Bulgarian Chemical Communications, Volume 48, Special Issue D (pp. 280 - 293) 2016

Geology, mineralogy and geochemistry of the Mazayjan massive sulfide deposit (Southern Sanandaj - Sirjan, Iran)

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Received June 26, 2016, Revised September 10, 2016

Copper mineralization of Mazayjan area occurred in Carboniferous metabasites of Suriyan metamorphic Complex (northeast Fars province) and within the southern part of Sanandaj–Sirjan structural province in Iran.

Metallic minerals composition observed in the region is simple and includes pyrite, chalcopyrite, malachite, covellite and iron oxides. The geological settings forming the deposit environment including mineralization at metabasitic section of Suriyan complex with the basaltic to andesitic primary composition, The nature of sub-alkaline tholeiitic related to oceanic basins for this metabasites and occurrance of subsequent metamorphic processes, presence of pyrite mineral as main sulphide phase, massive, layered and shearing structures, all indicate that Mazayjan copper deposit is a volcanogenic massive sulfide (VMS deposits) and probably of the besshi type. Point analysis studies (EPMA) showed that in terms of chemical composition, pyrite and chalcopyrite are uniform and homogeneous due to metamorphic processes in the area of interest. This indicates that metamorphic events in the region occurred after sulfide mineralization. In the other words, metamorphic processes cannot be introduced as the origin of copper mineralization in Mazayjan. Microscopic and probe analyses have shown that inclusions of chalcopyrite within pyrite, while valuable elements were not found whithin these minerals.

Keywords: Iran, Sanandaj-Sirjan, Mazayjan, Massive sulfide, Probe analysis.

INTRODUCTION

Massive sulfide deposits were introduced in the 1950s for the first time as a distinct group of deposits. Due to their relation with volcanic activities, they are commonly known as VMS, an acronym with different words, but very close concepts. For example, Sawkins [20] called these deposits volcanic-associated massive sulfide deposits. Large *et al*. [9] named them as volcanic-hosted massive sulfide deposits. Also volcanogenic massive sulfide deposits has been used by Franklin *et al*. [6].

VMS deposits are major source for copper and zinc elements, and secondary source for elements such as Pb, Ag, Au, Cd, Sc, Sn and Bi. Also the supply of a VMS mass is variable and ranges between 2.7 to 7.1 million tonnes have been reported [8-11].

It should be noted that massive sulfides mineralization at the Sanandaj- Sirjan structural state of Iran is well known and have been introduced by many researchers [1,2,5,12,14,15,18,19,21-24].

In the current study, after an introduction to the study area and research methods, we discuss issues related to copper mineralization at the Mazayjan area in the southern Sanandaj-Sirjan in three sections: geology, mineralogy and geochemistry. The results of these sections are presented separately.

GEOLOGICAL BACKGROUND

Study area

Mazayjan is located in the most eastern part of Bavanat city in Fars province and is bordered with Kerman (in east) and Yazd (in northern) (Fig. 1).

Mazayjan area is located in 240 Km northeast of Shiraz and at the southern part of Sanandaj- Sirjan state; therefore, follows the general geological conditions of the state.

Geology

Fig.2 shows the simplified geological map of Mazayjan area based on Noori's studies [13, 14] and Noori *et al*. [16]. This map is part of the Tootak White Mountain anticline which has a Northwest – Southeast trend same as most of the anticlines in Sanandaj-Sirjan [18-19]. The core of White Mountain anticline includes older Tootak series and its limb is made of Suriyan complex schists. In a geological section from the northeast to southwest of Mazayjan region three main geological units are exposed. These units in terms of age from older to younger include: Tootak metamorphic complex marbles, age of Devonian-Carboniferous, Suryan metamorphic complex schists, age of Carboniferous and non-metamorphic carbonate rocks, age of

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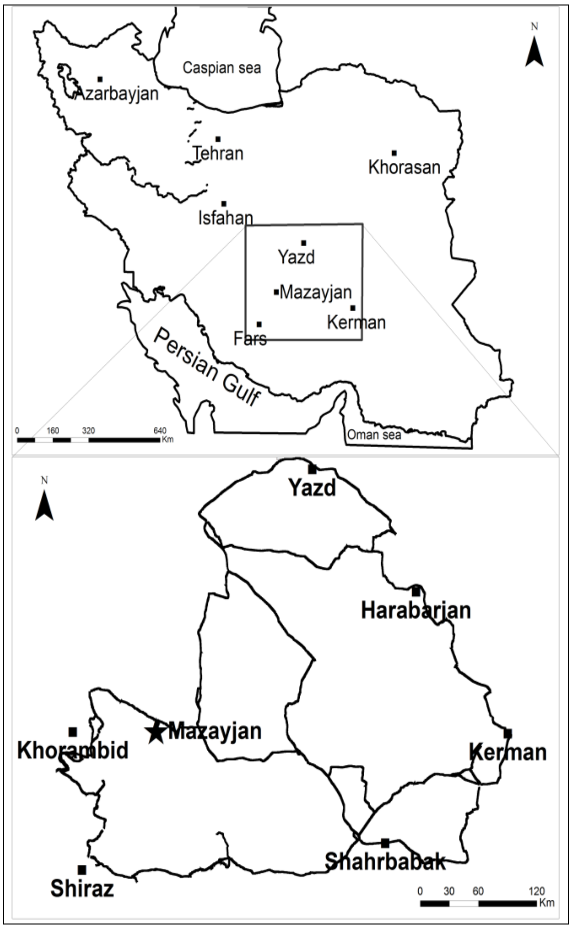


Fig. 1. Geographical location and access routes of Mazayjan.

Jurassic-Cretaceous. Since Suriyan metamorphic complex schists acted as the host rock of copper mineralization in Mazayjan region, therefore, will be discussed in more details (Fig. 3).

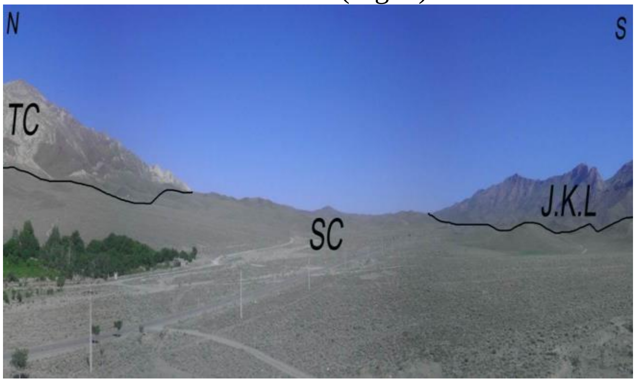


Fig. 3. Outcrop of rock units, view towards east. J.K.L: Jurassic-Cretaceous LimestoneSC: Suriyan omplex(greenschist & micaschist) TC: Tootak Complex

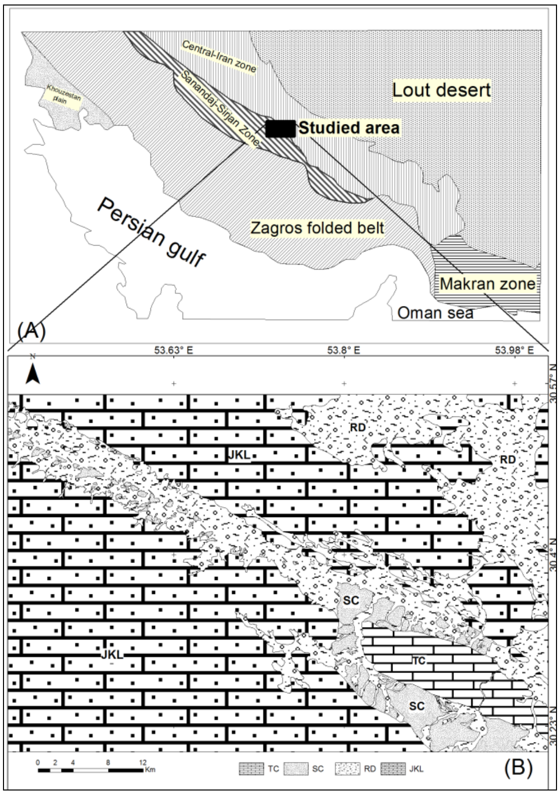


Fig. 2. (A) Study area in structural provinces map of Iran and (B) Simplified geological map of Mazayjan [22].
J.K.L: Jurassic-Cretaceous Limestone
RD: Recent deposit
SC:Suriyan complex(greenschist & micaschist)
TC:Tootak complex
TC: Tootak Complex

Stratigraphic column of the Mazayjan study area is shown in (Fig.4). Suriyans complex schists are between Tootak complex rock units and jurassic–cretaceous non-metamorphic carbonate rocks.

