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مطالعه مینرال شیمی و ترموبارومتری گرانیتوئیدهای منطقه بلند پرچین، شمالغرب ایران

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چکیده: شواهد صحرایی، سیماهای پتروگرافی و مطالعات ژئوشیمی نشان می‌دهد که گارنت - مسکویت گرانیتوئیدهای منطقه بلند پرچین از نوع S می‌باشند و دارای کنتاکت مشخص با سنگ میزبان (سنگهای دگرگونی) هستند. این گرانیتوئیدها دارای مجموعه کانیهای کوارتز، فلدسپار پتاسیم، پلاژیوکلاز؛ بیوتیت و کانیهای غنی از آلومینیوم (مانند مسکویت و گارنت) می‌باشند. ترکیب شیمیایی فلدسپار، پلاژیوکلاز، بیوتیت، مسکویت و گارنت در نمونه‌های مورد مطالعه نشان می‌دهد که فلدسپارهای پتاسیم از نوع ارتوز، پلاژیو کلازها غنی از آلبیت، میکای سفید از نوع مسکویت بوده، میزان آنیت-فلوگوپیت میکای سیاه نشانگر ترکیب بیوتیت و ترکیب شیمیایی گارنت‌ها نشان می‌دهد که غنی از آلماندین می‌باشند. دما و فشار لازم برای تشکیل این سنگها به ترتیب ۶۰۰ درجه سانتیگراد و ۵-۸ کیلوبار تخمین زده شده است. همه دماهای محاسبه شده برای فلدسپارها منعکس کننده تبلور مجدد در حالت ساب-سالیدوس می‌باشد. عدم وجود سنگهای معادل بیرونی، نوع سنگ (گرانیت)، وجود انکلاوهای غنی از میکا، سیماهای پترولوژی (وجود گارنت و مسکویت) و خصوصیات شیمیایی (پر آلومینوس) همگی بیانگر نوع S بودن گرانیتوئیدهای بلندپرچین می‌باشد. بنابراین این سنگها از ذوب بخشی سنگهای رسی دگرگون شده (متاپلیتها) بوجود آمده‌اند.

واژه‌های کلیدی: *کمپلکس ماهنشان، شیمی کانیها، ترموبارومتری، گرانیتهای نوع S، دگرگونی فشار پایین.*

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Study of mineral chemistry and thermobarometry of Boland Parchin granitoids, NW Iran

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Abstract: Field evidences, petrographic features and geochemical studies show that the garnet-muscovite granitoids of Boland Parchin area are S-type and they have sharp contact with the host rocks (metamorphic rocks). Granitoids of Boland Parchin contain minerals such as quartz, K-feldspars, plagioclase, biotite and Al-rich minerals (such as muscovite and garnet). Chemical composition of K-feldspars, plagioclase, biotite, muscovite and garnet in the studied samples show that K-feldspars are Or-rich component, plagioclase are Ab-rich, muscovite flakes are rich in the muscovite end-member, phlogopite-annite is the dominant constituent in biotite and chemical composition of the analysed garnets show that they are Alm-rich. Temperature and pressure have been calculated 600 °C and 5-8 Kbar respectively, for the formation of the granitoid rocks. All temperatures obtained from feldspar thermometry reflect sub-solidus re-equilibrium of the feldspars. Lack of equivalent extrusive rocks, existence of restitic micaceous enclaves (restitic biotite), mineralogical features (existence of muscovite and garnet) and chemical characteristics (peraluminous) indicate that Boland Parchin granitoids are S-type. Therefore the rocks are produced from partial melting of metapelites.

Keywords: *Boland Parchin, mineral chemistry, thermobarometry, S-type granite, low-P metamorphic*

Introduction

A variety of igneous and metamorphic rocks can be seen in Mahneshan Complex (Boland Parchin area). The Precambrian rocks in northwestern Iran were affected by regional and contact metamorphism. Microstructural and petrographical features and field relations show that formation of metamorphic complex is poly-metamorphic with three episodes of metamorphism (M_1 to M_3) and minimum two deformational phases (D_1 and D_2). The M2 metamorphic stage is characterized by a strong preferential alignment (S_2) and development a peak metamorphic assemblage, this metamorphism is temporally with D_2 deformation phase. Metamorphic rocks in the studied area followed a clockwise P-T path. The Barrovian-type (M2) evolution of the rocks indicate a collision tectonic clearly related to crustal thickening [1]. The low-P metamorphism took place after a medium-P event (Alpine orogenic activities overprint the Boland Parchin basement, M3 metamorphic phases; [1]). Intrusive rocks with granodiorite to granite composition are exposed in Mahneshan Complex. Granitiods in the Mahneshan area intruded into the Neoprotrozoic (?) metamorphic complex, composed of amphibolites, gneisses, mica-schist and meta-ultramafites rocks. In the view of genetic subdivision, granitoids of the study area are classified into two sub groups, S- and I-type granitoids. S-type granitoids are subject of this study. Gneissic fragments and biotite-rich restite occur as enclave within S-type granitoids [2]. S-type granitods in the Mahneshan and Boland Parchin area have been formed due to partial melting of the high grade metapelites. Investigation of the I-type granitoids is not presented in detail in the present study. The distribution of both I- and S-type granitoids in the Mahneshan area is apparently controlled by differences in source material (meta-basic and meta-pelitic nature of the protolith rocks). I-type granitoids derived from igneous source rocks and S-type granitoids are from sedimentary source rocks. I-types granitoids in the Ghar-e-Naz are found in association with mafic migmatites. Structures related to melting in mafic amphibolites are (1) layering composed of banded leucosome, mesosome and melanosome, (2) Melansome as mafic selvage around leucosome, (3) Scholen structure with floated fragments of the melanosome in leucosome, and (4) Stiktolitic structure as dispersed melanosome within leucosome. Late stage alteration processes recrystallized I-type granitoids as well as related mafic-migmatites and granulites to the amphibolite facies rocks [3]. The previous study of major and trace element composition of the Boland Parchin granitoids indicate that they are Volcanic Arc and syn-collision related products that derived from dehydration melting of metagreywackes and felsic pelites.

