

FRACTAL MODEL AND CLASSICAL BLOCK MODEL IN ORE RESERVE ESTIMATION: A COMPARISON

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ABSTRACT The characteristic possessed by many gold deposits is the erratic distribution for gold grade and abnormal distribution (high skewness) which would restrain the application of certain estimation methods especially geostatistics. Another method proposed in order to handle high skewness distribution is fractal model. In this paper one of the models, the number-size model would be compared with block model in estimating ore tonnage and metal (Au-Ag) tonnage for deposit with complex and erratic data distribution. For this purpose, the data obtained from channel sampling program in Ciurug vein, block South 3, level 500 and 600, Pongkor mines would be used as study case. The results show that the number-size fractal model so far could be applied only to the deposits with continuous dimension and grade distribution. For deposits with erratic grade distribution the fractal model has only limited use, which powerful generally to estimate bulk volume or ore tonnage since the dimension i.e. thickness has relatively high continuity.

Keywords: Fractal, number-size model, reserve estimation, Au-Ag, Pongkor

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ABSTRAK Karakteristik yang umum dijumpai pada banyak endapan emas adalah distribusi kadar emas yang eratik dan tidak mengikuti distribusi normal (gaussian) dikarenakan skewness yang tinggi dan pada gilirannya akan membatasi aplikasi beberapa metode estimasi khususnya geostatistik. Salah satu metode yang dapat digunakan untuk menangani populasi data kadar dengan skewness tinggi adalah model fraktal. Di dalam tulisan ini, salah satu model fraktal, number-size model akan diaplikasikan dalam perhitungan cadangan Au-Ag dengan distribusi data kadar yang kompleks dan eratik yang hasilnya akan dibandingkan dengan hasil perhitungan model blok. Dalam tulisan ini, data-data yang diperoleh dari program pemercontohan dengan metode alur di Urat Ciurug, Blok Selatan 3, Level 500 dan 600, Tambang Pongkor dipergunakan sebagai studi kasus. Hasilnya menunjukkan bahwa number-size model dari metode fraktal sejauh ini hanya dapat diaplikasikan untuk deposit dengan distribusi kadar dan dimensi yang kontinu. Untuk endapan dengan distribusi kadar yang eratik model ini terbatas penggunaannya, dan dalam kasus ini terbatas hanya pada estimasi volum ruah atau tonase bijih dikarenakan perhitungannya didasarkan pada distribusi data ketebalan yang cenderung kontinu.

Kata kunci: Fraktal, number-size model, estimasi cadangan, Au-Ag, Pongkor.

INTRODUCTION

Reserve estimation is still the most critical stage in mining feasibility study of certain ore deposits. The difficulties in estimation process varied based on the geological constraint, from the easiest one e.g. coal deposits to the trickiest one e.g. primary gold-silver deposit. An outstanding characteristics possessed by almost of primary

gold deposits is the presence of coarse gold grains which were randomly distributed (Dominy, 2000). This characteristic caused the erratic distribution for gold grade and abnormal distribution (high skewness). The distribution with high skewness would restrain the application of certain estimation methods especially geostatistics since this method is based on normal distribution (Wellmer, 1998). The common method such as log transformation has only limited use and could not cope with extreme skewness of such grade distribution.

The other classic methods in estimation beside geostatistics including inverse distance (ID) use linear interpolation to estimate the grade value in certain coordinate based on surrounding grade data. ID calculates the value using power which varied according to the erraticness of the data distribution. Usually the power used in calculation is two (inverse distance square), and for extremely erratic data, the power become infinite, and the estimation method is then called nearest neighbor point (NNP). In this extreme case, the grade parameter is considered as random variable.

Another method proposed in order to handle high skewness distribution is fractal model. The model so far is said to have been successfully dealing with many geological phenomena including grade and thickness distribution with relatively high continuity (Wang et. al., 2009). However, in this paper, the number-size fractal model as proposed by Mandelbrot (1983) and Wang et. al. (2009) would be compared with block model in estimating ore tonnage and metal (Au-Ag) tonnage for deposit with different geological setting and more complex and erratic data distribution. For this purpose, the data obtained from channel sampling program in Ciurug vein, block South 3, level 500 and 600, Pongkor mines would be used as study case.