Based on studies of [7], protolith of Suriyan metamorphic complex schists is divided into two groups. The first group are metapelites commonly composed of micaschist and some phyllite and represent metamorphosed clastic sedimentary facies, and the second group are metabasites that mostly made of greenschist and are rarely associated with amphibolites and indicate metamorphosed submarine basaltic volcanism. Most of the Suriyan metamorphic complex in Mazayjan area, are metabasites or greenschists, which is accompanied by a smaller micaschist and phyllite (Figs 5, 6).

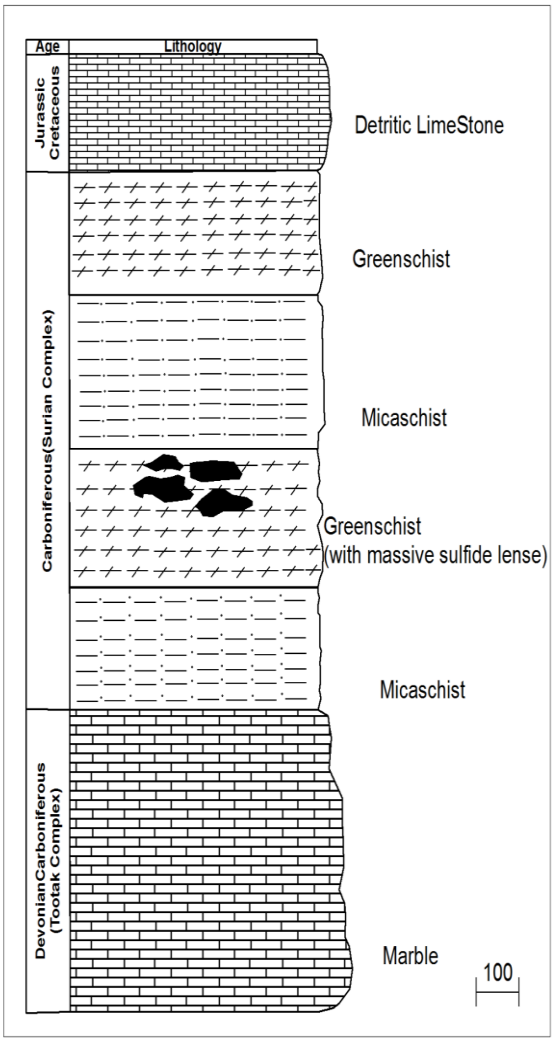


Fig. 4. Stratigraphic column of Mazayjan area.

Based on current studies, metabasites section of Suriyan metamorphic complex has played as Cu mineralization host rock (Figs. 7 and 8). This idea is in accordance with the findings of other researchers such as Musivand [12], Noori&Amiri [15], Fahandezh [5].

Field studies conducted in the area reveal that this section of the sedimentary basin of southern Sanandaj-Sirjan has been extremely active during the Devonian to Carboniferous and left behind clastic sediments. Later on, these sediments were accompanied by submarine basaltic eruptions. Then after metamorphism during either Hercynian [25] or former Cimmerian [24], Surian metamorphic complex was formed with a thickness of 3750m. This metamorphic complex is associated with the copper mineralization in parts of its outcrop area such as [20-25]. Field evidences suggest that

Fig. 5. The contact region of marbles of Tootak complex (TMC) with schists of the Suriyan complex (SSC) in the east of Mazayjan, view towards east.

Fig. 6. Greenschist of Surian complex Outcrop in north of Mazayjan.

Fig. 7. Copper mineralization as chalcopyrite in metabasites of the Suriyan complex in Mazayjan area.

Fig. 8. Malachite mineralization in oxidation zone of Mazayjan Cu deposit, greenschist of Suriyan metamorphic complex was host rock of this mineralization.

Mazayjan copper deposit was formed in a volcanic–sedimentary environment. Comparing with the origin of copper deposits, it reminds massive sulfides where high volume of submarine eruptions is associated with clastic sedimentary rocks. Another important observation in the Mazayjan is that specific alteration of massive sulfide deposits such as sericitization and chloritization is scarce or can be seen on a small extent, indicating these massive sulfide deposits are close to besshi type [13-15]. Occurrence of regional metamorphism after the alteration in besshi deposits is the reason for less exposure of altered rocks. Formation of iron hat or gossan in the upper part of studied basic schists is one of the special effects of alteration in Mazayjan area (Fig.9). Based on the studies in this iron hat, which represents supergene oxidant zone, a variety of secondary minerals such as malachite, chrysocolla, hematite, goethite and limonite have been formed. During the field studies, Iron hat is very important in identification of metal impregnation areas.

STUDY METHODS

First, Stratigraphic column of the study area was mapped to determine the rock units and their relationship in the field. Thin sections were prepared from hand samples and studied using Nikon polarizing microscope. During microscopic experiments, mineralogical and texture studies, were implemented while suitable samples were separated for detection and analysis device tests. Chemical analysis XRF and ICP was done by Kansaran Binalud Company.

After reviewing the regional studies, field surveys and samplings were carried out and then office studies were begun.

Fig. 9. Metabasites with chlorite alteration in greenschist of Suriyan complex.

Microscopic studies

This study has several major goals: detection of metallic and non-metallic minerals and exploring their relationship, identification of available textures, naming rocks, examination of rock alteration phenomenon in order to determine the origin of copper mineralization in the area, and selection of suitable samples for analysis device. All these items are presented separately.

Non-metallic minerals

Suriyan metamorphic complex metabasites are introduced as the host rock of copper mineralization; therefore, it is expected that most non-metallic minerals observed in thin sections include: Plagioclase (sometimes with sericitic alteration), tremolite–actinolite (occasionally chloritized), calcite, biotite and quartz (Fig.10). The integration of this mineralogy complex indicates minerals of greenschist facies that have experienced some alteration phases. Based on study of polished sections, opaque minerals presented in this set are pyrite and chalcopyrite.

Fig. 10. Limonite with goethite and other iron oxides in a samples of rocks in oxidant supergene zone (gossan or iron cap) in Mazayjan area.