Geological setting

The study area is located in south of Mahneshan town in western Zanjan Province of Iran. The area is limited to geographical latitude of 47 ° 07″ to 47 ° 45″ E and longitude of 36 ° 30″ to 37 ° 00″ N (Fig.1). In the context of the structural subdivisions of Iran, the Boland Parchin area has been assigned to various tectonic zones by different workers. It is included in the Central Iran Zone by [4], the Soltanieye-Misho Zone by [5], and at the junction of the Central Iran, Alborz-Azarbaijan and Sanandaj-Sirjan zones by [2]. Recently [6] and [7] have included the study area in the Sanandaj-Sirjan Zone. In the geological map of area, Published by geological survey of Iran [2], it is included between Alborz-Azerbaijan, Central Iran and Sanandaj-Sirjan Zones. Similarities in the stratigraphy, lithology and age data (relative and isotopic ages) of the protoliths of the Mahneshan complex and equivalent units from the Central Iran Zone suggest that the Mahneshan complex (Boland Parchin sub-area) has a Neoproterozoic-Early Cambrian age and experienced the Pan-African orogeny, therefore it is included in the Central Iran Zone. The supporting evidence for this idea as follow:

- Marbles within the Takab complex contain upper Cambrian fossils (e.g. Latouchella sp., Bemella sp. and Halkiera stenobasis [8]) which are similar to fossils from the Sorkhak marbles in the Central Iran Zone [9].

- The intrusion age of the granitic gneisses of the Takab metamorphic complex (~560 Ma; U/Pb zircon [10] is similar to U/Pb dates from basement rocks of the Saghand area in the Central Iran Zone [9].

- The metamorphic grade and deformational style of the metamorphic rocks in the Takab area and the Central Iran Zone are very similar.

In the mapped area, there is some evidence to suggest the presence of high land (Horst) in Precambrian time with NW-SE trending. This high land was widespread enough to form separate basins in the east (Pari) and west (Shirmard) of the quadrangle area during the Lower Paleozoic. Precambrian rocks crop out along this horst and Char Tagh fault (Figs.2, 3).

Analytical methods

Petrographic and mineralogical features of the granitoid rocks were determined by study of 50 thin sections. Major-element compositions of the Grt, Bt, Ms, Pl, Kfs minerals in selected granitoids were determined by wavelength-dispersive spectrometry using the Cameca SX100 m i c r o p r o b e a t t GeoForschungs Zentrum, Potsdam, Germany. The operational conditions were 15 kV, 10_20 nA specimen current. The analytical spot diameter was set between 3 and 5 mm, keeping the same current conditions. Representative mineral analyses of granitoids are presented in Tables1, 2 and 3.

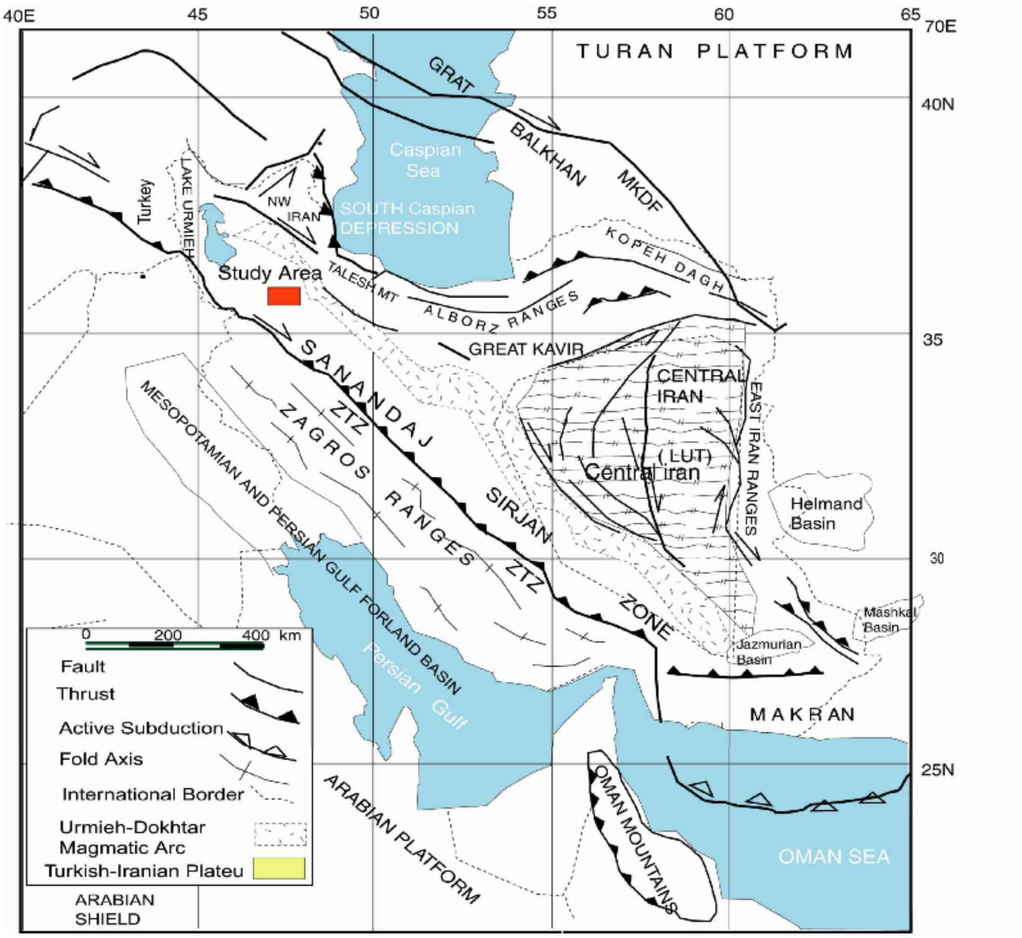

Fig. 1. Location of the study area on the structural subdivision map of Iran.

