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Geometrical Analysis of Fractures and Mineralized Veins of Gazkhizan Copper Deposit in Semnan Province, Iran

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Abstract

The Gazkhizan Copper deposit is located in the Troud-Reshm zone, Central Iran. It is situated in a shear zone bounded by the Anjilo and Troud sinistral strike-slip faults from the north and south, respectively. Mineralization is done by siliceous-shear veins along with copper mineralization. About 41 mapping points carried out around the fault outcrops, along with the interpretation of the Win Tensor software data and geometrical analysis of structural features paved our way to study the Riddle pattern in the region. The structural features include sinistral and dextral strike-slip faults, normal faults, reverse faults (rarely), and mineralized veins, as well as different types of shear zone fractures with different grades of copper ore. The mineralized veins in the area are frequent in four types including the R´, R, T, and X fractures, respectively. The highest number of the veins have been formed within the Riddle fractures. Because of the hybrid nature of the fractures, the veins are formed within the tensile fractures, and then they are aligned along the R fractures' strike by the clockwise rotations. The importance and necessity of this research work is as what follows. The definitive reserve of this mineralized area is 434,500 tons of copper ore with an average grade of 1.61% of copper. For this reason, it is necessary to determine and classify the fractures that host this reserve.

1. Introduction

The studied area is located in the north of Chah-Mousa, approximately 161 km from the southeast of Damghan. Chah-Mousa is a part of Troud-Reshm magmatic arc (Chah-Shirin), which is a part of the Central Iran structural zone. The relationship between fractures and mineralized in the Central Iran basin has been investigated by some researchers such as [1]-[5]. Formation and development of fractures is a function of active tectonics that have been investigated in some areas by [6]- [13]. Also new research works, e.g., [14]-[16] have been done near the studied area but the geometrical analysis of fractures is unique to this research work. The rocks are mainly middle to upper Eocene volcanic and to the lesser amount, volcanic-sedimentary with intermediate to mafic composition. The mineralization is in the form of mineralized veins. The siliceous-shear veins contain copper minerals (on the surface, mainly malachite, and to a lesser amount, azurite, as well as chalcocite, quinine, and bornite along with secondary and hydrous iron oxides). The Gazkhizan area is one of the several mining zones of Troud-Reshm magmatic arc, and the evidence of the old mining activities in this area is in the form of excavation zones. The highest copper grade has ever been obtained from this area is 6/78%, and the average copper grade in the ore zones has been estimated to be 0/7%. A total of 24 exploration boreholes were drilled in the west of Chah-Moosa. Meanwhile, aside from obtaining more information on the deposit volume, collating the required data for future plans was also taken into account. Borehole design was undertaken based on the obtained information from field studies, trenches, and through combining them with maps and profiles produced by the IP and RS geophysical operations. Given the restriction of excavation

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comparing with number and extent of the anomalous areas, boreholes were distributed. Based on the significance and priorities of the areas 24 spots were chosen for excavation in the west of Chah-Moosa exploration area. The average grade of Cu for all the boreholes was calculated to be 1/52%.

Based on the exploration studies, the copper mineralization has been formed by veins, and it is related to the tectonic regime. For the first time, the Gazkhizan mine was studied by [17], and the early exploration studies were conducted under the supervision of Mining and Trade organization of Semnan Province.

The studied area is located in the north part of Central Iran in the northern altitude of the Jandagh Desert (Troud-Reshm zone). The Gazkhizan mine is located in the northeast of the Troud-Reshm heights (Figure 1), and it is in the vicinity of the Chah-Mousa active mining zone. Geographic coordinates of the studied area are within 304275 and 305032 longitudes and 3929629 and 3928862 latitudes in the UTM system. This mining zone is located within 125 km southwest of Shahrood and 25 km north-west of Troud, in Semnan province.

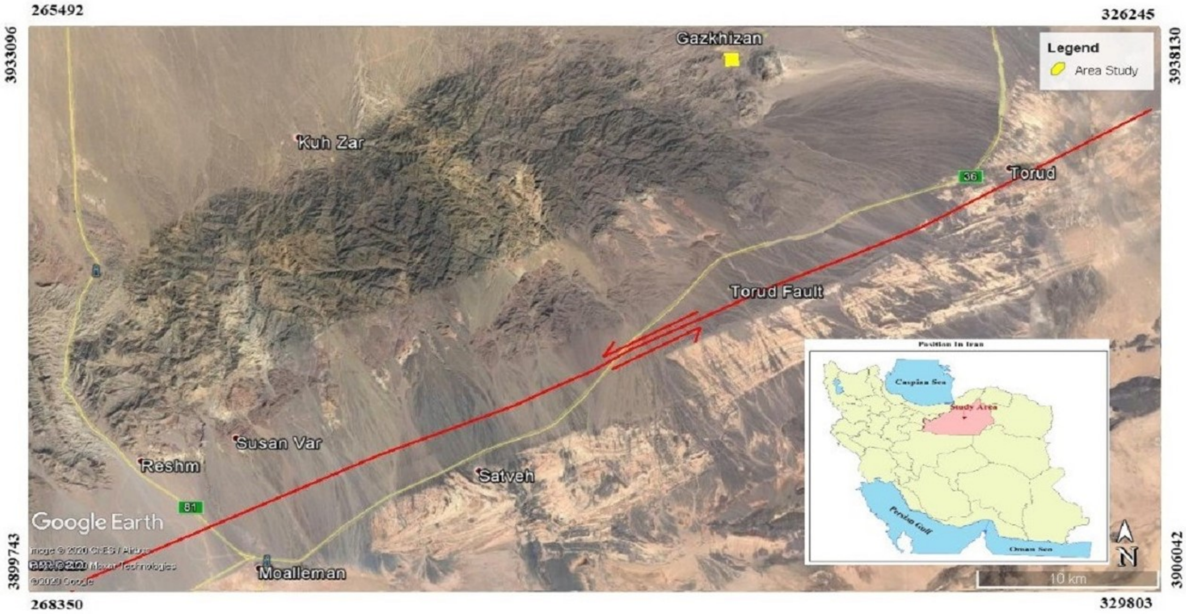

Figure 1. Geographical location of the Gazkhizan mineral area.

2. Materials and Methods

First, before conducting the field study phase, in order to recognize the fracture patterns, lineation and alteration zones, the high-resolution Landsat satellite images were studied. Also, topographic and structural maps (with 1:5000 scale) were produced (Figure 2). After that, the field study phase was conducted for studying the patterns of the (faults and joints) and copper veins. Field studies were conducted in 41 mapping stations close to the outcrops, veins, and mineralization anomalies. Field measurements included the strike, dip, slickenside of the faults, and the type of their filling in each point (Figure 3).

Geophysical data helped us to trace the faults and their directions. Rose diagrams were generated, and their data was interpreted by the Win tensor computer program to determine the pattern of the faults, joints and veins.

These measurements were exported into topographic maps coupled with the results of petrology, paleontology, and mineralogy analyses conducted on obtained samples. The updated geological maps in different scales were produced, digitized and georeferenced using the GIS and accurate location of the stations with 1:1000 scale was produced in ArcGis 9.3.

The slickensides were measured from the fault planes that had clear outcrops in the entire studied area. By analyzing the field data, four major sets of fractures with N-S, E-W, NE-SW, and NW-SE directions were recognized, which were dominant throughout the studied area. Amongst these four sets, the fractures set with N50 E strike to E-W and fracture set with N20W-45 strike and dip were more frequent. Therefore, all the faults and fractures in the studied area were classified within two main groups, NE to SW to E-W and NW-SE trends. The fault planes in the studied area are quite steep, and in most of the cases are almost vertical (Figure 4).

Based on the geometrical data and the interpretation of the fault mechanisms, it has been suggested that the fault plane outcrops with slickensides are the most suitable data for interpretation of the fault's mechanisms. The faults in the area based on the rake angle of their slickensides were classified into two groups. The rake-angle of the slickensides of the first group is less than 30°, which indicates the strike-slip mechanism. These strike-slip faults are dominant faults in the studied area. The rake angle of the second group is more than 30°, and they are dip-slip faults (mainly normal and in some cases reverse faults). However, most of the normal faults in the studied area have strike-slip component.

Figure 6 shows the general array of the slickensides of the faults in the studied area. The slickensides clearly declare the pure strike-slip mechanism or the strike-slip with normal (in some cases reverse) component mechanism.

Another brittle structural feature measured in the studied area is the joints, and about 979 joints were measured during the fieldwork phase (Figure 5). The measured veins were classified into four main groups N-S, E-W, NE-SW, and NW-SE strikes. Rose diagrams data of the measured joints showed that although these joints were widespread, their strikes were between N40-55 W and N35- 40 E. That average dip of the joints is between 70-80 degrees, and their dip direction varies between north to south due to their steep. The surface of the joints is rough, and joints are not curved along their strike. The swarm of the joints are more frequent around the fault zones and veins (Figure 6).

