Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2016/01/jls.htm
2016 Vol. 6 (S1), pp. 194-205/Najmi et al.
Research Article

REVIEW OF GEOLOGY AND GEOCHEMICAL EXPLORATION IN GOLCHESHMEH COPPER DEPOSIT, SOUTH OF NEYSHABOUR (NE OF IRAN)

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ABSTRACT
The Golcheshmeh copper deposit is located NE of Iran (south of Neyshabour) at the margin of Sabzevar Structural Zone. Based on geological and laboratory studies, the out cropped rocks consist of Eocene volcanic rocks such as andesite, basaltic- andesite and basalt that associated with the sedimentary and volcano sedimentary rocks including limestone, tuff and breccia. The alteration is hosted andesitic layers that includes carbonatization, propylitic and less argilic and sericitic. The carbonatization zone is the most important alteration in this area. Mineralization mainly occurs in relative Eocene age volcanic rocks as vein- veinlets, amygdaloidal fillings and some replacement and disseminated styles. According to the minerallography studies, the main ores containing copper are divided into types oxide and sulfide. Mineralization mainly consists of oxide phases and can be seen as contamination of surface fractures and pores or voids filler in host rocks. The main oxide minerals are malachite, azurite and chrysocolla and sulfide minerals are chalcocite, covellite, with some minorpyrite, chalcopyrite, bornite, digenit and also native copper. Chalcocite is the most abundant ore sulfide in this area. Chalcocite is the main sulfide ore in this region. There are probably two generations of them, the first generation is a primary ore that was formed directly in joints, cracks, and fractures from the ore-containing solution and is currently changing into covellites in some places; and, the second generation is chalcocite that was probably formed from the conversion of bornite and chalcopyrite through substitution and under supergene conditions. In most cases, the observed intergrowth between copper ores suggests the multi-stage mineralization in this region. Geochemical studies based on minor and trace elements obtained from this research indicate that the igneous rocks in this region are of the calc-alkaline basalt characteristics and, in terms of tectonic setting, could be attributed to subduction zone-related continental arc magmatism. Moreover, based on the performed geochemical analyses, the copper grade in the region varies from 13668 to 164000 g/ton, with iron anomalies seen therein. Based on identified characteristics this deposit is comparable to Man to and Keweenaw (Michigan) mineral types deposit.

***Keywords**: Golcheshmeh, Chalcocite, Andesite, Altration, Mineralization, Cu-Manto, Neyshabour*

INTRODUCTION
The Golcheshmeh copper deposit is located in the Center of Iran basin (Sabzevar Structural Margin Zone), approximately 220km SW of Mashhad and 40 km south of Neyshabour (Longitude 58° 42′ 09″ - 58° 44′ 48″, Latitude 35° 50′ 36″ - 35° 48′ 59″). The effects of the Alpine-Himalayan orogeny observed in many regions of Iran and Turkey have caused the interlocking of Kimmerian blocks in various areas. Central Iran is one of these blocks that, based on the classification introduced by Stockline and Nabavi (1972), is bounded by the Alborz Zone in the north, the Sanandaj-Sirjan Zone in the west, and by the Eastern Iran Zone in the east. The Golcheshmeh study area is also a part of this block, and is situated along the Sabzevar Margin Zone and north of the Great Dorouneh Fault (Figure 1) (Stocklin & Nabavi, 1972). Numerous magmatic activities of different eras can be seen in most structural zones of Iran. Plate convergences at the end of the Late Cretaceous Period, when the Neotethys Ocean’s path to Iran and Turkey was blocked, played an important role in the increased intensity of magmatism in the Eocene age

and formed numerous outcrops of igneous rocks in these regions. Subduction-related magmatism that happened from 35 to 50 million years ago was often accompanied by intrusive, shoshonitic volcanic and intermediate to acidic calc-alkaline rocks **(**Berberian & Berberian, 1981). The geochemistry of the rocks south to southeast of Neyshabur has been corresponded to that of the Urmia-Dokhtar Belt, and these rocks have been attributed to moderate to high-potassium series with calc-alkaline tendency and subduction-related continental arc magmatism (Ashraf Pour, 2007). The study conducted on volcanic and granitoeid rocks of the Arghash-Ghasem Abad region showed that the former were related to andesitic-basaltic rocks of the Golcheshmeh region and contained large quantities of Ba, Nb, and La, and showed depletion of the minor element Y, with S >500 and Ba>400 values indicating the presence of shoshonitic magmas (Alaminia *et al.*, 2013). The purpose of this study, prepare detailed geological, alteration and mineralization map with 1:5000 scales, review and details studies of geology, petrography, geochemistry, mineralization, mineralization type and to provide appropriate exploration model and compare that with similar deposits in other parts of Iran and other countries.

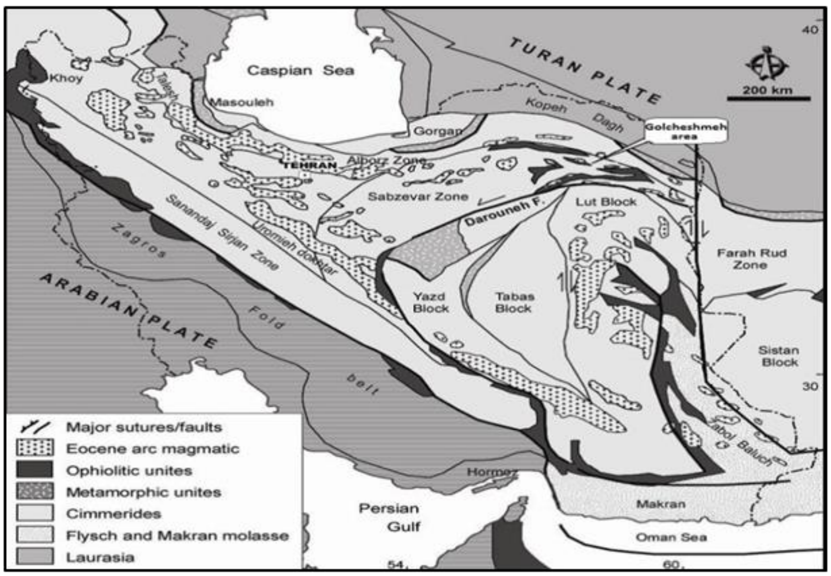

Figure 1: Simple Structural Map of Iran Sabzevar Zone has been Determined Location on the Study Area

