical characteristics. These samples have moderate REE contents (□REE=83-147 ppm), negative Eu anomaly (Eu/Eu^*=0.4-0.7), high field strength elements (HFSE) Nb, Ta, Ti… contents (□HFSE=70-130 ppm) and high light rare earth elements to heavy rare earth elements (LREE/HREE) ratios (average 6 ppm). Basis on the mineralogical, petrological and geochemical studies, it is clear that crystal plays an important role in generation of this rock. Also, granite samples possess geochemical signatures of active continental margin (enriched in large ion lithophile elements (LILE) Rb, K, U, Sr, Cs and Th with respect to Nb and Ti) and a post-orogenic geodynamic environment.

Key words: *Granophyric granite, I-type and A-type granitiods, Qorveh area, Sanandaj-Sirjan, Iran.*

INTRODUCTION

The Sanandaj–Sirjan plutono metamorphic zone (SSPMZ) is a narrow band lying between Sirjan and Esfandagheh towns in the southeast and Urumieh and Sanandaj in the northwest Iran (Mohajjel and Fergusson, 2000) (Fig. 1). This zone includes metamorphic rocks with acidic to intermediate intrusive and volcanic rocks belong to the Phanerozoic (Alavi, 1994). Simultaneous presence of the felsic rocks next to the mafic rocks is a general characteristic of the intrusive rocks in north part of SSPMZ (Sepahi, 2008). In the south of Qorveh area, there is a convoluted intrusive complex which mainly composed of diorite, gabbro, monzonite, quartz-monzonite and quartz-monzodiorite. Also, several granite veins with granophyric texture penetrated in the diorites and gabbro (Fig. 2). This rock is metaluminous with alkali affinity which possesses I- and A-type granitiod characteristics (e.g. metaluminous nature, SiO_2<70%, Na_2O > 3.2%, existence of sphene, high Zr ...). Hydrothermal alteration affected all rocks in the district and led to vast epidotization and chloritization.

Several studies about granitoids in Qorveh area have been carried out by researchers (i.e., Torkian *et al*., 2008; Torkian, 2010), but this granophyric veins never have been especially studied. Therefore, the objective of the present paper is the petrological and geochemical studies of these veins.

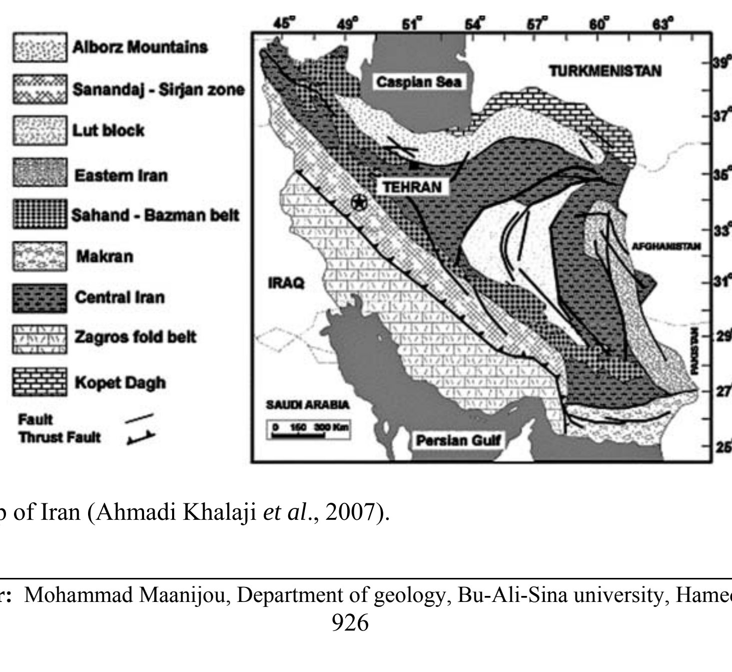

Fig. 1: Structural map of Iran (Ahmadi Khalaji *et al*., 2007).