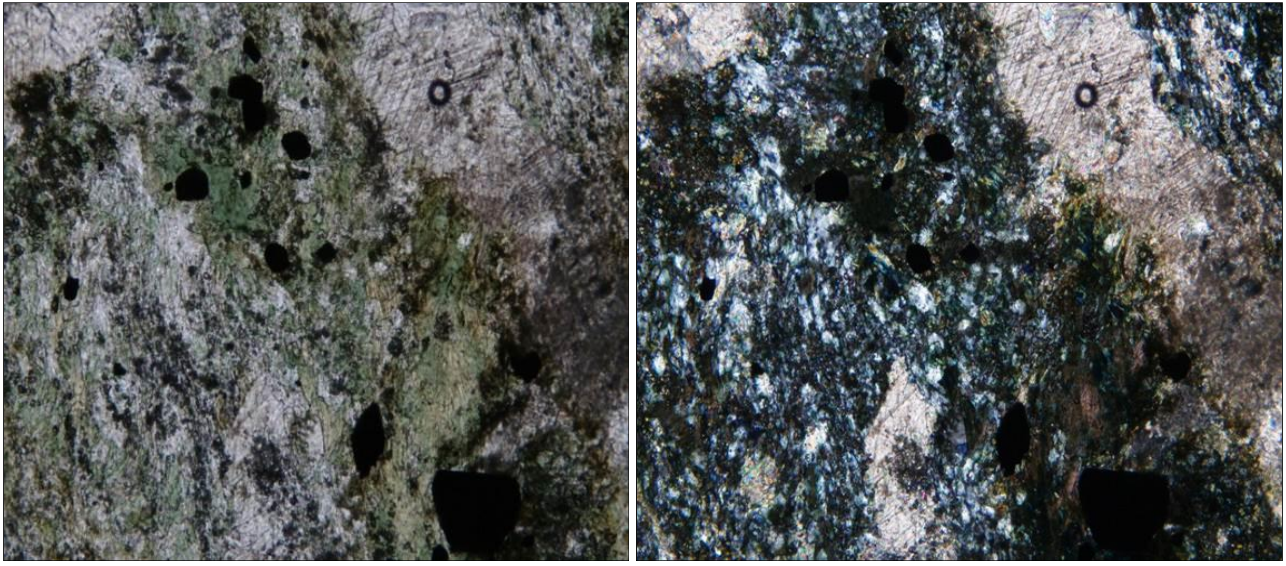
Metallic minerals:

Chalcopyrite, pyrite, marcasite, covellites and iron oxides are the most important metallic minerals found in rocks of this region.

Chalcopyrite. Chalcopyrite is the most important mineral containing Cu at Mazayjan area. Its dimension is usually about 20 to 50 microns, and its abundance is between 5 to 10 percent. In some sections, chalcopyrite has been observed as inclusions within pyrite and these two minerals, together, show the layered texture (Fig.11).

Moreover, growth of sulfides, in some cases indicates massive texture for them (Fig. 12). Both of these textures are important in determining the origin of these deposits.

Fig. 11: Accompanied by chlorite (Chl), plagioclase (Pl), calcite (Cc) whit opaque minerals in Suriyan basic schists.



Pyrite

Pyrite is the most common sulfide mineral of Suriyan basicschists in Mazayjan area. The abundance of this mineral is about 5 to 20 percent. Dimensions of pyrite is about 10 to 200 microns, rarely appears up to 2 mm in size (Figs. 11, 12, 13). The difference in grain size of pyrite in basicschists of Mazayjan area represents the graded bedding phenomenon which is commonly observed in the other massive sulfide deposits [20]. This phenomenon in pyrite is assumed to be related to periodic changes in super saturated degree of fluids at the time of discharge at the sea floor [20]. Pyrites observed in the Mazayjan area are mainly in the form of a banded texture (Fig.11) and in some cases sparse texture (Fig.13). In both cases, they usually show forms of brecciations.

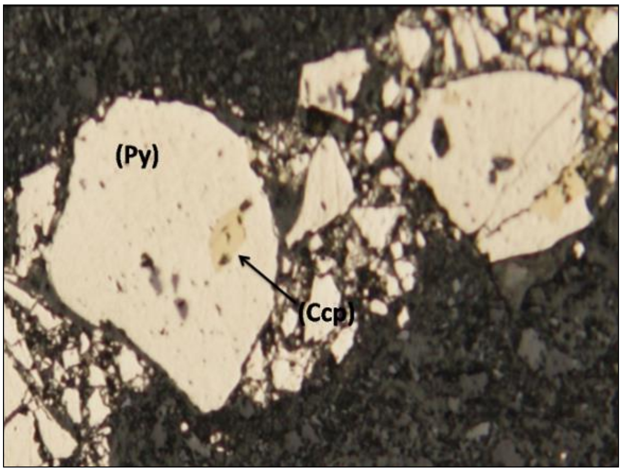


Fig. 12. Shearing bedded texture in Pyrites (Py) of Suriyan basicschist, Mazayjan. Pyrite crystals in this section contain inclusions of chalcopyrite (Ccp).

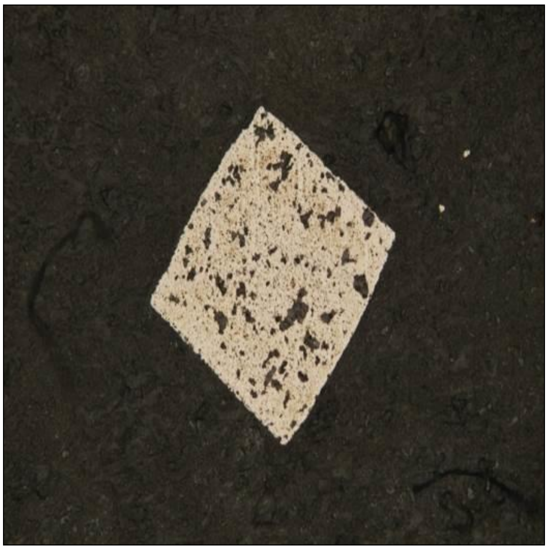


Fig. 13. Delayed crystallization of chalcopyrite compared whit Suriyan basicschists, Mazayjan area.

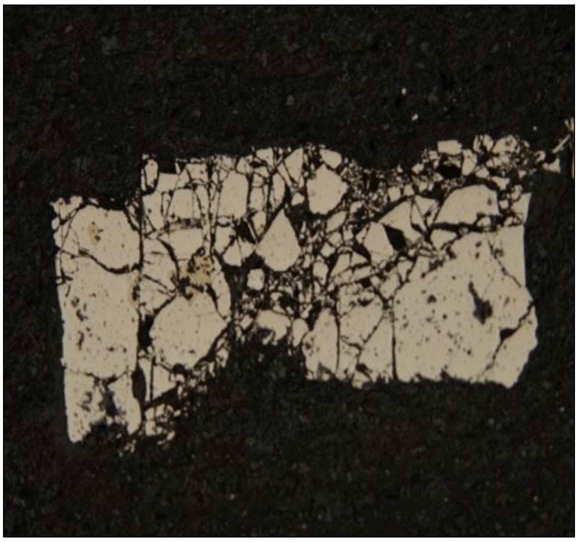


Fig. 15. Marcasite crystals with inclusions of chalcopyrite in Mazayjan metabasites.

