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Spatial Association of Copper Mineralization and Faults/Fractures in Southern Part of Central Iranian Volcanic Belt

[1]R. Derakhshani and [2]A. Mehrabi
[1]Department of Geology, Shahid Bahonar University, Kerman, Iran
[2]Geological Survey of Iran, Kerman, Iran

Abstract: To provide guides for exploration of porphyry copper mineralization at a district scale, we examine the spatial association between known copper deposits and strike-slip faults/fractures in South central Iranian volcanic belt. Studying of aerial photographs and preparing of photogeological map of the study area, beside various image processing techniques, helped us to reveal faults/features of this area. Field reconnaissance and local detailed mapping followed to corroborate the evidence. The integration of remote sensing and field checking resulted in preparing geological map of the area. After converting the map to the raster one, buffers around the faults/fractures are extracted. Then the spatial associations between the porphyry copper deposits and strike-slip faults/fractures are quantified using weights of evidence modeling. The porphyry copper occurrences are associated spatially with strike slip faults/fractures within distances of 1 km. In addition, based on these observations local strike slip faults/fractures related to regional strike slip faults systems are the most important foci for emplacement of copper-bearing porphyritic intrusions in the study area. Taking advantages of GIS, remote sensing technology and weights of evidence modeling, it is detected that the most concentrated place of porphyry copper in southern part of central Iranian volcanic belt is among the faults/fractures and through 1 km around them.

Key words: Porphyry copper, mineral exploration, remote sensing, GIS, faults, fractures, Iran, spatial association

INTRODUCTION

A qualitative and quantitative knowledge of the spatial associations of known mineral deposits with different geological features in well-explored areas is a factor in most exploration programs. This is encouraging because, for many countries, the geoexploration data available are more in the form of lithologic and structural maps (Honarmand *et al*., 2002; Ranjbar *et al*., 2001, 2004). It is therefore hypothesized that there are ways to classify or map mineral potential when the geology is known but systematic and comprehensive geoexploration data are lacking.

In recent years, based on plate tectonic theory, porphyry copper deposits in contrast to other hydrothermal deposits are invariably associated genetically with porphyry plutons localized along island and continental-arc strike-slip fault systems (Shahabpour and Doorandish, 2008; Hezarkhani, 2006a, b; Talebian and Jackson, 2002). It has long been recognized that certain types of mineral deposits are spatially associated with certain curvy-linear geological features (Carranza, 2004; Rahnama *et al*., 2008; Regard *et al*., 2004, 2005; Mayer and Sausse, 2007). The curvy-linear geological features dealt with here are those features that are faults or fractures. The spatial association between certain types of mineral deposits and curvy-linear geological features is due to the role of the latter in localizing mineralization. For example, faults/fractures provide channel ways for mineralizing fluids whilst igneous intrusions provide heat sources and cause chemical reactions with the intruded rocks

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Corresponding Author: Reza Derakhshani, Department of Geology, Shahid Bahonar University, Kerman, Iran Tel/Fax: +983412510643

that may bring about mineral deposition at or near the intrusive margins/contacts (Niemeyer and Munizaga, 2008). Qualitative knowledge about the spatial association between certain mineral deposits and curvy-linear geological features is, in fact, the general basis of area selection in many mineral exploration programs. The objective of this research is to determine the spatial association between certain mineral deposits and curvy-linear geological features, quantitatively using remote sensing and GIS.

MATERIALS AND METHODS

This study which is conducted in 2008 is concentrated on spatial association of copper mineralization and faults/fractures in southern part of central Iranian volcanic belt. Because the mathematical formulation of the weights of evidence method which was developed by Bonham-Carter (1994) is somewhat complex, the simplified and intuitive approach is adopted in this research. The linear structural features interpreted from shaded-relief images of a Digital Elevation Model (DEM) of the area. Shaded-relief images were calculated from the DEM by applying directional filters. The directional filters were designed to provide illumination from eight different directions: N, N45E, E, S45E, S, S45W, W and N45W. The different illumination sources were necessary to highlight fault/fracture lineament patterns that strike in different directions. The shaded-relief image exhibited in (Fig. 1) is illuminated from N45W. Lineaments representing faults/fractures (Fig. 1) were interpreted visually and digitized on-screen from the different shaded-relief images.

