The Intergrowth of Gold Precipitation base on Drift Effect in Pongkor Gold Mine

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ABSTRAK

Salah satu kegunaan pemodelan variogram di dalam geologi adalah mengetahui kontrol mineralisasi. Tulisan ini mendiskusikan keberadaan mineralisasi. Sampel grade dari Au ditransformasi ke fungsi logaritma, sebagai basis estimasi variogram. Parameter fitting merujuk pada model *weighted least squares* fungsi sferis. Delapan arah digunakan dalam mengestimasi, dengan memanfaatkan toleransi jarak 11.25^o. Atas dasar perhitungan fungsi eksperimental robust diperoleh beberapa parameter utama, empat di antaranya dipilih sebagai nilai yang reliabel. Informasi diperoleh bahwa efek drift terjadi pada arah Utara-Selatan yang dimulai pada jarak lag 325.05 m, di mana terdapat 32 pasangan sampel titik. Arah drift ini tegak lurus *vein* dimana Au terdistribusi dan mengindikasikan arah aliran mineralisasi Au.

Keyword: Variogram, *anisotropic geometry*, efek drift, mineralisasi

ABSTRACT

One of semi-variogram modeling utilities in geology used to determine the control of mineralization. The paper discusses the existence of gold mineralization. The grade samples of gold (Au) were transformed into logarithmic function as base of variogram estimation. Parameter of fitting based on spherical weighted least squares. Eight directions used for estimation with angle tolerance of 11.25^o. Several parameters obtained from calculation based on robust experimental function, four of them selected as reliable value. The drift effect occurs in Northeast-Southwest start at the lag distance of 325.05m, which has 32 samples of pair points. This drift direction is perpendicular from vein where Au distributed and indicated of Au mineralization.

***Keyword**: Variogram, anisotropic geometry, drift effect, mineralization.*

I. INTRODUCTION

Geostatistics is a statistical science that widely used in earth science for considering spatial or temporal relationships among the data (Hohn, 1988). In fact, Deutsch (2002) states that geostatistics studying of phenomena that vary in space and/or time. In geostatistics the presence of data (samples) will affect each other, where the effect can be observed in behavior that occurs in variogram.

Geostatistics is actually not just a tool for resources or reserve estimation in the mining industry but is also a mathematical-statistical modeling tool for natural phenomena (Matheron, 1963). Some parameters such as nugget, sill, drift and hole-effects are geostatistical parameters derived from geological terms, so that they may be used to describe a geological phenomenon. This paper presents gold mineralization study in quartz veins. Vein is tabular or flat lenticular epigenetic body composed largely of quartz, carbonates, or occasionally sulphates, sulphites or other materials (Barnes, 1988).

II. REGIONAL GEOLOGY

This study was conducted in the Ciurug vein of PT. Aneka Tambang, UBPE Pongkor. The village of Pongkor situated at elevation from 1,110m to 1,250m above sea level administratively located in the sub-region of Bayah Lebak regency, Banten province, Indonesia. Based on Geographic, the study area is bounded by latitude 106^{0}24'00"E - 106^{0}26'00"E and longitude 06^{0}44'00"S - 06^{0}46'00"S (Figure 1). Tectonically, this area is a part of the Indonesian Tertiary magmatic arc, named the Sunda-Banda arc of Late Miocene – Pliocene age (Carlie & Mitchell 1994 in Basuki et al. 1994). Regionally, the area included within the framework of regional geology of Bayah dome, South Banten (Figure 1).

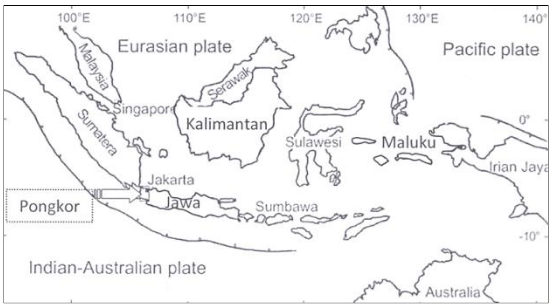

Figure 1. Location map and regional tectonic of Indonesia (modified from Marcoux & Milési 1994 in Warmada *et al*. 2007)

Bayah dome physiography is divided into three tectonic belts (Bemmelen, 1949 in Basuki et al. 1994). i) The Southern sedimentary Belt, consists of Palaeogene sediments discordantly covered by layers of younger sediment, generally folded and strongly faulted toward the West-Northwest and later broken by transverse faults with a North-South direction. ii) Older Volcanic Belt in the middle, which consists mainly of the Old Andesite Formation with sediments of Bayah old Palaeogene formations as inserts. This middle belt is the most potential in the formation of gold-silver epithermal deposits. iii) The Northern sedimentary belt, consists of geosynclinal sediments like Cimapang, Sarewah and Baduy Formations (Figure 2). Deposits are discordantly covered by a layer of volcanic Cimanceuri Formation of Pliocene age.