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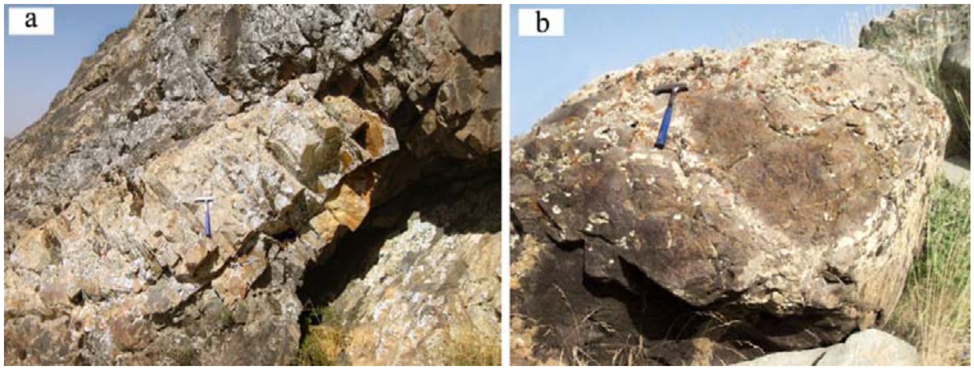

Fig. 2.a: Granite vein (light color) penetrated in diorite (dark color); b) diorite enclaves in quartz-monzonite.

Geological setting:

The tectonic history of SSPMZ has been summarized by many authors (Alavi, 1994). SSPMZ was part of northeast Gondwanaland and separated from the Eurasian plate by the Paleo-Tethys Ocean during the Paleozoic period, (Ahmadi Khalaji *et al*., 2007). The oceanic crust of the Neo-Tethys was subducted beneath the Eurasian plate During the Mesozoic (Shahabpour, 2005; Ahmadi Khalaji *et al*., 2007), and arc related magmatism (plutonic and volcanic) was occurred (Arvin *et al*., 2007). This subduction during Triassic-Jurassic time caused to Early-Cimerian metamorphic event that associated with the emplacement of intrusive bodies (Sabzehei, 1994). During the Tertiary period, the final closure of the Neo-Tethys and the collision of the Arabian and Eurasian plates took place (Berberian *et al*., 1983). The SSPMZ is characterized by deformed metamorphic rocks which are associated with numerous plutons and a widespread Mesozoic volcanism (Mohajjel and Fergusson, 2000).

Regarding to the geology map of Sonqor (Eshraghi *et al*., 1996) (Fig. 3) intrusive complex in this region belongs to Eocene-Oligocene. The age relation between rocks in this complex is unclear and radiometric dating has not been carried out, but regarding to the penetration of granite veins into the diorite and gabbro and presence of diorite enclaves in quartz-monzonite and quartz-monzodiorite, it is an axiom that felsic rocks in this complex are younger than diorite and gabbro (Fig. 2). Several fault with NW-SE trend brecciaed these rocks.

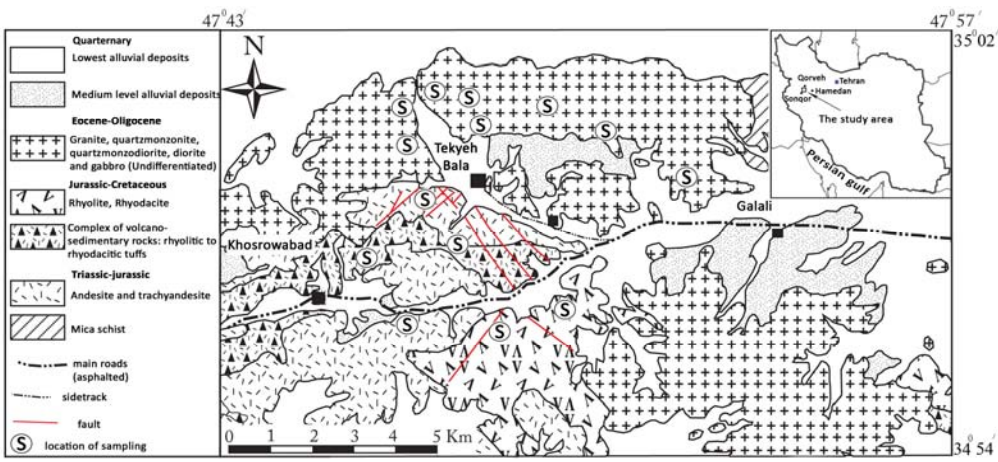

Fig. 3: Geological map of the study area (modified after Eshraghi *et al*., 1996).