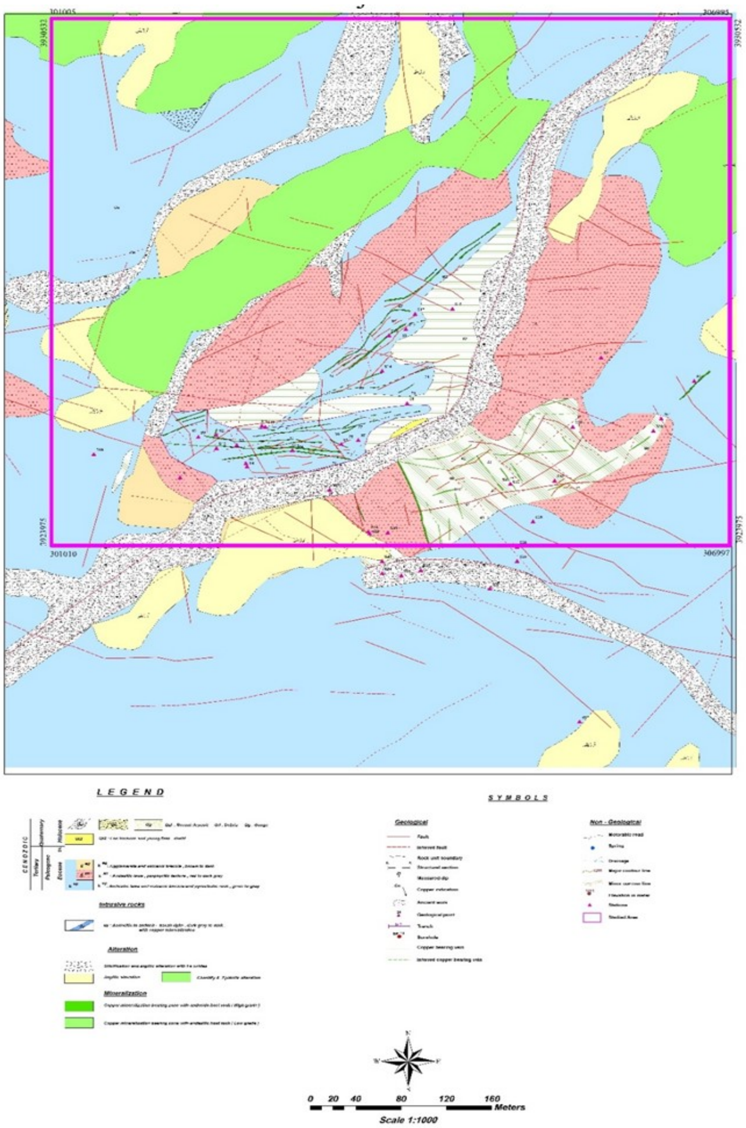

Figure 2. Geological-structural map of the Gazkhizan mineral area with the condition of fractures and its mineralized veins.

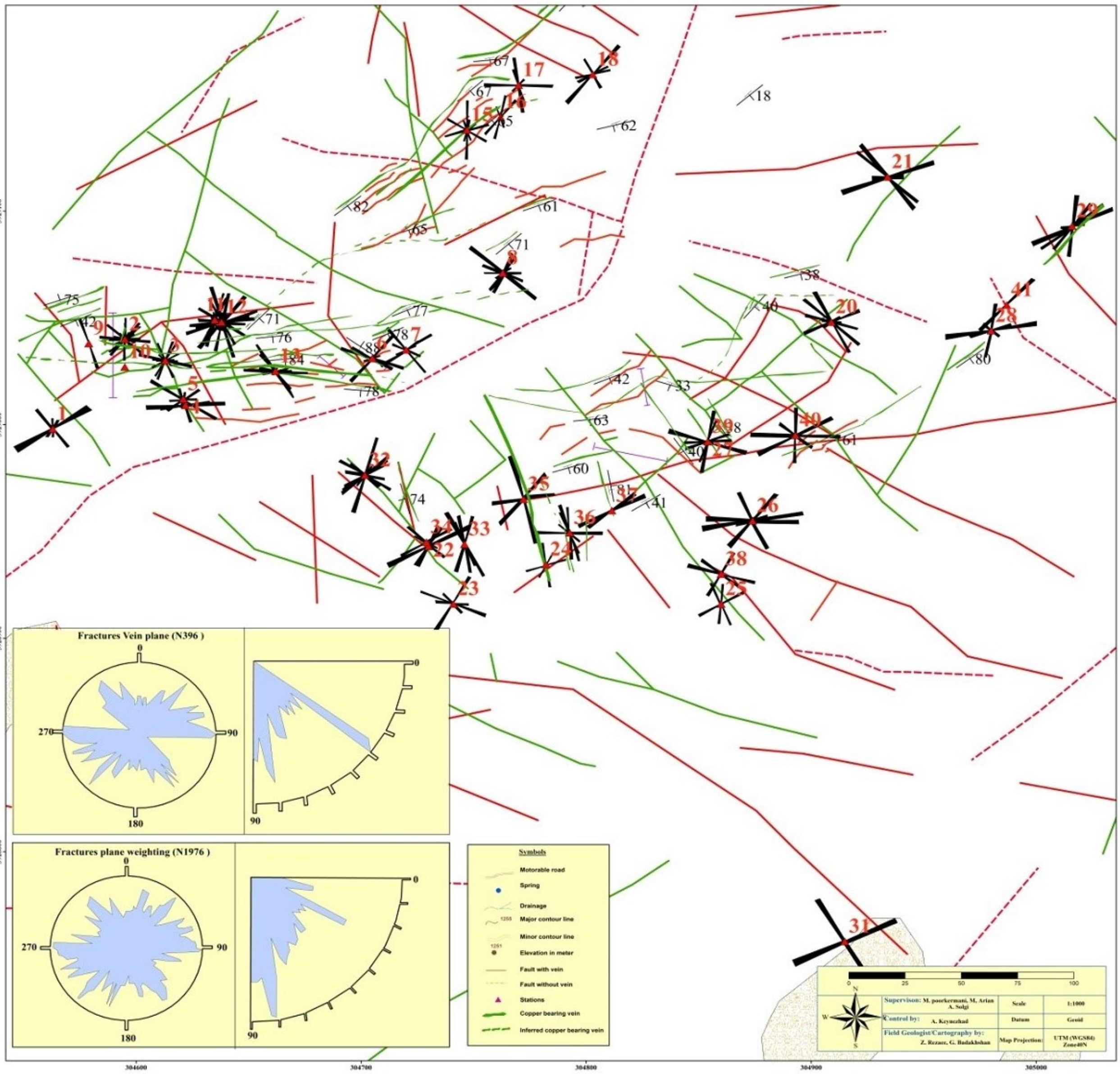

Figure 3. Map of mineralized and non-mineralized fractures of the Gazkhizan area with their residual diagrams in each geological station.

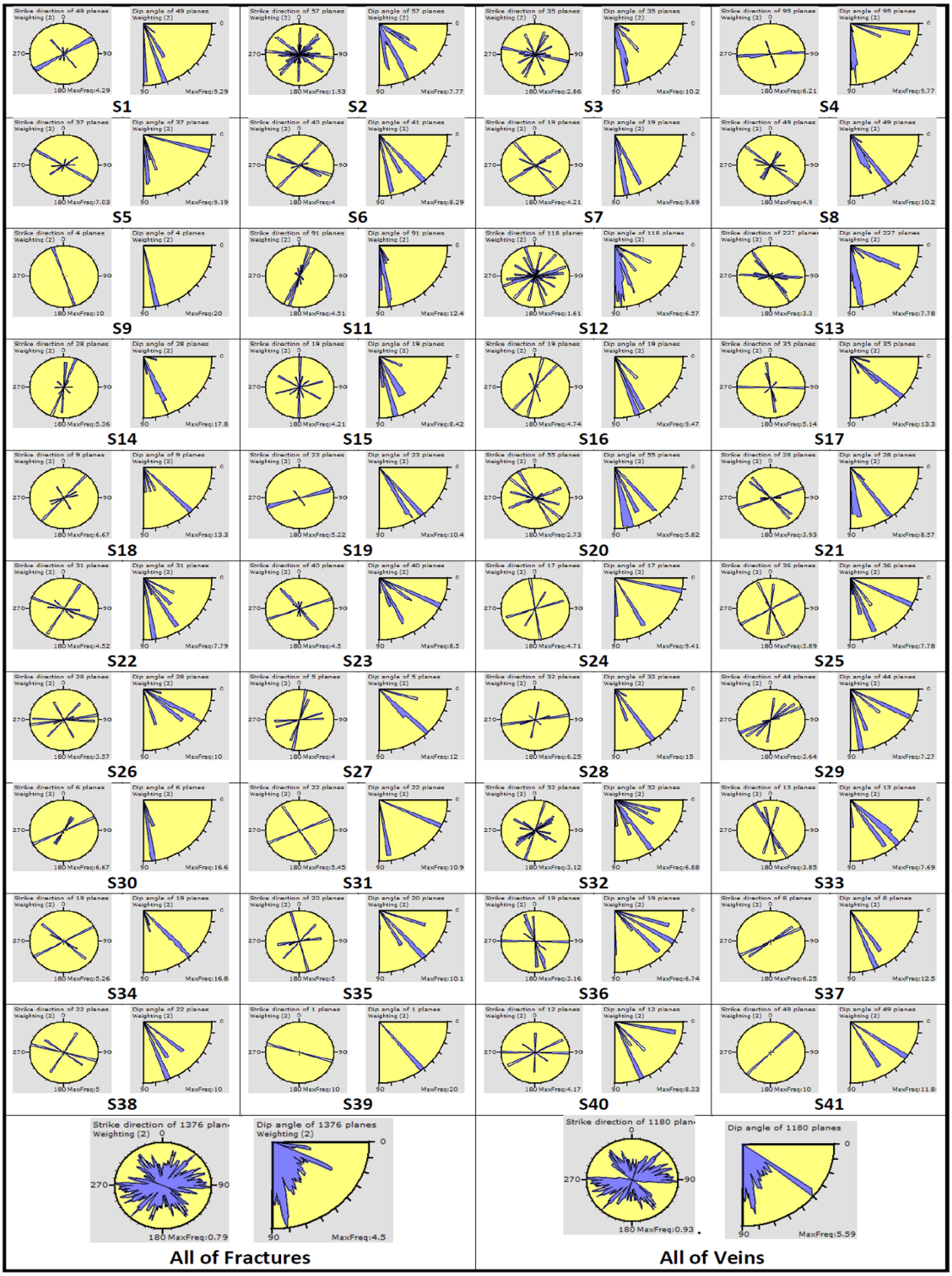

Figure 4. Diagrams of the directional rose and the slope value of fractures in the Gazkhizan region by geological stations and general data of fractures and types of mineralized fractures.

