

A CASE STUDY ON SUKARI GOLD MINE, EASTERN DESERT, EGYPT

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ABSTRACT

The presented work shows the behavior and variability of gold through its deposit at the area of interest. Geology of the deposit is studied to know the shape of it. Statistical analysis is applied firstly to the available data to show the distribution of gold. Gold behavior within the deposit is illustrated clearly by geostatistics through constructing variograms and selecting the suitable model. Before the geostatistics study, compositing is applied on the available data to eliminate the high variable samples.

KEYWORDS: Gold- Sukari- Geology- Statistics- Outliers-

Geostatistics- Variogram- Surpac.

1. INTRODUCTION

Sukari gold mine is located in the south-easterly region of the Eastern Desert of Egypt, approximately 700km from Cairo and 25km from the Red Sea and (fig. 1) shows the location of the area.^[1]

Geostatistics is a technique for analyzing the collected data taking in the consideration the location and the spatial characteristics. A geology database is created to study the behavior of gold within the rock. Three dimensional model of the deposit is created to show the mineralogy of gold. Statistics analysis is carried out to take indications about the gold. Depending on the collected data variograms have been carried out and the suitable models

chosen and fitted from which the behavior of gold in spatial is illustrated through the resulted parameters.

GEMCO Surpac version 6.5.1 program is the mining software which selected to do all required process for its ability to link all collected exploration data, define the position of each borehole and the grade within it from its top to bottom, make a mineralogy model for gold, make all statistics and geostatistics as variography for the deposit, drawing the topography and the ability of designing open pit.

2. OVERVIEW OF GEOLOGY

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. They are spread over almost the whole area covered by the crystalline basement rocks with the exception of its extreme northern part (fig. 2)^[2] shows the distribution of these locations.

Sukari Hill is situated within the tenement area and is approximately 2,300m long, 600m wide and 1,345m above sea level at its highest point. Surrounded by wide wadis (the Arabic term for valleys) and mountain ranges, Sukari Hill has hosted ancient mining communities spanning thousands of years from the Pharaohs to the Romans to the British.^[1] Sukari area is occupied mainly by highly tectonized serpentinites, volcanoclastic metasediments, intermediate to mafic metavolcanics, metagabbro-diorite and intruded by syn-orogenic granites and numerous dykes. Around Wadi Sukari, there is succession of coarse metatuffs interbedded with lapilli-metatuffs and metabasalt agglomerates.^[4]

Centamin plc Gold Mining Company divided Sukari granite into four mining zones from north to south; Pharaoh, Gazelle, Ra and Amun as obvious in (fig. 3).



Fig. 1: Location of sukari gold mine (Centamine.com).

Sukari gold deposit stratigraphically lies in a highly tectonized serpenti- nites, volcanoclastic metasediments, intermediate to mafic me-tavolcanics, metagabbro-diorite and intruded by syn- orogenic granites and numerous dykes (fig. 4).^[3]

Gold is associated with sulfides in quartz veins and in alteration zones.^[5]

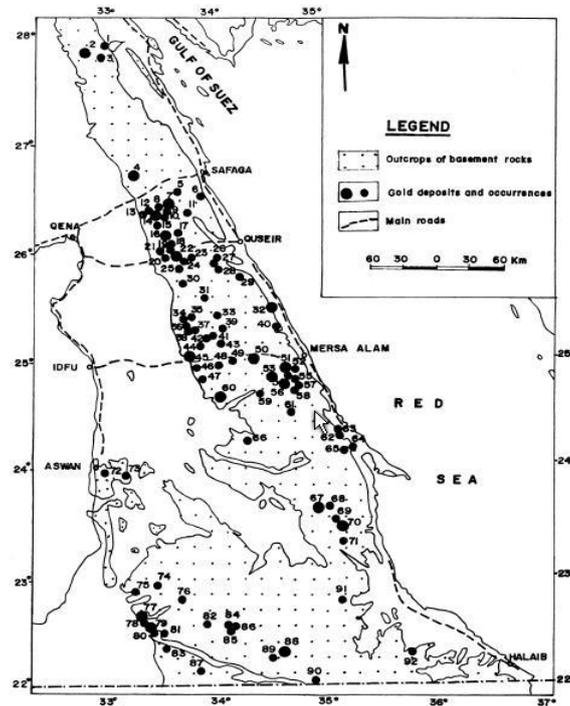


Fig. 2: Gold deposits, Eastern Desert (after AlRamlyet.al,1970).

