Presenting a model to investigate the role of fault density with mineralization in the Keybarkuh area, NE Iran

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Abstract

In terms of the structural location, Keybarkuh is located on the north part of the Lut Block; Doruneh fault is the most important tectonic structure in this region and has a great impact on the tectonic state of the area and Dashte bayaz fault in the north, Jangal fault in the south and Jabbar fault which is the main fault in the study area and pass from north to south of this area, are effective structures. Main rock units in this area are mostly made of andesite, tuff, and porphyritic andesite, which due to tectonic activities in the region, have numerous fractures, joints, and cracks. This study was identified places where have the high density of the conjugated faults and fractures and was examined the effect on mineralization and geochemical anomalies of base metals in the study area, for this purpose, data related to geological map, digital elevation model (DEM), and Landsat satellite images were used to identify and extract faults in the area. Fractal modeling for faults and litho-geochemical data were used to analyze the effect of fault density on the mineralization rate. According to the obtained models, the highest density of faults in the Keybarkuh region has a significant relationship area with base metal anomalies.

Key words: Keybarkuh, Conjugated faults, Fault density, fractal modeling

1. Introduction

The Keybarkuh area located approximately 70 km SW of the Khaf town and North part of the Lut Block (LB), in the East of Iran. Magmatic activities in the LB, which started from Jurassic and has reached its peak in tertiary. It is one of the unique features of this block. Therefore, those Tertiary volcanic-intrusive rocks, especially Eocene, with a thickness of about 2000 meters cover more than half of this block (Aghanbati, 2004). East of Iran and especially the LB due to having different tectonic positions in the past, followed by the presence of huge volumes of magmatism with various geochemical properties, it has a very good potential for the formation of different mineralization. For better understanding of geochemistry, age and origin of magma in associated with mineralized or non-mineralized intrusions, is a positive step towards the exploration of various deposits in eastern Iran (Karimpour et al., 2012). The LB is a micro-continental block that drifted from the northern margin of Gondwana during the opening of the Neo-Tethys in the Permian, which was Derivatived from the Eurasian continent during the closure of the Paleo-Tethys in the late Triassic (Sengor, 1990; Alavi, 1996; Golonka, 2004). The LB is surrounded by four major faults, namely the Doruneh fault in the north, the Jaz-Morian fault (basin) in the south, the Nayband fault in the west, and the Nehbandan fault in the East of the area (Gansser 1995; Bagheri and Stampfli, 2008; Karimpour et al., 2011).The LB has a great potential for mineralization of different types of ore deposits such as porphyry Cu, Cu–Au–Fe oxides, vein type, massive sulfide, Au-epithermal, intrusion-related goldsystems and Sn–W-skarns, which are associated with geological structures (faults and joints) and volcanic and plutonic rocks (Karimpour et al., 2011; Ahmadirouhani et al., 2017). There are several theories to explain the magmatism and tectonics evolution of the LB. It has been interpreted within an extensional setting (Jung et al. 1984). The presence of ophiolitic complexes in Eastern Iran between the Lut and the Afghan blocks, led (Saccani et al. 2010) to consider the subduction of the oceanic lithosphere at this zone (Motamedalshariati et al. 2016), while proposed that magmatism in the northern part of the LB obtained by the subduction of Afghan block beneath the LB. It is indicated that igneous rocks at the LB have a calc-alkaline arc signature. The polarity of the accretionary prism-fore arc basin, the structural vergence and younging of the accretionary prism to the southwest are consistent with a NW-dipping subduction scenario (Tirrul et al. 1983). Recently, asymmetric subduction models have been discussed for situations similar to that of the Lut Block (Arjmandzadeh 2011). Strike-slip faults play significant roles in the deformation of the Iranian plateau and especially in east of Iran. The most important tectonic complication in the vicinity of the Lut Block is the Doruneh Fault Which is extends some 900 km from the north to the Jazmorian basin in the south and is ~ 200 km wide (Stocklin and Nabavi 1973) .However, the Dasht-e Bayaz plain Fault is located to the east of the western direction in the southwest of the Darouneh fault and the mechanism for it is a strike-slip fault in the northeast of Iran, this fault is a sinistral fault which has conspicuous seismic and geological activities, while the role of the fault in the accommodation of active convergence is still debated(Baniadam et al., 2019). The Jangal and Khaf faults are other major faults of the region with an approximate length of 120 and 20 km to the northwest-southeast and slope to the northeast which is 10 km south of the Khaf and its adjacent faults. In general, the faults observed in the study area have dominant NNW-SSE and NE-SW corridors. These faults with east-west trend are also observed. Their horizontal displacement reaches more than their vertical displacement. Recent studies (Carranza and Hale 2002; Richards 2002) have shown that mineralization systems in the volcano-plutonic belts of the world have a very close relationship with the strike-slip faults formed in these arcs. The strike-slip faults seem to be capable of creating suitable environments for penetration of porphyritic magmatic strata due to their disruption in different locations. These masses also occur in magmatic arcs mainly associated with porphyry copper ores. On this basis, various spatial and temporal relationships between these masses and these faults have always been taken into account (Afzal et al. 2017a; Carranza and Hale 2002; Mohebi et al. 2015). The mineralization and faults, including minor faults to the northeast, mainly follow a NW-SE trend. The rose diagram shows the trends of the faults in the area. The structural features of the Keybarkuh fault zone were mapped using remote sensing and field observations. Furthermore, the faults rose diagrams were correlated with those prossessing.

