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APPLICATION OF CONCENTRATION-NUMBER AND CONCENTRATION-VOLUME FRACTAL MODELS TO RECOGNIZE MINERALIZED ZONES IN NORTH ANOMALY IRON ORE DEPOSIT, CENTRAL IRAN

ZASTOSOWANIE MODELI FRAKTALNYCH TYPU K-L (KONCENTRACJA-LICZBA), ORAZ K-O (KONCENTRACJA OBJĘTOŚĆ) DO ROZPOZNAWANIA STREF WYSTĘPOWANIA SUROWCÓW MINERALNYCH W REGIONIE ZŁÓŻ RUD ŻELAZA NORTH ANOMALY, W ŚRODKOWYM IRANIE

Identification of various mineralized zones in an ore deposit is essential for mine planning and design. This study aims to distinguish the different mineralized zones and the wall rock in the Central block of North Anomaly iron ore deposit situated in Bafq (Central Iran) utilizing the concentration-number (C-N) and concentration-volume (C-V) fractal models. The C-N model indicates four mineralized zones described by Fe thresholds of 8%, 21%, and 50%, with zones <8% and >50% Fe representing wall rocks and highly mineralized zone, respectively. The C-V model reveals geochemical zones defined by Fe thresholds of 12%, 21%, 43% and 57%, with zones <12% Fe demonstrating wall rocks. Both the C-N and C-V models show that highly mineralized zones are situated in the central and western parts of the ore deposit. The results of validation of the fractal models with the geological model show that the C-N fractal model of highly mineralized zones is better than the C-V fractal model of highly mineralized zones based on logratio matrix.

Keywords: Concentration-Number (C-N); Concentration-Volume (C-V); Fractal models; Iron ore; North Anomaly

Identyfikacja stref występowania surowców mineralnych jest kwestia kluczową przy planowaniu wydobycia i projektowaniu kopalni. Celem pracy jest rozróżnienie stref o różnej zawartości surowców mineralnych oraz pasma skalnego w środkowej części zagłębia Bafq (środkowa cześć Iranu) przy wykorzystaniu modeli fraktalnych typu koncentracja-liczba i koncentracja-objętość. Model koncentracja-liczba

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pozwala na wyróżnienie czterech stref występowania surowca, definiowanych poprzez progową zawartość żelaza w rudzie na poziomie 8%, 21%, i 50% oraz strefy <8% i >50% zawartości żelaza, co odpowiada pasmu skalnemu oraz strefie o wysokim stopniu zawartości rudy. Model koncentracja-objętość wskazuje na istnienie stref geochemicznych określonych poprzez progowe wartości zawartości żelaza: 12%, 21%, 43% i 57 % oraz strefy <12%, co odpowiada ścianie skalnej. Obydwa modele stwierdzają obecność stref o wysokim stopniu zawartości surowca w środkowej i zachodniej części złoża. Wyniki walidacji modeli fraktalnych przy użyciu modeli geologicznych wskazują, ze model fraktalny koncentracja-liczba lepiej odwzorowuje obecność stref o wysokiej zawartości rud niż model fraktalny typu koncentracja-objętość.

Słowa kluczowe: model koncentracja-liczba, model koncentracja-objętość, modele fraktalne, ruda żelaza, North Anomaly

1. Introduction

Recognition and delineation of mineralized zones from barren host rocks are important in mineral exploration, reserve evaluation and mine planning. Conventional methods for definition and mapping of different enriched zones in various ore deposits, for example, are based on geological and mineralogical studies considering variations in the proportions of ore minerals in different type of iron ore deposits (Cox & Singer, 1986; Hitzman et al., 1992). The Kiruna-type iron ores are generally dominated by iron oxides, either magnetite or hematite, which are known to occur in the Kiruna-Gällivare iron province in northern part of the Sweden and in the Bafq-Saghand iron region in the central Iran (Bonyadi et al., 2011; Shayestehfar et al., 2006; Samani, 1988). Variations of geochemistry and alterations are other useful parameters for identification of variously mineralized zones in Kiruna-type iron deposits (Hitzman et al., 1992; Laznicka, 2005; Sadeghi et al., 2012).

