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STRUCTURAL FORMATION AND ARRAGEMENT CONDITION OF COPPER-PORPHYRY MINERALIZATION IN THE GARADAG ORE FIELD

A.M. Ismayilova

Baku State University, Baku, Azerbaijan
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Abstract

The article deals with the structures that control the localization of copper-porphyry mineralization. The formation conditions of these deposits are characterized. It is believed that the formation of copper-porphyry deposits is related to the penetration of stock-like small granodiorite-porphyry intrusion bodies into the upper horizons of the Earth's crust.

Keywords: copper-porphyry, ore field, structure, intrusive masses

*Corresponding author.

E-mail address: aygun46@mail.ru (A. Ismayilova)

Modern ideas about the Garadag ore field were formed based on the researches by R.N. Abdullayev, A.Z. Abdullayev, D.M.Ahmadov, J.A.Azadaliyev, V.M. Babazadeh, S.A.Bektashi, A.M. Ismayilov, A.A.Masimov, S. M. Mikayilov, H.V.Mustafayev, V.G.Ramazanov, S.M.Suleymanov and others.

The Garadag ore field is geologically and structurally a fold-block structure and is considered one of the most important objects of the Gadabay ore region. The tectonic blocks are distinguished by their special structures here. This feature is also repeated in the small structural blocks observed in the Garadag ore field.

A large part of the ore area is represented by the plagiogranites of the Atabay-Slavyanka massif.

The Atabay-Slavyanka massif is broken by small intrusions such as stock-shaped and dyke-type granodiorite-porphyry, quartz-diorite porphyrite, etc.

Granodiorite-porphyry intrusives are considered one of the most important elements of the structure of the Garadag ore field. These bodies located along the ore-controlling structures create a close spatial and temporal relationship with the endogenous mineralization.

From this point of view, the copper-porphyry occurrences of the Garadag ore field do not differ from similar deposits in other regions [7, 8, 10, 13].

The close structural relationship of copper-porphyry mineralization with small intrusive bodies is noticeable above all in the localization of small intrusives and mineralization in the same disjunctive structures. This relationship is particularly characteristic for the Central part of the Garadag field. Such a relationship is also observed in the Kharkhar and Jayir occurrences. It is assumed that the arrangement of similar, stock-shaped small intrusive bodies can show the direction of mineralization zones discovered as a result of geophysical work in the area.

One of the specific elements of the geological structure of the Garadag ore field is the presence of explosive breccias of different ages. They can be found in almost all areas of the ore field. These explosive breccia structures, which correspond to tectonically weakened areas, are clearly identified regionally and locally.

The wide development of plagiogranite intrusives, small intrusive bodies with different compositions, which are similar to stock and dyke, and finally explosive breccias of different ages in the ore areas show that the ore-controlling lineament structures have not lost their activity for a long time and, in general, the high permeability of these structures. In its turn, this was reflected in the distribution of ore mineralization and the dispersion of ore components over a much larger area.

The author, having studied all the data she collected while studying the ore-controlling structures of the Garadag ore field, examined many researchers' opinions [1, 9, 12, 14, 15, etc.] about it, distinguished the following types of structures that control the concentration of copper-porphyry mineralization:

- regional structures that determine the arrangement of the ore region;
- the ore field and the structures that arrange the deposits;
- structures that control the localization of separate ore bodies;
- structures providing the arrangement and distribution of copper-porphyry mineralization in ore bodies.

The regional structures that control the arrangement of the known copper-porphyry deposits and occurrences within the ore region are Paleozoic large-scale northwest-oriented fold-fracture zones and depth.

Well-studied [16] fold and fracture zones consist of narrow anticlinal and synclinal folds. The main folding structure of the Garadag ore field is considered to be the Shamkirchay-Badakend anticlinal zone. Porphyry intrusives bearing copper-porphyry mineralization are exposed in its dome part. The anticline is separated from the Chardakhli syncline, which is located northeast of it, by a regional fault line. This disjunctive fracture intersects with the of Kharkhar ore-controlling fracture in the region of Chardakhli village. The Maarif-Maskhit syncline extending to the southwest from the Shamkirchay-Badakend anticline zone forms a contact flank with the latter. Most of the Garadag stockwork bodies are exposed here. The folding structures are complicated by disjunctive dislocations of the thrust type, which do not lose their activity for a long time and are considered a part of deep faults. These faults are considered to be separate fragments of the pre-Alpine Gadabay-Dalidagh lineament zone [9,14], extending for more than 200 km in the north-northwest (submeridional) direction. The lineament is determined by the thickness alterations of various sedimentary-volcanogenic formations, by the characteristics of folding and metamorphosed rocks, as well as by the development of mylonitized and brecciated zones of hydrothermal-metasomatically altered rocks (secondary quartzites, etc.) along the fault. Many plutonogenic hydrothermal copper-porphyry deposits, as well as various types of volcanogenic hydrothermal pyrite deposits were formed within the lineament zone, which are associated with small stock-shaped porphyry intrusives. It is believed [15] that many of the ore fields are located at the junction of the submeridional and near-latitudinal deep-seated disjunctive faults of the northwest-oriented deep fault. The study of various detaching cracks, cataclasites and mylonites shows that the faults have had a long and complex development history.