2. Geological setting of the Keybarkuh Area

Based on scattered geochronology data, magmatism of the LB is established by a variety of volcanic and volcanoclastic rocks, as well as subvolcanic stocks, commences during the Middle Jurassic (Shah-Kuh; Esmaeily, 2001), Klateh Ahani (Moradi et al., 2011) and Surkh Kuh granitoids with165–162 Ma age, continued in the Late Cretaceous, Bajestan (Jung et al., 1983), Gazu and Bazman. granitoids which is intruded in 76.6–74 Ma. Late Paleocene Vaghi and Junchi ignimbrites with 61–56 Ma (Jung et al., 1983), Middle Eocene to Early Oligocene (e.g., Malekzadeh Shafaroudi et al., 2015, Samiee et al., 2016, Etemadi et al., 2018, Nadermezerji et al., 2018, Etemadi et al., 2019) and finally ended with the eruption of Neogene basalts in Ferdows, Qal-e-Gonbad, Mud and East Neh and Nayband ((Jung et al., 1983; Walker et al., 2009). The andesitic volcanic erupted together with dacites and rhyodacites from Cretaceous (65 Ma) to early Neogene (15.5 to 1.74 Ma). The Neogene and Quaternary volcanic rocks from the western and eastern margins of the LB are similar in trace element chemistry to the average composition of oceanic island basalt and have a significant variation in chemistry with the Paleogene igneous rocks from the north-central part that follow both calc-alkaline and alkaline trends. Most of the magmatic activity in the LB occurred during the Middle Eocene to Early Oligocene (30–39 Ma ;) (Arjmandzadeh, Reza, et al.). Mainly, the volcanic rocks are intruded by the next series of subvolcanic intrusions that cause various mineralization. The eastern part of Iran had a complex tectonic history related to the evolution of the Sistan Ocean, between Lut (in Iran) and Helmand Blocks in Afghanistan (Fig.1a). This ocean Probably was opened by the Early Cretaceous (Babazadeh and DeWever, 2004) and its generation has been in progress during Middle Cretaceous (Zarrinkoub et al., 2012). The mechanism and final closure time of the Sistan Ocean as Late Cretaceous or Middle Eocene remain poorly understood. Various models of evolution are wider presented in the geodynamic setting and tectono-magmatic model section. The study area, located on the Sar-e-Chah-e-Shur and Mokhtaran 1:100000 geological sheets (Geological Survey of Iran, 1975; 1978). The Eastern Iran belt extends for 1000 km in the N–S direction, within the LB (Etemadi et al., 2020). The Khaf-Kashmar-Bardaskan Volcano-Plutonic and Metallogenic Belt (KKB-VPMB) crosses northeastern Iran that is regarded as a major component of a Paleogene Andean-type convergent margin (Fig.1b). The major rock types in the Keybarkuh area are Cenozoic calc-alkaline volcanic rocks and the spatially and temporally related subvolcanic intrusive stocks are exposed along the N-S direction. The volcanic rocks include basaltic andesitic to andesitic and basaltic lavas that are extensively altered in the vicinity of the younger intrusive rock. In general, the Paleocene-Eocene period in the study area is characterized by different volcanic and volcanic rocks, which can be subdivided into three units according to age and composition. The lower unit is thought to be Paleocene-Lower Eocene in age, consisting of agglomerates, rhyodacites, tuffs, and volcanic eruptions, it extends from north to south. The ~ 39 Ma U-Pb radiometric ages obtained by zircon from the host monzonite-diorite porphyries indicate a Middle Eocene age (Fig.2; Shafaroudi et al. 2015). The following alterations observed in the Keybarkuh area can be divided into 12 zones: carbonatization zone, intense propylitic zone, moderate propylitic zone, weakly propylitic zone, sericite -propylitic zone, argillic-propylitic zone, quartz-carbonate zone, poor sericitic zone, quartz-sericite zone, poor silica zone, silica zone, and silica-propylitic zone. In the central parts of the study area, there are some limited skarn parts in contact between the limestone's and intrusive bodies, which are poorly mineralized, as well as, intermediate basalt dykes are found in abundant intrusive and volcanic rocks(Fyzollahhi, Nahid, et al.). Ore mineralization in the sulfide zone contains pyrite, chalcopyrite, and galena, which occurs in veins and veinlets, along with silica and argillic alteration zones. In some areas, this mineralization is accompanied by magnetite, as well as silica veins, which occur in the contact of the intrusive bodies, and dykes with metamorphic rocks such as schists.

2.1. Structural setting and petrogenesis of intrusive bodies

The Central Iran section at the north of Lut Block is a complicated district including tectonized domains of the Taknar Zone and Sabzevar Zone Taknar Zone is a well-known Cadomian terrane which includes remarkable exposures of Late Neoproterozoic magmatic and (meta)-sedimentary rocks These igneous rocks consist of various kinds of volcanic and plutonic (both of felsic and mafic) bodies which have been formed during 572–528 Ma(Mazhari et al.2019); The dominant structures in this area are the Doruneh and Dasht-e-Bayaz left-lateral strike-slip faults, which are thought to accommodate right-lateral shear by rotating clockwise, away from the direction of maximum shortening (Jackson & McKenzie 1984; Jackson et al. 1995). Similar rotations have been suggested for strike-slip faults in eastern Tibet (England & Molnar 1990; Holt et al. 1991). The Dasht-e-Bayaz fault system was focused on in this paper (Walker et al. 2004). This is north of the active right-lateral faults of the Sistan suture zone as the Neh and Abiz fault systems (Fig. 3; Ghasemi, A., and Christopher J. Talbot, 2006), which may accommodate a large proportion of the ca 20 mm/yr−1 right-lateral shear between Iran and Afghanistan (Tirrul et al. 1983; Walker & Jackson 2002).

