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Determination of Chromites Prospects Using Multifractal Models and Zonality Index in the Parang 1:100000 Sheet, Iran

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Abstract Recognition of geochemical halos is one of the most important tools for exploration of undiscovered ore deposits. The aim of this study is prospecting for chromite deposits located in the Parang 1:100000 sheet, SE Iran, based on stream sediment data. To do this, geochemical zonality index and Concentration-Area (C-A) fractal modeling were used for chromite prospects determination. Multiplied values of Cr, Co and Ni as the zonality index for prospecting of chromite deposits and various geochemical anomalies were distinguished based on the C-A fractal model log-log plots which indicate four geochemical populations for Cr, Co, Ni and zonality index in the area with low intensive anomalies thresholds of 0.141 ppm, 17 ppm, 77 ppm and 7,943,282 ppm^3 respectively. Results obtained by the C-A modeling show that the high intensive anomalies for multiplication of Cr.Co.Ni and Cr are located in the western and central of the studied area. Finally, the result obtained by zonality index and the C-A fractal modeling and Cr anomalies was compared by log-ratio matrix which illustrates that the western and central parts of the area are associated with chromite prospects having a good correlation with the geological model in the Parang 1:100,0000 sheet.

Keywords C-A Fractal Model, Zonality Index, Chromite Ore Deposit

1. Introduction

Primary halos of mineral deposits are formed by interactions between host rocks, ore fluids and ore elements enrichment which occur within alteration zones [1-8].

Different geochemical methods presented in regard with geochemical features of primary halos. Stream sediment data is a common geochemical technique for identification of mineral deposits in a regional scale [9]. Beus and Grigorian [10] proposed a model for detection of prospects using the geochemical zonality index for different ore deposits in the various landscapes at the regional scale. Metallometric methods have been utilized for delineation of geochemical anomalies associated with mineralized area [11-13] which do not have enough efficiency for exploration in the following situations: (1) presence of significant heavy metal contamination of stream sediments due to mining activities ; (2) low relief areas of hydromorphic dispersion predominates over mechanical dispersion of metals from ore deposits [14]. Fractal/multifractal models established by Mandelbrot [15] have widely applied for delineation of geochemical anomalies from background. Fractal theory has been used to prospect ore deposits since 1980s [16-25].Cheng [19] proposed the Concentration–Area (C–A) fractal model for definition of different geochemical anomalies and background. In this paper, the C-A fractal modeling and zonality index were applied for prospecting of chromite deposits in the Prang 1:100000 sheet, SE Iran.

2. Geological Setting

The studied area was located in South Khorasan province and near to Birjand city in the ophiolite SE Iran belt which has more than 20 podiform chromite ore deposits [26] (Fig 1).The main formation and rocks in the studied area relate to Mesozoic ophiolites complex and Cretaceous sediments. The ophiolitic zone has all member of ophiolite sequences including; Listinvite, Radiolarite, Plagiogranite, Basic tuff, Diabase, Gabbro, Serpentinite and Ultramaphic rock mainly lherzolite and harzburgite.

The main Iranian ophiolites occur in Mesozoic and Paleozoic rocks (Fig1 a). The most of Mesozoic ophiolites are located among the Iranian plate in the north and the Arabian plate in the south, and have been grouped by Lensch and Davoudzadeh [27] and Stöcklin [28] into an outer and inner sub-belt. The inner sub-belt (Central Iran type) is located around the Central Iranian micro-continent and includes the Sabzevar, Nain-Baft, Esfandagheh, Makran and Birjand ophiolites [29-39].The ophiolitic complex of this zone is hosted by serpentinite andperidotites. Peridotitic host rocks consist of harzburgite and lherzolite in the ophiolites and wehrlite in the overlying cumulate sequence. Some chromite bodies occur in dunite layers in the cumulate contact [40].

3. Methodology

The studied area was gridded based on the distances between sample locations, and also the cell sizes were selected 200×200 m^2. The C-A log-log plots were generated for zonality index and different geochemical populations were distinguished. Furthermore, chromite prospects were generated based on results obtained by the C-A fractal model. Finally, the prospects were correlated with geological particulars with respect to log-ratio matrix proposed by Carranza.

