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Mineral Chemistry of Index Minerals and Their Implications in the Genesis of the Baba Ali Magnetite Skarn Deposit, Western Iran

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The Almoughlagh Batholith, consisting chiefly of quartz syenite and syenogranite rocks, belongs to the magnetite series granitoids, is mostly of I-type, metaluminous and calk-alkaline in nature. The batholoth invaded both the Baba Ali diorite and Songor Series culminated in thermal and hydrothermal metamorphic aureoles in which Baba Ali magnetite deposit formed. Petrography and geochemistry of the host rocks and index minerals such as garnet, pyroxene and magnetite reveal a descending temperature regime, beginning at the peak of thermal metamorphism (550 ºC) and ending with the main phase of magnetite mineralization (350-400 ºC). Mineral chemistry of prograde minerals namely garnet and pyroxene implemented to classify the Baba Ali as a typical Fe-Skarn deposit.

Key Words: Almoughlagh, Fe-Skarn, Baba Ali, Magnetite, Hydrothermal.

INTRODUCTION

The Baba Ali magnetite deposit is located in the western Sanandaj-Sirjan zone of Iran and also on the northeastern slope of the Almoughlagh Mountain (long. 48º 50'E-48º 15'E and lat. 34º 45' N-35º 00 N). The Almoughlagh Batholith forms the Almoughlagh Mountain with an outcrop area of 159.5 sq.km. Baba Ali deposit is approachable from Hamadan city (40 km). The entire mineralized area forms a complex, referred to as the Hamakassi deposits, constituting of four deposits, namely the Baba Ali, Chenar, Gelali and Tekyeah deposits, amongst which the Baba Ali happens to be the largest. The estimated ore reserve at the Baba Ali deposit is about 66 m with a grade of 61% for iron[1].

Geology setting and petrograph: Surrounding the Almoughlagh Batholith the rock formations 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

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is a volcano sedimentary sequence, constituted of alternating schistose and limy lithounits, interbedded with metamorphosed spilitic lava and andesitic tuff[2]. The Songhor series suffered the regional metamorphism and deformation in three successive orogenic phases, the Late Kimmerian (136 Ma)[3,4] followed by the Laramide (65 Ma)[5] and the Pasadenian (2 Ma)[4] phases, the latest accompanied by the emplacement of the Almoughlagh Batholith. The Late Kimmerian (Jurassic-Cretaceous) phase metamorphosed the Songhor series to the greenschist-lower amphibolite facies. Petrological characters of the Almoughlagh batholith have been studied earlier[4,6]. These authors described the Batholith as a ring complex, consisting mostly of quartz syenite porphyry, gabbro and diorite. Towards the eastern and southern margins of the Batholith, the rocks were reported to grade into gneiss with amphibolitic enclaves. Other authors have referred to the entire Batholith as the Almoughlagh diorite[7]. The present work revealed that the Almoughlagh Batholith is a complex body constituted chiefly of quartz syenite and syenogranite groups as mapable petrographic units. The areal spread of quartz syenite group is far extensive and in them one comes across remnant enclaves of meta-dioritic rocks. The modal composition varies from quartz syenite to quartz alkali-syenites to alkali-syenite and quartz-monzonite (Fig. 1).

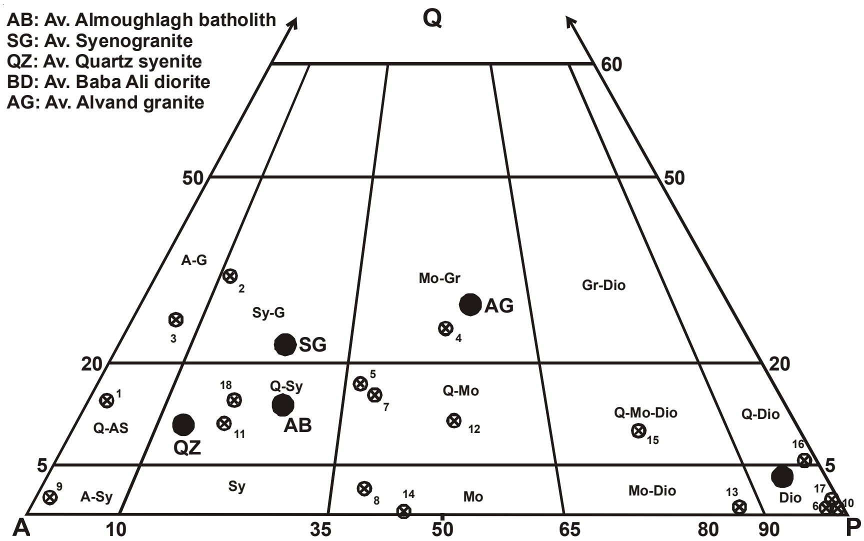

Fig. 1. QAP diagram showing petrographic variations of the Almonglagh batholith

Small enclaves of Baba Ali metadiorite occur within and on the margins of the Almoughlagh Batholith. They represent the unassimilated or unskarnized 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. Most skarn deposits of economic importance are formed in the contact metamorphic aureoles of intrusions of dioritic to granitic plutons in orogenic belts[8].