Fracture dislocations of different scales are well visible in aerial photographs [9]. The characteristic forms of the relief are typical for them: flattened valleys located one after the other, scarps in the relief, the feature of erosion fracturing, etc. The main characteristic of most fracture dislocations is their linearity. This is clearly visible in the form of lineaments on aerial photographs.

Most of the fracture dislocations (Gadabay, Maskhit, Kharkhar) are well deciphered in watersheds and exposed bare slopes – straight lines, sharply noticeable saddle shapes, linear elongated open bands corresponding to hydrothermally altered-quartzized, kaolinized, lionitized rocks, etc. are the main signs of faults. Faults can be identified based on indirect signs in areas covered by accumulations or modern sediments (Slavyanka transverse fault).

As a result of deciphering of cosmic and small-scale aerial photographs, Shamkir, Dashkasan and other large annular structures are split within Shamkir horst-uplift and Dashkasan graben-synclinorium. The diameter of these annular structures is up to 20-30 km. Relatively old and deeply formed Atabay-Slavyanka and Gilanbir plagiogranites, granitoid intrusives of Gadabay, Dashkasan, Barum-Barsum and Shamkir group were formed in the central part of the structures.

The studied Garadag ore field is located at the junction of the central, southwestern peripheral parts of the Shamkir annular structure and northeastern peripheral parts of the Dashkasan structure. The junction of the abovementioned annular structures is through the Maarif upthrust, which extends in the northwest direction.

Separated large annular structures were formed in the area where the very large pre-Caucasus and Yasamal faults developed, and according to their origin, they are undoubtedly attributed to volcanic-plutonic structures.

It is possible to distinguish plicative and disjunctive groups between the structures that arrange the ore field and deposits. In general, these two groups of structures control copper-porphyry mineralization. Deposits are located in the zone of deep fracture, change the initial state of local folding structures, complicate the folds, their limbs alter their initial state due to crushing of rocks and folds with higher degree. Significant localization of copper-porphyry mineralization occurs in the areas of the main ore-controlling structure, complicated by disjunctive fracture feathering from it.

It is possible to distinguish smaller annular faults, arched fracture and structural lines within the abovementioned large annular structures with a diameter of 2-3 km in the Gadabay ore region, which includes the Garadag ore field. A chain of small annular structures extends northwestward along the Slavyanka transverse fracture, corresponding mainly to the junctions of multidirectional faults.

Due to their geomorphological characteristics, the small annular faults observed in Garadag, Kharkhar, Arikhdam, Zahmat, Atabay, Gumlu and other locations have a round, rarely elliptical appearance in space and aerial photographs.

The described small annular structures are closely connected with separate volcanic edifice, subvolcanoes and small, near-surface intrusives by their nature, and are clearly deciphered in aerial photographs.

A large number of arched fractures and structural lines can be seen in the aerial photographs in the areas located in the north from Samanlig and Kharkhar villages. The nature of their formation is not always clear and is poorly confirmed by field observations. Probably, these annular structures were formed due to ancient, deeply active arched and other fault zones.

The fractures in the central part (Garadag Mountain) of the zones acted as a channel for the inclusion of magmatic bodies and when renewed as a result of subsequent tectonic processes, the structural lines have become more visible or they have played the role of a vent for the inclusion of young subvolcanic bodies. Undoubtedly, the mentioned structural and magmatic factors played an important role in the localization of copper-porphyry mineralization.

As a result of deciphering the space, medium and large-scale height images of the area surrounding the Shamkir uplift and especially the Gadabay ore region, as well as the survey on the Earth's surface, the north-west and north-east oriented regional fracture dislocations, which are not so large in size (from 5-10 to 20-30 sq. km), demarcate separate tectonic blocks, are separated. These blocks are characterized by their own geological structure and various oriented ore-bearing and ore-controlling dislocations that are considered important for mineralization.