Analytical technique:

A total of 30 samples were collected from these veins. Thin sections were prepared for all of these samples which studied by polarized light microscope. On the basis of petrographic observations, five samples with minimal effects of hydrothermal alteration were selected for whole-rock geochemical analysis (Table 1). Major elements and some trace elements (Ba, Sr, Nb, Y, Zn, and Zr) analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES) method with a lithium metaborate fusion. Other trace elements and REE were determined by inductivity coupled plasma-mass spectrometry (ICP-MS) and lithium metaborate fusion at the SGS laboratory in Toronto, Canada.

Petrography:

As mentioned above, granite crops out in several parts of the region as veins. This rock has grey color and middle size grain. General textures are subhedral granular and granophyric (Fig. 3). Granite consists of quartz (30-35%), orthoclase (20-25%), plagioclase (15-20%), hornblende (8-12%) and biotite (<10%). Accessory minerals are zircon, sphene, and apatite. Epidote, zoisite, chlorite and sericite are secondary minerals as results of hydrothermal alteration. Quratz crystals are anhedral with undulatory extinction. Plagioclases are sunbhedral with polysynthetic macle that have zoning and at the center alters to epidote (Fig. 3), because it is richer in Ca at the center. Some of orthoclases have apatite inclusion. Hornblende and biotite slightly altered to chlorite. Generally, granite is lesser affected by hydrothermal alteration than other rocks in the complex.

Geochemistry:

Major- and trace-elements contents of the representative granite samples are represented in Table 1. Sio_2 vs. Na_2O+K_2O classification diagram (Cox *et al*., 1979) is used for geochemical classification (Fig. 5). As visible, samples lie at granite field.

Major and trace elements:

The SiO_2 content of granite samples is 67%-70%. Their molar A/CNK ratios vary between 0.65 and 0.9 and thus, all samples are metaluminous (Debon and Lemmet, 1999). Also, in A/CNK vs. A/NK diagram (Shand, 1947) samples lie at metalominous field (Fig. 6a). Using Na_2O+K_2O-CaO (MALI index) vs. SiO_2 diagram (Frost *et al*., 2001), all of samples plot in the alkalic filed (Fig. 6b). Utilizing Fe-number vs. wt% SiO_2 diargram (Frost and Frost, 2008) all of samples plot in the ferroan field (Fig. 6c).

Granite samples have relatively high HFSE contents (70-130 ppm) and Zr contents (220-370 ppm). Nb contents of most samples are in range of I-type granites (20 ppm) after Chappell and White (1992). Trace element distribution patterns (spider diagram) for these samples are illustrated in Fig. 7. Samples are normalized with primitive mantle values of Sun and McDonough (1989). All samples show negative anomaly for Ba, Nb, Sr, P and Ti and positive anomaly for K, Cs, Rb, Th and Zr. High K, Rb, Th and low Sr, Ti and P suggest some upper crustal contamination during magmatic evolution (Harris *et al*., 1986; Chappell and White, 1992). Furthermore, high Ba/Th ratios (16-27 ppm) is ascribed to the contribution of sediments in magma genesis (Morata and Aguirre, 2003).

Table1: Major and trace elements contents

Sample					Granite
	TB04	TB15	TB18	TB77	TB80
SiO_2	67.5	70.8	68	69	67.6
Al_2O_3	13.6	13.5	13.9	13.8	14.8
CaO	1.19	1.13	0.99	1.13	1.55
Cr_2O_3	0.07	0.05	0.05	0.07	0.06
Fe_2O_3	2.67	2.46	2.56	2.5	3
K_2O	5.48	4.81	5.03	5.54	6.21
MgO	0.25	0.3	0.29	0.34	0.56
MnO	0.03	0.03	0.03	0.04	0.05
Na_2O	3.6	3.9	4.2	3.6	3.5
P_2O_5	0.06	0.05	0.05	0.04	0.06
TiO_2	0.35	0.34	0.34	0.31	0.42
LOI	0.6	0.49	0.52	0.81	0.71
Sum	97.8	98.5	98.9	98.3	99.2
Ba	610	490	540	600	690
Nb	20	10	20	20	20
Sr	120	80	80	110	120
Y	30	30	20	20	30
Zn	9	31	19	29	26
Zr	370	350	370	280	380
Ag	<1	<1	<1	<1	<1
Ce	28.9	63.7	76.6	92.8	27.6
Co	2.7	2.3	2.7	3	3.4
Cs	0.5	0.8	0.7	0.6	1.1
Cu	15	20	22	19	11
Dy	5.03	4.17	4.28	4.35	4.9
Er	3.14	2.69	2.74	2.92	3.2
Eu	0.57	0.79	1.01	0.65	0.84
Ga	19	17	20	18	17
Gd	4.22	3.9	4.31	4.26	4.16
Hf	9	8	10	8	10
Ho	0.98	0.87	0.9	0.91	1.04
La	14	32.2	41.6	55.4	13.4
Lu	0.54	0.54	0.44	0.5	0.52