Study Location: Pongkor Gold Mine Pongkor Gold Deposit

Mining rights of Pongkor gold deposits with total area \pm 4,058 ha was granted to PT Aneka Tambang Tbk. The mining activities in this area were commenced in 1994 using underground method. In December 2007, the total reserve and resource of Pongkor deposits, excluding inferred resource increased 5 % to 3.026 million tones, yielded 743,000 oz gold and 8.2 million oz silver (PT Antam Tbk., 2008).

Pongkor gold deposit is situated in north-east flank of Bayah dome (Figure 1). The geology of this area had already been described by several authors. The deposit itself formed the north-west part of circular structure (6 x 8 km) which was interpreted as caldera (tectono - volcanic depression), associated with ignimbrite volcanism (Milési et. al., 1999). Pongkor epithermal deposit was interpreted as low sulphidation epithermal or adularia-sericite (Basuki et. al., 1994 and Milési et. al., 1999) which was formed $2,05 \pm 0,05$ Ma based on $^{40}\text{Ar}/^{39}\text{Ar}$ dating in adularia (Milési et. al., 1999).

The mineralization was generally controlled by vein system structures. The vein system in Pongkor consists of nine quartz-adularia-carbonate veins, rich in manganese oxide and limonite, but poor in sulphide minerals. The length of these veins could reach 740 – 2700 m, and still continues to -200 m depth with several meter thickness. These veins cross cut three volcanic units to form fan structure (Figure 2). The veins considered to have economical value are Ciurug, Kubang Cicau, Ciguha and Pasir Jawa.

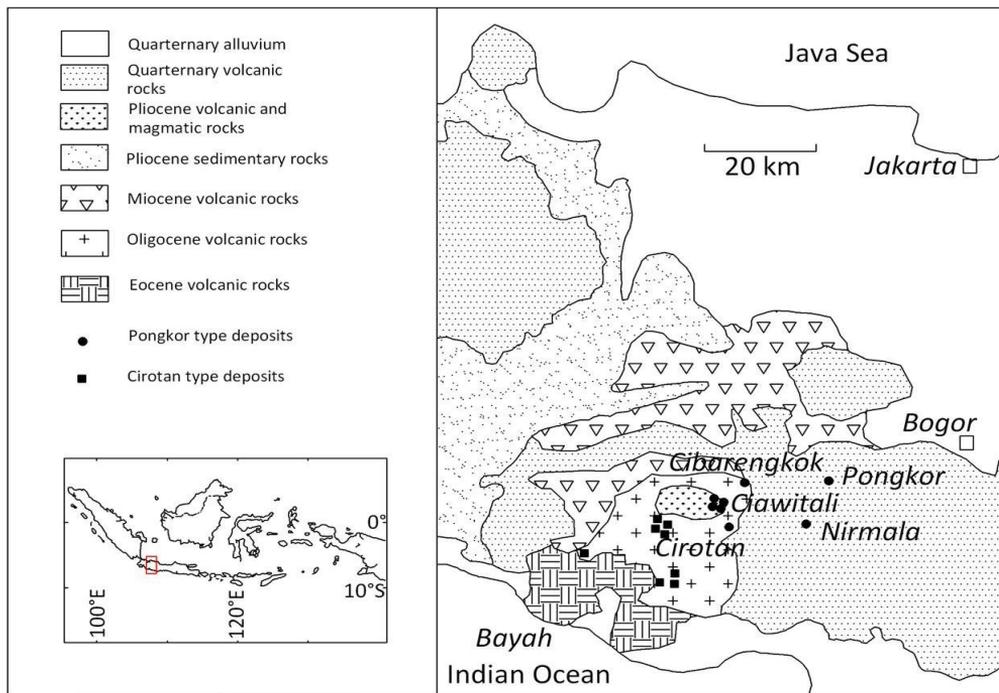


Figure 1. Regional geology of West Java, including selected associated epithermal deposits (Warmada and Lehmann, 2003).

METODOLOGY

Channel Sampling Data

Sampling program in Pongkor Au-Ag epithermal deposit is carried out in exploration and development stages. In exploration stage, the samples were usually obtained by core drilling, while in development stage, the program was executed by channel sampling which intersected the vein. In this paper, the data used were obtained from channel sampling. Each channel consists of several sub-channels which then were assayed for gold and silver separately. Table 1 summarizes the basic statistic for each parameter: thickness, Au content, Ag content, Au grade-thickness and Ag grade-thickness. The total length of sub-channels in a channel is then used as parameter thickness (t_i). The Au or Ag content was calculated based on sub-channels composite using length weighting.