Most of the linear fracture dislocations bearing endogenous ore mineralization are associated with the Atabay and Shamkir transverse bending and uplifts, as well as the Gadabay, Arikhdam, Slavyanka and Kerkesik-Mespos (Kharkhar) deep faults in the studied area of the Shamkir horst-uplift. They have caused the formation of weakened zones of intense crack and breaking zones, which are considered favorable for the movement of transverse structures and ore-bearing hydrothermal vents.

The intersection node of the abovementioned transverse uplifts, bending and deep-seated regional faults with younger plicative and disjunctive faults are very favorable for localizing ore occurrences, and these objects are considered particularly promising.

A clearer relationship of tectonics with mineralization is well visible in the Kharkhar tectonic block. The Garadag, Kharkhar, Jeyir and other copper-porphyry deposits, which are our research objects, are located at the junction of the northwest-oriented Kharkhar and Garaikh fractures with the deep-seated Slavyanka transverse fault (regeneration element of the Atabay transverse bending) in the block.

We observe the same situation for the deposits located slightly north of the Garadag ore field. The most famous Gadabay copper deposit of ore region is located in the northeast of the junction area where the Shamkir transversal uplift intersects the Arikhdam deep fault. The Arikhdam sulfur-copper pyrite occurrence is located in the Gadabay fault of the fracture of the same name, the Giziljachay sulfur pyrite occurrence is located in the Gadabay and Maarif fractures, the Bitti-Bulag copper-arsenic deposit is located in the junctions where the transversally oriented fault of the same name intersects with the submeridional Gadabay fracture, etc.

It should also be pointed out that the Lower Bajocian volcaniclastic sediments were also represented as ore-bearing either in the Gadabay ore field or in the areas located north of it (Arikhdam, Giziljachay, Bitti-Bulag, Samanlig). On the one hand, this greatly increases the perspective of the wide strip (up to 3 km) formed along the Gadabay fault, and on the other hand, it shows the penetration of the ore-bearing of the Jurassic rocks to a greater depth.

It is necessary to pay attention to one aspect. As shown, the Gadabay fracture is of an upthrust type and was formed after mineralization. From this point of view, the study of the Bitti-Bulag copper-arsenic deposit, located some distance from our research object, is practically interesting. In our opinion, one of the main reasons why borehole drilling conducted here in recent years did not give positive results was insufficient consideration of the tectonic position of the deposit. The eastern part of the deposit is covered with a very thick layer of sediments along the Gadabay upthrust. Accordingly, accurate geophysical and geochemical studies should be conducted here first, and only after a positive result we can raise the issue of drilling exploratory wells.

As mentioned above, the folds in the ore field are complicated by a large number of disjunctive dislocations. The latter porphyry stocks have caused intensive alteration of their rocks, especially the formation of secondary quartzite facies and localization of mineralization.

As a result of the conducted research, it was determined that the northwest and submeridional tectonic dislocations are mostly ore-bearing, while the northeast-oriented faults (except ancient uplifts, bending and minor feathering cracks) are non-ore, post-ore age, and reflect the common alterations (brecciation, breaking, silicification, lithonitization of rocks), which are characteristic of most faults.

The role of fracture dislocations is great among the structures that control the localization of separate ore bodies. This includes places where fractures meet feathering cracks, different oriented disjunctive fractures, cracked rock blocks between parallel fractures located close to each other, etc.

The general shape of the ore bodies is close to columnar stockwork. The stockwork body was formed as a result of the filling of different oriented crack systems with mineral matter. The internal structure of stockwork is complex. Differently oriented quartz-, quartz-molybdenite-, quartz-chalcopyrite veinlets, stockwork body, as well as pure pyrite veinlets and veined bodies cutting quartz-diorite and diorite-porphyrite dykes were developed here.

In general, the stockwork is located in intensively cracked rocks corresponding to two featherlike disjunctive dislocation zones. Layerlike copper-porphyry mineralization is observed in separate areas of the stockwork. The attitude of ore bodies alter gradually with depth. Most likely, this is due to the fracture of the ore body into microblocks of different directions during its fall.

Mineralization occurs in the form of linear veinlet-impregnated ore zones in places characterized by morphologically high cracking and permeability. The length of the largest ore zone (Central part of the Garadagh deposit, Kharkhar occurrence) is about 1.5-2.0 km and the width is 700-800 meters. These indicators are 1.5km and 90-210m respectively in the Maarif occurrence (there are two mineralization zones of the same size here), and 1.2km and 800m in Maskhit. The parameters of the remaining ore-bearing zones are small and extend up to several hundred meters.