MATERIALS AND METHODS

Methods

More than 50 polished slabs and thin sections were prepared from the volcanic rock samples collected from surface at the Golcheshmeh deposit for microscopic study. From these, 12 least altered samples were selected for bulk rock analysis.

Major elements were analyzed at the Iranian Mineral Processing Research Center (IMIDRO), on the 12 samples by XRF method. Employinga Magic Pro model analyzer manufactured by the Phillips Company in the Netherlands in which 15 grams of the powdered form of each of 12 samples were placed inside the instrument using the alkaline melting method.

Moreover, to carry out geochemical studies and analysis of rare earth and trace elements, eight of these samples were lithologically differentiated and sent to the SGS Laboratory in Serbia using the ICP-MS method for the analysis of 58 elements with a solvent (hydrochloric acid+?+Aqua regia). Geochemical studies on 15 debris samples taken from the trench localities and other exploration sites were carried out using the ICP-OES method.

Employing a sampling method for debris, the samples were taken at specified distances from the different parts of the mineral deposit including the trenches and other promising mineralization points. The samples were then ground and about 300 grams of each one were sent to be analyzed using the ICP-OES method at the Iranian Mineral Processing Research Center (IMIDRO).

RESULTS AND DISCUSSION

Results

3.1. Petrography

The volcanic rocks, the most dominant in the region and for this purpose, prepare the geology map with 1: 5000 scales (Figure2).

3.1.1. Limestone: This unit is outcropped in the eastern part of study area. In thin sections, this unit has Nummulitic microfossils with Mid-Eocene age (Figure 4-C & 3-A).

3.1.2. Agglomerate - Tuff: This unit is the low exposed is outcropped in central part of study area. In field study scales, this unit has andesitic parts from 1 to 10 cm in size (Figure 4-B).

3.1.3. Andesite: This unit is the most widely exposed volcanic rock in the study area. The main texture is porphyry and minor texture includes felti toglomerophyryin a fine grained matrix. It consists of ~ 20% phenocrysts, including 10–15 % plagioclase (variable from 1 to 7mm in size), <1 % K-feldspar, and <3 % opacitichornblende and omphacite pyroxene in a fine grained field. Accessory minerals are magnetite and zircon. This volcanic rock is extensively altered to carbonate, epidote, chlorite and clay minerals and minor sericite and iron oxide (Figure 4-A & 3-B).

3.1.4. Mega Andesite: This rock unit is outcropped in the central and western part of study area. In terms of mineralography mega andesite unit is similar to andesit. It consists of ~ 25% phenocrysts, including 10–15 % plagioclase (variable from 1 to more than 10 mm in size), <1 % K-feldspar, and <3 % opacitic hornblende and omphacite pyroxene. K-feldspars and plagioclases are weakly to moderately altered into carbonate and clay minerals (Figure 4-C).

3.1.5. Thrachyandesite: This unit is the low exposed and mainly is outcropped in central to southeast part of study area. The major texture is porphyry and minor texture trachytic. Phenocrysts~ 10 to 15% consisting of ~10 to12% K-feldspar (1 to 3mm), plagioclase (1 to 7mm), <3% opacitichornblende and omphacitepyroxene, also magnetite is the common accessory mineral.

In this rock unit, K-feldspars and plagioclases are weakly to moderately altered into carbonate and clay minerals (Figure 3-D).

3.1.6. Pyroxene Andesite: This unit is the widely exposed rock in the study area (same as andesite unit). Major texture is porphyry and minor are amygdaloidal and glomerophyry. Phenocrysts (≤ 15%) include~ 5 plagioclase (1 to 10mm), ~ 5 to 8% pyroxene (omphacite pyroxene, diopsid and augite) (0.5 to 5mm), <2% hornblende. Plagioclase and pyroxenephenocrysts are altered to carbonate, chloride and opaqe minerals (Figure 3-E).

3.1.7. Hornblendeandesite: This rock unit has a small outcrop where it occurs in the center and northwestern part of Golcheshmeh deposit. Main texture is porphyry and minor textures are amygdaloidal and glomerophyry.

It consists of ~ 10 to 15% phenocrysts, including 5 to10 % plagioclase (1 to 5 mm), 4 to 6 % opacitic hornblende (0.5 to 2 mm), < 2% pyroxene. Magnetite is a necessary mineral. Plagioclase and hornblendephenocrysts are altered to carbonate, epidote, chloride and opaqe minerals (Figure 3-F).

3.1.8. Andesite Basalt: This rock unit has a small outcrop in the eastern part of Golcheshmeh deposit next to limestone unit. The main textures are porphyry, amygdaloidal and glomerophyry. The phenocrysts consist of 5 to 10% plagioclase, ~ 5% iddingsitic olivine and <3% pyroxene (diopsid) (1 to 5mm, size of phenocrysts).

