Chapter 4

Geostatistical Analysis

4.1 Background

A relatively new theory was developed by Professor G. Matheron in France during the 1950's, which has overcome most of the problems which the statistical and conventional methods are incapable of solving. This method under the title of " The Theory of Regionalized Variables" applies variables which are spatially correlated with each other in a geological or other manner. Practically, the theory, however, is not restricted to only geological variables.

The method accounts for the relationship between the samples which have arisen from common geological process and captures this spatial correlation in a mathematical expression called the "variogram function" (Fig.4.1) This allows an estimation variance or mean squared error to be calculated for any estimate (David, 1977, Gershon, 1986; Whitchurch et al., 1987).

The semivariogram is therefore defined as half the mean squared difference of pairs of values at some distance, h, apart.

Semivariogram (or expressed as $\gamma(h) = \{\Sigma (x_i) - (x_i - h)\} / 2n$) ______ 4.1

When $\gamma(h)$ is called the semi-variogram (although some authors sloppily call it the variogram), h is stand for grade, x denoteds the position of one sample in the pair, x+h is the position of the other, and n is the number of pairs.

To illustrate the method of calculation, consider a set of samples taken at regular intervals of 1 metre along a straight line must be considered (Fig. 4.2). To generate semivariogram, it would be required to calculate the half mean squared differences of all the samples 1 metre apart (i.e. N-1 pair). Then the process for samples which are 2 metre apart (N-2 pairs) is repeated.

The aim of geostatistical method of interpolation of variable values (such as an ore grade) is called "kriging" after the South African mining engineer, Krige, D.G., who pioneered the theory in South African underground gold mines (Davis, 1976 ; Dagbert & David, 1986).

The estimator (also known as the "Best Linear Unbias Estimator" or BULE, in which the values of the samples are multiplied by weighting factors which are determined from a set of linear equation.

4.2 Definition of Some Important Geostatistical Terms

In the following context, several geostatistical terms are applied. To be familiar with these technical terms, some of them can be defined herein mostly following Clark (1979), journel (1974), and Evans (1951) (see also in Fig. 4.1).

Range is an increase in the separation distance can no longer cause a corresponding increase in the average squared difference between pair of values. Therefore, range is a distance (a) beyond which the variogram or co-variance value remains essentially constant, another word - the point at which the sill value is reached.

Sill is the plateau the variogram reaches at the range. The upper limit of any variogram model which has such a limit, i.e., which tends to 'level off' at large distances. Sill can also be defined as the variogram value (C + Co) for very large distance $\gamma(h)$.

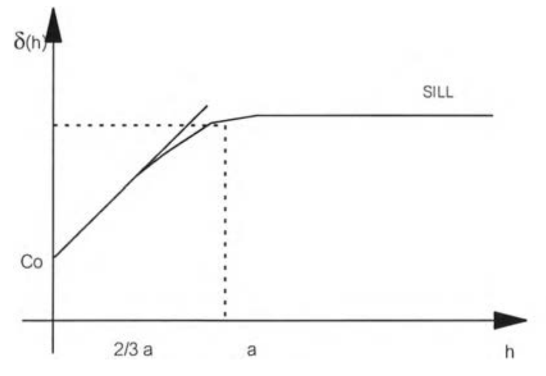


Fig. 4.1. Typical variogram plots (Royal and others, 1980).

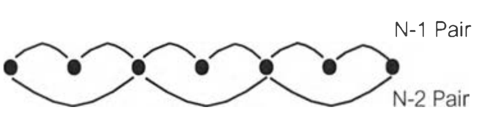


Fig. 4.2. Process of variogram generation (David, 1977).

nugget effect is the value of the variogram or covariance (Co) which provides a discontinuity near the origin and is generally attributable to difference in sample values over very small distance, e.g., two halves of core, and can include inaccuracies in sampling and assaying, and the associated random errors. The vertical jump from the value of zero at the origin to the value of the variogram at extremely small separation distances is call the "nugget effect". The ratio of the nugget effect and is usually quoted in percentage. The ratio of the nugget to sill is referred to as the relative nugget effect (quoted in %).

Cross validation is defined as a technique for testing the validity of a variogram model by kriging each sampled location with all of the other samples in the search neighborhood, and comparing the estimator with the true sample values. Interpretation of results, however, can often be difficult. Unusually large differences between estimation and true values may indicate the presence of "spatial outliners", or points which do not seem to belong with their surrounding.

Geostatistics means a methodology for the analysis of spatially correlated data. The characteristic feature is the use of variograms or related techniques to quantify and model the spatial correlation structure. Also includes the various techniques, such as kriging, which utilize spatial correlation models.

Kriging means a weighted-moving-average interpolation methods where the set of weights assigned to samples minimized the estimation variance, which is computed as a function of the variogram model and locations of the samples relative to each other, and to the point or block being estimated.

Kriging standard deviation is the standard error of estimation computed for kriging estimate. By definition, kriging is the weighted linear estimation with the particular set of weights which minimizes the computed estimation variance (standard error squared).

The relationship of the kriging standard deviation to the underlying assumptions. Therefore, kriging standard deviations should be interpreted with caution.

Lag is a distance class interval used for variogram computation.

Semivariogram is almost identical in meaning to the term 'variogram' (see variogram).

Variogram is a plot of variance (one-half the mean squared difference) of paired samples measured as a junction of the distance (and optionally of the direction) between samples. Typically, all possible sample pairs are examined, and grouped into classes (lag) of approximately, equal distance and direction. Variogram provides a means of quantifying the commonly observed relationship. The samples close together will tend to have more similar values than samples for apart.

4.3 Variogram Analysis

4.3.1 Variogram Model

Having calculated the experimental semi-variograms, an equation that best describes the values is found by fitting a curve to these experimental values to simplify further calculations. This curve is called a model variogram. The following observation (see Figs. 4.3 to 4.9) serve as an addition support for the argument that even with regularly gridded and well-behaved sample data, the exercise of fitting a function to the variogram model involves essential choices on the practitioners. The theoretical models developed to date can be simply divided into two main groups (Clark, 1976) :-

A) Variogam model with sill (see Figs. 4.3 to 4.6); and

B) Variogram model without sill (see Figs. 4.7 to 4.9).

