GEOSTATISTICAL ANALYSIS OF GOLD AND SULPHUR WITHIN SUKARI GOLD MINE, EGYPT

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Abstract—Gold and Sulphur can be analysed geostatistically through constructing of variograms. The present work, represents an attempt to show the variability of both gold and sulphur within Sukari deposit. It is important to review the geology of the deposit and also statistical analysis for the available data has been carried out to show the distribution of gold and sulphur. Then, variograms have been constructed for them and fitted to suitable models to show the similarity, for some extent, in the behavior of gold and sulphur variability within the deposit.

Index Terms— Geostatistics, Gold, Outliers, Sukari, Sulphur, Surpac. Variogram.

1 Introduction

Sukari gold deposit is situated 15 Km west of Marsa Alam along the Red Sea coast. Due to the pyrite the main ore mineral in Sukari gold mine, gold and Sulphur ratios should be analysed to determine the variability of both them (1).

Geostatistical techniques are the most recent techniques able to show behavior of gold and Sulphur within the deposit. Depending on the available data, three dimensional geologic model has been built to understand some mineralization characteristics of the deposit. Then statistical analysis has been carried out to illustrate the distribution of gold and Sulphur within the deposit. On the other hand, it is necessary to analyse the spatial continuity of gold and sulphur through constructing experimental variograms for various orientations. These variograms have been plotted about a common center to define the best fit ellipsoid through three dimensions that could quantify the average anisotropy of gold and sulphur.

GEMCOM Surpac software, version 6.5.1, was the mining software chosen for this study because of its availability and ability to accomplish all analytical and graphical tasks required for this study. First using the data to geological model interpretation and construction depend on rock type. Then data was validated and subjected to statistical analysis, followed by variography for both gold and Sulphur.

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2 MATERIALS AND METHODS

2.1 GEOLOGY OF SUKARI DEPOSIT

Gold deposits and occurrences located in the Nubian Shield have been known in Egypt since Predynastic times. More than 95 localities with gold mineralization are known in the Eastern Desert of Egypt (2).

Sukari gold deposit area covers about 2100 m length, 100 m width in south, and 600 m in north and this mine lies in the central part of the eastern desert of Egypt (fig. 1). Sukari gold deposit stratigraphically lies in a highly tectonized serpentinites, volcaniclastic metasediments, intermediate to mafic metavolcanics, metagbbro-diorite and intruded by syn-orogenic granites and numerous dykes (3) (fig. 2) (4). Centamin plc Gold Mining Company divided Sukari granite into four exploration zones from north to south; Pharaoh, Gazelle, Ra and Amun (fig. 1). The vein system occurs within a planner fault that separates granodiorite from mafic volcanic sequences. The volcanics in the footwall of the fault display a zonally developed NE-striking schistosity. The hanging wall contact with granodiorite is sharply defined and marked by about 10 cm of fault gouge.

Gold deposits contain appreciable amounts of sulphide minerals such as pyrite, galena, arsenopyrite, chalcopyrite, bornite, pyrhotite and sphalerite (5).The main ore mineral in Sukari is pyrite, which though predominantly occurs in the altered wallrock and to a lesser degree in the vein quartz itself (6). Gold is associated with sulfides in quartz veins and in alteration zones (7). Gold is mostly fine-grained. The Sukari gold deposit is an example of a significantly larger gold deposit in the Precambrian. Auriferous rocks at Sukari are porphy-

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ritic and fine grained felsic rocks, extensively altered and quartz veined.

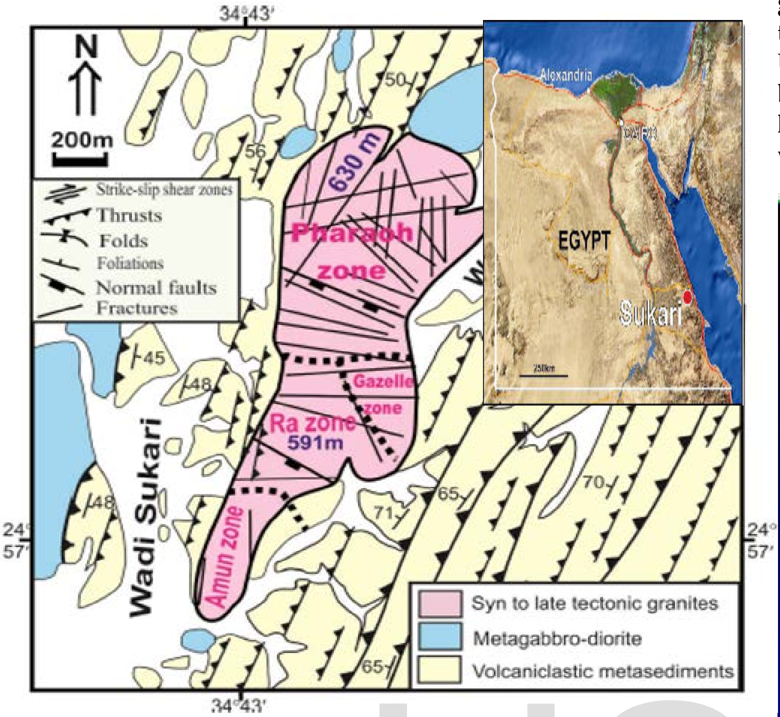

Fig. 1: Detailed geological map of Sukari gold mine area (after Abd El-Wahed, et al., 2016)

