Geostatistical analysis on distribution of gold veins

Nur Ali Amri[1)]; Abdul Aziz Jemain[2)]; Wan Fuad Wan Hassan[3)]; Jatmika Setiawan[1)]

[1)] Fakultas Teknologi Mineral UPN "Veteran" Yogyakarta , Jl. SWK 104 (Lingkar Utara) Condongcatur, Yogyakarta 55283, Indonesia

[2)] Fakulti Sains dan Teknologi Universiti Kebangsaan Malaysia, 43600 UKM Bangi Selangor DE, Malaysia

[3)] Fakulti Sains, Universiti Malaya 50603 Kuala Lumpur, Malaysia

Abstract

The distribution of gold minerals in the vein depends on the initial formation caused by hydrothermal process. The investigation in this work is related to the gold (Au) mineralization in Penjom Gold Mine in the state of Pahang, Malaysia. Gold mineralization in Penjom can be described as sheeted orogenic mesotermal veins and dissemination deposit in Permian sedimentary sequence of fine-grained sediments and volcanics. Variogram calculation results of gold values from 304 drill hole data obtained show that anisotropy phenomenon occurs in east-west direction which the minor range a_1=720 meters and major range a_2=2397 meters, while in southeast-northwest direction the minor ranges is a_1=935 meters and the major a_2=3401 meters. Isotropy phenomenon occurs in the southwest-northeast and north-south directions with each range of a = 1622 meters and a = 2143 meters respectively. After the release of 88 data based on variogram calculations of data outliers, anisotropy phenomenon still occurs in east-west direction with each a_1=199 meters and a_2=4828 meters, while in southeast-northwest direction the ranges are a_1=1316 meters and a_2=1829 meters respectively. Isotropy phenomenon occurs in southwest-northeast and north-south with the same range of a=1543 meters. In trials with various active lag 823.95, 411 975 and 205. 987, the drift occurs in east-west and northwest-southeast, and indicating similarty with the directions of lithologic structures.

Key words: *Geostatistics, area of influence, drift effect.*

Introduction

Gold is a precious metal found in form of mineral in rocks. Because of its unique physical and chemical properties, gold finds main uses in jewellery, long-term monetary investment, medical and insustrial purposes. Gold is derived from the earth's crust, resulting from geological hydrothemal processes of which the majority of the gold is found in epithermal and mesothermal orogenic type of gold deposits.

There are several gold formation processes, one of which is that gold as ion is transported in form of hydrothermal solution and deposited in open spaces filling in faults, veins and other fractures in rocks giving vein-type gold deposit. A vein is a tabular or flat lenticular epigenetic rock body composed largely of quartz, carbonates, or occasionally, sulphides and other minerals (Barnes 1988). Primary gold in veins and other types of deposits are weathered when exposed on the earth's surface producing placer gold deposit.

Most of veins are associated with faults, fracture fillings and shear zones which in these conditions allow for the effect of dilution on the rock side. In general, the difference between the assay inside vein and rock side is very striking. It is related to the contact with the rock side, impregnation on the rock side, as well as the branching pattern vein. In addition, vein thickness fluctuations are difficult to predict and have a limited range of possible occurrence of highly erratical levels, even unpredictable (Annels, 1992).

Generally, the gold is found together with a number of other minerals such as quartz, pyrite, chalcopyrite, arsenopyrite, etc (Craig & Vaughan 1981). Because of its presence deep in the earth reaching hundreds of meters, then to get to it requires knowledge about its occurrence and size of the reserve. Before reaching the stage of mining or production, it requires a few years of study, from the early activity, namely the exploration and development to the final mine closure stage.

In mining industry exploration stage includes early exploration and detail mining-stage exploration. Calculations using geostatistical rules in the exploration stage is very important to know the spatial characteristics of mineral distributions. Spatial characteristics are used as the basis for making estimates to calculate the amount of reserves.