Variogram Model with Sill

In cases where the semi-variogram increases with distance and levels off to a constant value after a certain distance, hence developing a sill, the following modeling methods are most commonly applied :-

1. The spherical model or Matheron model (Fig. 4.3)

The equation of spherical model is

$\gamma(h)$	=	Co + C [(3h/2a) -($h^3 / 2a^2$)]	at	$h \leq a$
	=	C-Co	at	$h > a$
	=	0	at	$h = 0$;

2. Exponential Model (Fig. 4.4)

The equation of exponential model is $\gamma(h)$ = Co + C [1 - exp(- h / a)] ;

3. Pure Nugget Effect Model (Fig. 4.5)

This model is shown by variance = sill. The equation of exponential model is

$\gamma(h) = 0$; h = 0 and $\gamma(h) =$ Co ; h > 0 ; and

4. Gaussian Model (Fig. 4.6)

This model is almost similar to the spherical model. It shows parabola in the first step and continues to spherical model in the end. The equation of gaussian model is

$$\gamma(h) = Co + C [1 - ex(- h^2 / a^2)]$$

when partial range = 1.73a (95% of sill), Effective range = a.

Variogram Model without Sill

Only three models are briefly described including :

1. De Wijsian Model (see Fig. 4.7)

Variogram will be increase when distance increase. The equation of De Wijsan model is

$$\gamma(h) \quad = A\, l_n + [\, h + B]$$

when $A = 3\alpha$ (coefficient of intrinsic dispersion from $[\gamma(h2) - \gamma(h1)] / [l_n(h2) - l_n(h1)]$, and B = Y-intercept = Co ;

2. Power model or linear model (Fig. 4.8)

when $\lambda = 1$

The equation of power model is $\gamma(h) = A\, h^2 + B$ when A = slope, B = Y-intercept, $\lambda = \quad 0 < \lambda < 2$; and

3. Hole effect model (Fig. 4.9)

The equation is $\gamma(h) = Co + C\, \{\, [1 - \sin(ah)] / ah\}$.

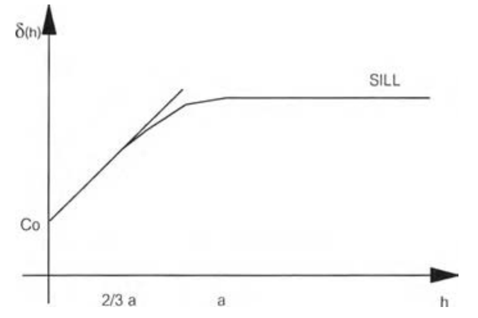


Fig. 4.3. Spherical variogram model.

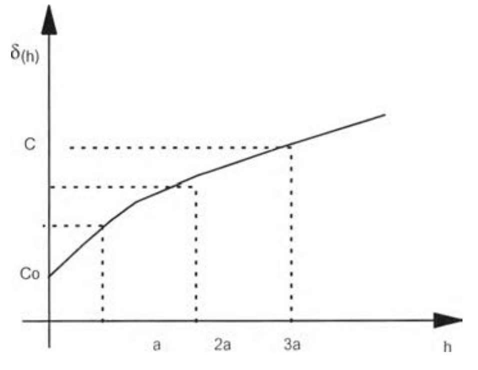


Fig. 4.4. Exponential variogram model.

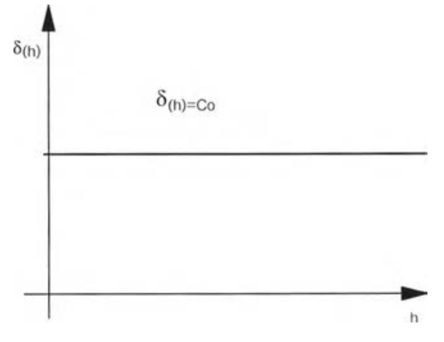


Fig. 4.5. Pure nugget effect variogram model, noting that variance (or h) = sill (or Co).

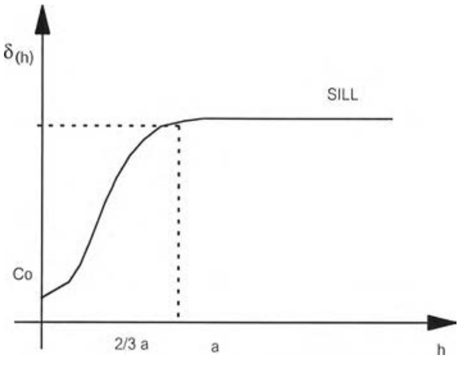


Fig. 4.6. Gaussian variogram model, showing parabola curve in the step and switching to spherical model at the end.

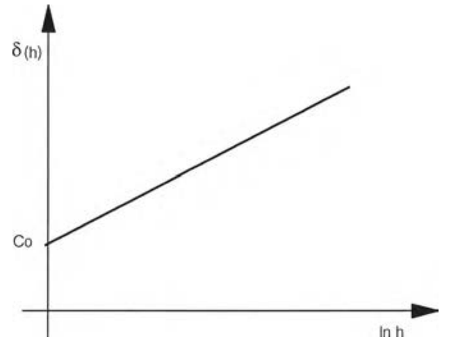


Fig. 4.7. De Wijsian variogram model, depicting the constant increase of variance at a constant distance increment.

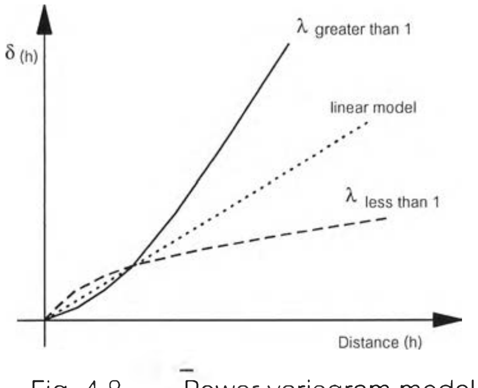


Fig. 4.8. Power variogram model.

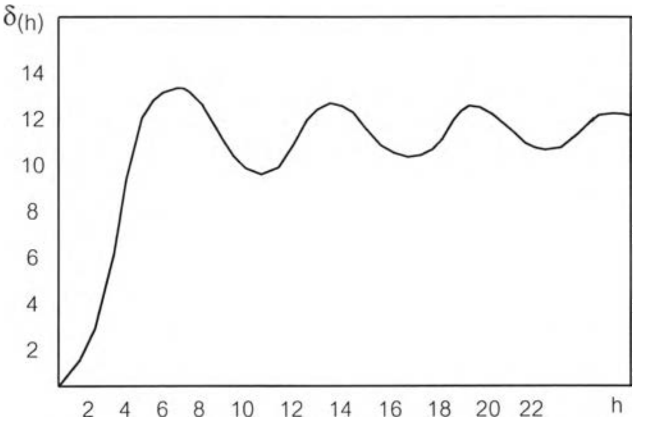


Fig. 4.9. The Hole Effect variogram model, illustrating the fluctuation of variance with increasing distance.

4.3.2 Measurement of Basic Statistical Values

All stored and treated data in FoxPro database were rearranged into a new format in the form of Geo_EAS. Then basic statistical values of individual variables from Sin Pun and Saba Yoi areas can be determined.