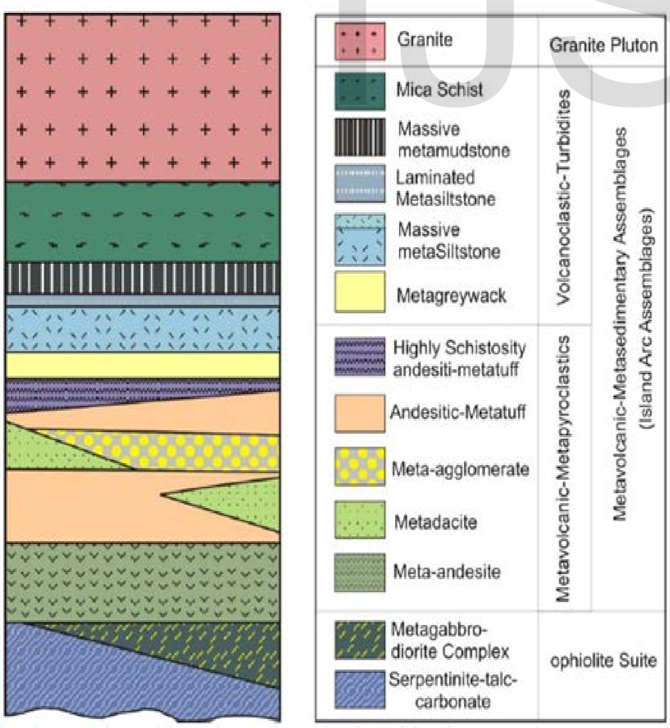

Fig. 2: Stratigraphic column in Sukari Gold Mine area (Harraz, 1991)

2.2 AVAILABLE DATA

Data collected from Centamin gold mine company in soft copy in csv files for Ra zone is located in north of sukari mine, this files included the collars, lithology, survey and assay.

Drillhole locations are provided in a plan view as shown in Fig. 3. Samples drilled by reverse circulation (RC) drill for grade control. In Sukari pit mine they use local grid because the deposit is oblique but in this study we use the coordinates UTM, WGS 48. The holes were drilled on a grid of 8 m in east by 12 m in north with sample length 1 or 2 meter. In all, 4342 holes reverse circulation holes where gold and sulphur ratio were obtained.

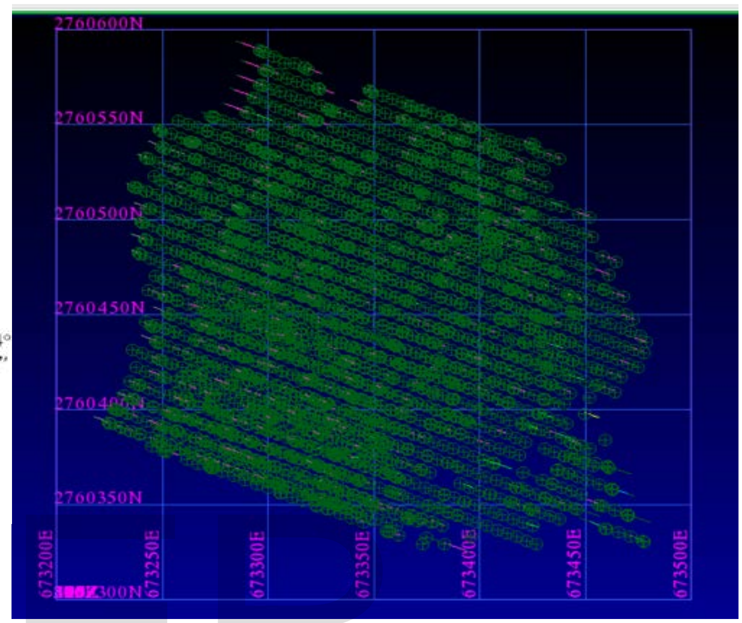

Fig. 3: Drill hole locations at X-Y of Ra zone

2.3 GEOLOGICAL MODEL CONSTRUCTION AND INTERPRETATION

According to the rock type and understanding of the orebody, constructed 27 oblique sections as shown for example in section no. 17 (fig.4). Sections were extracted at 10 meters intervals. This sections form a three-dimensional orebody (fig. 5).