Conditions And Regional Geology

The data for this study is based on Penjom Gold Mine, the mining company that is located a few kilometers of south-west Kuala Lipis, in the state of Pahang, Peninsular Malaysia. The bed rocks in the area belong to the Permian Raub Group, consisting of fine-grained sediments and volcanics. Bedrocks in the mine area is dominated by marine clastic sediments which in some places are carbonaceous, intermediate to acid volcaniclastics, and subordinate rhyolitic lava sequences. They belong to the Padang Tengku Formation of the Raub-group rock. This volcaniclastic and sedimentary association is intruded by a few shallow dipping sheets of tonalite unit as narrow sills and minor dykes of quartz porphyries, running almost parallel to the main mineralized shear zone. Tonalite is a major igneous intrusion within the area. Sedimentary sequence strikes about north-south and dip moderately to the east at 30^{o} (Metcalfe 2000).

A prominent structural feature of Peninsular Malaysia is the north-south trending Raub-Bentong Suture (RBS) that has accommodated considerable strike-slip movement and sustained over 100 km. Penjom mine which is situated about 20 km to the east of thi RBS, as well as other gold mines within the area are strongly affected by this feature by giving faults and structural features in almost north-south direction (Fig. 1). Structural analysis has indicated a regular geometrical pattern of repeated district scale fault trends (Kelau fault) which can be observed within most of the goldfields in the Central Belt (Tjia & Zaitun, 1985).

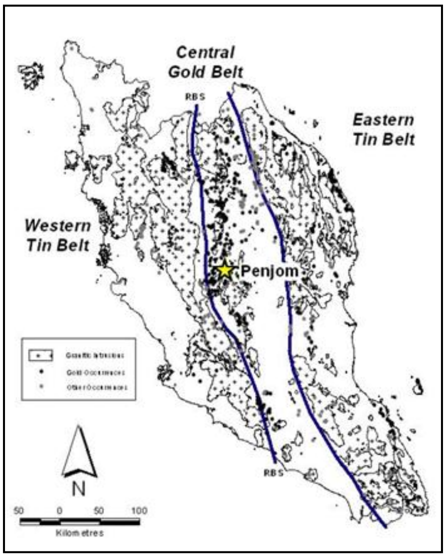

Figure 1. Map of Peninsular Malaysia showing the metallogenic belts, Raub-Bentong suture (RBS) and the location Penjom (Flindell 2003)

Mineralization at the Penjom gold deposit is structurally controlled and erratic laterally and vertically. The Penjom thrust is the dominant feature controlling the distribution of ore at Penjom and generally strikes NE (35^{o}) and dips to the southeast (30^{o}-40^{o}). Considerable shear stresses along the Penjom thrust have remobilized much of the carbon within the shale sequence to form a graphitic “alteration” zone. This, together with sheared and milled rock (fault gouge materials), makes the Penjom thrust an impermeable zone. Major gold mineralization took place within the footwall of this thrust (Wan Fuad & Heru Sigit 2002, Kamar Shah 2012).

Kamar Shah Arifin (2012) divided mineralization bodies in the Penjom deposit into four groups, namely sheeted vein, dissemination, massive and fragmental. Sulphide minerals mainly arsenopyrite and pyrite are dominant constituents embedded in quartz-carbonate veins. There are widespread occurrences of pyrite, arsenopyrite, sphalerite, galena, chalcopyrite, molybdenite, tetrahedrite and tellurides. The gangue minerals commonly associated with gold mineralization include quartz, feldspars, carbonates and graphite.

Objectives

The basic theory of investigation is geostatistics, which includes a variety of effects that may be caused by, among others the emerging or absence of drift, hole effect, nugget, sill, and the influence of geology that can be used as a basis to determine the various phenomena that occur in the existence of the data. By compiling the geological data and determining whether the amount of regional influence is isotropy or anisotropy, these phenomena can be used to determine the strength or direction of the mineralization. Following the fitting variogram and knowing the power and influence within the region, the kriging rule estimation can be performed on each sample for basic calculation of gold reserves.

Materials and Rules Data

Gold assay values (Au in ppm) analysed by fire assay-AAS method of core drilling samples on regular grid pattern, were obtained from the Penjom Gold Mine, Kuala Lipis, Pahang. Drilling is done on the coordinates up to 0.29562-0.49299 and 0.28798-0.49192.