The distribution of the three belts is caused by the formation of Bayah dome structures that have elongated shape with an axis trending northwest-southeast. Intrusive trend emerge at the back of the Bayah dome. The northern belt is located in north of the dome and the southern belt is located in the south of dome (Warmada et al. 2007).

Gold mineralization in the Pongkor area found in quartz veins associated with prophylitic alteration, argillic alteration and silicification. Primarily controlled by the structure and appears in the form of vein systems. Deposition Pongkor consists from 10 major sub-parallel veins of quartz-calcite with the general strike toward northwest-southeast trending. The one named Ciurug vein extends approximately 2,500m in length and 2.0-2.5m with direction 350^0E-N330^0E with dipping 55^0-70^0 to the east (Warmada et al. 2007; Syafrizal et al. 2009).

Most of these veins indicate supergene weathering that extensively producing secondary gold enrichment in the upper zone of the veins. Anomalous level of gold is found in quartz veins that are within a hydrothermal alteration zone which cover an area approximately 11 km x 6 km. In this alteration zone discovered quartz vein parallel to each other patterned common strike Northwest-Southeast direction (Syafrizal et al. 2009).

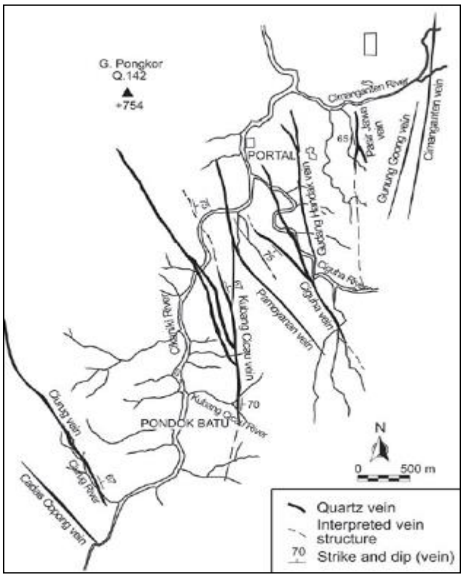

Figure 2. Pattern of the vein system in the Pongkor gold (Warmada *et al*. 2007)

III. GEOSTATISTICS

Matheron (1963) defines geostatistics as the study of the distribution in space, including all practical applications to problems that arise in the evaluation of ore deposition. Gold is part of the ore deposition in terms of Clark (1979), have notoriously erratic grade distribution, so when plotted on a histogram looks skewed. The existences of this type of gold grade, due among others to the early formation of gold ore elements driven by magma energy continuously into the crevices of rocks. As an impact, the distribution will be spatially interrelated, so the estimated value, the existence of both linkage and geological conditions that cause the correlation between these values can be resolved geostatistically (Matheron, 1963).

Regionalized Variable

Regionalized variable (Matheron, 1963) is a numerical function of the space changed from one place to another with apparent continuity, and variations that unexpressed with the usual mathematical functions. Therefore the variation is difficult to predict, if it stated random, nor is it not a random variable, so the variable showing the phenomenon and a special character.

Regionalized variable (Deutsch, 2002) is a variable that can have fluctuating values with changes on vary even location in example lithofacies, porosity, permeability, etc. Continuity of spatial variable have deterministic pattern that distinguishes of random variables. By assuming a certain degree of stationary, the variable is still considered as a random function. Regionalized variables mentioned in the article are the data of gold (Au in ppm) obtained from drilling in several locations in the Ciurug vein area of Pongkor. In data processing, first grade is transformed into the logarithmic.

Stationary

A random function categorized as stationary if the probability density functions at any point invariant to the simultaneous shift points. In contrast to the ideal conditions where the mineralized area is homogeneous, the correlation between two data $Z(\mathbf{s}_i)$ and $Z(\mathbf{s}_j)$ will form an intrinsic character of the area that not depend on the two points $\mathbf{s}_i$ and $\mathbf{s}_j$, but which has notoriously erratic grade distribution, so it is necessary to handle the case of stationary hypothesis (Clark,1979),.

