

# Geochemistry and Petrogenesis of Intrusive Pluton in North of Golpayegan (Central Part of Sanandaj-Sirjan Zone)

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Received 19 July 2014; revised 15 August 2014; accepted 11 September 2014

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## Abstract

Granitoid pluton in the north of Golpayegan is located in 10 km north of Golpayegan at Sanandaj-Sirjan zone. Dominant rocks of this region include granite, syenite, and gabbro. Granite type is granular with medium to coarse crystals and its mineralogical composition contains alkali feldspar + quartz + plagioclase + biotite + secondary minerals (opaque + sphene + apatite). Granite rocks have calc-alkaline and metaluminous to peraluminous nature, relative enrichment of Rb over Sr, and relative enrichment of LILE over HFSE elements. These granites, which are type I, are derived from the melting of metagreywackes and their tectonic setting is of upper continental crust and post-orogenic setting. Gabbroic type is older than other types of the pluton and is granular with medium to fine crystal. Mineralogical composition of these rocks is plagioclase + pyroxene + amphibole + biotite + secondary minerals (opaque). Based on geochemical characteristics of tholeiitic and metaluminous nature, relative enrichment of Ba and Sr elements over Rb, relative enrichment of LILE elements over HFSE, negative anomaly of Nb, Ba, and Ta, and positive anomaly of Pb are observed. Origin of this type is probably from enriched mantle and in-plane tectonic setting.

## Keywords

Granitoid, Sanandaj-Sirjan Zone, Golpayegan

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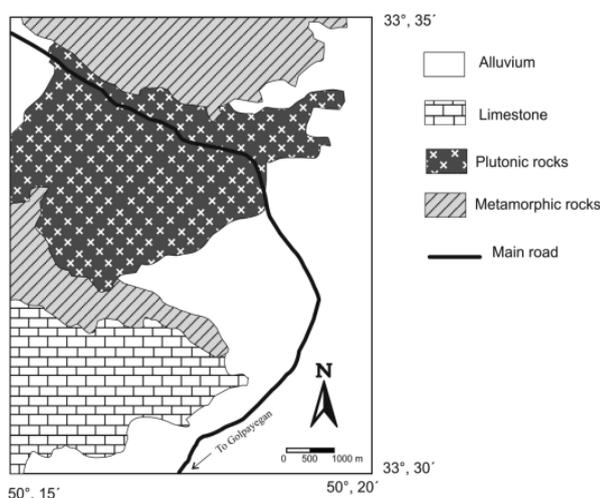
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## 1. Introduction

Intrusive pluton in the north of Golpayegan crops out in a region between longitude of  $50^{\circ}15'$  and  $50^{\circ}20'$  east and latitude of  $33^{\circ}33'$  and  $33^{\circ}35'$  north in the central area of Sanandaj-Sirjan zone (**Figure 1**). The studied area is located in the northwest of Isfahan province and south of Central province. The first study which has been performed on this zone is in the form of 1:250,000 detailed geological map by Tiele [1], in which rocks of the region are divided into metamorphic, plutonic and volcanic rocks. In the past, the studied area and its surrounding regions have been studied by different researchers such as Ebrahimi [2], Sharifi [3] and Ahmadi [4]. Stocklin [5], Tiele [1], and Ibrahimi [2] have considered Precambrian age as the metamorphism of this region. According to the studies by Sharifi [3], metamorphic age of this region is considered to include slate, calc-schist, metadolostone (Paleozoic), amphibolites, chlorite schist, metavolcanic (Mesozoic), and metagranite (Cretaceous-Paleocene). Therefore, intrusive bodies in the north of Golpayegan, which have cut the above-mentioned metamorphic rocks, definitely do not belong to Precambrian, and the alternative age of the intrusive bodies located in Golpayegan—east of Khomein is considered to be Mesozoic. Furthermore, age determination by K-Ar radiometry demonstrates that age of granite in Esfajerd is around 64.2 million years and that granites on the east of Cheshme Sefid have been injected around 58.4 million years ago, which represents their Cretaceous age [6].

## 2. Geology of the Studied Pluton

Sanandaj-Sirjan zone is a narrow strip of land on the southwest of Central Iran which is located at the immediate northeast of Major Zagros Thrust. Rock and structural characteristics of Sanandaj-Sirjan zone represent a deep trough or middle block split in Iran and Arabia Precambrian shield. Therefore, its geological characteristics are evidently different from those of the surrounding zones [7]. Sanandaj-Sirjan zone is like a metamorphic strip with a northwest-southeast trend in parallel to Zagros zone which is extended to Taurus zone in Turkey with similar characteristics. In this zone, several intrusive igneous phases have occurred, the most important of which have been at Middle-Late Triassic, Late Jurassic—Early Cretaceous, Late Cretaceous-Paleocene [8]. Most of the plutons of Golpayegan-Urmia set are of composite plutons, which include rocks with different compositions and ages. In this intrusive set, most bodies belong to Cretaceous-Paleocene period. In most of the composite plutons of this set, formation of basic rocks has priority over that of acidic rocks and distinct differences in the rock composition of this set indicates different origins of each rock group [9]. In some part of these intrusive sets, alkalisyenite-granite has been also observed. Imami [10] believes that there are some magma rocks in Iran which have appeared between two Jurassic and Cretaceous periods and have been attributed to both periods. Among these rocks at Sanandaj-Sirjan zone are granite-granodiorite bodies at Golpayegan zone. Berberian and King [11] state that translocation of acidic plutonic bodies in Middle Jurassic and Late Cretaceous—Tertiary (Golpayegan-Urmia intrusive belt) in the southern margin of Central Iran (Sanandaj-Sirjan zone) is the result of continued subduction and its final stages.