In order to study the internal structure of the stockwork ore body, we have tried to study the behavior of the ore veinlets in different horizons, which are considered to be part of the stockwork. For this purpose, the results of the horizon passing through the drill hole of cave No. 1, the drilled wells covering the depths of 1550-1060m (well # 36 – drilling point 1452.13 m, depth - 132.0 m; well # 125 – 1493.0 m, depth - 295.0 m; well #1b and 2b - 1545.4 m, depth - 238.0 m; well #4b – 1493.21, depth – 315.0m; well #173 – 1492.1 m, depth – 361.0 m; well #109 – 1492.4 m, depth – 306.0 m; well #179 – 1465.4 m, depth – 326.0 m; well #180 – 1418.5 m, depth – 283.5 m, etc.), the results of borehole drilling (# 150, 161, 160, 167, 296, 162, 163, 172, 171, etc.) used during creating the block diagram of the Garadag field (Fig. 1), geological sections along the exploration lines and other data were used as a reference point.

The analysis of the obtained results shows clearly that the thickness of the ore veinlets increases with depth in the Central part of the Garadag field; another aspect is also evident - the number of cracks per pogon meter decreases. These determined regularities caused the alteration of the quality characteristic of copper-porphyry mineralization.

On the other hand, these regularities show that copper-porphyry mineralization has structural zonation. Veinlet-impregnated type mineralization prevails in the upper horizons of the central part of the deposit, where methosomatism is widespread, while veinlet-vein type mineralization has developed in relatively lower horizons, where metasomatic processes and impregnated ore mineralization didn't occur so much. Probably, this process is related to the extensive occurrence of stretching and exposure processes in the cracks as they go deeper.

In general, the crack systems observed in the copper-porphyry stockwork of the Garadag deposit are attributed to different genetic types and, accordingly, play different roles in the localization of mineralization.

It was possible to distinguish the following genetic types of cracks in the deposit: 1) regionally developed cracks; 2) protoclastic (contraction) broken cracks developed in the dome part of the granodiorite-porphyry intrusive and located parallel to its surface; 3) cracks feathering from depth faults; 4) detaching cracks.

Contoured ore bodies corresponding to industrial amounts of copper usually occupy the upper part of veinlet-impregnated ore zones and pass gradually into poorly mineralized rocks with depth. The intensity of mineralization decreases gradually from the central parts of ore bodies to their edges and depth. According to the data of boreholes, the depth of distribution of primary ores in the ore zones is 400-500 m and probably more.

Hydrothermally altered (sericitized, chloritized, kaolinized, quartzized, etc.) granodiorite- and granosyenite-porphyries, quartz diorite-porphyries are included in the contour of the conditioned ores, which bear veinlet and impregnated mineralization.

Varying degrees of potassium spathization are observed. The mineralization of potassic spathization is poor, are represented by sulphide impregnations, especially by rare scattered chalcopyrite. The amount of sulfides increases significantly during the later process of sericitization and silicification.

Sericitization and silicification are associated with the ore bodies, especially in the inner parts of the ore-bearing zones. The amount of quartz-sericite veinlets and small zones bearing sulfide impregnations and vugs decreases with depth and is replaced by poor and then very poor impregnated-veinlet mineralization. This is noticeable especially in the Central area of the Garadagh field.

In general, the intensity of hydrothermal alteration of wallrocks in the Garadag ore field depends greatly on the intensity of cracking of these rocks.

Since hypogene ore mineralization in stockwork-type copper-porphyry deposits is somewhat scattered, the re-sulfide enrichment zone is of great practical interest. This zone is considered almost the only source of exploitation in some fields. The oxidation zone and also the near-surface washout subzone penetrate rarely deeper than 120-130 m in the Garadag deposit. Mineralization was mainly represented by malachite, hydroxides of iron and manganese, partly by azurite, sometimes by chrysocolla, and very rarely by wulfenite and powellite here.

The re-sulfide enrichment zone is clearly observed in separate boreholes at depths of up to 150-180 meters. The re-sulfide enrichment zone penetrates to a greater depth in intensively cracked and brecciated zones, especially in the upper horizons of these zones, in areas where quartz-sericite-sulfide mineralization is developed.

Structures that determine the localization and distribution of ore mineralization in ore bodies include micro-folding, small cracking, brecciation, cataclase and mylonitization in rocks.