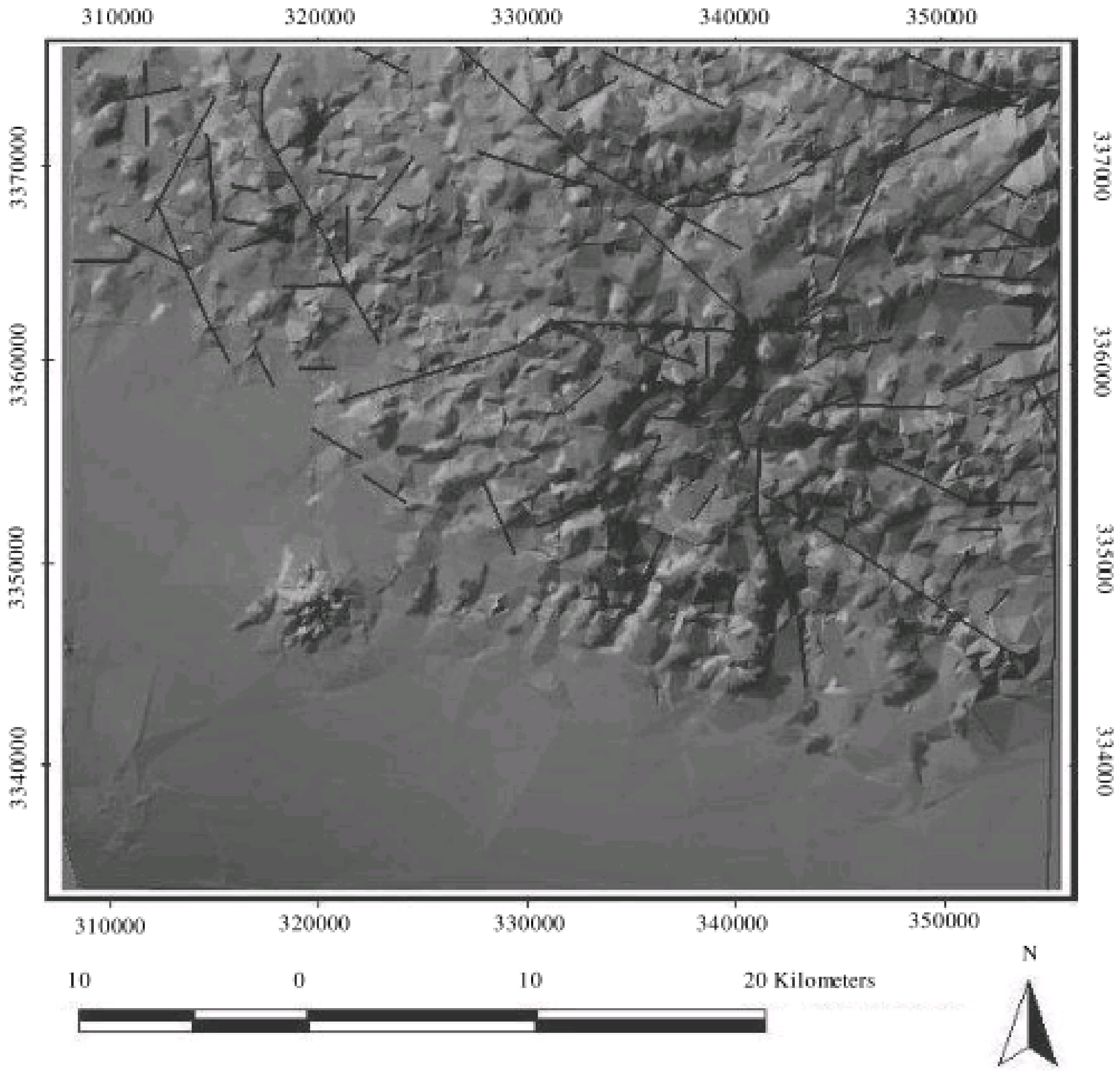

Fig. 1: Northwest-illuminated shaded-relief image of DEM of study area and faults/fractures interpreted from different shaded-relief images of DEM

Geology of the Area

The study area lies at the Southern part of Central Iranian Volcanic Belt, between 30º 7.5´ - 30º 30´N latitudes and 55°- 55º 30´E longitudes, in the North of Shahr-e-babak city. Meiduk mine is an active porphyry cupper mine there (Zarasvandi *et al.*, 2005; Tangestani and Moor, 2002) with a 1997.91 km^2 area. Figure 2 shows the location of the study area.

Geological data inputs to the GIS are derived and compiled from geologic maps of various scales. The contacts of mapped lithologic units were hand-digitized into vector format (Fig. 3).

The Central Iranian volcano-sedimentary complex, with Northwest-Southeast direction has 2000 km length and 150 km width extends as the same direction as Zagros (Berberian, 1995; Derakhshani and Farhoudi, 2005). The eruption of this belt started in the Cretaceous and in the Eocene it got to its highest activity.