The data taken from 30,757 grade assays were composited into 304 data, or as much of the core drill holes with a maximum thickness of 216.3 meters and a minimum thickness of 2 meters. Thickness data is used as a parameter in the region to find out the overall volume of the mine to search for reserves. Kishné et al. (2003) states that, in order not to interfere with the process of analysis, data outliers should “bootstraped” or be excluded. Based on the analysis, there were 88 deviant data, which in distinct lithologic and most of them lies in up to 0.29480-0.487742 and 0.29509-0.49019. It will be analyzed in a separate discussion.

There are two categories of data. The first, as it is with the assumption that the data are relatively free from human cases in the analysis or calculation error initially. This data is used to determine the geologic conditions or parameters based on calculations derived from the geostatistics calculations. Second, excluded data or “bootstraped” i.e. data is free from outliers conditions.

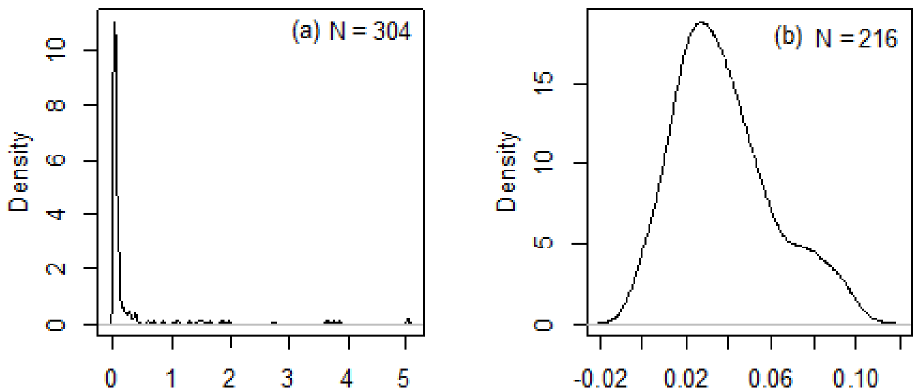

Figure 2. Histogram of (a) all Au data and (b) after Au data excluded

Outlier is defined as an observation that "appears" to be inconsistent with other observations in the data set (Barnett & Lewis 1985 in Walfish 2006). Data outliers (Rousseeuw & Zomeren 1990) can be identified, both graphs (box plot and scatter plot) or by mathematical formulas as Leverage values, Standardized DfFIT, Cook's distance, etc. While Thomas & Snowden (1990) states that the outliers can be identified from the skewness is positive, and if it will be continued to the variogram calculation, the estimation will be overestimate.

From some of 304 drilling data resulted at the distribution zone of gold with an average thickness of 90.7865 m (with maximum thickness of 216.3 m and a minimum 2 m), there is a minimum level of 0.02 ppm (Au) and a maximum of 0.50549 (50.549 ppm) ppb (Au) with coefficient of variance value is 3.0135 and the coefficient of skewness=4.9327. Because of the skewness value is 0.5957, and statistics visualization especially boxplot method obtained information that there were 88 of data outliers with a value greater than 99.8 ppm (Au) will interfered or excluded from the analysis.

After the data outliers is removed, the coefficient of variance is changed to 0.5864, (as before 3.0135) and the coefficient of skewness is 0.5957 (as before 4.9327), which minimum data is 0.02 and maximum 99.8. Its means that the distribution is normal relatively (Fig. 2). From the analysis, it is shown that 216 selected data are located in the same lithologic region.

Statistics

Univarian statistical analysis used to determine the characteristic of the gold assay data population. Several statistical parameters to note include maximum/minimum, mean, median and coefficient of variance (Velasco & Verma 1998). Dominy et al. 1997 in Roy et al. (2004) suggests, if the coefficient of variation over the 1.5, variogram should not be built, although geologically, it indicates of erratical levels as stated Wan Fuad & Heru Sigit 2002.

Table 1. Statistical parameter before (all grade) and after excluded (bootstrap)

Data	Min.	1st Qu.	Median	3rd Qu.	Max.	CV
All grade	0.02	0.251	0.431	9.69	505.49	3.0135
Bootstraped	0.02	0.209	0.379	5.08	99.80	0.5864

After bootstrapped the coefficient of variation changed to 0.5864 (Table 1) or less than 1.5, thus further calculations, especially with regard to variography and estimation can proceed.