**Figure 1.** Map of the study population [28].

Intrusive pluton in the north of Golpayegan is located in the central region of Sanandaj-Sirjan zone and is considered as a part of Tethys orogeny. The studied pluton can be divided into four parts in terms of petrology and field relations; different units of the petrology of the studied pluton are cut by metamorphic and non-metamorphic dikes. Here, this pluton diversity is briefly introduced: 1—Gabbro type, 2—Granite type, 3—Syenite type, and 4—Monzonite type.

### 2.1. Gabbro

This rock which crops out of the Schists in form of apophyses in this region contains coarse plagioclase crystals that seem to be mostly secondary with a granular-subophitic texture under the microscope (**Figure 2**).

### 2.2. Granite

Granites of the region crop out in the north of syenite pluton and inside metamorphic Precambrian rocks and have caused contact metamorphism. In field studies, granites have mainly medium to coarse crystals and emerge in grey color in most of the cases. Granitoid rocks in the north of Golpayegan include syenogranite and monzogranite with silica veins at the margin of the pluton (**Figure 3**).

### 2.3. Syenite

Syenites and quartz syenites which constitute the main volume of plutonic rocks of the region are injected into regional metamorphic rocks and cause contact metamorphism in them. These rocks which mainly crop out around Khomein-Golpayegan road are grey in the hand specimens. Syenite rocks contain different petrological sets from alkaline syenites to syenite.

### 2.4. Monzonite

These rocks appear in grey color in the hand sample.

### 2.5. Metamorphic and Non-Metamorphic Dikes

In this region, due to the presence of magmatism in multiple phases, dikes with the existing type of bodies are observed which are sometimes metamorphic and some other times non-metamorphic. Presence of rocks that are more basic than meatgranitoid and quartz syenite such as monzonite and gabbro (as xenolite) and fine-grained dikes of quartz syenite suggests the injection of magma at multiple stages (**Figure 4**).

## 3. Petrography

Gabbro has a granular-subophitic texture and its mineralogical composition contains plagioclase, clinopyroxene, amphibole, biotite, and secondary minerals (primary opaque, zircon, sphene, and apatite). Clinopyroxene appears in the form of euhedral and semi-euhedral crystals, which are extensively transforming into tremolite-actinolite and biotite (**Figure 5(a)**).

Granites of this region contain mineralogical composition of alkali feldspath, plagioclase, quartz, biotite, amphibole, and other minerals (apatite, sphene, and zircon). Perthite is abundantly present in these rocks (**Figure 5(b)**). Quartz is seen as anhedral crystals with occasional crystallization (**Figure 5(c)**). Apatite and sphene are also observed as inclusions and accessory in these rocks, respectively (**Figure 5(d)**).

Mineralogical composition of alkaline syenites includes alkali feldspar, plagioclase, amphibole, and accessory minerals (apatite and sphene). Texture of these rocks is granular, porphyric with medium-sized grains. Alkali feldspar are mostly perthit or with little microcline.

Mineralogical composition of the syenites of this region includes alkali feldspar, plagioclase, amphibole, quartz, and accessory minerals (apatite, sphene, zircon, and primary opaque). Perthit or it are abundantly found in these rocks (**Figure 5(e)**). Some plagioclase crystals are intact and some others are partially altered to kaolinite. Composition of plagioclases of these rocks is at the andesine level (based on Michel-Levy's table with the extinction angle of  $23^\circ$ ) (**Figure 5(f)**). Zircon is rarely seen in these rocks (**Figure 5(g)**).

Monzonite rocks are granular with frequent inclination to intergranular and porphyric with medium grains inclined to microlite. Alkali feldspath, plagioclase, amphibole, quartz, and secondary and accessory minerals



**Figure 2.** Filling fractured quartz veins are relatively pure (N 33°34'28"-E 50°13'20"—H: 2167 m).



**Figure 3.** Gabbro out crop within the schists.



**Figure 4.** Syenite dyke metamorphic.

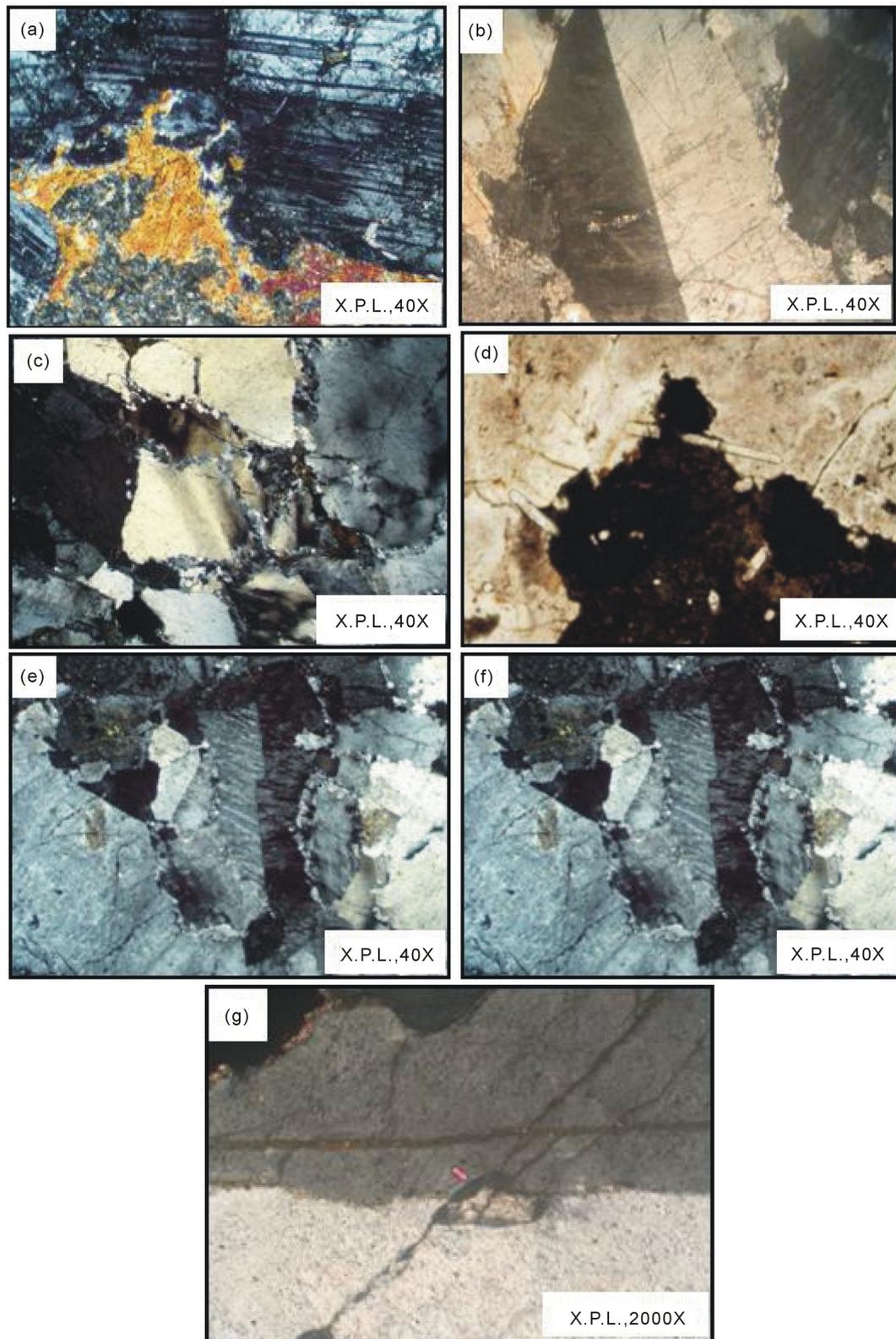
(apatite, sphene, zircon, and primary opaque) are among the constitutive minerals of these rocks.

