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Determination of relationship between silver and lead mineralization based on fractal modeling in Mehdiabad Zn-Pb-Ag deposit, Central Iran

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ABSTRACT

Main aim of this study is to determine relationship between lead and silver mineralized zones using the Concentration-Volume (C-V) fractal modeling and logratio matrix based on subsurface data in Mehdiabad Zn-Pb-Ag deposit, central Iran. First, Pb and Ag raw data were analyzed by statistical processes and their histogram have similar shape. Next, Geostatistical modeling was carried out for the Pb and Ag data and their distributions were estimated by ordinary kriging. Then, the C-V log-log plots were created for the Pb and Ag which show five populations as mineralized zones for both of them. Moreover, correlation between the Pb and Ag different mineralized zones were calculated by the logratio matrix. Overall accuracies (OAs) are higher than 90% for enriched and highly mineralized zones of these elements. However, these zones were validated with geological particulars which indicate that oxidized mineralization is situated in Black Hill (gossan) and Calamine mine and silver was enriched in cerussites. Results obtained by the fractal modeling represent that the main mineralization for Pb and Ag occur in the central and NW part of the Mehdiabad deposit especially in the oxidized mineralization.

1- Introduction

Rare and strategic metals are important as worth by-products in the different ore deposit types. One of them is silver in Zn-Pb deposits because Pb minerals specifically galena and cerussite hosts high value silver (Hitzman et al., 2003; Leach et al., 2010). It is an important parameter for huge Pb-Zn deposits with carbonate host rocks specifically Mississippi Valley Type (MVT) and Sedimentary Exhalative (SEDEX) such as Mehdiabad deposit, central Iran (Borg, 2009 and 2015; Leach et al., 2010; Boni, 2014; Maghfouri et al., 2017). Iran contains high abundant different types of Zn-Pb deposits especially the MVT and SEDEX deposits which can be contain high values of Ag, Ge, In and Cd (Rajabi et al., 2012 and 2015; Maghfouri et al., 2017). Conventional methods for determination of by-products in main ore minerals are mineralographical methods especially Scanning Electron Microscope (SEM), Electron Probe Micro Analysis (EPMA) and PIMA (Borg, 2005; Rajabi et al., 2012). These are expensive methods which cause mathematical methods are applied for this purpose. One of them is methodology based on fractal modeling that is established by Mandelbrot (1983).

Fractal models have applied in different branches of the geosciences especially for separation of different mineralized zones, geochemical/geophysical anomalies (e.g. Cheng et al., 1994 and 1999; Agterberg, 1995; Li et al., 2003; Afzal et al., 2011; 2012 and 2017; Zuo et al., 2015; Chen and Cheng, 2016). Concentration-Volume (C-V) fractal model is an essential method for distinguishing of the mineralized zones which is proposed by Afzal et al. (2011). In this paper, major mineralized zones for Pb and Ag were modeled in the Mehdiabad deposit (Central Iran) by the C-V fractal model and relationship between them was calculated by logratio matrix which is proposed by Carranza (2011).

2- Methodology

2- 1. C-V fractal model

Afzal et al. (2011) proposed the C-V fractal model for delineation of mineralized zones and barren host rocks in porphyry Cu deposits, this model can be expressed as:

$$V(\rho \le \upsilon) \propto \rho^{-a1}; V(\rho \ge \upsilon) \propto \rho^{-a2} \qquad (1$$

where $V(\rho \le \upsilon)$ and $V(\rho \ge \upsilon)$ indicate volumes (V) with concentration values (υ) smaller and greater than contour values (ρ), respectively, a1 and a2 are characteristic exponents. Based on the characterization, different mineralized zones in a studied ore deposit have fractal properties and are defined by power law relationships between their ore element concentrations and volumetric extensions. Represented breakpoints in the C-V log-log plots of concentration values versus volumes separate geochemical populations by threshold values. Breakpoints in the log-log plots outlined various populations of geochemical concentration values representing different lithological and mineralogical zonation. Delavar et al. (2012) used this method for definition of different mineralized zones in an Iranian MVT Zn-Pb deposit.