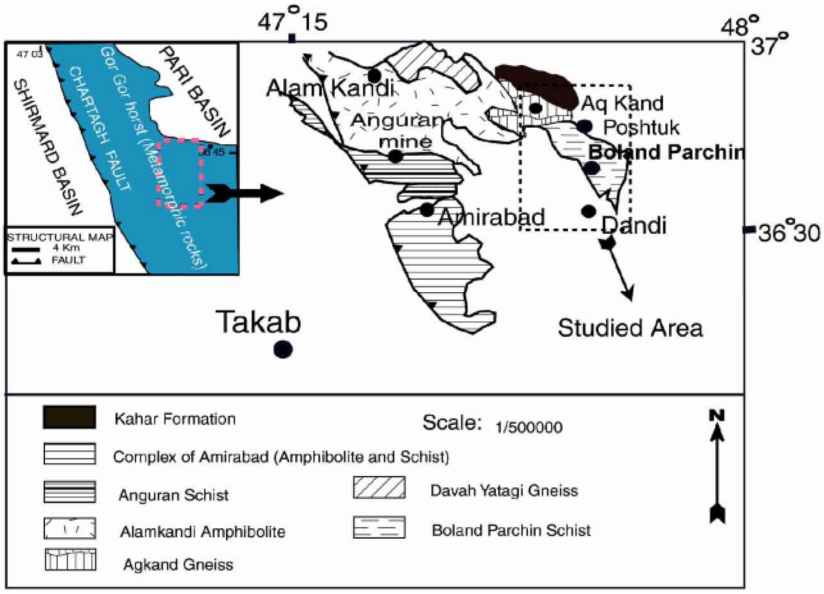

Fig. 2. The simplified geological and structural map of Mahneshan complex. Existence of an old horst (Gor Gor - Belghis and Ghebleh dagh), which late Precambrian–Paleozoic to Oligocene rocks is eroded. This horst has a trend of NW-SE. This high land was widespread enough to form separate depression in the east (Pari) and west (Shirmard) Precambrian rocks crop along with this fault.

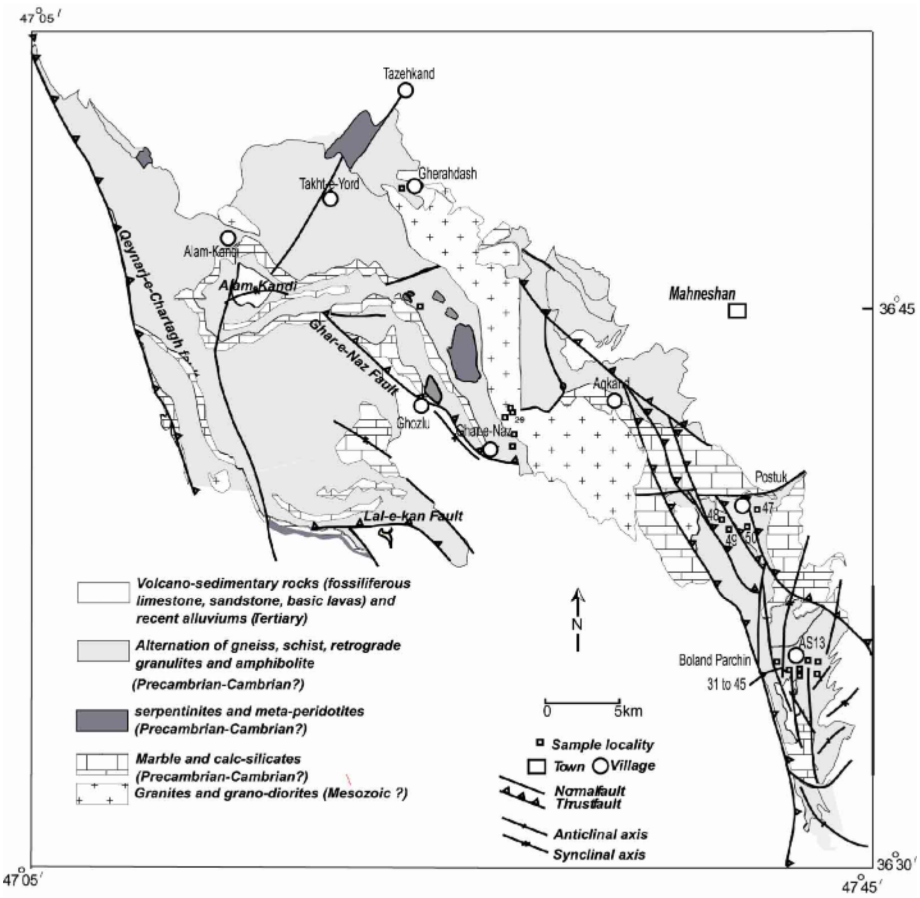

Fig. 3. Geological map and sample locations of the Mahneshan Complex (Boland Parchin ES of Mahneshan).

Table 1. Representative feldspar and garnet analyses and their structural formulae.

Sampel	47g	47g	47g	47g	47g	47g	47g	47g	47g	47g
Mineral	Pl	Pl	Pl	Kfs	Kfs	Kfs	Grt	Grt	Grt	Grt
SiO_2	66.36	66.96	66.93	65.40	65.20	65.06	36.70	36.32	36.54	36.57
TiO_2	0.00	0.02	0.00	0.00	0.05	0.01	0.02	0.09	0.02	0.02
Al_2O_3	21.97	21.60	21.65	18.90	19.05	18.81	20.80	21.30	21.20	21.27
Cr_2O_3	0.02	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	2.60	3.04	2.60	2.86
FeO	0.00	0.00	0.00	0.00	0.00	0.01	26.97	26.27	26.86	25.83
MnO	0.00	0.00	0.00	0.00	0.00	0.00	14.63	14.90	14.43	15.57
MgO	0.0	0.00	0.00	0.00	0.00	0.00	0.53	0.56	0.63	0.66
CaO	1.94	1.80	1.80	0.03	0.02	0.04	0.83	0.80	0.77	0.70
Na_2O	11.38	11.51	11.50	1.40	1.82	1.82	0.01	0.02	0.02	0.01
K_2O	0.34	0.37	0.25	15.33	14.86	14.71	0.02	0.01	0.01	0.01
Totals	102	102	102	101	101	100.4	102	103	102	103
Structurl Formulae on a basis of 8 oxygens							basis of 11 oxygens			
Si	2.871	2.885	2.888	3.27	3.26	2.253	2.94	2.90	2.923	2.915
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.001
Al	1.12	1.10	1.10	0.945	0.952	0.94	1.964	2.00	2.00	2.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe(3+)	0.00	0.00	0.00	0.00	0.00	0.00	0.157	0.18	0.156	0.172
Fe(2+)	0.00	0.00	0.00	0.00	0.00	0.00	1.807	1.75	1.80	1.72
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.993	1.00	0.98	1.05
Mg	0.00	0.00	0.00	0.00	0.00	0.00	0.063	0.07	0.075	0.08
Ca	0.09	0.08	0.083	0.00	0.00	0.00	0.07	0.07	0.066	0.06
Na	0.955	0.965	0.962	0.07	0.091	0.091	0.00	0.00	0.00	0.00
K	0.019	0.020	0.014	0.766	0.743	0.735	0.00	0.00	0.00	0.00
Totals	5.055	5.056	5.05	5.05	5.05	5.00	8.00	8.00	8.00	8.00

