زون‌بندی کانی‌شناسی و ژئوشیمیایی در کانسار اسکارنی باباعلی(باختر ایران)

نوشته: دکتر حسن زمانیان* ، دکتر بیژن یوسفی یگانه* و سید عارف علوی**

Mineralogical and Geochemical Skarn Zoning across the Baba Ali Deposit and its Economic Geology Applications, Western Iran

By: Dr. H. Zamanian *, Dr. B. Yousefi Yeganeh* & S.A. Alavi**

چکیده

کانسار اسکارن مگنتیتی باباعلی با سنگ میزبان دیوریتی دگرگون شده توده معدنی در بین سنگهای کوارتز سینیتی ودیوریتی وابسته به یک باتولیت واقع شده است.

مطالعات سنگ‌نگاری هشت زون اسکارنی با مجموعه کانیهای شاخص را از جنوب خاور به طرف شمال باختر نمایان می‌سازد. الگوی توزیع ژئوشیمیایی عناصر در این زونها تحت تأثیر توزیع کانیهای اسکارنی نوع پسرونده و پیشرونده است. حضور کانیهایی چون آندرادیت، سالیت، اکتینولیت واپیدوت، اسفن و ایدوکراز به عنوان سیلیکاتهای کلسیم از یک سو و نبود کانیهایی چون ترمولیت، فورستریت، فلوگوپیت، تالک و هومیت وهمچنین نبود کانیهای تیپ اسکارنهای منگنزی از سوی دیگر، همگی گویای قرارگیری این کانسار در گروه کانسارهای اسکارنی کلسیک است.

ترکیب شیمیایی EPMa (Electron Probe Microanalyzer) کانیهای گارنت وپیروکسن نشان از همسازی این کانسار با رده اسکارنهای آهن‌دار دارد. محتوی کم گوگرد موجود در این کانسار(۱/۵>) گویای تشکیل این کانسار در محیط جزایر کمانی است.

نسبت بالای بروناسکارن به دروناسکارن گویای تشکیل این کانسار در محیطی با ژرفای کم تا نیمه ژرف (۵ km >) است. تجزیه شیمیایی مگنتیت به روش EPMa نشان‌دهنده آن است که مگنتیت یک فاز خالص است. عدم وجود ناخالصیهایی چون Mg , Mn ,Zn , Ni, Ti, V, Cr در کانی مگنتیت بیانگر آن است که این کانی در دمای پایین تشکیل شده است. جانشین شدن کانیهای پسرونده گرمابی توسط مگنتیت در رخساره شیست سبز نشانه‌ای بر کانه‌زایی دما پایین مگنتیت است. جانشینی مجموعه کانیهای پیشرونده دمای بالا مانند گارنت و پیروکسن با دمای ۵۰۰-۵۵۰°C که توسط کانیهای گرمابی در راستای تشکیل مگنتیت صورت می‌گیرد، دلالت بر کانه‌زایی مگنتیت در دمای کمتر دارد. این شواهد ژئوشیمیایی وکانی‌شناختی دمای ۳۵۰-۴۰۰°C برای کانی‌زایی مگنتیت در این کانسار ارائه می‌دهند.

کلید واژه‌ها: مگنتیت، بابا علی، اسکارن، جزایر کمانی، باختر ایران.

Abstract

In the Baba Ali magnetite skarn deposit, the main load of magnetite ore body lies between the dioritic and quartz syenitic rocks of the batholith hosted mainly by meta-dioritic rocks. Petrographically from SE towards NW, eight zones with distinct mineral assemblage can be recognized. The geochemical distribution pattern of elements across the Baba Ali skarn zones is governed by the distribution pattern of the prograde and retrograde mineral assemblages. The presence of andradite, salite, actinolite, epidote, sphene and idocrase as the calc-silicate minerals, and the absence of minerals like tremolite, forsterite, phlogopite, talc, and humite and also minerals of manganoan skarns in these skarn zoning allow the grouping of the Baba Ali skarn deposit as a calcic Fe-skarn deposit. The EPMa compositions of pyroxene and garnet also are consistent with the Fe-skarn deposits. The average S content in the Baba Ali ore body is < 1.5 %. The low content of sulfide in the Baba Ali allots Island Arc type calcic Fe skarn characteristics to this deposit. The high ratio of exsoskarn by endoskarn (Extensive exsoskarn facies) indicates a shallow depth" hypabyssal "(< 5 km) for formation of the Baba Ali skarn. EPMa analysis of magnetite from the Baba Ali deposit show a rather pure magnetite phase, devoid of impurities such as Mg, Mn, Zn, Ni, Ti, V, and Cr. The absence of these impurities indicates a low temperature for formation of magnetite. Replacement of the hydrothermal (retrograde) minerals by magnetite also shows a low temperature within the green schist facies conditions for magnetite mineralisation. Replacement of the prograde assemblage i.e. garnet and pyroxene which formed in the 500 –550º C range by

hydrothermal minerals along with magnetite indicates that magnetite mineralisation occurred at relatively lower temperature. The inferred temperature of Fe mineralisation at the Baba Ali deposit is in the range of 350 –400^{o} C.

Keywords: Magnetite, Baba Ali, Skarn, Island arc, West of Iran.

Introduction

The Baba Ali deposit is located adjacent to the Almoughlagh Batholith (Fig 1-A), bounded between long. 48^0 50'E - 48^0 15'E and lat. 34^0 45' and 35^0 00' N in the western Sanandaj-Sirjan (S-S) Zone of Iran. It occurs within the meta-dioritic rocks, which intruded the Songhor Series lithounits. It is approachable from Hamadan city (~40km, Fig 1-C). The Baba Ali, Gelali, Chenar and Tekyeah deposits together form a magnetite assemblage which is called Hamakassi deposits. The Baba Ali is the largest one and its estimated ore reserve is about 66 mt with a grade of 61% for Fe (Central Iron Ore Co., 1991). The paper tries to characterize the mode of distribution of prograde and retrograde skarn minerals, and the pattern of distribution of elements, which are dependent on the distribution of minerals and have been governed by metasomatic and infiltration processes. These targets help to understand the spatial relationship of the metamorphic facies, which are critical and essential to understanding the mode of occurrence of the whole body of the deposit.