Zoning: 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. 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. 2).

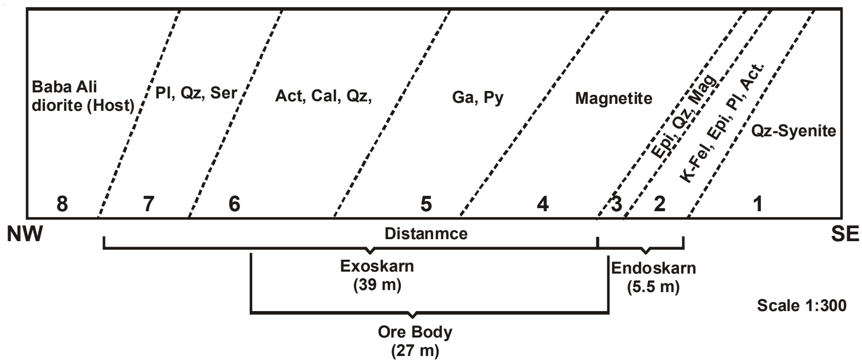

Fig. 2. Zoning, endo and exoskarn in the Baba Ali deposit. The most abundant minerals have been shown in each zone

Mineralogy and mineral chemistry of the index minerals (garnet, pyroxene and magnetite): Zone 5 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 like garnet, pyroxene and magnetite 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. 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 (Table-1, Fig. 3) as andradite (35 to 92 mol % andradite). Pyroxene also occurs as short idiomorphic to subhedral grains and rarely as long prismatic grains. Compared to garnet the pyroxene forms relatively coarser grains and the EMP investigation revealed the composition (Table-2, Fig. 3) 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 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. Magnetite is whitish gray without any anisotropy or exsolution product, indicating lack of any mix-crystal development[9]. This observation is also consistent with the EMP analyses (Table-3) of magnetite samples showing a rather pure magnetite phase, devoid of impurities such as Mg, Mn, Zn, Ni, Ti, V and Cr, which get readily incorporated in magnetite formed at high temperature. Magnetite occurs as idiomorphic, equigranular massive grains, as vein mineral filling open spaces and substituting pre-existing minerals like garnet, pyroxene, calcite, plagioclase, amphibole and epidote.