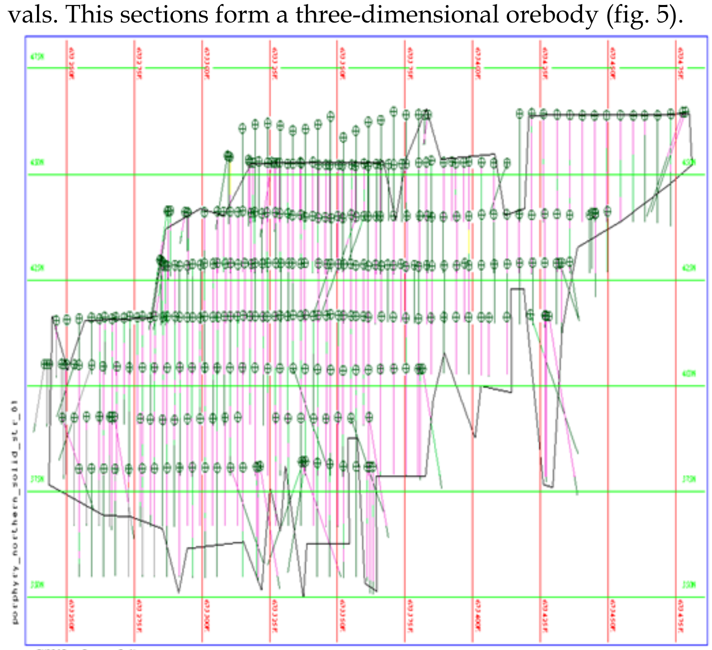

Fig. 4: Oblique section no.17 with interpretation

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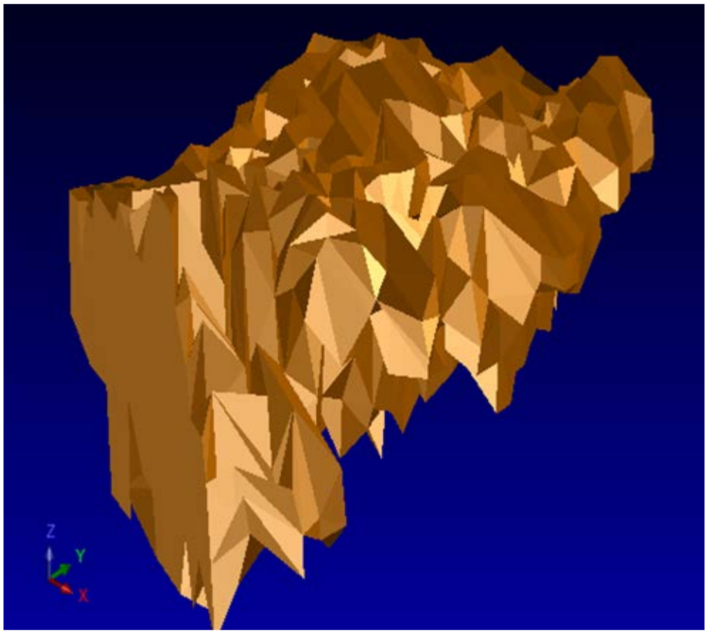

Fig. 5: Three-dimensional orebody of Ra zone

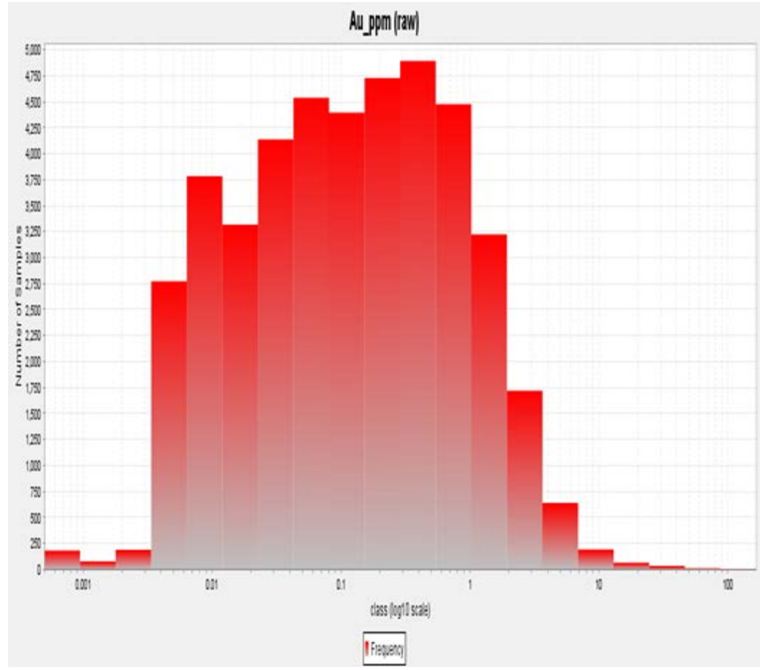

Fig.6: logarithmic histogram of gold

2.4 STATISTICAL ANALYSIS

The statistical analyses has been performed on three variables; grade of gold in ppm and grade of sulphur in percentage.

2.4.1 RAW STATISTICAL ANALYSIS OF GOLD AND SULPHUR

Statistical analysis was performed to show the sample distribution within the ore body. Table 1 gives the summary statistics of the data sets for Au ppm and S % in Ra zone. Fig. 6 and 7 show the histograms of Au ppm and S % that constructed for studied area.

Table 1: Summary statistics for Au ppm and S % in Ra zone.

Statistical parameters	Gold	Sulphur
No. of samples	43362	7045
Min. value	0.0005	0.0005
Max. value	165	3.54
Mean	0.56	0.164
Median	0.12	0.05
Variance	4.67	0.05
Standard Deviation	2.16	0.23
Coefficient of variation	3.85	1.38
Skewness	33.5	3.89
Kurtosis	1927	29.6

As could be deduced from table 1, gold values have coefficient of variation larger than for sulphur values. In addition, distribution of gold values are different than for sulphur. This refer only to the distribution of their values and not for spatial distribution which will be shown through geostatistical techniques.