Natural processes, especially geo-related sciences cannot be examined through Euclidean geometry (Davis, 2002). Mandelbrot (1983) proposed a new kind of geometry, which is able to explain and discuss processes in nature which was entitled “Fractal geometry”. Therefore, various approaches of fractal analysis were proposed and developed in different parts of geosciences especially geochemical exploration since 1980s, such as Number-Size (N-S: Mandelbrot, 1983), Concentration-Area (C-A: Cheng et al., 1994), Power Spectrum-Area (S-A: Cheng et al., 1999), Concentration-Distance (C-D: Li et al., 2003), Concentration-Volume (C-V: Afzal et al., 2011), Power Spectrum-Volume (S-V: Afzal et al., 2012) and Concentration-Number (C-N: Hassanpour & Afzal, 2013).

Further studies generally shows that geochemical data have multifractal nature, which indicates the variations in geological and geochemical environments, shallow weathering and mineralizing, and leads to enrichment of an element (Goncalves, 2001; Cheng & Agterberg, 2009; Afzal et al., 2010; Zuo et al., 2013).

Different geochemical processes can be obtained based on variations in the fractal dimensions derived via related geochemical data analysis. Log-log plots in the fractal/multifractal models are proper tool to describe and categorize geological population in geochemical data, because threshold values can be used as fracture points in these plots (Afzal et al., 2013; Hassanpour & Afzal, 2013).

In this study, C-V and C-N fractal models has been used for various Fe mineralized zones and wall rocks in the central block of North Anomaly iron ore deposit, Central Iran.

2. Methodology

2.1. C-N fractal model

Concentration-number model, which was defined by Hassanpour and Afzal (2013), can be adopted to explain how geochemical population is distributed without data pre-analysis. This model shows that there is a relationship between desired attributes (e.g., ore element in this study) and overall sample numbers. The C-N model can be defined by the following equation:

$$N(\geq \rho) = F\rho^{-D} \tag{1}$$

where ρ is element concentration and $N(\geq \rho)$ is overall number of samples having concentrations equal to or higher that ρ, also "f" is a constant and "D" is benchmark power for fractal dimensions of concentration distribution. Additionally, $N(\geq \rho)$ to ρ log-log plots show linear parts with different slopes which shows "–D" value, in proportion to different concentration ranges.

2.3. C-V fractal model

Concentration-volume model which is proposed by Afzal et al (2011), used to outline mineralized zones from wall rocks in different types of ore deposits, which can be expressed as follows:

$$V(\rho \leq \upsilon) \propto \rho_1^{-a}; \qquad V(\rho \geq \upsilon) \propto \rho_2^{-a} \tag{2}$$

where $V(\rho \leq \upsilon)$ and $V(\rho \geq \upsilon)$ respectively reveals volumes containing concentrations below or above threshold value of ρ, "υ" indicates mineralizing threshold, and "a_1" and "a_2" are fractal dimensions. Threshold values in this approach indicate the boundary between various mineralized zones and barren host rocks. To calculate $V(\rho \leq \upsilon)$ and $V(\rho \geq \upsilon)$, the estimated concentration block model with various geostatistical approaches are used.

3. Geological setting

North anomaly iron ore is located in 11 km of NW of Choghart Iron ore and Bafq district (Central Iran: Fig. 1). The Bafq region is situated in a metallogenic area in Central Iran structural zone with other mines and deposits such as Choghart (iron), Esfordi (phosphate-magnetite), Koushk (lead and zinc) and Chadormalu (iron and apatite). In this region, there are also Precambrian complexes with mineralization of U, Th, V, Mn, Mo, Ti, Ba, apatite, rare earth elements (REE), stratiform Pb-Zn massive sulphides and different types of Fe ore (Samani, 1988; Förster & Jafarzadeh, 1994; Daliran & Heins-Guenter, 2005; Jami et al., 2007; Sadeghi et al., 2012).

Based on two N-S faults, the North Anomaly is divided into three parts which called Eastern, Central and Western blocks, and among all, the Central block is the largest (Fig. 1). Lithological studies show that magmatic rocks (granite and rhyolite) and folded limestones were located in lower and upper parts of the deposit. There is a significant contact between limestone and light acidic rocks, especially in central block. Alluvium covered most parts of the area. Amphibole and albeit metasomatites are significant on the area, especially in central block (Fig. 2). There are many diabasic-syenitic dykes which were injected in most parts of the area (Afzal et al., 2009). A 3D geological model of ore was generated with RockWorks 15 software, as shown in Fig. 2.