Mo	<2	<2	<2	<2	<2
Nb	27	27	20	24	25
Nd	15.1	15.1	24.9	28.8	14.5
Ni	<5	<5	<5	8	8
Pr	3.46	3.46	7.16	8.82	3.58
Rb	98.7	98.7	130	96.5	121
Sm	3.8	3.8	4.5	4.7	3.7
Sn	9	6	5	<1	<1
Ta	1.8	1.8	1.5	2	2
Tb	0.71	0.71	0.67	0.7	0.76
Th	23.8	28.8	32.1	24.7	25.1
Tl	<0.5	<0.5	<0.5	<0.5	<0.5
Tm	0.48	0.48	0.43	0.45	0.52
U	5.83	5.83	6.11	5.96	6.33
V	20	20	39	15	31
W	1	1	<1	1	1
Y	29.1	29.1	24.2	23.7	25.5
Yb	3.6	3.6	3.1	3	3.5

NOTES: 1. Major elements reported as wt% and trace elements as ppm. 2. Total Fe measured as Fe_2O_3. 3. LOI: loss of ignition at 1100˚c.

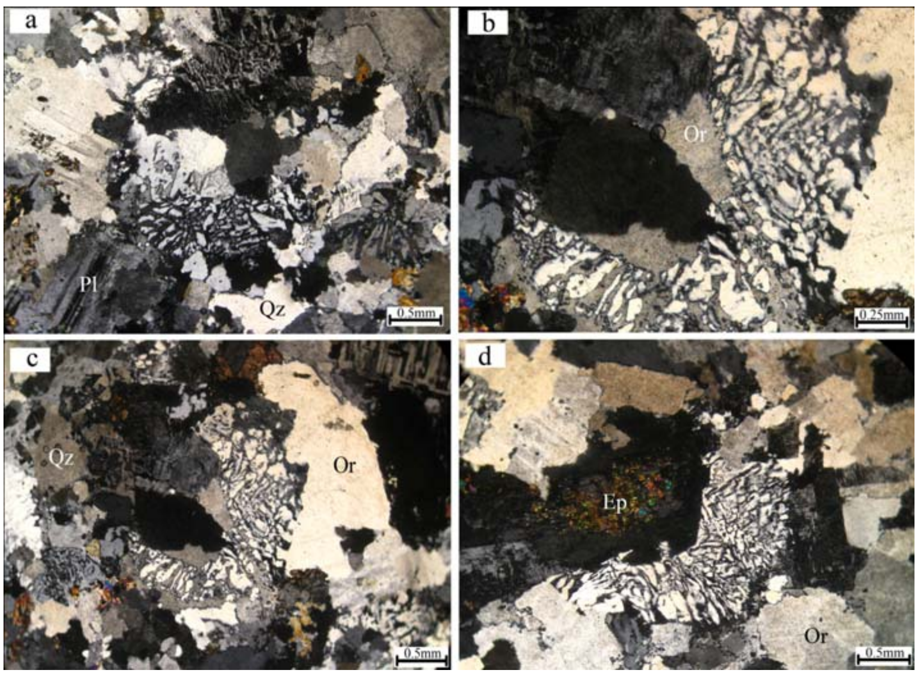

Fig. 4: Microphotograph of representative granite samples (crossed polarized light): a, b and c) granophyric texture d) epidotization at center of plagioclase. Or = orthoclase; Pl = plagioclase Qz= quartz (Whitny and Evanse, 2010).