Theoretically, if $\mathbf{s}_i \in \mathbb{R}^2$ is the location of the data on the two-dimensional Euclidean space and $Z(\mathbf{s}_i)$ as the data on the spatial location then the random process $\{Z(\mathbf{s}_i)$: $\mathbf{s} \in D\}$ is called spatial processes (Cressie, 1993; Clark, 1979). In the process $\{Z(\mathbf{s}_i)$: $\mathbf{s} \in D\}$ classified as stationary if it satisfies the following rules: i) $E[Z(\mathbf{s}_i)]=m$; the despite existence expectation of the data is exists and does not depend from $\mathbf{s}$ location. Thus, it is equal to the mean value. ii) Each additional lag distance or for all vectors $\mathbf{h}$ then $\{Z(\mathbf{s}_i)- Z(\mathbf{s}_j)\}$ has a finite variance that does not depend on $\mathbf{s}_i$, so it applies,

$$2\gamma(\mathbf{h}) = \mathrm{var}[Z(\mathbf{s}_i) - Z(\mathbf{s}_j)] = E\{[Z(\mathbf{s}_i) - Z(\mathbf{s}_j)]^2\} \quad \mathbf{h}=\mathbf{s}_i\text{-}\mathbf{s}_j \in \mathbb{R}^2.$$

Variogram

Maglione & Diblasi (2004) state that variogram (some authors said semivariogram or spatial semivariance) is an important tool in assessing the regionalized variables used to describe model and exploit spatial autocorrelation of the regionalized variable (Huang & Hu 2009). In mining geology, Pyrcz & Deutsch (2003) state that variogram is defined as relationship between the variability (geological distance) and lag distance (Euclidean distance).

Suppose that mineral grade of the ore body at the point $\mathbf{s}$ (here the dimension is 2) is a realization of the random process $\{Z(\mathbf{s})$: $\mathbf{s} \in \mathcal{D}\}$ and that is observed at certain points $\{\mathbf{s}_i$: i=1, ..., $n\}$ (almost square grid) of the ore body. Then the intrinsic stationary is determined by the first difference or expectation of $E(Z(\mathbf{s}+\mathbf{h}) - Z(\mathbf{s})) = 0$, $\mathrm{var}(Z(\mathbf{s}+\mathbf{h}) - Z(\mathbf{s})) = 2\gamma(\mathbf{h})$.

Using the set of power transformations proposed by Box & Cox (1964), Cressie & Hawkins (1980) found that the fourth-root of chi-square random variable has skewness of 0.08 and a kurtosis of 2.48. Using location such as the mean and the median, can be applied to the $|N(\mathbf{h})|$ with transformed differences $\left\{|Z(\mathbf{s}_i) - Z(\mathbf{s}_j)|^{0.5}; (i,j) \in N(\mathbf{h})\right\}$. These estimates are raised to the fourth power to make them back of correct scale and adjusted for bias. The result of robust variogram estimator as in Cressie (1993) formulated

$$\bar{\gamma}(\mathbf{h}) = \left(\frac{1}{2|N(\mathbf{h})|}\sum_{i=1}^{N(\mathbf{h})}[Z(\mathbf{s}_i) - Z(\mathbf{s}_j)]^{\frac{1}{2}}\right)^4 \Big/ \left(0.457 + \frac{0.494}{|N(\mathbf{h})|}\right).$$

$N(\mathbf{h}) \equiv \{(i,j): \mathbf{s}_i - \mathbf{s}_j = \mathbf{h}\}$ and $|N(\mathbf{h})|$ is the number of different elements.

The definition of theoretical variogram is based on regionalized random variables $Z(\mathbf{s}_i)$ and $Z(\mathbf{s}_j)$ where $\mathbf{s}_i$ and $\mathbf{s}_j$ is a representation of the spatial position (Bachmaier & Backes, 2008). A regional phenomenon characterized by the presence of several variables correlated with each other and in some cases required investigations simultaneously.

For the purposes of analysis, the experimental variogram needs to be replaced or fitted by the theoretical variogram that curve closest to the experimental variogram. In geostatistics, fitting the experimental variogram with theoretical variogram was also named the structural analysis. From various theoretical models, which are presented here is the spherical (Cressie, 1993).

Variogram behaviours

The increase in $\gamma(\mathbf{h})$ is an indicator of the degree to which the influence of the sample decreases with increasing distance from the sample site. Range (a) is the distance where the variogram becomes constant. This is a more precise definition for the concept of zone of influence. If $\lim_{|\mathbf{h}|\to\infty} \gamma(|\mathbf{h}|) = \gamma_\infty < \infty$ then γ_∞ is called as sill of variogram (Budrikaitė, 2005), which is a population variance, where no correlation between $Z(\mathbf{s}_i)$ and $Z(\mathbf{s}_j)$ or symbolized as or (c_0+c), so $0.5E[Z(\mathbf{s}_i) - Z(\mathbf{s}_j)]^2 = 0.5var(Z(\mathbf{s}_i) - Z(\mathbf{s}_j)) = \gamma(\mathbf{h})$ (Sarma, 2009).