2- 2. Logratio matrix

Carranza (2011) provided a method for calculation of overlapping values between two binary models. An intersection operation between results from the fractal model and different zones in the geological model (Table 1) was performed to obtain numbers of voxels corresponding to each of the four classes of overlap zones as represented in Table 1. Based on the obtained numbers of voxels, overall accuracy (OA) of the fractal model was evaluated with respect to the zonation model.

Table 1- Logratio matrix for comparing overlaps between classes in the binary geological model and the binary results of the fractal models (Carranza, 2011).

		Geological model	
		Inside zone	Outside zone
Fractal Model	Inside zone	True positive (A)	False positive (B)
	Outside zone	False negative (C)	True negative (D)
		Overall accuracy (A+D)/(A+B+C+D)	

3- Geological setting

The Mehdiabad deposit is located in the Yazd province (Central Iran) which is situated in Sanandaj-Sirjan structural zone (Fig. 1). There are early Cretaceous sedimentary rocks including shales, siltstones and dolomites (Maghfouri et al., 2015). Moreover, there are sulfidic ore minerals consisting of sphalerite, galena, pyrite, chalcopyrite and chalcocite with oxide ores consisting of cerussite, hemimorphite, hydrozincite and smithsonite (Maghfouri et al., 2017).

Study by Maghfouri (2017) shows that the Mehdiabad deposit is a syn-sedimentary Zn–Pb–Ba–(Cu) mineralization related to the SEDEX type according to the clastic-carbonate host rocks in relation between ore minerals and rock forming minerals, petrographical evidences and various geological/ geochemical features.

A thick Early Cretaceous sedimentary sequence is expanded with an unconformable lying on top of the Jurassic Shir-Kuh granite (Fig. 2). Early Cretaceous sediments of the Sangestan Formation cover the Shemshak Group meta-sediment rocks and the Shir-Kuh granite which initially formed a major Palaeo-relief (Maghfouri et al., 2017).Zn–Pb–Ba mineralization of the Mehdiabad deposit happened within the Taft Formation, as depicted in Fig. 2 (Maghfouri et al., 2015 and 2017). Furthermore, this mineralization occurs along two horizons which extend over a length of >4 km. The sulfide and non-sulfide ores of the first ore horizon are hosted by organic matter-rich shale, silty limestone, dolomite and silty shale of the Taft Formation. However, non-sulfidic ores of the second ore horizon are enclosed by limestone-shale and thin-bedded limestone of the Abkuh Formation as depicted in Fig 14 (Maghfouri et al., 2015; Maghfouri, 2017). The first ore horizon contains several ore bodies, namely Black Hill Ore (BHO), Central Valley Ore Body (CVOB) and East Ridge (ER) which are surrounded by hills and mountains (Fig. 3). The calamine mine is located in the NW part of this deposit which is the highest part of the oxide ore mineralization. Moreover, a gossan part occurs in the BHO with oxide minerals of Zn and Pb, as depicted in Fig. 3 (Maghfouri et al., 2017).