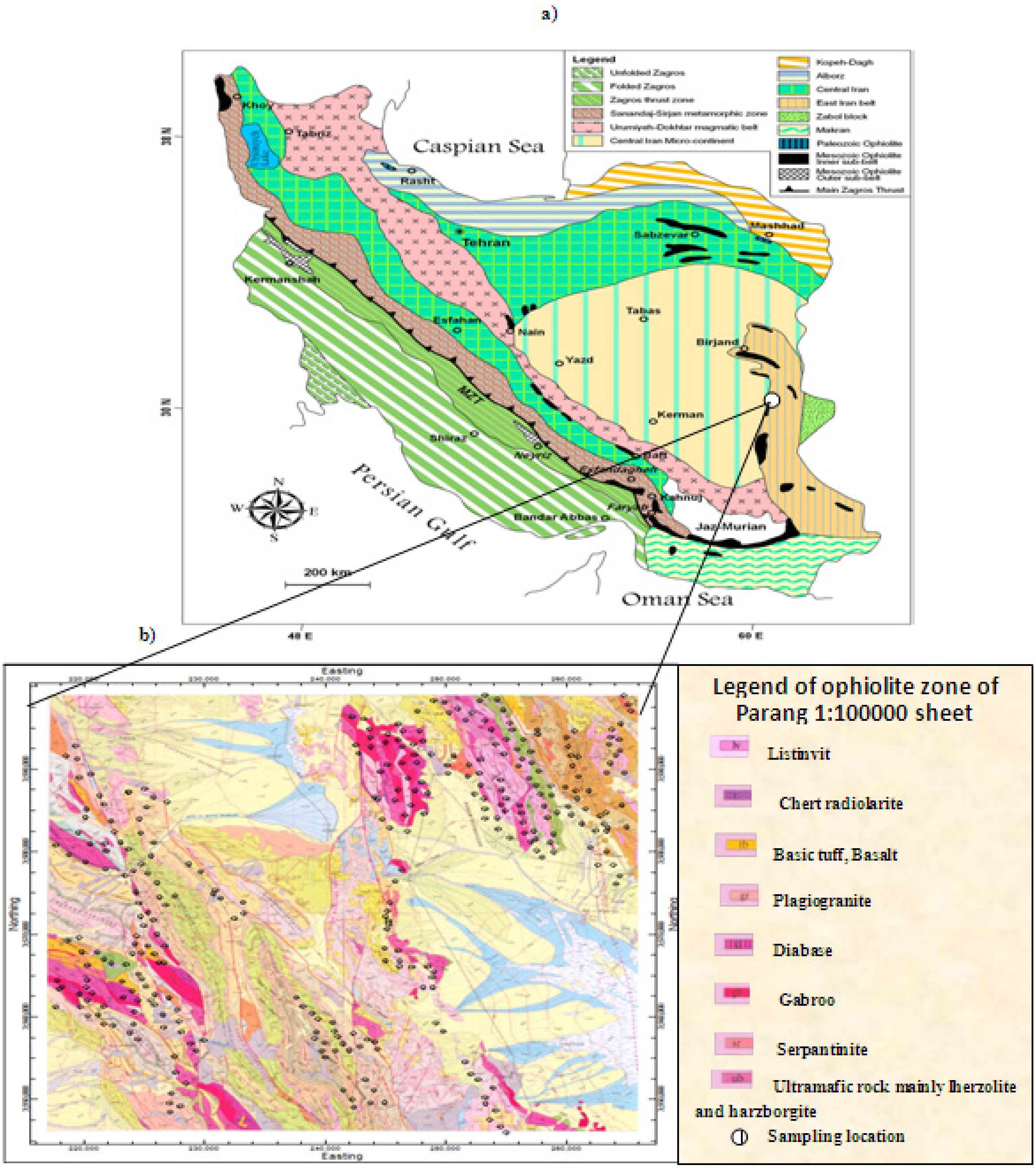


Figure 1. **a)** Schematic map of distribution of chromites sequences in Iran **b)** geological map of Parang 1:100000 sheet