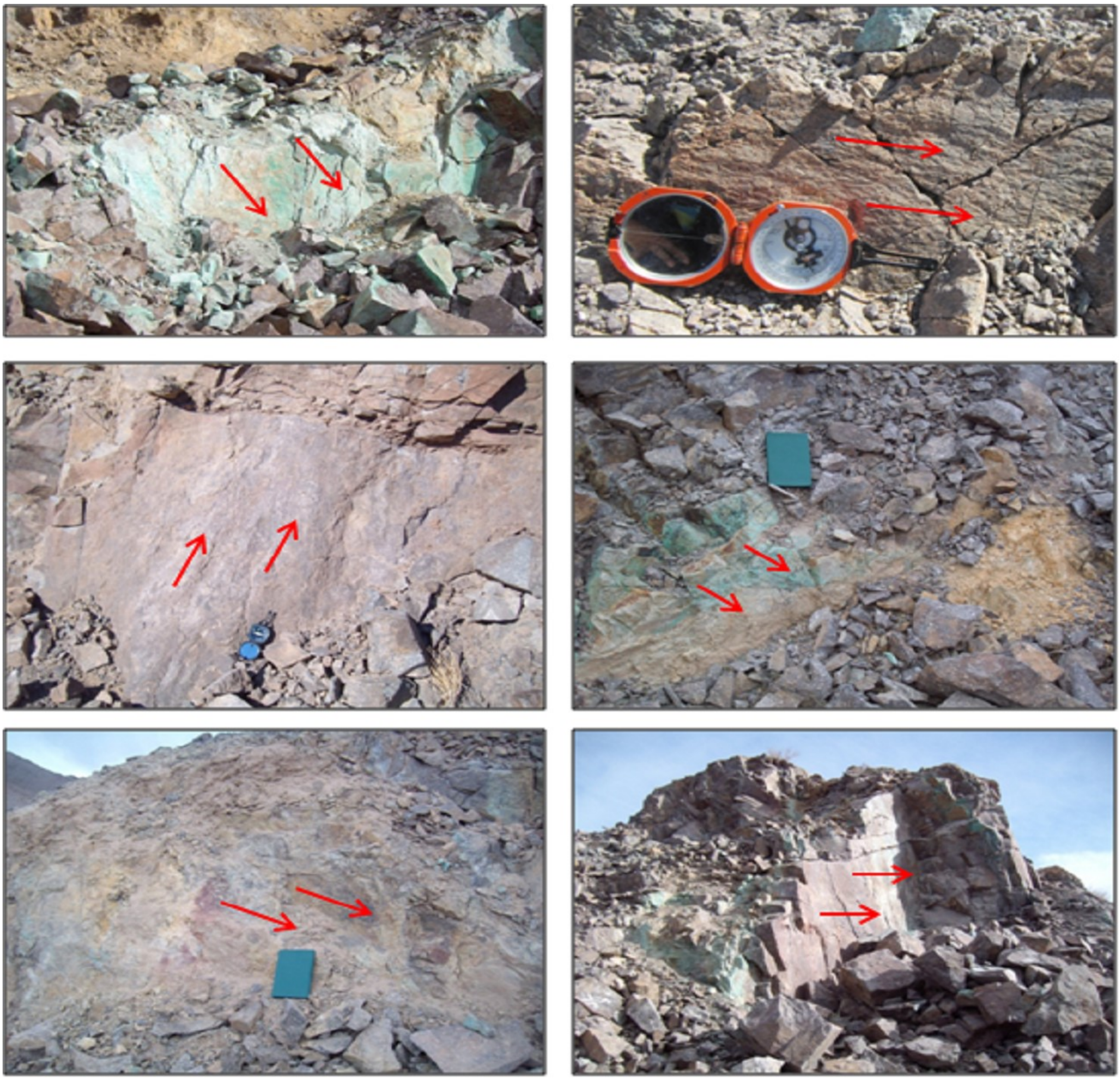

Figure 5. Scratch status of landslides on the surface of various faults in the region, which can easily identify the mechanism of motion of pure slip and slip with tensile and even inverted component.

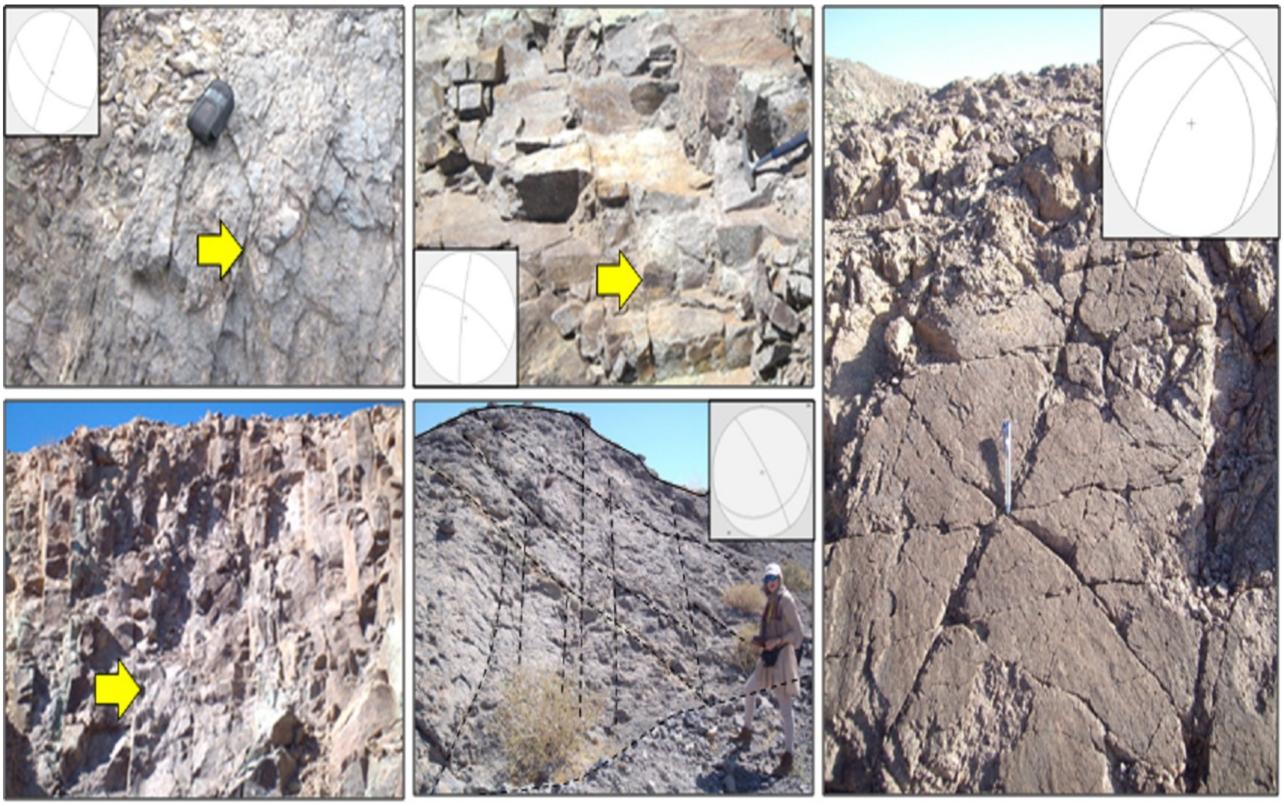

Figure 6. View of the joints of the Gazkhizan area. The status of their plates can be seen in stereographic diagrams.

3. Geological Setting

The Gazkhizan exploration zone is extended in the northeast of Troud-Reshm intrusive-volcanic arc. This area is a shear zone located between two sinistral strike-slip faults, and is bounded by them from south (Troud Fault) and north (Anjilo fault). The strike-slip movements of these faults not only have formed several major fractures, but also have reactivated the older faults and fractures. As a result of reactivation of the older fractures, an extensive local regime created, which led to the emplacement of post-Cretaceous deep to half-deep intrusive bodies in the Chah-Mousa and the Gazkhizan area.

Tectonic movements have occurred during several phases, and developed the mineralization. A major part of the mineralization in the area is the result of magmatism, and filled the existing joints and fractures [18]. The younger joints and fractures have been filled with calcite and limonite. The dominant strike of the fractures filled with the minerals is N245-65 and N225-45. The other fractures with different strikes are less important. Based on the tectonic model proposed by [19], up to Early Cretaceous, a sinistral compressive regime, which was created by the sinistral strike-slip movement of Troud fault and regional compressive stress of the region, was dominant in the area.

The thrust movements towards the east and sinistral shear movements of strike-slip faults and fractures with north-west -southeast trends are thought to be the results of this tectonic regime. After Cretaceous, this tectonic regime in a very short period changed to a tensional regime and caused widespread magmatism and after that turned to a dextral compressive regime that its evidence can be traced till present.

There are two main northeast-southwest and northwest-southeast trends for the regional structures in the south of the Gazkhizan and Chah-Mousa mining zone [20]. According to him, the northeast-southwest trend is the major trend of the fractures and played a major role in the formation of the mineralized veins and gabbroic dykes' emplacement. However, the author suggested that these fractures had the same strike with Troud and Anjillo faults, indicating that the emplacement of Chah-Mousa sub-volcanic bodies is related to the NE-SW fractures. NW-SE fractures are less important in the area, and possibly are younger than the NE-SW ones.

4. Results and Discussion

4.1. Fault patterns

Theoretically, when the maximum compressive stress and deflective tensile stress are horizontal, the strike-slip faults will be formed, and neighboring blocks and slip horizontally along with their strike. Therefore, depending on the direction of the block's movements along with the strike of the faults, a sinistral or dextral shear zone will be formed. Geometrical and kinematic analysis of shears with Riddle pattern is helpful for determining the shear zones related to faulting.

Simultaneous occurrence of the strike-slip shear zones and normal or reverse faults can be interpreted by combining the Riddle and elliptical strain analysis. The Riddle fractures were created and studied by [21] in the lab, by putting the clay block under the simple shear force. The Riddle model simply shows that in a shear zone depending on the inner friction angle (φ), the material under stress will form a complex of predictable structures in the specific strikes. In this research work, the inner friction angle in the Riddle model is 130° that was according to the average amount of crust.

In response to the stress the generated strike-slip faults, a number of geometrical structures will be formed into the shallow deep rocks. In this model, normal faults will be formed perpendicular to the shear zones and parallel to the main displacement zone. So far, many models have tried to determine the effective parameters in the creation of these shears. In all the experiments when the stress difference is enough to overcome the rock's shear strength, a number of shears will form (R shears from initially, and R′ shears form after that). P shear and finally D shear will be formed subsequently. Riddle shears (R) will develop within the same direction of the main displacement zone with $\varphi/_2$ angle (between 15-20 degrees). As the shear process continues, these structures will grow from both sides, and cause minor displacements in a curved path, correspondent to the strike of the normal faults. The R conjugate shears (R′) develop with an angle equal to 90-$\varphi/_2$ (between 60-75 degrees) to the main displacement zone in the opposite direction. P shears with $\varphi/_2$ angle to the main displacement zone is similar to R shears, and their shear direction is parallel to the main displacement zone.