Geology Setting

The S-S zone extends in the northwest- southeast direction parallel to the Zagros belt (Takin, 1972; Stocklin, 1968) .It runs from Urmiyeh to the northwest to Sirjan to the southeast (Fig.2). This zone is considered as the most active tectonic belt of Iran (Darvishzadeh, 1992). Rock formations ranging in age from the Precambrian to the Quaternary, are common to this zone and one comes across major stratigraphic unconformities that distinguish the Mesozoic and Tertiary formations. The S–S Zone experienced repeated magmatic intrusions in the Jurassic (140 Ma) representing by the granodiorites of Golpayegan, Cola Ghazi, and the Diorite of Deh Bid area. The second episode of magmatism which occurred in the Cretaceous – Paleocene (65 Ma) is represented by the Alvand, Burojerd, Arak, Aligodarz, Hassan Robat plutons. The South Ghorveh, Kamyaran, Kolasar, Pangwin and Golpayegan gabbro and diorites are the intrusions, intruded the S-S zone during the Oligomiocene age (37 Ma). Except with South Ghorveh, no mineralisation is however associated with any of these igneous intrusives. The Baba Ali magnetite deposits are located adjacent to the Almoughlagh Batholith (2Ma ?, Amiri, 1995), its age indicating the continuity of the magmatic activity in the S-S zone even beyond Miocene.

Surrounding the Almoughlagh Batholith the rock formations (Fig. 1-A) have been subdivided mainly into three main units, namely the Songhor Series (Triassic-Jurassic), Hamadan Schists (Jurassic) and the Limy Formations (OligoMiocene). The Songhor Series is a volcanosedimentary sequence, consists of alternating schistose and limy lithounits interbedded with metamorphosed spilitic lava and andesitic tuff (Barud, 1975). The proportion of volcanic rocks to sedimentary rocks, as layers and fragments, is more in the basal units of this sequence and decreases towards the upper, younger strata. The meta-volcanic rocks are graded to becoming more pelitic towards NE (Hamadan Schists) and devoid of limy lithounits (Darvishzadeah, 1992).

The Songhor Series suffered regional metamorphism and deformation in three successive orogenic phases, the Late Kimmerian (~136 Ma, Amiri,1995, Bellon and Barud,1975) followed by the Laramide (65 Ma, Darvishzadeah, 1992), and the Pasadenian (~2 Ma) phases, the latest accompanied by the emplacement of the Almoughlagh Batholith. The Late Kimmerian (Upper Jurassic) phase metamorphosed the Songhor Series to the greenschist - lower amphibolite facies. The dioritic outcrops which are the host rock of magnetite mineralization also show the features like fracturing, faulting and preferred orientation of minerals like amphibole and chlorite assigned to the Laramid deformation. Mylonitization is distinctly visible in both the meta-dioritic rocks and the Almoughlagh batholith, even on the outcrop scale.

The strike of mineralized zone in the Baba Ali deposit is, consistent with the trends of NE-SW faults, indicating the structural control for the mineralisation. The Almoughlagh Batholith has been described as a ring complex, consisting mostly of quartz syenite porphyry, gabbro and diorite (ValliZadeah & Cantagral, 1975; Amiri, 1995).The present work revealed that the Almoughlagh Batholith is a complex body, comprised chiefly of quartz syenite and syenogranite (Fig. 1-B) groups as mapable petrographic units. Syenites in general are less commonly porphyritic but the present quartz-syenites are and their modal composition varies from quartz syenite to quartz alkali-syenites to alkali-syenite and quartz-monzonite. The syenogranite group grades to alkali-syenogranite, monzogranite to syenogranite (Fig. 3).

Small enclaves of Baba Ali metadiorite occur within and on the margins of the Almoughlagh Batholith (Fig 1-B). They represent the unassimilated or remnants of rocks, which were subjected to regional metamorphism along with the Songhor Series. Petrographically, these rocks reveal relict igneous texture, are medium to coarse grained, consisting of phenocrysts of plagioclase (andesine to laboradorite) within the groundmass of tiny plagioclase, quartz and hornblende. The metadiorite rocks show feeble foliation defined by the minerals like actinolite, chlorite, sericite and epidote.

Mineralogical Zoning across the Baba Ali Deposit.

In skarn rocks hosting mineable ore, the mineralisation is consequent to regional and thermal metamorphism and the metasomatic /hydrothermal alteration successively. Most skarn deposits of economic importance are formed in the contact metamorphic aureoles of intrusions of dioritic to granitic plutons in orogenic belts (Einaudi & Burt, 1982).

In the Baba Ali magnetite skarn deposit the main load of magnetite ore body lies between the dioritic and quartz syenitic rocks of the batholith, hosted mainly by the meta-dioritic rocks (Fig. 4-A,B).Petrographically, one comes across a mineralogical zoning between the meta-dioritic rocks that show the effects of deformation only, to reaction zones in which new mineral assemblage was formed. From SE towards NW, eight such zones with distinct mineral assemblage have been recognized, away from the Almoughlagh quartz syenite (Fig. 5,6; Table1). The meta-dioritic rocks show the effects of hydrothermal alteration, resulting in a distinct skarn zoning.

Zone 1: Quartz-Syenite

The zone 1 consists of the quartz syenite of the Almoughlagh Batholith, the intrusion and the emanations from these rocks thermally metamorphosed the metadiorite and caused the skarnization. The modal composition of the rocks of this zone has been included in Table 1.

Zone 2: Altered Quartz-Syenite

Moving NW from zone 1 towards the ore body, the syenite rocks show more and more hydrothermal alteration features, the original igneous features disappearing gradually. The abundance of vein minerals like epidote, quartz, sphene, idocrase and magnetite distinguishes this zone from the zone 1. Magnetite occurs as scattered grains within veins, associated chiefly with epidote and quartz.