4. Concentration-Area Fractal Model

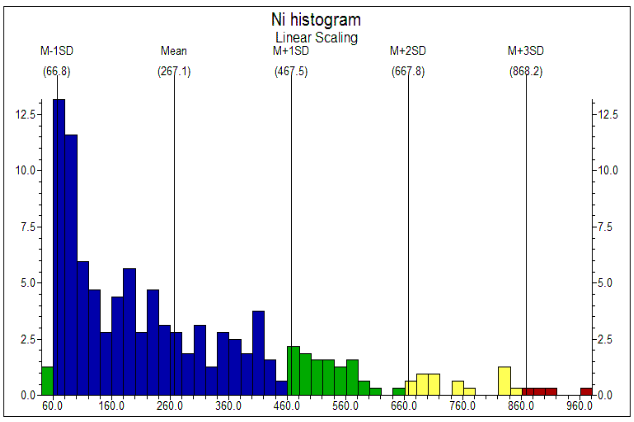
Cheng et al. [19] proposed the concentration–area (C–A) fractal model for delineation of geochemical anomalies and background due to the distribution of elemental concentrations. This model has the general form as follow:

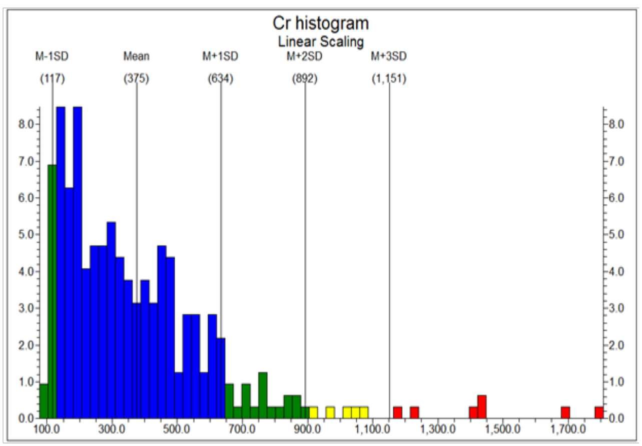
$A\ (\rho \leq \upsilon) \infty \rho\ \text{-a1};\ A\ (\rho \geq \upsilon) \infty \rho\ \text{–a2}$ (1)

Where $A\ (\rho \leq \upsilon)$ and $A\ (\rho \geq \upsilon)$ represent areas (A) with concentration values smaller or greater than contour value ρ, also υ represents the threshold ; a1 and a2 are characteristic exponents which denote fractal dimension. Threshold values in this model indicate boundaries between different geochemical populations.

5. Application of Multifractal Modeling, Factor Analyzes and Zonality Index

Multifractal model was applied for exploration of chromite prospecting in the Parang1:100000 sheet, SE Iran. The collected geochemical data consists of 320 stream sediment samples (Fig 1b) were analyzed by BRGM (French Geological Survey) for 33 elements utilizing ICP-MAS.