Table 2. Representative Feldspar, garnet, muscovite and biotite analyses and their structural formulae.

Sampel	47a	47a	47a	47a	47a	47a	47a	47a	47a	47a	47a	47a
Mineral	Pl	Pl	Pl	Kfs	Kfs	Kfs	Grt	Grt	Grt	Bt	Bt	Bt
							Cor	Iner	Iner			
SiO_2	66.60	66.41	66.84	65.9	65.8	66.05	36.51	36.92	36.65	32.9	35.52	36.06
TiO_2	0.02	0.01	0.00	0.50	0.38	0.00	0.01	0.08	0.05	0.44	0.00	0.36
Al_2O_3	21.70	21.76	21.73	19.41	19.31	19.38	21.01	20.78	21.06	20.27	20.40	19.56
Cr_2O_3	0.00	0.01	0.00	0.02	0.00	0.02	0.00	0.01	0.01	0.02	0.01	0.01
Fe_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	2.35	0.28	1.80	3.30	0.00	0.00
FeO	0.00	0.01	0.03	0.07	0.01	0.02	27.90	28.18	27.77	19.61	23.48	22.40
MnO	0.03	0.02	0.04	0.00	0.03	0.02	11.60	11.87	12.21	0.50	0.47	0.46
MgO	0.00	0.00	0.00	0.00	0.00	0.01	1.68	1.63	1.51	7.92	7.44	7.75
CaO	1.94	1.96	1.87	0.03	0.02	0.03	0.80	0.94	0.81	0.01	0.01	0.03
Na_2O	11.30	11.30	11.46	1.33	1.50	1.73	0.00	0.00	0.00	0.11	0.14	0.11
K_2O	0.18	0.11	0.20	15.72	15.36	15.07	0.00	0.00	0.00	6.09	9.13	9.52
Totals	101.7	101.6	102	101	101	102	101.8	101.9	101.7	91.18	96.61	96.27
Structurl Formulae on a basis of 8 oxygens												
Si	2.88	2.88	2.88	3.295	3.29	3.30	2.93	2.99	2.945	2.61	2.71	2.75
Ti	0.00	0.00	0.00	0.025	0.019	0.00	0.00	0.005	0.00	0.026	0.00	0.02
Al	1.11	1.11	1.105	0.97	0.965	0.97	1.99	1.986	1.995	1.895	1.83	1.76
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe(3+)	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.02	0.11	0.197	0.00	0.00
Fe(2+)	0.00	0.00	0.00	0.00	0.00	0.00	1.87	1.91	1.866	1.30	1.50	1.43
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.81	0.83	0.03	0.03	0.03
Mg	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.181	0.936	0.84	0.88
Ca	0.09	0.09	0.086	0.00	0.00	0.00	0.07	0.08	0.07	0.00	0.00	0.00
Na	0.95	0.95	0.96	0.066	0.075	0.086	0.00	0.00	0.00	0.017	0.21	0.016
K	0.01	0.006	0.011	0.786	0.768	0.753	0.00	0.00	0.00	0.617	0.89	0.93
Totals	5.04	5.04	5.05	5.05	5.05	5.1	8.00	8.00	8.00	7.63	7.82	7.82

Discussion

Petrography and field relations

Samples for this study were collected from Boland Parchin area. Figure 3 illustrates the sample localities and rock types. In the northern part of Aqkand Village the massive sequences of gneiss with enter-bed of amphibolite is crop out. These sequences in the northern part of Alemalu Village show typical petrological changes, and it consists of green mica schist, amphibolite with nematoblastic textures, biotite gneiss with porphyroblastic to granoblastic textures, granite gneiss with granoblastic texture and anatectic leucogranites. This sequence not only shows mylonitic fabric but also shows a main foliation with trend of NW-SE. On the other hand, evolution of these rock units from green schist to alkali granites show that evidence for progressive metamorphism ended by anatectic phenomena and formed leucogranites in the Boland Parchin area. This granitoids are typical S-type granitoids. The Mahneshan igneous rocks occur in a number of texturally and compositionally different sub-types:

1. Granitoid (anatectic alkali granite) white to light grey in color
2. Myrmekitic alkali- granite
3. Granodiorite

1) Granitoid (anatectic alkali granite)

These rocks are exposed in Ghazikandi, Ghozlo and Davehyataghi villages. The granitoid rocks are mainly composed of coarse-grained to medium grained, white to light grey, hypidiomorphic granular and anatectic alkali granite (Fig.4a, b). Modally, most samples of granitoids belong to leuco-granite to monzogranite. These granitoids were emplaced as large diapiric intrusions very later than their magmatic crystallization that produced brecciated halos instead of metamorphic aureoles around the granitoid masses. The mineralogy is generally composed of quartz, plagioclase, K-feldspar, garnet, biotite and muscovite. Garnet and biotite are the main mafic minerals. Locally, the veins contain concentrations of almandine-rich garnet, that are up to 10-15 mm in diameter (Fig.4b, c). The igneous rocks are pale grey, holocrystalline with coarse plagioclase, K feldspar, quartz and garnet crystals. The main textures of the rocks are granular porphyric, (with relatively larger K-feldspar and garnet crystals), and cataclastic texture (crushed minerals such as garnet).