## 4. Geochemistry

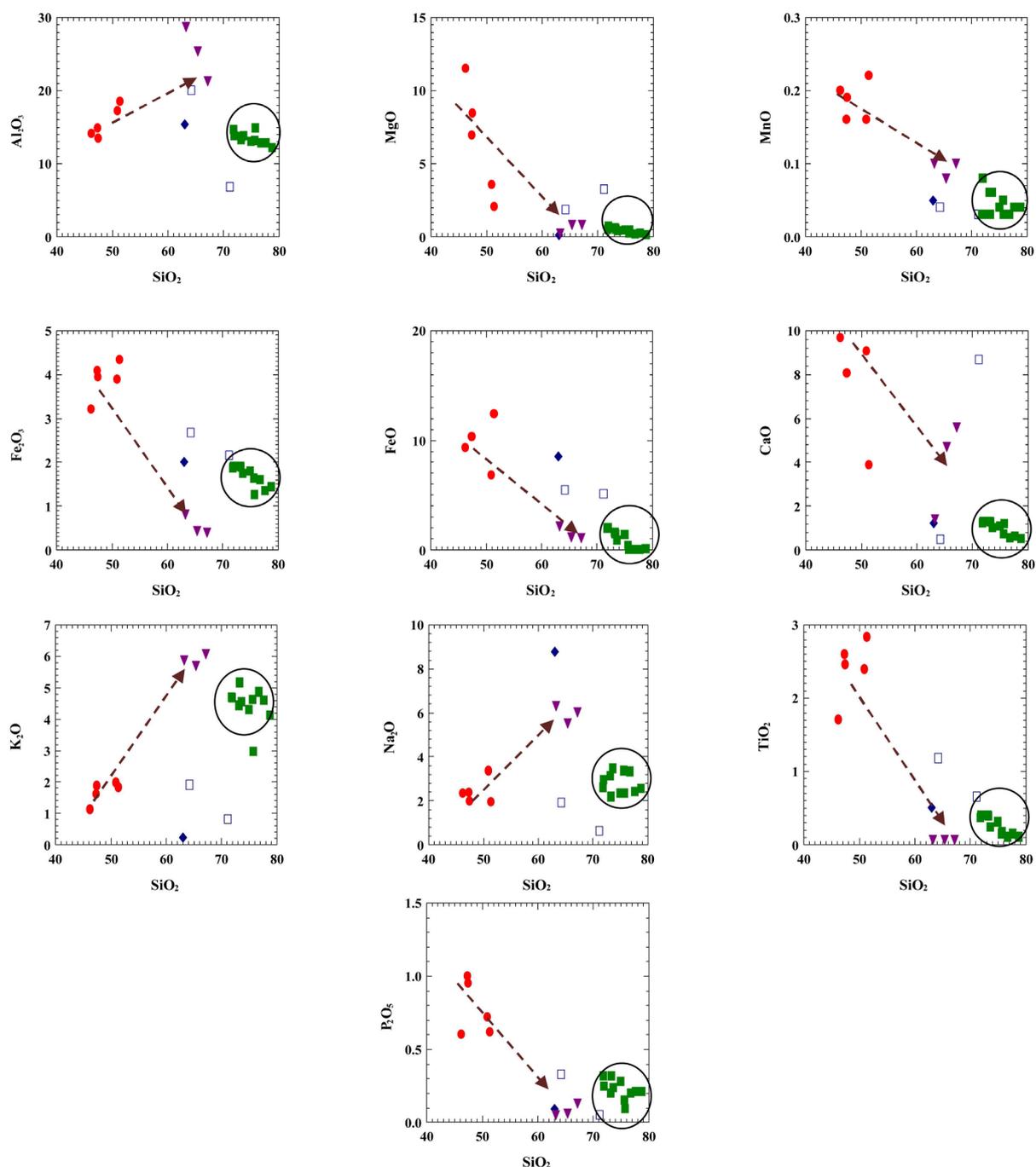
### 4.1. Geochemistry of Primary and Rare Elements

Variation rate of  $\text{SiO}_2$  is between 46% and 78%. In Harker diagrams [12], samples are classified into three distinct ranges, demonstrating different primary magmas for each (**Figure 6**).