Zone 3: Epidote and Quartz Zone

From zone 2 to zone 3, a rapid increase in epidote, vein calcite and magnetite is marked and the primary igneous minerals like K-feldspar, plagioclase and hornblende totally disappear. This zone shows the highest abundance of vein epidote (65% of the volume) and sphene (8% by volume) amongst all the skarn zones of Baba Ali. The following paragenetic sequence in the vein mineral assemblage could be established based on texture: calcite –quartz –sphene- (actinolite + epidote) - magnetite. This zone is immediately adjacent to the ore zone towards NW and makes, more or less, the footwall of the ore body (Fig.7). In field it appears similar to zone 2 (altered syenite) but microscopically the rocks revealed intense alteration. Zone 2 and 3 together form the endoskarn characterized by the abundance of vein minerals and magnetite grains.

Zone 4: Ore Zone

This zone is the main mineralized zone. The ore (50-100 % magnetite) is associated with epidote, calcite, actinolite, tourmaline, apatite, and quartz. From zone3 towards zone 4, there is a rapid increase in abundance of magnetite associated with these minerals. Magnetite occurs as idiomorphic, equigranular massive grains, vein mineral filling open spaces and substituting pre-existing minerals like garnet, pyroxene, calcite, plagioclase, amphibole and epidote (Figs.8,9). Magnetite grains show deformation features like brecciation, re-crystallization and shearing. Paragenetically, magnetite followed pyrite, showing intergrowth with chalcopyrite. Martite as an alteration product of magnetite is the second most widespread mineral while no primary hematite exists. Geochemically, magnetite from the Baba Ali deposit is devoid of impurities such as Mg, Mn, Zn, Ni, Ti, V, and Cr (Table 2) which readily are incorporated in the high temperature magnetite. Martite always occurs as alteration mineral forming pseudomorphs after magnetite. Pyrite, which is the third abundant mineral, occurs as early, idiomorphic and big crystals showing no anisotropy. Chalcopyrite usually occurs associated with pyrite both as co-existing and substituting mineral. Together with magnetite, it is filling the interstice of shattered pyrite grains. Chalcopyrite also forms vein and veinlet, filling open space among gangue minerals and also as inclusions in pyrite, exhibiting 'idioblastensieb' (Ramdohr,1980) texture. Chalcopyrrhotite ($CuFe_2S_3$) occurs as round spots (inclusions) on chalcopyrite showing brownish yellow reflection color (Fig.10). Such exsolution of pyrrhotite from chalcopyrite usually occurs below 450º C (Ramdohr, 1980) while at temperatures >450 ºC, it is said to be completely miscible. Secondary minerals like goethite and limonite, chalcocite and malachite occur as weathering products.

Microscopically, minor relicts of garnet and pyroxene grains are also observed in the rocks, which show that the rocks before the hydrothermal veining contained these minerals. The ore bearing veined-structure was superimposed over the earlier texture and mineral assemblage during skarnization. Amongst the vein minerals it was observed that magnetite formed as the latest and replaced other minerals. The paragenetic sequence calcite – quartz – (actinolite + epidote) – (tourmaline + apatite + epidote)- magnetite remains more or less similar to zone 3. This zone represents an assemblage that shows the association of phosphate (apatite) and borate (tourmaline) minerals with a magnetite and with low abundance of calcite.

Zone 5: Garnet, Pyroxene and Ore zone

This is the most informative zone of the Baba Ali skarn deposit, since it gives an opportunity to establish the intensity of thermal metamorphism before the rocks suffered hydrothermal veining and mineralisation. It is characterized by the index minerals of prograde facies of skarn deposit like garnet and pyroxene and preserves the skarn mineral assemblage beyond the zone of magnetite mineralisation. Garnet occurs as coarse, idiomorphic, stout grains and short prismatic grains, showing intergrowth with pyroxene (Fig.10). No zoning was observed either in garnet or in the pyroxene grains and neither of these minerals showed any inclusions. Microscopic as well as electron micro-probe analysis revealed the garnet composition (Fig.11-A) as andradite (35 to 92 mol% andradite). Pyroxene also occurs as short idiomorphic to subhedral grains and rarely as long prismatic grains showing intergrowth with garnet (Fig.10). Compared to garnet the pyroxene forms relatively coarser grains and the EPMa investigation revealed the composition (Fig.11-B) in the salite range (Di $_{66}$ Hed $_{44}$ to Di $_{53}$ Hed $_{47}$). The Fe $_{(t)}$ /(Fe $_{(t)}$ + Mg) ratio in the salite shows a narrow range between 0.36 to 0.44, while the Fe $_{(t)}$ /(Fe $_{(t)}$ + Al) ratio in the co-existed garnet shows a very broad range between 0.23 to 0.98. It is evident that the two minerals were formed at the threshold temperature of incorporating more and more iron in the garnet composition.

The rocks show a rapid decrease in the ore as well as in the abundance of actinolite and quartz, other minerals like tourmaline and apatite being absent. Amongst the vein minerals, epidote (pistacite) is predominant and has replaced both the garnet and pyroxene, occasionally forming pseudomorphs (Fig.10). No relict of plagioclase from the metadiorite was found associated with the mineral assemblage of zones 4 and 5.

Zone 6: Actinolite, Calcite, Quartz, and Chlorite zone

The zone 6, towards the dioritic host rock, is marked by the abundance of actinolite, quartz and calcite. Appearance of chlorite, decreasing abundance of epidote and magnetite and rapid decreasing of garnet and pyroxene are the other characteristics of this zone. Minerals like actinolite, quartz and chlorite as revealed by their relicts increasingly replace garnet and pyroxene. No primary igneous relict mineral of diorite could be seen in the rocks of this zone. Compared to other zones, this zone has the highest abundance of actinolite (30% by vol.) and calcite (25% by vol.) associated with magnetite.