P shears are less common than R and R′, and maybe bigger displacement is required for them to form. P conjugate shears can form with P shears exactly like R′ and R shears but they have less importance compared with the other shears. The direction of the P′ shears displacement is opposite of the main displacement zone.

Y shears and D shears form parallel to the main zone. R and P shears have En echelon pattern, while the R′ shears act as the interconnection between other shears. All the structures in this shear zone (including thrust and reverse faults as well as the fold axis) approximately are perpendicular to the main compressive stress within the 45° with the main displacement zone [22]. However, it should be considered that all the mentioned angles are measured clockwise in dextral shear zone and anti-clockwise in the sinistral shear zones.

4.2. Geometrical analysis of fractures

Geometrical analysis of the fractures in the studied area requires specific consideration of the particular geo-structural situation of the Gazkhizan area due to the fact of being located in the Troud-Reshm shear zone, which will be discussed further. The geometrical pattern of the structural elements in the Gazkhizan mining area is affected by the geometrical faults and fractures pattern of Troud and Anjilo sinistral strike-slip faults that bound the studied area from south and north, respectively. There was no evidence of folding in the studied area since all the structural elements of the area were formed under the brittle condition, possibly due to lithology of the area and rapid stress application which needs to be studied further.

The brittle structural elements of the area include faults, joints, and veins. Faults were measured during the field study in the area classified into three groups:

1. Most of the measured faults were strike-slip, and slickensides of their planes showed that both sinistral and dextral displacement. These faults correspond to the pattern of the shear zone faults, and confirm the Riddle fractures (R) and anti-Riddle (R′) and D fractures (Figure 7).

2. The second group of the faults are normal, based on their slickensides the three types of displacement can be recognized:

A) One sub-group of these faults does not show any displacement around their strike.

B) Another sub-group is conjugate faults with convergent dip that form grabens (Figure 8); they have usually been opening along with their strike.

C) The third sub-group is the combination of subgroup A and B, having both normal and strike-slip mechanism (Figure 9). These faults correspond to the patterns of shear zones faults, and confirm X and T fractures.

3. The faults of the third group are mainly the reverse ones that are not common in the area. The existence of them is essential in the shear zones because they modify the stresses produced by the shear movements. Along with the strike of these faults, no mineralized veins and no evidence of mineralization were sighted (Figure 10).

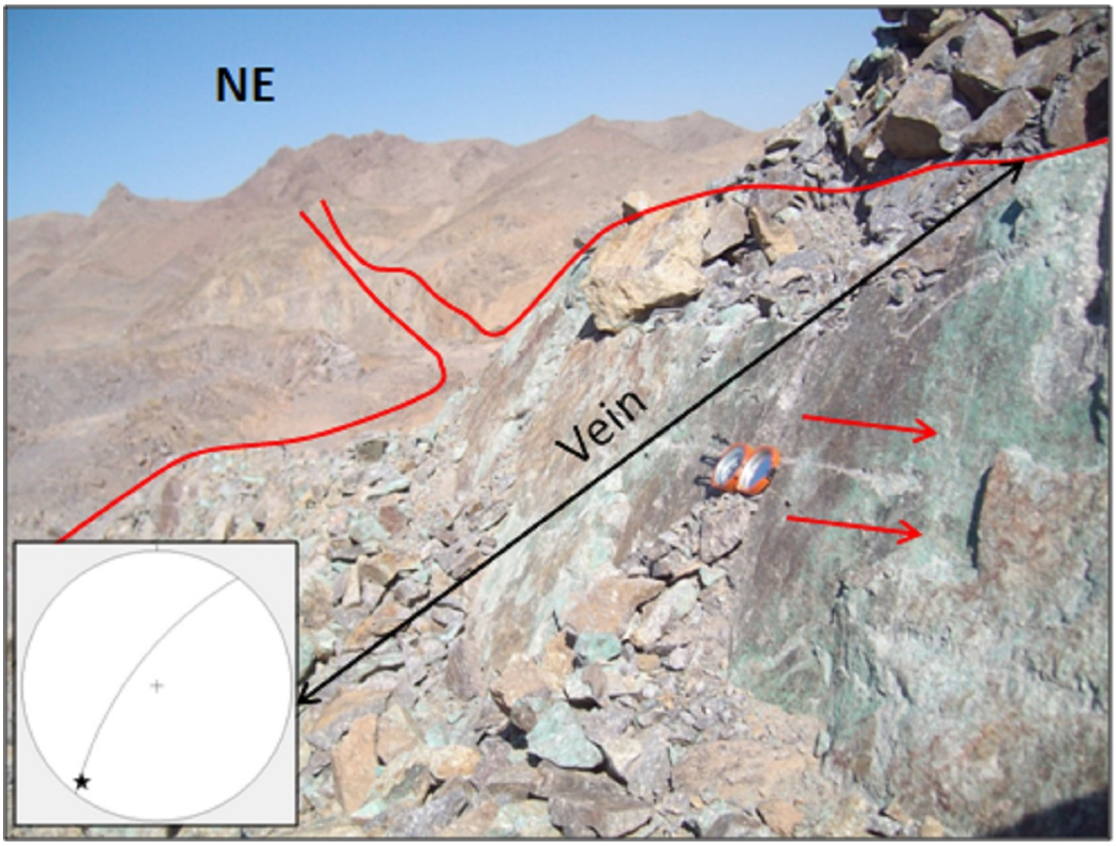

Figure 7. Left-slip faults along the R fractures along which copper ores are placed.

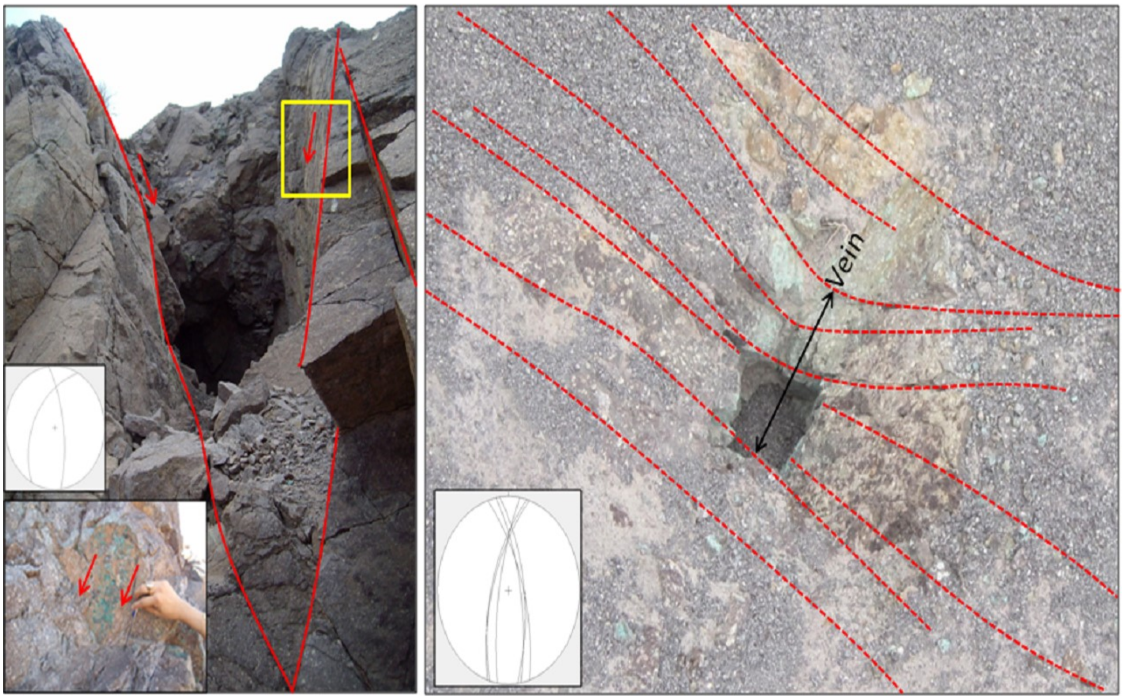

Figure 8. Pair of convergent (normal) tensile faults along T-fractures containing mineralized veins. (The view is in the figure on the top right.)

