Alteration and Mineralization at Daralu Porphyry Copper Deposit, South of Kerman, Southeast Iran

Mosayeb Salehian* and Majid Ghaderi

Department of Geology, Tarbiat Modares University, Tehran, Iran

*Email address: m.salehian@modares.ac.ir

Abstract
Daralu porphyry copper deposit is located 130 km south of Kerman, southeast Iran. The area lies in southern part of Urmieh–Dokhtar magmatic arc. The deposit is associated with granodioritic intrusive of Oligo-Miocene age which intruded Eocene volcano-sedimentary rocks. Copper mineralization was accompanied by both potassic and silicic-phyllic alterations. Four types of hypogene alteration are developed in the Daralu deposit: potassic, propylitic, argillic, silicic-phyllic. Hydrothermal mineralization studies within the Daralu deposit show four types of hydrothermal mineralization: (1) hypogene; (2) supergene; (3) oxidized and leached; (4) gossan. Hypogene copper mineralization appears to have been introduced during the transition from potassic to silicic-phyllic alteration and mainly during silicic-phyllic alteration. It occurs as disseminations and in veinlets. Three principal types of vein mineralization have been identified: Type-I which is characterized by quartz, chalcopyrite, magnetite and pyrite with minor bornite and molybdenite; Type-II contains chalcopyrite (as the main copper mineral in the Daralu deposit), pyrite and quartz, with traces of molybdenite ; and Type-III consisting of quartz and pyrite, with minor chalcopyrite. Supergene zone is very limited, covered mainly by an oxidized and leached zone. Gossan zone at the Daralu deposit is immature.

Keywords: *Porphyry copper, mineralization, alteration, hydrothermal, Daralu, Kerman.*

1. Introduction
The alteration footprint of porphyry deposits has proven to be the most useful guide to exploration, due to the enormous volume of rocks that are affected, and the distinctive mineral assemblages that are produced (Cooke et al., 2009). Most of the porphyry deposits exhibit a well developed zonal pattern of mineralization and wall rock alteration that identified those important for exploration of porphyry deposits. On the basis of remotely-sensed data, discriminating alteration zones in the Sarduiyeh geological sheet, south of Kerman province, as a result Daralu deposit reconnaissanced high possible mineralization (Tangestani and Hosseinjanezide, 2007). The objective of these studies is to illustrate types of hypogene alteration and hydrothermal mineralization zones and correlation types of hypogene alteration with hydrothermal mineralization. We have documented the alteration and mineralization characteristics of the Daralu deposit based on our research of thin sections and polished-thin sections of the drill cores and outcrops, observations from more than 13,000 m of drill core, and logs of 40 drill holes.

2. Geological setting

The Daralu porphyry deposit is within a belt of Eocene volcanic rocks and Oligo-Miocene subvolcanic granitoid rocks that form part of the 2000×50 km central Iranian volcano–plutonic copper belt. The mineralized and altered stock at Daralu is exposed with a surface outcrop of approximately 0.7 km^2, which is elongated within1.2 km long corridor of NW-SE trending and stock consists of four igneous phases: 1) quartz-diorite to granodiorite; (2) andesite + dacite; and (3) andesite + pyroclastics (4) diorite dykes. The quartz-diorite to granodiorite is volumetrically the most important and occurs within a 400 m wide in the center part of the deposit and hosts the most intense mineralization. These intrusive phases are cut by diorite dykes, which in the northwest parts of the Daralu stock, lack mineralization. Andesitic and dacitic in affect intrusive quartz-diorite to granodiorite to intensely altered as initial texture hardly recognized and in depth hosts part of the mineralization. Andesite and pyroclastics lie in northeast of the deposit and consist of little volume of rock area. Porphyry copper deposits emplacement was controlled by strike-slip faults parallel to the magmatic arc and NW-trending basement structures (Richards et al., 2001). Magma emplacement in the Daralu deposit is controlled by structure phenomenon. Two major fault systems are recognized at the Daralu area: 1) Fault system with NW– SE trending in relation with mineralization which facilitated magma ascent. 2) Fault system with NE-SW trending with no relationship with mineralization (Fig. 1).

3- Hydrothermal alteration types

Alteration assemblages in the Daralu porphyry copper deposit inclusive potassic, silicic-phyllic, propylitic and argillic.