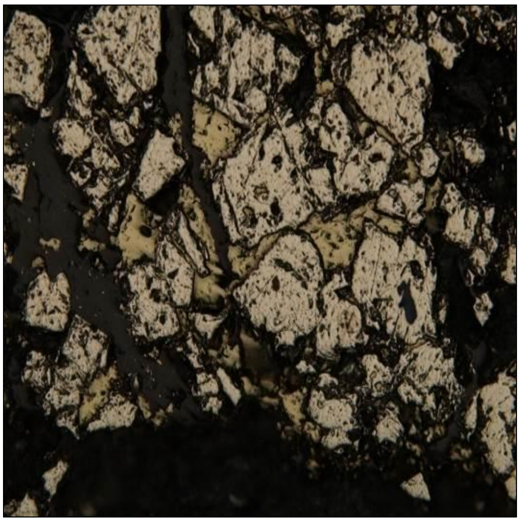


Figure 14: Pyrite automorph crystal with traces of embayment in Mazayjan basicschists

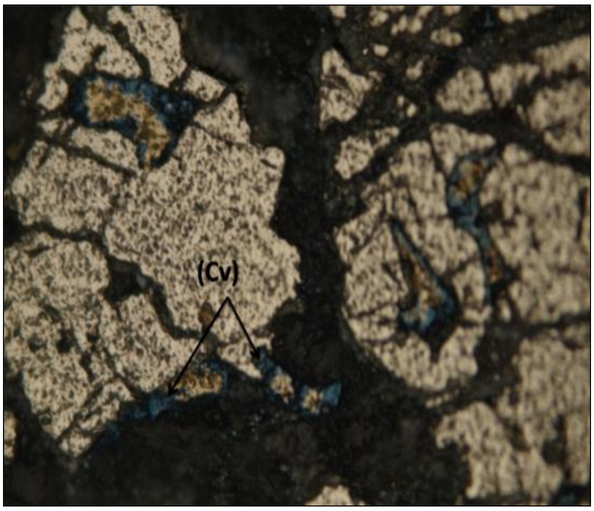


Figure 16: Chalcopyrite mineral is converted toc Covellite (Cv) in Mazayjan Basic schists.

Marcasite

In polished sections can be seen as rectangular-shaped crystals, retaining crushing traces and cataclastic textures created by tectonic forces (Fig.15). Marcasite abundance is about 2 to 4 percent. Presence of chalcopyrite inclusions is another characteristic of this mineral. Formation of marcasite instead of pyrites in Mazayjan schist, is related to decrease in temperature during crystallization of iron sulfides. Based on Deer et al. [4] marcasite has a lower crystallization temperature comparing to pyrite.

Covellite

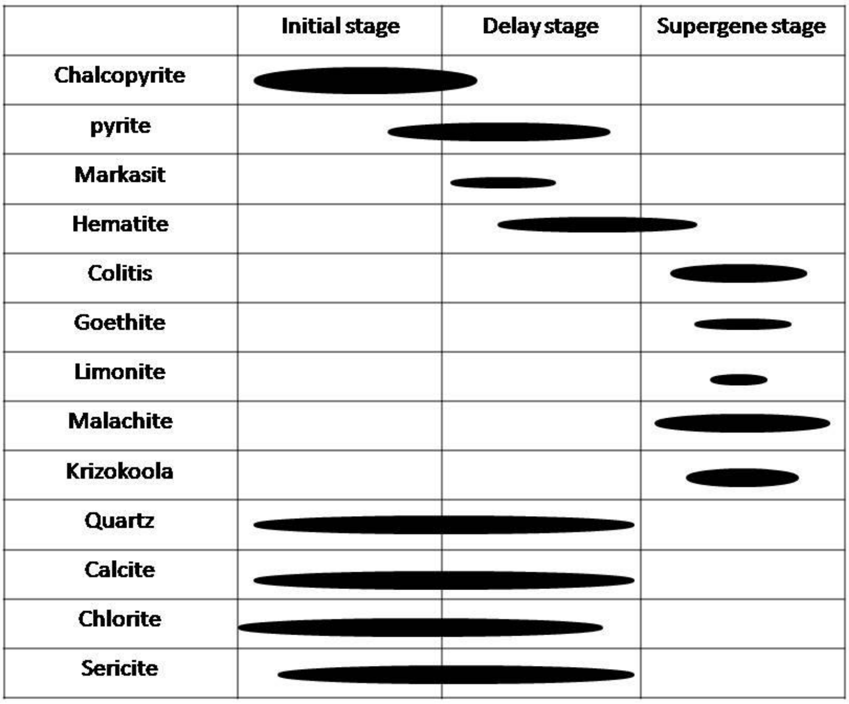
Covelliteis is formed as a secondary mineral because of the conversion of chalcopyrite, so often appears in the form of chalcopyrite as a pseudo-morph (Fig.16). Also, Covellites as a secondary mineral can grow into empty spaces. Its abundance is up to 3 percent in some sections.

Minerals of supergene zone

Malachite is the most important secondary mineral containing Cu in Mazayjan area. Its characteristic color is a great clue to identify areas of copper dissemination in the field. In thin sections, it fills fractures and pore spaces irregularly (Fig.17). This mineral is often associated with hematite and chrysocolla and is indicator of minerals of supergene zone.

In Fig.17 Chrysocolla shows banded colloidal texture, while hematite has a concentric colloidal texture in some sections of supergene zone rocks (Fig.18). But in both cases, it is assumed that colloidal texture is an indicative of rapid deposition of material from super saturated fluids during their mixing with the sub saturated fluids.

Table 1: Paragenetic sequence of minerals in Mazayjan copper index, according to microscopic studies



	Initial stage	Delay stage	Supergene stage
Chalcopyrite	▬	▬	
pyrite	▬	▬	
Markasit		▬	
Hematite		▬	▬
Colitis			▬
Goethite			▬
Limonite			▬
Malachite			▬
Krizokoola			▬
Quartz	▬	▬	
Calcite	▬	▬	
Chlorite	▬	▬	
Sericite	▬	▬	

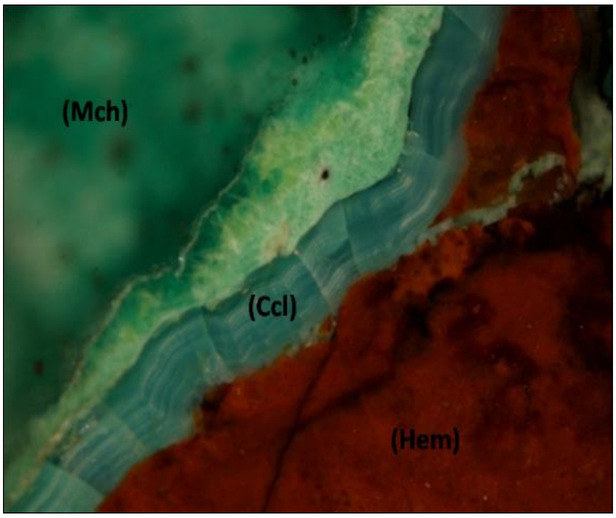


Fig. 17. Accompanied malachite (Mch) whit chrysocolla (Ccl) and hematite (Hem) in the rocks of iron hat zone in Mazayjan area.

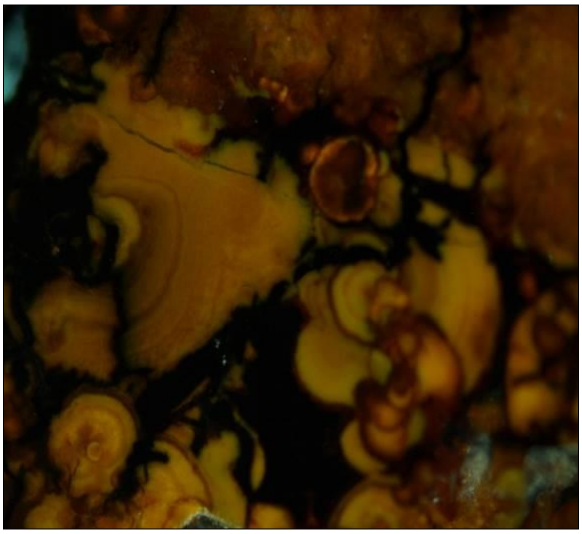


Fig. 18. Concentric colloidal texture in hematite, supergene zone of Mazayjan copper index.