Nugget effect is a condition in which the extrapolation curve toward $\mathbf{h}$=0 does not give $\gamma(0) = 0$, but $\gamma(0) = c_0$. It is said, mathematically that c_0 is the nugget effect (Matheron, 1962) if $\gamma(-\mathbf{h}) = \gamma(\mathbf{h})$ and $\gamma(0) = 0$, so it applies $\gamma(\mathbf{h}) \to c_0 > 0$ for $\mathbf{h} \to 0$. It is due to a variation in the micro-scale (small nuggets) which causes a discontinuity at the origin.

Drift effect is the phenomenon whereby an initially normal variogram–up until it reaches the sill–but then suddenly changed parabolic. The regionalized variable was no longer stationary. Drift can be obtained by calculating the average difference in the variables $\mathbf{s}_i$ and $\mathbf{s}_j$ in accordance with the direction of the vector **h**, especially when graphically visualized. In the regionalized variable theory, the concept of drift is one of the most important topics of a function and its represents the trend function of chamber geometry (Thakur et al. 2004).

Geometric Anisotropy

Geometric anisotropy is a condition which the variogram range changed in different directions (e.g. North-South, East-West etc.), while the sill has a fixed value (Budrikaitė, 2005). When visualized in a coordinate system will form elliptical, so the geometric anisotropy is often referred as the elliptic anisotropy (Sarma, 2009). If $a_{\max}$ is the major axis and $a_{\min}$ is stated of minor axis, anisotropy factor is expressed as $\lambda = \frac{a_{max}}{a_{min}} > 1$ (Dučinskas & Dreižienė, 2010).

IV. ANALYSIS AND DISCUSSION

Regional variables in this study using 128 sample points of gold (Au) as the results from core drilling in quartz veins Ciurug. Prior to the processing and computation with the R package, firstly the data transformed to the logarithmic. The results of variogram parameters were performed fit in eight directions with a tolerance angle 11.25^0, which is the main direction 0^0 shows the East-West, Northeast-Southwestern is 45^0, North-South is 90^0 while 135^0 showed Northwest-Southeast direction (Table 1). The variogram fitting curves, as comparison here used eight directions, are shown in Figure 3.

Table 1. Spherical variogram fitting parameters

Direction	Nugget	Sill	Range
E-W	0.249	0.711	258.42
NE-SW	0.239	0.696	290.73
N-S	0.217	0.598	157.74
NW-SE	0.239	0.696	180.00

Drift occurs in Northeast-Southwest direction starting from (lag) distance 325.05 of 32 couples where there is a sample point (Table 2). When compared with the existing of Pongkor vein, the Northeast-Southwest direction is indicated on perpendicular position to the vein, while the Northwest-Southeast direction or minor axis is indicated as parallel vein. It is likely drift effect can be used as a reference direction than the gold mineralization and associated elements.

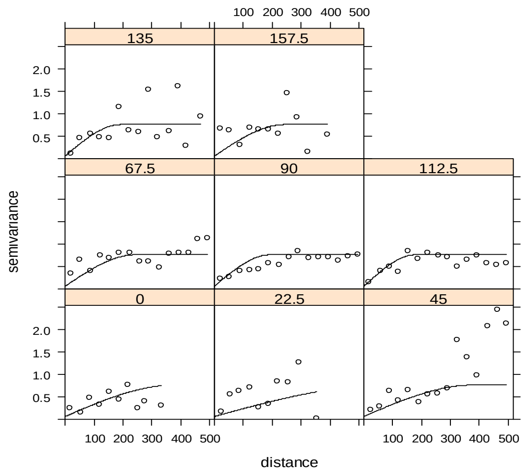

Figure 3. Variogram in eight directions

Table 2. Drift effect in the northeast-southwest and northwest-southeast

Northeast-southwest			Northwest-southeast		
Pairs	Distance	Variogram	Pairs	Distance	Variogram
12	24.52448	0.20520602	5	21.01102	0.11911420
45	53.19303	0.28754267	31	50.57594	0.46955211
51	88.29846	0.62705574	54	86.95703	0.55634956
64	118.91602	0.40996248	51	119.93728	0.48027844
69	155.11940	0.64488026	58	153.14873	0.45268476
65	189.29982	0.38738796	43	187.26833	1.15468385
27	221.43892	0.56033673	31	220.17979	0.62597362
49	255.76615	0.57136226	24	255.70885	0.60482024
42	290.73407	0.69691452	14	289.62194	1.53624886
32	325.04689	1.75346190	12	318.41445	0.48888953
19	356.33154	1.37737201	8	358.69619	0.62478250
16	391.64092	0.96619272	5	391.54148	1.62223445
10	430.92470	2.06409705	3	416.99202	0.28714334
3	461.73769	2.43079108	3	469.15259	0.93955649

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