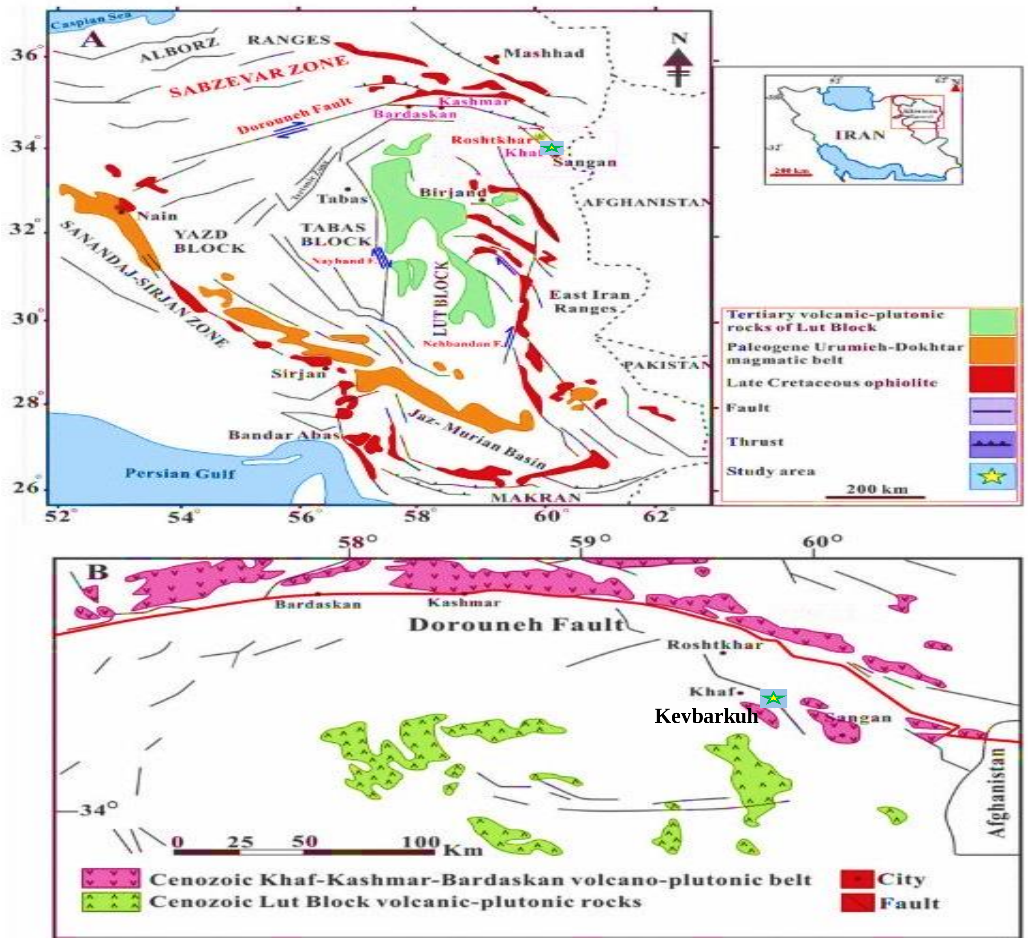


Fig. 1. (a) Simplified structural map of eastern Iran showing the location of the Keybarkuh area at the eastern edge of Dorouneh Fault (modified from Malekzadeh Shafaroudi et al. 2015). (b) The Khaf-Kashmar-Bardaskan volcano-plutonic Belt, and the southerly Cenozoic volcano-plutonic rocks of the Lut Block (Alizadeh et al. 2017).

The age data of Maherabad, Khopik, Deh Salm, Shaljami, and Shurab areas belong to mineral intrusions, so the age obtained also indicates the age of the relevant mining. Keyberkuh intrusive mass has alteration but has limited mineralization and in the Najmabad region, tertiary masses do not have any mineralization and alteration. Figure (3) shows the age of Tertiary intrusive masses east of the LB with spatial location. The age of all granitoids is Eocene to Lower Oligocene, they have age changes between 43/3 to 33/3 million years Sr isotope, and age (based on Rb-Sr, K-Ar, and UPb) data for representative samples of Lut block felsic rocks are given in Table 4. All of the granitoid rock formed during Tertiary time have (Sr87/Sr86) I <0.706, therefore the magma did not originate from the continental crust.

Shah Kuh, Klateh Ahani and Surkh Kuh (Mid Jurassic) have Sr87/Sr86 = 0.7081-0.7068. This means that the magma originated from the continental crust. The oldest igneous rocks dated within the LB are Klateh Ahani, Shah Kuh, and

Surkh Kuh (165-162 Ma) Middle Jurassic granitoid rocks. Bajestan batholith and Bazman granodiorite are dated at 77 and 74.2 Ma as Upper Cretaceous (Fig. 1). Gazu granodiorite, which is located within Tabas block, was also emplaced at 75.2 Ma. In the Early Paleocene time Vaghi ignimbrite (61.6 Ma) and Late Paleocene Junchi ignimbrite (56.7 Ma) erupted. Granitoid rocks of Middle to Late Eocene time (43.2-38.2 Ma) are found at several locations with the Lut Block. Granitoids younger than 38 Ma are not reported from the LB, but basalts are common (Fig. 4).