Paragenetic sequence of minerals

Table 1 shows paragenetic sequence of minerals extracted from microscopic studies of Mazayjan area. Since chalcopyrite has been seen commonly as inclusions within other minerals such as pyrite and marcasite, it is related to the first stage of crystallization. In the next step, pyrite and marcasite are formed and then, secondary supergene minerals such as covellitis, malachite and chrysocolla are developed. Secondary silicate minerals such as quartz, calcite, chlorite and a bit later sericite are formed in the early and late stages and show simultaneous crystallization with sulfide. minerals in the area. They can be considered as a guide for exploration operations

Geochemical studies

Geochemical studies include analysis of 6 samples to determine the abundance of major and minor elements using XRF (Table 2), 4 samples to determine the abundance of major, minor and trace elements using ICP (Table 2) and 7 samples to perform Point analysis identification (EPMA). The results of this data processing are presented as follows.

Table 2. Chemical analysis results (XRF& ICP)

Sample		**B2S16**	**B2S8**	**B5S13**	**B5S1**	**S10**	**S9**	**Sample**	**S1**	**S2**	**S4**	**S6**	**S7**	**B1S32**	**B1S6**	**B1S38**
XRF		◐	⬓	◧	◓	⬒	◨	**ICP**	□	■	+	×	▲	△	◑	◒
SiO2		45.11	46.57	48.68	49.12	61.15	48.75	**Ag**	0.11	0.16	3.7	0.19	1.6	0.17	0.15	0.17
TiO2		2.540	1.303	1.460	1.312	0.554	0.667	**Al**	73213	68957	11487	17081	22785	76871	54331	73376
Al2O3		12.35	14.88	13.25	14.35	16.87	15.65	**As**	5.9	1.7	1.8	6.5	2.1	1.8	2.3	1.8
Fe2O3		17.45	12.40	14.52	9.85	7.84	7.66	**Ba**	53	56	14	17	14	41	49	170
MnO		0.256	0.285	0.233	0.265	0.033	0.051	**Be**	0.3	0.2	<0.2	<0.2	<0.2	0.3	0.3	0.2
MgO		7.85	7.59	6.22	6.98	1.85	1.96	**Bi**	0.43	0.38	0.88	0.45	0.69	0.41	0.41	0.44
CaO		7.71	9.35	10.58	10.96	2.52	9.85	**Ca**	53823	69103	1391	2319	3535	75657	101071	42088
Na2O		0.82	1.84	1.67	2.64	3.05	0.93	**Cd**	0.25	0.23	1.9	0.23	3.6	0.24	0.24	0.24
K2O		0.45	0.16	0.15	0.03	1.70	2.53	**Ce**	14	11	2	5	4	16	11	9
P2O5		0.307	0.099	0.104	0.083	0.149	0.158	**Co**	188	149	218	540	324	32	41	33
SO3		0.429	0.001	0.328	0.001	0.002	1.248	**Cr**	127	111	19	38	31	193	98	174
LOI		4.40	5.02	2.33	3.86	4.05	10.28	**Cu**	14566	16542	117287	6974	54052	104	35	133
Cr (ppm)		37	173	105	197	8	24	**Fe**	66057	63934	15702	153765	119335	49945	44996	56592
Ni (ppm)		55	138	74	114	35	50	**K**	1449	1709	122	403	106	1630	1864	3724
Co (ppm)		1	3	2	5	6	4	**La**	5	5	1	6	2	8	4	4
V (ppm)		446	224	286	218	145	166	**Li**	10	9	4	9	9	11	16	16
Zn (ppm)		159	73	82	74	69	59	**Mg**	19235	17101	7985	10305	13104	18045	15853	20753
Rb (ppm)		17	17	16	16	50	73	**Mn**	2070	1968	157	331	581	922	1575	807
Cl (ppm)		54	56	62	58	58	56	**Mo**	0.83	0.89	1.1	1.05	1	1.01	1.13	1.01
Ba (ppm)		126	56	51	91	116	69	**Na**	11785	7841	188	216	268	13500	8776	12267
Sr (ppm)		128	237	179	253	247	376	**Ni**	409	76	89	35	64	97	37	33
Cu (ppm)		76	76	62	100	73	85	**P**	691	553	747	261	489	663	526	375
Pb (ppm)		10	9	13	4	11	12	**Pb**	5	5	14	15	7	6	6	6
Ce (ppm)		3	23	17	31	4	38	**S**	138	151	125547	195341	86837	970	5603	7289
La (ppm)		1	10	7	15	1	17	**Sb**	1.11	1.02	1.08	1.08	1.02	1.03	1.03	1.19
W (ppm)		7	6	5	3	1	9	**Sc**	37.4	31.4	7.3	10	13.4	28.7	29.6	37.2
Zr (ppm)		132	107	84	89	103	125	**Sn**	3.5	3.1	4.1	4.1	3.4	3	2.9	3.2
Y (ppm)		39	22	22	15	23	33	**Sr**	121	173	11	4	11	352	207	133
As (ppm)		137	65	9	75	21	90	**Th**	5.3	6.2	2.9	3.4	3.2	6.1	6.3	5.6
U (ppm)		3	4	2	6	5	3	**Ti**	8659	7271	1282	1833	2524	7624	5368	4422
Th (ppm)		1	2	3	5	3	2	**U**	2.7	1.8	3.3	3	2.4	2.5	19	2.8
Mo (ppm)		2	4	3	6	2	3	**V**	301	274	44	81	100	199	145	245
Ga (ppm)		16	13	15	14	17	17	**W**	5.39	6.77	5.98	1.03	16.56	6.67	7.48	4.12
Nb (ppm)		32	25	23	21	32	25	**Y**	34	36	8	7	14	24	24	18
								Yb	4.3	4.3	1.6	1.6	1.9	3	2.9	2.6
								Zn	189	185	946	102	955	60	47	77
								Zr	60	54	27	33	31	77	29	36

RESULTS

Chemical analysis results of XRF and ICP:

The mean frequencies of major elements of Mazayjan area are listed in table3. It can be seen that the mean frequency of copper in the analyzed samples is 2.62%. This value is considered purely economical for other massive sulfide deposits which are similar to Mazayjan area, and hence reminds the necessity to complete the exploratory studies in the area.

Table 3. Mean frequency of the major metal elements.

Mean frequency in ICP	Element name
2.62%	Cu
7.13 %	Fe
0.03%	Zn

The results were processed using Minpet software. At first, basic schists were named. These rocks generally sit in the range of basalt and sometimes andesite (Fig.19). It is confirmed by assuming that studied basic schists are sourced from submarine basaltic eruptions.

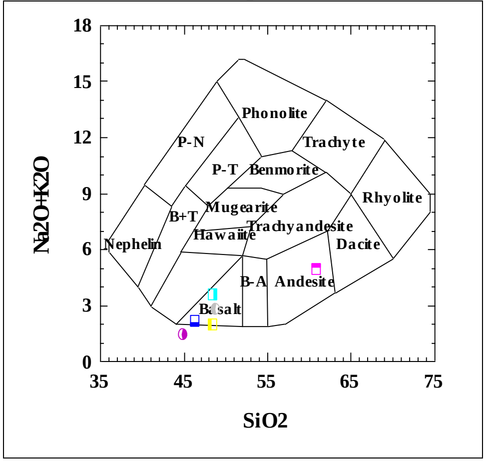


Fig. 19. Position of studied rock in (Base graph of Cox *et al.* [3])

[24-25] are used to determine the magma series. Based on these charts, studied rocks are located within the sub-alkaline and tholeiitic zones (Figs. 20, 21). Since oceanic crust is the origin of these rocks, the identified magma series would be correct.