Most of coarse-grained granites show subsolvus re-crystallization, in terms of two separate feldspar crystallization, containing both plagioclase and K-feldspar. This granites show migmatitic structures (Fig. 4a) and in some places are formed as boudin in metapelitc host rocks (Fig.4d).

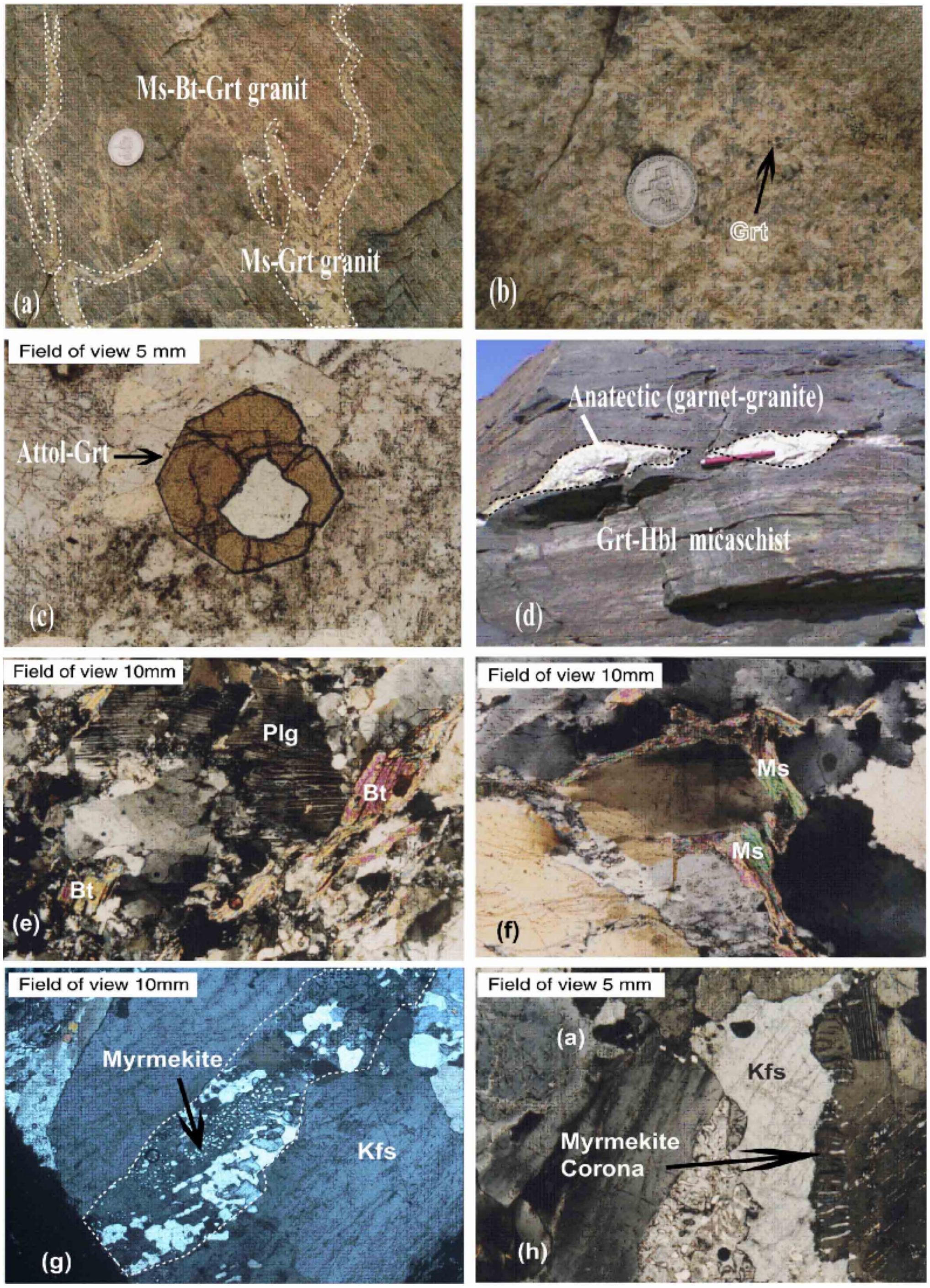

Fig. 4. a) S-type granite with migmatitic structure. b) S-type granite with garnet and muscovite. c) Granite with atole garnet texture. d) Anatectic (Garnet-granite) as boudinage in the Grt-Hbl schist. e, f) Deformed granite with kinked plagioclase and biotite. g) The symplectic intergrowth of quartz and K-feldspare as myrmekite. K-feldspar porphyroblast replaced by myrmekite. h) The symplectic intergrowth of quartz and plagioclase as myrmekite.

2) Myrmekitic alkali- granite (leucogranites, considered equivalent to Duran granite in the Zanjan area with a Precambrian age).

These rocks are exposed near Boland Parchin and Aqkand villages. The rocks are composed of quartz, K-feldspar, muscovite and less common plagioclase, garnet and zircon. The myrmekitic alkali- granites are dominated by K-feldspars (around to 60 wt %). The amount of plagioclase is 10 wt. % and quartz varies between 15 and 30 wt. %. In total, the amounts of dark mineral do not exceed than 5 wt. %. Large quartz crystals (>5mm) show undoluse extinction. There are no opaque minerals in some samples and the rocks are made of myrmekite, quartz, microcline and zoned plagioclase. There are idiomrpic garnet crystal (Fig.4c) in myrmekitic alkali-granite. These rocks are deformed regionally and in some parts small shear zones are developed. In most cases, myrmekite is associated with K-feldspar (Fig.4g), but in some places, it replaces albite plagioclase [3]. In the studied rocks, myrmekite is associated with K-feldspar (Fig.4g, h).

Field evidences and petrographic results show that the alkali-granites are S-type because of the following evidences:

1. There is not any mineralization with the alkali granite.
2. Existence of Al-rich minerals (such as Muscovite and Garnet) show that the granites have per-aluminous character and indicate the sedimentary source for them.
3. The accessory minerals such as titanite, alanite and magnetite, as indicators for I-type granites are not observed.
4. Alkali granite show migmatitic structure and preserved restitic biotite enclaves.
5. Field evidence and petrographic observations (minerals) of alkali granite show that they S-type granite.