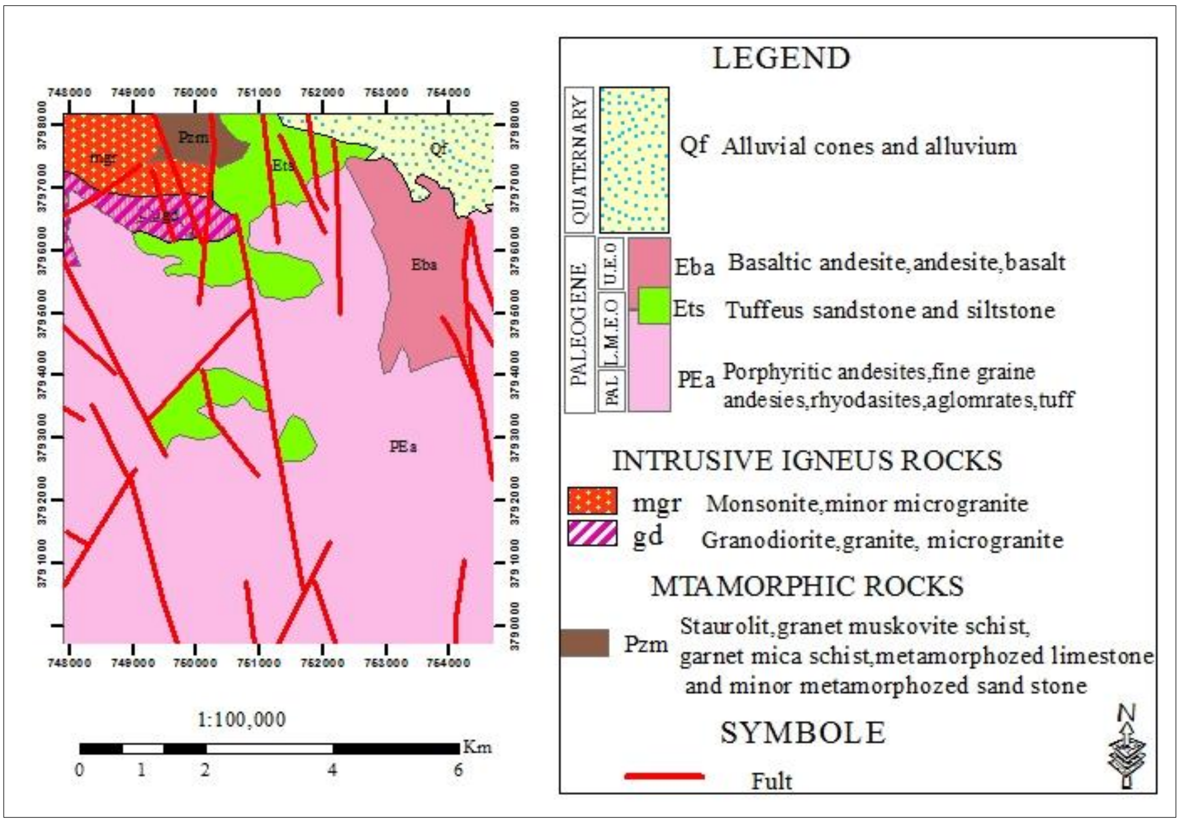
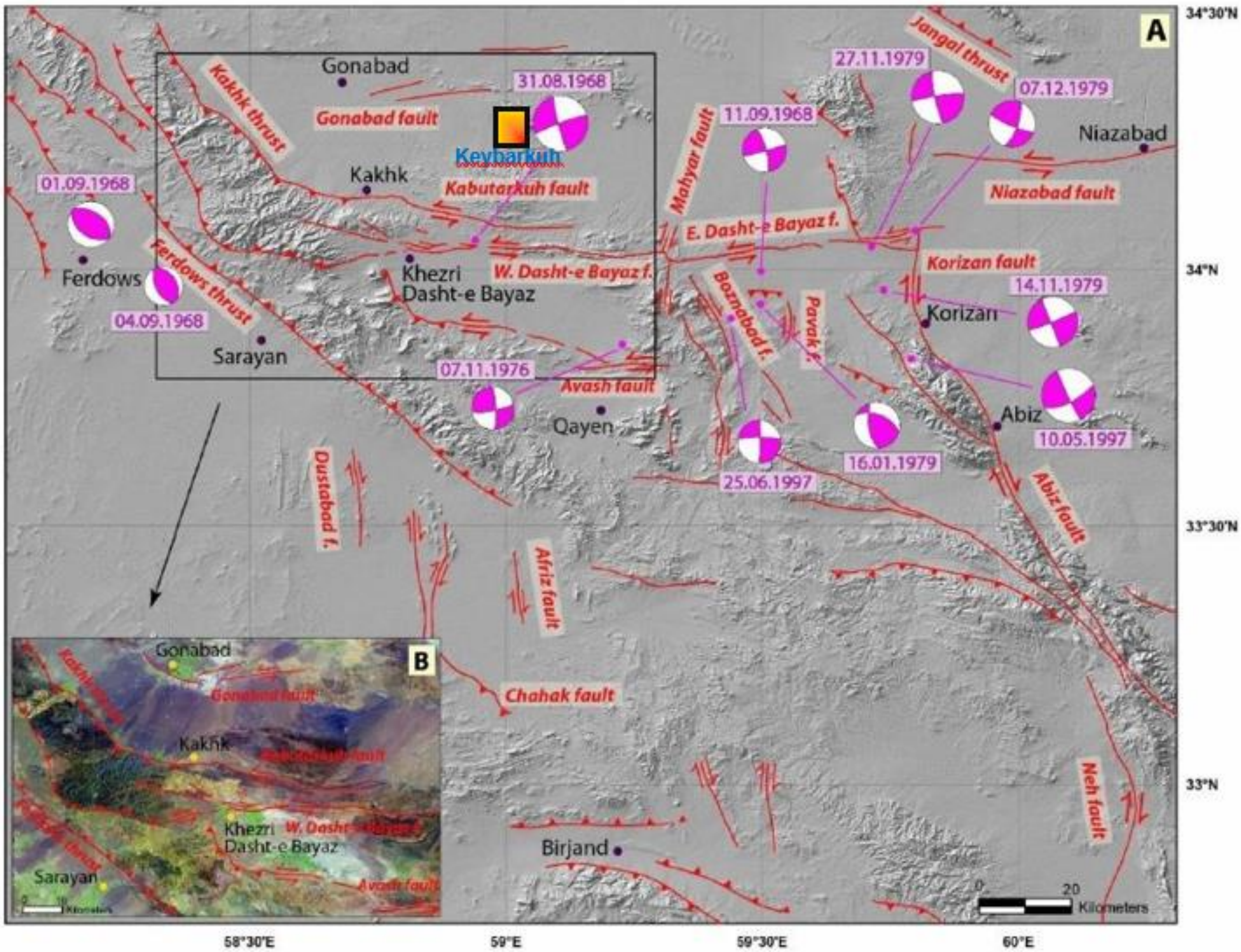


Fig.2.Geology map of Keybarkuh area (Mazhari, Seyed Ali 2016).


