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# Application of Power-Law Frequency Fractal Model for Recognition of Vertical Cu Distribution in Milloieh Porphyry Deposit, SE Iran

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**Keywords**

*Power-law frequency fractal model*

*Vertical distribution*

*Milloieh*

**Abstract**

Identification of the vertical and horizontal distributions for elemental grades is of an important sign in different mineral exploration stages. The main aim of this work is to determine the vertical distribution directional properties of Cu values in the Milloieh Cu porphyry deposit, Kerman (SE Iran) using the power-law frequency fractal model. This work is carried out based on four mineralized boreholes. The Cu grade vertical distribution in mineralized boreholes indicates a positively skewed distribution in the former and multi-modal distribution in the latter types. The power-law frequency analysis in nature represents that the Cu values in four mineralized boreholes are bifractal. The two sections of these graphs outline a break point of about 0.5-1% for Cu values and fractal dimension range of 1.70-4.97 in the mineralized boreholes.

## 1. Introduction

Recognition of the distribution of ore elements in different axes (X, Y and Z), specifically at exploratory boreholes, is a significant study, which is essential to evaluate the quality and interpret the quantity of mineral resources/reserves in the mine planning and extraction method selection. In the past decades, the distribution nature of the ore and trace elements in various rock types has been studied in different ore deposits (Ahrens, 1966; Monecke et al., 2001; Zou et al., 2009; Afzal et al., 2011; Khalili and Afzal, 2018). The proposed law states that the frequency distribution of most ore elements in rock units and ore deposits is positively skewed and that the distribution of ores is lognormal. The distribution of geochemical elements in boreholes also shows power-law relationships, which can be fitted into the fractal models (Sanderson et al., 1994; Monecke et al., 2001; Li et al., 2003; Rashidnejad Omran et al., 2011; Zuo and Wang, 2016; Soltani et al., 2019; Mirzaei et al., 2020).

The fractal theory has been developed by Mandelbrot (1983) and widely applied since 1980s, and also applying it to geosciences based on the fractal geometry has proved to be useful especially in geochemical explorations. This methodology has been mainly used to characterize the geological structures, some other features, and also for identification of the geochemical and geophysical anomalies and mineralized zones from background values (Cheng et al., 1994; Cheng, 1995; Carranza, 2009; Zuo, 2011; Zuo and Wang, 2016; Daneshvar Saein and Afzal, 2017; Afzal et al., 2018; 2019; Yasrebi et al., 2014; 2017). Furthermore, the fractal models are useful in mineral resource/reserve studies for detection of quantitative details of mineralization and mineral deposit parameters (e.g. Agterberg, 1993; Wang et al., 2006; Afzal et al., 2012; Karami and Afzal, 2015; Daneshvar Saein, 2017; Yasrebi and Hezarkhani, 2019). Zou et al. (2009) have applied three fractal models consisting of the vertical distribution characterization of Cu concentration in the Qulong copper deposit in Tibet, western China. Rashidnejad Omran et al. (2011); they have used this method in the eastern part of the Kahang porphyry deposit (Central Iran). On the other hand, the fractal methodologies based on the power law relationships have been used for

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surface studies or in block models. However, investigation of the exploratory boreholes by this method is rare. In this work, the power-law frequency model is utilized to characterize the vertical distribution of Cu to evaluate the mineralization continuity based on the borehole datasets in the Milloieh copper porphyry deposit located in SE Iran.

## 2. Power-law frequency fractal model

In this work, the power-law frequency fractal technique is utilized to calculate the frequency distribution of ore grades. This model has been demonstrated by many researchers including Turcotte, 1996; Zuo et al. 2009; Rashidnejad Omran et al., 2011, and has the common form of:

$$(N \geq c) \propto c^{-D} \quad (1)$$

$$\log (N \geq c) = C - D\log(c) \quad (2)$$

where $N(\geq c)$ is the sample number with elemental grade greater than c, C is a constant, and D is the fractal dimension. This methodology is a pretreatment technique without any estimation.