Geochemical studies

Previous geochemical evidences show that Boland Parchin granitoid is S-type and formed in the Syn-collision tectonic setting and the source of this granite can be volcanic arc rocks [11]. The supporting evidence are as follows:

SiO2: 70-76, Rock types is granite, calc-alkaline to alkaline-calcic affinity, peraluminous character, Na_2O/CaO: 2-4, Na_2O/K_2O: 0.4-2, negative anomaly of Nb-Ta.

Mineral chemistry

In order to identify the chemical composition of K-feldspars, plagioclase, biotite, muscovite and garnet in the studied samples, two fresh and representative samples from the igneous rocks of the Boland Parchin were chosen for mineral chemistry studies. Two polished thin sections of the rocks were analysed which their localities are shown in (Figures 3 and 4).

K-feldspar

Tables 1 and 2 include the microprobe analyses of K-feldspars in the studied samples (47a and 47g). In the two samples, feldspars are clear and fresh with minimal alteration effects. Most alkali feldspars are untwined and show patchy or lamellar exsolution of albite lamellae or intergrowth with plagioclase and myrmekite associated with K-feldspar. The grain size of the K-feldspars varies considerably from a few to more than 1 cm. Figure 5b shows the composition of the alkali feldspars on Ab-An-Or triangular diagram. According to the figure, K-feldspars are orthoclase-rich.

Plagioclase

Microprobe analyses of plagioclase in the 47a and 47g samples are provided in Tables 1 and 2. the grain size is similar to that of alkali feldspars, There are no noticeable differences between the compositions of plagioclases in two samples. In Figure 5b, composition of the plagioclases are plotted on Ab-An-Or triangular diagram. According to the figure, plagioclases are Ab-rich.

Muscovite

Muscovite analyses are listed in Table 3. The number of cations is calculated on the basis of 11 Oxygens. According to Figure 5a, after [12], muscovite flakes are rich in the muscovite end-member, paragonite is the second dominant component. The mole fractions of other components are negligible.

Biotite

Microprobe analyses of biotite are presented in Table.2. The oxide totals are between 91.18 and 96.61. The amount of Ti is 0.02 (apfu). The number of cations is calculated on the basis of 11 Oxygens. Figure 5d shows that phlogopite-annite is the dominant constituent in biotite.

Table 3. Representative Muscovite analyses and structural formulae.

Sampel	47a	47a	47g	47g	47g	47g
Mineral	Ms	Ms	Ms	Ms	Ms	Ms
SiO_2	47.43	47.42	46.95	46.80	47.00	47.24
TiO_2	0.50	1.30	0.13	0.16	0.12	0.10
Al_2O_3	36.90	36.94	37.36	37.36	37.42	37.90
Cr_2O_3	0.08	0.03	0.00	0.00	0.02	0.00
Fe_2O_3	1.57	1.80	0.00	0.00	0.00	0.00
FeO	0.35	0.41	1.41	1.36	1.41	1.39
MnO	0.07	0.00	0.04	0.00	0.03	0.00
MgO	0.90	0.84	0.43	0.42	0.49	0.47
CaO	0.00	0.00	0.00	0.00	0.00	0.00
Na_2O	0.43	0.57	0.64	0.60	0.60	0.60
K_2O	11.27	10.95	10.80	10.90	10.90	10.81
Totals	99.7	99	97.70	97.80	97.90	98.60
Structurl Formulae on a basis of 11 oxygens						
Si	3..03	3.00	3.04	3.034	3.035	3.031
Ti	0.024	0.06	0.00	0.00	0.00	0.00
Al	2.78	2.764	2.85	2.86	2.85	2.86
Cr	0.00	0.00	0.00	0.00	0.00	0.00
Fe(3+)	0.076	0.086	0.06	0.06	0.06	0.060
Fe(2+)	0.02	0.02	0.015	0.015	0.015	0.015
Mn	0.00	0.00	0.00	0.00	0.00	0.00
Mg	0.086	0.08	0.04	0.04	0.05	0.045
Ca	0.00	0.00	0.00	0.00	0.00	0.00
Na	0.05	0.07	0.08	0.07	0.075	0.75
K	0.92	0.887	0.89	0.90	0.90	0.886
Totals	7.00	6.98	6.987	7.00	6.991	6.98

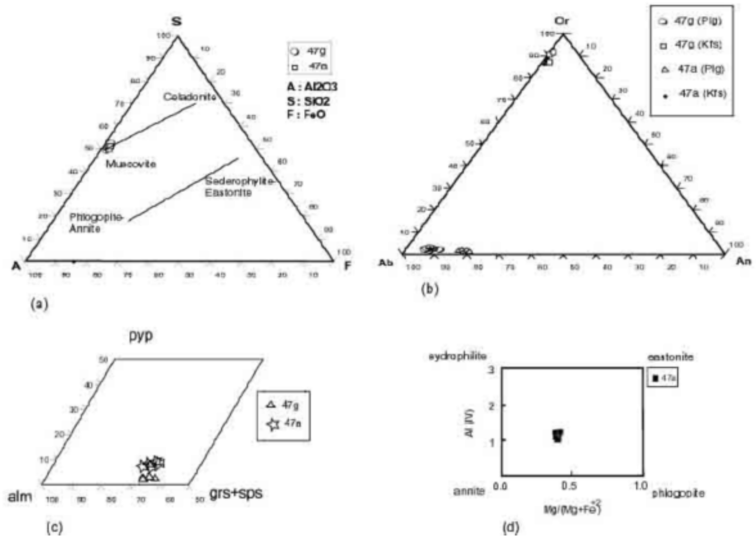

Fig. 5. a) Chemical compositions of muscovites from metapelits of Mahneshan. Is (Per 11 Oxygens) against Fe+Mg. b) Compositions of the Mahneshan igneous feldspars, plotted on the An-Ab-Or diagram. c) Analaysed white micas plotted on SAF (SiO2, Al_2O_3, FeO) diagram of [12]. d) Plot of Ti (per 11 oxygens) as a function of Fe/(Fe+Mg) for biotite from different metamorphic zones.