Rocks of tholeiitic gabbroic, syenite, and granite types are alkaline and metaalumin, tholeiitic and metalumin-



**Figure 5.** Selected microscopic images of rock groups studied (in crosspolarized light XPL): (a) Clinopyroxene; (b) Perthite; (c) Quartz recrystallization; (d) Apatite inclusions in amphibole; (e) Perthite orthose; (f) Polysynthetic plagioclase; and g) Zircon.



**Figure 6.** Change the major element oxides than silica (Harker diagrams) [12].

ous, and calc-alkaline and metaluminous to peraluminous, respectively.

According to Harker diagrams, igneous rocks of the region are classified into two groups. The first group belongs to gabbro-syenite family, the crystallization-magmatic differentiation trend of which justifies the role of element variations. The second group is granitoid family which is distinct and away from gabbro, has a different age, and shows a different behavior in geochemical diagrams.

Increasing amount of  $\text{SiO}_2$  justifies decreased levels of  $\text{MgO}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{FeO}$ ,  $\text{TiO}_2$ , and  $\text{MnO}$  through the crystallization of amphibole and biotite ferromagnesian minerals, variations of  $\text{Al}_2\text{O}_3$  and  $\text{CaO}$  through the crystallization of plagioclase, and decreased  $\text{P}_2\text{O}_5$  through the crystallization of apatite. Linear and negative variation

trends of CaO and P<sub>2</sub>O<sub>5</sub> relative to SiO<sub>2</sub> which are occasionally seen in the studied samples have been stated as the characteristics of type I granite [13], because phosphorus available in type I granite acts as a compatible element due to the crystallization of apatite; indeed, in case other factors do not get involved in the intrusion or extrusion of these elements. In the existing samples, a scattering is observed in a specific silica range in the gabbro and syenite samples, while continuity and proximity of data are seen in most of the granite samples. It seems that, in a specific range of silica, high variation of elements cannot be attributed to primary and magmatic differentiation processes, since they are crystallized in specific steps of the differentiation of particular minerals with determined distribution coefficients of rare elements. Abnormal increase in the level of several elements in a specific silica range clearly demonstrates the effect of secondary phenomena. In Harker diagrams related to rare elements, two rock groups can be distinguished similar to primary elements; the first one is gabbro-syenite family and the second is from granitoid family (Tables 1-3).

## 4.2. Spider Diagrams of Incompatible Elements

Concentrations of incompatible elements in rocks are normalized in relation to a specific standard which is typically chondrite meteorite; in this regard, REE elements are specifically important. Normalization with respect to chondrites is considered important from two perspectives [14]; first, frequency variations of elements with even and odd atomic numbers are removed and second any separation of rare earth elements (REEs) with respect to chondrites can be easily detected. REEs are normalized according to Boynton data [15] which is widely accepted by most petrologists [14] (Figure 7).

Light rare earth elements (LREE) show a higher level of enrichment than high rare earth element (HREE), which is caused by one of the following factors: 1) low melting of mantle materials, 2) limited melting of enriched mantle, and 3) product of the final process of crystallization.

Eu negative anomaly is the result of the establishment of relative reduction conditions dominating its emergence and intrusion into feldspar structure; crystallization and the accompanying separation of feldspars cause this negative anomaly. Eu amount is substantially controlled by feldspars (especially in granitic magmas). In granitic magmas, Eu<sup>2+</sup> is compatible with plagioclase and alkaline feldspath and their differentiation from granitic molten or their deposit on the origin leads to the formation of Eu negative anomaly [14] [16]. LREE enrichment over HREE can be due to the presence of magma at the primary stages of melting or final stages of differential crystallization and also presence of hornblendes in the molten of these rocks.

Presence of relative enrichment of LREE over HREE in diagrams related to the region's gabbros indicates relative enrichment of LREE incompatible elements in origin rocks; such an origin can be enriched or evolved mantle. Also, due to the higher level of apatite, titanite, and rutile blades, REE content is higher than that of other types.

In spider diagrams, all the samples are normalized according to primary mantle [17] (Figure 8).

The following cases are among the issues that should be taken into account when interpreting these diagrams:

1) Higher enrichment of LILE over HFSE elements; Kelemen [18] proposes that depletion of HFS in magma reflects the interaction between magma and depleted peridotite.

2) Negative anomaly of Bn, Ba, Zr, and Lu and positive anomaly of Sm, Nd, and Th

According to Wilson [19] and Rollinson [14], Nb drop in the spider diagram of incompatible elements can be due to two factors: either magma impregnation with mantle materials or their relationship with subduction. Nb negative anomaly is the indicator of continental rocks and might indicate the involvement of crust in magma processes [14].

In granite and syenite rocks, enrichment of LILE over HFSE and negative anomaly of Lu, Ba, and Zr and positive anomaly of Nd and Th can be observed.

Concentration of other rare elements in Golpayegan's rocks is controlled by special minerals. For example, concentration of Zr, P, Sr, Ti, and Nb is controlled by zircon, apatite, plagioclase, ilmenite, and rutile, concentration of Rb, Cs, Ba, Na, Ca, Al, and Si is controlled by feldspars, and that of Cr, Co, Ti, Fe, and Mg is controlled by ferromagnesian minerals like biotite, respectively.