Geostatistics

Variogram

Geostatistics is a rule which the main element is regionalized variables, or is a spatial variable that depends on the spatial location. The primary gold, particularly gold inside the vein is a natural phenomenon in the form of spatial sprinkles, so the positioning can be mathematically formulated as a regionalized variable. Region in the investigation means, an area containing gold mines in Penjom with a value of the spatial variable.

Variogram is the main tool of spatial variables or geostatistics theory that quantified the size and intensity of spatial variation, provide the basis optimum interpolation or estimation through kriging rules (Webster & Oliver 2007; Emery 2007). Huang & Hu (2009) states that the variogram is a geostatistical basis for describing, modeling, and exploiting the spatial autocorrelation of the spatial variables. One of the important things in variogram modeling is to determine the control of mineralization (Coombes 2009).

Estimated classical variogram by Matheron (1962) in Cressie (1993) stated as follows:

$$2\hat{\gamma}(\mathbf{h}) = \frac{1}{|N(\mathbf{h})|} \sum_{N(\mathbf{h})} (Z(s_i) - Z(s_j))^2; \ \mathbf{h} \in R^d \quad (1)$$

where $N(h) \equiv \{(s_i, s_j) : s_i - s_j = \mathbf{h}; i, j = 1,...,n\}$ and $|N(\mathbf{h})|$ is a different sample pairs point separated by vector **h.**

In a practice, the data values are not just limited to form a regular pattern (regular) as it is commonly known. Thus, it is necessary to use a rule for calculating $\gamma(\mathbf{h})$ semivariogram. The sum of n samples be shown as the value of $Z(s_i)$, i=1, ..., n. To estimate $\gamma(\mathbf{h})$ in the direction θ variogram with distance **h**, then there is a provision, the maximum deviation is within the area direction (angle) of $d\theta$ and deviation distance along h. All the sample pairs of vectors $Z(s_i)$ and $Z(s_j)$ on θ_{ij} direction that is the interval direction θ-$d\theta$ and θ+$d\theta$, are treated equally. Likewise, all sample pairs s_i and s_j are located at a distance $\mathbf{h}_{ij}$ and were among interval **h**-d**h** and **h**+d**h** will be treated equally. $Z(s_i)$ and $Z(s_j)$ is used for semivariogram estimated of direction θ and distance **h**. For the record, that the direction and distance used in the fitting is done the average direction and distance than the overall sample pairs by taking into consideration (mean value than θ_{ij} and $\mathbf{h}_{ij}$, respectively) and the nominal price θ and **h** (Rendu 1981; Igúsquiza & Dowd 2001). The grade semivariograms are in the directions N 0° E, N 45° E, N 90° E, and N 135° E with angle tolerance of 22.5.

Nugget effect and sill

Nugget effect is a condition in which the extrapolation of the curve leading to **h**=0 does not produce $\gamma(0) = 0$, but $\gamma(0) = C_0$. Or, mathematically C_0 is nugget effect if $\gamma(-\mathbf{h}) = \gamma(\mathbf{h})$ and $\gamma(0) = 0$, so applicable $\gamma(\mathbf{h}) \to C_0 > 0$, as **h** → 0. While the sill is the maximum variance contained in a distribution, where the mean does not depend anymore to distance between samples. Nugget effect indicates a sprinkling of erratical data (Annel 1992).

Sill is the maximum variance contained in a distribution, a condition where the distance does not have a spatial effect, and this is an area of statistics. In “normal” conditions, the sill is the boundary between the geostatistical and classical statistics.

Drift

Drift is the phenomenon in which a variogram that initially behave normally – that is up until it reaches the sill – but then suddenly a parabolic rise. Its mean, that the regionalized variable was no longer stationary (Thakur et al. 2004). Drift can be determined by calculating the average difference in the variables s_i and s_j in accordance with the direction of the vector **h**, especially when visualized graphically. Average difference is, mathematically formulated:

$$\Delta(h) = \frac{1}{2N(\mathbf{h})} \sum_{i=1}^{N(\mathbf{h})} \left\{ \tfrac{1}{2} \left[Z(s_i) - Z(s_j) \right] \right\} \quad (2)$$

Fitting variogram

Various theoretical variogram is linear, Gaussian, spherical, etc. It is said that the condition of R^d and d ≥ 1:

Linear: $\gamma(\mathbf{h};\theta)=\begin{cases}0, & \mathbf{h}=0\\ c_0+b_l|\mathbf{h}|, & \mathbf{h}\neq 0\end{cases}$, (3)

where $\theta=(c_0, b_l)'$ and $c_0 \geq 0$, $b_l \geq 0$.