Zone 7: Altered Diorite zone

This is the zone of altered dioritic rocks (Table 1) characterized by the gradual decreasing of actinolite, calcite, and epidote, compared to zone 6 and increasing appearance of sericite, plagioclase, K-feldspar, and quartz. This zone has the highest abundance of quartz (42% by vol.) and sericite (10% by vol.) indicating effects of hydrothermal alteration induced by the Almoughlagh granitoids. Garnet and pyroxene are absent but calcite continues to occur as intersertal and even as vein mineral in this zone. The zones 4, 5, 6, and 7 together constitute the exoskarn (Fig 5). Thus, the exoskarn in the Baba Ali deposit is much wider than the endoskarn; the ratio exoskarn (39m radius) to endoskarn (5.5 m radius) is 7.0. The ore body with the width of nearly 27m is mostly within the exoskarn, but some mineralisation is also associated with zones 2 and 3, within the endoskarn. The extensive exoskarn confirms that the role played by the dioritic host rock was comparable to any carbonate host rock that is usually known to form a geochemical barrier for precipitating the metal content of ore bearing fluids.

Zone 8: Peripheral metadiorite zone

The peripheral metadiorite exposures bear the same characteristics described earlier for the Baba Ali diorite. Occurrence of calcite as the only vein mineral and intersertal re-crystallized grains that have promoted the mineralisation is significant.

Geochemical variation across the skarn zones

The geochemical distribution pattern across the skarn zones is said to be governed by the different rates of mobility and activity of elements, under the influence of prevailing temperature, depth and host rock composition (Zharikov, 1970). The samples of the skarnized zones show a contrasting composition with those of diorite shoulders to the NW and syenite shoulders to the SE. The mineralized zones 4 and 5 show lower Al_2O_3(8%)compared to both in the diorite and the syenite (Table 3 & Fig.12) but indicate also that the precursor rocks were not low in Al_2O_3. This is especially shown by rocks of zone 3, having a very low MgO, high CaO, fairly high FeO (total) and high Al_2O_3 (11.64 %). Lying adjacent to the mineralized zone, this zone is dominated by the presence of epidote and actinolite. In general, the CaO is much lower than that of Al_2O_3, similar to the general abundance SiO_2 in these skarn zones. The higher CaO in zone 4 and 3 indicates local presence of calcite veins. SiO_2 in these skarn zones remains much lower than the samples forming the shoulder, except in zone 7 and 3, which shows abundance of vein quartz. Of interest is the low TiO_2 in the mineralized zone, showing that the magnetite is not associated with Ti minerals. Due to the presence of sphene with average modal percentage of 8% in the zone 3, Ti shows a peak in this zone. Zone 4 and 6 also show some minor peaks of MnO. The peak of P_2O_5 between zone 3 and 4 shows the presence of abundant apatite. The Na_2O and K_2O curves show the gradual disappearance of the feldspar from the dioritic shoulder, giving way to sericite and chlorite in skarn zone. Between the two, Na_2O is somewhat higher (between 1 to 2%), probably because of the relict plagioclase and amphiboles. The main mineralized zones (4 & 5) show depletion in SiO_2, K_2O, Na_2O compared to rocks of zone 2 and 3 as well as of 6 and 7. These happen to be the components expected to be contributed by the Almoughlagh granitoids. MgO shows a fluctuating abundance in the skarnized rocks, showing highs in zone 2, part of zone 4 and in zone 6 reflected in the increased abundance of actinolite and chlorite. Similarly, fluctuating is the distribution pattern of CaO, which is high in zone 3, part of zone 4. These components are expected to have been extracted from the assimilated metadiorite.

Discussion and conclusion

Skarn rocks are classified usually on the basis of the dominant calc-silicates mineral assemblage into calcic skarns and magnesian skarn (Korzhinskii,1955; Zharikov, 1968; Rose & Burt,1979; Enaudi et al.,1981). Recently the third group of skarn deposits, namely manganoan type has been proposed by Chinese geologist(Zhao et al., 2003).The manganoan skarn type bears manganese-rich minerals like Johansenite, Mn-hedenbergite, Mn-diopside ,bustamite, pyroxmangite, rhodonite, serpentine, etc. The presence of andradite, salite, actinolite, epidote, sphene and idocrase as the calc-silicate minerals, and the absence of minerals like tremolite, forsterite, phlogopite, talc, and humite and aforementioned minerals of manganoan skarns allow the grouping of the Baba Ali skarn deposit as a calcic Fe-skarn deposit. The pyroxene and garnet compositions fall well within the field recognized (Meinert, 1992) for these minerals from Fe-skarns (Fig.11). The average S content in the Baba Ali ore body is < 1.5 percent. The low content of sulfide for the deposit has been considered as one of the characteristics of the Island Arc type calcic Fe skarn deposits (Einaudi et al., 1981). It automatically reflects also towards the lesser possibility of association of Cu, Zn, Co, Au and Ni as sulphides, which again emboldens the recognition of the present deposits as calcic Fe-skarn deposits of the Island arc environments (Einaudi et al.,1981). The high ratio of exsoskarn by endoskarn (Extensive exsoskarn facies (Fig. 5) indicates a shallow depth" hypabyssal "(< 5 km) for formation of the Baba Ali skarn.

The Fe mineralisation is a part of the skarnization process. The high temperature facies of magnetite ore accompanies most typically the phases of andradite and rarely the re-crystallization of ferromagnesian pyroxene. The medium temperature facies accompanies the phases of actinolite and the epidotization in the calcic skarns. The same accompanies the phase of serpentization and phologopite formation in the Mg skarn. The low temperature magnetite facies accompanies the chloritization in calcic skarn and serpentization in Mg skarn (Zharikov, 1970). In Baba Ali deposit the prograde assemblage i.e. pyroxene and garnet which is an indicator of the temperature range of 500-550°C (Zharikov, 1970) is overprinted by the hydrothermal minerals, showing descending trend of temperature of mineral deposition. The following evidences show that the deposition of magnetite belongs to Zharikov's lower temperature facies.

1- The EPMa analysis of magnetite from the Baba Ali deposit show a rather pure magnetite phase, devoid of impurities such as Mg, Mn, Zn, Ni, Ti , V, and Cr (Table 2) which readily are incorporated in the high temperature magnetite. The absence of these impurities indicates a low temperature magnetite facies (Ramdohr, 1980).

2- Presence of exsolved lamellae of pyrrhotite within chalcopyrite (chalcopyrrhotite) represent temperature of exsolution between 250–400 °C (Ramdohr, 1980).

