



RESEARCH PAPER

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Evaluation of alteration zones in choghart iron ore deposit (Bafg Area, Central Iran)**Zohreh Hossein Mirzaei Beni^{1*}, M. H. Emami², S. J. Sheikhzakariaee³, A. Nasr Esfahani⁴**¹*Department of Geology, Science and Research Branch, Islamic Azad University (IAU), Teheran, Iran*²*Department of Geology, Science and Research Branch, Islamic Azad University, Eslamshahr (Tehran), Iran*³*Department of Geology, Science and Research Branch, Islamic Azad University, Teheran, Iran*⁴*Department of Geology, Islamic Azad University (IAU), Isfahan branch (Khorasgan), Iran***Key words:** Choghart, Ore deposit, Alteration, Rhyolite, Bafq.

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Abstract

The Choghart iron ore deposit is located 12 km northeast of Bafq and 125 km southeast of Yazd. The Choghart iron oxide-apatite is placed within felsic volcanic tuffs, rhyolite rocks and volcanic-sedimentary sections belonging to the lower Cambrian period. Sodic alteration is one of the most comprehensive alterations in this mine. The main minerals in this zone are magnetite, hematite, secondary albite (checkers albite), apatite, calcite and amphibole. Other alterations in this deposit are calcic, silica and low temperature alterations. Calcic alteration specified with presence of magnetite and amphibole minerals (major minerals), feldspar and apatite (minor minerals) and hematite. Sodic and calcic alterations are associated with mineralization and silica and low temperature alterations have little relevance with mineralization. Low temperature alterations are the final step of alterations and hematite, martyt, chlorite, epidote, sericite and calcite formed in this stage. There is a limited sulphide phase in Choghart deposit. Pyrite is the most important sulfide phase in all of alterations which can be seen in the scattered shape and with magnetite that represents the next hydrothermal activities. P content is low in all of alterations but its content in sodic alteration is lower than other alterations.

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Introduction

The origin of massive iron oxide deposits related to igneous rocks has been the subject of a long-standing and heated debate for the last hundred years. These deposits are usually composed of magnetite-hematite-fluorapatite with varying amounts of amphiboles. They occur worldwide and range in size from large high-grade orebodies to small dikes and veinlets. They are usually found in volcanic-plutonic terrains. Among these deposits, the so-called Kiruna-type ores have attracted the most attention. Several genetic models have been proposed for this specific type of massive iron oxide deposits but in the main, they are considered to be magmatic segregation deposits.

There are more than 80 identified magnetic anomalies in the Bafq mining district, and the region is believed to host over 2 Gt of iron oxide ore. Most of the deposits are unexploited or only partially mined. Choghart is the first deposit of its kind exploited in the Bafq mining district.

The Choghart Iron Ore mine is located 13 km northeast of Bafq city at 55° 28' E and 31° 42' N. This

region is of 400 km length and 200 km width and is located on the volcanic-plutonic arc of the early Cambrian period known as the Kashmar-Kerman arc. The Choghart Iron Ore is located in Precambrian Formation of Central Iran. Rocks of the study area are sedimentary, volcanic, intrusive, schist, marble and gneisses. This complex is influenced by metamorphism (Contact and Burial) and metasomatism processes and has caused great variety of rocks and minerals around Choghart area (Jami, 2005). But as a whole, the complex which make the rocks of the ore body has completely two different facies; these two facies are mostly green and light rocks which are applied generally with different names by geologists (Daliran, 2002). 1) The light rocks which are made up of high percent of quartz and feldspar are named as Cratophyer. 2) The greatest part of the green rocks of the area, have been formed due to the low metamorphism of igneous rocks is named as Greenstone (Williams, 2010). In this research we evaluated the alteration zones in Choghart iron ore deposit. These alteration zones are calcic, silica and low temperature alterations.