## 3. Geological setting and sampling

The Milloieh copper deposit is situated 80 km NE of Sirjan (SE Iran) and the Cenozoic Urumia-Dokhtar magmatic belt (Figure 1). The Urumia-Dokhtar magmatic belt is one of the main regions of copper mineralization in the world, and is a part of the Himalaya-Alp orogenic belt. The most important feature of this magmatic belt is the presence of calc-alkaline intrusive masses that have penetrated from Oligocene to Miocene of volcanic units. Many of these intrusive masses with porphyry texture have copper-molybdenum mineralization. This magmatic belt extends from NW to SE Iran. The Iranian large porphyry copper deposits within this belt such as Sarcheshmeh, Sungun, Meiduk, and Darehzar are shown in Figure 1 (Shahabpour, 1994; Richards, 2015). According to the exploratory studies, three major mineralization zones for this area have been considered: Milloieh (1), Milloieh (2), and Milloieh (3), which are located in the western part of the area. The rock facies of Milloieh (1) and Milloieh (3) include dark porphyry andesite, while the rock facies in Milloieh (2) are composed of light-colored tuff crystals. There are volcanic, volcano-plutonic, and pyroclastic rocks. The pyroclastic rocks are crystalline tuffs, and green and grays tuffs. There are intrusive units with dioritic and grenodioritic compositions. In addition, the volcanic rocks include andesitic and andesitic tuffs. The ore elements are chalcopyrites, covelites, chalcocites, and pyrites with minor ores including malachites, azorites, and magnetites. The alteration zones are located as a ring such as classic model for porphyry deposits that are propylitic, argillic, and phyllic from the marginal to the central parts of the studied deposit. Few index minerals for potassic alteration were detected in depth cores.

Four boreholes were drilled in the crystal and green tuffs, diorites, and andesitic tuffs. These four Cu mineralized datasets were obtained by continuous sampling every 2 m along and within these borehole in the mineralized zones, respectively. The samples obtained were analyzed by the ICP-OES method in the Zarazma Co., Tehran, Iran. The rock ore properties and the statistical results of analysis of the boreholes datasets are summarized in Table 1.

**Table 1. Basic information and statistical properties of the four mineralized borehole data obtained from the Milloieh copper deposit.**

| Borehole name | Depth (m) | Number of samples | Cu Max (ppm) | Cu Min (ppm) | Cu Mean (ppm) | Std Dev. | CV |
|---|---|---|---|---|---|---|---|
| BH02 | 48 | 19 | 14500 | 440 | 4100 | 0.49 | 1.20 |
| BH04 | 51 | 10 | 8500 | 460 | 2800 | 0.11 | 1.25 |
| BH05 | 27 | 4 | 30300 | 900 | 10800 | 1.38 | 1.28 |
| BH07 | 36 | 11 | 9000 | 120 | 1600 | 0.32 | 1.98 |

## 4. Results and discussion

### 4.1. Frequency distribution of Cu

The property of frequency distributions of element concentrations are usually evaluated by the histograms that are displayed as arbitrarily chosen, linearly scaled concentration intervals on the frequency of individual analyses whose results fall in a particular class within the interval on the ordinates. The histograms are depicted in Figure 2 and show that distribution of the Cu values in the mineralized boreholes is positively skewed. On the other hand, there are L shapes in the histograms, which indicate that low grade data is more than high grade samples (Figure 2).