Fig. 2 Gold deposits and occurrences in the Eastern Desert of Egypt (compiled from Kochine and Bassuni, 1968). (1) Umm Mongul; (2) Umm Balad; (3) Wadi Dib; (4) Fatira; (5) Abu Marawat; (6) Wadi Gasus; (7) Semma; (8) Gebel Semna; (9) Abu Qarahish; (10) Kab Amiri; (11) Sagi; (12) Gidami; (13) Hamana; (14) Erediya; (15) Abu Had; (16) Atalla; (17) Rebshi; (18) Umm Esh; (19) Fawakhir; (20) Hammamat; (21) Umm Had; (22) El Sid; (23) Umm Selimat; (24) Hammuda; (25) El Nur; (26) Kareim; (27) Kab El Abyad; (28) Tarfawi; (29) Sherm El Bahaari; (30) Zeidum; (31) Wadi Zeidum; (32) Umm Rus; (33) Sigdit; (34) Talat Gadalla; (35) Abu Muawaad; (36) Daghabag; (37) El Hisimat; (38) Bokari; (39) Umm Samra; (40) Abu Dabbad; (41) Abu Qaria; (42) Umm Saltit; (43) Bezah; (44) Umm Selim; (45) Barramiya; (46) Dungash; (47) Samut; (48) Umm Hugab; (49) Urf El Fahid; (50) Atud; (51) Sukkari; (52) Umm Tundebe; (53) Hanglaliya; (54) Kurdeman; (55) Sabahia; (56) Umm Ud; (57) Allawi; (58) Lwewi; (59) Dweig; (60) Hamash; (61) Geli; (62) Qulan; (63) Kab El Rayan; (64) Sheialik; (65) Abu Rahaya; (66) Wadi Khashb; (67) Umm Eleiga; (68) Betan;

(69) Qurga Rayan; (70) Hutit; (71) Kalib; (72) Kurtunos; (73) El Hudi; (74) Hariari; (75) Um Shira; (76) Neqib; (77) Haimur; (78) The Nile Valley (Block E); (79) Umm Garaiart; (80) Marahib; (81) Atshani; (82) Murra; (83) Filat; (84) Seiga I; (85) Seiga II; (86) Umm Shashoba; (87) Abu Fass; (88) Umm Tuyur; (89) Betam; (90) Umm Egat; (91) Kurbiai; (92) Romit.

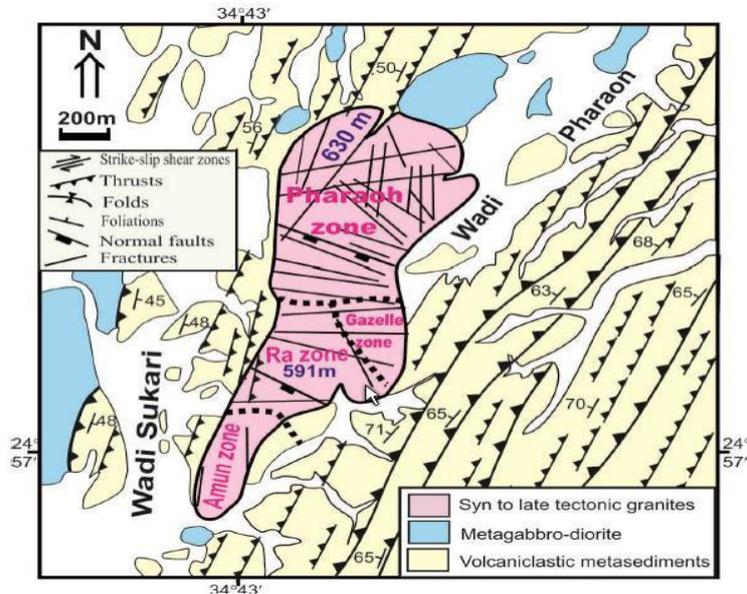


Fig. 3: Detailed geological map of Sukari gold mine area (after Abd El- Wahed, et al., 2016).

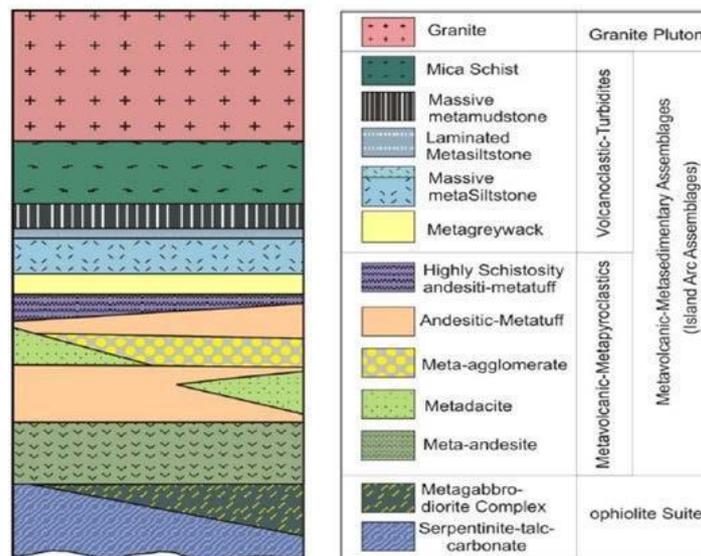


Fig. 4: Stratigraphic column in Sukari Gold Mine area (Harraz, 1991).