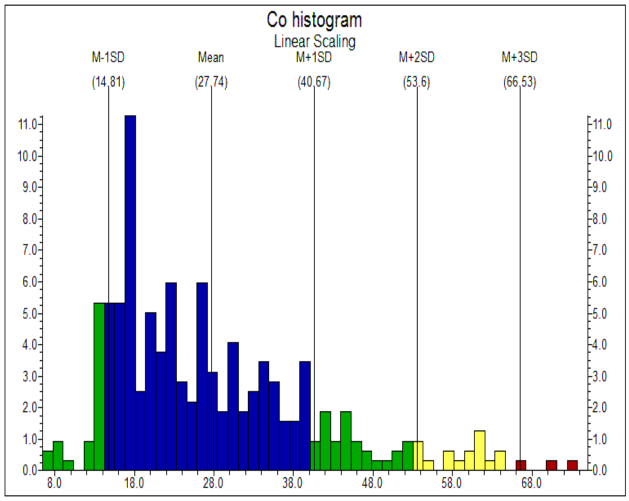


Figure 2. Histogram plots of Cr, Co and Ni

This research investigated Cr, Co, Ni elements and an exploration indicator for chromite deposits prospecting which was proposed based on the multiplied values of these elements as the zonality index. However, the association of Co, Ni and Cr values could be a suitable indicator for prospecting of chromite deposits as well as statistical parameters of the data (Fig 2 and Table 1). Histograms of Cr, Co and Ni show multimodal distribution, as depicted in Fig. 3. The geochemical maps were generated for Cr, Co, Ni and the zonality index using IDS (Inverse Distance Squared) by Rock Works software package.

The C-A log-log plots were generated for Cr, Ni, Co and zonality index as depicted in Fig 3. For application of the C-A fractal model, the calculated values in cells were sorted based on decreasing values and cumulative areas were calculated for grades corresponding to those areas.

According to the log-log plots, four geochemical populations were distinguished for Cr, Co, Ni and zonality index as illustrated in Fig 4. First threshold value for Cr is 141 ppm and its enriched part commences from1496 ppm which is located in the SW and western parts of the area.

The Cr values lower than 141 ppm can be defined as the background and the second population is between 141 ppm and 512 ppm that relates to weak anomalies. The Cr values between 512 ppm and 1496 ppm indicate the main anomalies. Co and Ni anomalous threshold is 17 ppm and 77 ppm respectively however; the values higher than 54 ppm for Co and 501 ppm for Ni demonstrate enrichment parts of the elements which are situated in the northern, central and western parts of the area (Fig. 4).

Table 1. Statistical parameters for Cr, Co and Ni

Statistical Parameters Elements	Mean	Standard Deviation	Variance	Median	Skewness	Kortosis
Cr	379	286.40	82027	312	3.53272	23.35886
Co	27.73	12.93	167.211	24	1.073	0.77643
Ni	267	200.35	40140	208	1.184	0.90321