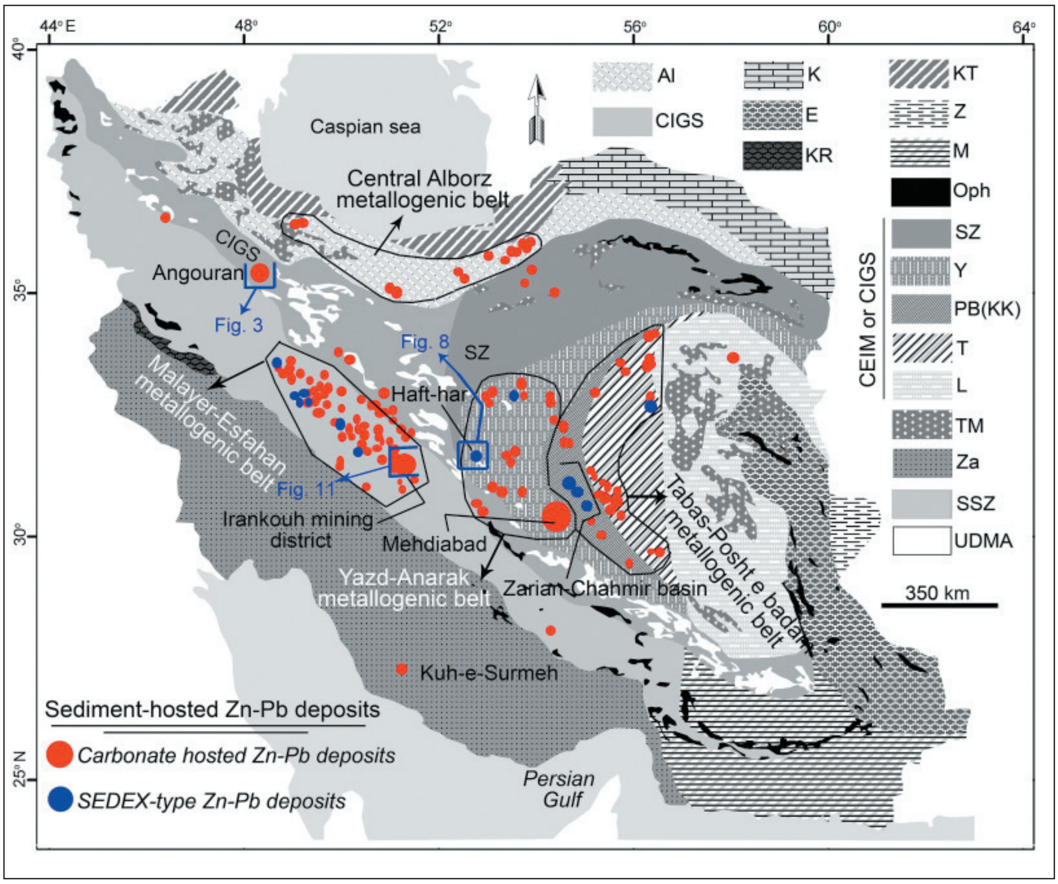

Fig. 1- Distribution map of sediment hosted Zn–Pb deposits and location of Mehdiabad deposit (Al, Alborz zone; CIGS, Central Iranian geological and structural gradual zone; E, East Iran ranges; K, Kopeh-Dagh; KR, Kermanshah Radiolarites subzone; KT, Khazar-Talesh-Ziveh structural zone; L, Lut block; M, Makran zone; Oph, ophiolite belts; PB, Posht-e-Badam block; SSZ, Sanandaj-Sirjan zone; T, Tabas block; TM, tertiary magmatic rocks; UDMA, Urumieh-Dokhtar magmatic arc; Y, Yazd block; Z, Zabol area; Za, Zagros ranges; Maghfouri et al., 2017).

4- Discussion

4- 1. Dataset

The dataset includes 18176 rock samples data from 208 boreholes with different lengths of cores. These data were analyzed by Zar Azma Company. These data should be composited for geostatistical modeling (Davis, 2002). Length of data equal to 1 m was determined as selected composite for geostatistical/fractal modeling. In addition, outlier data for lead and silver were calculated and corrected by Dörfel method. Histograms of Pb and Ag indicate that there are not normal elemental distributions (Fig. 4). Means of the Pb and Ag are 1.3% and 30 ppm, respectively. Thus, correlation coefficient between Pb and Ag was calculated which is +0.76. This shows a positive and direct relationship between lead and silver mineralization in this huge deposit.

4- 2. Fractal modeling

In this stage, geostatistical modeling was carried out based on Ag and Pb data using ordinary kriging method by Datamine studio software. Cell's dimensions are 25 m × 25 m × 10 m for X, Y and Z respectively. Final block model consists of 33343 cells with Pb and Ag averages equal to 1.4% and 34 ppm, respectively. Based on the results, the C-V log-log plots were generated for Pb and Ag which show five populations for these elements (Fig. 5). Enriched zones for silver and lead commence from 316 ppm and 10% respectively. Moreover, main mineralization for Ag began from 100 ppm and lead major mineralization is ≤ 4% (Table 2). Highly mineralized zones for Pb and Ag are 4%-10% and 100 ppm- 316 ppm, respectively. Furthermore, backgrounds for Ag and Pb in this deposit equal to ≥ 2.5 ppm and ≥ 0.15% correspondingly.