Another important note in the geochemical study of these rocks is determination of their tectonic environment. After applying necessary corrections to the percentage of iron oxides using the Irvine and Baragar method, tectonic environment of Mazayjan basic schists were determined using the chart of Pierce *et al.* [17], (Fig.22). On this basis, environment of studied rocks is within the range of mid-oceanic and oceanic islands. This environment is consistent with Mazayjan field observations, because shows accompaniment of hosted copper basic schists with metamorphosed clastic rocks. On the other

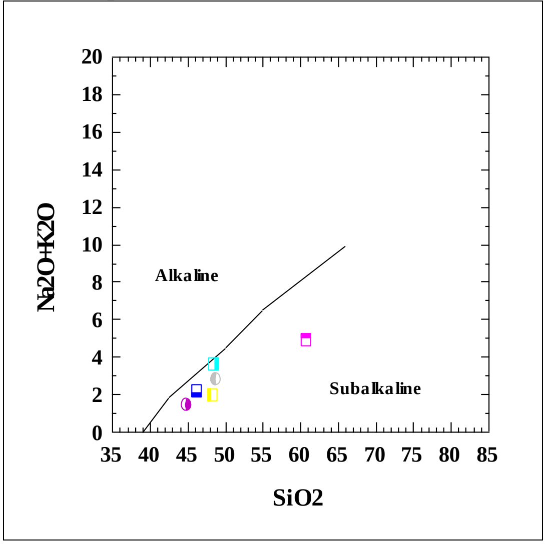


Fig. 20. Position of studied rock in Irvin and Baragar chart (1971).

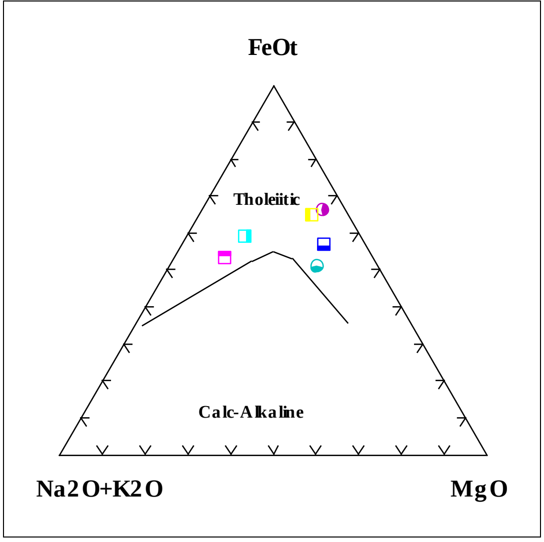


Fig. 21. Position of Mazayjan basicschists in Irvin and Baragar chart (1971) to determine the magmatic series.

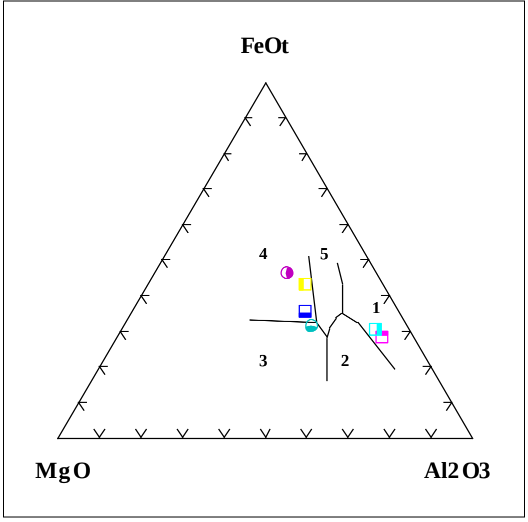


Fig. 22. Position of Mazayjan basic schists in oceanic environments (MORB and oceanic islands) in Pierce and et al chart (1997).

hand this could represent relationship between Mazayjan copper deposits with oceanic sedimentary basins similar to massive sulfide deposits. In order to study distribution of trace element, abundance of these elements in studied rock samples were normalized relative to the oceanic crust and the spider diagram was drawn (Fig. 23). The diagram shows that in comparison with the abundance of elements in the oceanic crust, abundance ratio of most normalized minor elements in the Mazayjan basic schists are in the range of 1. This fact points to their common origin. Based on these spider diagrams, one can conclude that the basic schists which hosted copper mineralization in Mazayjan area are similar to oceanic crust basic rocks in terms of distribution of trace elements.

Abundance of element such as Rb, Th and U relative to normalized oceanic crust (Figure 23), is higher. Considering the lithophile geochemical behavior of these elements and their low concentration in the oceanic crust, this situation can be explained as a result of the impregnation of these samples.

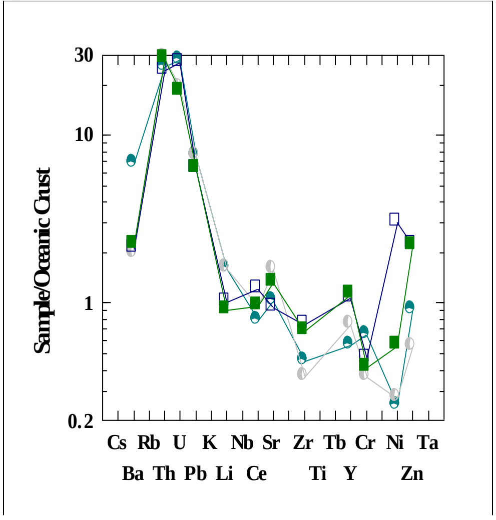


Fig. 23. Spider diagram of trace elements frequency of normalization studied rocks relative to the oceanic crust.

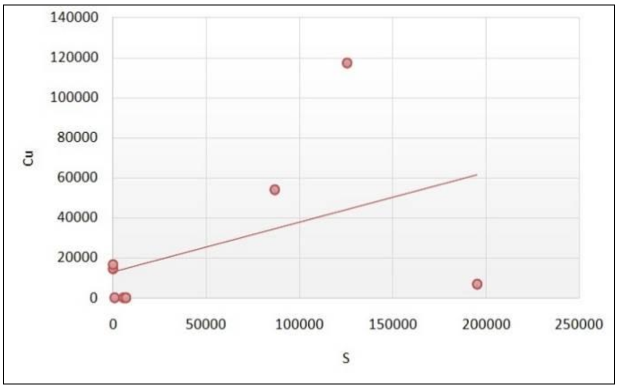


Fig. 24. Correlation chart of copper- sulfur for Basicschists, host of Cu mineralization in Mazayjan area.

Correlation charts between copper and iron with sulfur were drawn using the results of chemical analysis of samples (Figs. 24-25). As one can see correlation between metals with sulfur is a strong and positive value. Both copper and iron elements are concentrated in sulfide phases such as pyrite and chalcopyrite. The idea is completely consistent with the results of microscopic studies and point analysis.

Results of EPMA point analysis

Microscopic studies and device analyses showed that Pyrite and chalcopyrite are the main phases of metallic minerals in the study area. At the next stage point analysis started on these minerals. The current study follows several major goals: First, accurate determination of chemical and mineralogical composition of the main metallic mineral phases; Second, identification of probable inclusion minerals in major phases; third, identification of probable precious elements present in the primary phase.