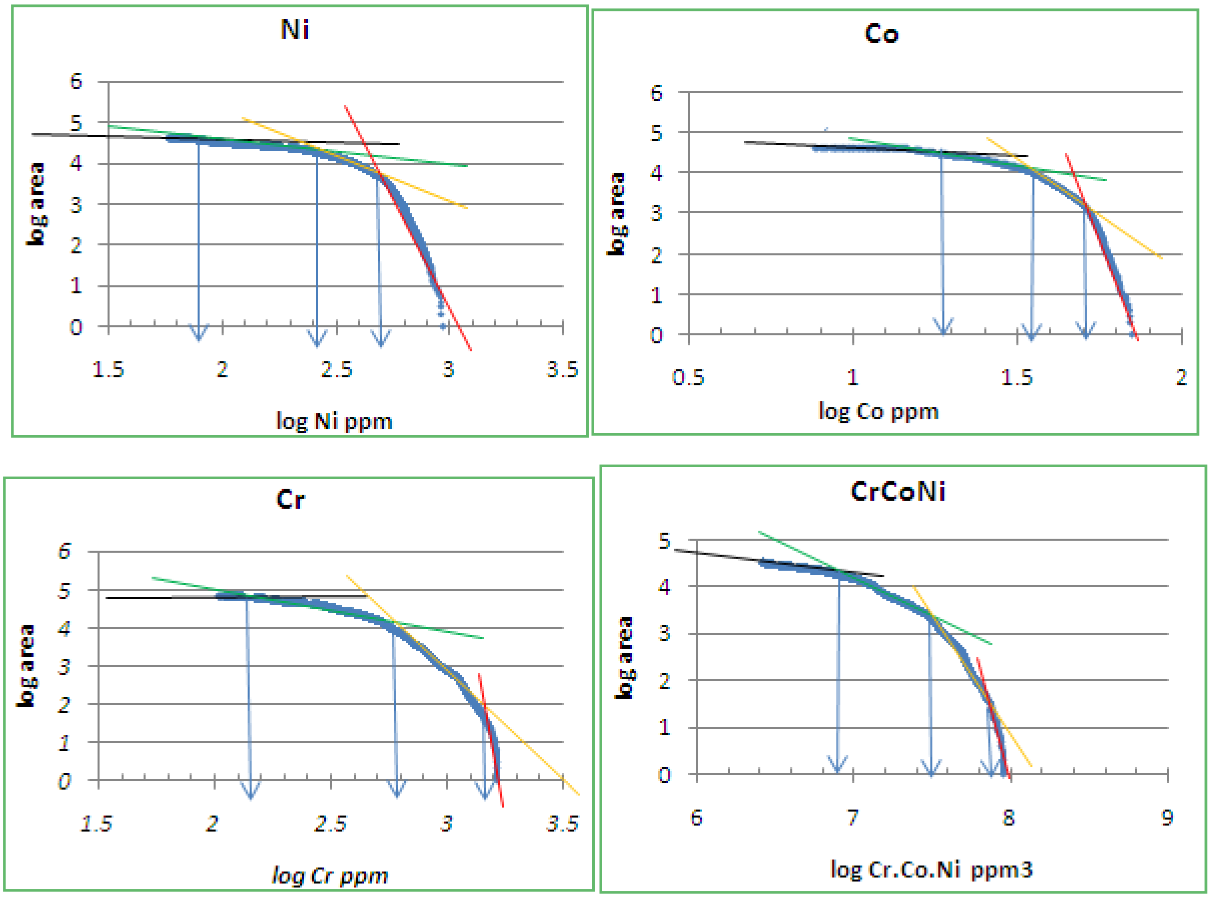
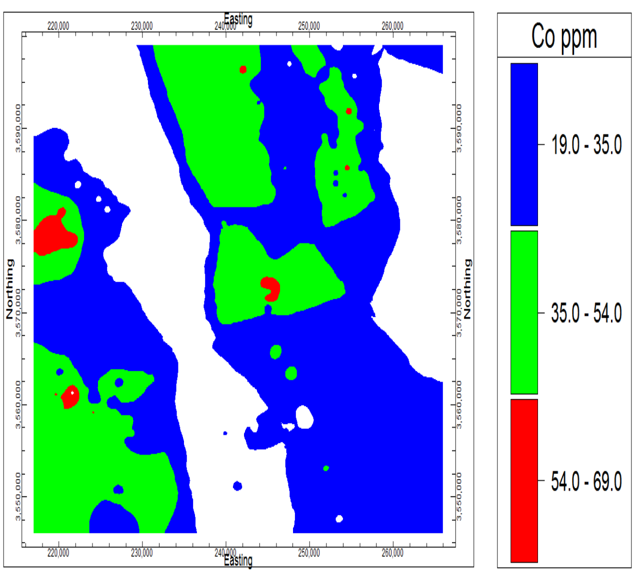
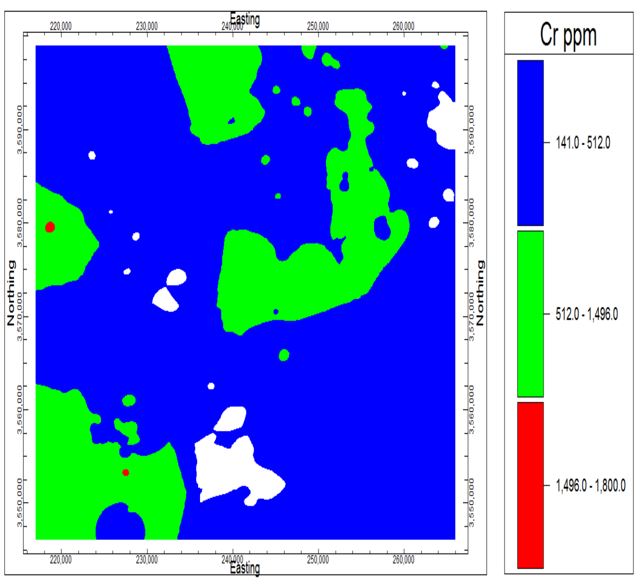