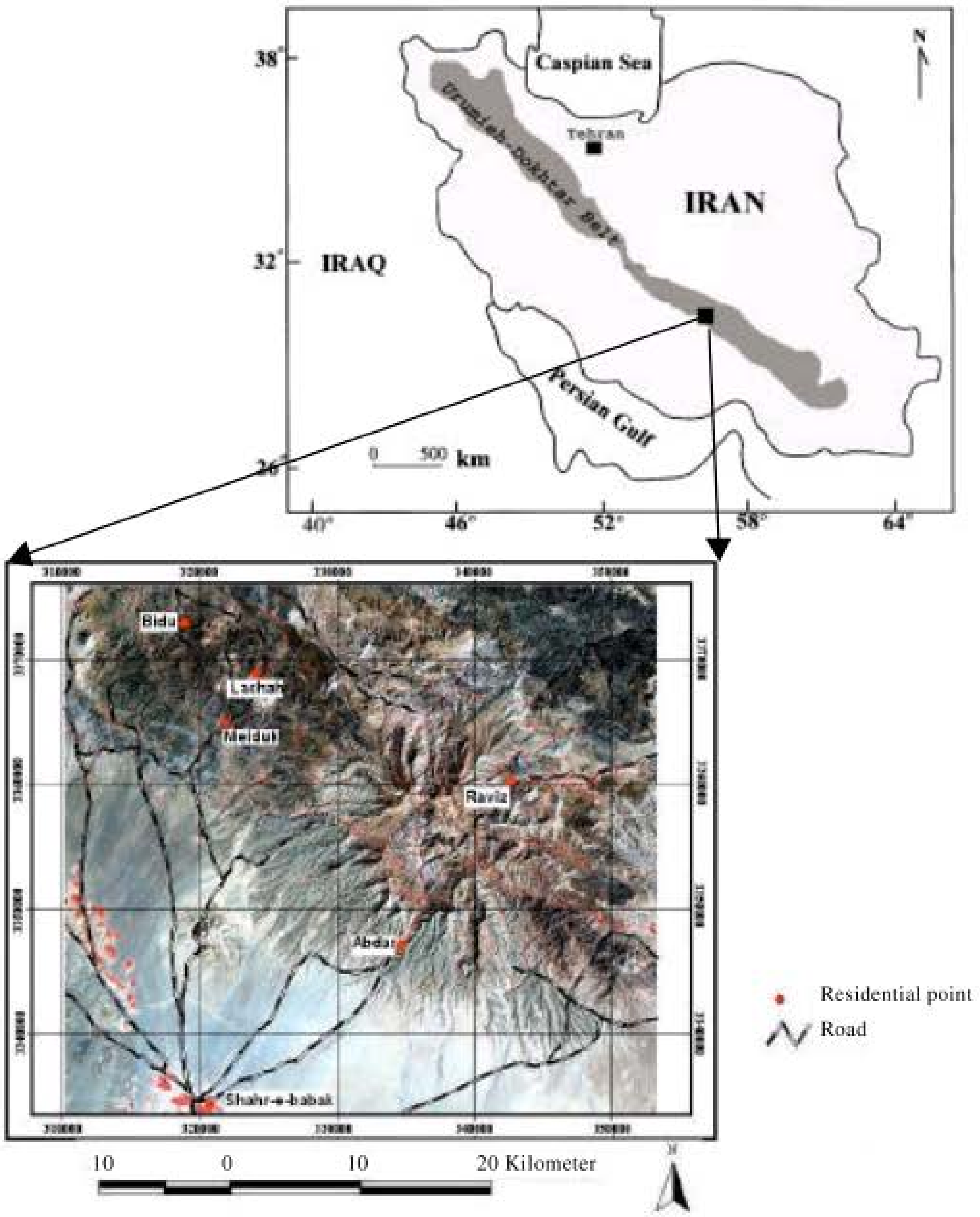

Fig. 2: Location of study area

Most of the area we are studying is consisted of volcanic-alluvial parts of Eocene period. One of the dominant features of this area is the great amount of volcanic Eocene rocks that have been under consideration as the main ore creating part (Derakhshani and Abdolzadeh, 2009b). From the middle Oligocene to Miocene, the injection of diorite to granodiorite bodies creates the porphyry copper of the zone and most of related occurrences. Also, in many areas extensive layers have covered these intrusive bodies in guise of little diorites and stock. After that dykes and stocks of diorite-quartz diorite in upper Miocene had been implementing to plutonium cycle in the area (Derakhshani and Abdolzadeh, 2009a). This area has three important mines of porphyry copper named as Meiduk, lachah and Chah- Mesi and 81 copper indexes is known in this area (Table 1).