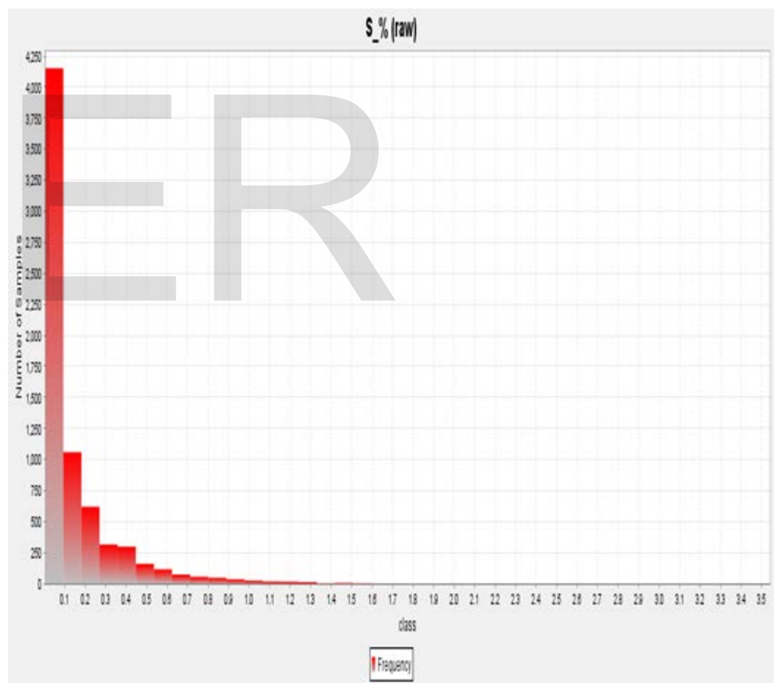

Fig.7: histogram of Sulphur

From logarithmic histogram of gold (Fig. 6) the gold mineralization is characterized by highly positive skewed distribution as is expected for gold and may be mixed population exist. To overcome this problem need to subdivide the data if possible, reveal the outliers or top cuts, and use indicator variograms. From grade of Sulphur histogram (fig. 7) shows that the distribution tend to be positively skewed like gold distribution. Drillhole intervals of varying lengths have values 1 or 2 m.

2.4.3 COMPOSITING AND STATISTICAL ANALYSIS

First, the choice of composite length is important. Instead, we eliminate the need for length-weighting by making all of the

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drillhole intervals the same length as one meter in a process known as compositing.

Then, upper cuts or outliers are often applied to highly variable deposits such as gold to limit the disproportionate influence of a few high-grade outlying samples. There are many methods which can be used to determine a top cut value, which use concepts such as, histogram, confidence interval, percentile, from this equation (Mean + 2 S.D.) and experience (8&9). From Table 1 statistics of gold and (Fig. 6) logarithmic histogram and cumulative distribution of gold we can determine a top cut value, few extreme high-grade values above 15 ppm. Thus, an upper cut-off grade of 15 ppm was applied to the data prior to estimation by reducing all grades above 15 ppm to 15 ppm.

Table 2 shows the summary statistics of gold composited at 15 ppm and 1 meter length and then Fig. 8 illustrate the distribution of gold at 15 ppm top cut after compositing at 1 meter length when plotted using a logarithmic transformation.

Table.2: Summary statistics of gold composited

Number of samples	63159
Min. value	0.0005
Max. value	15
Mean	0.53
Median	0.13
Variance	1.5
Standard Deviation	1.2
Coefficient of variation	2.3
Skewness	6.5
Kurtosis	61.8

Comparing the statistics of the original with those of the composited data in Tables 1 and 2 the number of samples of composited data greater than the original data because we divided all samples above 1 meter to 1 meter. While the mean and the median are almost constant, the variance is decreased after the compositing, as have the coefficient of variation, Standard Deviation, and the Skewness. This emphasizes the nature of gold deposits, characterized by the presence of structures such as small and thin veins and veinlets as well as nuggets.

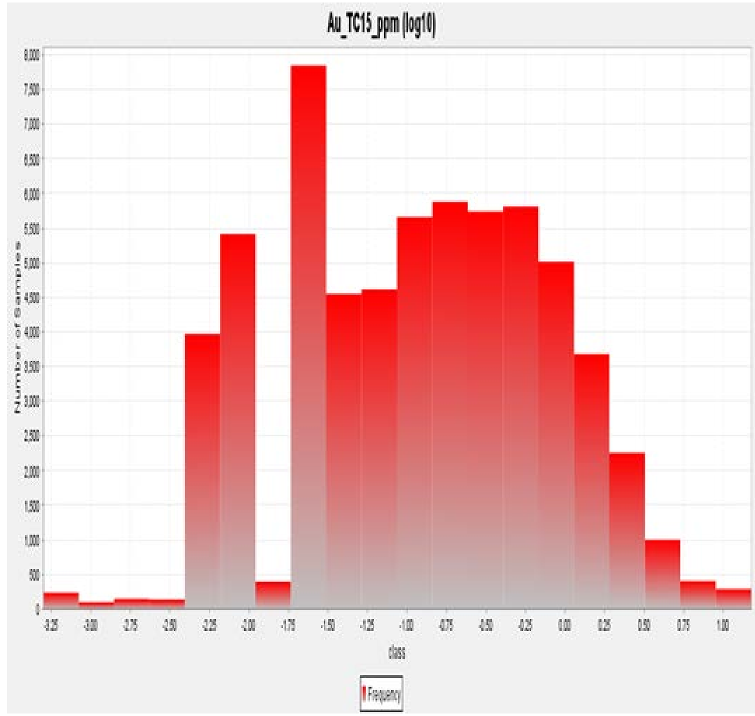

Fig.8: Logarithmic histogram of gold at 15 ppm top cut composited at 1 meter length

2.5 VARIOGRAPHY

Variography will supply useful parameters for the estimation and to know the spatial variability by using versus of variogrphy. Parameters that can be identified from variography are maximum search distance, anisotropy ratios (Major/Semi Major; Major/ Minor), nugget value, sill value and range.

2.5.1 OMNIDIRECTIONAL VARIOGRAM

The first step in variography is to generate an omni-directional (all directions) variogram. This is used to identify an appropriate sill value for directional variography. The pairs are selected based only on their separation distance, and not on the orientation of the pairs. In three dimensions, the search from each point takes the shape of a sphere (10). To achieve an omni-directional Variogram, set the tolerance 90 degrees. By using compositing data at 1 meter and top cut at 15 ppm for gold, and this parameters azimuth: 0°, plunge: 0°, spread angle: 90°, lag: start from 5 m. in fig. 9 fitting of experimental omni-directinal variogram for god and also fig. 10 for sulphur.