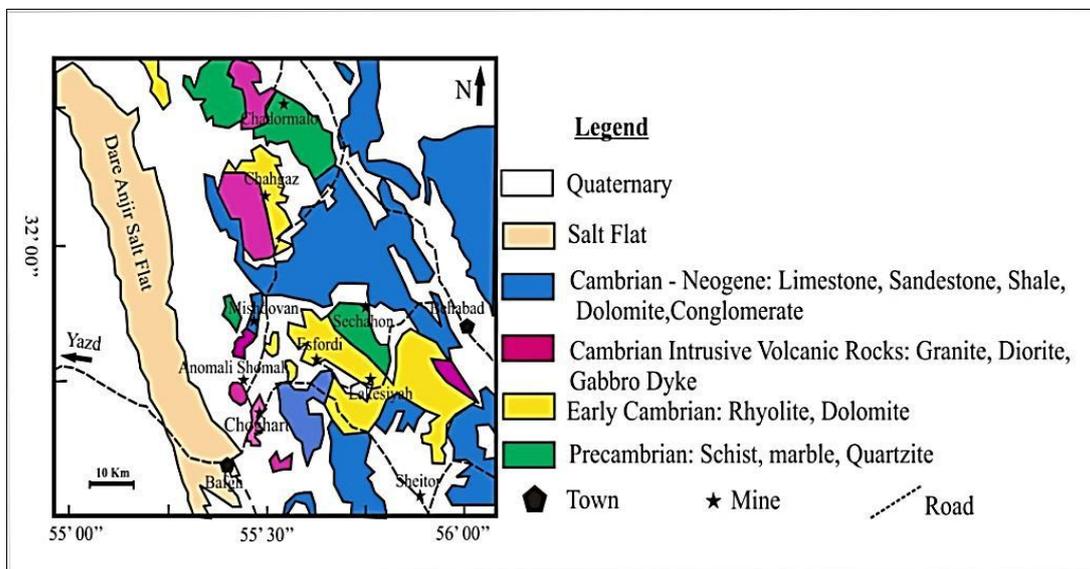


Fig. 1. The map of Bafq - Saghand district and position of active mines (adapted from Torab, & Lehmann, 2007).

Material and methods

Sampling method

During the field observations, 150 rock samples were collected from two parts of the study area. After

studying the manual sample, 125 thin sections and 10 polish sections preparation and was studied with polarizing microscope. EMPA analyzes by using a microprobe model SX 100- CAMECA was done on

amphibole (13 points) and feldspar minerals (17 points) in 5 sodic - calcic alteration rocks in the Mineral Research and Technology Centre in Karaj, Iran (Table 2,3). We drawing diagrams about

plagioclase composition in Sodic alteration and amphibole corresponds in the calcic alteration with this data and using from Excel, GCDKit, Igpct, and Minpet programs.

Table 2. Microprobe data of feldspar minerals in sodic - calcic alteration zones in the Choghart deposit.