Chondrite-normalized REE (Rare Earth Elements) patterns for intrusive rocks are illustrated in Fig. 8. Samples are normalized with values of Boynton (1984) and show relatively fractionated pattern (La_N/Yb_N=2.6-9) patterns, medium Eu anolamy (Eu/Eu*= 0.4-0.7) and relatively flat HREE (Heavy Rare Earth Elements) patterns (Gd_N/Lu_N= 1-1.2). Granitoid rocks with small to moderate negative Eu anomaly and high LREE/HREE ratios require residual plagioclase and garnet in the source (Cullers *et al*., 1984). Contribution of partial melts of subducted sediments to mantle wedge-derived basalts can also lead to low HREE and high LREE/HREE ratios in arc rocks (Kay *et al*., 2005).

Discussion:

Tectonic setting:

All of samples plot in the VAG (volcanic arc granites) field and near the WPG (within plate granite) field boundary in the geotectonic classification diagram (Pearce *et al*., 1984) (Fig. 9). Moreover, as mentioned earlier, all of samples are enriched in Cs, K, Rb, and Th with respect to Nb and Ti (Table 1; Fig. 7). Magmas with these geochemical characteristics are attributed to subduction-related environments (Sajona *et al*., 1996). Also, in Batchelor and Bowden (1985) diagram, the granite samples lie at post-orogenic field (Fig. 10).

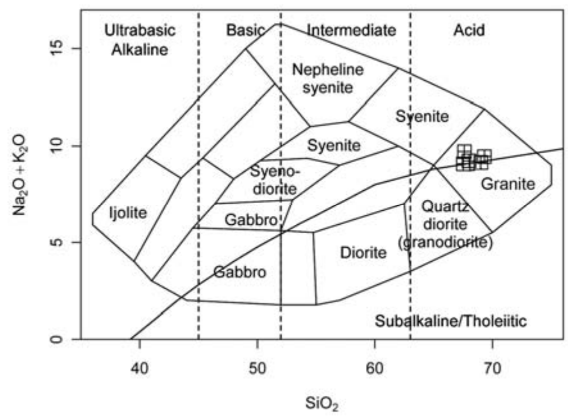

Fig. 5: Geochemical classification diagram (Cox *et al*., 1979) for granite samples.

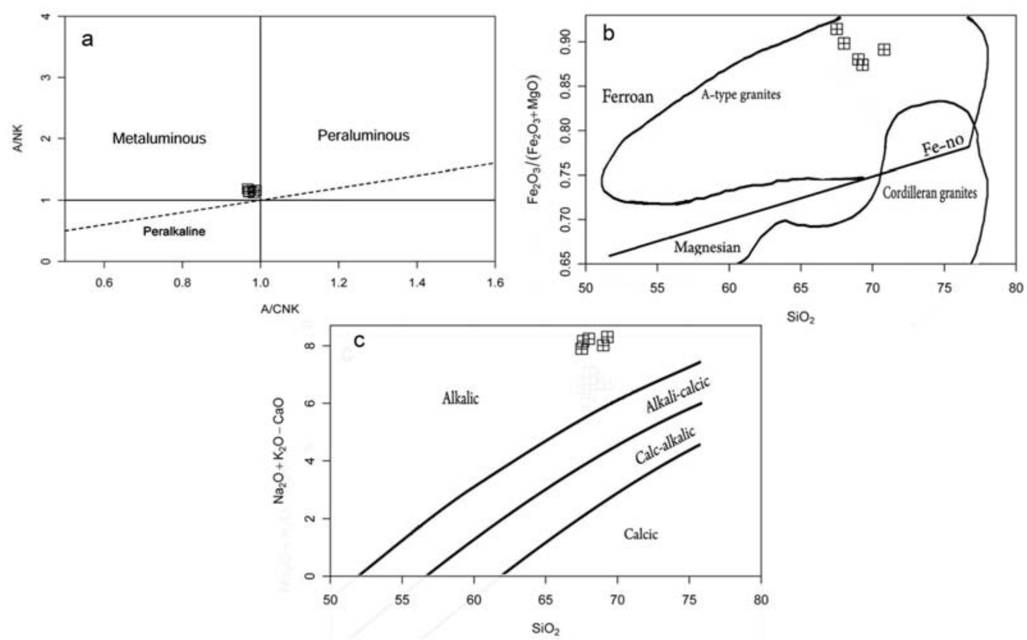

Fig. 6a: A/CNK vs. A/NK diagram (Shand, 1947); b) Fe number vs. SiO_2 diagram (Frost and Frost, 2008); c) MALI index vs. Sio_2 diagram (Frost and Frost, 2008).