3. AVAILABLE DATA

Data consists of 231 boreholes contain more 80,000 samples belongs to pharaoh zone in Sukari mine collected by Centamine gold mining company in soft copy. It was taken as xlxx file and is extracted in four files in csv files which include collar and survey as mandatory tables, geology and sample as optional tables. The data of these tables include the location of boreholes, depth from, depth to, assay of each sample, dip and azimuth. (fig. 5) shows the boreholes location in three dimension and distribution of gold values within the whole depth of each hole.

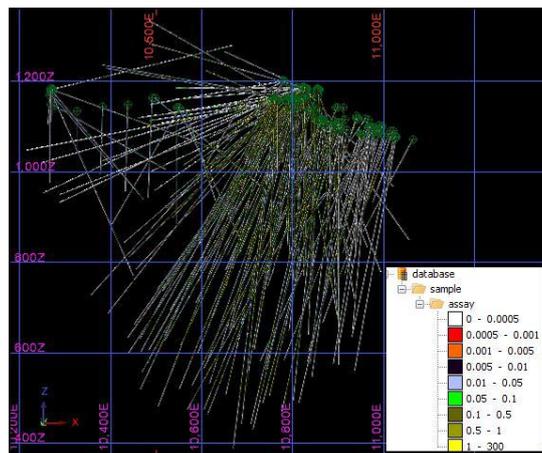


Fig. 5: Boreholes location and distribution of gold within each borehole.

4. TOPOGRAPHY AND MINERALIZATION

Studying the area of interest topography is very important to know the shape of the surface and (fig. 6) shows it in the three dimensions direction.

Also sections are applied to understand the mineralogy of the gold deposit in the area of interest to show the ore body and constructed in three dimensions as shown in (fig. 7).



Fig. 6: Topography of the studied area.



Fig. 7: Ore body in three dimensions.

5. STATISTICAL ANALYSIS

The calculations had been done on the assay in gr/ton on the exploration data of pharaoh zone. Statistical analysis give an indication about the mineralization of gold deposit within the host rock and body of the ore and table 1 gives a summary for the results.

Table 1: Important results of statistical analysis.

Statistics parameter	Gold
Minimum value	0.0005
Maximum value	241
Mean	0.21
Median	0.016
variance	2.432
Standard Deviation	1.559
Coefficient of variation	7.412
Skewness	106.088
Kurtosis	14723.608

These data from table 1 only show the distribution of gold deposit not the spatial analysis which take the position of sample also in consideration. It's also obvious that the samples have high coefficient of variation which express the precision and repeatability of the assay.

5.1 HISTOGRAM

Histogram is a statistical analysis tool for knowing the frequency of each grade. (Fig.8) shows the histogram of assay which has class consists of 60 bins.

5.2 NORMAL DISTRIBUTION CURVE

One of most important tools of statistics which show and describe how values are distributed further away from the mean in both directions.(Fig.9) shows the normal distribution.

From histogram and normal distribution curve it's noticed that the gold mineralization is highly positive skewed so spatial study must be performed by variography.

5.3 PROBABILITY CURVE

A probability distribution is a tool for indicating the values that have random variable. Probability curve provides the probabilities of occurrence of different samples. (Fig.10) shows the probability curve.

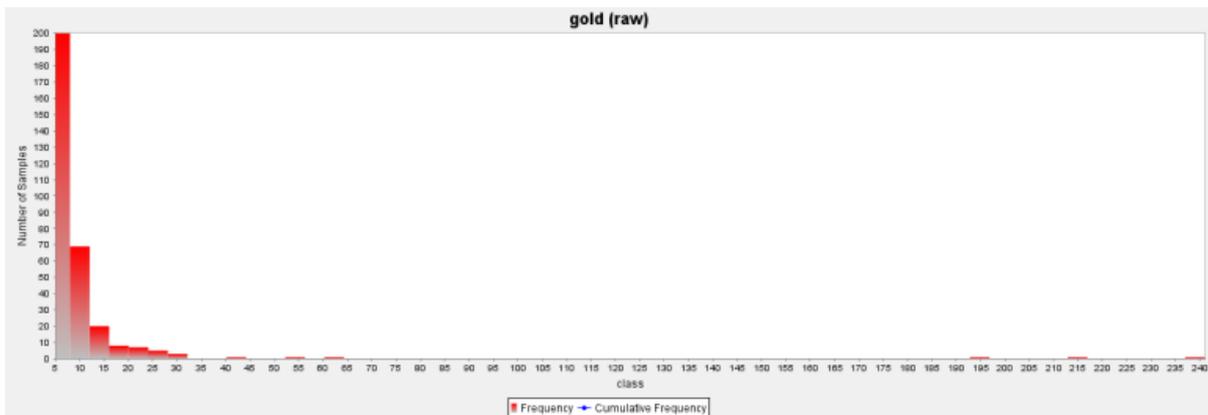


Fig. 8: Histogram of gold.