Pyroxene phenocrysts are altered to carbonate and minor chloride. Amygdals were filled by carbonate (Figure 3-G).

3.1.9. Basalt: This rock unit is the least exposed volcanic rock in northwest of the study area. Major texture is porphyry and contain <15% phenocrysts of plagioclase, pyroxene (augite, augite- diopsid), opacitic hornblende and iddingsitic olivine. Hornblende and pyroxene phenocrysts are altered to carbonate (Figure 3-H).

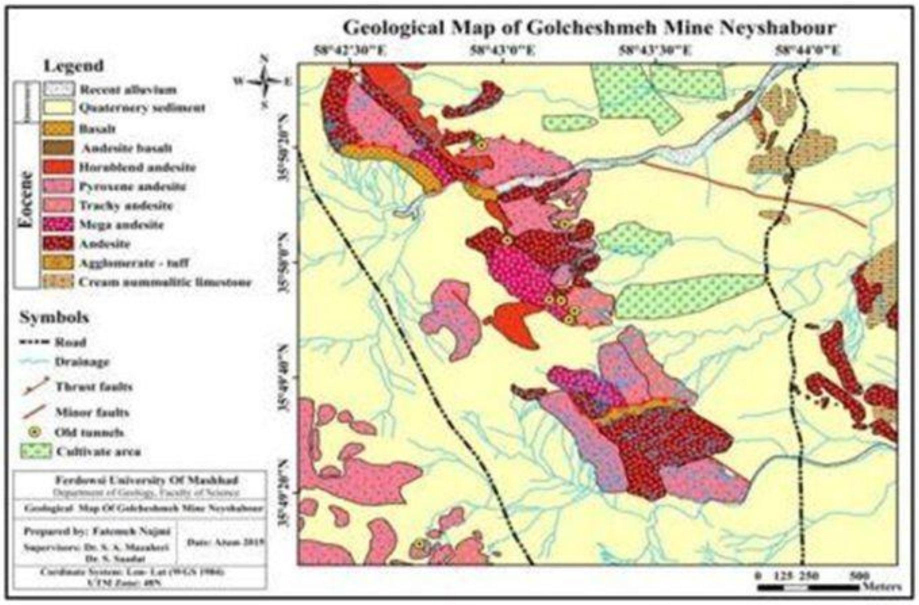

Figure 2: Geological Map of Golcheshmeh Area (1:5000)

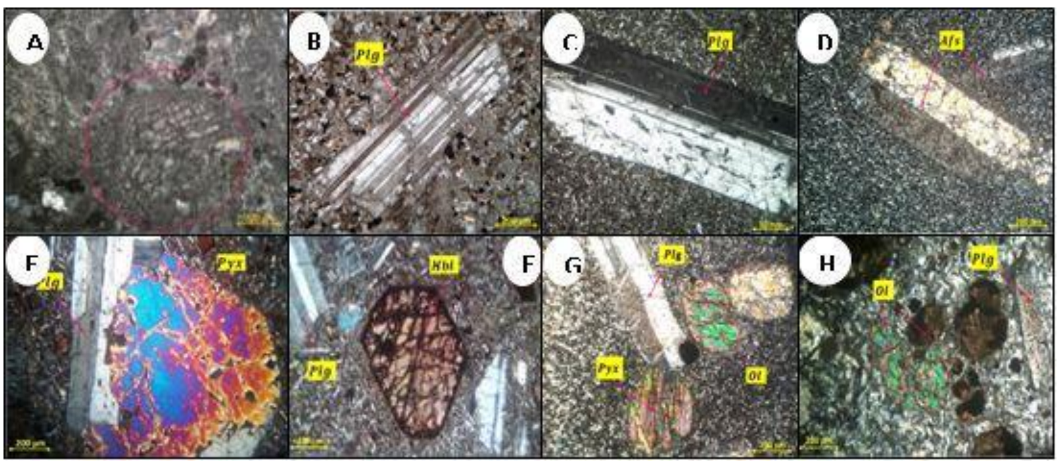

Figure 3: A: Limestone Unit with Nummulitic Microfossils; B: Andesite Unit; C: Megaandesite Unit; D: ThrachyAndesite Unit; E: Pyroxene Andesite; F: Hornblend Andesite Unit; G: Andesite Basalt Unit; H: Basalt Unit
(Plg= Plagioclase, Afs= K-feldspar, Ol= Olivine, Pyx= Pyroxene, Hbl=Hornblend, Chl= chloride)

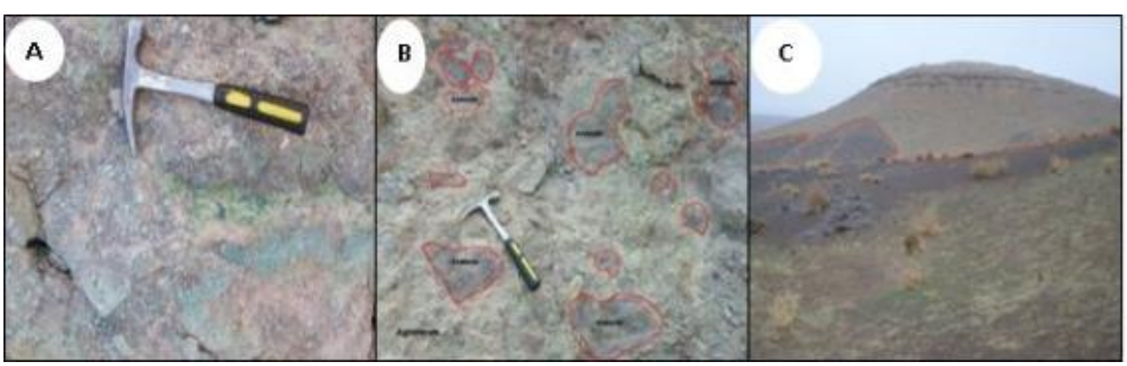

Figure 4: A: Andesite Unit; B: Agglomerate – Tuff Unit; C: Limestone Units

3.2. Altration

Based on field and laboratory results, the alteration intensity of the host rocks is represented by three groups of strongly (> 50 %), moderately (30−50 %), and weakly (< 30 %) altered rocks where carbonate alteration has affected all exposed volcanic rocks at Golcheshmeh deposit in an area of 15 km^2 (Figure 5).