To obtain grade-thickness parameter (l_i), the thickness of a channel (t_i) was multiplied with Au or Ag content in the channel. Based on modeling (Prasetyo et. al., 2009), the geometry of Ciurug vein block South 3 is almost tabular, elongates NNW-SSE and plunges $60^\circ - 70^\circ$ to the east (Figure 3). Based on Table 1, only thickness parameters show relatively low variation for both levels. Au or Ag content revealed lower mean and variation for deeper level (Level 500). Grade thickness both for Au and Ag shows interesting phenomena since the variation increased insignificantly after multiplication with thickness parameters as pointed out by coefficient variation values. The decreasing value of skewness after multiplication of metal content with thickness (grade-thickness) indicated the distribution which was close to normal (*gaussian*) distribution.

Table 1. Statistical summary of thickness, metal content, and grade thickness for level 500 and 600, Ciurug, Block South 3.

	Parameters	Number	Min.	Max.	Mean	Standard deviation	Coefficient Variation	Skewness
Level 500	thickness (m)	132	3.4	15.9	10.1	2.46	0.24	0.49
	Au content (g/t)	132	3.13	37.42	12.24	5.77	0.47	1.65
	Au grade-thickness (m*g/t)	132	21.88	381.66	123	60.09	0.49	0.48
	Ag content (g/t)	132	61.24	636.92	183.64	95.83	0.52	2.06
	Ag grade-thickness (m*g/t)	132	231.28	7395.44	1892.73	1197.99	0.63	1.00
Level 600	thickness (m)	300	3.2	23.2	14.15	3.81	0.27	0.21
	Au content (g/t)	300	1.44	173.22	29.2	24.34	0.83	2.71
	Au grade-thickness (m*g/t)	300	7.5	2355.69	413.25	340.02	0.82	0.52
	Ag content (g/t)	300	50.55	1732.98	264.17	191.66	0.73	2.99
	Ag grade-thickness (m*g/t)	300	251.25	23568.5	3758.59	2829.58	0.75	0.68

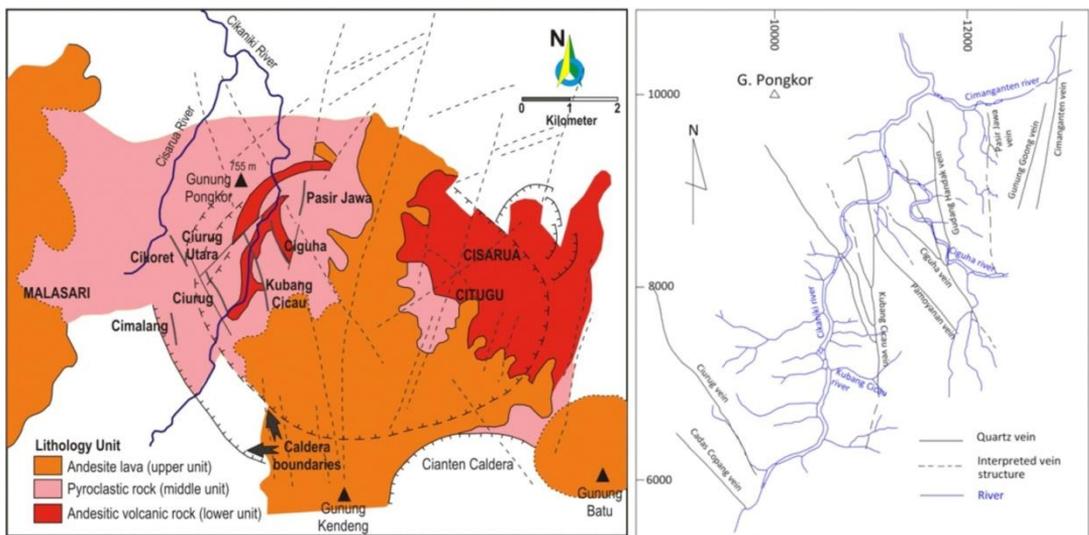


Figure 2. Left: Regional geological map of Pongkor, showing the interpretation of caldera, main structures and main gold bearing veins (Syafriзал, 2006). Right: Vein system in Pongkor gold-silver deposits (Warmada and Lehmann, 2003).