Figure 3. C-A Log-log plots for Cr, Co, Ni and zonality index





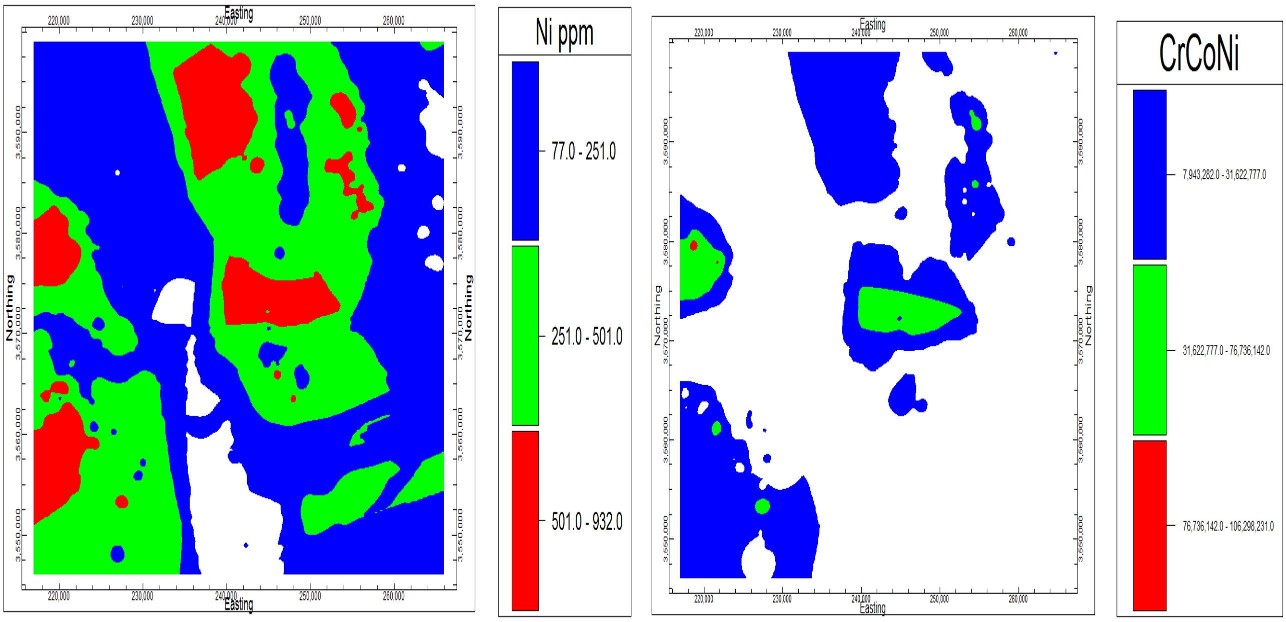


Figure 4. Geochemical anomaly maps of Cr, Co, Ni and multiplied halos of Cr.Co.Ni

The C-A fractal model was utilized for zonality index to show different geochemical populations. The first event for the zonality index occurs at values below 7,943,282 ppm^3. The high intensive anomaly for zonality index happened with values higher than 76,736,142 ppm^3. The high intensity anomalous parts of the zonality index are located in the western and SW parts of the area as well as the high intensive anomalies for Cr (Fig. 4).

6. Correlation between Geological Particulars and Multifractal Modeling

For validation of the resulted chromite prospects, correlation between geological and zonality index models was carried out using the log-ratio matrix. Carranza has proposed this matrix to additional investigation of spatial correlations between two different binary models.

The results obtained by the C–A fractal modeling were simplified into tow binary geochemical maps including anomaly and background. Each binary geochemical background anomaly map is crossed with certain part of geological map that ore deposits could be occurrence there. To apply this intersection operation between two binary maps, four overlap conditions happen where the intersection area is calculated for measuring performance of binary geochemical anomaly mapping. Two errors may happen namely; type 1 error (T1E) including the ability of the analysis to background zones and type 2 error (T2E) relates to the ability of the analysis to anomaly zones which lower values of T2E is more important than lower values of T1E. Moreover, high values of overall accuracy (OA) show strong correlation (Table 2).