3.2.1. Strong Carbonate: This alteration in the northwest part of study area has affected andesite and pyroxene andesite units. Nearly, the 70 to 75 % plagioclase and pyroxenephenocrysts are altered to carbonate.

3.2.2. Moderate Carbonate: This alteration in the central part of study area has affected andesite unit and about 40 to 50% plagioclase phenocrysts altered to carbonate.

3.2.3. Weak Carbonate: This alteration in the central and south-eastern part of Golcheshmeh area has affected pyroxeneandesite and andesite units and about 20 to 25% pyroxenes and plagioclases are altered to carbonate.

3.2.4. Moderate Carbonate- *Weak Argilic:* This alteration in the southeast part of study area has affected andesite, thrachyandesite and pyroxene andesite units. About 35% of plagioclase and pyroxene minerals are altered into carbonate and ~10% of plagioclases altered to Clay minerals**.**

3.2.5. Moderate Carbonate- *Weak Propylytic:* This alteration in the northwestern part of study area has affected hornblende andesite unit that~ 25 to30% plagioclase and hornblende minerals, are altered to carbonate and ~5 to 10% them are altered into epidotandchlorite.

3.2.6. Moderate Propylytic: This alteration in the east part of study area has affected andesite basalt unit that ~30 to 35% of plagioclase and pyroxene minerals are altered to epidoteand chlorite.

3.2.7. Weak Propylytic: This alteration has affected pyroxeneandesite and hornblende andesite unit in the central part of Golcheshmeh deposit. About 5 to 10% of plagioclase, pyroxene and hornblende minerals are altered to epidoteand chlorite.

3.2.8. Weaksericitic: This alteration in the west part of study area has affected pyroxene andesite unit and about ~10% of plagioclases are altered to sericite.

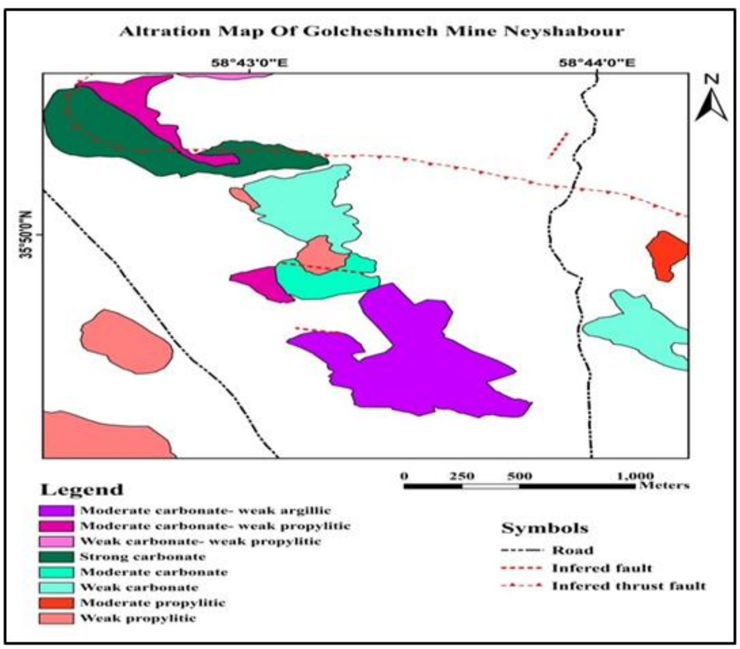

Figure 5: Alteration Map of Study Area

3.3. Mineralization

Evidence for Copper mineralization is widespread in the Golcheshmeh area. Copper mineralization mainly consists of the oxide phase including secondary copper carbonate (malachite, azurite), copper silicate (chrysocolla) and, probably copper hydrochloride (Atacamite**)** ores. In most parts of the Golcheshmeh region, copper oxide ores can be observed, and have influenced most rock units, particularly andesites and pyroxene-andesites, in the form of contamination or replacement in plagioclases, amygdaloidal fillings, and veins and veinlets with thicknesses of (0.5-5 centimeters).

Based on study more than 18 polished slabs and sections chalcocite is the main sulfide ore in this region and is observed in the form of thin veinlets (<1 cm) in the central and southwestern parts of the region, mainly in the mega andesites, andesites and pyroxene-andesites units. In addition, in the available sections, there are signs indicating that other sulfide minerals such as minorpyrite, chalcopyrite, bornite, covellite, a small quantity of digenite, and also native copper are present.

The presence of these sulfide ores may support the view that there are probably two generations of chalcocites. The first generation is a primary ore that was formed directly in the joints, cracks, and fractures from the ore-containing solution and is currently changing into covellites in some places; and, the second generation is chalcocite that was probably formed from the conversion of bornite through substitution and under supergene conditions. In most cases, the observed intergrowth between copper ores suggests multi-stage mineralization in this region (Figure7).