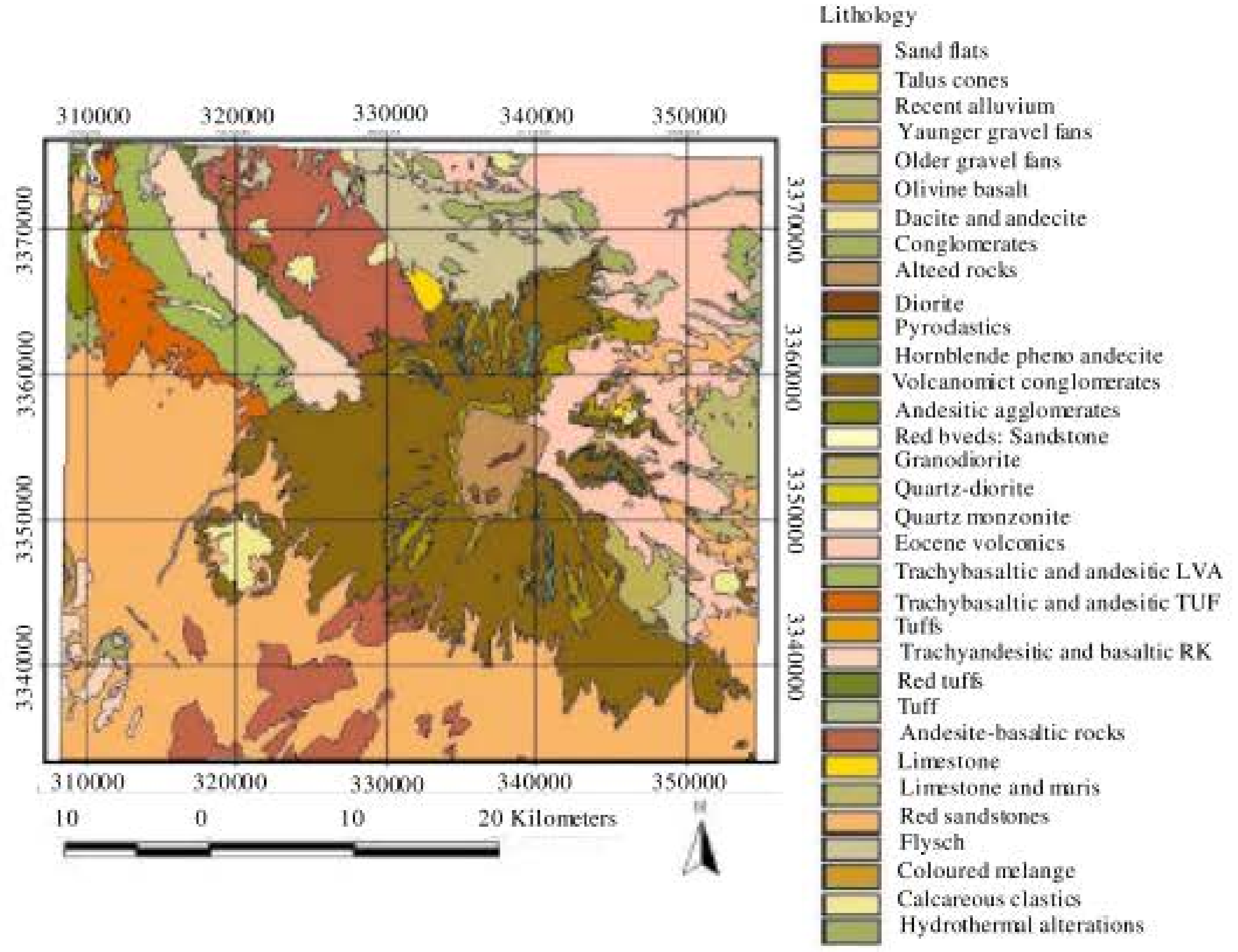

Fig. 3: Geological map of study area

Table 1: Porphyry copper mines, explored deposits and prospects

	UTM coordinates	
Name	Easting	Northing
Meiduk	324631.2187	3367360.00
Chah messi	321607.1250	3365115.75
Sara	321221.3750	3370245.75
E-medvar	317236.3437	3350938.50
Kahtokarha	309132.8437	3364516.75
W-shahrebabak	313859.3750	3339658.00
Kang	311811.0625	3362960.25
Dare tangle	314608.5937	3370118.25
S-silicate vein	323906.3125	3366025.00
Koh golab	318299.4375	334829.75
Hernashk	318508.5312	3361799.50
S-meiduk	320003.4062	3364707.50
Darbiduye silicat v.	318784.4687	3364707.50
Darbiduye	318308.8125	3371579.75