3-1 Potassic alteration

Potassic alteration is present at the core of the deposit and as halos around the veins to a depth of 120-240 meters and overprinted by the silicic-phyllic alteration zone. This alteration consists of biotite, magnetite, anhydrite, K-feldspar (orthoclase) and quartz. The potassic alteration is manifested by replacement of preexisting phenocrysts within groundmass or crystallization of secondary veinlets. Replacement biotite was formed most commonly by the replacement of amphiboles(Fig.2a), plagioclase and other ferromagnesian phenocrysts in the matrix of rock. This alteration displays a close spatial association with mineralization.

3-2 Propylitic alteration

Propylitic alteration occurs in northern and southern peripheral parts of the system that is distal to the core potassic and its peripheral phyllic alteration zones (Fig.1). Epidote, chlorite, albite, calcite and pyrite characterize this alteration assemblage. Calcite and epidote replaced plagioclase(Fig.2b). These types of rocks are generally green in color, which is due to the abundance of epidote and chlorite.

3-3 Silicic-phyllic alteration

The contact between potassic and silicic-phyllic alterations is gradual and developed at the peripheral parts of the potassic alteration zone. The phyllic alteration is characterized by the replacement of rock-forming silicates such as plagioclase and amphibole by sericite and quartz accompanying by variable amounts of pyrite. In the phyllic alteration zone, plagioclase has been partly or completely replaced by sericite(Fig.2c). The copper grades at Daralu are also associated with silicic-phyllic alteration and largely reflect the presence of disseminated chalcopyrite. Pyrite forms up to 5 vol. % of the rock and occurs in veins and disseminations. Silicification is an extensive phenomenon in this alteration zone that lends a bleached white color to the rocks. This observation is based on some drilling data.

3-4 Argillic alteration

The argillic alteration is exposed in the north and northeast parts of the study area(Fig.2d). The altered rocks are soft and light-brown to yellow color, and are characterized by jarosite, commonly associated with hematite, limonite and clay minerals. The primary rock textures in the argillic zone not able to be seen. Field observations indicate that local argillic alteration assemblages are adjacent to the phyllic alteration zone. pyrite is widespread in the argillic alteration zone. Feldspar is pervasively altered to clay. Table.1 shows Relative mineral abundances in various alteration zones in the Daralu system.

4- Hydrothermal mineralization zones

Mineralization at Daralu is mainly associated with granodiorite porphyritic stocks. On the basis of observed and logged drill cores and outcrops of stocks, four types of hydrothermal mineralization are distinguished: 1) hypogene; 2) supergene; 3) oxidized and leached; 4) gossan.

4-1 Hypogene zones

The highest Cu values occur at depths of 120 m to at least 240 m below the present erosional surface that is the boundary between the potassic and silicic-phyllic alterations with weak mineralization in the propylitic alteration. The ore occurs essentially in disseminations, veins, and veinlets. Hypogene mineralization is characterized by chalcopyrite, pyrite, bornite, covellite and molybdenite. Chalcopyrite mineralization is either disseminated or it is in the veins, and is typically concentrated in the potassic zone proximal to the contact between the potassic and silicic-phyllic zones. Bornite and covellite are rare primary minerals, which are intergrown with chalcopyrite. Disseminated and vein-hosted pyrites characterize the phyllic zone. There is also a positive correlation between silicification and copper mineralization. Figure 3 shows the relationship between mineralization and alteration. The mythology of porphyry deposits is that mineralization occurs in a random array of veins, known as a stockwork. The reality is that the stockwork is typically defined by two or three preferred vein orientations, with conjugate or orthogonal relationships. Scheme of vein classification can help to understand the temporal and thermal evolution of the system (Cooke et al., 2009). The Daralu deposit is characterized by multiple crosscutting generations of vein mineralization: Type-I which is characterized by quartz, chalcopyrite, magnetite and pyrite with minor bornite and molybdenite; Type-II containing chalcopyrite (as the main copper mineral in the deposit), pyrite and quartz, with traces of molybdenite; and Type-III consisting of quartz and pyrite, with minor chalcopyrite.

4-1-1 Type-I veins

Type-I veins are generally the first veins to form. These veins are irregular, discontinuous, vary in thickness between 0.65 and 4 mm. Chalcopyrite is the most important sulfide mineral, and occurs mainly along vein margins and magnetite occurs in the central part of the vein. Quartz comprises from 75 to 95% of volume of the veins. The veins form in association with potassic alteration.