Sample No. 891-MZ4 is one of the pyrite samples studied using probe analysis. In order to accurately identify the chemical composition of

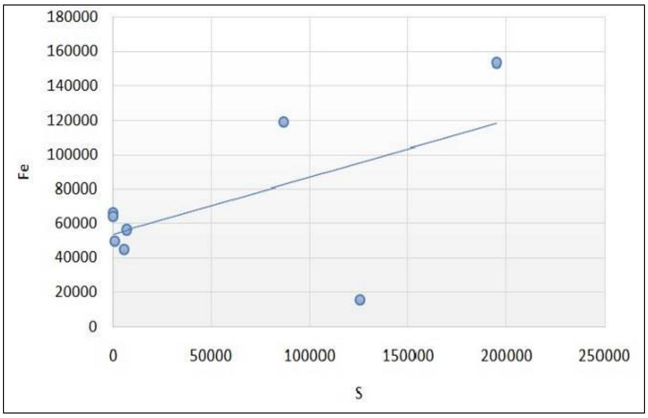
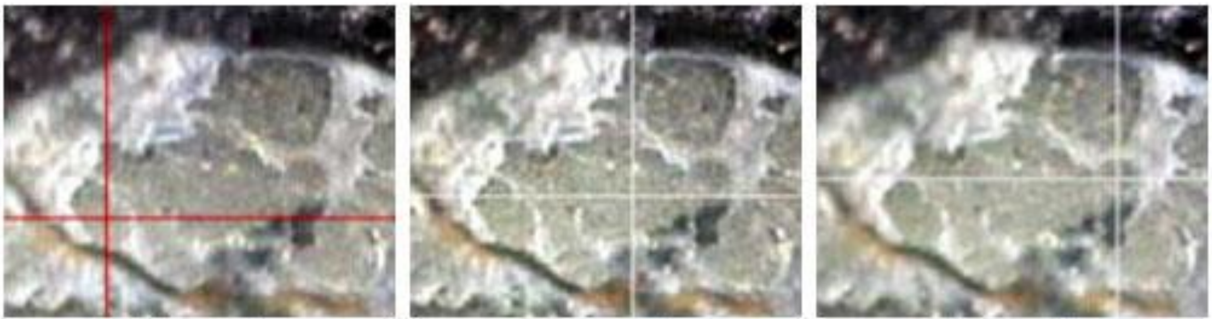


Fig. 25. Iron–sulfur correlation diagram for Mazayjan studied samples

mineral and potential zonings, three points were analyzed. Point 1 is located in the center and points 2 and 3 are at the margins of mineral (Fig.26).

Concentrations of iron and sulfur elements are lower in the margin and higher in center. It may be related to the alteration processes because these processes generally begin from margin of mineral.



Formula	Mass[%]	Molecule[%]
Al_2O_3	5.13	2.14
SiO_2	7.55	5.35
S	46.13	61.24
K_2O	0.11	0.05
CaO	0.45	0.34
TiO_2	0.29	0.15
Fe	40.12	30.58
Ni	0.12	0.08
Cu	0.06	0.04
Zn	0.03	0.02
ZrO_2	0.01	0.00

Formula	Mass[%]	Molecule[%]
Al_2O_3	1.14	0.46
SiO_2	1.55	1.05
S	50.33	64.15
K_2O	0.01	0.00
CaO	0.25	0.18
TiO_2	0.00	0.00
Fe	46.29	33.87
Ni	0.31	0.21
Cu	0.08	0.05
ZrO_2	0.04	0.01

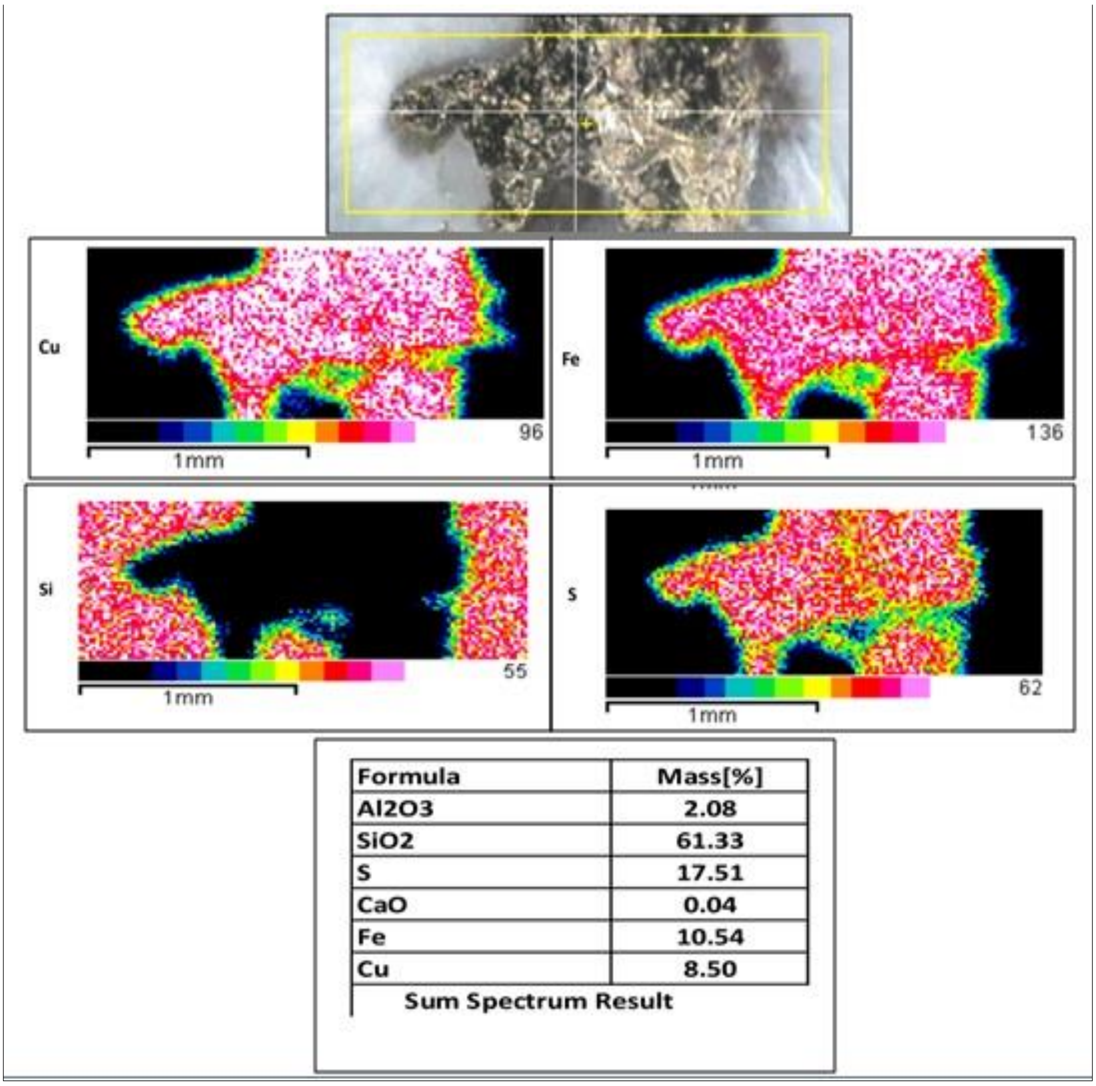
Formula	Mass[%]	Molecule[%]
Al_2O_3	6.43	2.80
SiO_2	15.7	11.58
S	40.61	56.15
K_2O	0.16	0.08
CaO	0.59	0.46
TiO_2	0.00	0.00
Fe	35.96	28.54
Ni	0.18	0.13
Cu	0.35	0.25
ZrO_2	0.02	0.01

Fig. 26. Electron probe micro-analysis (EPMA) in a sample of pyrite from Mazayjan area in a central point and two marginal points.