Garnet

The grain size of garnets is up to 1.5 cm in diameter. Garnet compositions are presented in Tables 1 and 2. In general, the garnets are Fe-rich with almandine component varying between 80 and 90 %. Totals oxides are between 99.85 and 102. Ti has not been detected or may occur in very low amounts. Figure 5c shows the chemical composition of the analysed garnets on the Alm, Pyp and (Grs, Sps) triangular diagram. Stoichiometry and the Fe3+ content of garnets were calculated based on eight cations and charge balance constraints for O = 12.

Thermobarometry

There are not many suitable assemblages in the Boland Parchin igneous rocks for thermobarometry. Pressure and temperature during formation of the studied granites were estimated using conventional geothermobarometric methods. Two feldspares phase relations thermometry (e.g. [13], [14]), Fe-Mg exchange between garnet and biotite thermometer using calibrations of [15] and [16] were applied to granites. Solution models of [17] and [18] are used for garnets. For pressure estimation of the formation of granites GPMB (garnet-plagioclase-moscuvite-biotite) barometer [19] were employed. Garnets with highest Mg contents and biotites with highest Ti content were used to find P-condition.

Using thermometery of Solvocalc program, temperature for formation of granitoids are 510 to 540 ºC at 5 and 7 Kbar pressures respectively, (Fig. 7). [13] Derived an improved graphical thermometer by making some modifications to [20] thermometer. Composition of the Boland Parchin igneous feldspars plotted in this graphical thermometer in (Fig .6) give a yield temperature below 350 ºC. These temperatures are far below the solidification temperature of the granitic magma. Therefore all temperatures obtained from feldspar thermometry reflect sub-solidus re-equilibrium of the feldspars. The calculated temperature by Fe-Mg exchange between garnet and biotite thermometer using calibrations of [15] and [21] is 583 ºC for granitoids. The pressure estimated for the formation of granitoids of Boland Parchin area, using GPMB barometry (garnet-plagioclase-moscuvite-biotite) pressure, is 4.5 kbar.

Using multiple equilibria calculation and THERMOCALC (3.2) program, temperature and pressure have been calculated for the formation of the granitic rocks. The results of thermobarometry using multiple equilibria calculation and THERMOCALC (3.2) program are 626±50ºC and 8.3±2 kbar.

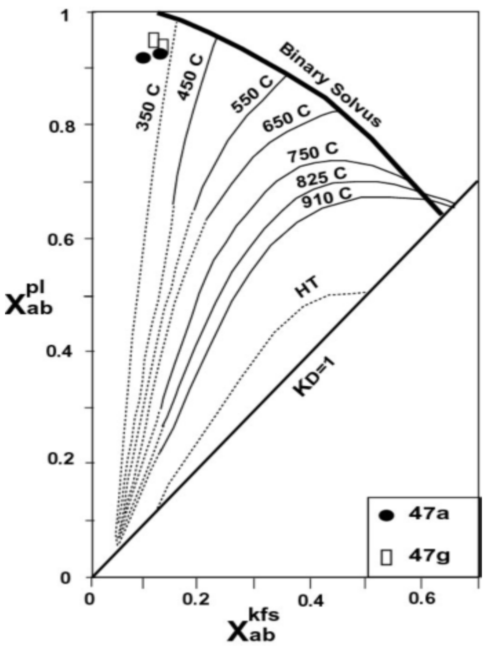

Fig. 6. Two feldespars phase relations thermometry of granitoid (graphical thermometer).

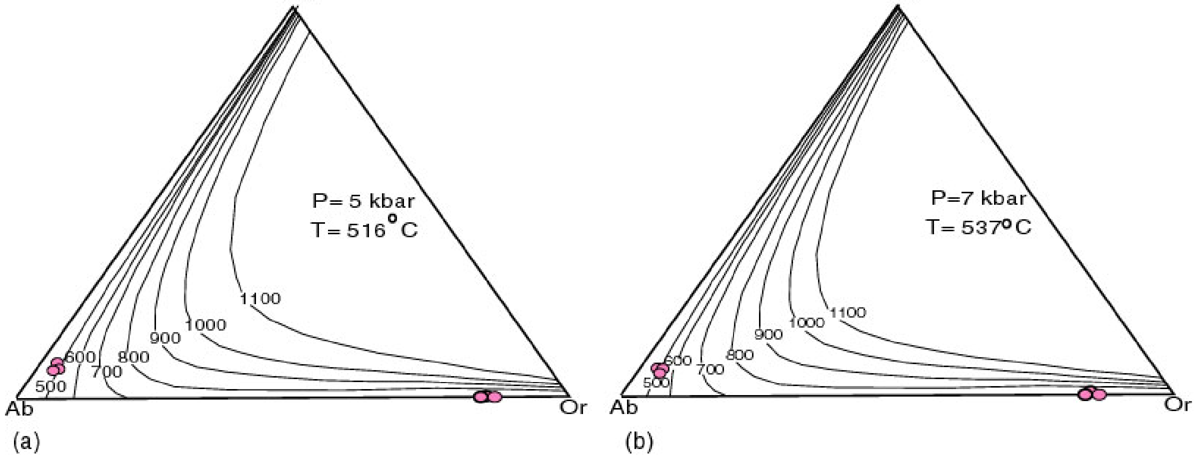

Fig. 7. Using thermometery by Solvocalc program, temperature for formation of granitoids is calculated 510 to 540 °C for the maximum pressure (5 and 7 Kbar).

Conclusion

Field evidences and petrographic results, lack of extrusive equivalent of rocks, existence of restitic micaceous enclaves (restitic biotite) and mineralogical features (existence of muscovite and garnet) all indicate that Boland Parchin granitoids may be S-type.