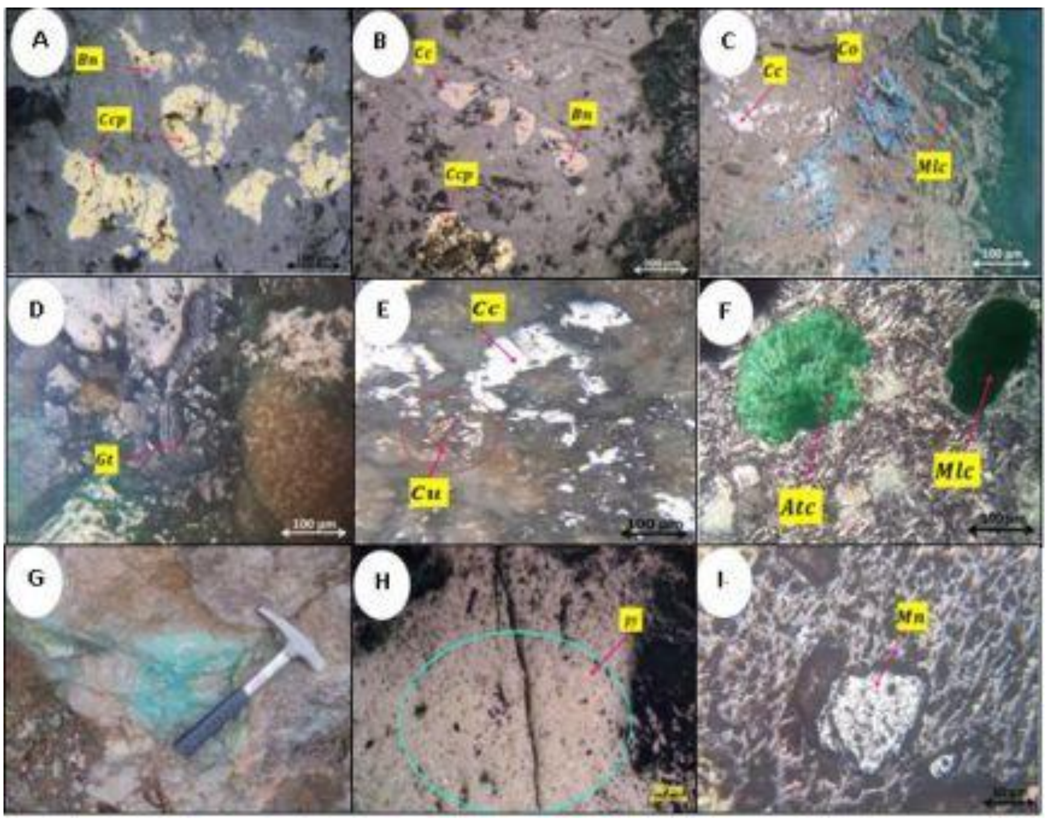

Figure 6: A: Chalcopyrite Bornite are Converted to Chalcocite; B: Bornite are Convertad into Chalcocite; C: Chalcocite Chalcocite Converted into Covelite and Mallachite; D: Geothite with Colloform Texture; E: Presence Chalcocite and Native Copper; F: Amygdal Fillings by Malachite and Atacamite; G: Oxide Copper Mineralization Consists of Contamination Malachite, Chrysocolla; H: Presence of Primary Pyrite; I: Presence of Magnetite
(Ccp= Chalcopyrite, Bn= Bornite, Cc= Chalcocite, Co= Covelite, Mlc= Malachite, Cu= Native copper, Gt= Geothite, Atc= Atacamite, cb= Carbonate, Mn= Magnetite)

There is also the possibility that greater quantities of chalcocites have changed into malachite and chrysocolla under oxidizing conditions. In addition to these ores, there are signs indicating the presence of magnetite in many places that have mainly formed from the decomposition of hornblendes present in the region.

In the Golcheshmeh region, the major factors in mineralization are strong fault activities and tectonic forces that have caused the formation of joints, fractures, veins, and veinlets in most areas. These structures have turned into channels for the movement, and infiltration, of copper-containing solutions that, eventually, have resulted into concentration, and higher economic grade, of the mineral (Figure 6). Considering the existing evidence, mineralization in this region is comparable to that Manto and Keweenaw (Michigan) mineral types deposit (Richards, 1989).

3.4. Geochemical Exploration

Geochemical exploration studies were conducted on rock units with potential for copper mineralization and on quarries in the region to determine the copper grade. For this purpose, 15 debris samples were taken from the ore and the andesitic host rock, and all of them were analyzed to measure their Cu, Ag, Zn, Pb, Fe and Mo contents, as well as the contents of other elements, using the ICP-OES method. The results of this analysis are presented in Table 1.

Seven of the samples were taken from the quarries in the region to determine the copper grade, and the rest from areas where no drilling had taken place but there were signs of copper mineralization. Results of sample analyses showed the copper grade of the samples was high and the places where they were taken could be viewed as new exploration drilling sites.

Based on the results from the geochemical analysis of the samples, the average copper grade varied from 13668 to 16400 ppm, which was a high grade considering the host rock was andesitic (Figure 2 and Table 1). The Ag content ranged from 1 to 12.1 ppm, Mo from 1 to 6 ppm, and Ti from 2600 to 5795 ppm. The Zn content ranged from 48 to 111 ppm, pb from 10 to 180 ppm, Fe from 20400 to 37800 and as from <10 to 51 ppm (Figure 7).