Table 1: Continued

	UTM coordinates	
Name	Easting	Northing
E-meiduk station	319712.3750	3365831.25
W-meiduk station	318494.5625	3366195.50
Nw-bandovan	322085.0000	3361877.00
N-kamkoiye	321295.0625	3362508.75
Se–chah messi	321987.8437	3364565.50
S-meiduk	320986.0312	3364397.00
Nw -meiduk	321115.3125	3367737.00
Latela	324440.6562	3369323.75
Abdar 1	338028.3750	3354411.00
Abdar 2	333629.5937	3344778.50
Abdar silicat v.	337432.3125	3353622.00
Reshkan	340353.7187	3374908.50
Sw–golab	348291.1250	3343513.00
Hosein abad	347716.5625	3359796.75
Sw-pishosta	347017.0312	3351661.75
Darkhooni	346200.2187	3351968.00
Golab	349480.0937	3343367.00
Kohe medvar	349101.0625	3346292.50
Se–hamdin	355264.1562	3364172.00
Badamestan	353739.6250	3349547.25
Goori	354811.1875	3356777.25

RESULTS

In this research, after the preparation of digital topographic map of the area on 1.25000 scale and the contour interval of 20 m, Digital Elevation Model (DEM) of the area was prepared, using ILWIS software.

It is obvious that calculation of weights to estimate spatial association requires polygonal domains. Our study domain, however, are both point (like porphyry copper deposits) and curvi-linear geological features (like faults and fractures). To convert these point and curvilinear domains into polygonal domains, distance buffering was performed. Determining the spatial associations of interest involved the following steps.

Studying the Landsat satellite images and air photos, it was observed that the area under survey has a great number of fractures, so by using remote sensing software and laplacian, directional and sobel filters linear structures of the area were identified. Figure 4 shows the lineaments that were obtained in the area. These lineaments are checked in the field and finally 202 faults identified in the study area. Faults map converted to raster form vector form.

Using ArcGIS software, buffer zones of 500 m intervals were constructed around each of the faults. Each of the 500 m wide buffer zones was introduced as a class. This process defined that how much area are occupied by each class. For example 631 km^2 of the study area are occupied by 500 m wide buffer zone. Also, 1000 m buffer wide zone surrounds 1017 km^2 of the study area around faults.

Preparation and digitizing of the porphyry copper deposits map as a point map of mineral deposit was the next step. This map is rasterised too. Then it is overlaid on the buffered fault map by using spatial data modeler software. The porphyry copper deposits are counted for each buffer as the next step.

Numbers of mineral deposit points within and outside a buffer domain is determined by crossing or overlaying each of the raster maps of the buffer domains with the raster map of porphyry copper deposits.

For example, it is counted that 50 porphyry copper deposits are located in 500 m wide buffer zone and 71 porphyry copper deposits are located in 1000 m wide buffer zone. Base on the numbers