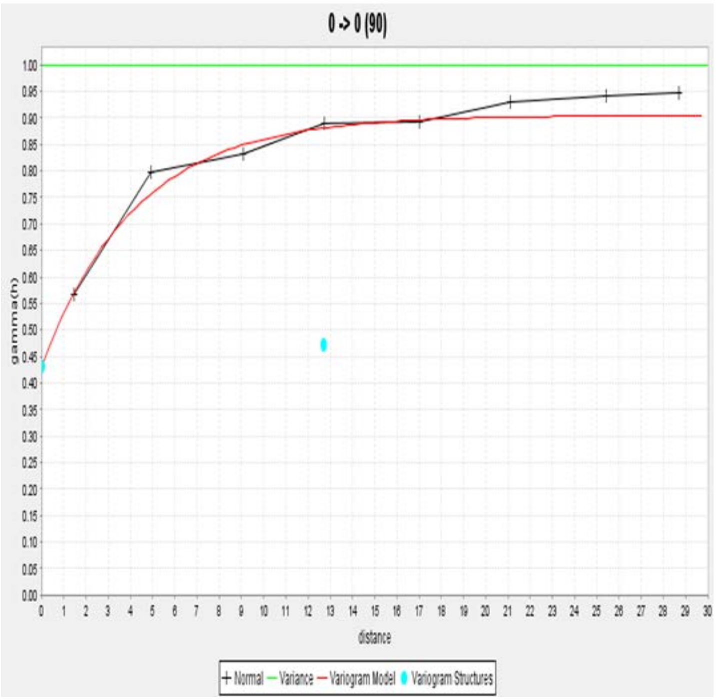

Fig. 9: Omni-directional variogram model for gold

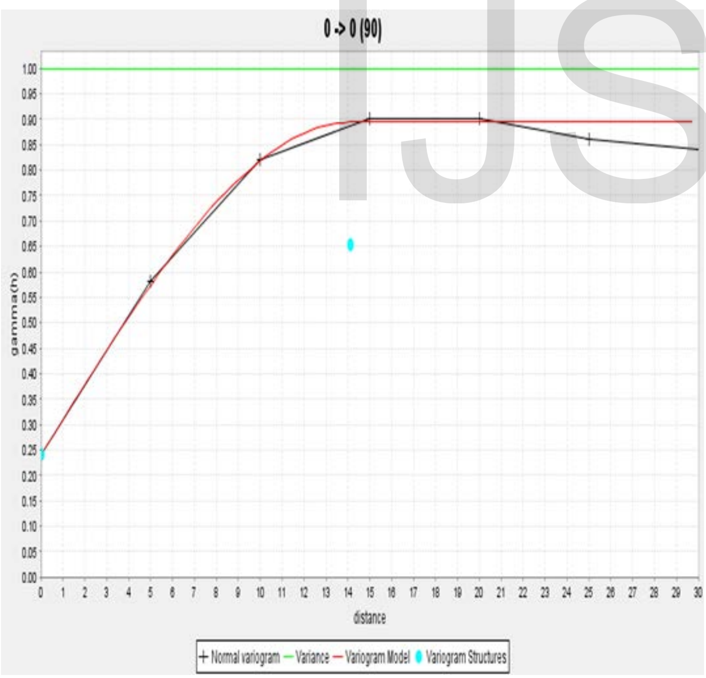

Fig. 10: Omni-directional variogram model for Sulphur

2.5.2 DOWNHOLE VARIOGRAM

Downhole variogram is important as it assesses the spatial relationships between the closest sample spacing in deposit, to determine the appropriate nugget value for directional variogram. One meter composite length has been selected at top cut 15 ppm, and these parameters lag: 1 m, max distance: 20 m. See fig. 11 fitting of experimental downhole variogram for god and also fig. 12 for sulphur.