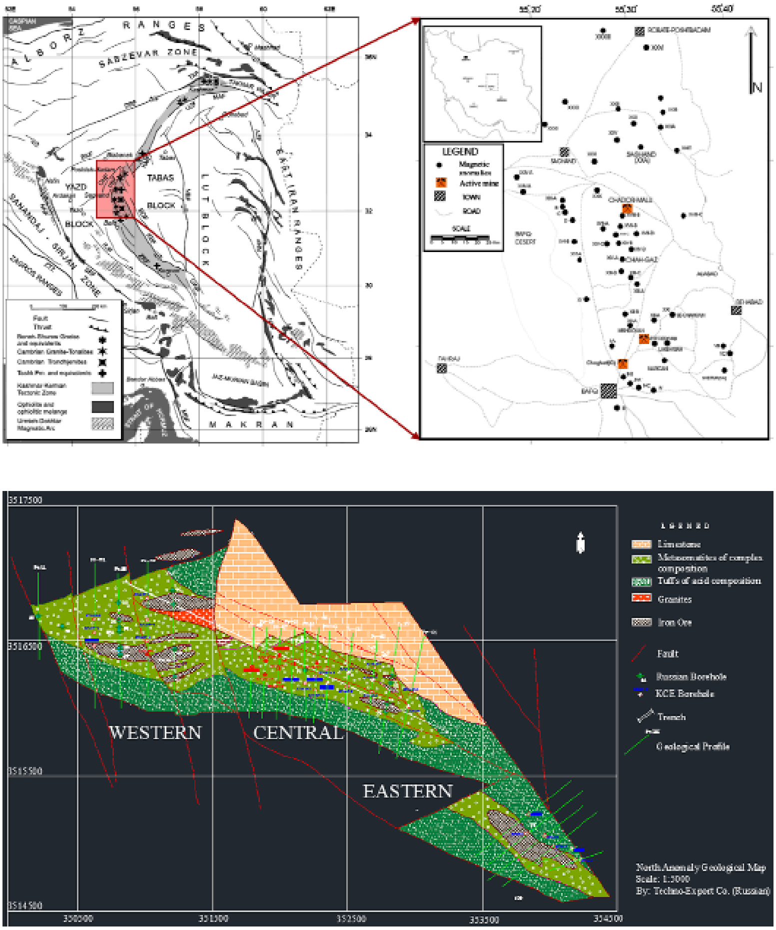

Fig. 1. The metallogenic district of Bafq (Sadeghi et al., 2013) and geological map of the North Anomaly deposit

4. C-N and C-V multifractal modeling

From 23 drillcores in the deposit, 1241 lithogeochemical samples have been collected at 2 m intervals. According to the Fe histogram, there is a multimodal distribution of Iron in this ore with Fe mean equal to 20.5% (Fig. 3). The experimental semi-variogram for the Fe data in this deposit illustrates a range and nugget effect of 178.9 m and 85.7, respectively (Fig. 4) which used to estimation of concentration distribution by ordinary kriging (OK) approach by Datamine studio software. The voxel sizes for block modeling and geostatistical estimation were determined 10 m ×10 m ×10 m in X, Y and Z dimensions, respectively.