3- Replacement of the hydrothermal (retrograde) minerals like actinolite, epidote, chlorite, sphene, tourmaline and idocrase by magnetite show a low temperature within the green schist facies conditions.

4- Replacement of the prograde assemblage i.e. garnet and pyroxene which formed in the 500 –550° C range by hydrothermal minerals along with magnetite, occurred at relatively lower temperature.

In the light of the above arguments one may conclude that the Fe mineralisation at the Baba Ali deposit occurred in the range of 350 –400° C, since the lower temperature limit of calcic skarn is considered to be 350° C (Zharikov,1970).

Table1- Variation of the Prograde, hydrothermal and ore minerals across the Baba Ali

Modal Percentage	**Zone 1**	**Zone2**	**Zone3**	**Zone4**	**Zone5**	**Zone6**	**Zone7**	**Zone8**
Plagioclase	12	10	0	0	0	0	28	60
K-Feldspars	38	40	0	0	0	0	2	2
Quartz	12	8	20	5.5	2	33	32	4
Hornblende	22	0	0	0	0	0	0	13
Actinolite	0	9	2	5	2	30	11	10
Calcite	0	0	5	5	3	25	9	10
Epidote	5.5	20	65	7	15	3	0	0
Ore	2.5	3	8	75	25	4	3	0.2
Chlorite	0	2	0	0	0	5	5	0
Sericite	0	0	0	0	0	0	10	0
Garnet	0	0	0	0	30	0	0	0
Pyroxene	0	0	0	0	23	0	0	0
Tourmaline	0	0	0	3.5	0	0	0	0
Sphene	7	8	0	0	0	0	0	0
Total	99	100	100	101	100	100	100	99.2

Table2- EPMa analysis of magnetite grains from Baba Ali skarn deposit.

Al_2O_3	MgO	FeO(t)	MnO	TiO_2	Cr_2O_3	NiO	CoO	ZnO	V_2O_5	Total
0.187	0.081	85.38	0.072	0.097	0.041	0.011	0.00	0.176	0.00	86.049
0.399	0.063	71.64	0.00	0.018	0.089	0.00	0.005	0.366	0.010	72.59
0.22	0.169	83.61	0.041	0.015	0.029	0.00	0.022	0.84	0.019	84.9
0.229	0.10	84.18	0.054	0.00	0.270	0.01	0.042	0.67	0.00	85.86

Table3- Variation of major oxides across the Baba Ali skarn zones.

Zones	Al2o3	Cao	FeO (T)	K2O	Mg O	MnO	Na2O	P2O5	SiO2	TiO2	Interval	Samples
Zone1	15.83	4.91	2.89	1.43	1.15	0.01	7.56	0.28	64.34	0.94	0	BC14
Zone 2	14.46	7.54	6.23	0.1	1.74	0.08	5.07	0.55	59.2	1.19	2	BC13B
Zone2	10.66	10.82	9.08	0.5	15.24	0.17	2.52	0.39	44.52	1.419	2	BC12C
Zone3	11.64	14.79	9.04	0.03	0.21	0.1	1.61	0.14	60.32	0.212	0.01	BC11B
Zone 4	8.77	9.02	35.73	0.1	3.33	0.15	2.03	3.45	28.56	0.017	3	BC10
Zone 4	7.78	2.98	53.22	0.1	12.2	0.11	1.68	0.05	21.06	0.055	4	BC9
Zone 4	8.05	4.31	50.74	0.11	3.58	0.97	1.75	0.303	25.14	0.014	4	BC8
Zone 4	8.46	2.43	52.18	0.25	1.42	0.05	1.87	0.192	22.28	0.43	10	BC7C
Zone 4	7.27	7.24	55.03	0.01	0.78	0.03	1.62	0.03	10.42	0.025	9	BC6A
Zone 5	7.719	2.1	58.85	0.03	1.06	0.01	1.63	0.1	12.84	0.07	5	BC3 B
Zone 6	11.46	4.08	12.64	2.6	9.33	0.5	2.61	0.2	39.47	1.22	1	BC2
Zone 7	14.52	4.86	1.8	1.68	1.08	0.02	3.73	0.13	66.69	0.41	10	BC 1B
Zone 8	17	7.8	6.9	1.03	4	0.18	4.24	0.3	51	1.03	10	BC0

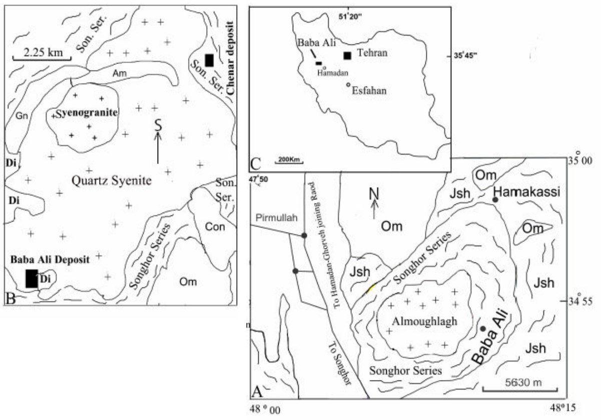

Fig. 1-A) Simplified Geological map of the Baba Ali region
B) Geological map of the Almoughlagh Batholith
C) Location map of the Baba Ali region
Di.: Diorite; OM.: Oligomiocene Formation;
Jsh.: Jurassic Schist (Hamadan Schist); Gn.: Gneiss;
Am.: Amphibolite; Son. Ser.: Songhor Sreies;
Con.: Conglomerate

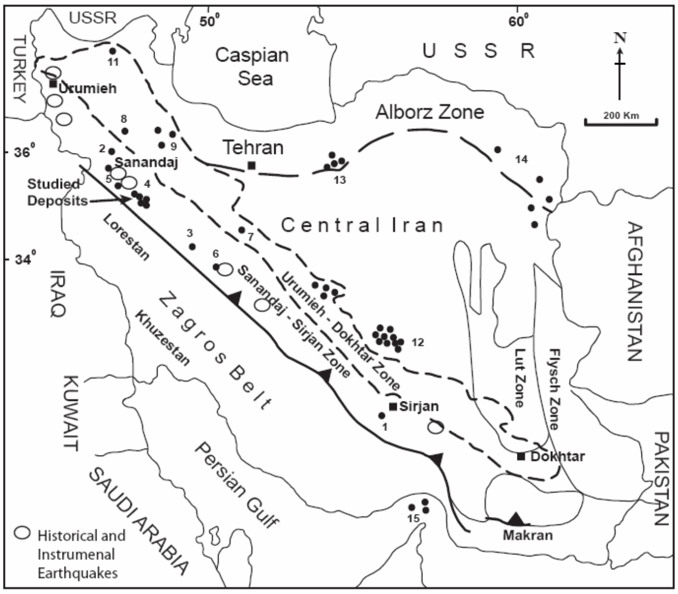

Fig.2- Tectonic Zones of Iran (Modified after Berberian & King,1981; Nabavi,1971) Nos. 1-15 refer to iron deposits.