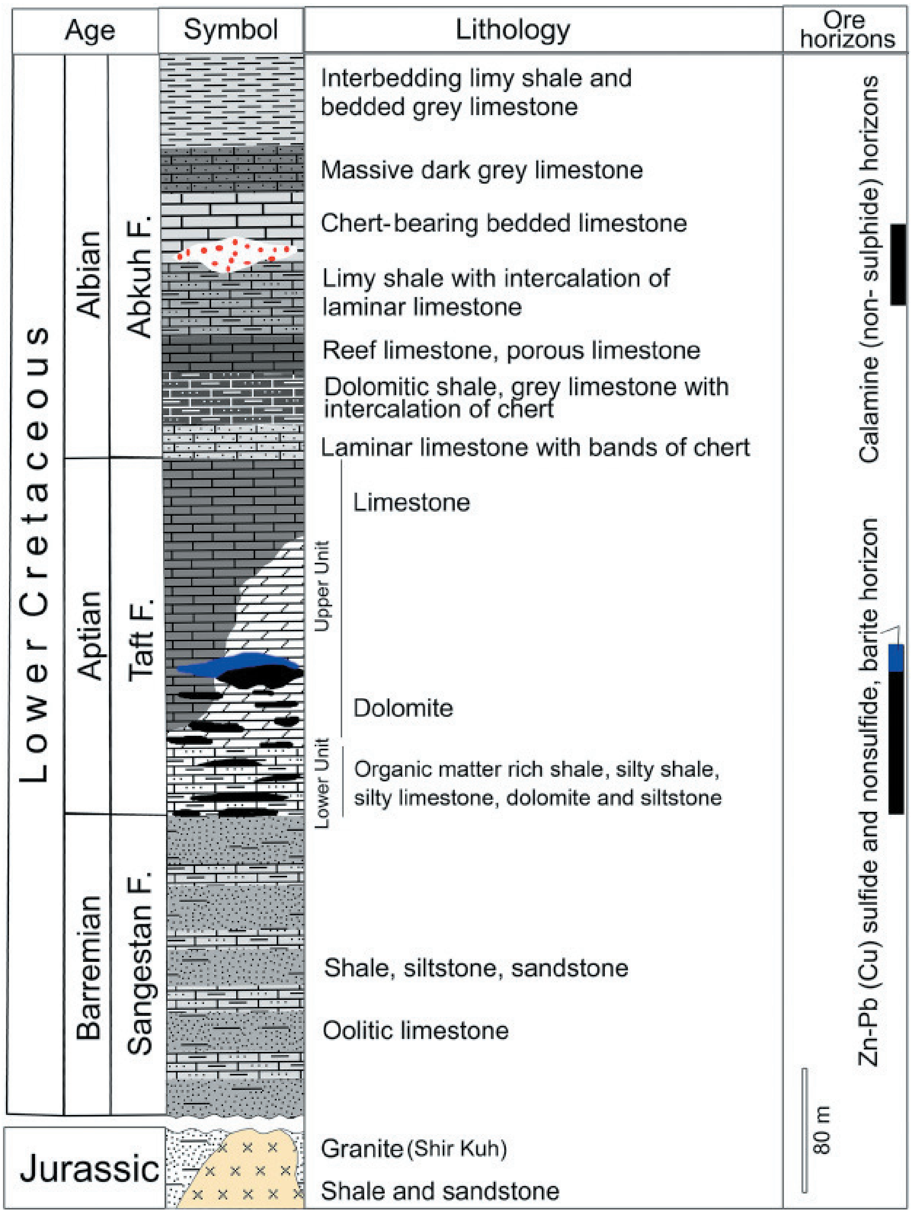

Fig. 2- Regional stratigraphic sequence of the Mehdiabad deposit (Nabavi, 1972; Majidifard, 1996; Maghfouri et al., 2017).