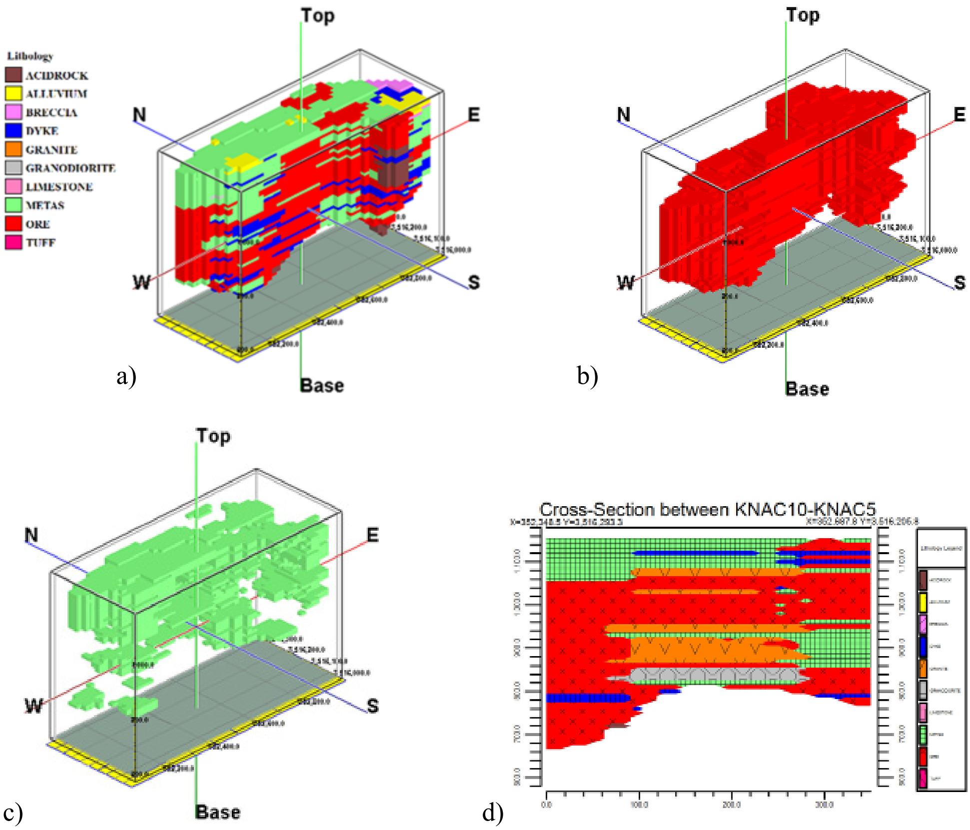

Fig. 2. 3D geological data based on drillcores in the North Anomaly deposit: (a) geological model of the deposit (b) High concentration iron ore (c) metasomatic unit (d) A geological cross-section of the iron ore

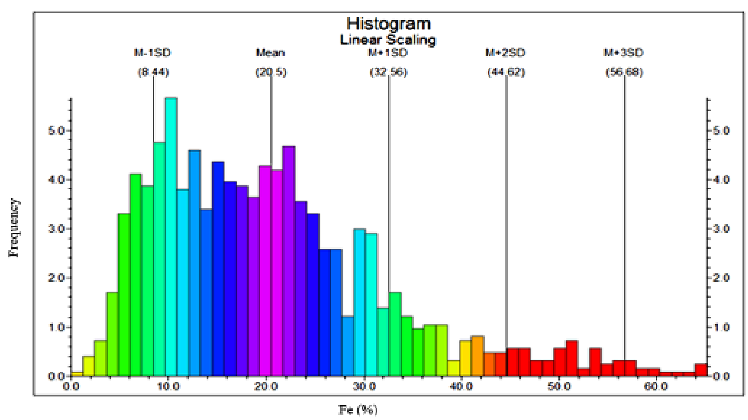

Fig. 3. Histogram of Fe concentration in drillcore samples of Central block in the North Anomaly deposit

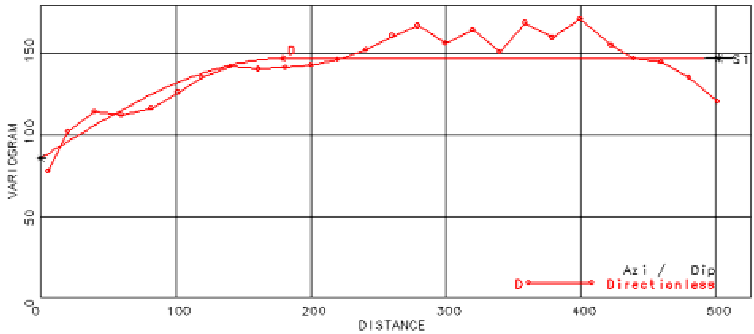

Fig. 4. Variogram of Fe in the Central block

4.1. C-N fractal modeling

Based on the C-N log-log plot, there are four populations for Fe in the area. The first threshold is equal to 8% and lower values shows wall rocks (Table 1). The second Fe threshold is 21% and Fe values between 8 and 21% show weakly mineralized zone. The third threshold is equal to 50% and Fe values between 21% and 50% indicate moderately mineralized zone (composition of hematite and magnetite) and Fe values higher than 50% reveal highly mineralized zone (magnetite part). Moreover, the results obtained by the C-N fractal modeling show that proper parts for extraction of iron ore could be proposed in the highly and moderately mineralized zones which contain Fe values higher than 21% especially higher than 50%.