## 5. Discussion

### 5.1. Magmatic Origin

According to geochemical characteristics, the studied gabbro rocks have alkaline nature. Based on the spider

**Table 1.** Chemical analysis of granite rocks of intrusive pluton in north of Golpayegan.

Sample	64 m	21 m	103 m	105 m	20 m	39 m	22 m	26 m	37 m	38 m	91 m
<b>SiO<sub>2</sub></b>	75.62	76.73	73.22	73.64	71.87	75.02	77.68	78.81	73.33	75.77	72
<b>TiO<sub>2</sub></b>	0.14	0.1	0.4	0.24	0.37	0.3	0.14	0.1	0.39	0.17	0.4
<b>Al<sub>2</sub>O<sub>3</sub></b>	13.1	12.78	13.18	13.82	14.59	13.07	12.79	12.15	13.63	14.83	13.75
<b>Fe<sub>2</sub>O<sub>3</sub></b>	1.64	1.6	1.9	1.47	1.87	1.8	1.34	1.34	1.89	1.25	1.9
<b>FeO</b>	0.4	0.03	1.61	0.9	1.98	1.38	0.04	0.03	1.42	0.04	2.01
<b>MnO</b>	0.05	0.04	0.06	0.06	0.05	0.06	0.06	0.05	0.04	0.08	0.08
<b>MgO</b>	0.21	0.16	0.62	0.36	0.49	0.45	0.21	0.12	0.49	0.43	0.7
<b>CaO</b>	0.73	0.54	1.3	1.01	1.21	1.08	0.61	0.51	1.25	1.19	1.28
<b>Na<sub>2</sub>O</b>	3.33	3.3	3.12	3.43	2.6	2.33	2.42	2.55	2.14	2.32	2.95
<b>K<sub>2</sub>O</b>	4.62	4.83	4.41	4.54	4.7	4.29	4.6	4.12	5.14	2.95	4.66
<b>P<sub>2</sub>O<sub>5</sub></b>	0.15	0.2	0.2	0.24	0.32	0.28	0.21	0.21	0.32	0.09	0.25
<b>Ba</b>	110	50	280	220	455	344	80.2	39	428	634	230
<b>Rb</b>	255	237	41.2	32.5	281	302	270	333	230	72.2	11.1
<b>Sr</b>	30	20	360	530	132	114	44.1	26.2	129	475	480
<b>Y</b>	20	20	40	20	13	16.8	14.6	11.7	18.5	2.7	20
<b>Zr</b>	90	70	490	190	9.07	4.61	18.8	19.2	5.41	17	130
<b>Nb</b>	20	10	90	40	32.4	30.6	28.2	21.6	30.3	7.84	40
<b>Th</b>	8.8	8.3	8.3	1.7	18.3	20.8	11.9	9.39	20.1	2.48	2.6
<b>Ga</b>	20	18	24	21	22.4	22.3	18.9	19.4	20.9	17.5	18
<b>Zn</b>	23	26	102	100	58.8	54.4	33.7	27.3	46	55.3	118
<b>Cu</b>	6	9	36	32	3.52	5.5	10.5	5.17	24.3	4.28	44
<b>Hf</b>	3	2	10	3	0.52	0.42	1.14	1.09	0.41	0.67	3
<b>Cs</b>	14.9	15.9	0.9	5.2	33.2	27.7	18.9	40.9	16.6	1.57	3.2
<b>Ta</b>	3.3	3.9	6.5	1.5	3.42	3.05	6.59	4.19	3.48	0.55	1.6
<b>Co</b>	1.8	1.1	22.1	36.1	6.54	5.42	2.52	2.19	6.46	2.57	48.7
<b>U</b>	2.89	3.14	2.32	0.62	2.76	4.45	5.33	4.17	3.5	0.79	0.84
<b>W</b>	14	28	2	2	6.02	4.08	55.4	16.1	16.3	2.62	1
<b>La</b>	16	11.6	50.3	19.5	62.2	49.4	17.7	13.4	46.6	6.85	32.1
<b>Ce</b>	28.2	21.4	92.4	35.4	96.6	114.3	32.1	24.7	113	13.6	56.6
<b>Pr</b>	3.25	2.37	9.9	4.34	10.5	10.8	4.06	3.12	9.88	1.6	6.35
<b>Nd</b>	10.8	8.3	35.5	17.8	31.4	31.8	17.8	13.9	26.7	5.71	23.8
<b>Sm</b>	2.5	2	6.8	3.8	6.78	6.74	2.92	2.3	6.34	2.08	4.4
<b>Eu</b>	0.18	0.11	1.64	1.63	1.22	0.97	0.26	0.19	1.1	0.95	1.61
<b>Gd</b>	2.37	2.02	6.21	3.76	5.96	5.91	2.6	2.1	5.81	1.03	4.3
<b>Tb</b>	0.48	0.43	1.08	0.63	0.88	0.91	0.47	0.37	0.97	0.15	0.72
<b>Dy</b>	3.11	2.92	6.44	3.68	3.42	4.37	2.82	2.15	4.46	0.65	3.85
<b>Ho</b>	0.65	0.58	1.35	0.71	0.57	0.47	0.6	0.46	0.84	0.11	0.77
<b>Er</b>	2	1.74	4.24	2.02	1.33	1.64	1.47	1.14	1.92	0.26	2.11
<b>Tm</b>	0.34	0.28	0.54	0.26	0.28	0.28	0.33	0.28	0.37	0.1	0.26
<b>Yb</b>	2.2	2.1	4	1.6	1.2	1.36	1.78	1.51	1.84	0.28	1.7
<b>Lu</b>	0.3	0.26	0.58	0.23	0.07	0.13	0.16	0.13	0.18	0.08	0.28