Table 1: Results of Analysis Rock Sample with ICP-OES Method

Types (ppm) **Sample No.**	**Cu**	**Ag**	**Zn**	**Pb**	**Fe**	**Mo**	**Ti**	**As**
S2	126000	4.8	75	69	22600	3	4500	<10
S3	164000	3.4	111	171	24200	3	2600	14
S6	78447	8.1	73	52	20400	6	4600	<10
S7	94220	5.5	59	52	21500	4	4300	17
S10	50993	7.8	60	61	29600	<1	4300	<10
S15	64908	1.8	64	118	27400	3	4400	<10
S17	75995	3.9	61	180	37800	3	3500	51
S19	36754	1.2	53	90	31900	3	4600	10
S30	89001	6.5	81	45	28800	4	4400	<10
S35	68936	2.7	57	38	33200	4	4200	<10
Gc1	13668	<1	48	10	33400	<1	5271	18
Gc5	30774	3.6	72	60	37100	<1	5795	32
Gc8	19621	2.8	62	40	37500	<1	5532	28
Gc10	23285	<1	56	21	33400	<1	5076	23
Gc11	29302	12.1	61	47	31400	<1	4532	28

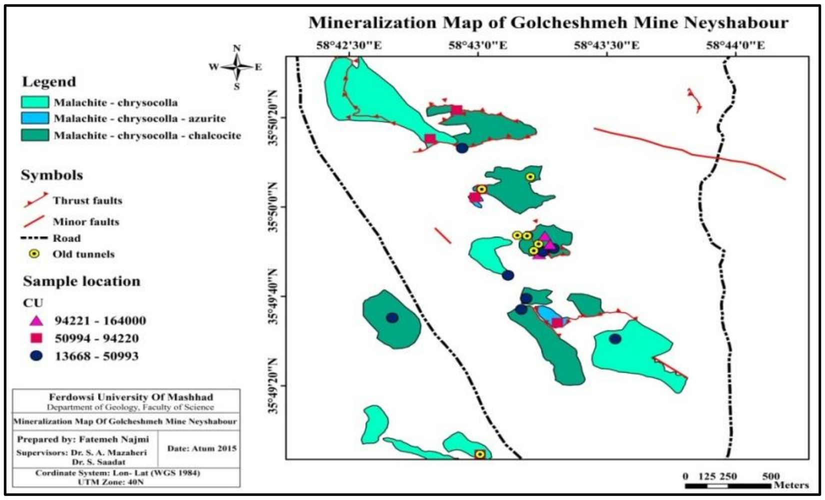

Figure 7: Mineralization and Geochemistry Map of Study Area

Discussion

4.1. Petrology and Geochemistry of Trace Elements

After examining the thin sections, carrying out petrographic studies, and considering field evidence and relationships, 12 of the samples taken from the volcanic layers that had experienced the least degrees of alteration were selected and analyzed using an XRF techniques to determine their main oxide and trace element contents. Moreover, after studying the results of the analysis for major elements, all of the samples were analyzed to determine their trace and rare earth element contents. Based on the diagram of SiO_2 versus K_2O, the volcanic rocks of the Golcheshmeh region are in the range of shoshonite magma series (Figure 9-A) (Peccerillo & Taylor, 1976).

Based on the diagram of SiO_2 versus Zr/Ti_2O ratio, 10 of the 12 samples were in the range of andesite to trachy andesite and one in the range of alkali andesitic basalt and also one sample showed movement resulting from intense altrations that these results thoroughly conform to primary and field observations (Figure 8-E) (Winchester & Floyd, 1977).

In order to separate igneous rocks from magmatic series AFM diagram ($A=K_2O+Na_2O$, $M=MgO$, $F=FeO_t$) was used and it indicates that all of samples are of the calc-alkaline basalt characteristics (Figure 9-C) (Irvine & Bargar, 1971).

In the ternary diagram (MgO, FeOt, Al_2O_3), the volcanic rocks of the region also belong to the andesitic orogenic series, one of the samples exhibits movement due to intense alterations (Figure 9-D).

Rare earth elements offer an important pattern for magmatic processes and evolution and are used to determine the extents of enrichment and depletion of rocks in relation to a primary standard.

Considering the types of rocks in the Golcheshmeh region, a normalized spider diagram was used in studying the rare earth elements in the area in relation to the average basalt content in oceanic crust (MORB) and chondrite. In the normalized diagram of the samples, which was drawn in relation to the MORB standard, was used (Pearce, 1983).

In this diagram, the rocks in the region exhibit enrichment with respect to the LFS elements such as Rb, K, and Ba and some types of depletion with respect to the HFS elements such as Ce, Ti and Nb, that this is one of the distinguishing characteristics of subduction zone-related rocks (Figure10-A) (Pearce, 1983).

The normalized spider diagram was used in relation to chondrites to compare rock chemistry with compositions of chondrites and with the behavior of trace elements in the magma (Gerlach *et al*., 1988) (Figure-10-B). In this diagram, depletion of elements with low mobility (HFS) such as Y, Nb and Th, enrichment of mobile elements (LIL) such as K, Rb, and Ba are observed as well, which could be indicative of the presence and accumulation of these elements during the late stages of magma crystallization (Rollinson**,** 1993).