Granitoids of Boland Parchin, contains minerals such as Quartz, K-feldspars, Plagioclase, Biotite and Al-rich minerals (such as Muscovite and Garnet). Chemical compositions of K-feldspars, Plagioclase, Biotite, Muscovite and Garnet in the studied samples show that K-feldspars are Or-rich, plagioclase are Ab-rich, muscovite flakes are rich in the muscovite end-member, phlogopite-annite is the dominant constituent in biotite and chemical composition of the analysed garnets show that they are Alm-rich. Pressure and temperature of formation of the studied granitoids were estimated using conventional geothermobarometric methods. Temperature and pressure for the formation of the granitoid rocks have been calculated 600°C and 5-8 Kbar respectively. All temperatures obtained from feldspar thermometry reflect sub-solidus re-equilibrium of the feldspars. Subsolidus re-crystallization of the igneous rocks is related to cooling events and exhumation. The Boland Parchin granitoids magma has started to crystallize in a relatively low temperature. The estimated pressure and temperature for granitoid crystallization is well consistent with the P-T condition of the associated metapelites at the peak of metamorphism, corresponding to the depth of ca. 17-24 km.

References

[1] Saki A., Moazzen M., Modjtahedi M., Oberhänsli R., *"Determination of P-T conditions of metamorphism of Mahneshan Complex, NW Iran"*, Iranian Journal of Geoscinces and Mineralogy, (2007) Article IN PRESS.

[2] Babakhani A.R., Ghalamghash J., *"Geological map of Iran, 1:100,000 series sheet Takht-e-Soleiman"*, Geological Survey of Iran, Tehran. 1990.

[3] Hajalioghli R., Moazzen M., Droop G. T. R., Oberhancli R., Bousquoet.T R., Jahangiri A., Ziemman M., *"Serpentine polymorphs and P-T evolution of metaperidotites and serpentinites in the Takab area"*, NW Iran Mineralogical Magazine, April, 2007, Vol. 71(2), pp. 203–222.

[4] Nabavi M.H., *"An Introduction to the Geology of Iran"*, Geological Survey of Iran, 109 pp. (1976), (in Persian).

[5] Eftekhar Nejad J., *"Tectonic classification of Iran in relation to depositional basins. Journal of Iranian Petroleum Society"*, 82, 19_28 (in Persian) (1980).

[6] Alavi M., *"Regional stratigraphy of the Zagros Fold-Thrust belt of Iran and its proforeland evolution"*, American Journal of Science, 304, 1_20. (2004).

[7] Gilg H.A., Boni M., Balassone G., Allen C.R., Banks D., Moore F., *"Marble-hosted sulfide ores in the Angouran Zn-(Pb_Ag) deposit, NW Iran: interaction of sedimentary brines with a metamorphic core complex"*, Mineralium Deposita, 41, 1_16 (2006).

[8] Hamdi BP, *"recambrian_Cambrian deposits in Iran. In: Treatise of the Geology of Iran (A. Hushmandzadeh, editor). Geological Survey of Iran, Tehran"*, 20, 1-535. (1995).

[9] Ramezani J., Tucker R.D., *"The Saghand region, central Iran: U-Pb geochronology, petrogenesis and implications for Gondwana tectonics"*, [American Journal of Science, Vol. 303, September, 2003, P. 622–665].

[10] Stockli D.F., Hassanzadeh J., Stockli L.D., Axen G., Walker J.D., Dewane T.J., *"Structural and geochronological evidence for Oligo-Miocene intraarc low-angle detachment faulting in the Takab- Zanjan area, NW Iran"*, Abstract, Programs Geological Society of America, 36,319(2004).

[11] Saki A., Moazzen M., Abdolahi M., *"Study of geochemical, geodynamic and source of granitoid of Boland Parchin area, NW Iran"*, Proceeding of 26th symposium on Geoscinces, Tehran, Iran.

[12] Lambert R. St. J., *"The mineralogy and metamorphism of the Moine schists of The Morar and Kroydart districts of Inverness-shire"*, Transactions of the Royal Society of Edinburgh, (1959), 63, 553.

[13] Brown W. L., Parsons I., *"Towards a more practical two-feldspar geothermometer"*, Contribution to Mineralogy and Petrology, 76, 1981, 369-377.

[14] Haselton H. T., Hovis G. L., Hemingway B. S., Robie R.A., *"Calorimetric investigation of the excess entropy of mixing in analbite-sanidine solid solutions: lack of evidence for Na, K short-range order and implication for two feldspar thermometry"*, American Mineralogist. 1983, 68, 398-413.

[15] Bhattacharya A, Mohanty L, Maji A, Sen SK, Raith M., *"Non-ideal mixing in The phlogopite-annite binary: constraints from experimental data on Mg-Fe partitioning and a reformulation of the biotite-garnet thermometer"*, Contrib Mineral Petrol (1992), 111: 87-93.

[16] Thompson AB., *"Mineral reactions in pelitic rocks: II. Calculation of some P-T-X (Fe-Mg) phase relations"*, American J. of Science, (1976), 276: 401-454

[17] Helffrich G, Wood B., *"Subregular model for multicomponent solutions"*, Am Mineral (1989), 74: 1016-1022

[18] Ganguly J., Saxena S., *"Mixing properties of aluminosilicate garnets: constraints from natural and experimental data, and applications to geothermobarometry"*, American Mineralogist, (1984) 69: 88-97.

[19] Hoisch TD, *"Equilibria within the mineral assemblage Qtz+Ms+Bt+Grt+Pl and implications for the mixing properties of octahedrally-coordinated cations in Ms and Bt"*, Contrib Mineral Petrol 108: (1991) 43-54.

[20] Seck H.A., *"Der Einfluss des Drucks auf die Zusammensetzung Koexistierender Alkalifeldspat und Plagioklase im system* $NaAlSi_3O_8$-$KAlSi_3O_8$-$CaAl_2Si_2O_8$-H_2O*"*, Contribution to Mineralogy and Petrology, 1971b, 31,67-86.

[21] Thompson AB, *"Mineral reactions in pelitic rocks: II. Calculation of some P-T-X (Fe-Mg) phase relations"*, American J. of Science, (1976) 276: 401-454

[22] Nadimi A., *"Evolation of the Central Iranian basement"*, Gondwana Research xx (2006) xxx-xxx. ARTICLE IN PRESS (2007).

[23] Saki A., Moazzen M., Moayyed M., *"Geothermobarometry of metapelites of southwest Mahneshan"*, Iranian Journal of Crystallography and Mineralogy, Vol 12, Num 2, (2004), 215-230.