Sin Pun Area

It is observed statistically that the ash content of Nong Wa P1-P4 coal seam falls within the average range of 26-28% whereas that of the M seam averages a little higher at 30%. Variance measured from coal samples becomes quite high. This is probably due to the contrast in analyzed values up to 30%. Sulphur contents fall in the average range of 4-5% for P seams and increase up to 6.5% in M seam.

From these statistical values, it is likely that both ash and sulphur contents increase as depth increases. Statistical values of individual variables for Sin Pun area are depicted in Table 4.1-4.5.

Saba Yoi Area

Arithmetic mean of ash content from coal seams of Saba Yoi area ranges from 28 to 36 %. Variances of analytical coal values for the S1, S2, and S4 seam are not high, as compared with those of the P seams in the Sin Pun area.

As stated in Tables 4.6-4.9, the contrast between the minimum and maximum values of coal data for the S1, S2, and S4 seams is approximately 8%, which is much lower than that of the S3 seam-up to 51%. This is due essentially caused by the difference in coal values of about 20%. However, the sulphur contents of Saba Yoi individual coal seams are averaged at 2%.

Table 4.1. Statistic values for P1 seam, Nong Wa deposit, Sin Pun area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	536323.7	909653.3	27.206	2017.867	28.032	4.179	1.435
Variance	156858.2	44089.16	99.992	695662.6	50.612	3.184	0.008
Std. Dev.	396.053	209.974	10	834.064	7.114	1.784	0.091
Coef. Var.	0.074	0.023	36.755	41.334	25.379	42.696	6.33
Skewness	0.063	0.481	-0.695	0.306	1.018	0.005	0.148
Kurtosis	1.988	2.336	2.425	1.758	2.599	1.822	3.531
Minimum	535707.8	909400	6.8	823	20	1.52	1.26
25th %tile	535916.6	909456.9	18.365	1402.25	23.042	2.26	1.392
Median	536398.2	909599	28.07	1726	25.25	4.2	1.44
75th %tile	536528.1	909797.7	35.375	2784	29.645	5.465	1.47
Maximum	537006.9	910098.6	39.66	3347	42.23	6.86	1.64

Table 4.2. Statistic values for P2 seam, Nong Wa deposit, Sin Pun area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	536296.1	909660.8	23.564	2501.471	28.146	5.091	1.385
Variance	186627	41652.84	83.612	567879.5	32.348	2.839	0.008
Std. Dev.	432.004	204.09	9.144	753.578	5.688	1.685	0.087
Coef. Var.	0.081	0.022	38.806	30.125	20.207	33.096	6.268
Skewness	0.336	0.141	-0.625	-0.207	0.683	-0.53	-0.363
Kurtosis	1.842	2.691	2.465	2.023	1.948	2.523	2.045
Minimum	535707.8	909300	4.26	1100	22.11	1.46	1.22
25th %tile	535909.4	909482.1	15.997	1845.25	23.245	3.835	1.322
Median	536282	909695.8	25.55	2592	26.08	5.2	1.39
75th %tile	536578.3	909795.4	30.688	3063.75	31.628	6.335	1.447
Maximum	537006.9	910098.6	37.13	3659	38.06	7.59	1.51

Table 4.3. Statistic values for P3 seam, Nong Wa deposit, Sin Pun area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	536265	909671.4	27.647	2131.25	27.718	4.81	1.433
Variance	192824.8	37174.43	110.076	878453.9	22.776	5.519	0.013
Std. Dev.	439.118	192.807	10.492	937.259	4.772	2.349	0.112
Coef. Var.	0.082	0.021	37.948	43.977	17.218	48.843	7.819
Skewness	0.703	0.419	-0.727	0.046	1.263	-0.18	-0.153
Kurtosis	2.615	2.666	2.558	2.177	3.338	1.513	1.714
Minimum	535707.8	909398.1	5.47	494	23.3	1.13	1.25
25th %tile	535905.7	909507.8	20.51	1492	24.45	2.09	1.31
Median	536240.9	909675.8	28.97	2157	26.325	5.265	1.455
75th %tile	536499.6	909797.4	36.94	2652	28.34	6.99	1.53
Maximum	537208.7	910098.6	39.53	3659	38.89	7.89	1.58

Table 4.4. Statistic values for P4 seam, Nong Wa deposit, Sin Pun area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	536400.7	909615.1	27.909	2142.294	28.266	5.141	1.365
Variance	219061.7	47934.23	67.994	612670.6	28.895	5.488	0.019
Std. Dev.	468.04	218.939	8.246	782.733	5.375	2.343	0.138
Coef. Var.	0.087	0.024	29.545	36.537	19.017	45.568	10.124
Skewness	0.259	0.525	-0.511	0.008	0.683	-0.356	0.255
Kurtosis	2.029	2.464	2.349	2.198	2.596	1.848	1.572
Minimum	535707.8	909300	11.08	842	19.91	0.8	1.22
25th %tile	536000.1	909404.4	19.472	1442.75	25.135	3.31	1.22
Median	536398.2	909597.2	30.72	2392	26.85	5.81	1.36
75th %tile	536578.3	909773.4	32.563	2593.25	28.485	7.318	1.467
Maximum	537208.7	910098.6	40.34	3659	39.2	7.92	1.61

Table 4.5. Statistic values for M seam, Nong Wa deposit, Sin Pun area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	536421.4	909592.1	30.628	2152.333	24.684	6.936	1.372
Variance	201625.9	31720.29	54.787	1026495	20.602	8.746	0.014
Std. Dev.	449.028	178.102	7.402	1013.161	4.539	2.957	0.117
Coef. Var.	0.084	0.02	24.167	47.073	18.388	42.641	8.544
Skewness	-0.413	-0.332	-0.635	-0.932	-0.17	-0.898	0.043
Kurtosis	2.017	1.782	2.067	2.665	1.475	3.926	1.791
Minimum	535707.8	909300	18.09	160	18.09	0.46	1.22
25th %tile	535917.8	909417.9	22.507	1181.5	19.945	6.092	1.237
Median	536503	909650.3	29.95	2337	24.78	7.18	1.39
75th %tile	536675.9	909700.1	36.693	2906	28.778	7.65	1.425
Maximum	536998.1	909798.4	38.11	3091	29.94	11.14	1.54