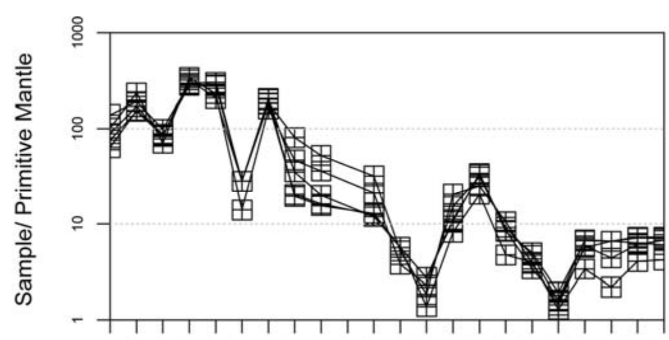

Fig. 7: Trace element spider diagram normalized by primitive mantle values (Sun and McDonough, 1989).

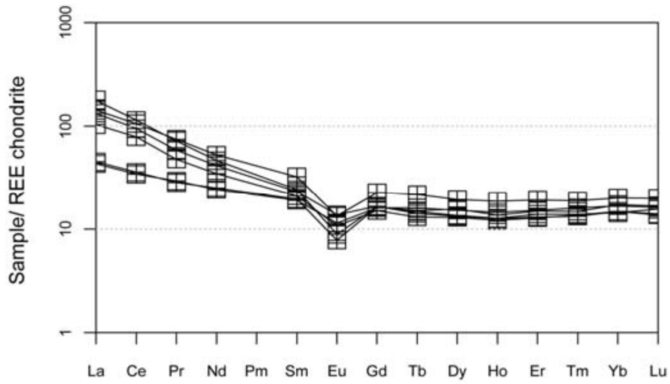

Fig. 8: REE distribution patterns normalized by chonderite values (Boynton, 1984).

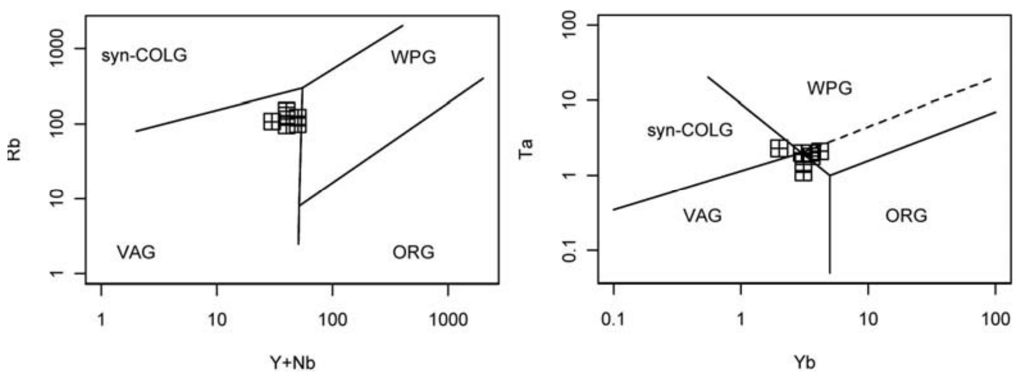

Fig. 9: Geotectonic discrimination diagrams (Pearce *et al*., 1984).

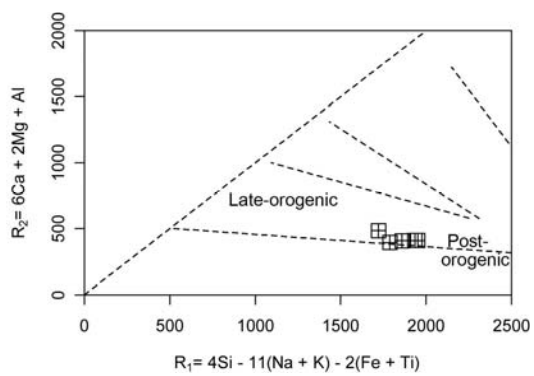

Fig. 10: Geotectonic regimes discrimination diagram (Batchelor and Bowden, 1985).