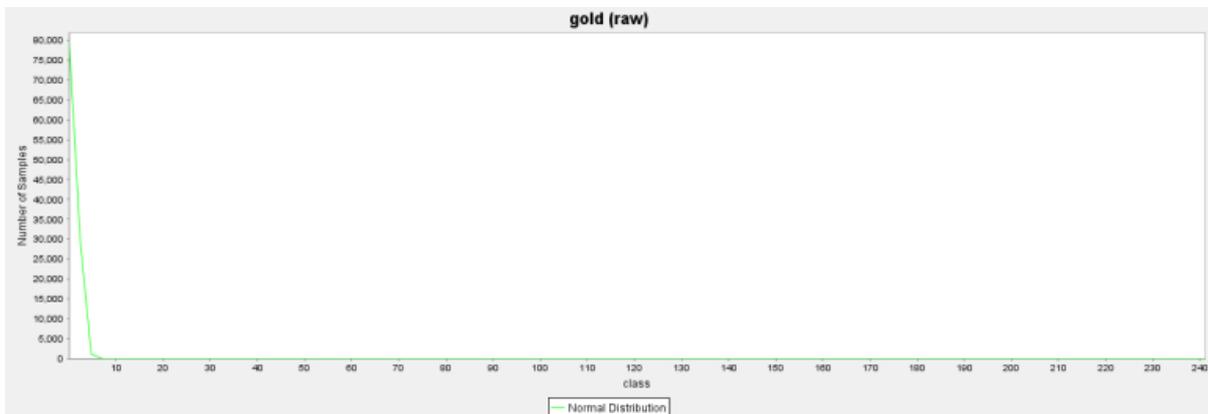


Fig. 9: Normal distribution curve of gold.

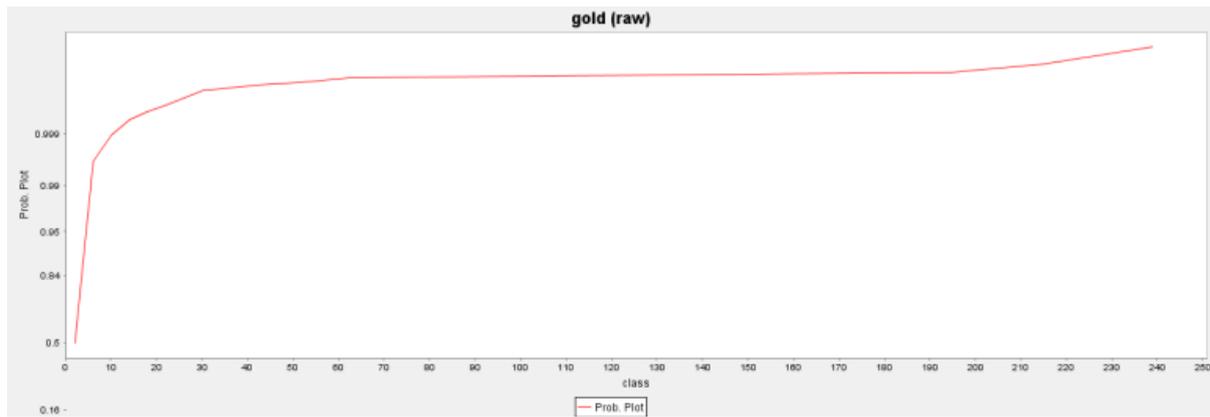


Fig. 10: Probability curve of gold.

5.4 COMPOSITING AND STATISTICAL ANALYSIS

Compositing is the process of eliminating the length weighting through making all of the drillholes intervals have the same length as one meter and it is a very important tool.

Also outliers or top cuts are applied to eliminate the high variable samples to be unconsidered in calculations. There are several methods for determining the top cut value as, histogram, confidence interval, percentile, from this equation (Mean + 2 S.D.). The top cut value is determined from table 1, histogram and distribution of gold which found to be 10gr/ton, a cut off grade of 10 gr/ton was applied to the previous data for further estimation by reducing all grades above 10 gr/ton.

Table 2 shows the summary of statistics results of gold composited at10 gr/ton and 1 meter length and the (Fig. 11, 12 and 13) show the histogram of assay which has class consists of 60 bins, normal distribution curve and probability curve for gold respectively at 10 gr/ton top cut after compositing at 1 meter length.

Table 2: Important results of statistical analysis at 10 gr/ton top cut after compositing at 1 meter length.

Statistics parameter	Gold
Minimum value	0.0005
Maximum value	9.980
Mean	0.19
Median	0.016
variance	0. 331
Standard Deviation	0. 575
Coefficient of variation	3.06
Skewness	7.216
Kurtosis	76.345

Comparing results of table1 with table 2 it's found that the mean and the median are almost constant, the variance, coefficient of variation, Standard Deviation, Kurtosis and the Skewness are decreased after the compositing. 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.