Table 4.6. Statistic values for S1 seam, Ban Khok Tok deposit, Saba Yoi area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	710260.5	726240.3	36.402	2196.556	22.461	1.936	1.368
Variance	106653.4	101839.4	5.83	8181.778	10.785	0.056	0.008
Std. Dev.	326.578	319.123	2.415	90.453	3.284	0.236	0.089
Coef. Var.	0.046	0.044	6.633	4.118	14.621	12.183	6.475
Skewness	0.039	-0.28	0.135	0.512	-1.064	-0.03	-0.362
Kurtosis	1.962	1.822	2.62	2.261	3.646	2.782	2.367
Minimum	709766.1	725751.9	32.37	2091	15.3	1.52	1.21
25th %tile	709966.9	725879.3	34.803	2104.5	20.557	1.777	1.29
Median	710271.4	726228.1	35.82	2195	23.47	1.97	1.37
75th %tile	710485	726426.8	37.78	2243.25	24.195	2.05	1.408
Maximum	710780.6	726627.3	40.71	2363	26.73	2.35	1.48

Table 4.7. Statistic values for S2 seam, Ban Khok Ok deposit, Saba Yoi area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	712218.6	725434.1	33.797	2261.111	24.312	1.491	1.35
Variance	44995.78	98519.49	6.028	70356.86	2.878	0.043	0.004
Std. Dev.	212.122	313.878	2.455	265.249	1.696	0.207	0.066
Coef. Var.	0.03	0.043	7.265	11.731	6.978	13.913	4.871
Skewness	-0.307	-0.806	0.508	-0.996	0.818	-0.167	-0.45
Kurtosis	1.476	2.769	2.04	3.679	2.184	1.436	1.589
Minimum	711936.5	724801.6	30.75	1683	22.59	1.2	1.26
25th %tile	711961.1	725202	31.628	2125.75	23.003	1.273	1.265
Median	712266.8	725438.4	33.08	2307	23.55	1.5	1.37
75th %tile	712369.9	725643.5	34.86	2336.5	24.823	1.673	1.398
Maximum	712458.8	725770	38	2579	27.29	1.72	1.43

Table 4.8. Statistic values for S3 seam, Ban Sao deposit, Saba Yoi area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	709343.7	728719.4	28.198	2453.241	27.52	1.475	1.351
Variance	214902.4	407153	51.024	167788.2	14.965	0.032	0.004
Std. Dev.	463.576	638.085	7.143	409.62	3.868	0.179	0.062
Coef. Var.	0.065	0.088	25.332	16.697	14.057	12.158	4.568
Skewness	-0.311	0.618	-0.073	-0.204	-0.579	0.867	0.088
Kurtosis	2.304	2.585	1.676	2.48	2.342	3.075	1.608
Minimum	708458.2	727828.9	18.34	1661.85	19.56	1.25	1.27
25th %tile	708963.8	728227.5	19.965	2139.058	24.54	1.32	1.29
Median	709405.3	728616.6	28.45	2501.55	27.85	1.45	1.35
75th %tile	709705.4	728970.8	32.982	2611.647	30.275	1.54	1.395
Maximum	710096.9	730031.7	38.19	3123.28	32.18	1.88	1.45

Table 4.9. Statistic values for S4 seam, Ban Sao deposit, Saba Yoi area.

Value	Easting (UTM)	Northing (UTM)	Ash (%)	CV (kcal/kg)	Moisture (%)	Sulphur (%)	Density (g/cc)
Mean	709612.9	728484.4	36.256	1936.896	25.159	1.803	1.387
Variance	58753.38	213325.1	12.479	226344.6	16.871	0.291	0.003
Std. Dev.	242.391	461.871	3.533	475.757	4.107	0.539	0.051
Coef. Var.	0.034	0.063	9.744	24.563	16.326	29.899	3.645
Skewness	1.252	0.785	0.073	0.653	-1.26	1.126	-0.421
Kurtosis	3.292	1.978	1.625	2.647	3.572	2.913	2.625
Minimum	709405.3	728018.6	31.68	1378.58	16.82	1.31	1.3
25th %tile	709436.9	728171.8	32.88	1477.865	21.792	1.438	1.337
Median	709559.9	728227.5	37.26	1991.3	26.59	1.52	1.39
75th %tile	709612.5	728580.3	37.842	2082.212	27.035	1.862	1.41
Maximum	710096.9	729231.4	41.22	2802.81	29.48	2.84	1.46

4.3.3 Variogram Parameters

Several parameters involved in the variogram construction and analysis in this study include number of pairs, direction, tolerance angel, and lag spacing. After all the data are stored in the form of Geo_EAS format, the Geo_EAS software program can sort the number of pairs in all directions (isotropic) search using Prevar subprogram created by Englund (1991). Prevar is a preprocessor program for variogram analysis. All variogram calculation use the distance and relative direction between pair of points in the sample area. The output of Prevar is a "pair comparison file" (pcf). The pcf contains the input data file content along with distances and relative directions between pair of sample points. Limits may be imposed on the X and Y coordinate values or on the distance between points in a pair. If no limits are specified, all sample points are used for calculation. The pair comparison file can become quite large if there are many points in the data file. It is recommended that some limits on the distance between points be specified. In a situation like those of Sin Pun and Saba Yoi areas where the samples are not regularly spaced (see Figs 3.2 & 3.8), approximation must be introduced into calculation (see Clark, 1979, Isaaks & Srivasta va, 1989, Evan, 1995). Supported that one needs to calculate the experimental variogram value for a distance in a specified direction (e.g., north-east, south-west). The chance of finding any pairs at exactly this separation with irregular sampling is quite small, a 'tolerance' or each specification is, therefore, placed. Fig. 4.10 illustrates the size of the tolerance, lag spacing and search area (-area which related sample data are counted). This is rather a circular argument, since the structure still becomes unknown until the semivariogram is constructed (Journal, 1974; Thomas, 1992). For a good practice, a narrow range of 'δh' values and tolerance-angle values are simulated. In general case, the $\gamma(h)$ or variogram is frequently small relative to the sample spacing. In this investigation, the tolerance angles used for analysis are selected - 5°, 15°, 25°, 35°, and 45° (see in Fig. 4.11). One may agree, from an example shown in Table 4.10, that with specific direction and lag spacing (i.e., 157.5° and 280 m, respectively, numbers of pairs at 25°, 35°, and 45° tolerance angles are almost similar. But if also taking into account on Table 4.11, one may realize that the 45° - tolerance Zscore for these specific direction and spacing is closer to 0 than those of the others. However, the good result after changing orientation is that of 45° at E-W direction (Tables 4.10 and 4.11). This is probably due to the limited amount of drilled-holes. However, according to Isaaks & Srivastava (1985), the angular tolerance of 40° was applied to their variogram analysis. In this study, determination on the samples mutually related to each other in several directions is applied by using Geo_EAS computed designed software. The angle 0° is assigned to represent easting direction, then the direction is moved clockwise to every 22.5° (Table 4.11).