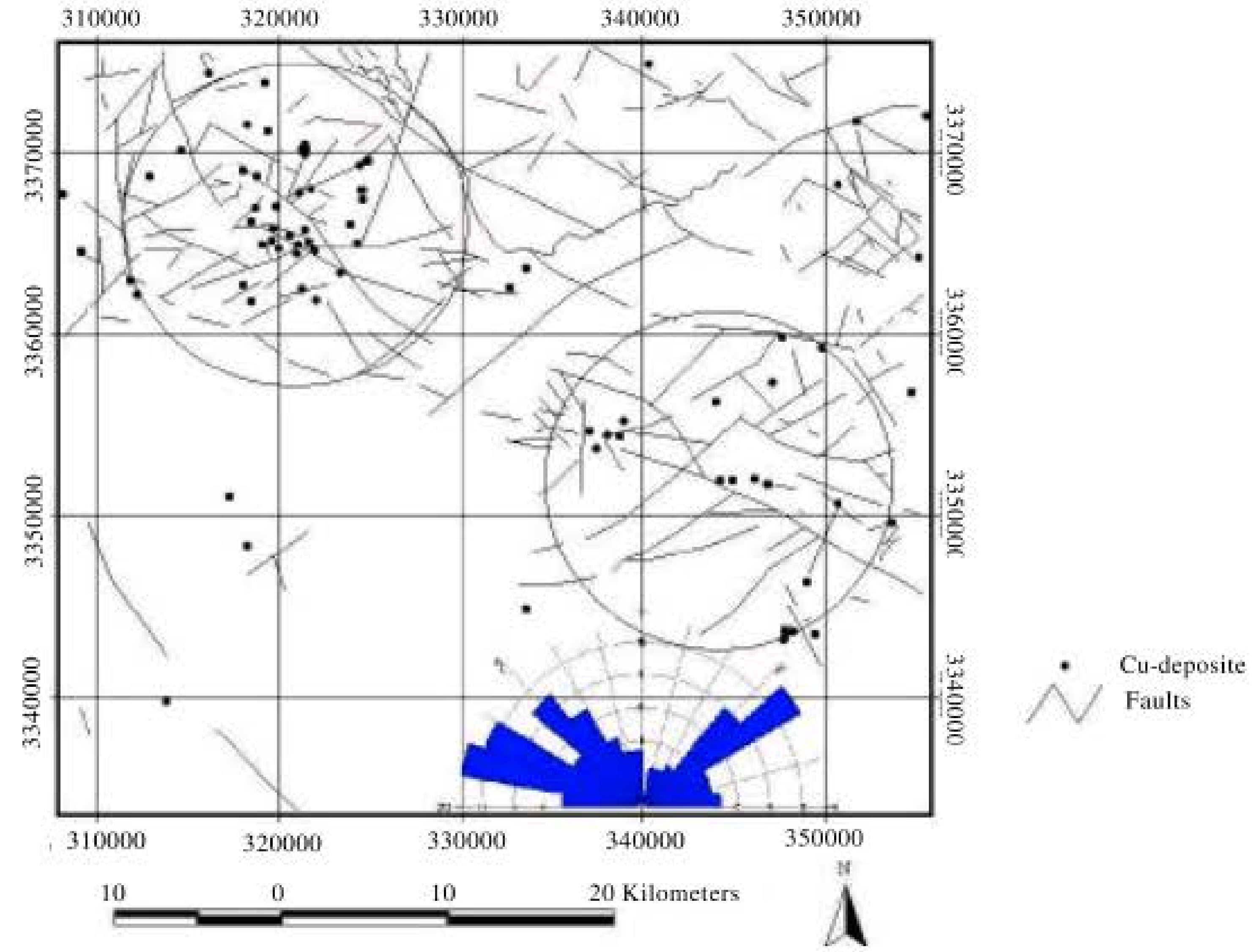

Fig. 4: Strike-slip faults and fractures map and porphyry copper deposits in the study area

of deposits which are located in and out of a specific buffer zone, W+ and W- factors of that buffer are calculated and regarding that, S(W+) , S(W-) and finally Studentised C are calculated. This process is done for each buffer zone in the study area.

According to the mentioned process, the number which is calculated for 3500 m buffer zone is 1.9021 that is the minimum one among buffers calculated numbers. Base on the weights of evidence method, this number show that spatial association of copper mineralization and faults is in its minimum state in 3500 m wide buffer zone. However, the spatial association of copper mineralization and faults is positive in 500 to 2000 m wide buffer zones, the number that is calculated for 1000 m wide buffer is 4.3662 that is the maximum one among buffers calculated numbers.

This maximum number gives the cutoff distance buffer at which there is optimal spatial association between faults and deposit points. So, the most association of copper mineralization and faults could be seen in 1000 m wide buffer zone around faults.

Regarding to the weights of evidence method, 1 km wide buffer zone could be introduced as well defined distance for spatial association of copper mineralization and faults in the study area.

DISCUSSION

This study synthesizes results of the research work to develop and demonstrate methodologies for geologically-constrained predictive mapping of mineral potential. The contents of the different published scientific papers, however, were modified slightly in this article to avoid superfluity and achieve consistency of the study.

Qualitative knowledge about the spatial association between certain mineral deposits and curvilinear geological features is, in fact, the general basis of area selection in many mineral exploration programs. However, the degrees of spatial associations of mineral deposits with curvilinear geological features can be different from one area to another so that qualitative knowledge alone is inadequate for assessing mineral potential. A quantitative knowledge of the spatial associations between known mineral deposits and curvi-linear geological features in a particular area is more important.

Here, the spatial association between the porphyry copper deposits and strike-slip faults fractures are quantified using weights of evidence modeling. The weights of evidence method have been developed by Bonham-Carter and Cheng (2008). Because the mathematical formulation of this method is somewhat complex, the simplified and intuitive approach was adopted in this research. Given the presence or absence of a domain (e.g., a zone of proximity to a linear geological feature), a scoring or weighting can be performed between that domain and a set of points (e.g., mineral deposits). The weighting yields (1) W+ weights within the domain (DP) and (2) W- weights outside the domain (DA). Note that T = DP + DA; T is the total area being studied. Because the areal coverage of a deposit is much smaller than the domain being considered, the weights of evidence are estimated by taking the natural logarithms (loge) of the probability ratios

$$W+ = \text{loge} ((\%\text{ deposits in DP}), (\%\text{ of total area occupied by DP})) \tag{1}$$

$$W- = \text{loge} ((\%\text{ deposits in DA}), (\%\text{ of total area occupied by DA})) \tag{2}$$

The weights W+ and W- represent unitless measures of the spatial association between the deposits and a given domain. (W+) > 0 and (W-) < 0 imply positive spatial association, (W+) < 0 and (W-) > 0, imply negative spatial association and (W+) = (W-) = 0 imply no spatial association. The variances of the weights can be calculated as:

$$s^2\ (w+) = \frac{1}{mD_p} + \frac{1}{bD_p} \tag{3}$$

$$s^2\ (w-) = \frac{1}{mD_A} + \frac{1}{bD_A} \tag{4}$$

where, mDP and mDA are respectively the number of pixels with mineral deposits inside and outside a given domain; bDP and bDA are respectively the number of pixels without mineral deposits inside and outside a given domain. Note that DP = mDP + bDP and DA = mDA + bDA.