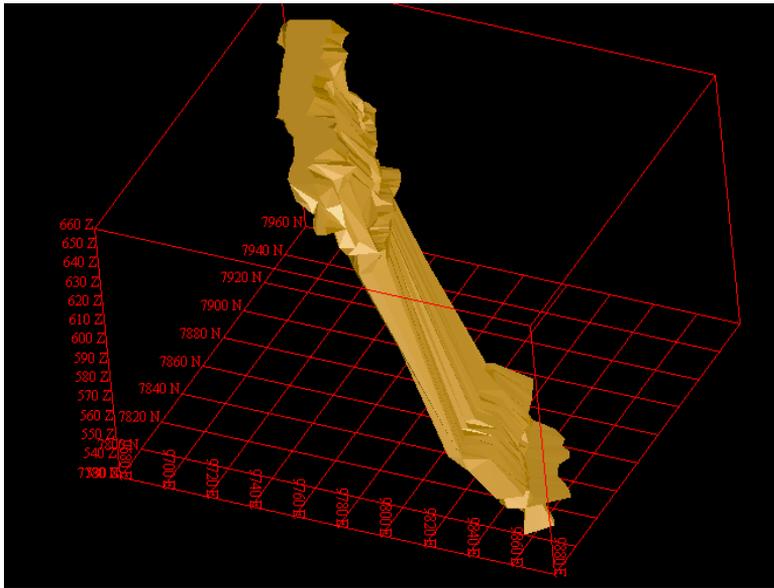


Figure 3. Geometry modeling of Ciurug vein, block South 3, level 600 and 500. Red grid in the figure signifies 100 mN x 100 mE x 100 mZ (Prasetyo, et.al., 2009).

Reserve estimation by classical block model

Reserve estimation by classical block model had been carried out by Prasetyo, et. al. (2009) by dividing the deposit bulk volume into smaller units named cells. Modeling and reserve estimation used three method: NNP, IDS, and Kriging to obtain ore tonnage and metal tonnage with three variable cell sizes: 1 m, 2.5 m and 5 m. However in this paper, ore tonnage and metal content figures used as comparator for fractal model calculation were obtained by NNP method with cell size 1 m (Table 2), considering the erratic nature of grade data in the deposit.

Number-size fractal modeling

It is assumed before that the exploration data were distributed with constant spacing, both vertically (*h*) and horizontally (*w*). So that the mineralized area (*A*) covered by exploration data or channel sampling could be written as (Wang et. al 2009):

$$A = whC_a \tag{1}$$

C_a is the total number of channel sampling which intersect the mineralization zone. Please note here that the value of *h*, *w*, and *A* were obtained from the projection of ore body to the vertical plane since the ore body dip exceeds 45° (Figure 4).

The length of each channel could be considered as vein thickness (*t_i*). The data of grade-thickness (*l_i*) is obtained by multiplying the length of channel with its grade. For a channel consists of several sub channel, length weighting must be used to obtain the grade-thickness data. The two variables (*t_i* and *l_i*) contribute to the ore tonnage (*O*) and metal content of the deposits (*M*) as stated by these formulas:

$$O = \sum_{i=1}^{C_a} O_i = \sum_{i=1}^{C_a} wht_i = wh \sum_{i=1}^{C_a} t_i = \frac{A}{C_a} \sum_{i=1}^{C_a} t_i \tag{2}$$

$$M = \sum_{i=1}^{C_a} M_i = \sum_{i=1}^{C_a} whl_i = wh \sum_{i=1}^{C_a} l_i = \frac{A}{C_a} \sum_{i=1}^{C_a} l_i \tag{3}$$

Table2. Reserve estimation in Ciurug vein, block South 3 by NNP (from Prasetyo et. al., 2009).

Level	Cell size (m)	Volume (m ³)	Density (t/m ³)	Tonnage (t)	Average grade (g/t)	Metal Content (kg)	
500	Au	1	18,891	2.36	44,583	13.25	590.86
		2.5	18,859	2.36	44,508	13.76	612.22
		5	18,875	2.36	44,545	14.98	667.18
	Ag	1	18,891	2.36	44,583	199.46	8,892.72
		2.5	18,859	2.36	44,508	199.26	8,868.63
		5	18,875	2.36	44,545	197.98	8,818.82
600	Au	1	75,812	2.36	178,916	28.17	5,039.42
		2.5	78,109	2.36	184,399	27.59	5,085.95
		5	75,500	2.36	178,180	28.24	5,031.77
	Ag	1	75,812	2.36	178,916	258.91	46,323.12
		2.5	78,109	2.36	184,338	256.15	47,218.84
		5	75,500	2.36	178,180	273.64	48,756.64