Lag spacing applied in the variogram analysis was simulated at a given distance, e.g. 200 m, 400 m, 600 m, 800 m etc., until variogram models of individual parameters can be figured out. It should be pointed out again that there are 3 main parameters in the variogram construction -lag spacing, direction, and tolerance angle. For analyzing the variogram model with the application of Geo_EAS software, simulation was able to perform with respect to these 3 variogram parameters simultaneously. Followings are the examples of analyzing the variogram models of the P1 seam ash data (15 bore-holes), Nong Wa deposit, Sin Pun area. As shown in Figs. 4.13 and 4.14 and Table 4.13, the variogram model becomes pure nugget for every tolerance angle and lag spacing. Therefore, it is quite probable that there is no relationship among paired samples, using these parameters, unless sampling pattern and analysis are regarded incorrect. So simulation was done continuously, but in this case the direction was changed from 0° to 22.5° with similar varying lag spacing and tolerance angles (Table 4.12). Similar situation was encountered for Saba Yoi ash content data when using the parameters quoted in Table 4.14, being pure nugget model. Once again, simulation was performed using the varying direction as 45°, 67.5°, 90°, 112.5°, 135°, and 157.5°, respectively with the same values of the other variogram parameters, and the result became clearly the pure-nugget effect variance. In this case, it is regarded that there is no mutual relationship of samples with respect to these parameters applied.

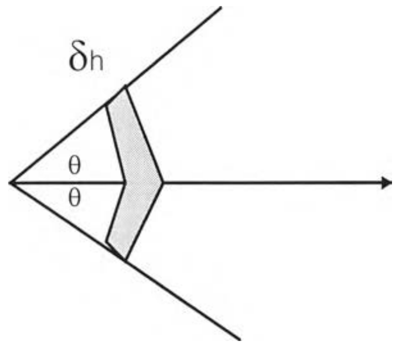


Fig.4.10. Search area defined by tolerances on angle (θ) and distance between pairs in experimental variogram.

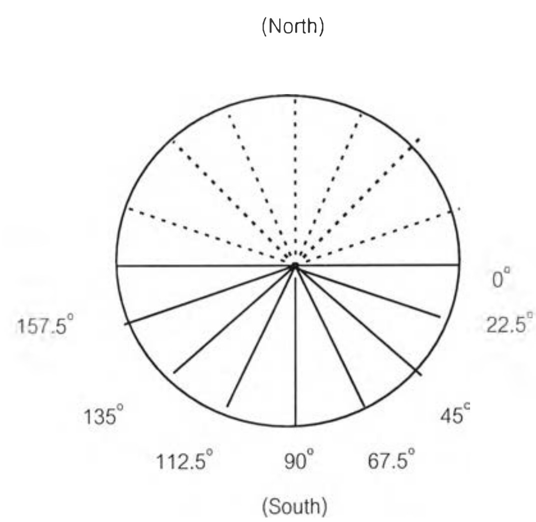
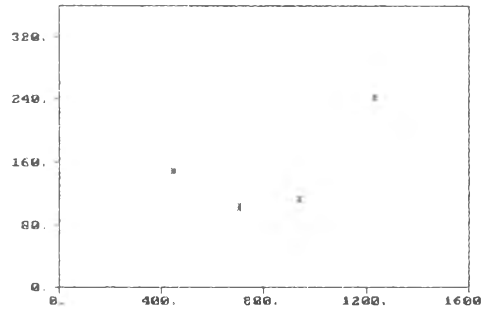
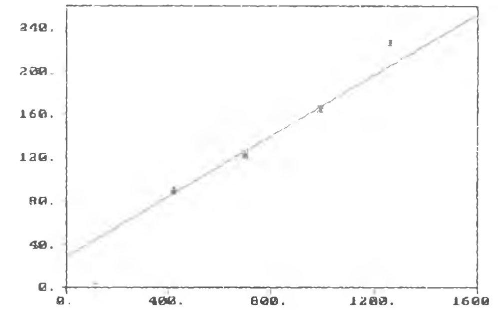


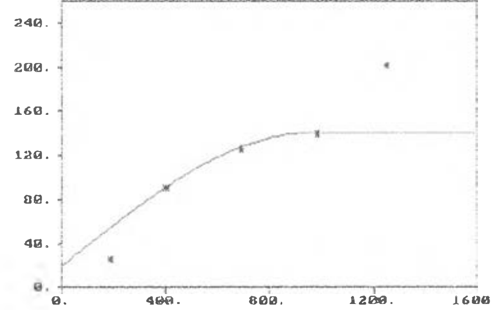
Fig. 4.11. Tolerance angle testing applied in this study with 22.5° for individual divisions as sectors. (see also Table 4.12).



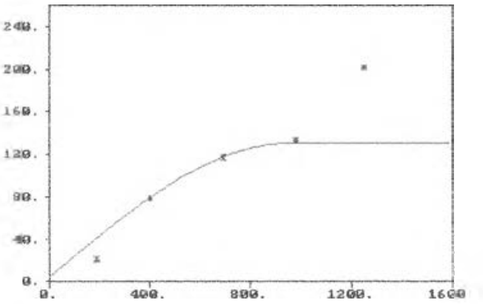
Tolerance angle 5° Indicating nugget-variance models



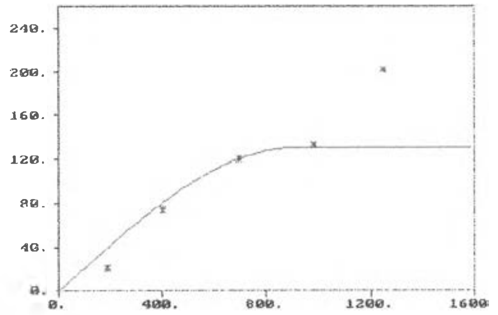
Tolerance angle 15° with linear model, nugget = 28, sill = 70, and R-major = 500 m.



Tolerance angle 25° with spherical model, nugget = 20, sill = 120, and range = 950 m.



Tolerance angle 35° with spherical model with nugget = 5, sill = 125, and range = 950 m.



Tolerance angle 45° with spherical model, nugget = 0, sill = 130, and range = 900 m.

Fig. 4.12. Test of tolerance angles for ash content (%), P1 seam, Sin Pun area, at fixed direction 157.5° and lag spacing 280 m. Noted that x-axis is distance (m) and y-axis indicates variance.