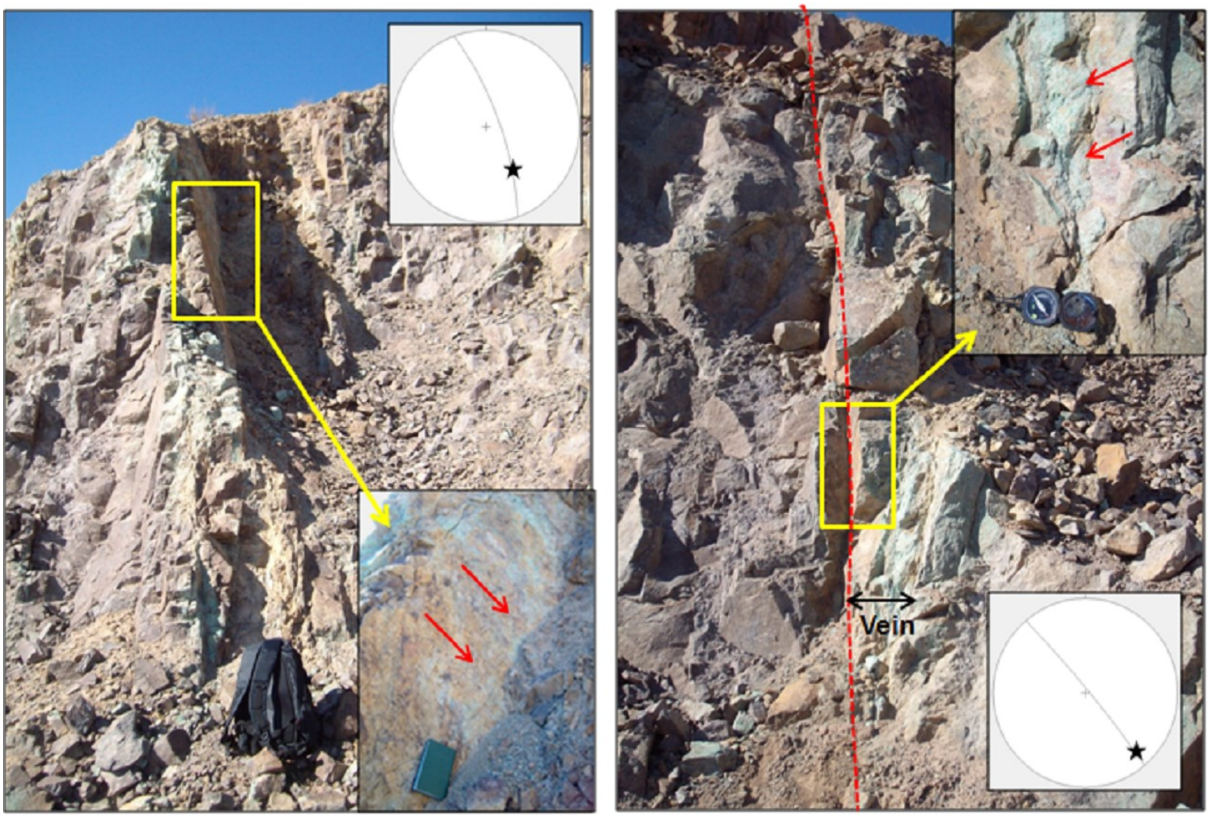

Figure 9. Tensile faults with strike-slip component (oblique strike-slip) along X-fractures containing mineralized veins.

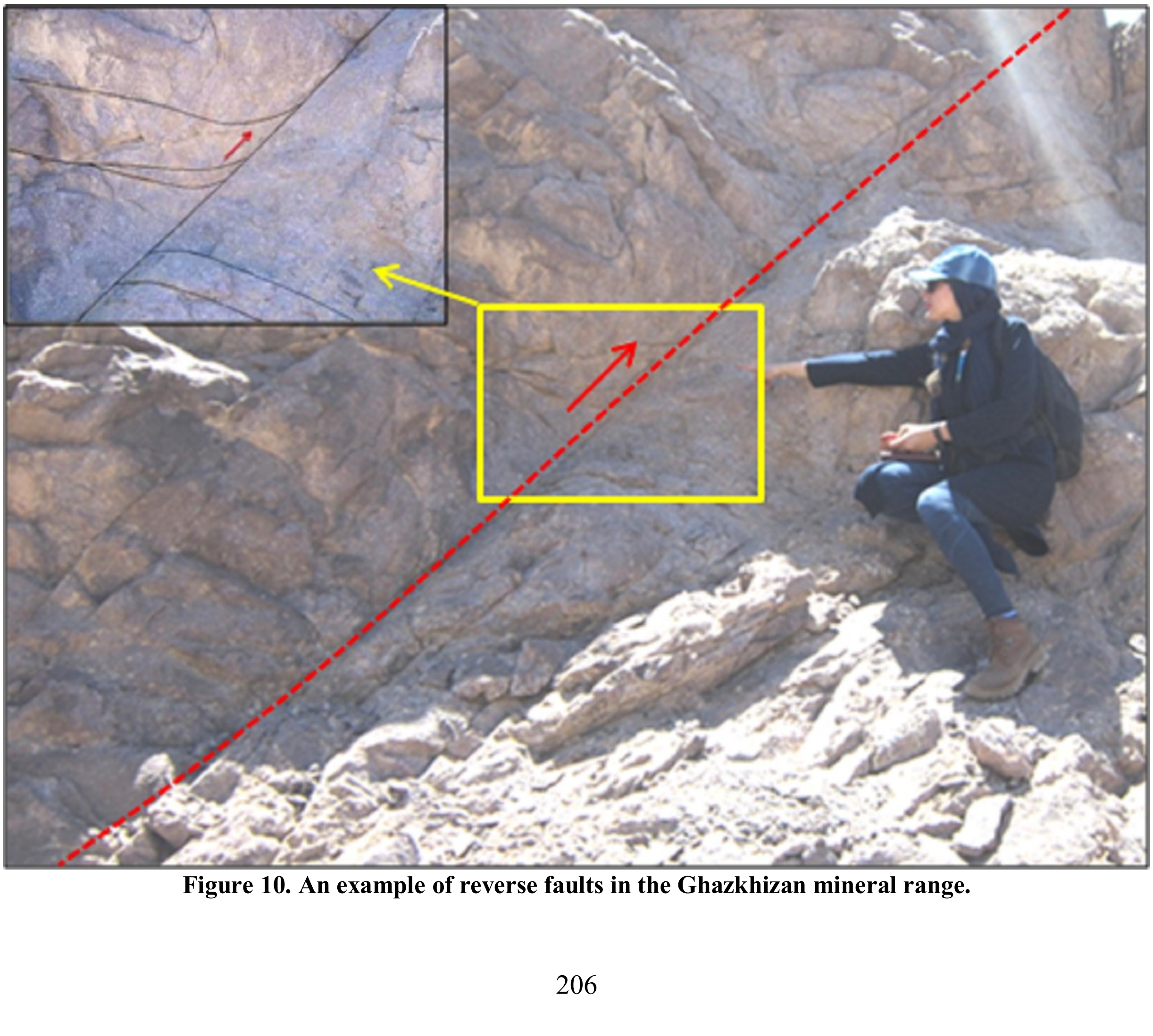

Figure 10. An example of reverse faults in the Ghazkhizan mineral range.

4.3. Riddle fractures

These fractures are the main ones in the area, and in fact, the main veins in the Gazkhizan area flowing along have been formed around but parallel to that. As we can see in the Rose diagrams of the fractures, that have N050E strike to E-W (including D fractures). The dip angles of the fault planes are between 60 to 90°. Some of the Riddle fractures of this area have been raptured, and mineralized veins that have been emplaced in them. Some of these faults are in the smaller scale, and they do not have any rapture or their raptures are very small, and mineralization in them are in the form of tiny malachite veins along their strike. The importance of these fractures has the following generations:

A. Some of these fractures despite showing the pattern of Riddle faults, are dip-slip (Figure 11). They have wide raptures, and contain thick mineralized veins.

B. Some of these fractures are pure dextral strike-slip, and have minor rapture, and regularly contain mineralized veins.

C. Some of these faults are pure dextral strike-slip without any sign of mineralization along with their strike.

From the type A to the type C, the fractures become older. The type A Riddle fractures have N50E strike to E-W. There are two theories for their formation:

1) Considering the direction of the shear in the shear zone, T tensile fractures have rotated during the time, and have become parallel to the pattern of the Riddle faults. They have obtained dextral slip components. Therefore, the normal dip-slip component is older than the strike-slip component in these faults.

2) The second theory indicates that these faults have pure Riddle strike-slip but due to location in a tensile basin, they have been opened under the influence of tensile stress, and the mineralized veins have emplaced through them. In this way, the strike-slip shear is older than the tension mechanism. Since there was no evidence of both normal and strike-slip slickensides in any sample, we were not able to study these theories; as a result, they need further research works.

These faults with sinistral strike-slip function are the least frequent in the area. Unlike the Riddle faults, the anti-Riddle faults are in small scale, and they have N-S trend. These fractures have no veins, and sometimes they show sign of copper mineralization as malachite minerals. Also, kaolinitic and limonitic alteration is quite frequent along with their strike.

Tensile fractures are the second group of the important fractures in the Gazkhizan area. They have N20E-40 E strike and dip for the T fractures and N20W-45W strike and dip for the X tensile-strike-slip fractures. The dip angle of these fractures is between 75 to 90°, and in the rare case in the small faults, the dip is between 40 to 45°. These fractures are classified into three groups:

1) Small normal faults that usually are single ones with low dip angle, and there is no sign of opening and mineralization along with their strike. It seems that these faults have been formed in the area during the reduction of tensile stress in the area, and they usually have a role in the dip-slip displacement of other fractures. In some cases, they have mineralization along with their strike.

2) There are conjugate normal faults with average length with convergent dip. They are strike-slip with the dip-slip component, and are more frequent in the form of graben. These faults mainly have X shear fractures, and their strike and dip are N20W-45W. These conjugate faults contain mineralized veins with signs of intense mining in them. They show moderate opening along with their strike. This opening and tensile component along with the strike of these faults are because of gradual Riddle tensile process in the area.

3) Other normal faults aside from the normal mechanism have the strike-slip mechanism. The main mechanism of these faults is normal but due to some local shear stress, they have obtained strike-slip components. These faults have mineralized veins along with their strike in the area. They are more correspondent with T fractures and have N20E-40E strike and dip. However, in some cases, they are quite steep between 70° to vertical.

Opening these fractures is quite considerable, and reaches to several meters and plus to mineralized veins have different types of alteration (argillitic, limonitic and hematitic), the reason of strike-slip components in these faults were discussed in the Riddle fractures section.

In the Troud-Reshm shear zone, systematic fractures have occurred gradually in different directions with development of the shear zone, and from older to younger, include X, D, P, R′, R, T, which all of these fractures were recognized and studied. Our field measurements in the studied area confirmed the emplacement of mineralized veins along with the strike of the most of the fractures. Mineralization mostly had the form of old malachite. Mineralization in this mining zone includes the forms of veins and without veins.

1) Mineralization within the veins is in the form of a few centimeters to a few m thick veins, which is economically importance. These veins are located within the R > X > R′ > T fractures, which have the most frequent in R fractures and least frequent in T fractures.

2) Mineralization in the non-vein form is in the widespread mineralization; it has patches inside the host rock, within the fractures. These patches have been dispatched from magma by deep local fractures and tensile forces. It has been documented within the D and P fractures. Table 1 summarizes the mineralized fractures of the Gazkhizan mining area.