Element																	
Sapl. No	2	2	2	5	5	5	6	6	6	7	7	7	8	8	8	8	
point. No	Fels-par 2	Fels-par 2	Fels-par 3	Fels-par 4	Fels-par 5	Fels-par 6	Fels-par 7	Fels-par 8	Fels-par 9	Fels-par 10	Fels-par 11	Fels-par 12	Fels-par 13	Fels-par 14	Fels-par 15	Fels-par 16	Fels-par 17
SiO ₂	68.73	64.79	65.25	62.35	63.74	68.5	67.58	66.80	66.90	64.45	63.75	63.74	68.65	67.17	67.47	66.89	65.07
TiO ₂	0	0	0	0.000	0.06	0	0.00	0.00	0.00	0.06	0.00	0.06	0	0.06	0.00	0.06	0.00
Al ₂ O ₃	17.94	22.34	18.640	18.080	18.08	18.94	18.56	19.65	19.26	17.50	18.65	18.08	19.5	19.55	19.41	19.58	18.03
FeO	0.26	0.12	0.000	0.000	0.04	0	0.00	0.00	0.00	0.04	0.09	0.04	0	0.04	0.04	0.05	0.18
CaO	0.22	0.11	0.000	0.000	0.00	0.12	0.12	0.40	0.00	0.00	0.00	0.00	0.1	0.00	0.00	0.33	0.00
Na ₂ O	11.87	12.32	0.350	0.350	16.37	11.85	11.78	11.16	0.36	16.89	15.45	16.37	10.56	12.00	11.65	11.50	1.01
K ₂ O	0.71	0.12	15.500	16.450	0.25	0.09	0.05	0.07	11.50	0.33	0.350	0.25	0.09	0.03	0.05	0.06	15.14
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P ₂ O ₅	0.000	0.000	0.000	0.000	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.28	0.00	0.28
Total	99.73	99.80	99.740	97.230	98.54	99.5	98.09	98.08	98.02	99.27	98.29	98.54	98.9	98.85	98.90	98.47	99.70
Formula																	
Si	12.120	11.420	12.022	11.912	11.981	12.034	12.044	11.900	12.196	12.057	11.900	11.981	12.059	11.897	11.947	11.887	11.880
Ti	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.008	0.000	0.008	0.000	0.008	0.000	0.008	0.000
Al	3.728	4.662	4.047	4.071	4.005	3.921	3.898	4.126	4.138	3.858	4.110	4.005	4.037	4.081	4.050	4.101	4.110
Fe	0.018	0.018	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.006	0.014	0.006	0.000	0.006	0.006	0.007	0.000
Ca	0.042	0.021	0.000	0.000	0.000	0.023	0.023	0.076	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.063	0.000
Na	4.058	4.229	0.125	0.130	3.925	4.036	4.070	3.854	0.127	4.031	4.040	3.925	3.596	4.120	3.999	3.962	0.120
K	0.160	0.027	3.643	4.009	0.09	0.020	0.011	0.015	2.674	0.120	0.120	0.09	0.020	0.007	0.011	0.014	4.040
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.001	0.001	0.003	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Total	20.125	20.377	19.838	20.122	20.016	20.03	20.047	19.971	19.136	20.080	20.180	20.016	20.03	20.119	20.030	20.042	20.178
Formula																	
An	0.976	0.488	0.000	0.000	0.000	0.554	0.558	1.935	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.556	0.000
Ab	95.275	98.878	3.320	3.100	97.730	98.952	99.165	97.691	4.542	97.116	97.120	97.730	99.836	2.268	99.720	98.107	2.880
Or	3.750	0.634	96.680	96.900	2.268	0.494	0.277	0.374	95.458	2.884	2.880	2.268	0.164	97.730	0.280	0.340	97.120

Table 3. Microprobe data of amphibole minerals in sodic - calcic alteration zones in the Choghart deposit.

Element														
Point No.	Amph 1	Amph 2	Amph 3	Amph 4	Amph 5	Amph 6	Amph 7	Amph 8	Amph 9	Amph 10	Amph 11	Amph 12	Amph 13	Amph 13
Sample No.	2	2	5	5	6	6	6	6	7	7	7	8	8	8
SiO ₂	52.24	52.66	53.29	54.13	53.24	52.44	53.89	52.81	53.41	55.53	55.21	54.79	54.36	54.36
TiO ₂	0.31	0.12	0.18	0.15	0.35	0.23	0.45	0.33	0.42	0.1	0.01	0.06	0.35	0.35
Al ₂ O ₃	1.89	2.02	1.09	2.39	1.68	1.25	1.83	2.71	1.10	0.42	0.18	1.28	0.67	0.67
Cr ₂ O ₃	0	0.01	0.03	0.04	0.02	0.03	0.01	0.05	0.05	0.05	0.05	0.01	0.03	0.03
FeO	3.36	3.88	15.64	12.47	4.26	11.97	13.4	12.27	12.81	11.07	11.77	15.52	15.12	15.12
MnO	0.16	0.22	0.4	0.08	0.07	0.05	0.75	0.34	0.66	0.17	0.13	0.23	0.15	0.15
MgO	27.15	27.13	14.53	15.78	26.28	19.51	14.35	16.44	15.65	18.31	17.01	14.67	15.01	15.01
CaO	12.28	12.14	12.74	12.45	11.91	12.1	12.56	12.06	12.42	12.25	12.55	10.01	10.46	10.46
Na ₂ O	0.71	0.17	0.32	0.28	0.58	0.66	0.39	0.50	0.44	0.18	0.12	1.01	1.62	1.62
K ₂ O	0.29	0.16	0.13	0.18	0.08	0.05	0.14	0.21	0.11	0.12	0.11	0.17	0.15	0.15
H ₂ O	2.01	2.01	2.23	2.10	2.09	2.18	2.11	2.14	2.40	2.07	2.13	2.09	2.08	2.08
Total	100.4	100.52	100.58	100.05	100.56	100.47	99.88	99.86	99.47	100.27	99.27	99.84	100.09	100.09
Formula														
Si	7.48	7.58	7.48	7.76	7.46	7.53	7.59	7.59	7.78	7.88	7.95	7.94	7.55	7.55
Ti	0.03	0.01	0.02	0.02	0.04	0.02	0.04	0.04	0.05	0.01	0.00	0.01	0.04	0.04
Al	0.35	0.34	0.18	0.40	0.45	0.21	0.46	0.46	0.19	0.07	0.03	0.22	0.11	0.11
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Fe	0.40	0.46	1.84	1.49	0.50	1.44	1.47	1.47	1.56	1.31	1.42	1.88	1.76	1.76
Mn	0.03	0.06	0.05	0.01	0.04	0.01	0.10	0.10	0.08	0.02	0.02	0.03	0.02	0.02
Mg	5.79	5.70	3.88	3.37	5.70	4.17	3.52	3.52	3.40	3.87	3.65	3.17	3.13	3.13
Ca	1.88	1.87	1.92	1.91	1.79	1.86	1.86	1.86	1.94	1.86	1.94	1.55	1.56	1.56
Na	0.20	0.05	0.09	0.08	0.16	0.18	0.14	0.14	0.12	0.05	0.03	0.28	0.44	0.44
K	0.05	0.03	0.02	0.03	0.01	0.01	0.04	0.04	0.02	0.02	0.02	0.03	0.03	0.03
Mg/(Mg+Fe)	0.94	0.93	0.68	0.69	0.92	0.74	0.70	0.70	0.69	0.75	0.72	0.63	0.64	0.64