A
B
34°30'N
34°N
33°30'N
33°N
58°30'E
59°E
59°30'E
60°E
Gonabad
Gonabad fault
Kakhk thrust
Kakhk
Keyharkuh
Kabutarkuh fault
Ferdows
Ferdows thrust
Khezri
Dasht-e Bayaz
W. Dasht-e Bayaz f.
E. Dasht-e Bayaz f.
Sarayan
Mahyar fault
Boznabad f.
Pavak f.
Korizan fault
Korizan
Niazabad
Niazabad fault
Jangal thrust
Avash fault
Qayen
Abiz
Abiz fault
Dustabad f.
Afriz fault
Chahak fault
Birjand
Neh fault
31.08.1968
01.09.1968
04.09.1968
11.09.1968
27.11.1979
07.12.1979
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25.06.1997
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20
Kilometers

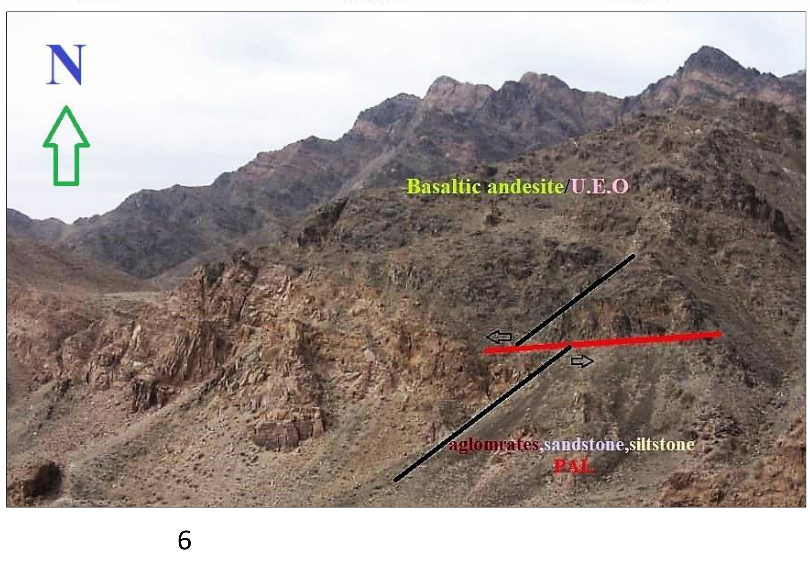

N
Basaltic andesite/U.E.O
aglomrates,sandstone,siltstone
PAL

Fig.3 a) Major fault map of Fig.3 b) Dykes that formed by tectonic activity and effective on mineralization. Fig.3 c) Fault boundary which separating Upper Eocene basaltic andesite units in the top and, Paleocene sandstone, siltstone, and agglomerate at the bottom of the image.