Based on 3D modeling of Fe data and threshold obtained by the fractal model, mineralized zones with Fe high concentration (>50%) are located in the central and western part of the deposit (Fig. 6). Areas with moderate mineralization are in the NW to SE trend, and parts with weak mineralization are in marginal parts.

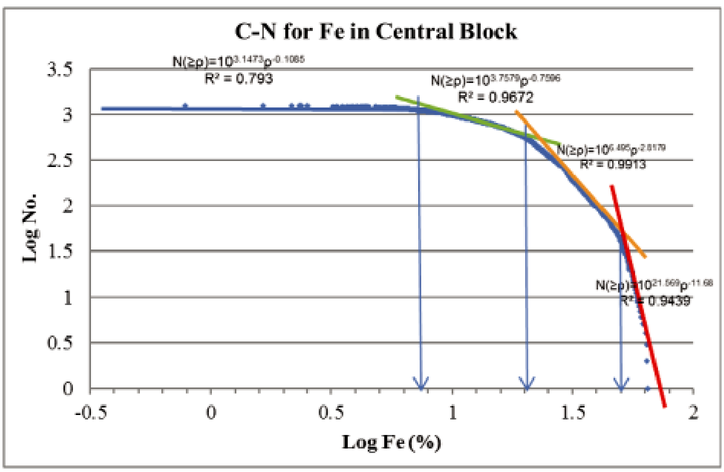

Fig. 5. C-N log-log plot for Fe values in the deposit

TABLE 1

Mineralized zones in the central block of the North Anomaly iron ore deposit based on C-N model