Petrogenesis:

Negative Ba and Sr anomalies in rocks are associated with negative Eu anomalies, indicating evolution by fractionation of K-feldspar and plagioclase (Ahmadi Khalaji *et al*., 2007). Granite samples relatively flow alkali-feldspar fractionation trend in Eu/Eu^* vs. Ba (Henderson, 1982) (Fig. 11a). Also, these samples made a regular trend in the Zr/Nb vs. Y/Nb diagram (Sabah, 2008) (Fig. 11b) suggesting that crystal fractionation plays an important role in magma evolution.

The granophyric granite veins in the study area have I-type granitiod characteristics (e.g. metalumious nature, SiO_2<70%, Na_2O > 3.2%, existence of sphene, Nb=18-25 ppm…) and in Rb-P_2O_5 and SiO_2-P_2O_5 discrimination diagrams (Chapple and white, 1992) relatively fallow I-type trends (Fig. 12). These samples also possess some A-type granitiod fitures (high HFSE, Zr and Fe number) and in (Y+Nb+Ce+Zr) vs. (Na_2O+K_2O)/CaO and Ga/Al vs. (Y+Nb+Ce+Zr) diagrams (Whalen *et al*., 1987) plot at near the A-type and I-S-type boundary (Fig. 13). Moreover, most ferroan granitoid (Fig. 6) are A-type (Frost *et al*., 2001; Frost and Frost, 2008). A-type granitoids are relatively potasic, have high $FeO_t/(FeO_t+MgO)$, Zr and other HFSE and because of such granitoids are rarely deformed and are inferred to have intruded long after the youngest deformation event called ‘anorogenic’ (Loiscelle and Wones, 1979). Eby (1992) further classified the A-type granitoids into A1 (intra-plate) and A2 (orogenic) sub-types (Fig. 14). A2 granitoids have mixed geochemical signatures of continental crust and island arc and are considered to form in a post-orogenic setting (Eby, 1992; Wu *et al*., 2002). Bonin (2007) suggested that A-type granitiods that plot within the VAG field and close to the WPG boundary in Pearce *et al*. (1984) diagrams, mostly are post-orogenic, aluminous, subsolvus, enriched in Rb, REE, Y and Th and are A2-type. There are several suggestions about origin of A-type granitiods, but one of newest of them suggested that crustal melting cannot produce such magma solely and variation sources contributed to generation A-type magma. Also, as it occurs in association with mafic igneous rocks, A-type granite is likely derived from contaminated mantle-derived mafic magma (Bonin, 2007).

As discussed earlier, granite samples possess geochemical properties which did show that crustal contamination have important role in their genesis (high LREE/HREE and Ba/Th ratios, high Th, K, Rb and low Sr, Ti and P contents) which is consistent with such a petrogenetic model.

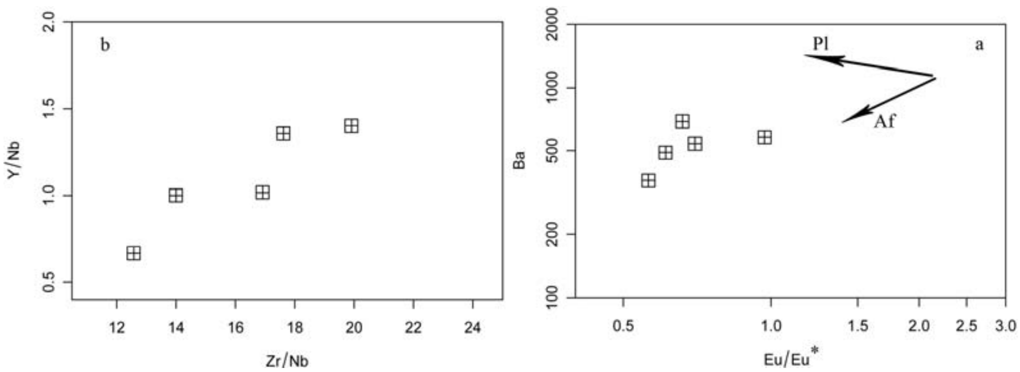

Fig. 11. a: Eu/Eu* vs. Ba plot for the granite samples. Af and Pl are Reyleigh fractionation trends calculated for removal of alkali feldspar (Aa) and plagioclase feldspar (Pl). (Af–Pl trends calculated after Henderson, 1982); b) Zr/Nb vs. Y/Nb plot for the granite samples (Sabah *et al*., 2008).