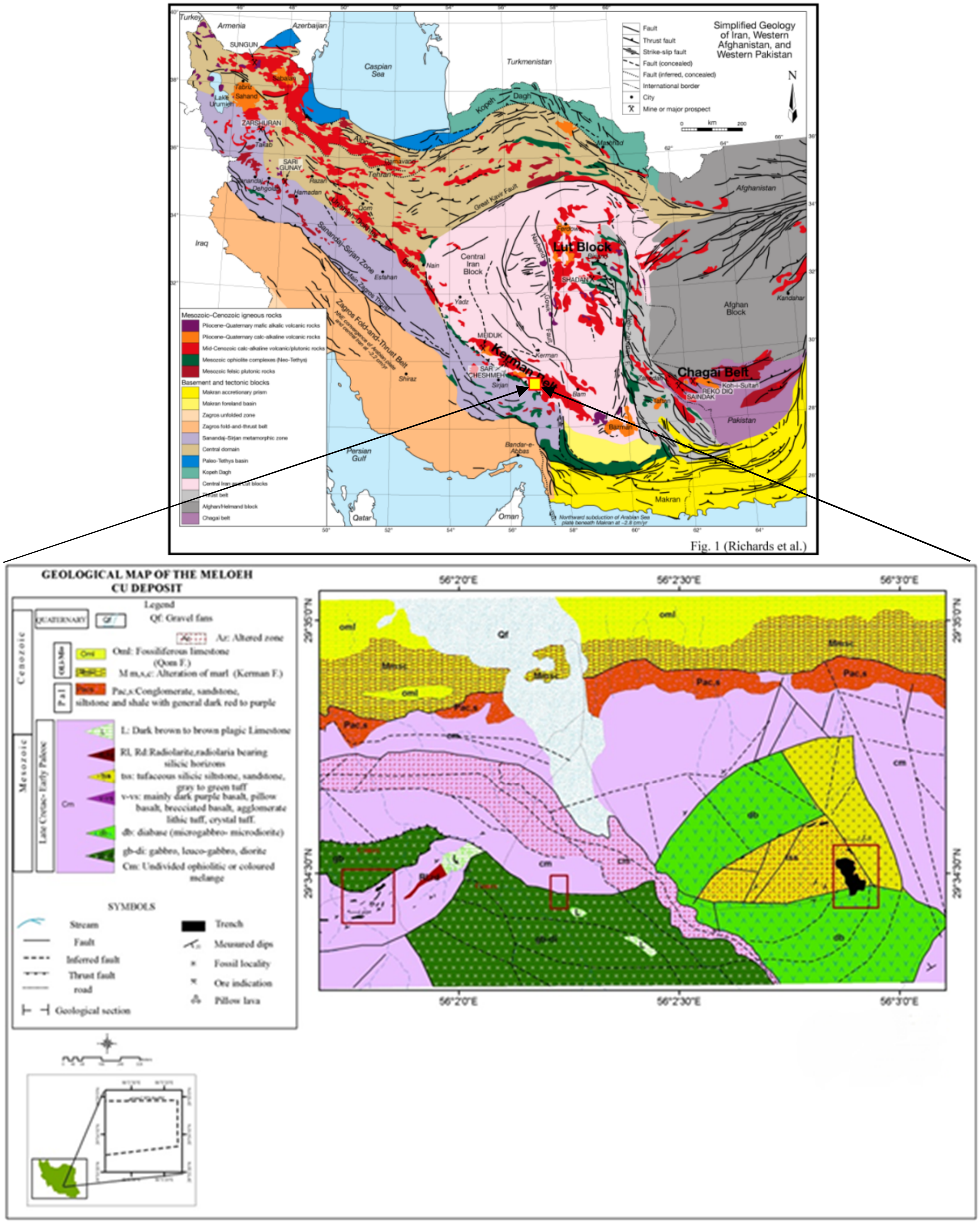


**Figure 1. Location of the Milloieh copper deposit (Yellow Square) on the map of the Iran structural zones (Richards et al. 2006) and geological map of the Milloieh area in scale of 1:10000.**

### 4.2. Power-law frequency distribution of Cu values

The results derived via the power-law frequency model for the mineralized boreholes are depicted in Figure 3 and are listed in Table 2. The log–log plots of cumulative number versus Cu values reveal that the Cu concentration variation distribution in the mineralized boreholes satisfy a bifractal model. The two sections of the plot identify a cross-over point between the 0.56% and 1.09%, values, as shown in Table 2. for Cu values less than and greater than these values, fractal dimension 1, and range from 0.36 to 3.66, in the mineralized rocks, i.e. fractal dimension 2 in this deposit.