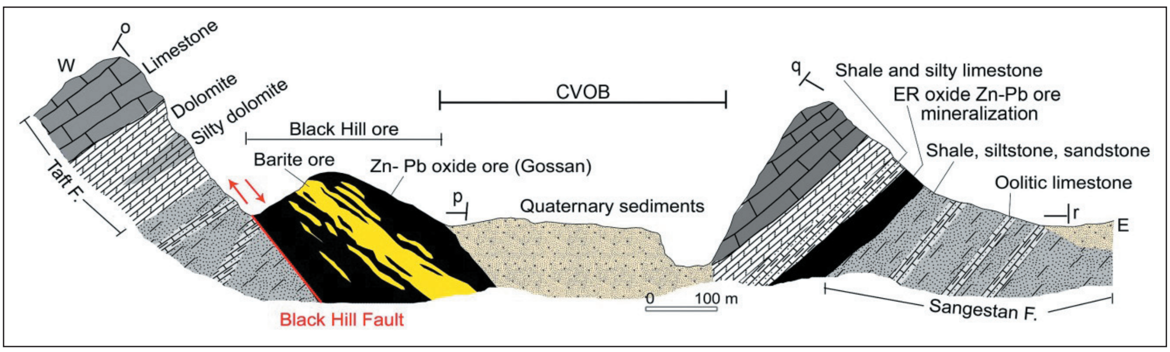

Fig. 3- One of the W-E cross section in the Mehdiabad deposit (Maghfouri et al., 2017).

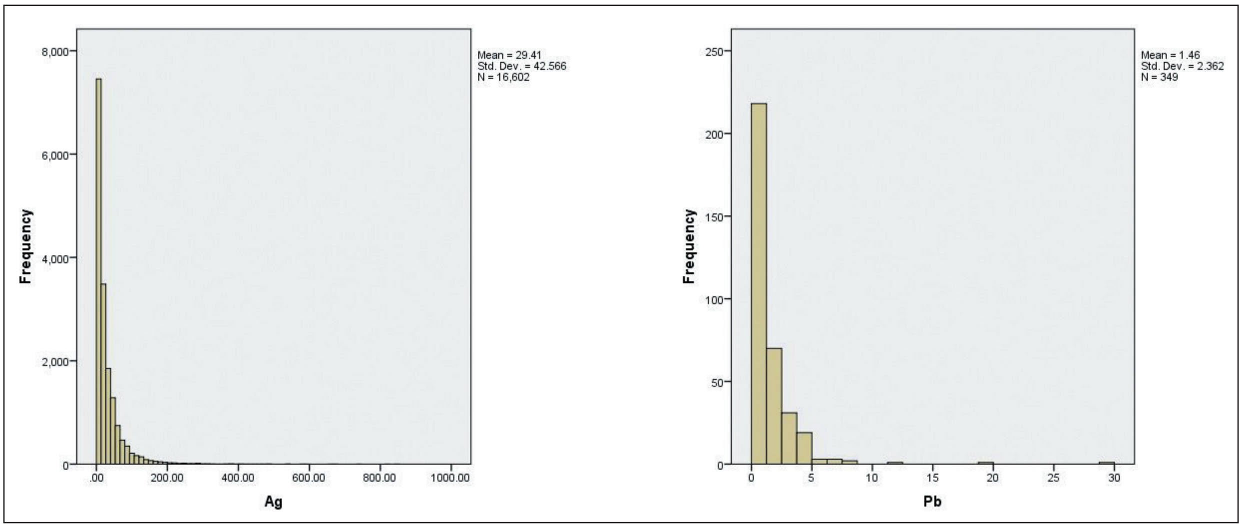

Fig. 4- Ag and Pb histograms in the Mehdiabad deposit.