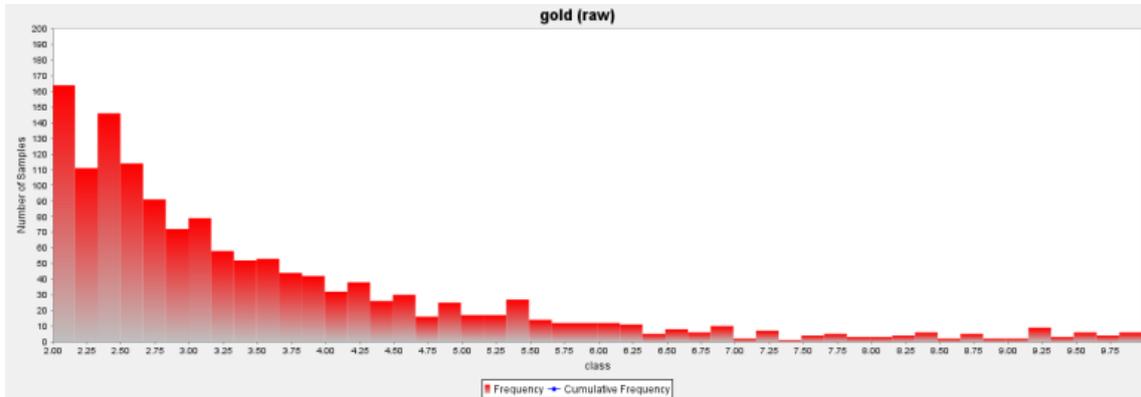


Fig. 11: Histogram of gold at 10gr/ton top cut composited at 1 meter length.

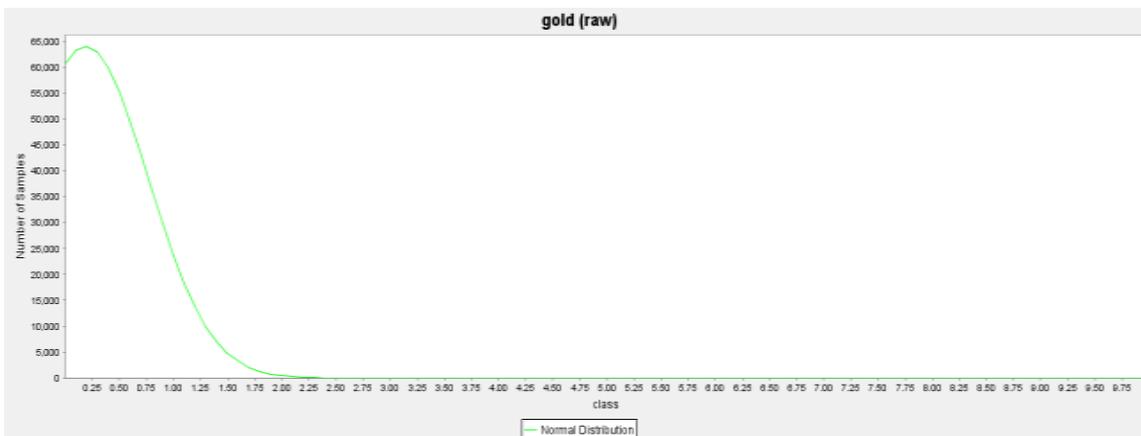


Fig. 12: Normal distribution curve of gold at 10gr/ton top cut composited at 1 meter length.

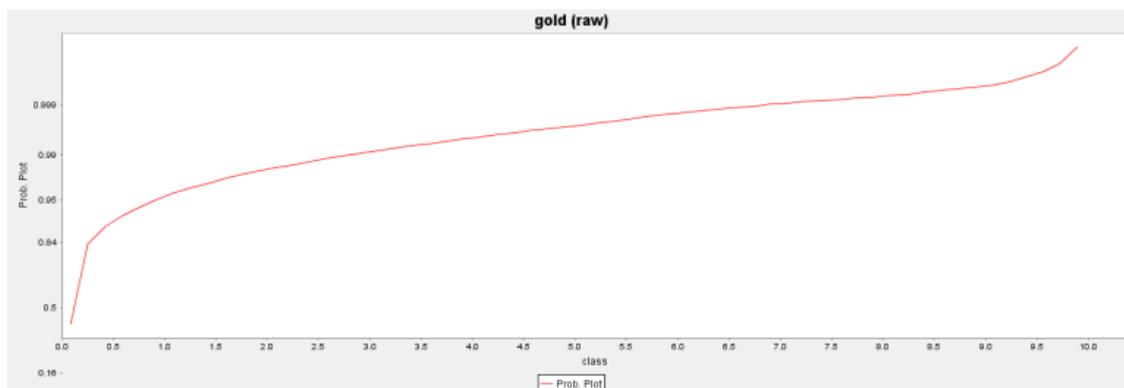


Fig. 13: Probability curve of gold at 10gr/ton top cut composited at 1 meter length.

6. VARIOGRAPHY

variography tool supplies a perfect indication about the behavior of deposit and the spatial variability by constructing the various variograms. There are three main parameters gained from these variograms sill “C”, nugget effect “C_o” and range “a”. In this study there are several variograms were constructed as anisotropic, downhole and directional variograms which include major, semi major and minor variograms. Also a variogram map is constructed in two dimension 2D.