A large part of dykes intrusion into plagiogranite and granodiorite-porphyry intrusives is directly related to the elements of crack tectonics in Garadag, Kharkhar and other areas. In its turn, this provides a good opportunity to study the crack tectonics of copper-porphyry ore zones.

The abovementioned material shows the great importance of crack tectonics in the localization of copper-porphyry mineralization in Garadag, Kharkhar and other deposits.

It has been determined that the Slavyanka transverse fault formed prior to mineralization and is an ore-controlling structure (the western part of the fault does not bear ore), and played an important role in the formation of multidirectional micro fractures and cracks that arranged later veinlet-impregnated, vug-veinlet type minralization.

In order to determine the relationship between small cracks and large disjunctive dislocations, volume cracks of rocks were measured in minings and drill cores. Maximum cracking (up to 50-150) is observed in the zones where disjunctive dislocations develop. The volume cracking decreases dramatically up and down along the section from the dislocation zone and falls to 25-50 cracks per linear meter. There is another aspect that proves the connection of small cracking with large disjunctive dislocations: it is the dimensions of the bedding elements of the cracks; the direction of small cracks (60-70°, 270-280°, 310-320°) usually coincides with the direction of large disjunctive dislocations.

The study of mining and drill cores in the Garadag ore field also shows that copper-porphyry mineralization is more intensively localized in small crack zones in quartz-sericite metasomatites that develop in the zone of influence of disjunctive dislocations.

In order to physically substantiate the ideas about the formation of ore localizing structures, we have also studied the physico-mechanical properties of rocks, more precisely, their elasticity and porosity.

As it is known, the alteration of the elasticity modulus of rocks depends greatly on the alteration of their porosity and mineral composition. For this reason, the elasticity modulus and Poisson's ratio change regularly in metasomatized rocks.

The largest porosity belongs to granodiorite-porphyrites. The rocks of the diabase and diorite-porphyrite dykes do not differ much from each other in terms of their porosity. They have a small elasticity modulus (E= $5{,}53\text{-}5{,}97 \times 10^{-5}$ kg/cm^2), and their Poisson's ratio (0,25-0,27) is relatively large. The abovementioned figures allow to classify dyke rocks as plastic rocks that are less suitable for friable dislocation.

We have repeatedly mentioned above that copper-porphyry deposits in the Garadag ore field are related to granodiorite-porphyry stocks, and as for mineralization, it is mainly localized in quartz-sericite metasomatites. We have tried to distinguish to what extent the elasticity and porosity of rocks alter in a section through the Central ore zone in the Garadag field.

Porosity increases in rocks that have undergone sericitization. As a result of subsequent processes, when silicification occurs on these rocks, the porosity decreases again. The elasticity modulus of granodiorite-porphyries, which are subjected to hydrothermal metasomatism, is $9.5\text{-}9.8 \cdot 10^{-5}$ kg/cm^2, Poisson's ratio - 0.22-0.24. As the degree of sericitization in these rocks increases, their elasticity modulus decreases to $8.5\text{-}7.0 \cdot 10^{-5}$ kg/cm^2 and Poisson's ratio - 0.20-0.14. If silicification occurs on sericitized rocks, the elasticity modulus increases again - 8.1-9.0 x $10 \cdot 10^{-5}$ kg/cm^2, but Poisson's ratio - 0.17-0.16 - remains almost at its previous level.

The porosity of the rocks increases slightly during the process of sericitization, and the rock has an effusive structure. In its turn, this leads to a decrease in the elasticity modulus of the metasomatized rock.

As a result of silicification of sericitized rocks, quartz fills very small cracks and pores, causing an increase in elasticity modulus. Regarding the fact that Poisson's ratio is low during this process, it should probably be explained by the formation of crystalline quartz grains and aggregates during the silicification of rocks.

As it can be seen, the alteration of elastic properties of rocks is closely related to the alteration of mineral content and porosity during sericitization and silicification.

The above suggests that besides major dislocations and various lithological factors, microcracking played an important role in the distribution of copper-porphyry mineralization within the contour of the ore bodies and determines the shape and size of the ore bodies significantly.

Conclusion

1. The regional structures that control the arrangement of the known copper-porphyry deposits and occurrences within the ore region are large northwest-oriented folded-fracturing zones and depth faults that were laid down in the Paleozoic.

2. It is possible to distinguish plicative and disjunctive groups between the ore field and the structures that arrange its deposits.

3. The role of fracturing dislocations is great among the structures that control the localization of separate ore bodies.

4. Structures that determine the localization and distribution of ore mineralization in ore bodies include microfolding, microcracks, brecciation, cataclase and mylonitization in rocks.

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