As we can see from the table, copper mineralization is quite frequent in all shear zones fractures but the fractures with mineralized veins are common within T, R, R′, and X fractures, respectively, and mostly they have been emplaced along the strike of Riddle fractures. As mentioned before, the Gazkhizan area is heavily emplaced by these strike-slip Riddle faults, and most of the fractures in the area have been formed parallel to major Riddle fractures. After them, the X fractures that contain mineralized veins are the second most frequent fractures in the area. Although these fractures are the youngest fractures of the shear zone and are frequent in the developed shear zone, they have a high frequency in the studied area. It confirms that the Gazkhizan shear zone is developed, and the opening rate of the cracks and normal component of the faults confirms that this area is located within a tensile zone.

The mineralized veins within R′ anti-Riddle fractures are the third most frequent type of mineralization in the area, and finally, the mineralized veins within the tensile T fractures are the least frequent one. The thickest mineralized veins are located within the Riddle fractures, and in some cases, their thickness reaches up to 4 m (Figure 14). The densest alteration activities have also occurred in the Riddle fractures due to hydrothermal processes. However, almost most of the veins in the studied area regardless of their fracture type, associate with limonite alteration. However, in the Riddle veins plus to limonitic alteration, kaolinite and hematitic alterations exist as well (Figure 15). It should be mentioned that amount of the dip in all the veins change between 37° to vertical.

Chemical analysis of copper vein suggested that the Riddle fractures had the maximum grade of copper; as mentioned before, the Riddle fractures have the most and thickest copper veins along with the widest range of alteration. The T and R′ fractures have the minimum copper grade. At the time of formation of the P and D fractures, the mineralization was in its lowest thin peak form and scattered malachite patches. As the shear zones developed at the time of formation of the X fractures, mineralization peaked up again and formed mineralized copper veins with high copper grade. It suggests that the mineralization in the Gazkhizan area took place in two mineralization phases with a short gap (Figure 16). Based on the type and grade of mineralization in them, they had the same genesis based on the displacement occurred by these fractures in the Eocene rocks, that must be post-Eocene. This theory should be discussed further that.

From the beginning of the regional studies, the location of the Gazkhizan mineral zone on the left shear zone in Troud-Rashm prepares the geologists to face specific types of fractures in these areas if such fractures are found in abundance in all this shear zone [23]. Geometrical analysis of these fractures showed the existence of three important categories. Most of the faults had a strike-slip mechanism, and the scratch status of the landslides confirmed both left and right sections. The correspondence of these faults with the pattern of shear zone faults indicated Riddle (R) and anti-Riddle (R ') and D fractures. The second group of the faults have a normal mechanism. The scratch status of landslides in the faults showed three different types of movement: A: A group of these faults are single faults and no openings can be seen along with them. B: The other group is in the form of fault pairs with convergent slope and have a graben shape, which usually has openings along with them. A: The next category is a group of faults that includes first and second types; in addition to the normal mechanism, there is a non-slip mechanism, and in other words, these faults are oblique slip. All of these faults have openings. The correspondence of these faults with the pattern of shear zone faults indicates the X and T fractures, and the third category of faults includes small inverted faults that are rarely visible in this area, and along with these fractures, no mineralized veins or even scattered mineralization were seen. Further investigation of these faults showed continuous dynamics and active motion. Existence of a large number of older faults with slip scratches with dual components such as normal slip faults with left or right components, and on the other hand, the existence of newer faults with pure slip slope or pure slip extension mechanism shows regional dynamics. These dynamics are moved left on the regional shear zone in a clockwise direction, and as long as the Trudeau and Angelo faults are active, this clockwise movement of fractures will continue. This movement and rotation have caused the old fractures to change from one type to another and show a dual mechanism, and new fractures with a pure mechanism are created. For example, old T-fractures with a purely normal mechanism rotate clockwise in place of the Riddle fractures, and have a strike-slip component, and are in fact hybrid (dual). This is why in the studied area, most of the mineralized veins are expected to be along with the T fractures, and are now located along with the Riddle fractures, and in place of T fractures, new, vein-free tensile fractures have been formed. This clockwise rotation and hybridization are seen in all fractures, and the involvement of X fractures in this process can be considered as an indication of the advanced shear zone such as Central Alborz

Since the strike-slip faults are the most significant structural elements of the Gazkhizan mining area, they play a remarkable role in every proposed tectonic scenario that can explain all the structural features of the area. Geometrical analysis of the sinistral and dextral strike-slip faults as well as other structural features including normal faults and reverse faults (in rare cases), and mineralized with different grades of copper along with the strike of various fractures of Troud-Reshm shear zone helped us to determine and propose the Riddle pattern of this area.

Systematic fractures formed in a different direction at the same time with the evolution of the shear zone and from older to younger are T, R, R′, P, D, and X, which all of them were recognized and studied in this research work. The X fractures indicate the development of the shear that is advanced, and it seems that all the mentioned fractures are turning to each other in the clockwise direction, in the most of the cases the strike-slip faults with normal components or normal faults with the strike-slip component are dip-slip faults and their fault planes are very steep to vertical. The other scenario that can be proposed for this area is that it is located in a tensile zone that to some extent is supported by the field evidence. However, it needs further investigations. The results of this research work indicate that the structural features of the studied area provide a suitable environment for precipitation of the hydrothermal fluids; field observation indicates that the fractures are very deep.

Copper mineralization is widespread in all the fractures of the shear zone but the fractures with mineralization veins were emplaced in T, R, R′, and X fractures of the shear zone in age order, and most of the veins were emplaced along with the strike of Riddle fractures. The Gazkhizan is heavily impacted by Riddle strike-slip faults, and most of the fractures have been formed parallel. The emplaced veins in the X fracture are the second most frequent fractures that the mineralized veins emplaced through the R′ anti-Riddle fracture are the third frequent fractures, and finally, the T tensile fracture is the least frequent one. The reason behind that is because of the advanced shear zone and clockwise rotation of the structures; in fact, the fractures of this area turn to each other and are hybrid.

In other words, most of the R fractures previously were T fractures but due to ongoing clockwise shear, they turned to R, and in some cases, D fractures. This fact justifies the existence of the strike-slip faults with normal components and normal faults with strike-slip components are, in fact, oblique-slip faults. It can be concluded that the veins first, formed within the tensile fractures and gradually were elongated along with the strike of R fractures due to gradual clockwise rotation. Meanwhile, younger T and R fracture were formed and obtained pure normal and strike-slip components, respectively. With considering the age order of the fractures in the shear zone and the grade of the copper obtained from the mineralized fractures, one phase of mineralization with two peaks and one through phase for the area can be concluded.

Totally ~562 m of excavation was undertaken, and 191 core samples were collected. Based on the obtained results, the core sample number 4 from BH18 on the east of area B shows the highest Cu grade up to 6.78% for 3 m. This borehole also has the highest average of Cu grade amongst all the boreholes (2/42%), and the lowest average grade belongs to boreholes BH24 on the west of area D.

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with the strike of one of the Riddle fractures of the Troud-Reshm shear zone and minor dextral strike-slip that have been formed around but parallel to that. As we can see in the Rose diagrams of the fractures, that have N050E strike to E-W (including D fractures). The dip angles of the fault planes are between 60 to 90°. Some of the Riddle fractures of this area have raptured, and mineralized veins that have been emplaced in them. Some of these faults are in the smaller scale, and they do not have any rapture or their raptures are very small, and mineralization in them are in the form of tiny malachite veins along their strike. The importance of these fractures has the following generations:

A. Some of these fractures despite showing the pattern of Riddle faults, are dip-slip (Figure 11). They have wide raptures, and contain thick mineralized veins.

B. Some of these fractures are pure dextral strike-slip, and have minor rapture, and regularly contain mineralized veins.

C. Some of these faults are pure dextral strike-slip without any sign of mineralization along with their strike.

From the type A to the type C, the fractures become older. The type A Riddle fractures have N50E strike to E-W. There are two theories for their formation:

1) Considering the direction of the shear in the shear zone, T tensile fractures have rotated during the time, and have become parallel to the pattern of the Riddle faults. They have obtained dextral slip components. Therefore, the normal dip-slip component is older than the strike-slip component in these faults.

2) The second theory indicates that these faults have pure Riddle strike-slip but due to location in a tensile basin, they have been opened under the influence of tensile stress, and the mineralized veins have emplaced through them. In this way, the strike-slip shear is older than the tension mechanism. Since there was no evidence of both normal and strike-slip slickensides in any sample, we were not able to study these theories; as a result, they need further research works.