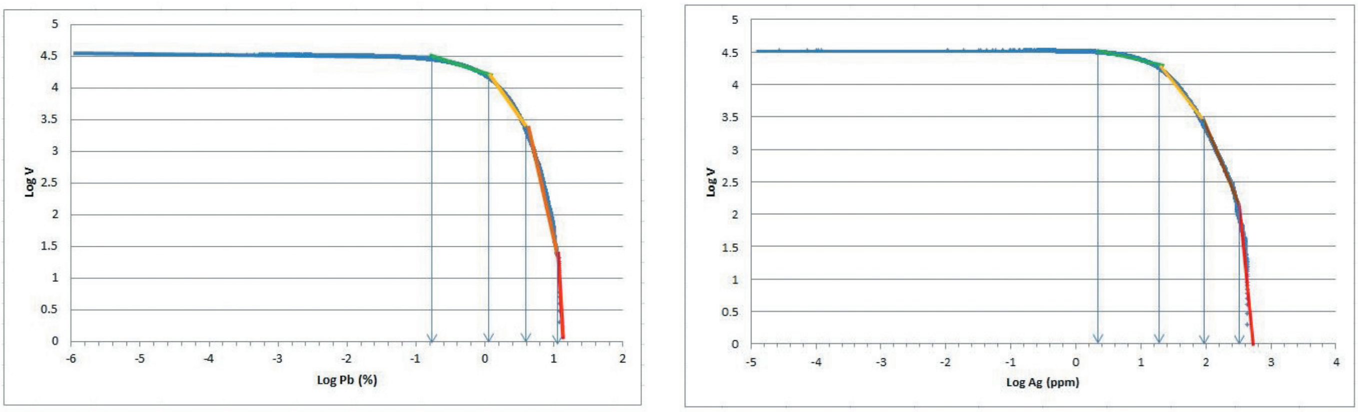

Fig. 5- Pb and Ag C-V log-log plots.

Table 2- Pb and Ag threshold values for different mineralized zones in the Mehdiabad deposit.

Mineralized zones	Weakly	Moderately	Highly	Enriched
Pb threshold (%)	0.15	1	4	10
Ag threshold (ppm)	2.5	20	100	316

Various mineralized zones for Ag and Pb were illustrated in the Table 2. Based on this fractal modeling, main mineralization of Pb and Ag occur in the western and NW parts of this deposit (Fig. 6) which are associated with Black Hill and Calamine mine in this deposit. Enriched zone for silver and lead are located in the central and western parts of the Mehdiabad deposit with respect to gossan with Pb-Zn oxide mineralization (Figs 6-7).

4- 3. Correlation between Pb and Ag mineralized zones

In this phase, correlation between the Pb and Ag mineralized zones derived via fractal modeling was calculated using the logratio matrix. The OA between Enriched elemental zones (Pb≥ 10% and Ag≥ 316 ppm) is 0.99 which is an excellent correlation between Ag and Pb enrichment (Table 3). However, correlation between highly Pb and Ag mineralized zones is significant because its OA equal to 91%, as depicted