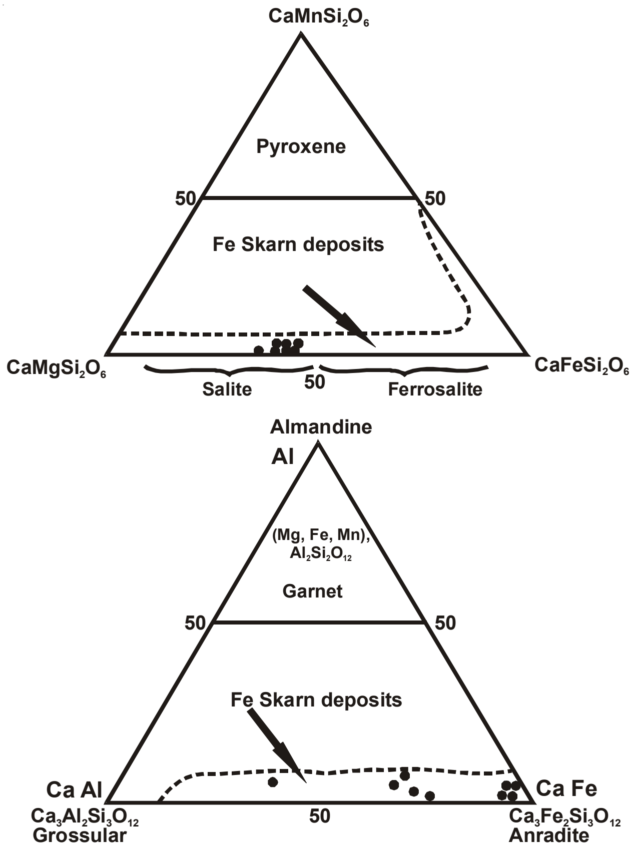

Fig. 3. Composition of garnet and pyroxene for Baba Ali Iron Skarn deposit

TABLE-1
EMP ANALYSIS OF GARNETS FROM BABA ALI DEPOSIT

Sample	Na_2O	K_2O	CaO	SiO_2	Al_2O_3	MgO	FeO(T)	MnO	Cr_2O_3	TiO_2	Total	Fe Mol%	Mg Mol%	Mn Mol%
Bc.6.c4	0.346	0.019	24.132	50.98	0.688	10.404	11.45	0.48	0.00	0.032	98.54	0.124	0157	0.005
Bc.6.c7	0.213	0.000	15.08	52.78	0.31	11.713	9.512	0.407	0.00	0.033	100.05	0.103	0.176	0.004
Bc.6.c8	0.228	0.00	24.55	50.95	0.32	10.79	10.199	0.43	0.047	0.027	97.565	0.11	0.162	0.004
Bc.6.c12	0.306	0.023	22.46	51.94	0.401	10.71	11.113	0.46	0.007	0.028	99.541	0.12	0.167	0.005
Bc.6.c14	0.36	0.001	23.24	51.02	0.49	10.68	10.89	0.65	0.00	0.035	97.366	0.118	0.164	0.007
Bc.c.617	0.312	0.034	23.44	50.43	0.43	11.52	11.11	0.54	0.002	0.029	98.62	0.12	0.173	0.005
Bc.6.c18	0.44	0.007	26.11	52.33	0.32	10.89	9.03	0.72	0.003	0.04	99.89	0.097	0.136	0.007

TABLE-2
EMP ANALYSIS OF PYROXENES FROM BABA ALI DEPOSIT

Sample	Na_2O	K_2O	CaO	SiO_2	Al_2O_3	MgO	FeO(T)	MnO	Cr_2O_3	TiO_2	Total	Fe Mol%	Mg Mol%	Mn Mol%
Bc.6.2	0.009	0.02	34.76	36.03	5.037	0.22	21.47	0.35	0.00	0.37	98.28	0.10	0.003	0.003
Bc.6.3	0.00	0.00	23.752	36.48	20.90	0.20	13.97	0.09	0.012	0.045	95.3	0.067	0.003	0.009
Bc.6.9	0.00	0.08	35.33	35.60	7.57	0.27	18.47	0.36	0.26	0.46	98.18	0.09	0.004	0.003
Bc.6.11	0.00	0.002	23.78	37.05	21.415	0.03	13.01	0.025	0.00	0.07	95.4	0.06	0.003	0.000
Bc.6.14	0.00	0.00	34.60	34.61	5.52	0.14	21.20	0.00	0.00	0.24	96.4	0.10	0.002	0.00
Bc.c.15	0.043	0.00	33.27	34.25	0.47	0.23	26.63	0.20	0.022	0.09	95.3	0.13	0.0032	0.002
Bc.6.c16	0.00	0.00	33.71	35.01	0.44	0.24	26.86	0.315	0.00	0.00	96.6	0.13	0.0035	0.003
Bc.6	0.00	0.025	33.65	34.817	0.48	0.26	26.68	0.27	0.0	0.035	96.2	0.13	0.004	0.002
Bc.6.18	0.02	0.00	35.16	34.61	6.38	0.28	18.34	0.26	0.12	0.64	95.74	0.09	0.004	0.0002
Bc.6.19	0.092	0.036	34.50	35.64	6.67	0.35	17.88	0.38	0.031	0.46	96.00	0.08	0.0052	0.004

TABLE-3
EMP COMPOSITIONS OF MAGNETITE FROM THE BABA ALI DEPOSIT

Al_2O_2	MgO	FeO(t)	MnO	TiO_2	Cr_2O_3	NiO	CoO	ZnO	V_2O_5	Total
0.128	0.280	86.59	0.000	0.007	0.009	0.046	0.000	0.000	0.022	86.83
0.580	0.095	71.82	0.000	0.000	0.098	0.000	0.000	0.000	0.000	72.58
0.096	0.020	85.50	0.000	0.060	0.000	0.000	0.000	0.000	0.026	85.70

Conclusion

The compositions of pyroxene and garnet that fall well within the field recognized[10] for these minerals from Fe skarns show that the Baba Ali deposit can be classified as Fe Skarn deposit (Fig. 3). The main phase of Fe mineralization in the present case did not accompany the crystallization of phases like andradite and salite during the peak temperature of skarnization. A descending trend of temperature (550-350 ºC), beginning with the formation of garnet-pyroxene assemblage and ending with the magnetite mineralisation can therefore be assumed during the skarnization and mineralization. The main phase of Fe mineralization occurred in the temperature range of 350-400 ºC, since the lower temperature limit for formation of calcic Skarn is held[11] to be 350 ºC. The magnetite mineralization represents therefore a low temperature facies. Magnetite mineralisation in hydrothermal conditions related to igneous intrusions of intermediate composition has been reported form many a region around the Pacific[12]. The iron mineralization in Baba Ali skarn deposit with a limited extent of thermal aureole, extensive exoskarn and association of hydrothermal minerals with magnetite should have taken place at shallow (mesoabyssal) depth.

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