4-1-2 Type-II veins

Type-II veins generally crosscut Type-I veins. These veins are continuous and planar structures with parallel walls. The volume ratio of chalcopyrite to pyrite is 2:1. Chalcopyrite and pyrite are located mainly in a narrow discontinuous layer in the vein centers, but in some cases they are disseminated through the quartz. Their thickness varies from 5 to 35 mm, concentrating mainly in the potassic zone.

4-1-3 Type-III veins

These late-stage veins crosscut both types I and II veins. Type-III veins are characteristic with silicic-phyllic alteration zone, and are generally continuous, commonly layered, and vary in thickness from 5 to 40 mm. Pyrite is an important sulfide mineral and the only copper mineral is chalcopyrite. Quartz is abundant and coarse grained in Type-III veins.

4-2 Supergene zones

Supergene enrichment is an economically important weathering process that concentrates some metals (e.g., Cu and Ag) within the weathering profile while others are lost (Hartley and Rice, 2005). This zone has lesser extension in the Daralu deposit and its thickness at part of the district is variable. Chalcocite, bornite, covellite, along with lesser amounts of native copper at the top of the zone are distinguished at supergene zones. Bornite and covellite form replacement rims around chalcopyrite. Enrichment is a function of uplift, climate, initial rock composition (especially pyrite) and structure (Anderson 1982; Chavez 2000). Due to low ground water table, rough morphology and low pyrite to chalcopyrite ratio, a fit supergene zone did not form.

4-3 Oxidized and leached zones

The mineral assemblages characteristic of the oxidized and leached zone are Fe-oxides and hydroxides (goethite, hematite, and limonite), sulfates (jarosite and chalcanthite), carbonates (malachite and azurite), silicates (chrysocolla) and manganese-oxides. Thickness of the oxidized-leached zone is 2-25 meters with 0.2% Cu on average. Malachite and azurite are abundant as disseminations and veins at part of the deposit. Chalcanthite occurs as stalactitic-shaped like and green to light blue color in central part of the deposit in effect of rapidly oxidizing copper minerals and arid climates. In these zones, pyrite and chalcopyrite are not completely oxidized and copper solutions in downward acidic fluids depositing as carbonate copper in surface therefore downward acidic fluids contain rare copper for constituting suitable supergene zones.

4-4 Gossan zones

In the Daralu deposit, gossan consists of hematite, jarosite, goethite and limonite. Jarosite and goethite are abundant at part variant deposit but hematite and limonite exist very minor. These zones have the most extension in northwest of the deposit and the dominant alterations include argillitization and jarositization. Copper carbonates are abundant copper minerals in these zones. Gossan as classification to two set by Atapour (2007): 1- mature gossans contain abundant hematite with variable amounts of goethite and jarosite; 2- immature gossans consist of iron-oxides, malachite, azurite and chrysocolla. Therefore, based on this classification, the gossan at the Daralu deposit is immature.

5- Conclusions

Alteration and mineralization studies on more than 13,000 m of drill cores and logs of 40 drill holes and field observation have shown that:

1- The Daralu deposit contains patterns manifesting the porphyry copper deposits of model presented by Lowell and Guilbert.

2- Mineralization is mainly associated with granodiorite porphyritic stocks.

3- Highest Cu values occur at boundary between the potassic and silicic-phyllic alterations and also a positive correlation between silicification and copper mineralization.

4- Supergene zone has lesser extension and the gossan at the deposit is immature.

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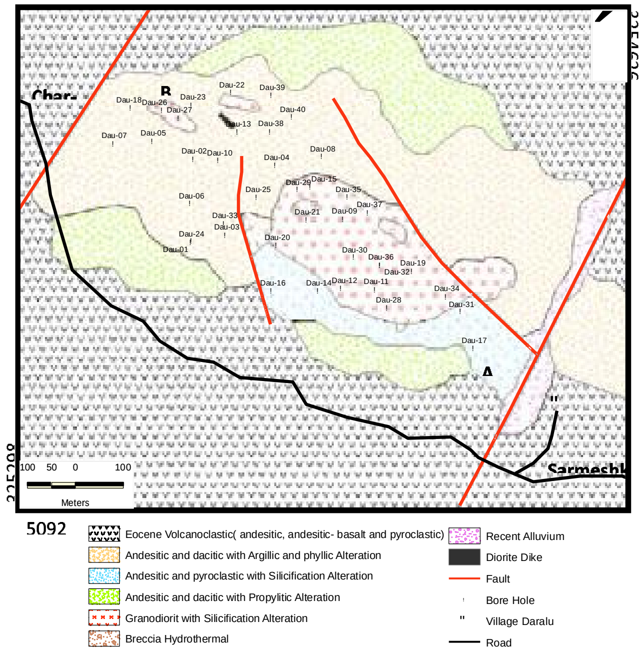