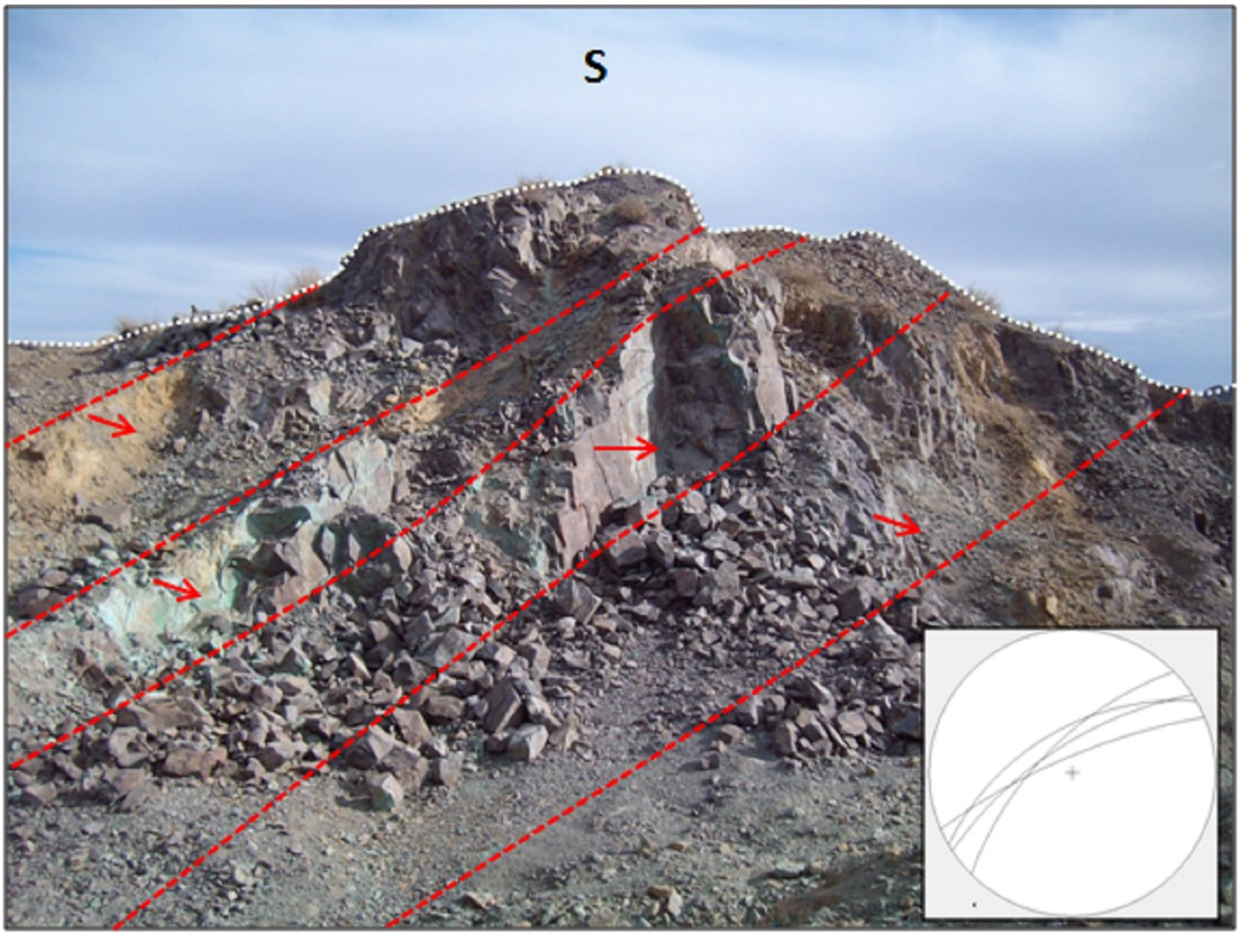

Figure 11. Riddle faults at station S1 with a straightforward strike-slip mechanism and in some cases with a tensile component that has been associated with mineralization.

4.4. Anti-riddle fractures

These faults with sinistral strike-slip function are the least frequent in the area. Unlike the Riddle faults, the anti-Riddle faults are in small scale, and they have N-S trend. These fractures have no veins, and sometimes they show sign of copper mineralization as malachite minerals. Also, kaolinitic and limonitic alteration is quite frequent along with their strike.

4.5. Tensile fractures

Tensile fractures are the second group of the important fractures in the Gazkhizan area. They have N20E-40 E strike and dip for the T fractures and N20W-45W strike and dip for the X tensile-strike-slip fractures. The dip angle of these fractures is between 75 to 90°, and in the rare case in the small faults, the dip is between 40 to 45°. These fractures are classified into three groups:

1) Small normal faults that usually are single ones with low dip angle, and there is no sign of opening and mineralization along with their strike. It seems that these faults have been formed in the area during the reduction of tensile stress in the area, and they usually have a role in the dip-slip displacement of other fractures. In some cases, they have mineralization along with their strike.

2) There are conjugate normal faults with average length with convergent dip. They are strike-slip with the dip-slip component, and are more frequent in the form of graben. These faults mainly have X shear fractures, and their strike and dip are N20W-45W. These conjugate faults contain mineralized veins with signs of intense mining in them. They show moderate opening along with their strike. This opening and tensile component along with the strike of these faults are because of gradual Riddle tensile process in the area.

3) Other normal faults aside from the normal mechanism have the strike-slip mechanism. The main mechanism of these faults is normal but due to some local shear stress, they have obtained strike-slip components. These faults have mineralized veins along with their strike in the area. They are more correspondent with T fractures and have N20E-40E strike and dip. However, in some cases, they are quite steep between 70° to vertical.

Opening these fractures is quite considerable, and reaches to several meters and plus to mineralized veins have different types of alteration (argillitic, limonitic and hematitic), the reason of strike-slip components in these faults were discussed in the Riddle fractures section.

4.6. Mineralized veins

In the Troud-Reshm shear zone, systematic fractures have occurred gradually in different directions with development of the shear zone, and from older to younger, include X, D, P, R´, R, T, which all of these fractures were recognized and studied. Our field measurements in the studied area confirmed the emplacement of mineralized veins along with the strike of the most of the fractures. Mineralization mostly had the form of old malachite. Mineralization in this mining zone includes the forms of veins and without veins.

1) Mineralization within the veins is in the form of a few centimeters to a few m thick veins, which is economically importance. These veins are located within the R > X > R´ > T fractures, which have the most frequent in R fractures and least frequent in T fractures.

2) Mineralization in the non-vein form is in the widespread mineralization; it has patches inside the host rock, within the fractures. These patches have been dispatched from magma by deep local fractures and tensile forces. It has been documented within the D and P fractures. Table 1 summarizes the mineralized fractures of the Gazkhizan mining area.

Table 1. Status of mineralized veins in fractures with mineralization of the Gazkhizan mineral area.

Mineralization Phase	Alteration Degree	Alteration	Thickness	Copper Grade		Relative Frequency	Copper Vein	Fracture Type Sorted by formed in Shear zones
				Average	Maximum			
1	Low	Limo	<30cm	1.81	4.65	Moderate	*	T
	High	Limo,Kao,Hema	<4m	2.42	6.78	Very High	*	R
	Low	Limo	<70cm	1.65	3.2	High	*	R’
There is evidence of scattered non-vein mineralization along the strike of these fractures							-	P
"							-	D
2	Moderate	Limo,Kao	<20CM	1.88	3.41	High	*	X

As we can see from the table, copper mineralization is quite frequent in all shear zones fractures but the fractures with mineralized veins are common within T, R, R´, and X fractures, respectively, and mostly they have been emplaced along the strike of Riddle fractures. As mentioned before, the Gazkhizan area is heavily emplaced by these strike-slip Riddle faults, and most of the fractures in the area have been formed parallel to major Riddle fractures. After them, the X fractures that contain mineralized veins are the second most frequent fractures in the area. Although these fractures are the youngest fractures of the shear zone and are frequent in the developed shear zone, they have a high frequency in the studied area. It confirms that the Gazkhizan shear zone is developed, and the opening rate of the cracks and normal component of the faults confirms that this area is located within a tensile zone.

The mineralized veins within R´ anti-Riddle fractures are the third most frequent type of mineralization in the area, and finally, the mineralized veins within the tensile T fractures are the least frequent one. The thickest mineralized veins are located within the Riddle fractures, and in some cases, their thickness reaches up to 4 m (Figure 14). The densest alteration activities have also occurred in the Riddle fractures due to hydrothermal processes. However, almost most of the veins in the studied area regardless of their fracture type, associate with limonite alteration. However, in the Riddle veins plus to limonitic alteration, kaolinite and hematitic alterations exist as well (Figure 15). It should be mentioned that amount of the dip in all the veins change between 37° to vertical.

Chemical analysis of copper vein suggested that the Riddle fractures had the maximum grade of copper; as mentioned before, the Riddle fractures have the most and thickest copper veins along with the widest range of alteration. The T and R´ fractures have the minimum copper grade. At the time of formation of the P and D fractures, the mineralization was in its lowest thin peak form and scattered malachite patches. As the shear zones developed at the time of formation of the X fractures, mineralization peaked up again and formed mineralized copper veins with high copper grade. It suggests that the mineralization in the Gazkhizan area took place in two mineralization phases with a short gap (Figure 16). Based on the type and grade of mineralization in them, they had the same genesis based on the displacement occurred by these fractures in the Eocene rocks, that must be post-Eocene. This theory should be discussed further that.

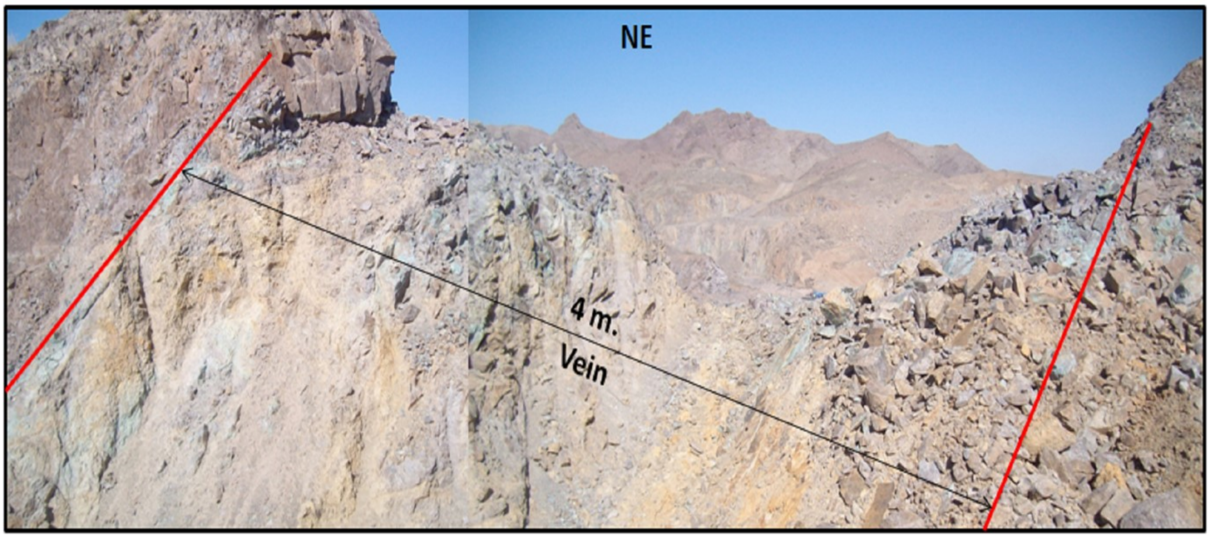

Figure 14. Existence of mineralized veins with a thickness of about 4 m in Riddle fractures of the Gazakhizan area in S27 with extensive limonite alteration.