Table 4.10. Numbers of pairs at various tolerance angle testing for ash content (%), P1 seam, Sin Pun area, at fixed direction 157.5° and lag spacing 280 m.

pair no.	5°	15°	25°	35°	45°
1	-	1	7	9	9
2	4	9	18	22	24
3	3	15	25	27	31
4	5	9	11	13	13
5	2	4	5	5	5

Table 4.11. The result of cross validation of tolerance angle testing for ash content (%), P1 seam, Sin Pun area, fixed direction 157.5° and lag spacing 280 m.

angle (°)	R-minor (m)	Mean of difference	Zscore
5	-	-	-
15	210	0.739	0.049
25	450	0.061	0.007
35	450	0.065	0.004
45	490	0.018	-0.001

Table 4.12. A comparison between angles used in the variogarm analysis and the direction for related samples, ash content, Nong Wa P1 seam (see also Fig. 4.11).

Angel (degree)	Direction
0	E-W
22.5	ESE-WNW
45	SE-NW
67.5	SSE-NNW
90	S-N
112.5	SSW-NNE
135	SW-NE
157.5	WSW-ENE

Trials and errors were also done for all the ash data of 17drill-holes of the P2 seam with three involving variogram parameters using the variable values of tolerance angle and lag spacing. All the results of variogram analysis point to the pure nugget effect model. Simulation was done so far for the data of seams P3, P4, M, S1, S2, S3, and S4. As a result, the pure nugget effect models were virtually encountered.

A great care was taken into account for the data in the FoxPro database system. It is obvious that the concentration of Sin Pun data occurs mostly in the northern and central parts of the Nong Wa deposit area, and only few are in the south. A new selection for variogram analysis was applied to the Nong Wa area without the drill-hole data in the south. For the Saba Yoi area, it is observed that individual coal seams occur discontinuously in various sub-basins (deposits).

Data of seams S1 and S2 are more concentrated in the Ban Khok Tok and Ban Khok Ok deposit, respectively (see also Figs 3.10 and 3.11), and those of S3 and S4 are in Ban Sao deposit (see Figs 3.12 and 3.13). So a new selection have been made for the uses of the coal seam data which appear more in the coal sub-basins (or deposits). Therefore, a new data set were selected from the FoxPro database system and reformatted It using the Geo_EAS software for variogram analysis utilizing the same parameters as previously analyzed. After a specific direction to which samples are mostly related was identified, calculation was applied to the variogram model of each parameter in the data set, including ash content (%), calorific value (kcal/kg), moisture content (%), sulphur content (%), and density (%).

As a result (see Tables 4.15 and 4.16), lag-spacing appropriate to individual data sets and variables were determined in order to make a configuration of curve fitting of those variables with the variogram model assigned, as previously described. It is quite important to note herein also that variogram construction had to be performed in accordance with the cross validation analysis.

The reason beyond this application is to check the level of confidence of the model being used, and to compare between the values computerized and the values from the actual analysis with variable lag spacing. Theoretically, if variogram model is changed, the result of cross-validation remained unchanged. Then, the variogram model after cross-validation was applied successfully for the geostatistical estimation (see also Gurba, 1994, Gillies et al., 1987).

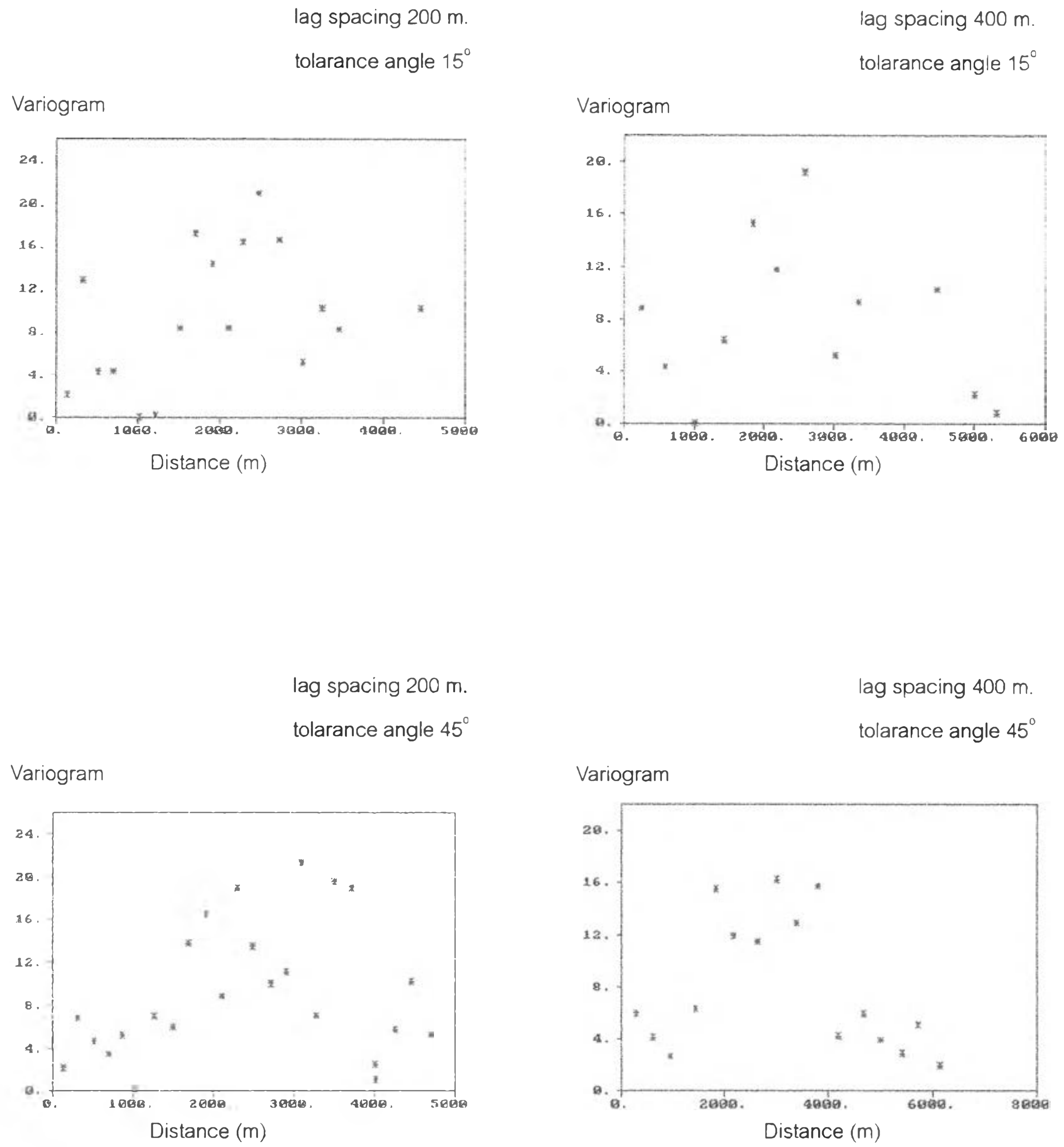


Fig. 4.13. Examples of variogram model from testing direction 0° (east-west) of S1 seam, Saba Yoi area.