**Table 2.** Chemical analysis of gabbro rocks of intrusive pluton in north of Golpayegan.

Sample	12 m	11 m	13 m	30 m	88 m
SiO <sub>2</sub>	51.33	47.51	50.9	47.41	46.2
TiO <sub>2</sub>	2.83	2.45	2.39	2.59	1.7
Al <sub>2</sub> O <sub>3</sub>	18.49	13.74	17.16	14.85	14.14
Fe <sub>2</sub> O <sub>3</sub>	4.33	3.95	3.89	4.09	3.2
FeO	12.38	10.36	6.84	10.34	9.3
MnO	0.22	0.19	0.16	0.16	0.2
MgO	2.04	8.45	3.57	6.93	11.5
CaO	3.88	8.07	9.06	8.08	9.67
Na <sub>2</sub> O	1.94	1.96	3.34	2.38	2.34
K <sub>2</sub> O	1.82	1.86	1.97	1.6	1.12
P <sub>2</sub> O <sub>5</sub>	0.62	0.95	0.72	1	0.6
Ba	326	146	179	371	300
Rb	46.9	85	37.8	21.3	212
Sr	120	314	493	845	90
Y	58.1	31	32.3	20.4	20
Zr	114	15.9	280	26.6	230
Nb	111	67.4	72.3	63.5	30
Th	10.6	8.82	9.18	3.25	18.6
Ga	352	24	22.6	17.1	23
Zn	211	156	139	130	44
Cu	16.6	119	49	63	5
Hf	2.98	0.64	0.44	1.94	6
Cs	0.7	6.34	1.93	0.88	11.8
Ta	7.79	4.02	3.28	4.39	3.3
Co	3.88	67.6	33.7	50.3	4.7
U	2.2	2.06	2.5	0.97	7.84
W	1.19	1.54	2.05	0.33	4
La	108	49.7	34.6	37.8	43.1
Ce	147	112	53.8	78.5	82.9
Pr	17.3	11.9	6.95	9.36	9.04
Nd	53.9	72.7	33.5	36.3	32.3
Sm	12.3	9.14	5.54	6.64	6.2
Eu	1.66	2.42	1.52	2.02	0.57
Gd	12.5	9	5.68	5.69	5.05
Tb	2.27	1.46	1.11	0.88	0.84
Dy	12.3	6.77	5.57	4.74	4.09
Ho	2.72	1.47	1.29	0.96	0.82
Er	6.42	3.28	3.26	2.22	2.2
Tm	1.22	0.65	0.73	0.36	0.3
Yb	5.67	3.03	3.51	2.08	2
Lu	0.54	0.31	0.32	0.26	0.36

**Table 3.** Chemical analysis of syenite and monzonite rocks of intrusive pluton in north of Golpayegan.

Sample	40 m	41 m	42 m	18 m	122 m	155 m
SiO <sub>2</sub>	67.2	65.4	63.2	64.22	63	71.16
TiO <sub>2</sub>	0.07	0.07	0.07	1.17	0.51	0.65
Al <sub>2</sub> O <sub>3</sub>	21.3	25.38	28.7	20.05	15.41	6.82
Fe <sub>2</sub> O <sub>3</sub>	0.4	0.44	0.81	2.67	2.01	2.15
FeO	1.12	1.15	2.18	5.45	8.5	5.1
MnO	0.1	0.08	0.1	0.05	0.05	0.03
MgO	0.8	0.8	0.2	1.84	0.12	3.22
CaO	5.6	4.7	1.4	0.47	1.23	8.68
Na <sub>2</sub> O	6.02	5.53	6.3	1.19	8.77	0.6
K <sub>2</sub> O	6.08	5.7	5.87	1.88	0.23	0.8
P <sub>2</sub> O <sub>5</sub>	0.13	0.06	0.05	0.33	0.09	0.05
Ba	150	140	238	142	20	90
Rb	153.2	178.9	200	81.5	5.5	23.7
Sr	83.5	86.1	340	70.9	130	300
Y	41	43.8	12.5	13.4	80	10
Zr	993	999.8	589	18.5	880	120
Nb	211.2	178.9	76.1	24.1	130	30
Th	30.1	30.2	14.5	18	17.2	3.9
Ga	28.8	31.4	33.2	20.4	44	12
Zn	9	10.1	56	47.8	9	81
Cu	5	2.6	4.4	92.5	7	80
Hf	25.9	27.3	15.5	0.78	19	3
Cs	0.6	0.7	3.5	0.56	0.2	1.1
Ta	11.4	11.4	6.1	2.77	9.7	2.1
Co	1	0.7	0.9	14.8	1.4	13.7
U	5.7	5.5	4.6	3.38	3.24	0.71
W	6.7	2.5	1.9	2.38	4	6
La	180.5	190	75.3	51	90	11.5
Ce	319.5	330	133	123	168	22.7
Pr	34.5	34.1	12.8	12.8	18.4	2.85
Nd	100.1	98.2	39.1	45.3	65	10.9
Sm	13.1	13	5.2	8.05	12.7	2.1
Eu	1.92	2	0.7	1.38	1.35	0.52
Gd	9.28	9.33	3.45	6.83	12.6	1.76
Tb	1.32	1.46	0.5	0.9	2.2	0.32
Dy	7.3	8.07	2.3	3.82	13.5	1.8
Ho	1.4	1.5	0.5	0.62	2.88	0.35
Er	4.1	4.5	1.2	1.51	8.32	0.99
Tm	0.7	0.8	0.2	0.3	1.26	0.5
Yb	4.18	4.5	1.2	1.58	8.5	0.8
Lu	0.7	0.8	0.2	0.29	1.23	0.12