Table 2: Some Major (wt%), Trace and REE Element (ppm) Analyses of Representative Fresh Rocks with ICP-MS Method from Golcheshmeh Deposit

Sample no Types	Xrf2	Xrf4	Xrf14	Xrf15	Xrf17	Xrf29	Xrf30	Xrf49	Xrf3	Xrf7	Xrf23	Xrf34
SiO_2	53.62	56.88	58.87	57.68	52.46	58.01	56.06	44.32	57.54	57.42	57.74	54.96
TiO_2	0.82	0.98	1.12	0.8	0.93	0.77	0.82	0.92	0.74	1.11	1.03	0.93
Al_2O_3	18.68	18.45	18.45	18.31	15.57	17.25	17.44	13.68	18.1	18.55	18.08	18.37
FeOt	4.74	3.92	3.75	3.68	6.68	3.74	4.05	4.12	3.23	3.37	3.31	4.72
SrO	0.08	<0.05	<0.05	<0.05	0.06	<0.05	0.06	<0.05	0.05	0.05	0.05	0.07
MgO	3.68	2.97	1.55	2.71	8.55	3.82	4.37	<0.05	3.96	2.6	2.73	2.82
CaO	5.28	2.7	3.63	3.59	7.49	3.96	3.05	15.02	3.74	3.52	3.51	5.26
Na_2O	5.25	4.88	4.02	4.05	3.08	4.32	5	4.75	4.32	4.15	4.06	4.57
K_2O	4.52	6.14	5.24	6.16	2.31	4.6	5.56	5.85	6.23	6.38	6.48	5.01
P_2O_5	0.88	0.98	0.87	1.04	0.73	0.89	0.79	0.53	1.54	0.95	1.09	1.49
LOI	2.44	2.01	2.05	2.01	2.16	2.54	2.35	9.54	1.5	1.49	1.89	1.79
Total	99.99	99.96	99.6	100.08	100.02	99.95	99.55	99.83	100.95	99.59	99.97	99.99
Ba	464	336	316	876	474	456	454	520				
Rb	99.5	70.6	94.9	99.8	96.8	117	109	131				
Sr	600	233	136	300	691	346	424	325				
Zr	138	125	136	166	111	159	132	131				
Nb	16.9	18.9	19.8	21.2	14.5	20.9	17.3	20.2				
La	18.1	3.0	3.4	1.6	1.21	8.3	14.9	19.5				
Ce	35.5	5.99	7.01	12.0	44.5	16.6	28.4	37.2				

Pr	4.33	0.77	0.86	1.59	5.39	2.0	3.38	4.14
Nd	16.9	3.03	3.36	6.58	22.0	8.21	13.3	14.7
Sm	3.73	0.91	0.95	1.79	5.19	2.01	2.76	2.84
Eu	1.26	0.38	0.32	0.87	1.73	0.71	1.00	0.96
Gd	3.45	0.82	0.85	1.45	5.08	1.84	2.58	2.59
Tb	0.48	0.13	014	0.26	0.81	0.3	0.41	0.38
Dy	2.96	0.89	1.05	1.65	4.59	1.94	2.36	2.36
Ho	0.57	0.17	0.23	0.33	0.87	0.37	0.5	0.45
Er	1.80	0.62	0.71	1.20	2.59	1.43	1.53	1.49
Tm	0.25	0.11	0.11	0.15	0.34	0.2	0.21	0.22
Yb	1.6	0.7	0.8	1.3	2.2	1.4	1.3	1.5
Lu	0.25	0.12	0.13	0.21	0.34	0.23	0.23	0.24
Y	16.1	4.8	6.2	9.6	24.7	11.0	13.3	12.6
Cs	0.98	3.34	3.96	3.65	2.55	3.63	1.15	2.91
Ta	1.27	1.22	1.15	1.31	1.45	1.34	1.18	1.49
Hf	3.27	2.92	3.33	3.86	3.13	3.75	3.14	3.31
Ga	16.1	16.3	15.5	17.6	18.3	18.0	15.2	13.6
Th	4.5	0.9	1.4	2.4	4.9	2.4	3.4	5.5
U	1.2	0.2	0.2	0.4	1.5	0.5	1.2	2.1
V	264	382	377	460	288	441	358	397
W	2.4	2.6	1.7	1.4	1.4	2.9	1.6	2.2