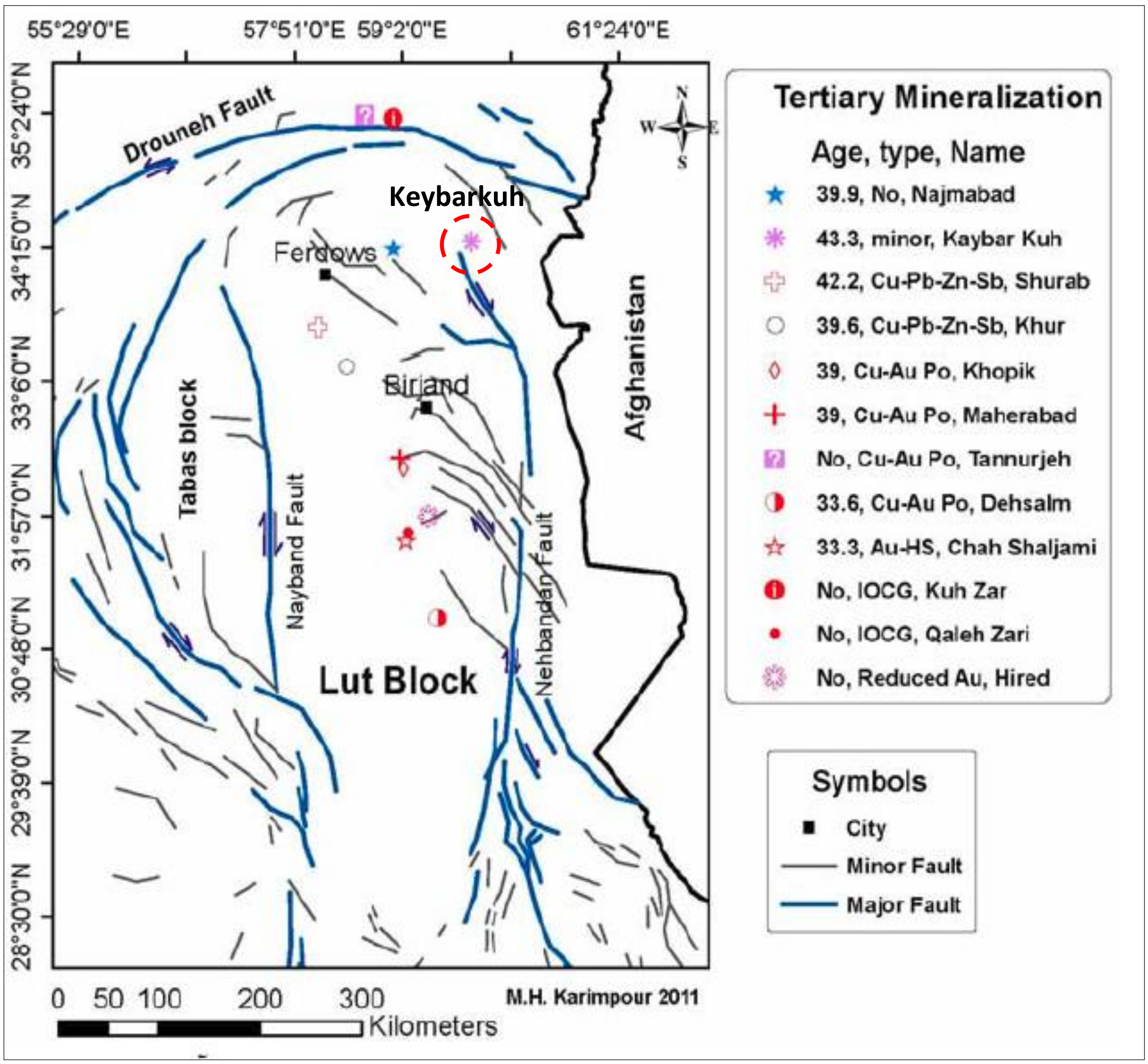
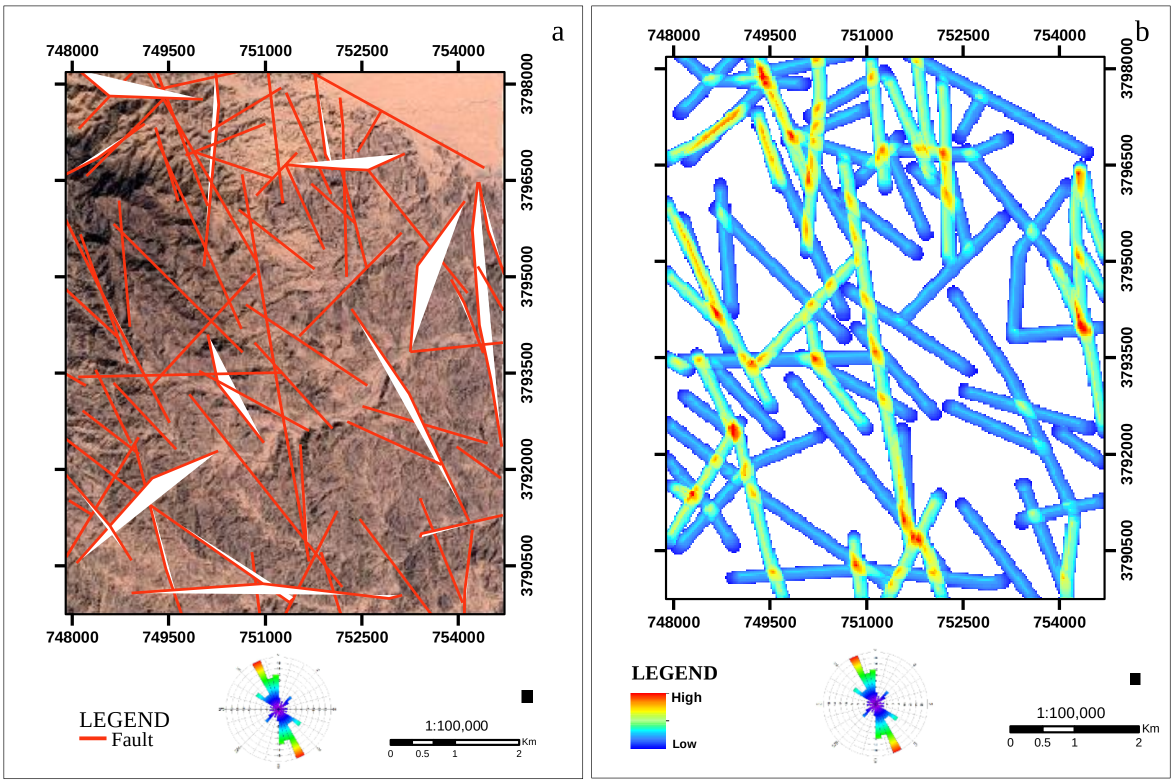


Fig. 4. Map showing Location, Isotopes, and age of granitoid and volcanic rocks within Lut

3. Methodology

In this study, the aim is to identify areas where the fault density is higher than other areas because the areas can play an important role in mineralization, so classifying and providing a model for these areas can lead to a view for the next stages of exploration; for this purpose, first, the faults of the study area were identified and extracted using spot satellite images (Fig.5 a). In the next step, a network was defined for the faults to determine their density in this network (Fig.5 b), and finally using the Concentration-Area(C-A) fractal method, the model of the faults density in the Keybarkuh area was determined. In addition, to investigate the effect of this density on the amount and extent of mineralization, the relationship between geochemical samples that have a high grade of Cu, Pb, Zn, Au, and Ag with high-density areas was investigated.



(Fig.5 a) Status of the Faults and (Fig.5 b) density model of them in Keybarkuh area

3.1. Concentration-Area (C–A) multi-fractal model

The C-A fractal model was developed by Cheng et al. (1994) to separate the anomalous area from the background. The general formula for this model and its parameters is as follows :

$A\ (\rho \leq \upsilon)\ \alpha\ \rho - a1;\ A\ (\rho \leq v\ \alpha\ \rho - a2)$

A (ρ): areas with a concentration greater or less than the ρ υ: threshold value a1 and a2: index of fractal dimension In this model, the threshold limits are the boundaries separating geochemical anomalies from each other and the background (Pourgholam et al. 2021, Afzal et al. 2010, 2014, 2016; Ahmad Faraj et al. 2019 Heidari et al. 2013; Sahsavar et al 2019).