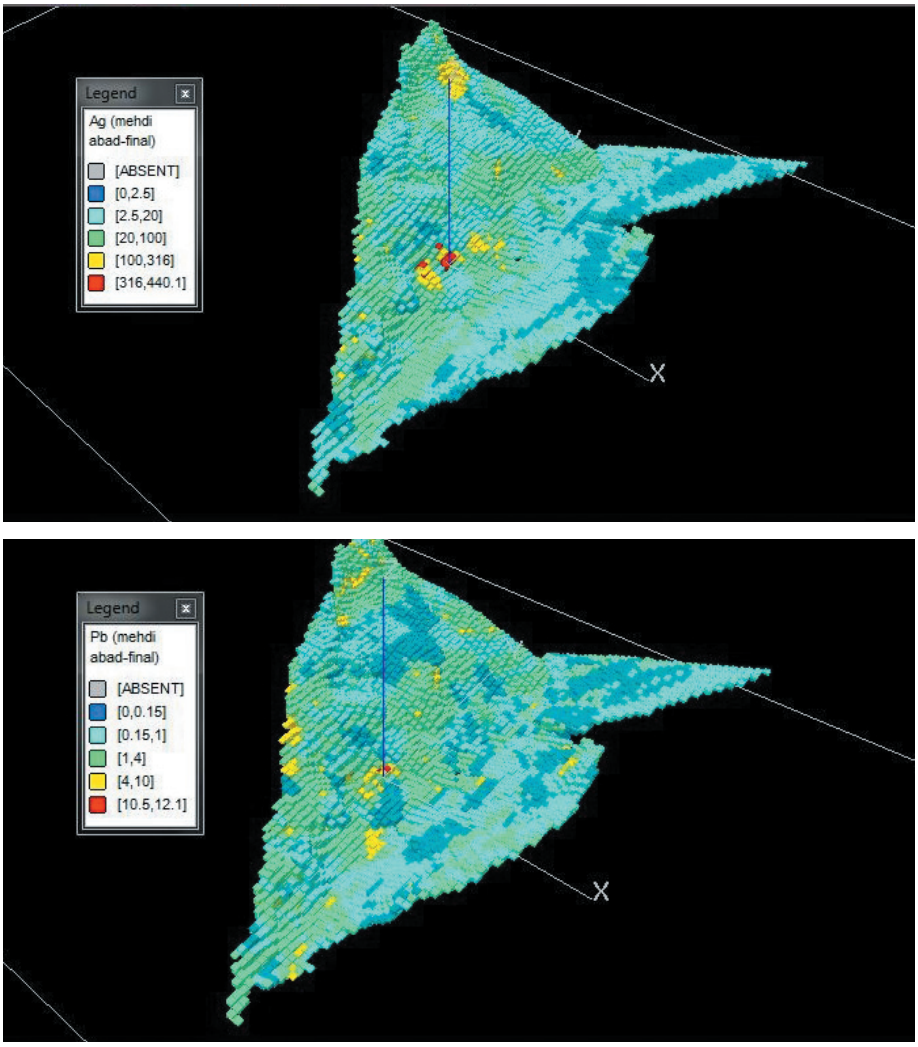

Fig. 6- 3D block models for Ag (a) and Pb (b) based on the C-V fractal model.

in Table 4. On the other hand, there are association between high and enriched mineralized zones for Ag and Pb. In addition, the OA between moderately zones of Pb and Ag is 68% which indicates that there is a direct relationship between Ag and Pb mineralized zones (Table 6).

4- 4. Validation with geological particulars

At last, the Pb and Ag mineralized zones were validated and compared with geological particulars especially mineralographical data. Enriched mineralized zones for Pb and Ag were located in the Black Hill within the Pb oxidized ores (gossan) specifically cerussite in this study deposit. Moreover, highly mineralized zones of these elements occur mainly in the Calamine mine (NW part of this deposit). There are high values of oxidized ores especially smithzonite, cerussite, hemimorphite, hydrozincite with wFe-oxy/hydroxides and clay minerals. These evidences show that the silver mineralization has been related to oxidized mineralization for lead.

Table 3- Logratio matrix for comparing overlaps between Pb and Ag enriched zones obtained by the C-V fractal model.

		Pb≥ 10%	
		Inside zone	Outside zone
Ag≥ 316 ppm	Inside zone	8	87
	Outside zone	42	33206
		Overall accuracy = 0.996131122	