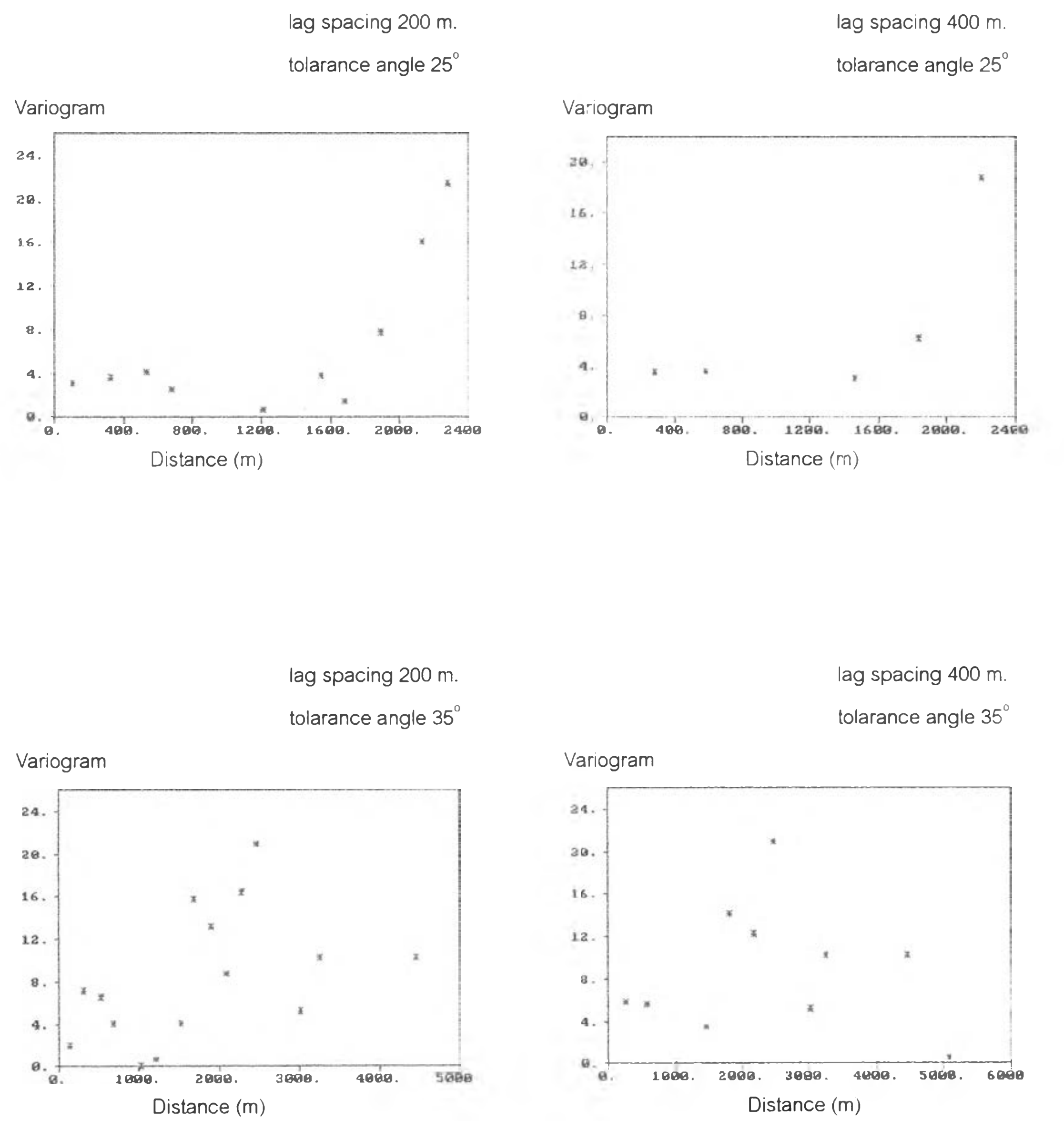


Fig. 4.14. Examples of variogram model (mostly nugget-effect) from testing direction 22.5° with lag spacing at 200 and 400 m and tolerance angle at 25° and 35°, S1 seam, Saba Yoi area.

Table 4.13. Results of variogram model with fixed direction (at 0°) and varying lag spacings and tolerance angle, comuted by Geo_EAS program.

Direction	Tolerance angle (degree)	lag spacing (m.)	Variogram model
0	5	200	pure nugget effect
0	5	400	pure nugget effect
0	5	600	pure nugget effect
0	5	800	pure nugget effect
0	15	200	pure nugget effect
0	15	400	pure nugget effect
0	15	600	pure nugget effect
0	15	800	pure nugget effect
0	25	200	pure nugget effect
0	25	400	pure nugget effect
0	25	600	pure nugget effect
0	25	800	pure nugget effect
0	35	200	pure nugget effect
0	35	400	pure nugget effect
0	35	600	pure nugget effect
0	35	800	pure nugget effect
0	45	200	pure nugget effect
0	45	400	pure nugget effect
0	45	600	pure nugget effect
0	45	800	pure nugget effect

Table 4.14. Result of variogram model with fixed direction at 22.5° and varying tolerance angles and lag spacing computed by Geo_EAS program.

Direction	Tolerance angle (degree)	Lag spacing (m.)	Variogram model
22.5	5	200	pure nugget effect
22.5	5	400	pure nugget effect
22.5	5	600	pure nugget effect
22.5	5	800	pure nugget effect
22.5	15	200	pure nugget effect
22.5	15	400	pure nugget effect
22.5	15	600	pure nugget effect
22.5	15	800	pure nugget effect
22.5	25	200	pure nugget effect
22.5	25	400	pure nugget effect
22.5	25	600	pure nugget effect
22.5	25	800	pure nugget effect
22.5	35	200	pure nugget effect
22.5	35	400	pure nugget effect
22.5	35	600	pure nugget effect
22.5	35	800	pure nugget effect
22.5	45	200	pure nugget effect
22.5	45	400	pure nugget effect
22.5	45	600	pure nugget effect
22.5	45	800	pure nugget effect

Table 4.15. A summary of values of variogram parameters used for variogram analysis of Sin Pun coal seams, calculated by Geo_EAS software.