Results and discussion

Petrographic, mineralogical studies and other evidence suggested that two main types of alteration

zones are in the choghart deposit that one of them associated with iron mineralization and another has a slight correlation with iron mineralization. Sodic and

calcic alterations associated with mineralization and Carbonate and silic alterations have slight correlation.

Sodic alteration

Sodic alteration is a comprehensive alteration associated with mineralization in the Choghart area which a large amount of storage were formed in the host rocks. The main minerals in this zone are magnetite, hematite, secondary albite, apatite, calcite and amphibole. The secondary albite (checkers albite) is the important mineral of this type of alteration. For formation of this alteration, hydrothermal fluids which are rich from alkaline elements changed the mineralogical composition of rhyolites and created new minerals according to the conditions of hydrothermal fluids. The fluid that makes this alteration is the first fluid which separate from the magma and have high salinity, temperature and rich from gases F, B and CO₂ (Hitzman, 2000). With addition of K⁺ and Na⁺ to construction of minerals such as plagioclase, a certain type of plagioclase with abnormal tissue formed. The reactions show the formation of checkers albite with little amount of potassium in sodic alteration zone.

- (1) $CaAl_2Si_2O_8 + 2K^+ + 4SiO_2 \rightarrow 2KAlSi_3O_8 + Ca^{+2}$
- (2) $CaAl_2Si_2O_8 + 2Na^+ + 4SiO_2 \rightarrow 2NaAlSi_3O_8 + Ca^{+2}$
- (3) $KAlSi_3O_8 + Na^+ \rightarrow NaAlSi_3O_8 + K^+$

In the process (1) Anorthite is converted into K-feldspar as result of K⁺ replacement which is accompanied by release of Ca⁺² ions. In the process (2) calcium plagioclase is converted into albite as a result of replacing Na⁺ ion. In the process (3) K-feldspar is replaced by Na⁺, which is associated with the formation of albite (Carten, 1986). Microprobe analysis on the sodic altered rocks showed that the composition of plagioclase is in the albite range (Fig. 2). Secondary albite has specific tissue. The small albite blades are like checkerboard and each of these units is like irregular square (Fig. 3). This tissue attributed by many geologists as sodic metasomatism of potassic feldspar (Carten, 1986). This tissue is as a result of sodic metasomatism on the acidic rocks (Moore & Liou, 1979).

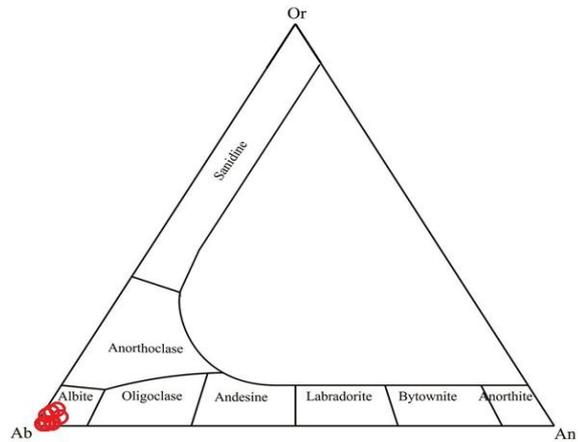


Fig. 2. Plagioclase composition in Sodic alteration of Choghart deposit, based on microprobe analyzes (Lake *et al.*, 1997).