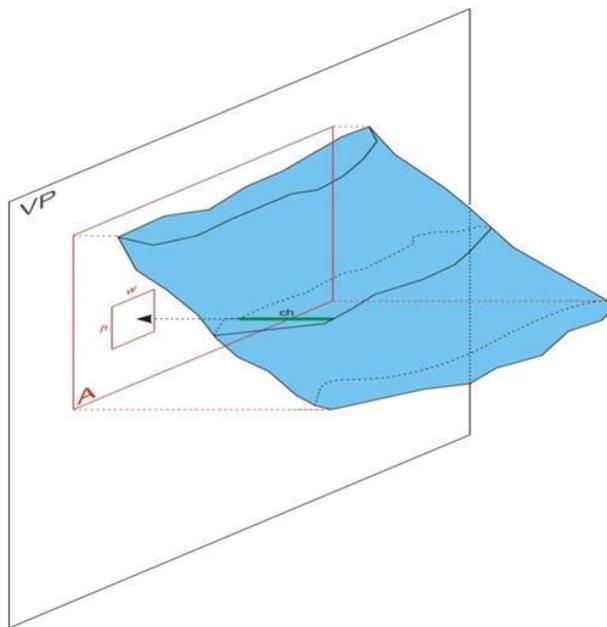


Figure 4. The vertical projection of ore body (blue). Mineralized area (A) bounded by solid red line in vertical plane (VP). Channel sampling (ch or green line) intersects ore body and projected into VP with projection area wh .

If ore body thickness (t_i) and grade-thickness (l_i) were assumed as continuous variable, they could be formulated in number-size model (Mandelbrot, 1983) as:

$$N(\geq r) = Cr^{-D} \tag{4}$$

or could be rewritten as

$$\ln N(\geq r) = -D \ln r + \ln C \tag{5}$$

In these equations, r represents the thickness variable (t_i) or grade thickness (l_i), while $N(\geq r)$ represents the accumulative number of the data which value is no less than r . D and C are fractal dimension and capacity constant respectively.

Plotting between r and $N(\geq r)$ in ln-ln scale graphic (Figure 5) produces a straight line with gradient $-D$. If the $\ln r - \ln N(\geq r)$ plotting could be fitted by single straight line, it is said that the data has simple fractal distribution. In the case that the fitting requires more than one straight line, the data then was said to have bifractal distribution. Each straight line represents one segment (Figure 6) which has different fractal models (C and D value) and bounded by threshold value R_i ($i = 1, 2, 3, \dots, n$).

Equation 1 could be used if the channel spacing is constant. For exploration program with irregular spacing could use capacity constant C_1 value and fractal dimension D_1 value to obtain wh^* value (Equation 6) which required to calculate ore and metal tonnage as written in Equation 2 and 3. The C_1 and D_1 values could be determined graphically from the first segment along with the r_{min} value.

$$wh^* = \frac{A}{C_a} = \frac{A}{C_1 r_{min}^{-D_1}} \tag{6}$$

With the wh^* value, ore tonnage (O) and metal content (M) for deposit with irregular sampling spacing could be calculated using these equations:

$$O = \rho V = \rho \int_{t_{min}}^{t_{max}} wh^* \frac{dN(\geq t)}{dt} dt$$

$$O = \rho V = \rho \frac{wh^* CD}{1-D} (t_{max}^{1-D} - t_{min}^{1-D}) \tag{7}$$

with $D > 0$, and $D \neq 1$

$$M = \rho \int_{l_{min}}^{l_{max}} wh^* \frac{dN(\geq l)}{dl} dl = \rho \frac{wh^* CD}{1-D} (l_{max}^{1-D} - l_{min}^{1-D}) \tag{8}$$

with $D > 0$, and $D \neq 1$

In bifractal model which threshold range ($\Delta \ln r$, in this case $\Delta \ln t$ or $\Delta \ln l$) is quite wide, the Equation 7 and 8 could be expressed as:

$$O = \rho \sum_{i=1}^{n-1} wh^* \frac{C_i D_i}{1-D_i} (T_{i+1}^{1-D_i} - T_i^{1-D_i}) \tag{9}$$

$$M = \rho \sum_{i=1}^{n-1} wh^* \frac{C_i D_i}{1-D_i} (L_{i+1}^{1-D_i} - L_i^{1-D_i}) \tag{10}$$

For both equation above, T_{i+1} and L_{i+1} are maximum value of t and l for each segment, while T_i and L_i are minimum value for t and l in each segment respectively. C_i and D_i are capacity constant and fractal dimension in segment i .