Research Article

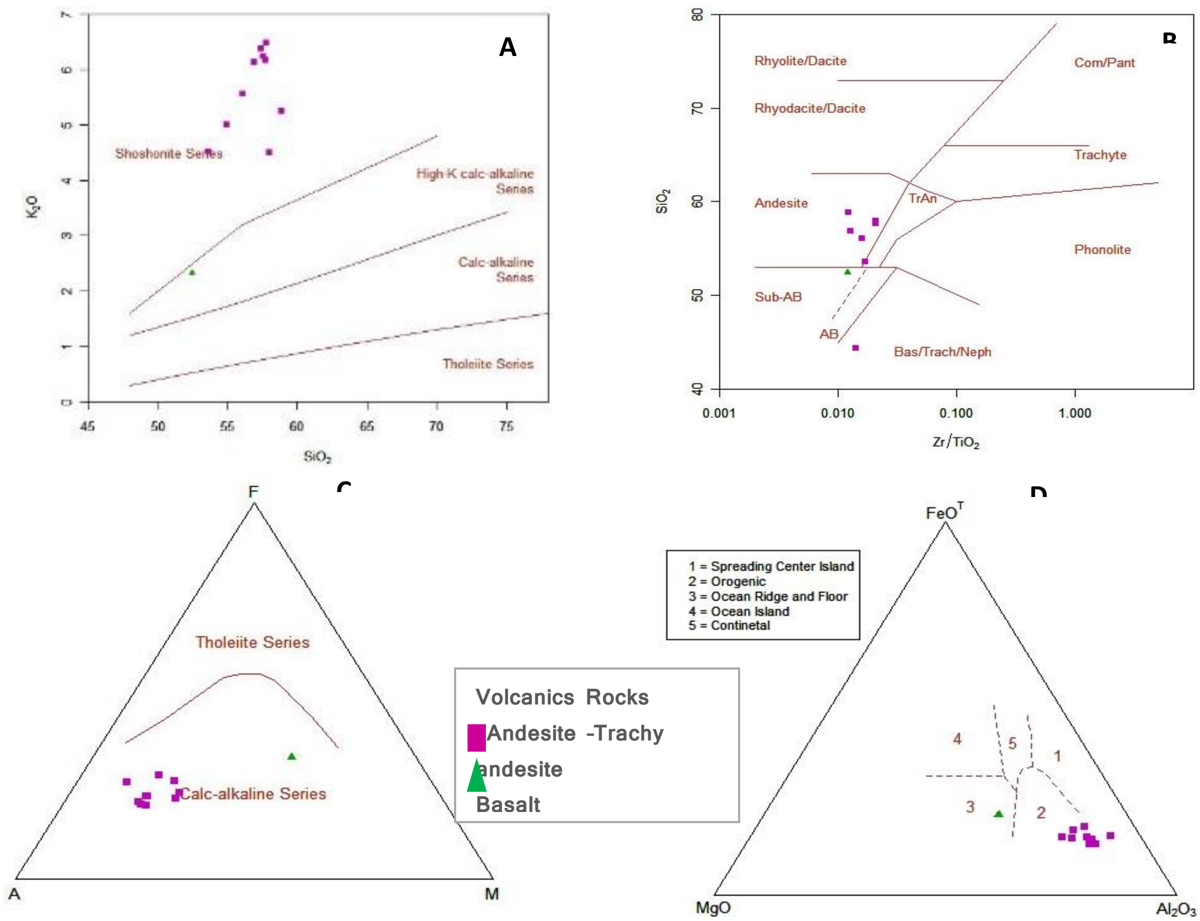

Figure 9: A: K_2O (wt%) vs. SiO_2 (wt%) Diagram Showing the Classification (Peccerillo& Taylor, 1976), the Golcheshmeh Volcanic Rocks are Classified Shoshonite Series; B: (SiO_2) vs. (Zr/TiO_2) Plots (Winchester & Floyd, 1977), the Diagram Classify the Volcanic Rocks as having Composition Ranging from Andesite to Trachyandesite and Alkali Andesite Basalt Composition; C: AFM Plot of Analyses of the Volcanic Rocks. Skaergaard (Tholeiitic) and Cascade (Calc-Alkaline) Trends are from ((Irvine &Bargar, 1971), the Golcheshmeh Volcanic Rocks Delineate Acalc-AlkalineTrend, D: The Ternary Diagram (MgO, FeOt, Al_2O_3), Showing the Volcanic Rocks Belong to the Andesitic Orogenic Series

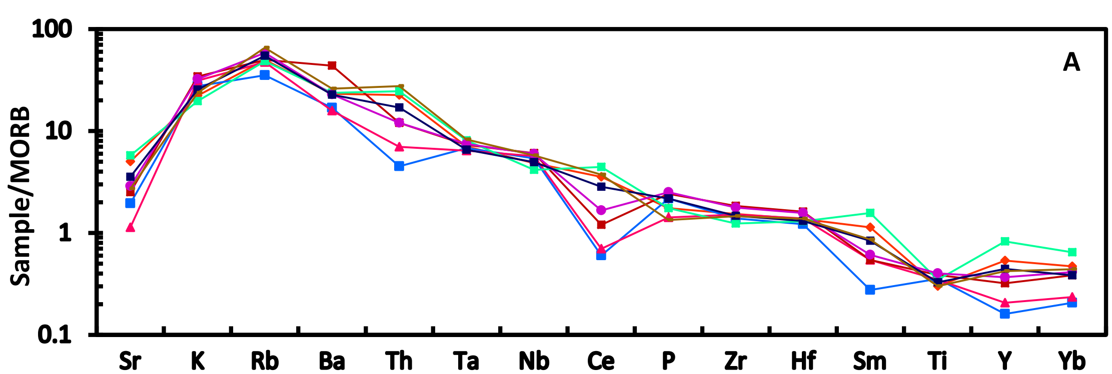

Figure 10: MORB-Normalized Trace Element Spider Diagram

Conclusion

Based on field and laboratory studies and geochemical analysis, mineralization in the Golcheshmeh region occurred in the suitable tectonic setting (along the margin of Sabzevar Zone) related andesitic units, and the active tectonic plates caused the creation of joint systems and formation of cracks, veins, veinlets, and fractures in the region rocks. These have turned into channels for the infiltration of copper containing solution from the depths to the surface resulting in the expansion of copper mineralization in the region. Copper mineralization occurred mainly in the form of oxides (malachite, azurite and chrysocolla and atacamite), and in some cases copper sulfides (chalcosite), in the major andesitic units in the Golcheshmeh region that, based on results of the geochemical analyses, have a considerable grade due to the presence of copper. Furthermore, despite some differences the mineralization type, with respect to the lithology type (andesitic- basaltic unit), extension and alteration zones (carbonate, propylytic, sericitic), types of ores in the region (malachite, chalcosite, covelite, native copper), and paragenetic sequence in relation to shape, variety, and expansion is similar to that in Manto and Keweenaw (Michigan) mineral types deposit (Table 3). Based on geochemical behavior of trace elements, rock units in this region are classified in meta-aluminous field and are belonged tocalc-alkaline magmatic series with shoshonite tendency. The study of the geochemical behavior of trace and rare earth elements (REE) in this region points to the occurrence of a kind of enrichment of the LFS elements such as Ba, K, and Rb and the depletion of HFS elements such as Th, Ti, and Ce. This can demonstrate the characteristics of subduction zone-related rocks that are associated with the presence of magmatic arcs.

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