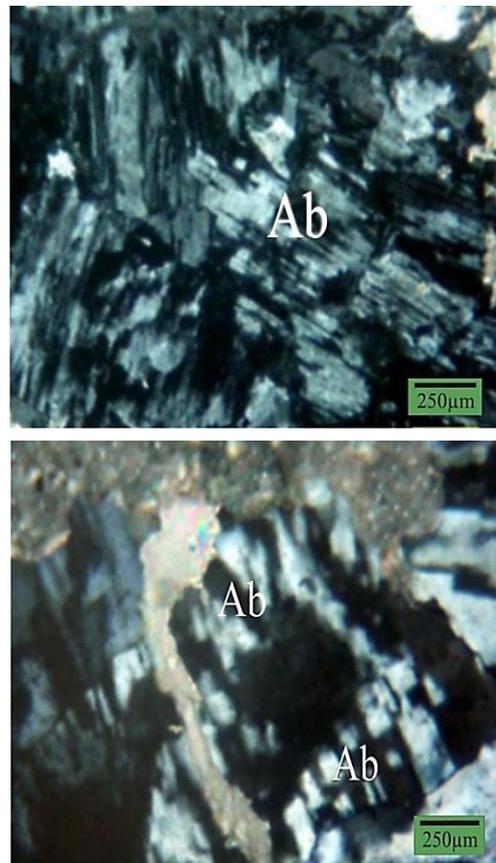


Fig. 3. Checkered albite in the sodic alteration (in light XPL).

Calcic Alteration

Choghart host rock deposits composed from Rhyolite and tuff rhyolite rocks of the Lower Cambrian that in the North and East of deposits have been severely calcic alteration. This alteration specified with

presence of magnetite and amphibole minerals (major minerals), feldspar and apatite (minor minerals) and hematite. This alteration is the youngest alteration phase with variable grade of iron mineralization which cuts sodic alteration. So calcic alteration is form after sodic alteration. The main and final stage of iron ore mineralization is associated with this alteration.

Based on microprobe analyzes, amphibole minerals of this zone are in the calcic range (Fig. 4) and are from the tremolite - actinolite type (Fig. 5). Tremolite enriched in MgO than actinolite. Tremolite - actinolite are enriched from CaO (% 10/01 - 12/74), MgO (% 14/35 - 27/15), SiO₂ (% 52/24 - 55/53) relative to the other amphiboles. Calcic amphiboles have $Ca < 0.5$, $(Ca + Na) \geq 1$, $(Na + K) < 0.5$ and $0.5 < Na < 1.5$ (Carten, 1986). Macroscopic and microscopic evidence shows that actinolites can be found in euhedral form and have occupied spaces between other minerals (Fig. 6).

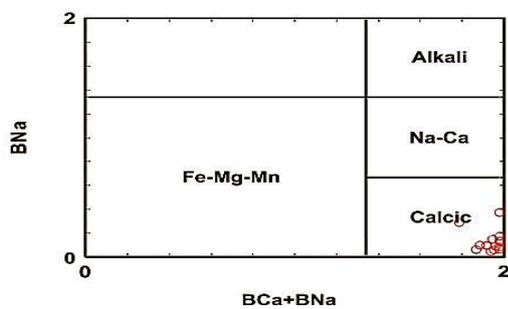


Fig. 4. Amphibole corresponds in the calcic alteration zone of Choghart deposit based on microprobe analyzes (Lake *et al.*, 1997).