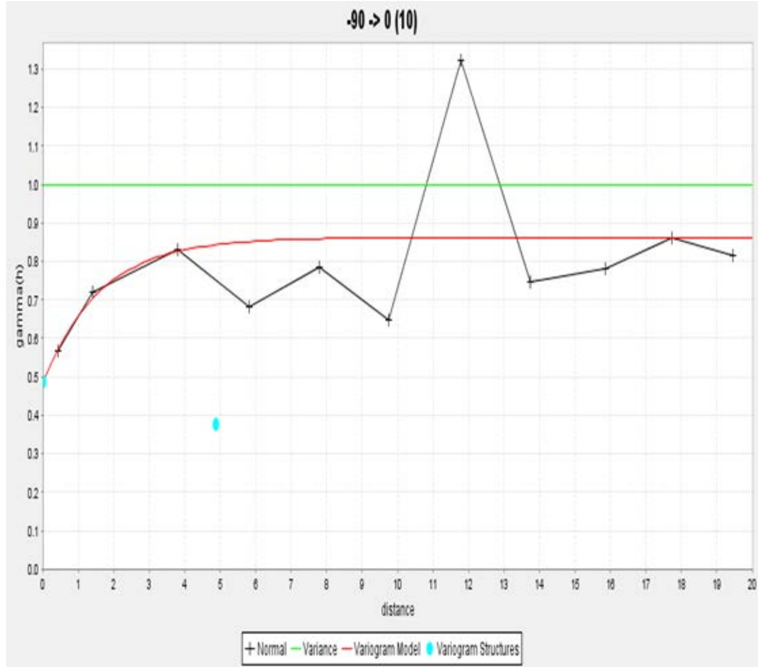

Fig. 11: Downhole variogram midel for gold

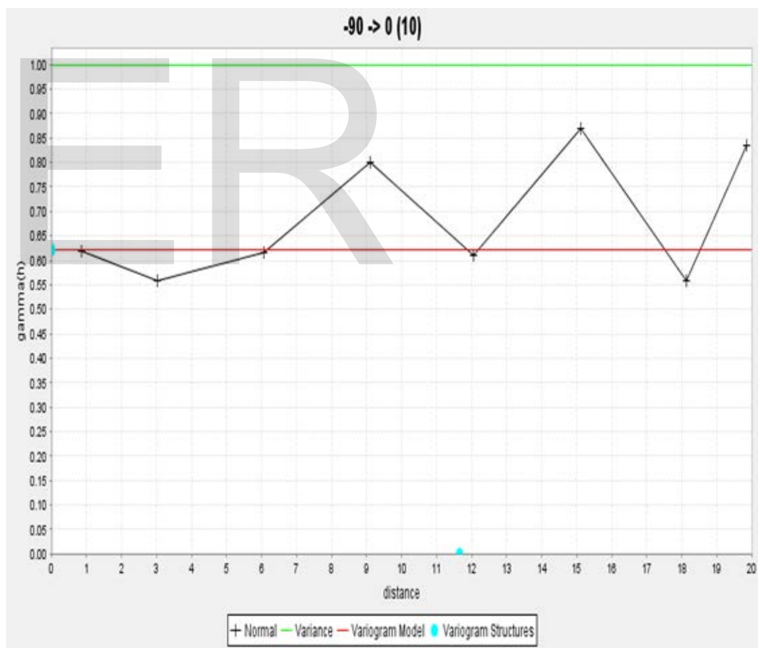

Fig. 12: Downhole variogram model for Sulphur

2.5.3 DIRECTIONAL VARIOGRAMS

The latest step in variography is to generate a directional variogram. A directional variogram is one in which all sample pairs are oriented in a particular direction. The first set of variograms are usually assessed on the horizontal plane, then different dip/dip directions are tested to match geology dip etc. ultimately you are looking for the best variogram with the longest range (major direction). There's no need to run a full 360° sweep because, by definition, variograms are symmetrical about 180°. Variogram maps can be used to define the anisotropy ellipsoid. From both of primary variogram map (the

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major), the longest, and secondary variogram map (semi-major), we can get the third candidate perpendicular to one another (minor), and calculation of anisotropy ellipsoid parameters.

By definition, the range of the major axis must be equal to or longer than the range of the semi-major axis for a given sill. Also, the range of the semi-major axis must be equal to or longer than the range of the minor axis for a given sill. It is often difficult or impossible to interpret the experimental variogram for the minor direction. If you cannot get a visually acceptable minor variogram, but you do have good quality variograms for the major and semi-major axes, you may choose to continue, and determine the ratio for the minor axis based on other factors, such as geometry.

By using compositing data at 1 meter and top cut at 15 ppm, and use this parameter Plane dip: 0°, dip direction :0° number of variogram: 36 with angular increment: 10 and spread: 7, lag: start from 5 m, and max distance: 40 m.