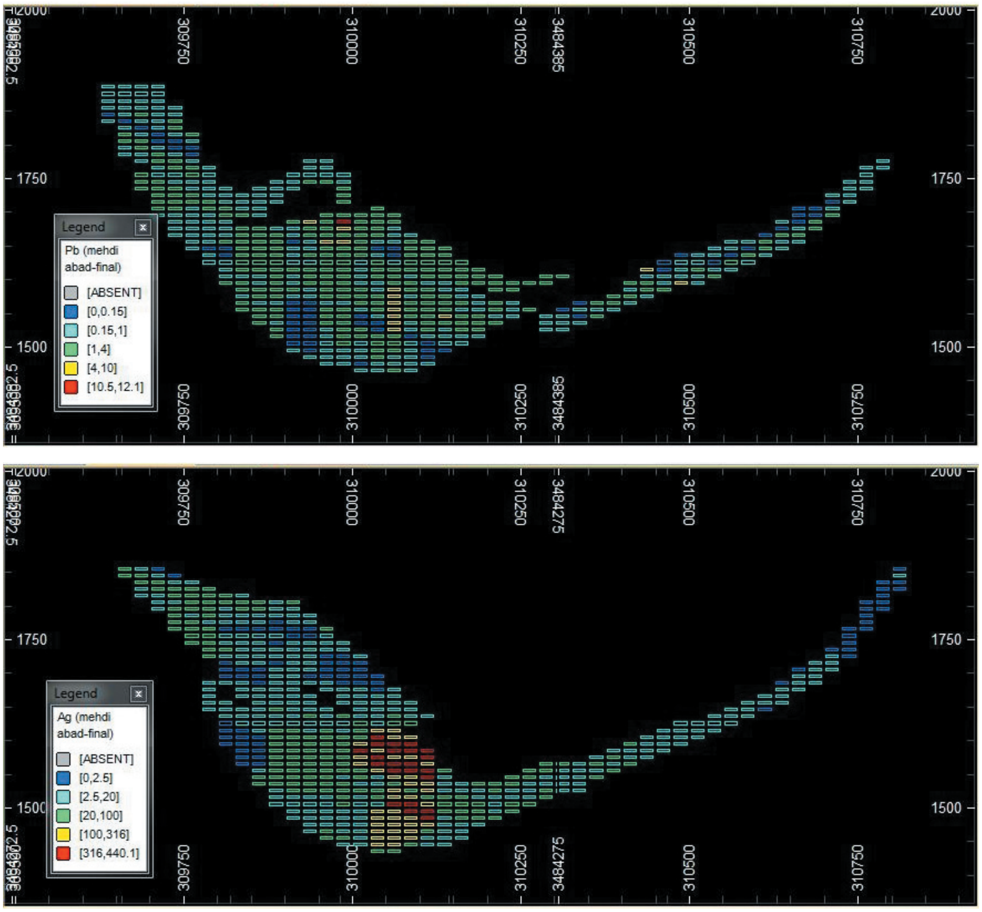

Fig. 7- Schematic W-E cross sections for Pb (a) and Ag (b) block models in the study deposit.

Table 4- Logratio matrix for comparing overlaps between highly Pb and Ag zones obtained by the C-V fractal model.

		10%>Pb≥ 4%	
		Inside zone	Outside zone
100≥Ag> 316 ppm	Inside zone	8	87
	Outside zone	42	33206
		Overall accuracy = 0.996131122	

Table 5- Logratio matrix for comparing overlaps between moderately Pb and Ag zones obtained by the C-V fractal model.

		10%>Pb≥ 4%	
		Inside zone	Outside zone
100≥Ag> 316 ppm	Inside zone	8	87
	Outside zone	42	33206
		Overall accuracy = 0.996131122	

5- Conclusion

Results derived via combination of the C-V fractal modeling and logratio matrix indicate that this hybrid method is proper for delineation of various mineralized zones in a MVT deposit based on multi-elemental data. This hybrid method reveals relationship between different mineralized zones of various ore elements. Furthermore, results obtained by this study represent that there are a highly correlation between lead and silver mineralization in the Mehdiabad deposit especially in the central and NW parts of this deposit. Results derived via the C-V fractal and logratio analysis show that there are high intensive mineralization for both of them in the oxidized ores specifically in the Black Hill and Calamine mine (western and NW parts of the deposit). Consequently, major silver mineralization is related to the cerussite ores in this deposit. Finally, this study revealed that combination between the C-V fractal modeling and logratio matrix can be used for finding relationship between mineralized zones of different elements in various ore deposit types as a future challenge.

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