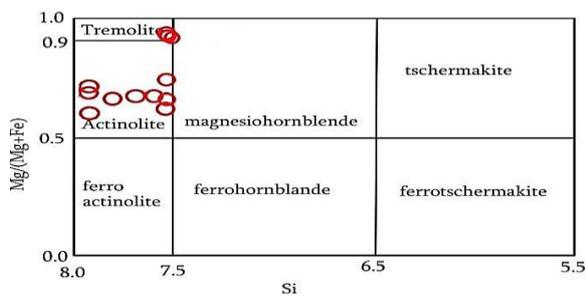
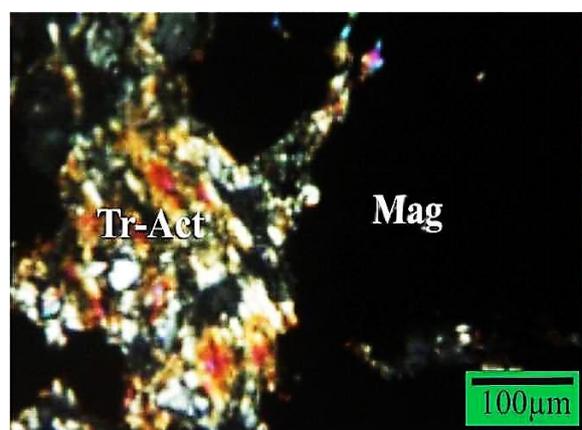
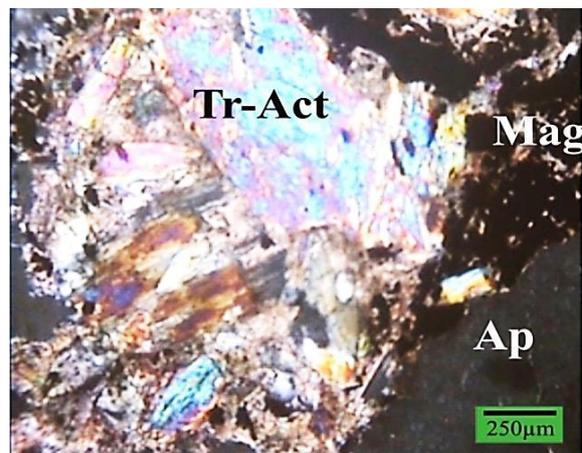
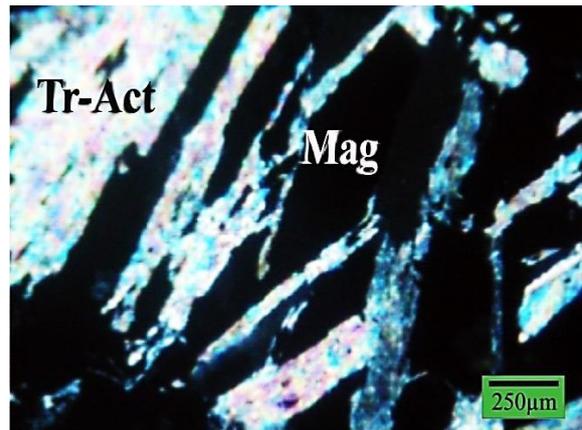


Fig. 5. Amphibole corresponds in the calcic alteration zone of Choghart deposit based on microprobe analyzes (Lake *et al.*, 1997).