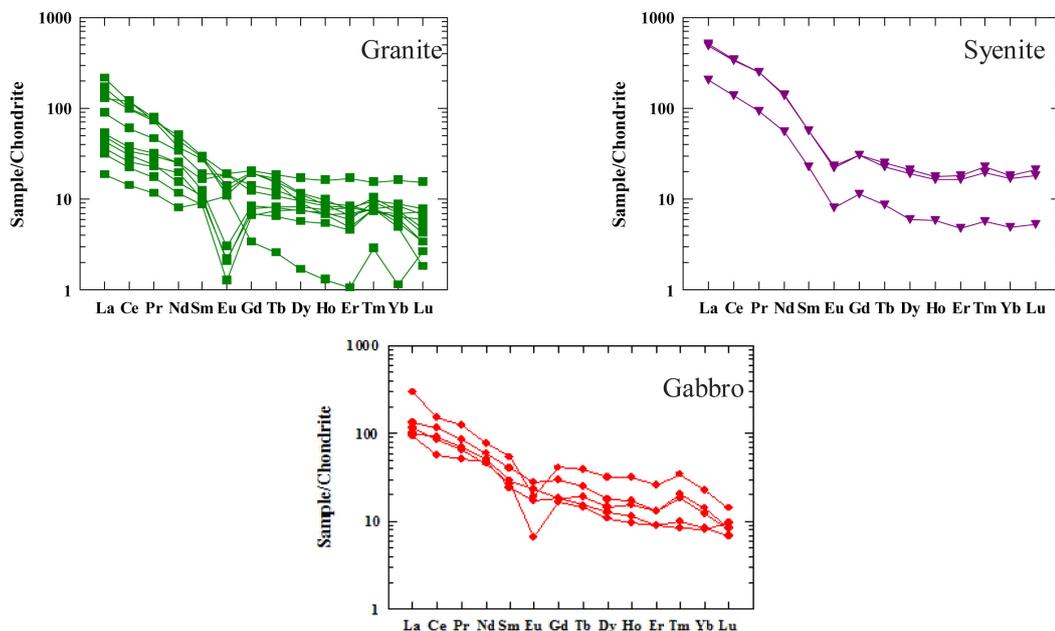


Figure 7. Normalized REE patterns relative to Chondrite.

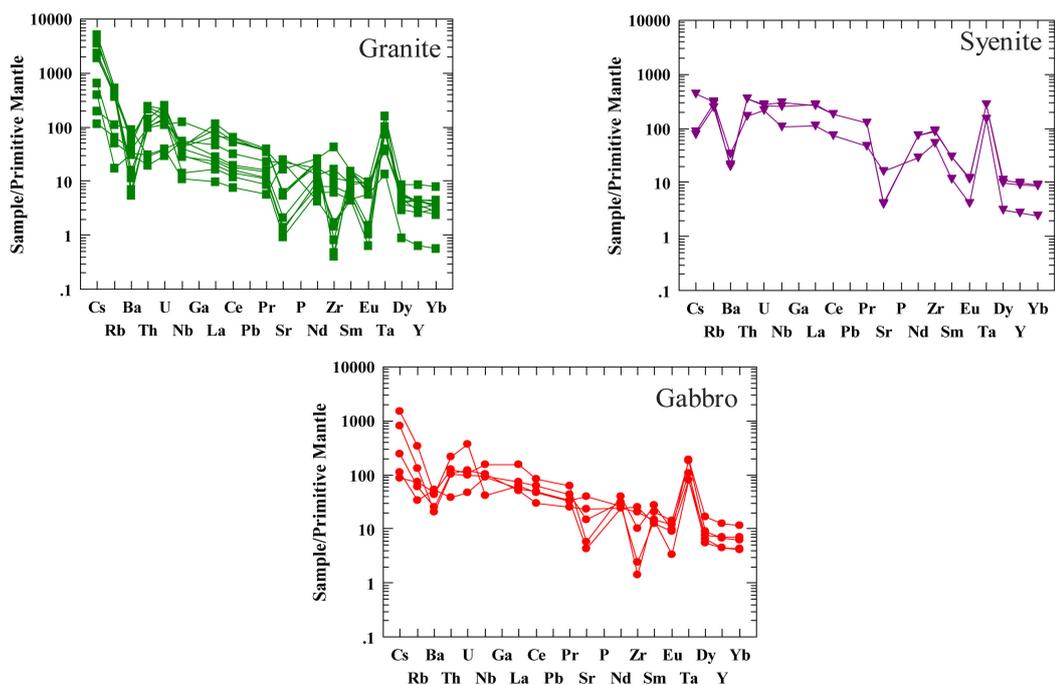


Figure 8. Frequency of spider diagrams normalized in compatible elements relative to Primitive Mantle.

diagrams, these rocks of LILE elements are enriched over HFSE elements and Nb negative anomaly is observed in them. Gabbro rocks contain a high level of MgO which demonstrates their crystallization from a primary basic magma. Relative enrichment of CaO and Sr elements, relatively high level of Al<sub>2</sub>O<sub>3</sub>, and their metaalumin nature indicate high-temperature condition at their origin. Primary mantle rocks, transformed lithosphere mantle, and primary gabbro rocks in deep crust are considered as the source or origin rock for this type. For the formation of low-silica metaalumin molten by melting without water of metabasaltic origin, more than 1100°C temperature is required [20]. In case of the presence of such temperature at origin, such molten is characterized by

low  $Mg\# < 44$  ( $MgO + 0.9 FeOT \cdot 100$ ) and high  $Na_2O > 4.3$  wt% [9]. Gabbro rocks of this type do not have such a characteristic. In order to identify the presence or absence of enrichment at the origin of studied mafic rocks, ratios of Zr-Nb incompatible elements are used, in which mafic magma constituting the studied rocks is originated from an enriched mantle source (**Figure 9(a)**).