Table 2. Log ratio matrix for comparing correlation of geochemical modeling results with geological model. A, B, C, and D represent numbers of pixel in overlap between the binary geological model and the binary results of geochemical model (Carranza 2011).

		Geological model	
		Inside	Outside
Geochemical model	Inside	True positive A	True negative B
	Outside	False positive C	False negative D
		T1E C/(A+C) T2E B/(B+D)	
		Overall accuracy (A+D)/(A+B+C+D)	

Table 3. Log ratio matrix for comparing correlation of high anomaly of Cr and multiplied halos with geological model

		Geological model	
		inside	Outside
High anomaly of Cr	Inside	4	5
	Outside	6295	58564
		T1E 0.999365 T2E 8.53694E-05	
		Geological model	
		inside	Outside
High anomaly of multiplied halos of Cr.Co.Ni	Inside	6	14
	Outside	6293	58555
		T1E 0.999047 T2E 0.000239091	
		Overall accuracy 0.902772	

Different anomalies of Cr and the zonality index were appended into geological map and correlation between these anomalies and geological ophiolites sequences were distinguished by using log-ratio matrix. As mentioned above, numbers of cells in overlaps between binary geological model and different parts of the geochemical maps were calculated. Based on the log-ratio matrix, high intensive anomalies defined by means of C-A multifractal modeling for Cr and multiplied halos shows good association with ophiolite sequences and OA for these models is 0.81 (Table 3). However, main anomalies defined by means of C-A multifractal modeling for multiplied halos are lower than multifractal Cr modeling and show more correlation (Table 4). Furthermore, comparing of the results of weak anomaly for Cr and zonality index obtained by the C-A fractal model reveals that OA for zonality index is higher than the main Cr anomalies (Table 5).

Table 4. Log ratio matrix for comparing correlation of main anomaly of Cr and multiplied halos with geological model

		Geological model	
		inside	Outside
Main anomaly of Cr	Inside	1023	7107
	Outside	5276	51462
		T1E 0.7386 T2E 0.1381	
		Overall accuracy 0.809105	
		Geological model	
		Inside	Outside
Main anomaly of multiplied halos of Cr.Co.Ni	Inside	217	1861
	Outside	6082	56708
		T1E 0.9656 T2E 0.0318	
		Overall accuracy 0.8776	

Table 5. Log ratio matrix for comparing correlation of weak anomaly of Cr and multiplied halos with geological model

		Geological model	
		Inside	Outside
Weak anomaly of Cr	Inside	6219	41301
	Outside	80	17269
		T1E 0.127 T2E 0.705	
		Overall accuracy 0.3621	
		Geological model	
		Inside	Outside
Weak anomaly of multiplied halos of Cr.Co.Ni	Inside	2132	14380
	Outside	4167	44189
		T1E 0.6616 T2E 0.2455	
		Overall accuracy 0.7141	

7. Conclusions

Results obtained by this study show that the combination of zonality index and the C–A fractal modeling is an applicable tool to prospect ore deposits. Elemental distribution of Cr, Co and Ni shows that their enrichment is located in the western part of the area. Multiplied values of Cr, Co and Ni as a zonality index were applied for demonstration of the new chromite prospects. Distribution of the zonality index indicates an enriched zone in the western and central parts of the area which are introduced as a suitable region for detailed exploration. The obtained results via the C-A fractal modeling for Cr has the good association with multiplied halos of Cr.Co.Ni model but the area is prospected for Cr mineralization based on the zonality index modeling which has more agreement with geological evidence. Moreover, due to log-ratio matrix, multiplied halos modeling has better concord with geological model which shows advantage exploration index versus Cr modeling. The overall accuracy of the weak anomaly of Cr and weak anomalies of multiplied of Cr.Co.Ni are equal to 0.3621 and 0.7141 respectively. Furthermore, OAs are 0.8091 and 0.8776 for the main mineralization of Cr and the zonality index. Finally, in the high intensive anomalies, values of overall accuracy are approximately equal so the results of two models in the enriched zones are equal.

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