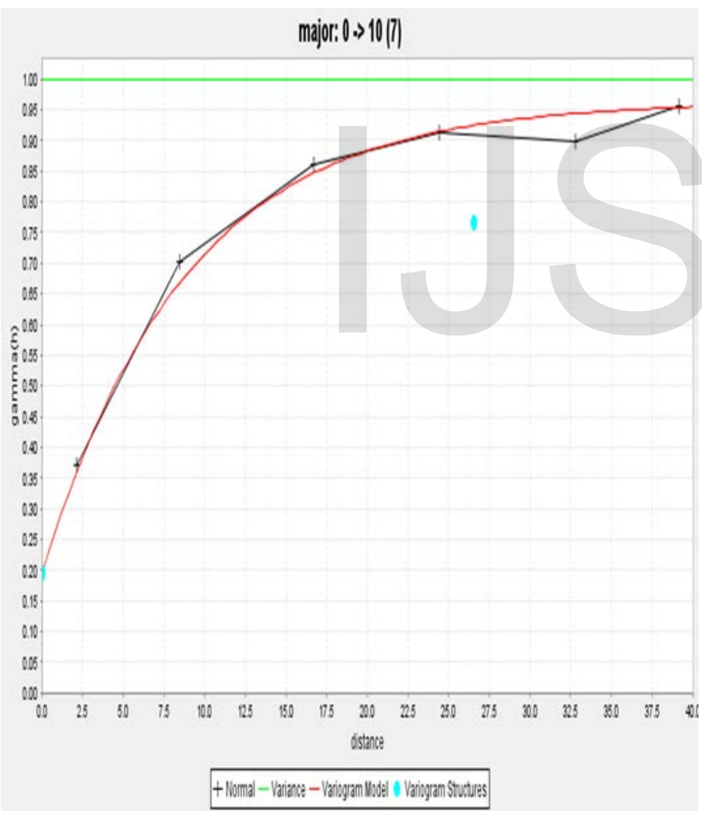

Fig. 13: The major variogram model for gold

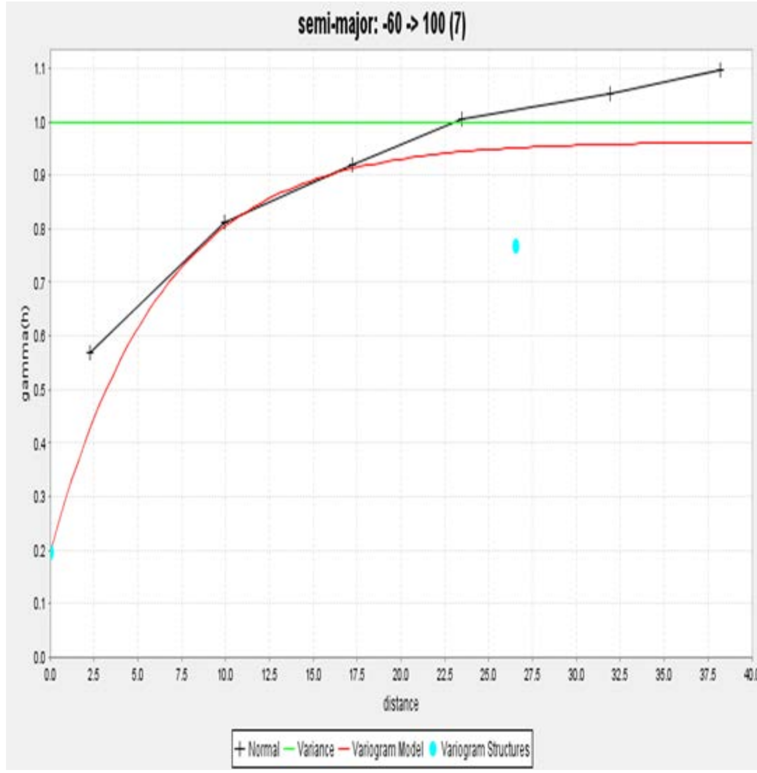

Fig. 14: The semi-major variogram model for gold deposit

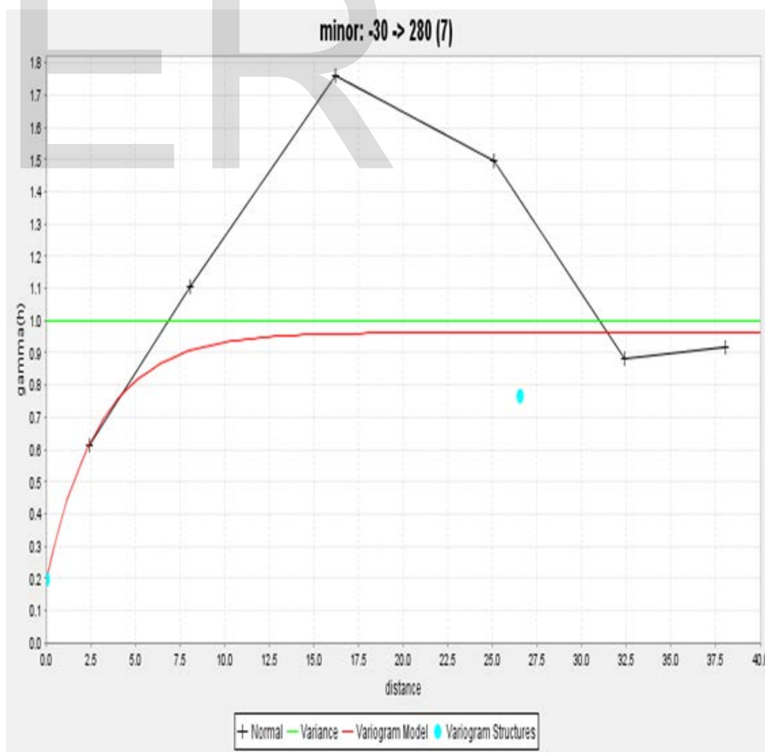

Fig. 15: The minor variogram model for gold

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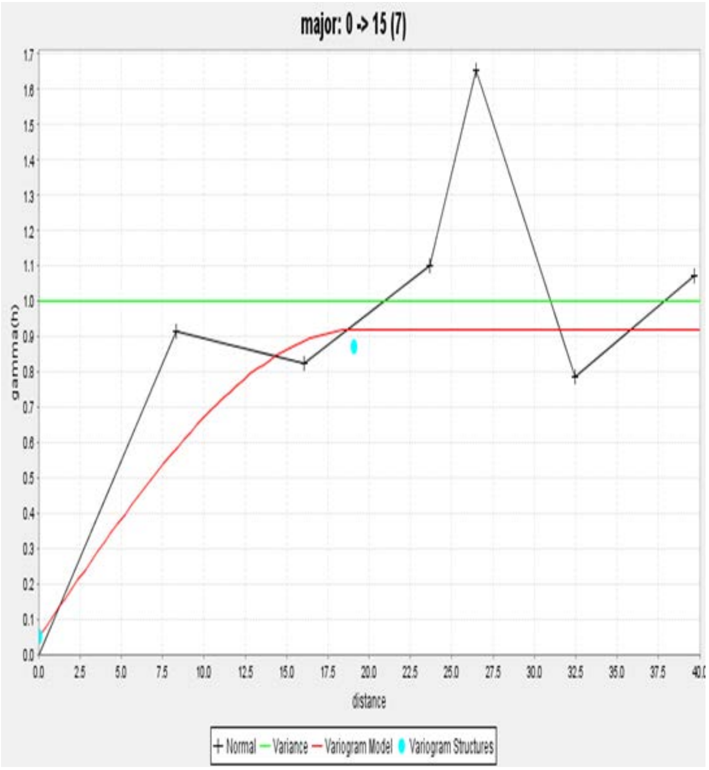