4. Application of C-A multi-fractal model

In this study, the C-A fractal model was used to extract and separate places with high intensity of fault density. According to the C-A fractal log-log diagram, detected 5 populations for this parameter (Fig6) the first population involves amounts with intensity lower than 4 which these amounts could be known as the background of the faults density. In these zones, there are no intersections between faults, and the number of faults, fractures, and joints is very low. The second population involves amounts among 4 to 5, which these amounts are the first anomaly of faults density in the Keybarkuh area. The third population involved amounts among 5 to 6 that these amounts are the second anomaly of faults density. The fourth population involved amounts among 6 to 8 that these amounts are the third anomaly of faults density and finally the fifth population involved amounts more than 8 which are a high anomaly of faults density and in this area, there are most intersections between faults and the number of faults, fractures, and joints are very more than the other area (Fig7)

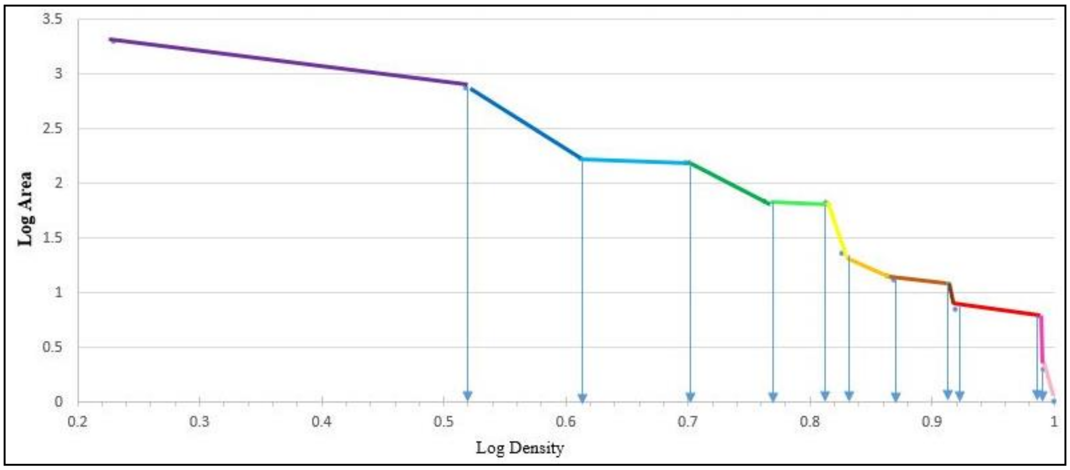


Fig6. Log-Log plot of fault density for Keybarkuh area

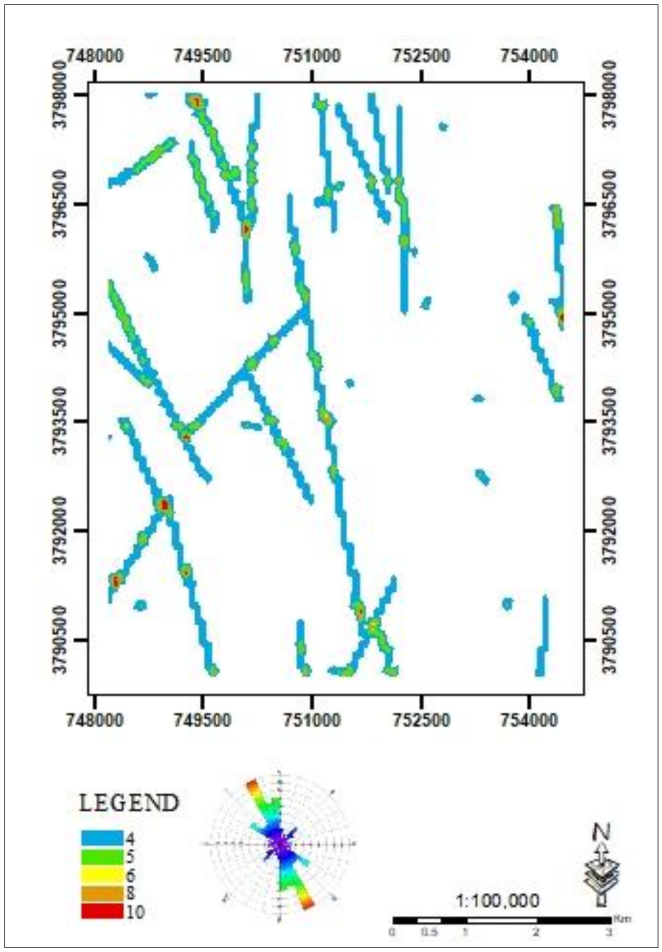


Fig 7.C-A fractal model of fault density in Keybarkuh area

5. Correlation between Fault density and mineralization in Keybarkuh area

The fractal model of the Keybarkuh faults shows four important anomalous parts in the northern, eastern, southern, and southwestern parts. As well as Small, anomalies are seen in the central parts of this area along the long central faults. The point to be discussed in this section is whether these areas are effective in metal mineralization or not? For this purpose, from the rock samples removed from the area for geochemical studies, 23 high-grade samples with anomalous amounts of metallic elements of gold, silver, copper, lead, and zinc were matched with these areas and the final result was examined (Fyzollahhi, Nahid, et al.). The results show that these rock samples have compatible with fault anomalies. This can confirm the positive and effective role of fault density and fractures in mineralization (Fig 8).