6.1 OMNIDIRECTIONAL VARIOGRAM

Omnidirectional or anisotropic variogram is a semivariogram used for computing and modeling to explore the overall spatial continuity of the dataset of collected data.

The pairs are selected according to only the distance between them not the direction.

(Fig.14) shows it at azimuth 0°, plunge 0°, and spread 90°. The lag was 1.5m and maximum distance was 100m after compositing data at 1 meter length and 10gr/ton for gold.

6.2 DOWNHOLE VARIOGRAM

In the downhole direction the spacing between sample is usually quite different from the spacing in other directions and it's important for the spatial relationship between the closest sample spacing. It gives a good indication for the three parameters of the variogram.

(Fig.15) shows it at composite length 1 meter by fixed length and top cut 10gr/ton, minimum sample included 75%. The lag was 1.5m and maximum distance was 100m and max value 10.

6.3 DIRECTIONAL VARIOGRAM

It's the last step of variography to produce a directional variogram to study the gold deposit at an oriented direction and the one possibility for combining the geometric anisotropy into a variogram model is to compute a directional variograms. An important aspect of performing any geostatistical evaluation is to understand how data values change over distance and direction. Because it's important to study the variography from all directions, a variogram map in 2D is constructed to be studied.

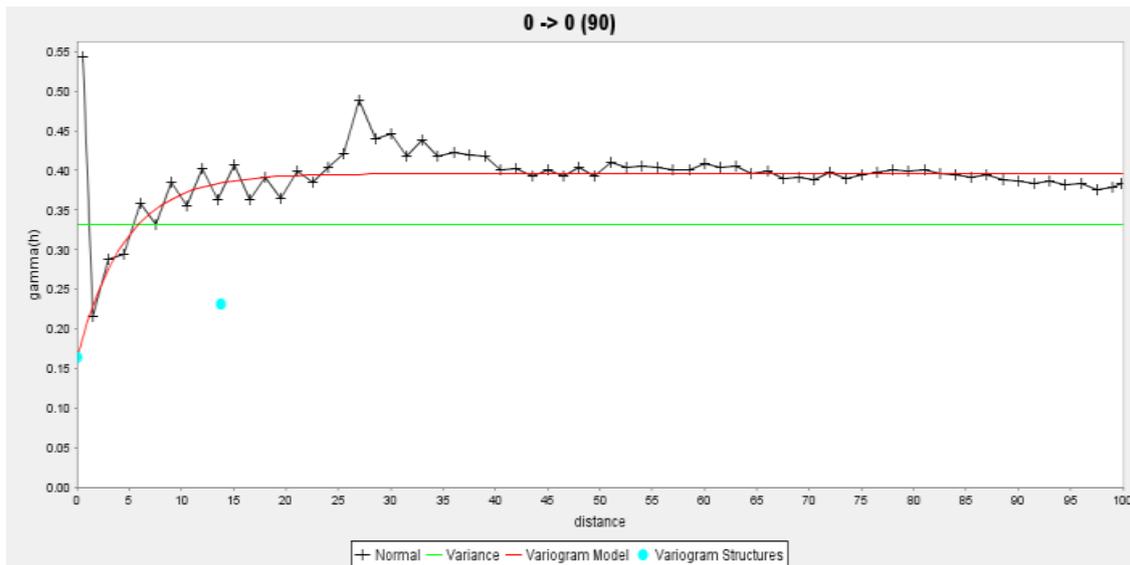


Fig. 14: Omnidirectional variogram of gold.

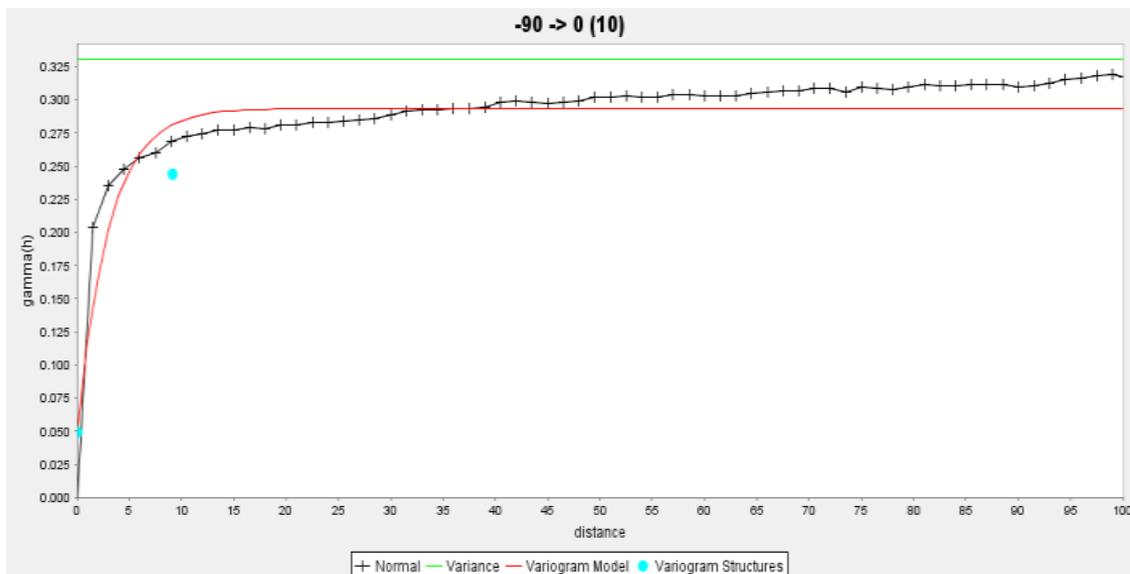


Fig. 15: Downhole variogram of gold.