**Table 2. Fractal dimensions of Cu in the Milloieh copper porphyry deposit calculated by the power-law frequency model.**

| Borehole name | Fractal dimension 1 | $R^2$ | Break point | Fractal dimension 2 | $R^2$ |
|---|---|---|---|---|---|
| BH02 | 0.18 | 0.92 | 0.63 | 2.51 | 0.92 |
| BH04 | 0.42 | 0.95 | 0.56 | 3.66 | 0.97 |
| BH05 | 0.89 | 0.98 | 1.09 | 0.36 | 0.99 |
| BH07 | 0.34 | 0.97 | 0.63 | 0.89 | 0.99 |

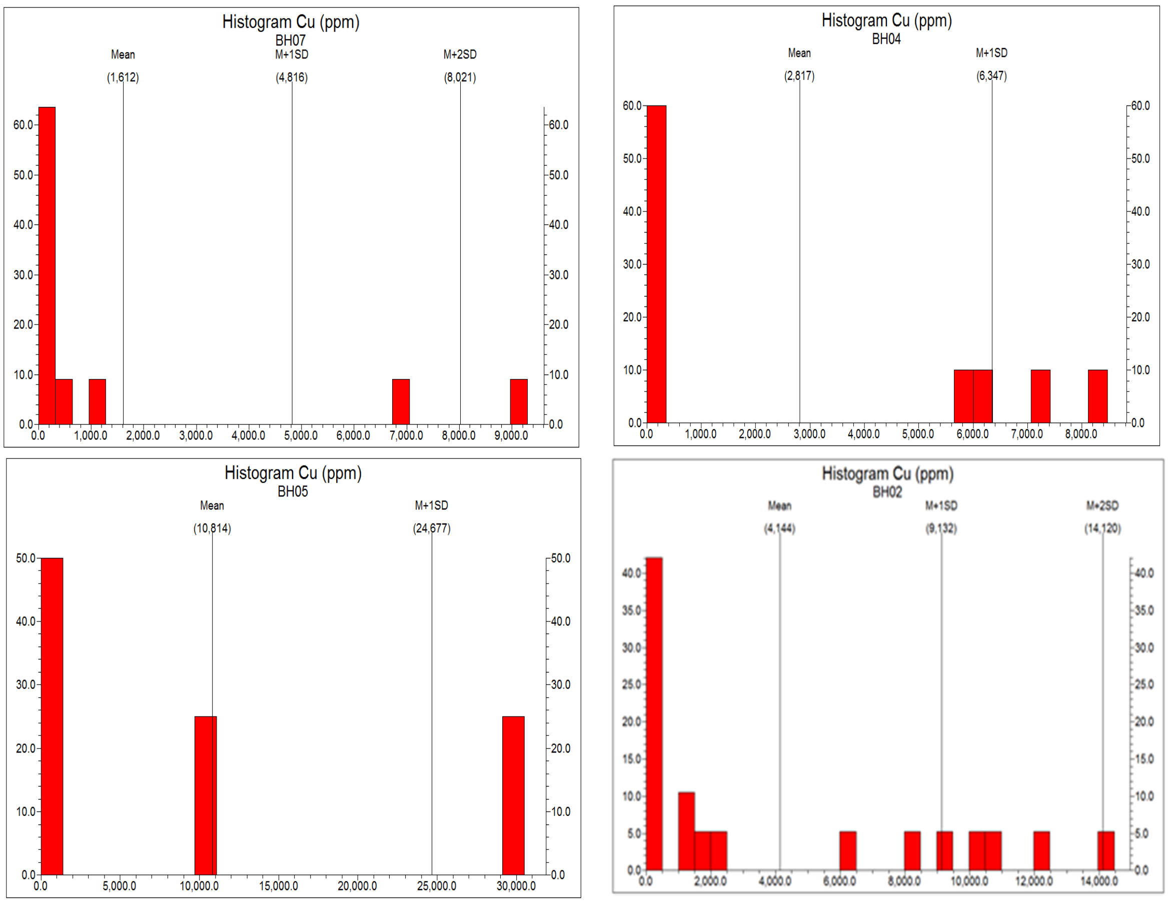


**Figure 2. Histograms of Cu values for four mineralized boreholes.**

A bigger fractal dimension of mineralization indicate a more homogeneous mineralization. The fractal dimensions are calculated from the frequency of the Cu values, and can reflect the Cu concentration value proportion. A larger fractal dimension also reveals lower Cu values greater than certain specific Cu grades. It means that the Cu concentrations change slowly along the depth of borehole, indicating a more homogeneous mineralization. The Coefficient of Variation (CV), which is the standard deviation divided by the average, identifies the degree or range of change. In the case of an approximate average of Cu value, a low CV implies the elemental grades changing slightly along the borehole depth. In other words, it means a more homogeneous mineralization. Therefore, the fractal dimensions of mineralization are inversely related to the CV values. The regression line between the fractal dimensions and the CV values is depicted in Figure 4. The squared correlation coefficient "R2" is 0.29, which reveals a weak correlation between the two variables.