Fig. 16: The major variogram model for Sulphur

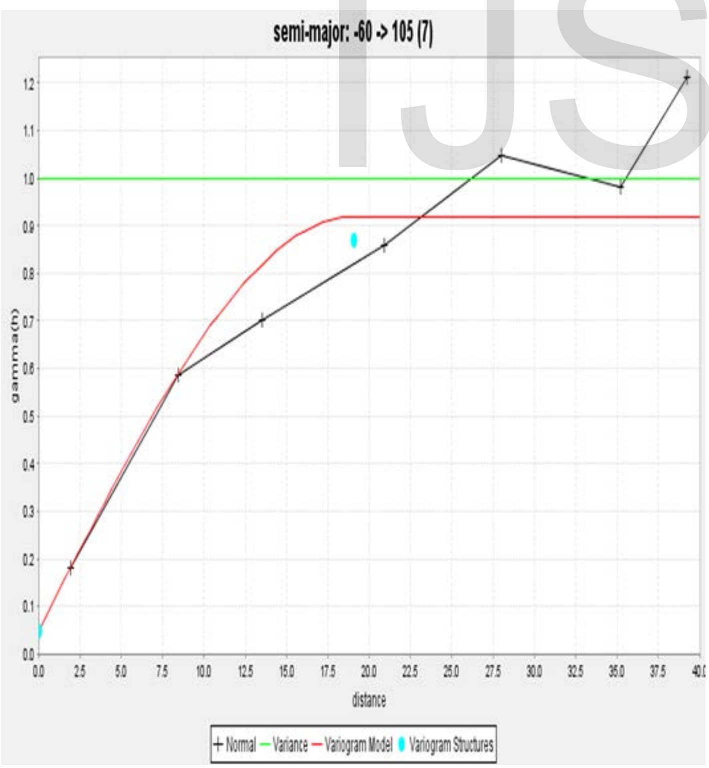

Fig. 17: The semi-major variogram model for Sulphur

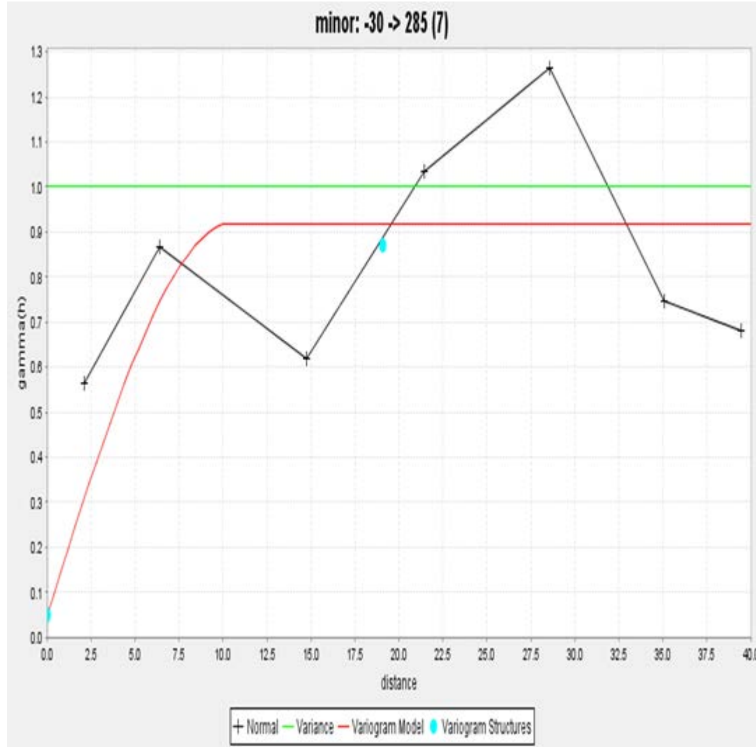

Fig. 18: The minor variogram model for Sulphur

3 RESULTS AND DISCUTION

Summarizing the results of variogram models and anisotropy parameters in tables as following:

3.1 SUMMARY THE RESULTS OF THE VARIOGRAM MODELS

The following table represents the variogram models for gold and sulphur.

Table 3: summary the results of the variogram models for gold and sulphur

		Omni-directional	Downhole	Directional
Gold	Model type	Exponential		
	Nugget	0.43	0.49	0.2
	Sill	0.47	0.38	0.77
	range	12.7	4.89	26.57
Sulphur	Model type	Spherical	Nugget effect	Spherical
	Nugget	0.24	0.62	0.05
	Sill	0.65	-	0.89
	range	14.12	-	19.08

From this table revealed that the variogram parameters; nugget effect, sill, and range of influence varies clearly from in the different variograms. Directional variogram for gold and sulphur satisfied the largest range and sill, but nugget effect is the lowest. This result could indicate that the behavior of gold and sulphur within the deposit tend to be similar.

3.2 SUMMARY THE RESULTS OF ANISOTROPY PARAMETERS

The following table represents the anisotropy parameters of gold and sulphur also shown in the attached fig. 19.

Table 4: summary the results of anisotropy parameters at ellipsoid plunge is equal zero for gold and Sulphur

	Ellipsoid bearing	Ellipsoid dip	Major/ Semi-major ratio	Major/ Minor ratio
Gold	10	-60	1.4	2.9
Sulphur	15	-60	1	1.8

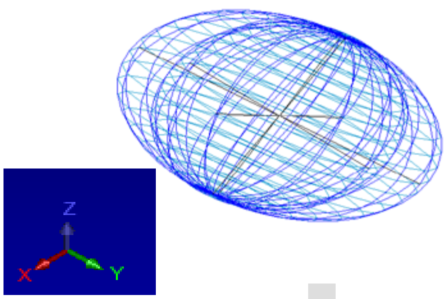

Fig 19: Ellipsoid for gold and sulphur

This result confirm the fact that gold follows Sulphur as it is found in the deposit, and hence searching for Sulphur could give indication about the presence of gold.

4 CONCLUSION

1. Statistical analysis confirmed the ratio of gold genesis where high coefficient of variation is recorded.
2. Constructing geologic model, based on rock type interpretation, showed that the orebody, porphyry surrounded by black shale and schist as foot wall and hanging wall as sediments. Also, it showed the presence of andesite dyke and quartz vein.
3. Geostatistical analysis through constructing different variogram help in understanding the relationship between genesis of both gold and sulphur.
4. The percentage of sulphur increases, with increasing the depth.

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