For each binary domain, the contrast C combines these weights into an overall measure of the spatial association with a set of points and is defined simply as:

$$C = (W+) - (W-) \tag{5}$$

Hence, for a positive spatial association, C will have positive values; C will have negative values in the case of negative spatial association. The maximum C usually gives the cutoff distance buffer at which there is optimal spatial association between a given domain and a set of points. However, in cases of a small number of points (or deposits) such as the present cases, the uncertainty of the weights could be large, so that C is meaningless. In cases of a small number of points, a useful measure to determine the most significant cutoff distance is to calculate the studentised value of C. The Studentised C, calculated as the ratio of C to its standard deviation, C/s(C), indicates the statistical significance of the spatial association. The standard deviation of C is calculated as:

$$s(C) = \sqrt{s^2\ (w+) + s^2\ (w-)} \tag{6}$$

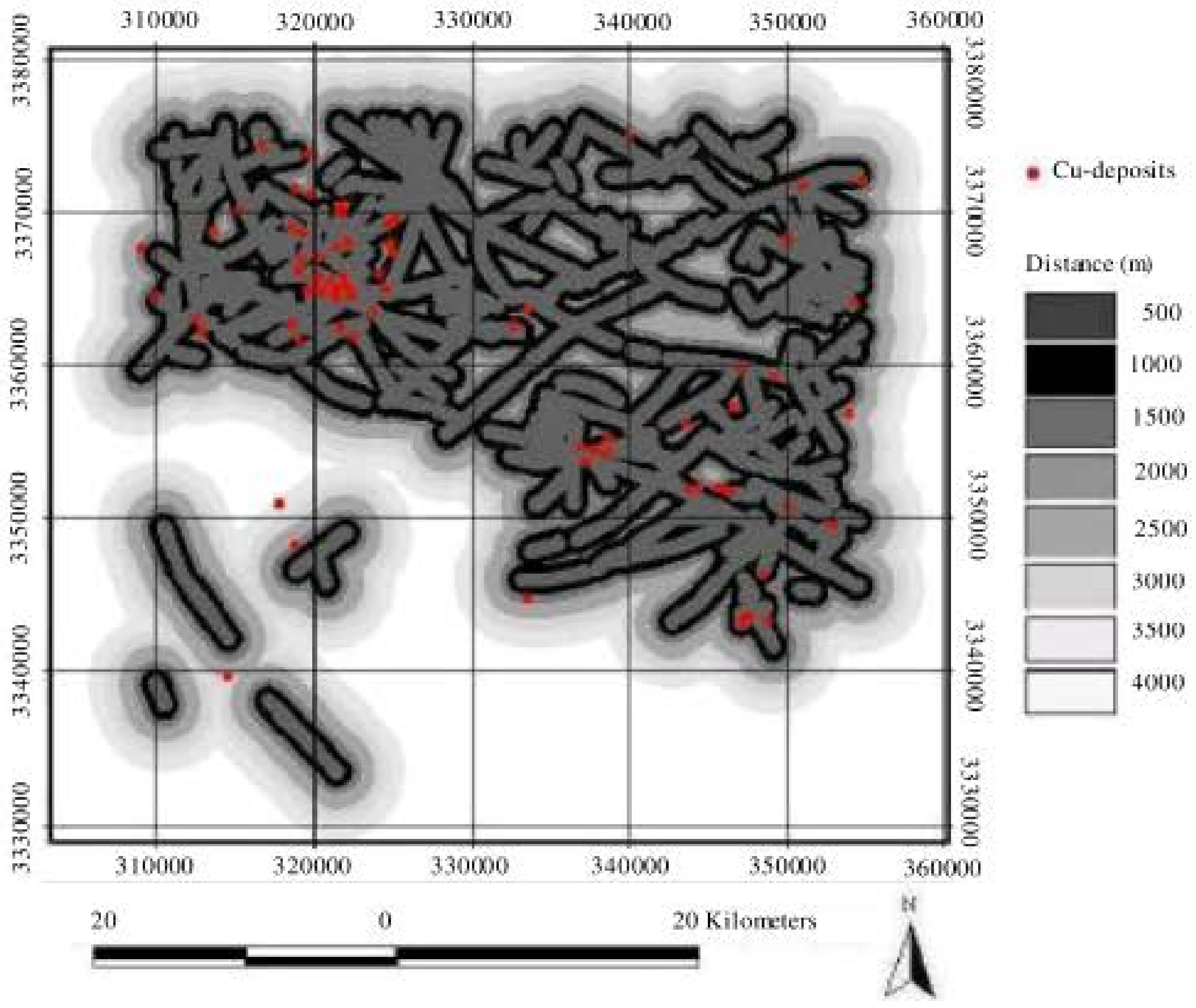

Fig. 5: Representation of optimum distance between Porphyry copper deposits and strike-slip fault fractures

Ideally, a Studentised C greater than 2 suggests a statistically significant spatial association. Due to the small number of mineral deposits in the study areas, the cutoff distance within which their spatial association with a given domain is optimal was chosen based on the maximum Studentised C (Fig. 5).

From the discussion above, it is obvious that calculation of weights to estimate spatial association requires polygonal domains. Present study domain, however, are either point or linear geological features. To convert these point and linear domains into polygonal domains, distance buffering was performed. Determining the spatial associations of interest involved the following steps.

- Digitize strike-slip faults/fractures as lines
- Rasterize the maps of linear and generate maps portraying distances away from these features
- Re-classify maps portraying distances to strike-slip faults/fractures into a series of binary domains representing buffered corridors of distances away from the strike-slip faults/fractures. The domain within a particular cumulative distance indicates presence of strike-slip faults/fractures; the domain outside the cumulative distance indicates its absence
- Digitize mineral deposits as points
- Rasterize point map of mineral deposits
- Determine number of points within and outside a binary domain by crossing or overlaying each of the raster maps of the binary domains with the raster map of mineral deposits
- Calculate the weights according to Eq. 2 and 3
- Determine C and Studentised C