An important aspect of performing any geostatistical evaluation is to understand the anisotropy of the data, or which direction has the longest continuity, and how data values change with regard to that direction, as well as the two mutually perpendicular directions.

Firstly, the primary variogram map “the major” is constructed then the secondary variogram map “the semi major” constructed and from them the minor variogram map is get. (Fig.16, 17 and 18) show major, semi major and minor variograms respectively.

Calculations done by using compositing data at 1 meter and top cut at 10 gr/ton, and using these parameters: Plane dip 0° , dip direction 30° number of variogram 36 with angular

increment 10 and spread 22.5, lag1.5m, and max distance 100 m. Table 3 gives a summary for the results of variograms.

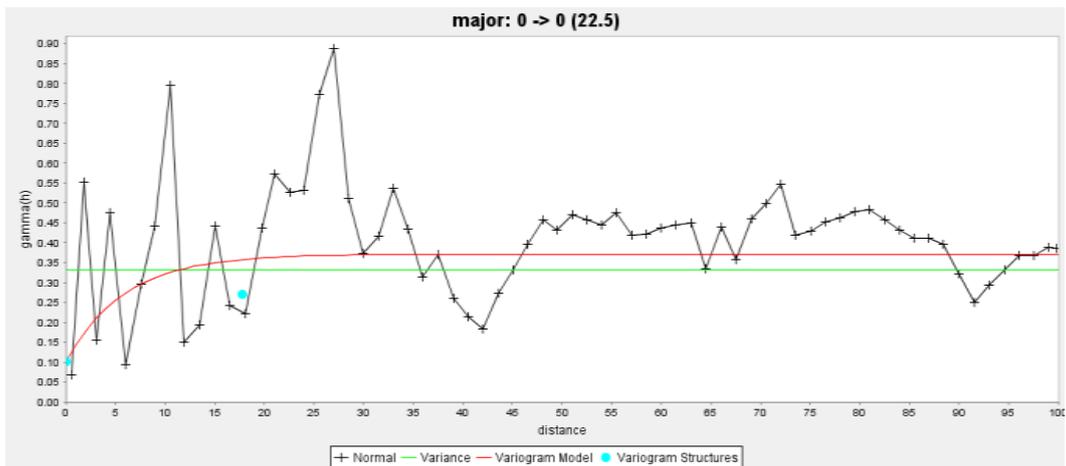


Fig. 16: Major variogram of gold.

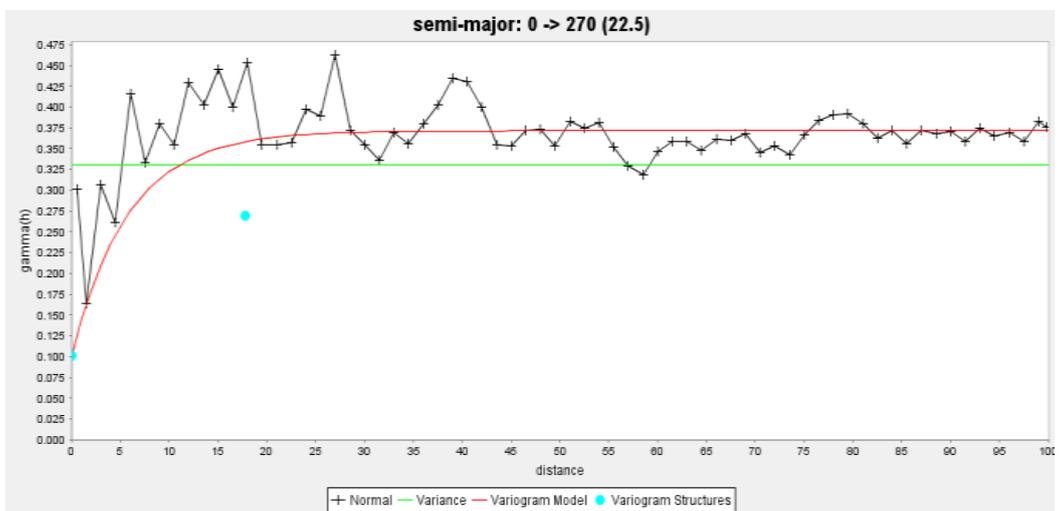


Fig. 17: Semi major variogram of gold.