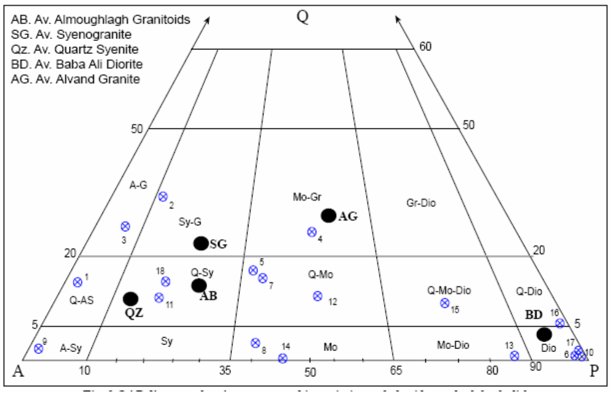

Fig.3- QAP diagram showing petrographic variations of the Almoughlagh batholith.

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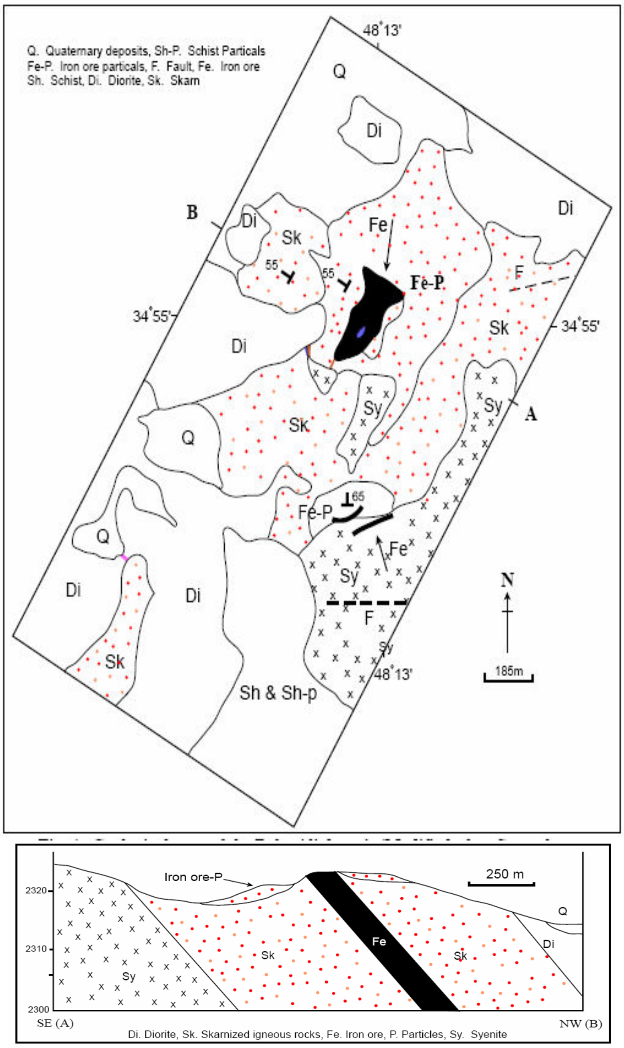
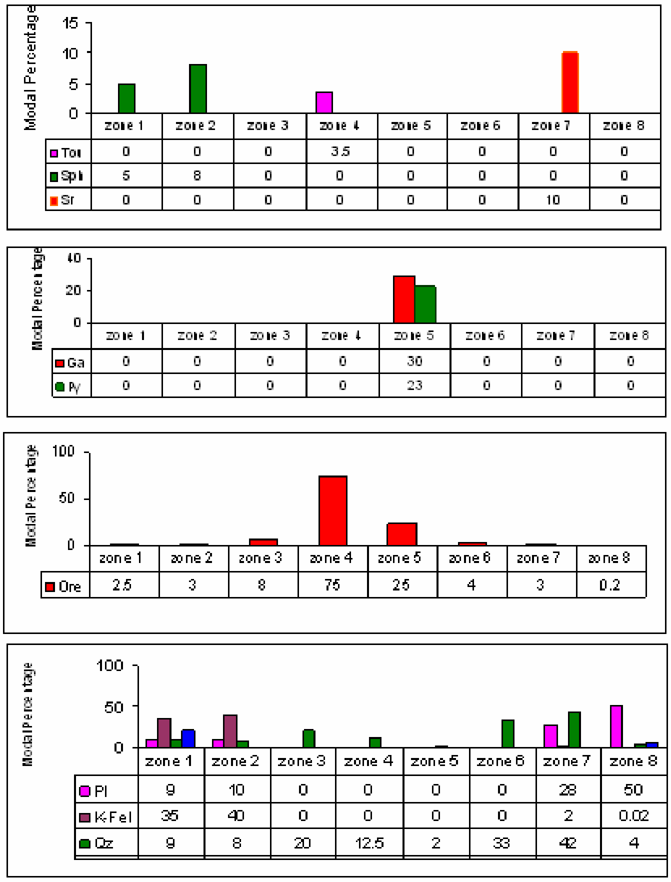


Fig.4- A) Geological map of the Baba Ali deposit
(Modified after Central Iron ore Co., 1991) 48
B) Geological cross section of the Baba Ali deposit.