Concentration of valuable elements such as copper, nickel and cobalt is low. Another important observation is that there is not any specific zoning among the present elements. This indicates the influence of metamorphic processes on pyrites of Mazayjan area. It has been proved that recrystallization processes due to metamorphism eliminate the combination zoning and homogenization of sulphides which generally have primary combination zoning inherited from environmental conditions and several physico-chemical changes (Mizuta, 1988).

The lack of combination zoning in the pyrites of Mazayjan area suggests that this mineral in terms of age has formed before taking place of metamorphic processes in the area. In the other words, metamorphism of plates and basic rocks has occurred after formation of pyrite. As a supplementary confirmation it worth mentioning that chalcopyrite samples of studied area also don’t have combination zoning (Fig.27).

In case of S-16 sample, as the backscatter images show, the context of studied mineral consists of sulfur, iron and copper without any regional structure. The chemical composition of mineral is quite uniform and homogeneous. It should be noted that marginal regions of the S-16 sample in (Fig.27), show a weak zoning, which can be due to the occurrence of subsequent alteration and contamination. With this reasoning, one can conclude that metamorphism processes are not responsible for copper mineralization in the Mazayjan area, but have led to some other subsequent changes such as homogenization. According to the probe studies, valuable elements have not been observed as impurity in pyrite and chalcopyrite samples.



Formula	Mass[%]
Al2O3	2.08
SiO2	61.33
S	17.51
CaO	0.04
Fe	10.54
Cu	8.50

Sum Spectrum Result

Fig. 27. Back scattering images and probe point analysis in a chalcopyrite (samples of Mazayjan area).

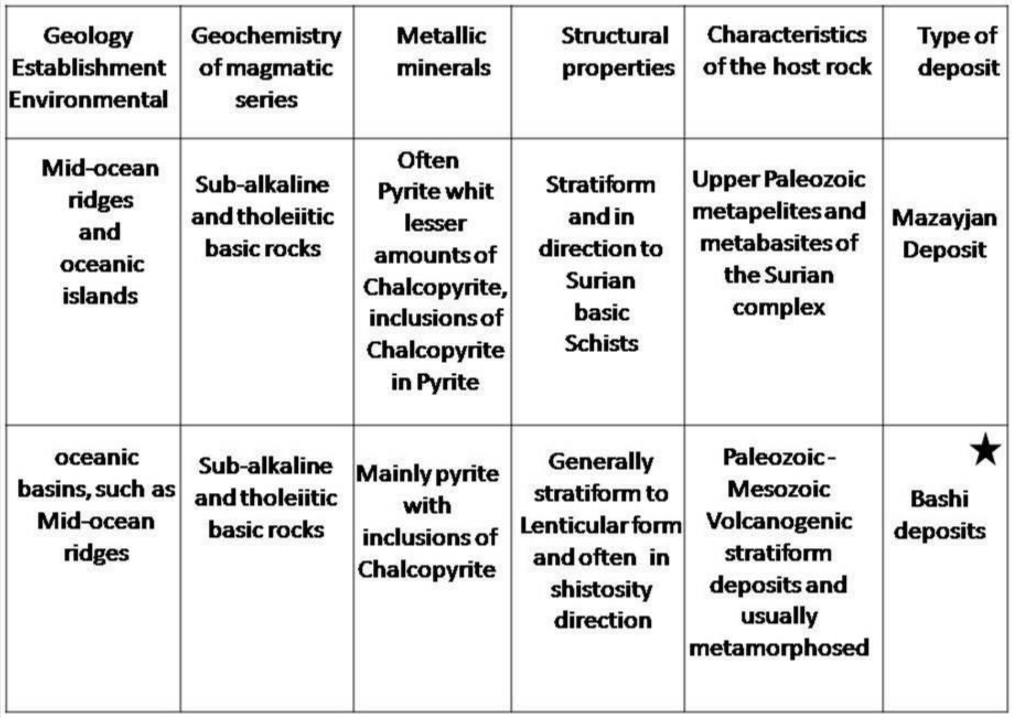
Comparing characteristics of Mazayjan copper deposits with various massive sulfide deposits suggest that this deposit is very similar to besshi type massive sulfide deposits (Table 4). Some of these characteristics include the geological environment, geochemistry of magmatic series in Mazayjan deposit, lithological conditions, mineralogy and mineralization of the region. Therefore the origin of Mazayjan deposit can be included in massive sulfide deposits Sanandaj-Sirjan structural province of Iran.

DISCUSSION AND CONCLUSIONS

The most important results of the current study can be summarized as follows:

- Metamorphosed basic rocks such as green schist and amphibolite are host of Cu mineralization in Mazayjan area. These rocks and metapelitic rocks such as micaschist and phyllite all together, form Suriyan metamorphic complex. So, the geological environment of host rock for Cu mineralization in Mazayjan area can be assumed to be the ocean floor basic eruptions similar to massive sulfide deposits.
- The most important metallic minerals identified in the study area are pyrite, chalcopyrite and covellite. These minerals in addition to other minerals such as chlorite, calcite and epidote make up the Suriyan complex metabasites. Secondary minerals such as malachite, chrysocolla, limonite and goethite were also observed in gossan zone.
- Geochemical studies showed basic rocks which are generally in the range of basalt and some in the range of andesite, are considered as sub-alkaline rocks and imply oceanic environments (MORB and oceanic islands). Spider diagrams prove the latter issue.
- According to probe studies, pyrite and chalcopyrite samples have a uniform chemical composition. This suggests the influence of metamorphic processes on the studied samples, and is interpreted as the time of copper mineralization in Mazayjan, has been earlier than the time of metamorphism in the area.

Table 4: Comparative study of Mazayjan copper deposit whit besshi type massive sulfides.



Geology Establishment Environmental	Geochemistry of magmatic series	Metallic minerals	Structural properties	Characteristics of the host rock	Type of deposit
Mid-ocean ridges and oceanic islands	Sub-alkaline and tholeiitic basic rocks	Often Pyrite whit lesser amounts of Chalcopyrite, inclusions of Chalcopyrite in Pyrite	Stratiform and in direction to Surian basic Schists	Upper Paleozoic metapelites and metabasites of the Surian complex	Mazayjan Deposit
oceanic basins, such as Mid-ocean ridges	Sub-alkaline and tholeiitic basic rocks	Mainly pyrite with inclusions of Chalcopyrite	Generally stratiform to Lenticular form and often in shistosity direction	Paleozoic - Mesozoic Volcanogenic stratiform deposits and usually metamorphosed	★ Bashi deposits

* Gibson *et al*. [8]

- For various reasons, environmental conditions of Mazayjan copper deposit, is similar to massive sulfides conditions. First, eruptive basic rocks in the sedimentary basins have been host of copper mineralization, and due to metamorphism transformed to metabasites afterwards. Second, metallic minerals are limited to sulfide minerals such as pyrite, chalcopyrite and covellite and Mazayjan deposit has a simple mineralogy composition. And third, elements such as copper and iron have been positively correlated with sulfur. This behavior comes from geochemical characteristics of massive sulfides.
- In terms of comparison, characteristics of Mazayjan copper deposits are close to besshi type massive sulfide deposits. This comparative study has been shown in Table 4.

Acknowledgements. *This paper represents a part of results obtained from the research project of "Study of Copper mineralization in Bavanat region" which has been approved and performed in the Research deputy department of Islamic Azad University of Shiraz. We are grateful from partners in this department. We also acknowledge Dr. Mosayeb Sabzeie for his comments on the improvement of interpretations*.

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