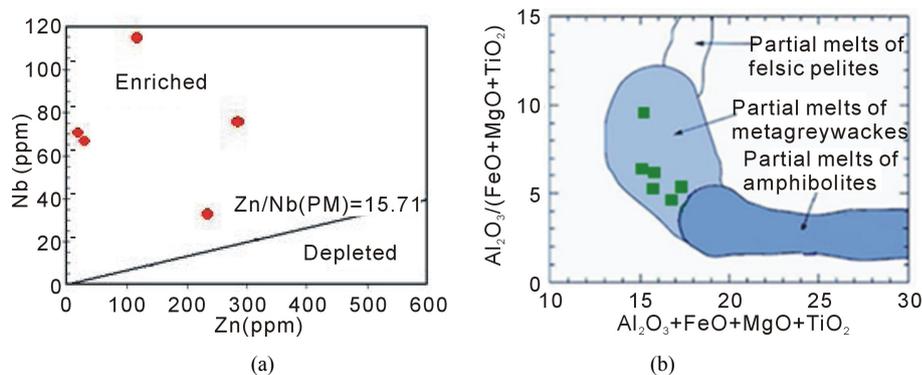
According to Chappell and White [21], classification regarding granite rocks, north Golpayegan's felsic rocks are of type I based on the following field and mineralogical observations:

- Lack of aluminium silicate minerals including muscovite, andalusite, cordierite, and garnet.
- These rocks are weak peraluminous which is among the characteristics of type I granite.
- Presence of hornblendes in the mineralogical composition of granites.
- Lack of mica-enriched and metamorphism enclaves.
- Presence of primary titanites and lack of monazite.
- Positive relationship of Th variations against  $SiO_2$ .
- $P_2O_5$  diagram with respect to  $SiO_2$  for the studied samples shows a negative trend which is regarded among the characteristics of type I granite [13].

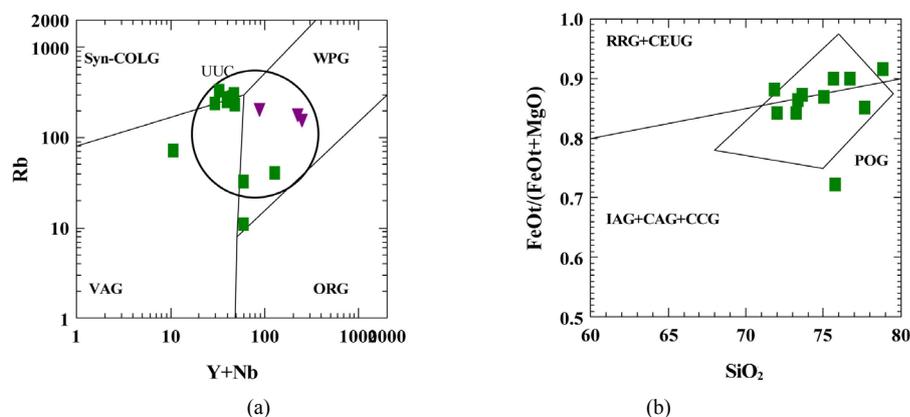
Using the diagrams introduced by Patino Douce [22], origin of granites can be attributed to the melting of metagreywackes (**Figure 9(b)**). Establishment of mafic magma with high temperature beneath the continental crust is the main factor for melting and producing a high amount of felsic magma.

## 5.2. Tectonic Setting

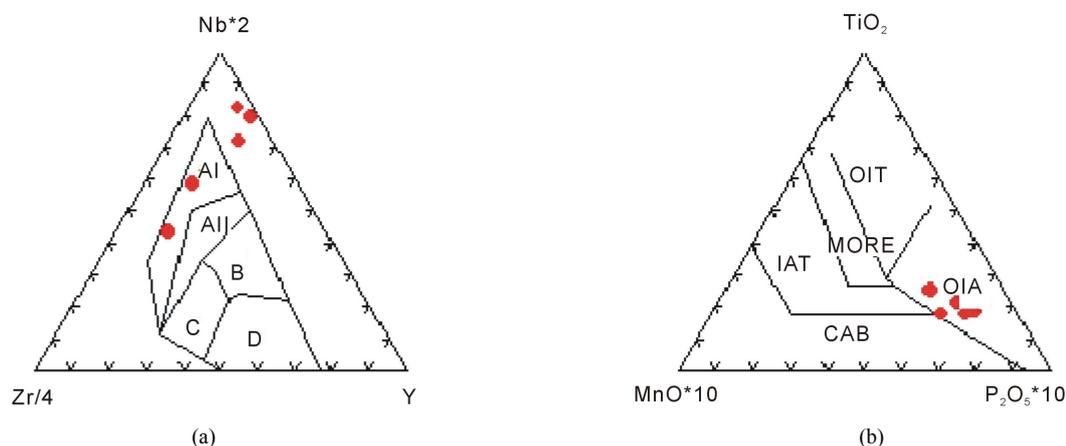
According to Rb-(Y + Nb) diagram [23], the studied granite is located within WPG and VAG ranges (**Figure 11(a)**). In Pearce's diagrams, when the granite samples are located at WPG and VAG boundaries, they are most probably related to POG post-orogeny period. Furthermore, medium composition of upper continental crust (UCC position) is also added to this diagram [24] (**Figure 10(a)**). In Maniar and Piccoli's [25] diagrams ( $FeOt/(FeOt +$



**Figure 9.** The Origins: (a) Determine the origin of enriched and depleted gabbro [17]; (b) Determine the origin of the granitoid [22].



**Figure 10.** Graphs distinct tectonic granitoid: (a) [23]; (b) [25].



**Figure 11.** Graphs distinct tectonic gabbros: (a) Diagram Zr-Nb-Y [27]; (b) Diagram MnO-TiO<sub>2</sub>-P<sub>2</sub>O<sub>5</sub> [26].

MgO vs. SiO<sub>2</sub>), the studied granite samples belong to post-orogeny granite (POG) (Figure 10(b)).

In MnO-TiO<sub>2</sub>-P<sub>2</sub>O<sub>5</sub> [26] and Zr-Nb-Y [27] diagrams, gabbro samples are located within in-plane range (Figure 11).

## 6. Conclusion

The above investigations show that magmatism in the north of Golpayegan has been the result of a very complex subduction so that suture zone is accompanied by alkaline magmatic activities after orogeny and tectonic collision and eruption after the formation of a very thick crust. This magmatism is of post-orogeny and post-collision type and is related to tensile fractures after orogenic phases.

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