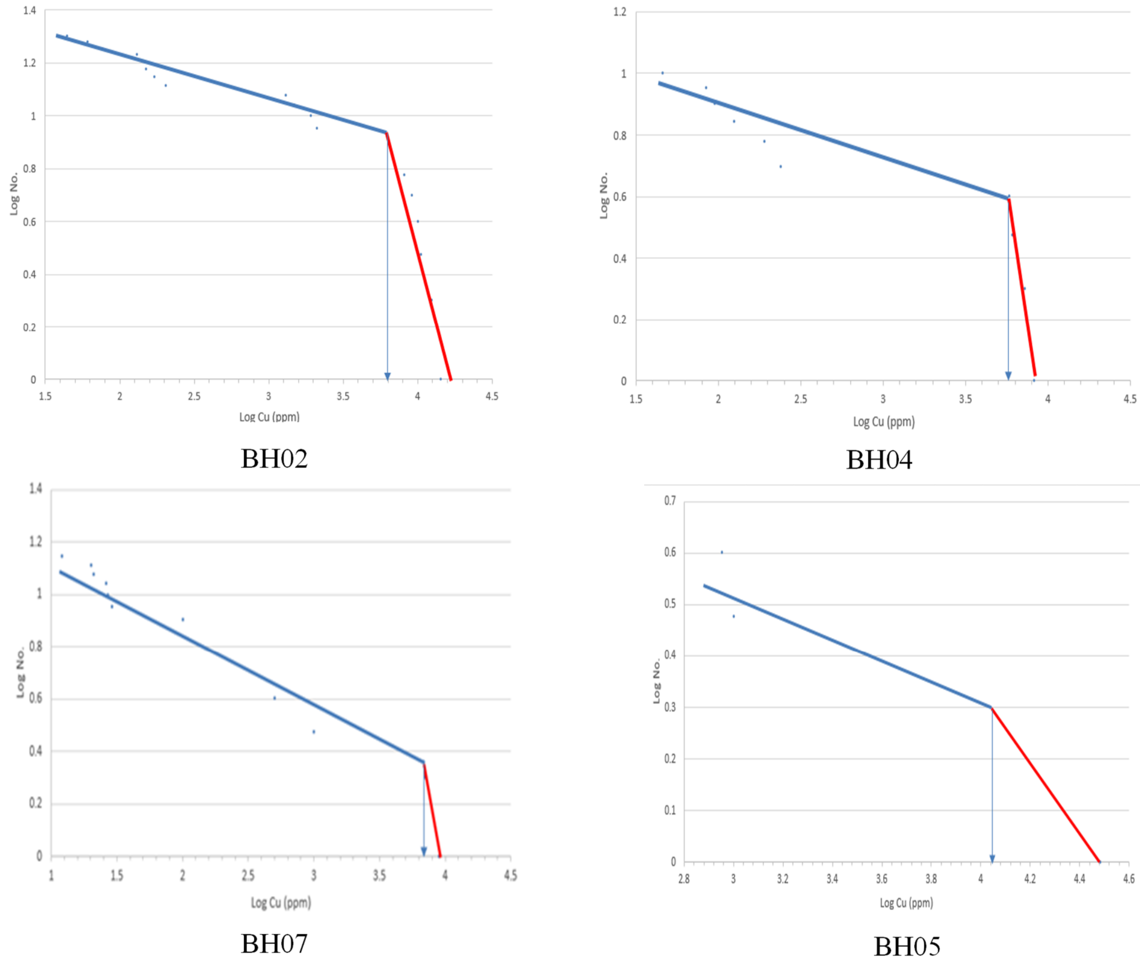


**Figure 3. Log–log plots of cumulative numbers versus Cu grade in four mineralized boreholes.**

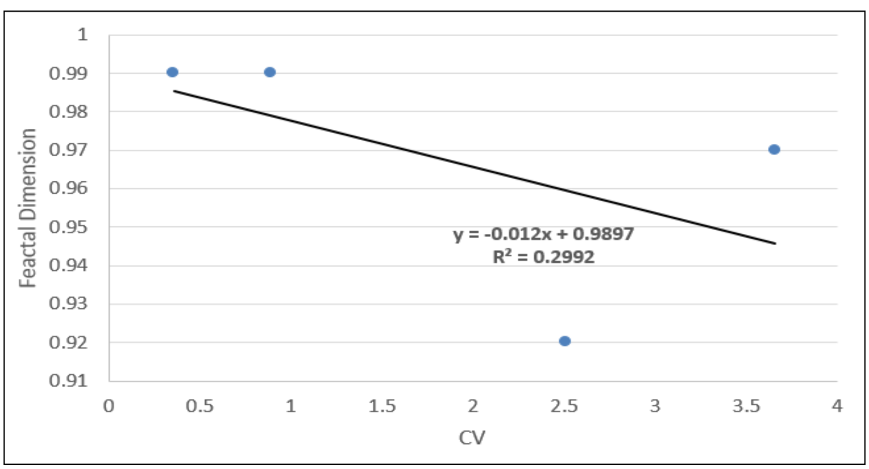


**Figure 4. Plot of fractal dimensions for Cu mineralization versus CV along with the illustrated regression line.**

## 5. Conclusions

The continuity of ores is a key role in the interpretation of potential mineralization assessment in a target deposit. The mineralization potential in depth can be identified by characterizing the vertical distribution of elemental concentrations of the mineralized zones in borehole datasets. In this work, the fractal dimensions obtained by a power-law frequency model were utilized to delineate and interpret the irregularities and the continuity of Cu mineralization in the Milloieh deposit. The results obtained exhibit that the vertical distribution of Cu grades in mineralized boreholes has different characteristics: the former has a positive skewed distribution character and exhibits a bifractal model, while the latter satisfies a multimodal distribution. It can be shown that there is a low grade mineralization in depth