Table 2: Variation of weights and contrasts for cumulative distances from strike-slip fault fractures respect to porphyry copper deposits

C/s(C)	s(C)	C	s(W-)	W-	s(W+)	W+	No. points	Area-Km^2	Distance buffer (m)
4.1655	0.2283	0.9509	0.1743	-0.4545	0.1474	0.4964	50	631.93	500
4.3662	0.3059	1.3357	0.2801	-0.9754	0.1230	0.3603	71	1017.81	1000
4.0664	0.5905	2.4013	0.5792	-2.0949	0.1150	0.3064	81	1221.00	1500
3.3922	0.7182	2.4364	0.7091	-2.2146	0.1140	0.2218	82	1337.85	2000
2.9190	0.7188	2.0983	0.7098	-1.9410	0.1138	0.1572	82	1421.65	2500
2.4004	1.0089	2.4219	1.0026	-2.3066	0.1129	0.1153	83	1497.05	3000
1.9021	1.0104	1.9219	1.0041	-1.8547	0.1128	0.0671	83	1566.84	3500
							84	1690.01	4000

Base on the results which are mentioned in the previous section, there is positive spatial association between the strike-slip faults/fractures and the porphyry copper deposits as indicated by the contrasts C (Table 2).

This spatial association between porphyry copper deposits and faults is due to the role of the latter in localizing mineralization. This finding is supported by some other papers that are published in other areas (Carranza, 2004; Mayer and Sausse, 2007; Zarasvandi *et al.*, 2005). Faults and fractures could provide channel ways for mineralizing fluids whilst igneous intrusions provide heat sources and cause chemical reactions with the intruded rocks that may bring about mineral deposition at or near the intrusive margins/contacts. So, findings of this research correlate with the aim of the project. The positive spatial association is statistically significant within 500 to 2000 m; however, according to the highest Studentised C, it is optimal within 1000 m. There is very little published work on the large scale analysis of spatial association of copper mineralization and faults/fractures in southern part of central Iranian volcanic belt and to the best of our knowledge, this is the first study of its kind that concentrates on the quantitative interpretation of this spatial association by taking advantages of weights of evidence modeling, GIS and remote sensing technology.

CONCLUSION

Based on the weights of evidence method, the porphyry copper occurrences are associated spatially with strike-slip fault fracture within distances of 1 km.

In addition, the porphyry plutons are associated spatially with strike-slip fault fracture and contacts of batholithic plutons within a distance of 1 km and 1.5 km, respectively.

After these quantifications of spatial associations, it could be implied that strike-slip fault zones can canalize magmatic fluids and are favorable loci for the emplacement of porphyry plutons. Consequently, these zones are favorable targets for exploration for porphyry mineralization.

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