If the conditions R^1, R^2, and R^3 then,

$$\text{Gaussian: } \gamma(\mathbf{h};\theta)=\begin{cases}0, & \mathbf{h}=0\\ c_0+c_g\left(1-\exp\left(-\frac{|h|^2}{a_g^2}\right)\right), & 0<|\mathbf{h}|\leq a_g\\ c_0+c, & |\mathbf{h}|\geq a_g\end{cases} \quad (4)$$

$\theta=(c_0, c_g, a_g)'$ where $c_0 \geq 0$, $c_g \geq 0$, andn $a_g \geq 0$.

$$\text{Spherical: } \gamma(\mathbf{h};\theta)=\begin{cases}0, & \mathbf{h}=0\\ c_0+c_s\{(3/2)(|\mathbf{h}|/a_s)-(1/2)(|\mathbf{h}|/a_s)^3, & 0<|\mathbf{h}|\leq a_s\\ c_0+c_s, & |\mathbf{h}|\geq a_s\end{cases} \quad (5)$$

$\theta=(c_0, c_s, a_s)'$ where $c_0 \geq 0$, $c_s \geq 0$, and $a_s \geq 0$.

Analysis And Discussion

Analysis variogram

Range is an area of influence that indicates, how long or widespread influence of sample to sample. From the calculation, influence of the sample were still going on between the minimum distance 720 meters (minor) and a maximum was 2397 meters (major). This condition is reflected the anisotropy phenomenon that occurs in an east-west direction. While on a northwest-southeast direction, the influence between samples occur at minimum 935 meters (minor) and a maximum along of 3402 meters (major). Isotropy condition occurs in the northeast-southwest with a range 1623 meters and north-south with a range of 2143 meters.

Table 2. Geostatistical parameters all grade

Direction	Nugget	Sill	Range		Area of Influence (m^2)	Model
			Minor	Major		
E-W	0.001	4.22	720.5	2397.16	5,428,442	Ellipse
NE-SW	0.159	3.82	1622.76	1622.76	8,276,223	Cycle
N-S	0.001	3.66	2143.00	2143.00	14,433,411	Cycle
NW-SE	0.207	4.05	935.31	3401.75	9,999,562	Ellipse

In the east-west direction, influence between two samples occurs in an elliptical area of 5,428,442 m^2. While on a northwest-southeast direction between two samples influence still occurs in an elliptical area of 9,999,562 m^2. In the northeast-southwest influence occurs in an area of 8,276,223 m^2 (cycle). While the north-south direction between samples influence occurs in a cycle area of 14,433,411 m^2 (Table 2).

The direction of gold deposition occurred with significant distribution is in the northwest-Southeast, with an area of influence 9,999,562 m^2 in the ellipse form with 935 meters minor axis and the major axis is 3401 meters. Its can be seen from the position of the biggest nugget i.e. 0.207 (see Table2).

Variogram on excluded data

Variogram parameters calculated after “bootstrapping” the data states that small value of nugget relatively, near the abscissa distance lag i.e. 0.004. Although it is not too extreme, anisotropic condition exists on the east-west and northwest-southeast where each minor-major axis is 1889-4586 and 1288-1865. The model is Gaussian with active lag 463.58, distance interval 30.91 and degree tolerance 22.5.