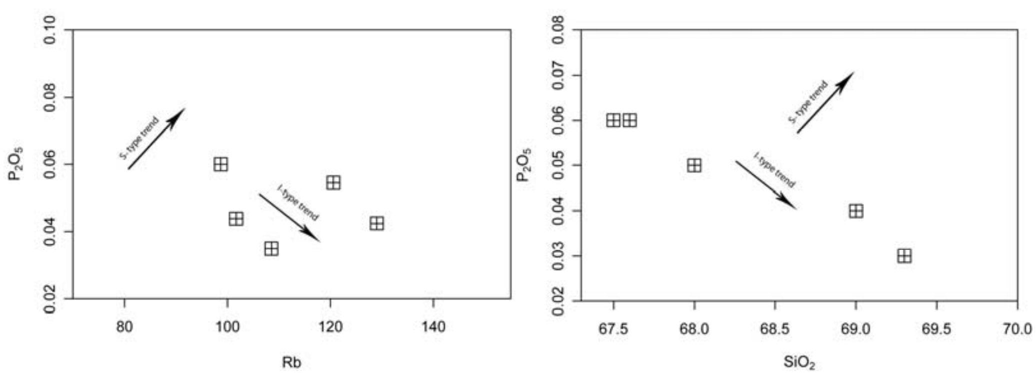

Fig. 12: I-type and S-type granitoids discrimination diagram (Chapple and white, 1992). As visible, most of samples flow I-type trend rather than S-type.

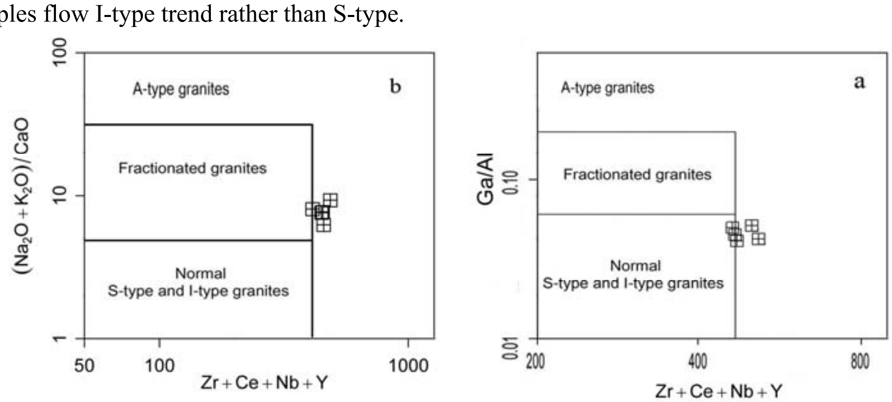

Fig. 13: Separation between A-type, I-type, S-type and fractionated granites (Whalen *et al*., 1987).

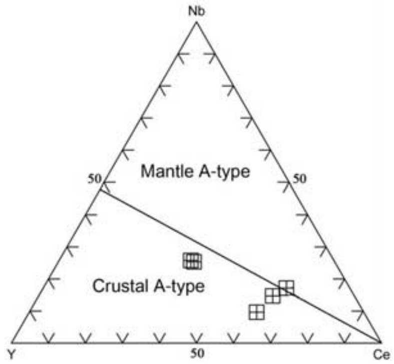

Fig. 14: The granite samples in Nb-Y-Ce plot (Eby, 1992).

Conclusion:

Granophyric granite veins penetrated into the igneous intrusive complex in south of Qorveh area are metalomious, alkalic which have high LREE/HREE and Ba/Th ratios. Their geochemical properties are consistent with active continental margins. Fractional crystallization plays an important role in generation of them. Granite samples have I-type geochemical characteristics, but their post-orogenic tectonic regimes, high K, Zr, relatively high HFSE contents and ferroan property of them, make it similar to A-type granitiods and A2 sub-type. However, several A-type granite have been reported from SSPMZ recently (Sepahi and Athari, 2006; Mansouri-Esfahani, 2009) but, Bonin (2007) believes that in the case of post-orogenic igneous suites, it is not always straightforward to define whether they are A-type, or highly fractionated I-type.

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