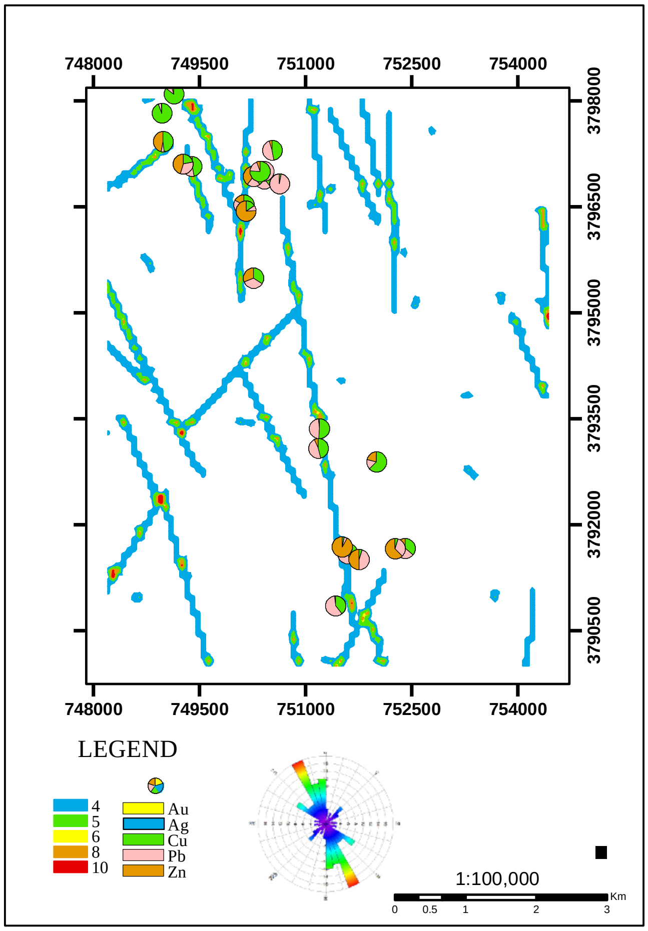


Fig. 8. Fractal model of the meridional faults with its logarithmic diagrams

The rock samples that are situated in the northern parts of the study area have a high amount of Cu and by moving to the southern parts of the study area, the amount of Pb and Zn in the samples increases. As well as, mineralogy studies on samples taken from the study area shows the most type of mineralization in that (Fig. 9)

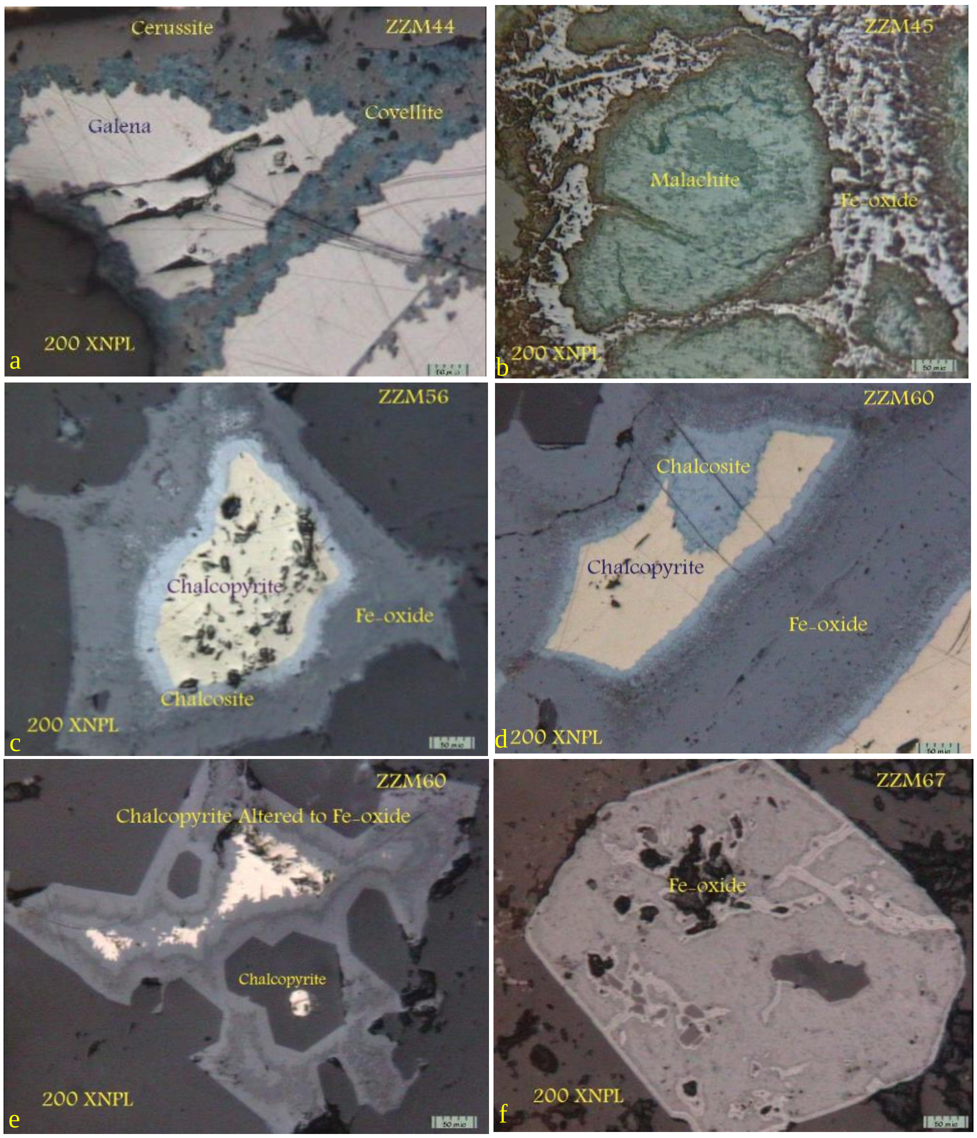


Fig. 9. Pictures of polished sections of rock samples belonging to the Keybarkuh area; a) galena, crosstie, covellite, b) malachite and Fe-oxides; c) chalcopyrite, chalcocite, Fe-oxide d) chalcopyrite, chalcocite, Fe-oxide e) chalcopyrite altered to Fe-oxide, chalcopyrite, f) Fe- oxide

6. Conclusion

The results obtained by this study in the keybarkuh area show that tectonic is an effective factor on mineralization and the C-A fractal model is a suitable method for present a model to investigate and show the effect of this factor on the mineralization by classification the faults density in a mineralized area and compliance with mineralization. According to the results of this model, the amount of faults density in the north, south, and southwest of the study area is higher than the other parts of that. As well as the mineralization data show that the grade of Cu in the north part of the study area is higher than the other part of the keybarkuh area in return amount of Pb increase to the south parts of the study area. The thin polish section, which is taken from the mineralized area that is connected with the faulted zone shows that the most mineralization in the study area accorded as chalcopyrite and galena. In some sections, the mineralization is in oxide phases like malachite with iron oxide minerals.

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