Table 3. Geostatistical parameters after excluded data

Direction	Nugget	Sill	Range		Area of Influence (m^2)	Model
			Minor	Major		
E-W	0.004	0.64	1889.67	4586.47	27,238,832	Ellipse
NE-SW	0.004	0.22	1461.16	1461.16	6,709,964	Cycle
N-S	0.004	0.22	1461.16	1461.16	6,709,964	Cycle
NW-SE	0.004	0.24	1288.65	1865.42	7,555,003	Ellipse

Drift analysis

In this investigation, for all three active lags (823.95, 411.975 and 205. 987) the drift occurs in both directions i.e. east-west and northwest-southeast which according to Metcalfe (2000) in a line with the sedimentary rocks along strike and the direction of northwest-southeast (Table 4). And it would seem apparent that the average price drift further away from the position of the abscissa. This occurs in both directions i.e. east-west and northwest-Southeast.

Table 4. Drift effect on direction east-west and northwest-southeast direction

	E-W direction			NW-SE direction		
Lag class	Average distance	Average drift	Pairs	Average distance	Average drift	Pairs
1	34.27	-0.002854	560	36.13	0.140990	483
2	83.03	0.071582	1006	83.44	0.030044	899
3	137.66	0.187278	1028	137.34	0.060289	1099
4	189.07	0.386039	827	191.86	0.078085	1082
5	243.46	0.363551	404	245.45	0.116045	932
6	303.14	0.618226	329	300.75	0.163527	668
7	357.04	1.355416	413	356.54	0.734487	765
8	412.49	1.922172	458	412.97	1.348686	922
9	468.19	2.109447	524	463.57	1.661324	833
10	518.94	2.183491	449	521.54	1.777527	553
11	560.57	1.891813	75	574.51	1.906973	469
12	-	-	-	630.21	1.835178	209
13	-	-	-	683.80	1.775271	178
14	-	-	-	744.52	-1.229143	280
15	-	-	-	787.14	-2.166777	185

Results of the estimation

The comparison between the original data (Z all data) with estimated data (Z estimation) are relatively linear with mean error (ME)=-0.04, mean square error MSE)=5.675E-02 and mean absolute error (MAE) is 1.8868. This suggests that the data on the estimation is relatively similar to the original data, and it became the important base in a final calculation of reserves.

Table 5. Comparison of statistical parameters between Z real and Z estimation

	Min.	Max.	Median	Mean	Var.
Z real data	0.02	9.98	3.44	3.79	0.052
Z estimation	1.55	6.79	3.79	3.83	0.005

Conclusion

One of the information obtained from the drift phenomenon is, from three lags being tested is known that the drift occurs in both directions i.e. east-west and northwest-southeast its same with Metcalfe (2000) analysis that the sedimentary rocks along strike and the direction of northwest-southeast.

The results showed the similarities calculation between the original data (Z real data) with estimated reserves (Z estimation) are linear. This suggests that the data on the estimation is relatively similar to the real data, and it became an important base in the final calculation of reserve.

Acknowledgements

The writers wish to thank the Penjom Gold Mine Kuala Lipis, Pahang, Malaysia particularly Mr Brian New and Mr Zakaria Endut who have provided data and other informations needed and the generous assistance given to facilitate this study. The authors also wish to thank Mr. A. Rodhi for the various discussions, comments, suggestions and valuable inputs.

Refferences

Annels, A.E. 1992. *Mineral deposit evaluation: A practical approach*. London. New York. Tokyo. Melbourne. Madras: Chapman & Hall.

Barnes, J.W. 1988. *Ore and minerals: Introducing economic geology*. Milton Keynes, Philadelphia: Open University Press.

Barnett, V. & Lewis, T. 1985. *Outliers in statistical data*. New York: John Wiley & Sons, 2d edition.

Coombes, J. 2009. Mentoring in mining: A handbook for geoscientists managing teams. *Coombes Capability*. 80 p.

Craig, J.R. & Vaughan, D.J. 1981. *Ore microscopy and ore petrography*. New York: John Wiley & Sons.

Cressie, N. 1985. Fitting variogram models by weighted least squares. *International Journal of Mathematical Geology* 17 (5), no. 5: 563–586.

Cressie, N. 1993. *Statistics for spatial data*. New York. Chichester. Toronto. Brisbane. Singapore: John Wiley & Sons, Inc.

Emery, X. 2007. Reducing fluctuation in the sample variogram. *New York: Springer-Verlag, Stoch Environ Res Risk Assess* 21: 391-403.