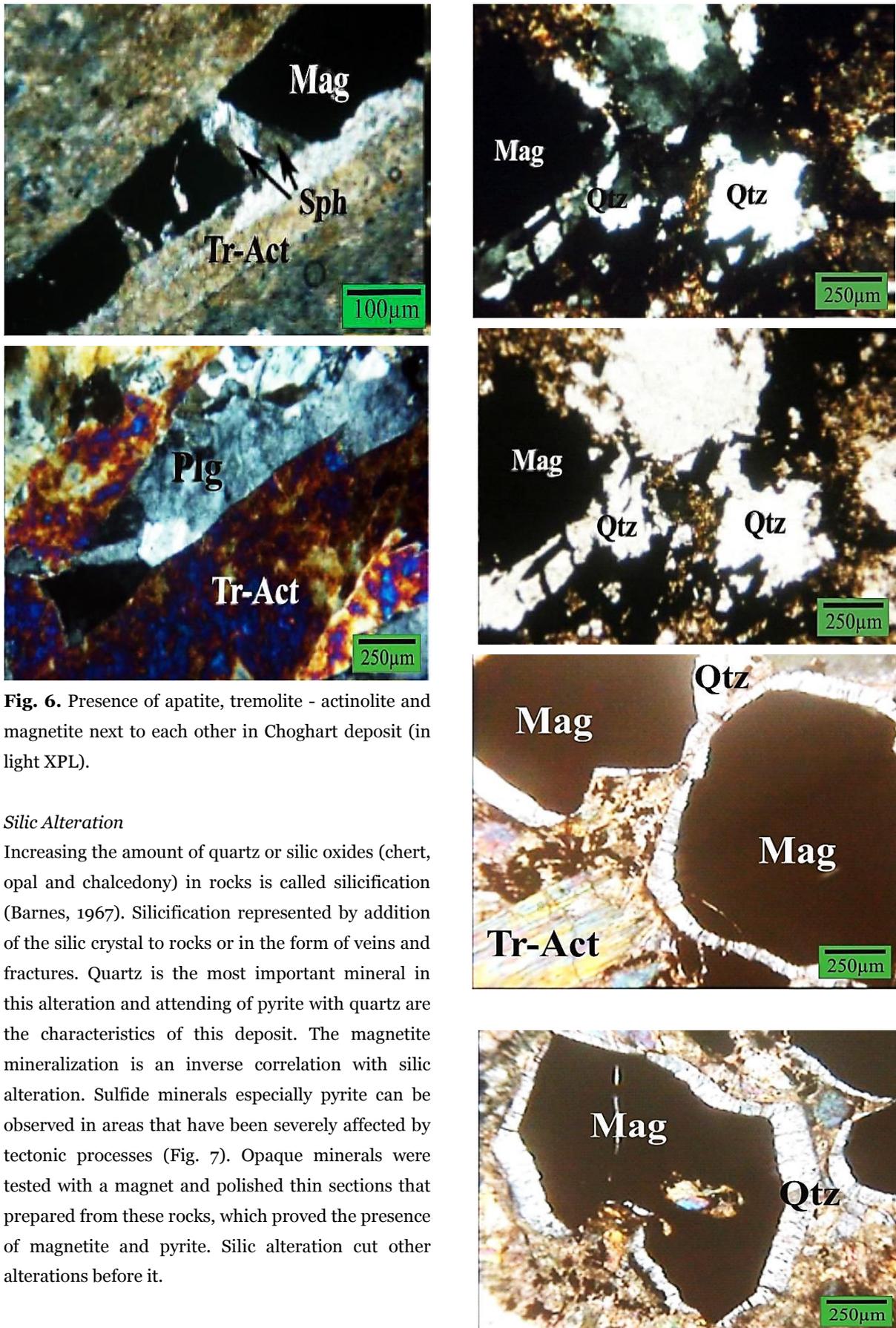


Fig. 6. Presence of apatite, tremolite - actinolite and magnetite next to each other in Choghart deposit (in light XPL).

Silic Alteration

Increasing the amount of quartz or silic oxides (chert, opal and chalcedony) in rocks is called silicification (Barnes, 1967). Silicification represented by addition of the silic crystal to rocks or in the form of veins and fractures. Quartz is the most important mineral in this alteration and attending of pyrite with quartz are the characteristics of this deposit. The magnetite mineralization is an inverse correlation with silic alteration. Sulfide minerals especially pyrite can be observed in areas that have been severely affected by tectonic processes (Fig. 7). Opaque minerals were tested with a magnet and polished thin sections that prepared from these rocks, which proved the presence of magnetite and pyrite. Silic alteration cut other alterations before it.

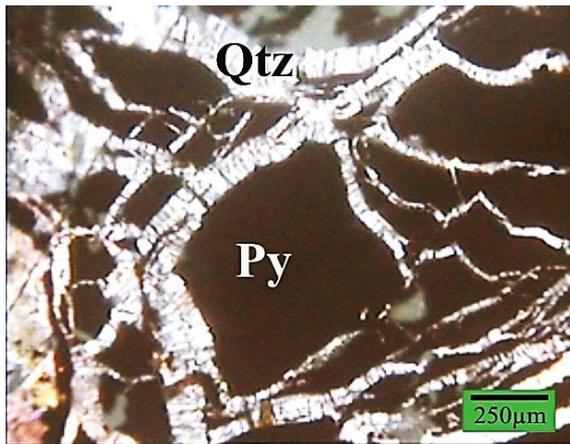


Fig. 7. Quartz, magnetite, pyrite in silic alteration in Choghart deposit (in the Light XPL).