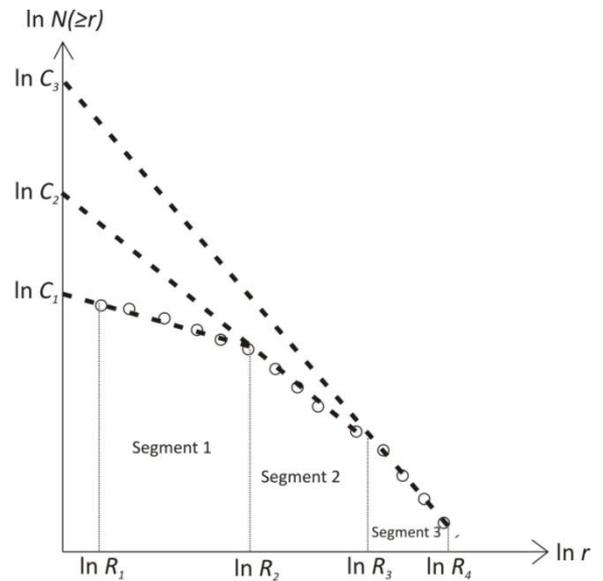


Figure 5. $\ln r - \ln N(\geq r)$ plot yield three segment bifractal model (Wang et. al. 2009).

Reserve Estimation by Number-Size Fractal Model

Fractal model in reserve estimation used the same approach as block method: the estimation was carried out separately for each level. Level 600 was confined between 608.175 msl and 654 msl while level 500 was confined between 534 msl and 569 msl (Figure 3). Total mineralized area (A) for each level was determined directly by projecting the ore body to the vertical plane, resulting 4580 sqm and 1981.88 sqm for level 600 and level 500 ore body respectively. Fractal modeling of thickness and grade-thickness of the deposit using number-size model revealed bifractal model, which all of them consisted of three segments (Figure 6). The fitting of each segment using linear equation yielded relatively high coefficient correlation ($r^2 \geq 0.812$). The lowest one was the first segment in bifractal

model for thickness level 500. The fractal parameters for each segment (T_i or L_i , C_i , and D_i) used in reserve estimation including the estimation results was resumed in Table 3 – 5 below. The results were obtained by using Equation 9 and 10.

From Figure 6 for thickness parameters, first segment in $\ln t$ axis was bound by $\ln T1$ (minimum) and $\ln T2$ (maximum). $D1$ was the gradient of first segment while $\ln C1$ was intercept of the first segment with ordinate. $T1$, $T2$, and $C1$ value used in calculation was obtained from the antilog of $\ln T1$, $\ln T2$, and $\ln C1$ respectively. The same rules were applied for second and third segments. The maximum T value in third (final) segment was called as $Tmax$. For grade thickness parameters, the fractal parameter T was switched to L .

Table 3. Bifractal parameters for thickness (t) and estimated ore tonnage.

Level	Orebody area (m ²)	SG	Fractal parameter						Total ore tonnage (t)		
600	1,982	2.36	T1	3.2	T2	10.1	T3	15.65	Tmax	23.2	171,349.08
			D1	0.137	D2	1.868	D3	10.43			
			C1	365.768	C2	22,247.84	C3	4.50E+14			
500	4,580	2.36	T1	5.5	T2	7.35	T3	9.95	Tmax	15.9	53,632.29
			D1	0.598	D2	1.348	D3	7.286			
			C1	373.531	C2	1,664.03	C3	1.85E+09			

Table 4. Bifractal parameters for gold grade-thickness (l) and estimated gold tonnage.

Level	Orebody area (m ²)	SG	Fractal parameter						Au tonnage (t)		
600	1,982	2.36	L1	7.503	L2	89.903	L3	405.341	Lmax	2355.69	4.332
			D1	0.024	D2	0.589	D3	2.364			
			C1	320.217	C2	4,675.07	C3	2.01E+08			
500	4,580	2.36	L1	21.876	L2	70.123	L3	89.388	Lmax	381.656	0.690
			D1	0.129	D2	0.704	D3	3.013			
			C1	198.343	C2	2,232.77	C3	1.06E+08			

Table 5. Bifractal parameters for silver grade-thickness (*l*) and estimated silver tonnage.