Fig.1 Detailed geological map of the Daralu area

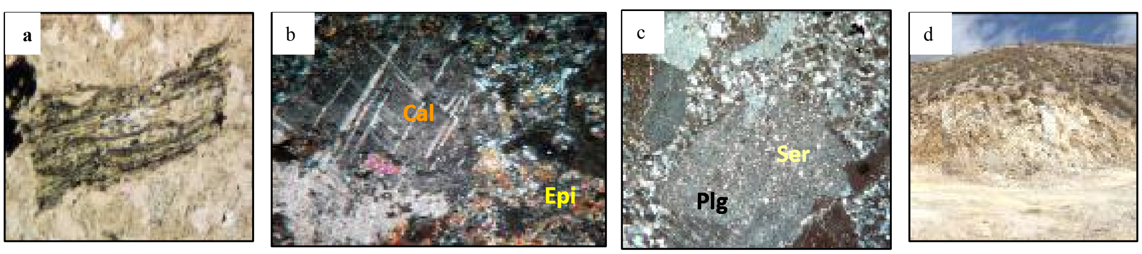
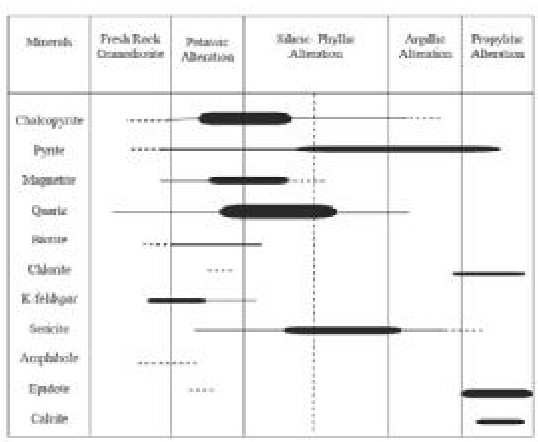


Fig.2 a) Secondary biotite from potassic alteration zone. b) Replacement plagioclase to calcite and epidote in propylitic alteration. c) Plagioclase replaced by sericite in silicic-phyllic alteration. d) Argillic alteration in northeast parts deposits.

Table.1 Relative mineral abundances in various alteration zones in the Daralu system.



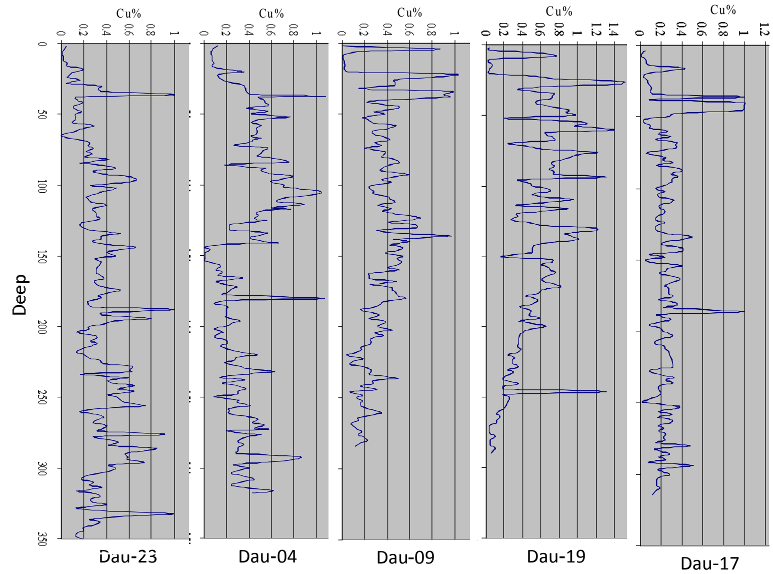


Fig. 3 Section along A-B in Fig. 2 illustrating the position of diamond drill holes and the pattern of hypogene alteration zones (potassic, silicic-phyllic and argillic) in relation with mineralization.