The low temperature alterations

In choghart deposit, low temperature alterations are the final step of alterations. At this stage, hematite, martyt, chlorite, epidote, sericite and calcite formed. The diversity of mineralogy is in these alterations.

Calcite (CaCO_3) is transparent to translucent and in the Rhombohedron form. Calcite is one of the most common and extensive rock-forming minerals. More carbonate alteration is visible in the form of calcite. Calcite is as final minerals in choghart deposit and its formation is due to the influence of solution containing carbonate in the host rocks, dykes and veins (Fig. 8).

Hematite observed in the blade and stranded form and also in the previous mineralization sections with calcite. Martyt is abundant in shallow areas. Petrographic and mineralographic studies of ore in the Choghart deposit shows that sodic alteration has the most extension alteration and accessory with albite-magnetite mineralization. Calcic alteration has limited extension and accessory with magnetite-actinolite mineralization. Low temperature alterations such as silic, chlorite, sericite, epidote and calcite alterations have less important in the Choghart deposit.

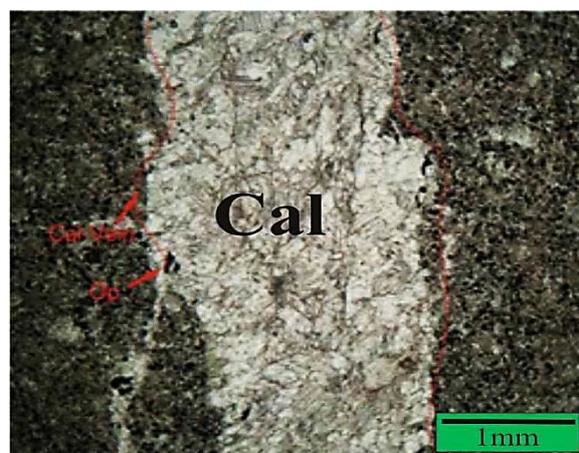
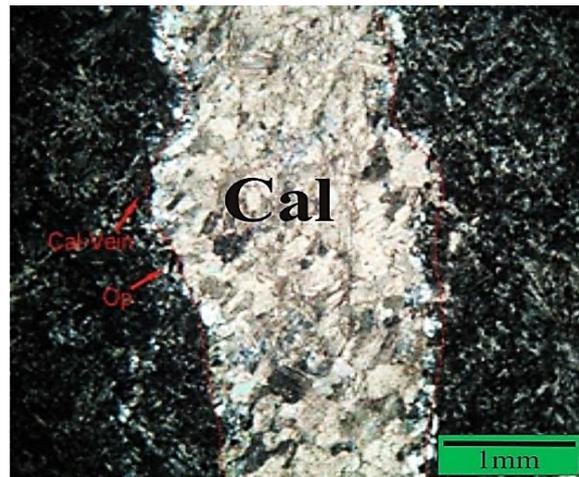


Fig. 8. Calcite filling the fractures in carbonate alteration in Choghart deposit (in light XPL and PPL).

Conclusion

Petrography and mineralogy of the ore body and other evidence showed that two main types of alteration (sodic and calcic) accessory with ore mineralization in Choghart deposit. sodic alteration is a comprehensive alteration and the main minerals in this alteration are magnetite, hematite, secondary albite, apatite, titanite and calcite. The secondary albite (checkers albite) is the important mineral of this type of alteration. Microprobe analysis of the sodic altered rocks showed that the composition of plagioclase is in the albite range. Calcic alteration specified with presence of magnetite and amphibole minerals (major minerals), feldspar and apatite (minor minerals) and hematite. This alteration is the youngest alteration phase with variable grade of iron mineralization which cuts sodic alteration. Based on microprobe analyzes, amphibole of this zone are in

the calcic range and are from the tremolite - actinolite type. Quartz is the most important mineral in silic alteration and attending of pyrite with quartz are the characteristics of this deposit. Silic alteration cut sodic and calcic alterations.

In choghart deposit, low temperature alterations are the final step of alterations. At this stage, hematite, martyt, chlorite, epidote, sericite and calcite formed. The diversity of mineralogy is in these alterations. The main processes of mineralization are creating two types of ore (low grade and high grade). Then diabase dikes injected into the fractures of rocks. In the final stage, hydrothermal alteration with lower temperatures has been cut ore deposit.

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