	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6	zone 7	zone 8
Tor	0	0	0	3.5	0	0	0	0
Spl	5	8	0	0	0	0	0	0
Sr	0	0	0	0	0	0	10	0

	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6	zone 7	zone 8
Ga	0	0	0	0	30	0	0	0
Py	0	0	0	0	23	0	0	0

	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6	zone 7	zone 8
Ore	2.5	3	8	75	25	4	3	0.2

	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6	zone 7	zone 8
Pl	9	10	0	0	0	0	28	50
K-Fel	35	40	0	0	0	0	2	0.02
Qz	9	8	20	12.5	2	33	42	4

Fig. 6- Variation of major minerals across the Baba Ali skarn zones.

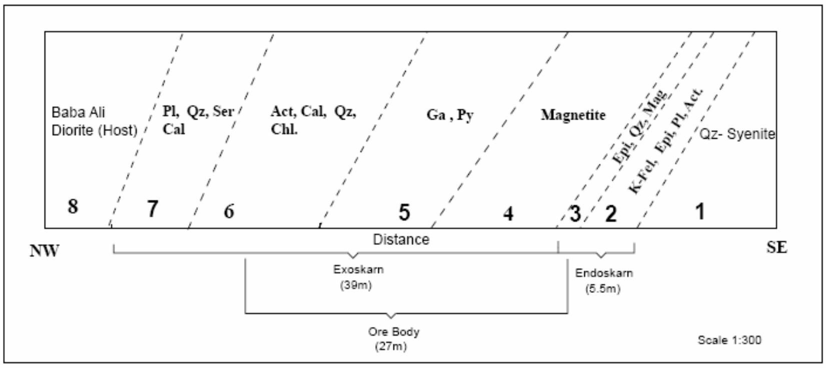


Fig.5- Zoning, Endo and Exoskarn in the Baba Ali deposit. The most abundant minerals have been shown in each zone.
Pl: Plagioclase, Qz: Quartz, Ser: Sericite, Cal: Calcite; Act: Actinolite, Chl: Chlorite, Ga: Garnet, Py: Pyroxene,
Mag: Magnetite, K-Fel: K-Feldspar, Epi: Epidote, Tal: Talc, Tre: Tremolite, An: Antigorite, QZ-Mo: Quartz Monzonite.

Fig.7 -Ore body and its spatial relation with quartz syenite footwall in the Baba Ali deposit.

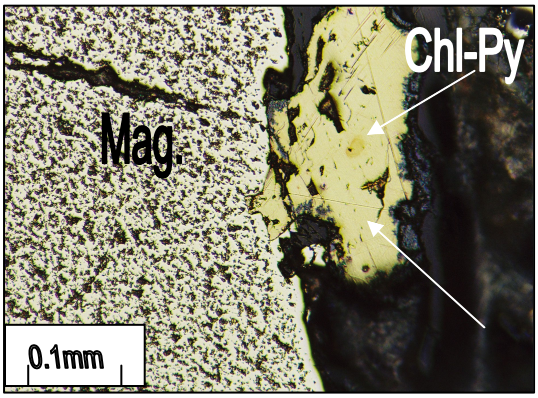


Fig .10- Chalcopyrrhotite (Chl-Py) within chalcopyrite in the Baba Ali ore body

Fig .8- Magnetite replacing calcite vein

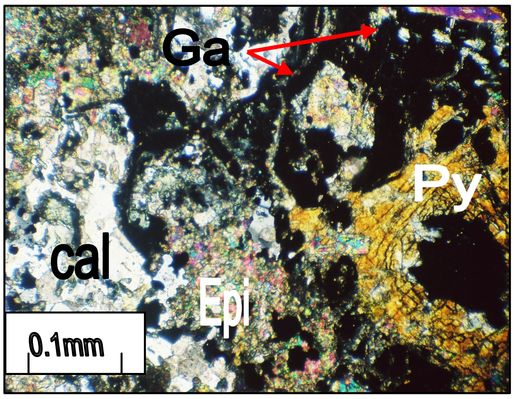


Fig .9- Co-existing pyroxene and garnet replaced by calcite, epidote and magnetite during the hydrothermal alteration in Baba Ali skarn.