Level	Orebody area (m ²)	SG	Fractal parameter						Ag tonnage (t)		
600	1,982	2.36	L1	251.25	L2	1,119.75	L3	2,976.75	Lmax	23568.5	40.090
			D1	0.044	D2	0.641	D3	2,299			
			C1	386.836	C2	27,446.66	C3	1.92E+10			
			L1	485.2	L2	1,107.09	L3	1,403.35			
500	4,580	2.36	D1	0.371	D2	0.925	D3	2,426	Lmax	7395.44	9.303
			C1	1,403.89	C2	67,507.91	C3	4.29E+09			

Table 6. Comparison between classic block model (BM, Table 1) and number-size fractal model (FM) in reserve estimation. Dev. signifies the deviation between two models.

Level	Metal	Ore tonnage (t)			Metal content (t)			Average grade (g/ton)		
		BM	FM	Dev. (%)	BM	FM	Dev. (%)	BM	FM	Dev. (%)
600	Au	178,916	171,349	-4.4	5.039	4.332	-16.3	28.166	25.282	-11.4
	Ag				46.323	40.090	-15.5	258.910	233.967	-10.7
500	Au	44,583	53,632	16.9	0.591	0.690	14.3	13.250	12.865	-3.0
	Ag				8.893	9.303	4.4	199.460	173.459	-15.0

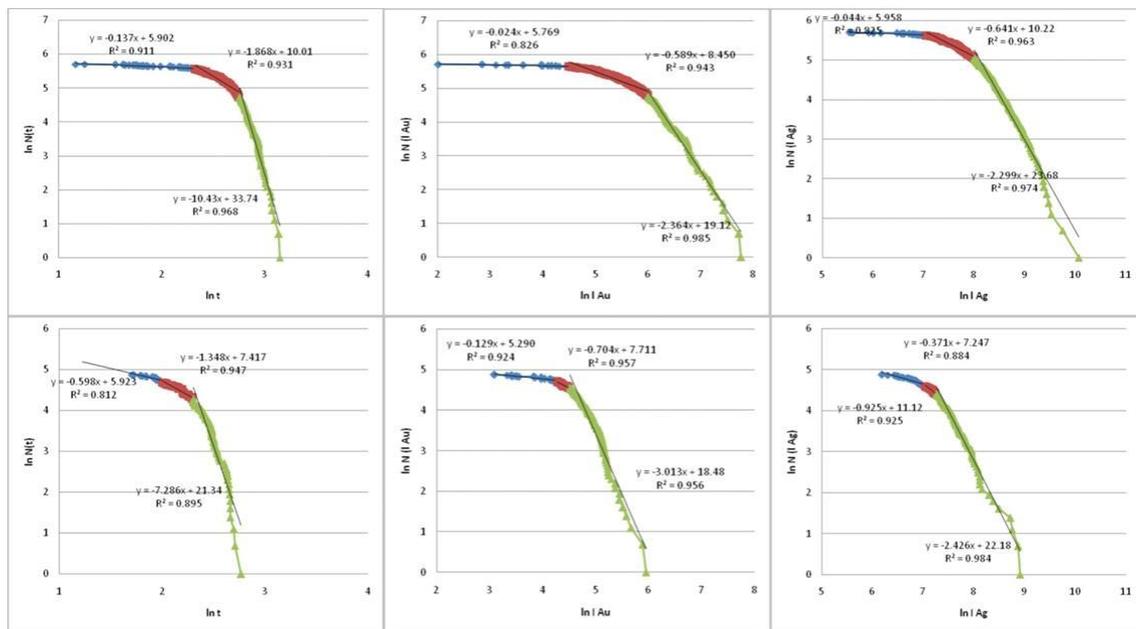


Figure 6. Bifractal model for thickness and grade-thickness. First row: level 600, second row: level 500. Left: thickness parameters, middle: gold grade-thickness, right: silver grade-thickness

DISCUSSIONS

Thickness and grade-thickness parameters in Ciurug vein, block South 3, level 600 and 500 could be modeled by bifractal models, so that the resource estimation could be carried out with fractal method. Both levels show similar model so it could be deduced that the model could estimate the same vein system with extended dimension (the deeper levels or gaps between levels in Ciurug). This is possible since self similar characteristic of fractal allows the recurrence of small part in the whole system. In this case, the bifractal modeling of thickness and grade-thickness parameters in both levels which are similar could be possibly occurred in more extended levels in the same vein system.