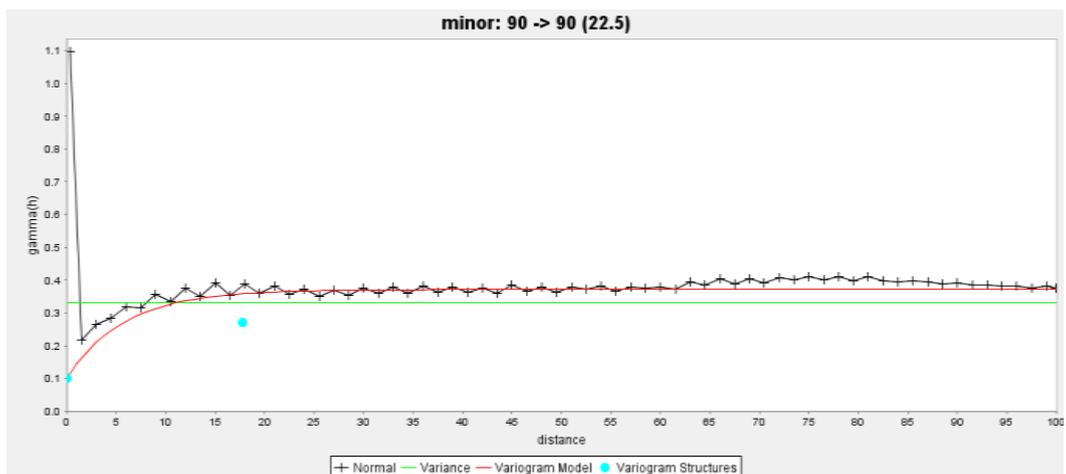


Fig. 18: Minor variogram of gold.

(Fig.19), (Fig.20) show a 2D major and semi major variogram maps respectively.

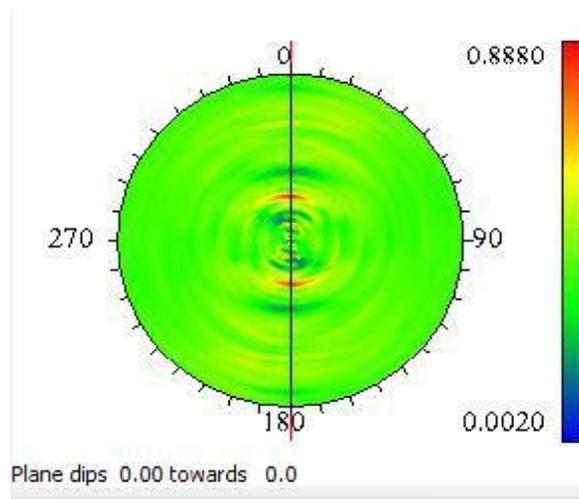


Fig. 19: 2D major variogram map of gold.

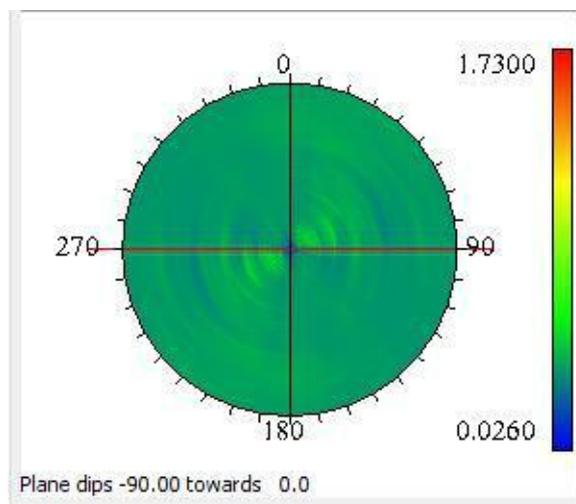


Fig. 20: 2D semi major variogram map of gold.

Table 3: Variogram parameters and the relation with its type.

Variogram type	Model type	Nugget effect C_0 % ²	Sill C % ²	Range am
Omnidirectional	exponential	0.165	0.231	13.724
Downhole		0.049	0.244	9.175
Directional		0.102	0.268	17.789

The results from table 3 show that there's no continuity in the gold deposit according to the produced nugget and range.

7. CONCLUSION

1. Through geology study it's shown that gold is associated with sulfides in quartz veins and Sukari area is occupied mainly by highly tectonized serpentinites, volcanoclastic

metasediments, intermediate to mafic metavolcanics, metagabbro-diorite and intruded by syn-orogenic granites and numerous dykes.

2. High coefficient of variation is recorded as a result from statistical analysis of exploration data.
3. Outliers are applied to eliminate the high variable samples through 1 meter length compositing at top cut 10 gr/ton before geostatistical study.
4. Comparing results before and after compositing it's found that the mean and the median are almost constant, the variance, coefficient of variation, Standard Deviation, Kurtosis and the Skewness are decreased after the compositing which emphasizes the nature of gold deposits characterized by the presence of structures such as small and thin veins and veinlets as well as nuggets.
5. It's observed from variograms results that there's no continuity in gold deposit according to recorded nugget and range of variogram types.

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