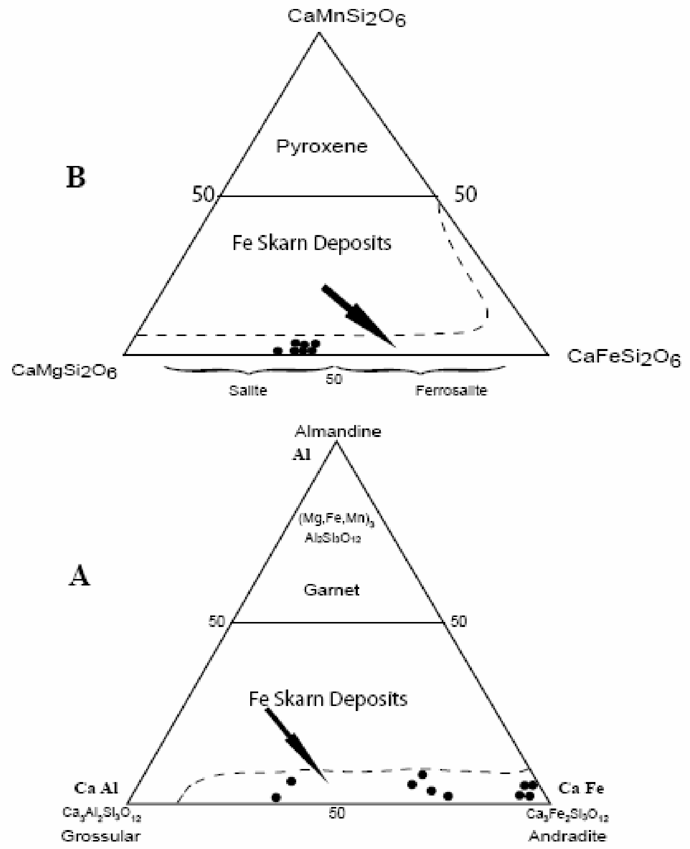
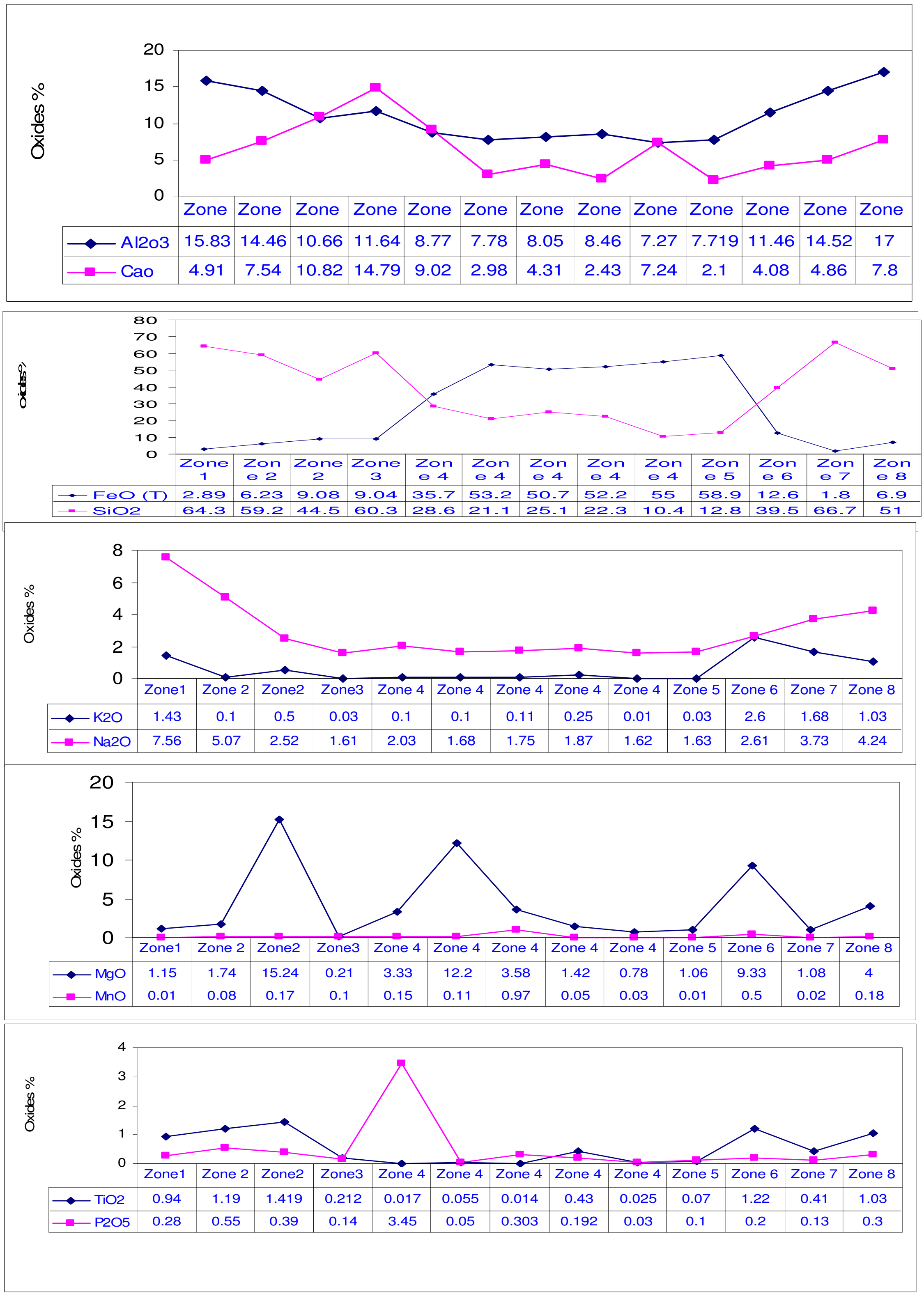


Fig.11- Composition of garnet and Pyroxene for Baba Ali Iron Skarn deposit (After Meinert,1992).



	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone
Al2o3	15.83	14.46	10.66	11.64	8.77	7.78	8.05	8.46	7.27	7.719	11.46	14.52	17
Cao	4.91	7.54	10.82	14.79	9.02	2.98	4.31	2.43	7.24	2.1	4.08	4.86	7.8

	Zone 1	Zone 2	Zone 2	Zone 3	Zone 4	Zone 4	Zone 4	Zone 4	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
FeO (T)	2.89	6.23	9.08	9.04	35.7	53.2	50.7	52.2	55	58.9	12.6	1.8	6.9
SiO2	64.3	59.2	44.5	60.3	28.6	21.1	25.1	22.3	10.4	12.8	39.5	66.7	51

	Zone1	Zone 2	Zone2	Zone3	Zone 4	Zone 4	Zone 4	Zone 4	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
K2O	1.43	0.1	0.5	0.03	0.1	0.1	0.11	0.25	0.01	0.03	2.6	1.68	1.03
Na2O	7.56	5.07	2.52	1.61	2.03	1.68	1.75	1.87	1.62	1.63	2.61	3.73	4.24

	Zone1	Zone 2	Zone2	Zone3	Zone 4	Zone 4	Zone 4	Zone 4	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
MgO	1.15	1.74	15.24	0.21	3.33	12.2	3.58	1.42	0.78	1.06	9.33	1.08	4
MnO	0.01	0.08	0.17	0.1	0.15	0.11	0.97	0.05	0.03	0.01	0.5	0.02	0.18

	Zone1	Zone 2	Zone2	Zone3	Zone 4	Zone 4	Zone 4	Zone 4	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
TiO2	0.94	1.19	1.419	0.212	0.017	0.055	0.014	0.43	0.025	0.07	1.22	0.41	1.03
P2O5	0.28	0.55	0.39	0.14	3.45	0.05	0.303	0.192	0.03	0.1	0.2	0.13	0.3

Fig.12- Variation of Major oxides across the Baba Ali skarn

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* گروه زمین شناسی، دانشگاه لرستان، خرم آباد، ایران
**دانشگاه آزاد اسلامی واحد خرم آباد، ایران

*Dep. of Geology, Lorestan University, Khoram Abad, Iran
** Azad Islamic University of khoram Abad, Iran