based on statistical parameters, frequency of ore grades, and fractal modeling. This methodology can be improved for detection of potential of mineralization in depth for different ore deposits.

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# کاربرد روش فرکتالی فروانی توان جهت تعیین توزیع عمودی عیار مس در کانسار مس پورفیری میلویه، جنوب شرق ایران

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**چکیده:**

شناخت نحوه توزیع عمودی و افقی عیار عناصر نقش مهمی در فازهای گوناگون اکتشاف مواد معدنی دارد. هدف اصلی این مقاله، بررسی و تعیین مشخصات توزیع عمودی عیار مس با استفاده از مدل فرکتالی فراوانی توان در کانسار مس پورفیری میلویه واقع در استان کرمان و جنوب شرقی ایران است. این پژوهش براساس داده های چهار گمانه اکتشافی در زون کانه‌دار است. توزیع عمودی عیار مس در گمانه‌های حفرشده در زون کانه‌دار نشانگر چولگی مثبت با توزیع فراوانی چندمدی می‌باشد. انجام این مدل فرکتالی بر روی این چهار گمانه نشانگر توزیع تک فرکتالی و دو جامعه‌ای در هر یک از این گمانه‌ها است. در این گمانه‌ها نقطه شکست نمودارهای فرکتالی در عیارهای بین 0/5 تا یک درصد و نیز تغییرات بعد فرکتال بین 1/7 تا 4/97 است.

**کلمات کلیدی:** روش فرکتالی فراوانی توان، توزیع عمودی، میلویه.