Flindell, P. 2003. *Avocet Mining – Exploration and Development Across Central and Southeast Asia,* Australia Institute of Geoscientists (AIG), Mineral Exploration Discussion Group (SMEDG). 10 Oct., Sydney, 8ppFlindell, P. (2003). Avocet Mining – Exploration and Development Across Central and Southeast Asia, Australia Institute of Geoscientists (AIG), Mineral Exploration Discussion Group (SMEDG). 10 Oct., Sydney, 8pp

Heriawan, M.N., Syafrizal, Widodo, L.E., Airlangga,E., Rustiawan, W. 2009. Analisis kerapatan data eksplorasi dan estimasi Sumberdaya dengan pendekatan geostatistik pada endapan nikel laterit di daerah Halmahera Timur. *Jurnal Teknologi Mineral* 16 (2): 89 – 102.

Huang, B. & Hu, T. 2009. BLPP approach for the estimation of the variogram parameters. *New York: Springer-Verlag, Environ Earth Science* 59: 421-428.

Kamar Shah Ariffin, 2012. Mesothermal Lode Gold Deposit Central Belt Peninsular Malaysia. Intech: Earth Science, chapt 15, Imran Ahmad (edt.). http://www.intechopen.com/books/earth-sciences

Metcalfe, I. 2000. The Bentong-Raub Suture zone. *Journal of Asian Earth Sciences* 18: 691-712.

Ortiz, C. J. & Deutsch, C.V. 2002. Calculation of uncertainty in the variogram. *International Journal of Association for Mathematical Geology* 34 (2): 169-183.

Rendu, J.M. 1981. *An introduction to geostatistical methods of mineral evaluation*. Johannesburg: South African Institute of Mining and Metallurgy.

Rousseeuw, P.J., & Zomeren, B.C. van. 1990. Unmasking multivariate outlier sand leverage points. *Journal of the American Statistical Association,* 85: 633-651.

Roy, D., Butt, S.D. & Frempong, P.K. 2004. Geostatistical resource estimation for the Poura narrow-vein gold deposit. *CIM Bulletin ProQuest Science Journals*, Feb. (1077): 47-51.

Thakur, R.T., Loc'h, G.L., Chaudhari, P.K. & Singh, B. 2004. Non–Stationary Advanced Geostatistical Modelling Technique: A Case Study. *Proceeding 5th Conference & Exposition on Petroleum Geophysics, Hyderabad, India*, p.: 508-511.

Thomas, M. & Snowden, V. 1990. Improving reconciliation and grade control by statistical and geostatistical analysis. *Bulletin AIG* (*Strategies for grade control*) 10: 49-59.

Tjia, H.D. 1989. Tectonic history of Bentong Bengkalis suture. *Jurnal Geologi Indonesia*, hlm. 73-85.

Tjia, H.D. and Zaitun H. 1985. Regional Structures of Peninsular Malaysia, *Sains Malaysiana*, 14, pp. 95-107

Velasco, F. & Verma, S. P. 1998. Importance of skewness and kurtosis statistical tests for outlier detection and elimination in evaluation of geochemical reference materials. *International Journal of Mathematical Geology* 30 (1): 109–128.

Walfish, S. 2006. A Review of Statistical Outlier Methods. *US Pharmacopeial Convention, Rockville, MD* 2 Nov. USP 29–NF 24: 1-5.

Wan Fuad, W.H. & Heru Sigit, P. 2002. Type deposits of primary gold mineralization in the Central Belt of Peninsular Malaysia. *Proceedings, Geo. Society of Malaysia*, *Annual Geo. Conf*, Kota Bharu, Kelantan, Malaysia, p. 111-115.

Wan Fuad, W.H. & Heru Sigit, P. 2003. *Analisis bendalir terkepung pada terlerang kuarza yang mengandungi emas di kawasan lombong Penjom, Kuala Lipis, Pahang dan Lubok Mandi*, Geo. Society of Malaysia Bulletin, 46, hlm. 359-363 (*in Malay language).*

Webster, R. & Oliver, M.A. 2007. *Geostatistics for environmental scientists*. Second Edition. England: John Wiley & Sons Ltd.