%Fe	Mineralized zones
< 8%	Wall rocks
21-8	Weakly
50-21	Moderately
> 50	Highly

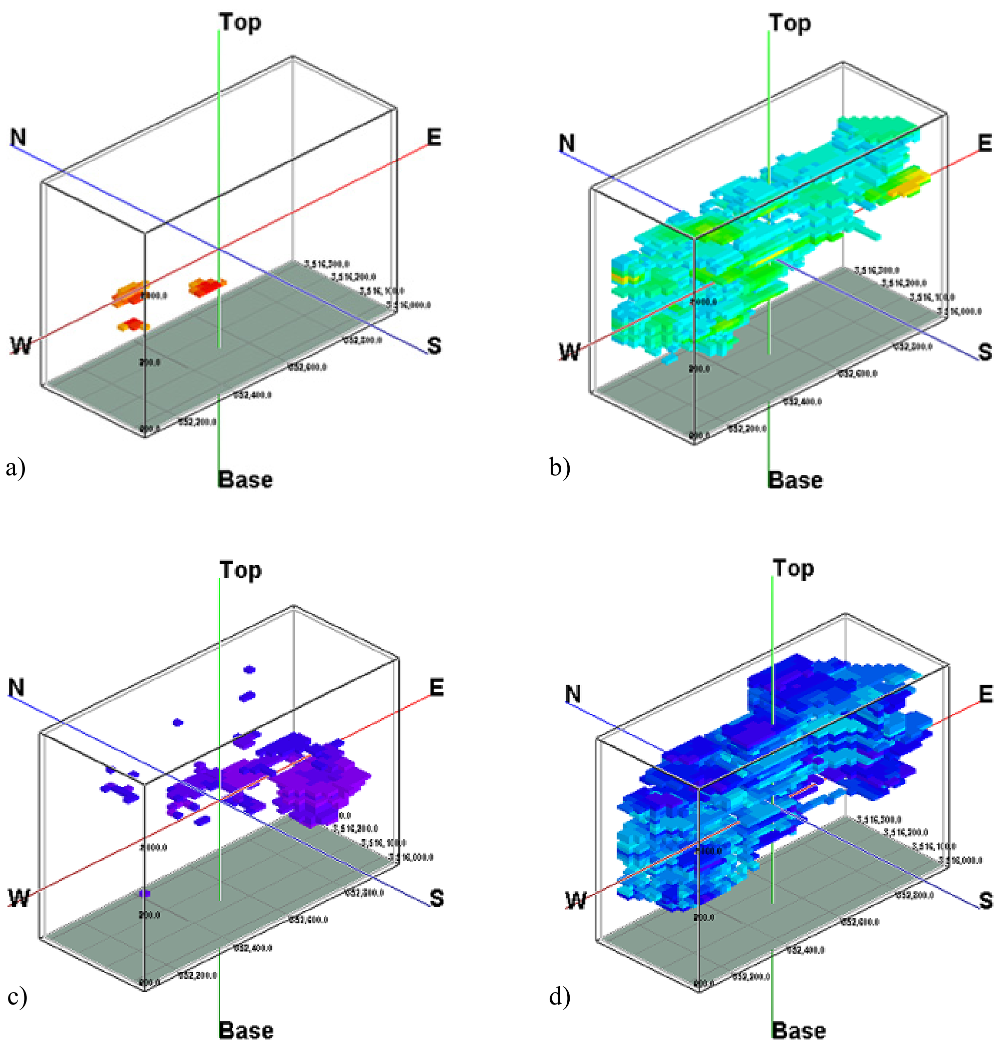

Fig. 6. Different zones in the Central block of the North Anomaly Iron ore deposit based on defined thresholds in C-N model: (a) parts with highly mineralization; (b) zones with moderately mineralization; (c) areas with weak mineralization; and (d) wall rocks

4.2. C-V fractal modeling

Based on 3D model on the deposit, volumes corresponding with different concentrations of Fe are utilized to calculate a concentration-volume fractal model. Threshold values of Fe in the C-V log-log plot are recognizable (Fig. 7), which indicates a nominal relationship between Fe concentrations and related volumes. Depicted log-log plot shows threshold values corresponding to 4 breakpoints equal to 12%, 43%, 21% and 57%. Based on this plot, mineralized zones with very high concentration have >57% Fe which could be proposed as an enriched zone (Table 2). Fe concentration range between 43% and 57% shows highly mineralization which can be classified in magnetite part. Fe concentration between 21% and 43% shows moderately mineralization and 12 to 21% Fe indicates weakly mineralized zone. Fe concentrations lower than 12% illustrated wall rocks in the ore deposit. It can be illustrated that there are proper parts for iron ore extraction consisting of moderately, highly and enriched zones which have Fe values higher than 21%. Additionally, main parts of iron ore are higher than 43%.

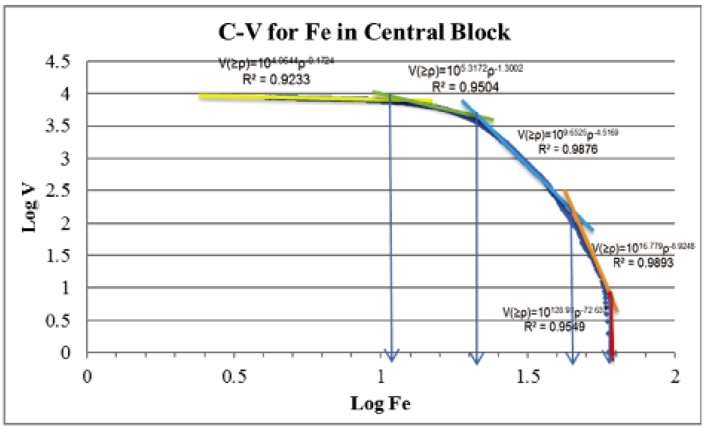

Fig. 7. C-V log-log Plot for Fe values in the central block of the North anomaly iron ore

Based on the C-V fractal model, highly mineralized zones are located in the central part of ore deposit (Fig. 8). However, such areas are so rare in the western parts. Zones with moderate mineralizing are occurred in the northern and eastern parts. Barren wall rocks are also exist in the marginal areas in the ore deposit.