The number of the data indirectly affects the modeling, especially in fitting process of bifractal segments to obtain capacity constants and fractal dimensions. In fitting, the least coefficient correlation ($r^2 = 0.812$) occurs in first segment of thickness parameter for level 500. Generally the first segments show the least coefficient correlation compared to the other segments'. This is probably due to the positive skewness of $\ln t$ and $\ln l$ distributions (Table 1) which means that the data were centered in low values, so that the plotting of the lowest r values to the next value in $\ln r - \ln N(r)$ would drastically decrease (Figure 6) and could not be fitted with a straight line. In spite of high value of standard deviation, the thickness and grade-thickness showed low coefficient variation (< 1), which means they posed relatively low variability (Heriawan and Koike, 2008) and seemed insignificantly contribute to the low coefficient of correlation in fitting. To cope with this problem, if the coefficient correlation obtained was very low, the segment could be divided into more segments to obtain higher coefficient correlation value. This also means that skewness still play a role in the number-size fractal modeling although there is no clear correlation between skewness and reserve estimation error (Table 6).

From the third parameters: T or L , C and D , all C parameters in the third segment had the extreme

values compared to the values of the other segments. These extreme values gave the highest contribution to the final estimation results (tonnage). High capacity constants were directly affected by the fitting process in the third segments. The steeper fitting line obtained the higher capacity constant. The steepness of this line was directly contributed by the presence of outlier values which cause abrupt drop in the plotting of high r value to the next value in $\ln r - \ln N(r)$ (Figure 6).

Table 6 shows the deviations between classic block model and number-size fractal model for three outputs: ore tonnage, metal content and average grade in both levels. The results reveal the greater value for ore tonnage obtained by fractal model than of block model for level 500 and vice versa for level 600. This is probably due to the different principle in defining ore body outline and bulk volume calculation. In block model, bulk volume and ore tonnage were calculated as solid mass which was confined by surface outline, while fractal model the bulk volume and tonnage were simply obtained by multiplying the thickness with area parameter. This result was consistent with the results obtained for metal content which was greater in level 500 and vice versa for level 600, since the metal content calculation was directly affected by bulk volume and tonnage. The least error in average grade for gold level 500 was contributed by the least percentage difference between ore tonnage and metal content.

Level 600 yielded the biggest deviation, which was probably related to the genetic characteristics of ore deposit. Gold and silver in level 600 were known to occur via more complex processes, not only involved hypogen process but also supergene (Griffie et. al., 2002; Warmada and Lehman, 2003). So that in estimation by FM the complex genetic process yielded the greater error than of level 500 which were simply involved hypogen process. In block model estimation, qualitative characteristic of ore genetic had already been represented by range parameter A as stated before, the skewness could play a role in estimation by number-size model especially in fitting process (Figure 5 and 6).

The role could be diminished by better fitting, which means the fractal model could cope with skewed distributions, something few methods could manage. However, the disadvantage of this method is its futility to estimate local value with certain coordinates (Wang et. al., 2009). In fact, this disadvantage had to be reviewed from self similar point of view as explained before. Other limitation of number-size fractal model is applicable only to continuous variables whereas according to Dominy et. al. (2000), thickness variable and furthermore grade variable are discrete variables. So that the fractal model application in this case has only limited use if thickness and grade were assumed as continuous variables. However in this study case the assumption seems inadequate as stated by significant deviation in calculation results between classic block model and number size fractal model (Table 6). The erraticness of grade distribution could be used as reference on how far the continuity assumption could be applied. Therefore in this discussion the number-size fractal model estimation results were compared with block model results using NNP which is generally used for randomly distributed or erratic data. In this case the continuity is almost non-existent or could be said as discrete. The limitation of continuity assumption was showed in Table 5. The thickness variables had the least error due to high continuity of the thickness variables, roughly showed in Figure 5, where the thickness looked to change gradually. The metal contents in other hand with greater error mean that the grade variable could not be thoroughly assumed as continuous variable.

CONCLUSIONS

Number-size fractal model so far could be applied only to the deposits with continuous dimension and grade variables. For deposits with erratic grade variable the fractal model has only limited use which powerful generally to estimate bulk volume or ore tonnage since the dimension e.g. thickness has high continuity.

The genetic characteristics should be considered in fractal-model estimation because as stated

before the process overprinting in ore genesis could affect variable continuity. The failure of this model to predict local value should be reviewed further by applying its principle: self similarity. However it must admit that this model is easy to use, and does not require sophisticated software and advance mathematical background.

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