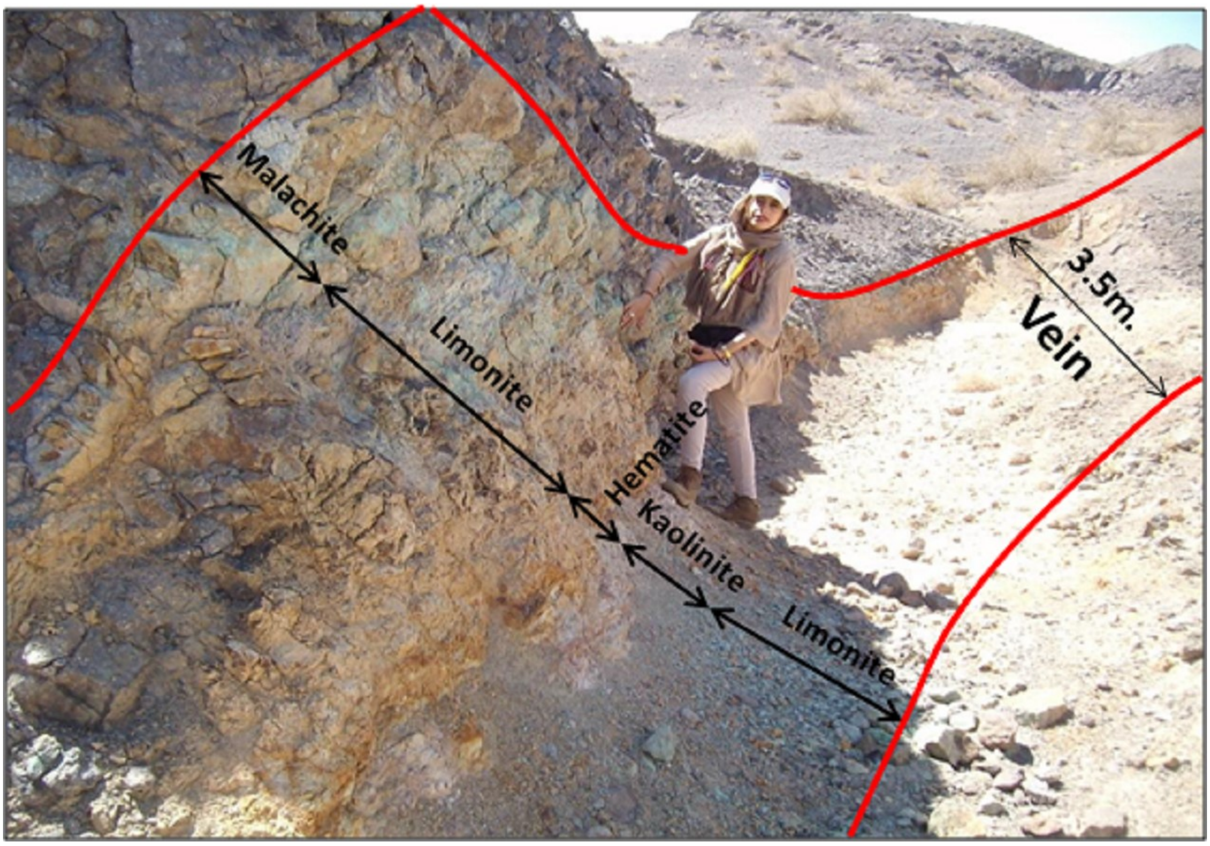

Figure 15. Existence of limonitic, kaolinite, and hematite alterations along with malachite ores in Riddle fractures of the Gazkhizan area in S30 (look north).

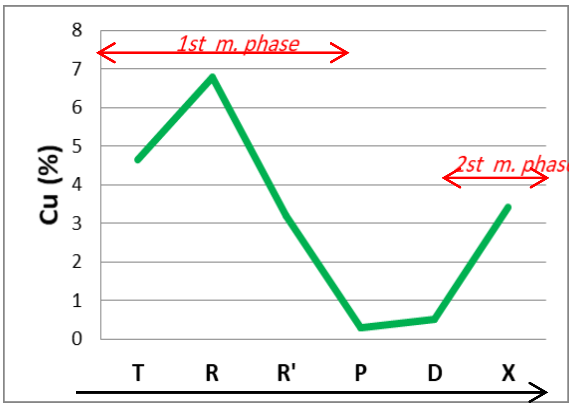

Figure 16. Hypothesis of formation of two phases of vein copper ores mineralization with respect to the order of fractures and the percentage of copper grade in Gazkhizan mineral range.

4.7. Discussion

From the beginning of the regional studies, the location of the Gazkhizan mineral zone on the left shear zone in Troud-Rashm prepares the geologists to face specific types of fractures in these areas if such fractures are found in abundance in all this shear zone [23]. Geometrical analysis of these fractures showed the existence of three important categories. Most of the faults had a strike-slip mechanism, and the scratch status of the landslides confirmed both left and right sections. The correspondence of these faults with the pattern of shear zone faults indicated Riddle (R) and anti-Riddle (R ') and D fractures. The second group of the faults have a normal mechanism. The scratch status of landslides in the faults showed three different types of movement: A: A group of these faults are single faults and no openings can be seen along with them. B: The other group is in the form of fault pairs with convergent slope and have a graben shape, which usually has openings along with them. A: The next category is a group of faults that includes first and second types; in addition to the normal mechanism, there is a non-slip mechanism, and in other words, these faults are oblique slip. All of these faults have openings. The correspondence of these faults with the pattern of shear zone faults indicates the X and T fractures, and the third category of faults includes small inverted faults that are rarely visible in this area, and along with these fractures, no mineralized veins or even scattered mineralization were seen. Further investigation of these faults showed continuous dynamics and active motion. Existence of a large number of older faults with slip scratches with dual components such as normal slip faults with left or right components, and on the other hand, the existence of newer faults with pure slip slope or pure slip extension mechanism shows regional dynamics. These dynamics are moved left on the regional shear zone in a clockwise direction, and as long as the Trudeau and Angelo faults are active, this clockwise movement of fractures will continue. This movement and rotation have caused the old fractures to change from one type to another and show a dual mechanism, and new fractures with a pure mechanism are created. For example, old T-fractures with a purely normal mechanism rotate clockwise in place of the Riddle fractures, and have a strike-slip component, and are in fact hybrid (dual). This is why in the studied area, most of the mineralized veins are expected to be along with the T fractures, and are now located along with the Riddle fractures, and in place of T fractures, new, vein-free tensile fractures have been formed. This clockwise rotation and hybridization are seen in all fractures, and the involvement of X fractures in this process can be considered as an indication of the advanced shear zone such as Central Alborz.

5. Conclusions

Since the strike-slip faults are the most significant structural elements of the Gazkhizan mining area, they play a remarkable role in every proposed tectonic scenario that can explain all the structural features of the area. Geometrical analysis of the sinistral and dextral strike-slip faults as well as other structural features including normal faults and reverse faults (in rare cases), and mineralized with different grades of copper along with the strike of various fractures of Troud-Reshm shear zone helped us to determine and propose the Riddle pattern of this area.

Systematic fractures formed in a different direction at the same time with the evolution of the shear zone and from older to younger are T, R, R′, P, D, and X, which all of them were recognized and studied in this research work. The X fractures indicate the development of the shear that is advanced, and it seems that all the mentioned fractures are turning to each other in the clockwise direction, in the most of the cases the strike-slip faults with normal components or normal faults with the strike-slip component are dip-slip faults and their fault planes are very steep to vertical. The other scenario that can be proposed for this area is that it is located in a tensile zone that to some extent is supported by the field evidence. However, it needs further investigations. The results of this research work indicate that the structural features of the studied area provide a suitable environment for precipitation of the hydrothermal fluids; field observation indicates that the fractures are very deep.

Copper mineralization is widespread in all the fractures of the shear zone but the fractures with mineralization veins were emplaced in T, R, R′, and X fractures of the shear zone in age order, and most of the veins were emplaced along with the strike of Riddle fractures. The Gazkhizan is heavily impacted by Riddle strike-slip faults, and most of the fractures have been formed parallel. The emplaced veins in the X fracture are the second most frequent fractures that the mineralized veins emplaced through the R′ anti-Riddle fracture are the third frequent fractures, and finally, the T tensile fracture is the least frequent one. The reason behind that is because of the advanced shear zone and clockwise rotation of the structures; in fact, the fractures of this area turn to each other and are hybrid.

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تحلیل هندسی شکستگی‌ها و رگه‌های معدنی کانسار مس گزخیزان در استان سمنان، ایران

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چکیده:

کانسار مس گزخیزان در زون ترود-رشم ایران مرکزی قرار دارد. این منطقه در یک زون برشی واقع شده است که به ترتیب از شمال و جنوب توسط گسل‌های امتداد لغز انجیلو و ترود محدود شده است. کانی سازی توسط رگه های سیلیسی- برشی همراه با کانی سازی مس انجام می‌شود. حدود ۴۱ نقطه نقشه برداری انجام شده در اطراف رخنمون‌های گسل، همراه با تفسیر داده‌های نرم افزار Win Tensor و تحلیل هندسی ویژگی‌های ساختاری، راه ما را برای مطالعه الگوی ریدل در منطقه هموار کرد. ویژگی‌های ساختاری شامل گسل‌های امتداد لغز راست‌لغز، گسل‌های معمولی، گسل‌های معکوس (به ندرت) و رگه‌های معدنی و همچنین انواع شکستگی‌های ناحیه برشی با عیارهای مختلف سنگ معدن مس است. رگه‌های معدنی منطقه در چهار نوع شکستگی به ترتیب ´R، R، T و X فراوان است. بیشترین تعداد رگه‌ها در شکستگی‌های ریدل تشکیل شده است. به دلیل ماهیت ترکیبی شکستگی‌ها، رگه‌ها در شکستگی‌های کششی تشکیل شدند و سپس با چرخش‌های جهت عقربه‌های ساعت در امتداد ضربه شکستگی‌های R قرار گرفتند. اهمیت و ضرورت تحقیق به شرح زیر است: ذخیره قطعی این منطقه معدنی ۴۳۴۵۰۰ تن سنگ مس با عیار متوسط ۱/۶۱ درصد مس است. به همین دلیل تعیین و طبقه بندی شکستگی‌های میزبان این ذخیره ضروری است.

کلمات کلیدی: معدن گزخیزان، ترود، کانی سازی، الگوی ریدل، پهنه برشی، ایران مرکزی