TABLE 2

Zones in North Anomaly Iron ore deposit based on defined thresholds in C-V model

Fe (%)	Mineralized zones
< 12%	Wall rocks
21-12	weak mineralization
43-21	moderate mineralization
57-43	high mineralization
> 57	Very high mineralization

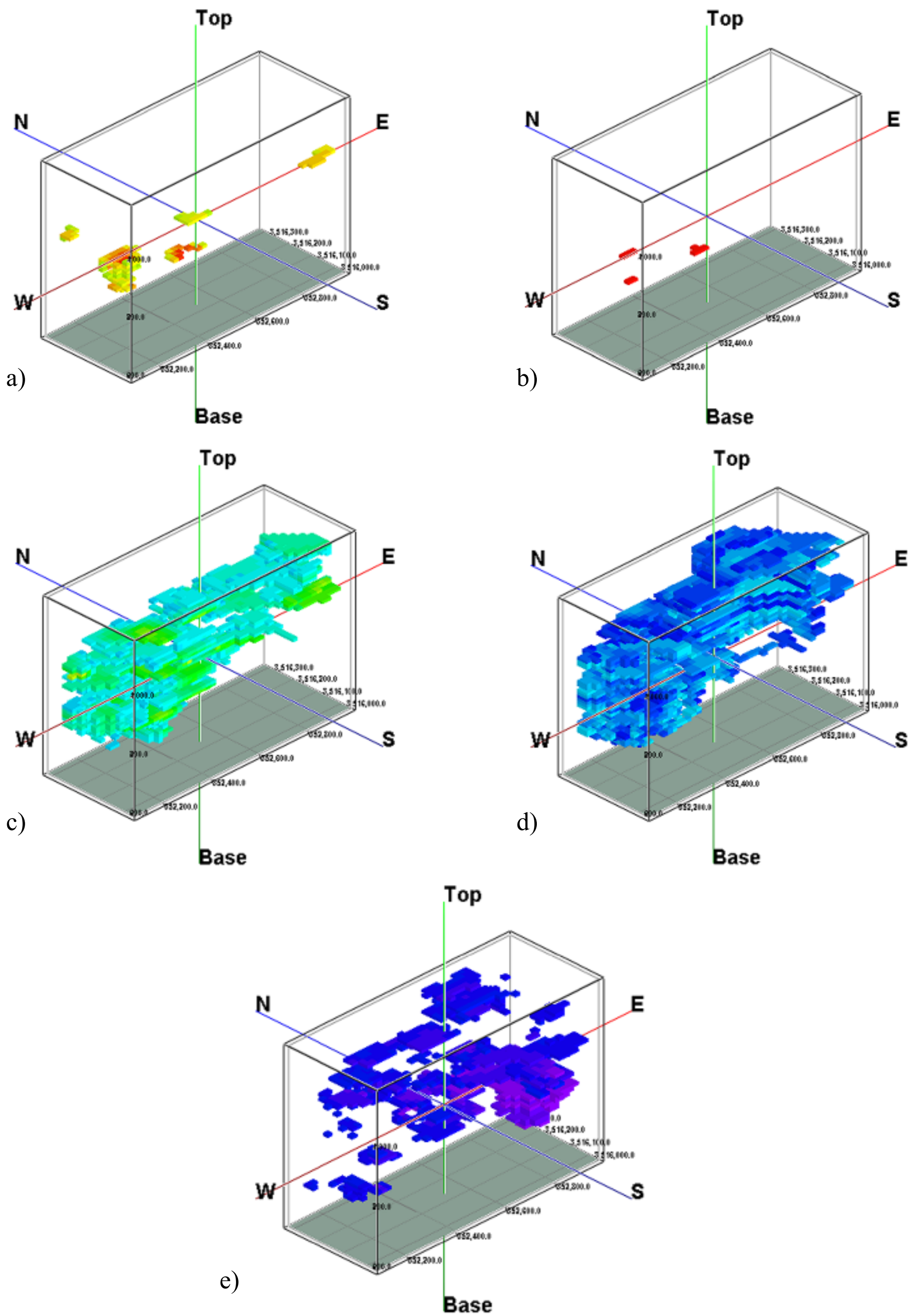

Fig. 8. North Anomaly Iron ore deposit based on defined thresholds in C-V fractal model: (a) Enriched zone areas; (b) areas with high mineralization; (c) areas with moderate mineralization; (d) areas with weak mineralization; and (e) wall rocks

5. A Comparison between fractal models and geological model of mine

For validation of results obtained by fractal modeling and comparison between the fractal models, the results derived via the C-V and C-N fractal modeling were collated with iron ores which resulted by geological modeling.

To compare between fractal models with geological data, Logratio Matrix (Carranza, 2011) was used. Using obtained numbers, type I error (T_1E), type II error (T_2E), and overall accuracy (OA) are calculated according to geological model of the deposit, in which we try to lower T_2E more than T_1E because T_2E requires a decision for ore deposit (such as efforts made, time and cost) for no achievement. Moreover, for each fractal model, OA values for C-N and C-V in mineralized zones are compared as follows (Table 3). The matrix contain of four parameters including A (Subscription voxels between fractal and geological models), D (Voxels which are not in any of the models), B (Correlated voxels with fractal model but not with geological model) and C (Correlated voxels with geological model and not with fractal model).

Comparison between high concentration zones in geological model and highly mineralized zones in fractal models shows that C-V fractal model has better correlation with the geological model (Table 4). OA for C-V and C-N in high concentration zones are 0.486 and 0.487, respectively, which indicates that C-N model yields better results for defining high mineralization Fe zones in the deposit.

TABLE 3

Matrix for comparing performance of fractal modeling with geological mode. A, B, C and D represent number of voxels in overlap between classes in geological binary models and binary results of fractal models (Carranza, 2011)

Geological Model			
Outside zones	Inside zones		
False positive (B)	True positive (A)	Inside model	fractal model
True negative (D)	False negative (C)	Outside model	
Type II error =B/(B+D)	Type I error =C/(A+C)		
OA =(A+D)/(A+B+C+D)			

TABLE 4

Overall accuracy, Type I error and Type II error with respect to high grade ore zone resulted from geological model of highly mineralized zones obtained through C-N and C-V fractal models

High grade ore zones of geological model					
Outside zones		Inside zones			
0	B	9	A	Inside zone	C-V fractal model of enriched mineralized zones
8287	D	8760	C	Outside zone	
1	Type II error	0.998974	Type I error		
0.486126591		OA			

High grade ore zones of geological model					
Outside zones		Inside zones			
9	B	119	A	Inside zone	C-V fractal model of highly mineralized zones
8269	D	8650	C	Outside zone	
0.998913	Type II error	0.986429	Type I error		
0.492051387		OA			

High grade ore zones of geological model					
Inside zones		Inside zones			
0	B	39	A	Inside zone	C-N fractal model of highly mineralized zones
8278	D	8730	C	Outside zone	
1	Type II error	0.9955	Type I error		
0.487886432		OA			

TABLE 5

OA, TE1 and TE2 with respect to geological model of moderately mineralized zones obtained through concentration-number and concentration-volume fractal models.

High grade ore zones of geological model					
Outside zones		Inside zones			
1737	B	3181	A	Inside zone	C-V fractal model of moderately mineralized zones
8269	D	8650	C	Outside zone	
0.790167	Type II error	0.637245	Type I error		
0.570305626		OA			

High grade ore zones of geological model					
Inside zones		Inside zones			
1328	B	3517	A	Inside zone	C-N fractal model of moderately mineralized zones
6950	D	5252	C	Outside zone	
0.16042	Type II error	0.59892	Type I error		
0.61400833		OA			

6. Conclusion

In many cases, the most important challenge in finding mineralized zones is difference in type of geological and mineralogical units. However, conventional geological modeling based on the drillcore data is generally important to understand the spatial structure of understanding and mathematical applications. Considering these issues, using such sets of established approaches based on mathematical analysis such as fractal modeling is inevitable.

In this study, the C-N and C-V fractal models are utilized to examine various zones of iron mineralization in the central block of the North anomaly iron ore deposit. The both models illustrated high mineralization in the deposit with threshold values of Fe for these two models are equal to 50% and 57% based on the results obtained by the C-N and C-V model. Moderately mineralized zones in the central and eastern parts contain Fe values between 8 to 21% and between 21 to 43% in the C-N and C-V models, respectively. The results derived via C-N model shows values less than 8% as the weakly mineralized zones and wall rocks, whereas C-V model indicates wall rocks as values lower than 12% and defines weakly mineralized zones between 12 to 21% Fe. Based on the both of them, the main mineralization were commences from 21% Fe which could be show that the mineable reserves are situated in the zones contain Fe values higher than 21%.

According to the results obtained by the fractal and geological models in the iron ore deposit, highly mineralized zones in the fractal models have strong and significant relationship with high concentration mineralized zones in the 3D geological models, especially in the C-N model.

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