Seam	Variable	Direction (degree)	Tolerance angle (degree)	Lag spacing (m)
P1	Ash	157.5	45	280
	CV	157.5	45	280
	Moisture	157.5	45	150
	Sulphur	0	45	180
	Density	157.5	45	190
P2	Ash	157.5	45	140
	CV	0	45	240
	Moisture	157.5	45	170
	Sulphur	157.5	45	240
	Density	157.5	45	260
P3	Ash	157.5	45	160
	CV	157.5	45	160
	Moisture	0	45	190
	Sulphur	157.5	45	210
	Density	22.5	45	280
P4	Ash	157.5	45	250
	CV	157.5	45	200
	Moisture	157.5	45	310
	Sulphur	22.5	45	280
	Density	157.5	45	150
M	Ash	157.5	45	170
	CV	157.5	45	220
	Moisture	157.5	45	350
	Sulphur	157.5	45	200
	Density	0	45	330

Table 4.16. A summary of values of variogram parameters used for variogram analysis of Saba Yoi coal seams, calculated by Geo_EAS software.

Seam	Variable	Direction (degree)	Tolerance angle (degree)	Lag spacing (m)
S1	Ash	90	45	240
	CV	90	45	280
	Moisture	112.5	45	260
	Sulphur	112.5	45	200
	Density	90	45	260
S2	Ash	67.5	45	130
	CV	45	45	180
	Moisture	-	45	-
	Sulphur	90	45	160
	Density	67.5	45	150
S3	Ash	112.5	45	320
	CV	112.5	45	330
	Moisture	45	45	330
	Sulphur	22.5	45	330
	Density	112.5	45	400
S4	Ash	-	45	-
	CV	-	45	-
	Moisture	-	45	-
	Sulphur	112.5	45	300
	Density	112.5	45	320

4.4 Results of Variogram Analysis

Results of variogram analysis from several variable of coal seams indicate mostly the spherical models (see Tables 4.15 and 4.16). Few are regarded as gaussian and linear models. However, some variables of specific coal seems (e.g. S4 seam) cannot define any relationship of data to each other, giving rise to pure nugget model. The overall selections of the variogram results from the start to the end (variogram model) are exhibited in Appendix D.

4.4.1 Variogram Analysis of Ash Contents (%)

The example of ash content is made by using P1 seam as a representative for the *Sin Pun* area (see Table 4.15). After simulation 5 lag numbers are identified it is discovered that first lag spacing, or herein called lag no. 1, is assigned at a distance between 0 and 280 m, lag no. 2 (the second lag spacing) is from 280 to 560 m, lag no. 3 from 560 to 840 m, lag no. 4 from 840 to 1,120 m, and lag no. 5 from 1,120 to 1,400 m. These ranges of lag spacing are applied to variogram analysis in this study. As shown in Table 4.17, lag no. 1 consists of 9 numbers of pair with the average distance of 185.249 m (computed from distance-column 4 in Table 4.18).

The variogram value estimated based upon these parameters is 21.117. It is also noted that the orientation used in this study is based upon the direction or trend, another word E-W orientation means samples being concerned or related are aligned more or less in the E-W trend. Therefore, the orientation of related samples at 0° is automatically applied to 180° for computer calculation. The analysis of P1-seam ash content shows mostly mutual relationships in the WSW - ENE direction (157.5°) at the tolerance angel of 45° and with lag spacing 280 m. These variogram values of parameters are then applied for variogram-model construction shown in Table 4.17. In this model, the nugget effect (Co) equals 0, sill (C) equals 130, and range is 900 m. Table 4.17 shows a result of variogram parameter values plotted as variogram in Fig. 4.15. The spherical model variogram is encountered occur as a result of relationship among samples, shown in Tables 4.17 and 4.18. It is noted that on the table 4.18, pair means relationship between the first and the second data sample points (as 15 : 10 in the first row in the table, respectively). The 1^{st} value of the second column means value of ash content of the first sample, 2^{nd} value of the third column indicates value of the second sample, distance in the fourth column is the length between two given samples, direction in the fifth column is orientation of the second sample as viewed from the first, and difference^2 of the last column means square of difference in values [(1^{st} - 2^{nd} values)^2] (see also equation 4.1). It is noted that the value in the last column (difference ^{2}, in Table 4.18) are arranged in an increasing order from the top row. Result from Table 4.18 reveals that selected lag results can give rise to the orientation with maximum related sample values at 157.5^o and its opposite direction, as compared with those of the other orientations (not shown herein).

Parameters obtained from variogarm model were then tested by cross validation method in order to check values obtained from kriging estimation (column3; estimate, Table 4.19) diviating form the actual values, P1 seam, cross validation test is shown in Table 4.19. It was found from Table 4.19 that 'Zscore' (the last column) indicates the ratio of kriging standard (the fifth column or kriging of standard diviation, see also chapters 1 and 3) and their difference (the forth column). Zscore is very close to zero (0), then the result of analysis is quite reliable. If it is not, the result become unreliable. So small values in 'Difference may give rise to the decreases in Zscore. As a result, a group of data analyzed are regarded reliable. Since after estimation, the mean of P1 seam ash content (27.206) expressed as estimate in the 3^{rd} column is different from the mean from the analysis (27.244) expressed as variable in the 2^{nd} column, giving rise to the value of difference (0.038) expressed as difference in the 4^{th} column and Zscore of 0.000.

Although the Zscore of the maximum value is rather high (1.505), the rest values of Zscore are close to 0, giving rise to the reliable result. Furthermore, the result of cross validation can indicate the search distance used for estimation, since values of the mean of difference and Zscore can be changed based upon the change in search values. For the ash content of Nong Wa P1 seam, the most appropriate search distance after simulation is 470 m.

For **the *Saba Yoi* area**, is made by using S1 seam as a representative for the ash content (see also Table 4.16). It is discovered that lag no.1 is between 0 and 240 m, lag no. 2 is between 240 and 480 m, lag no. 3 is between 480 and 720 m, lag no. 4 is between 720 and 960 m, and lag no. 5 is between 960 and 1200 m. It is observed, after simulation, that the analysis of S1 seam ash content shows mostly mutual relationships in the N-S direction (90°) at the tolerance angle of 45° and with lag spacing of 240 m. Fig. 4.16 shows a spherical model simulated from 5 lags and 19 concerned pairs, and the average distances and variogram values are shown in Table 4.20.

The nugget effect (Co) at 3, sill (C) of 2.1, and the range at 380 m are used for S1 seam data. Table 4.20 shows result of variogram parameters values plotted as variogram in Fig. 4.16 occur as a result of relationship among samples, shown in Tables 4.20 and 4.21. Result from Table 4.21 reveals that selected lag result can give rise to the maximum related sample value at 90 direction (and opposite), compared to those of the other orientations.

Parameters obtained from variogarm model were then tested by cross validation method. After estimation, the mean of S1 seam ash content (36.402) is different from the mean from the analysis (36.525), giving rise to the value of difference (-0.382). As the results for the ash content of Ban Khok Tok S1 seam, the most appropriate search distance after simulation is 270 m.

Table 4.17. Results of lag spacing, numbers of pair average distance at direction 157.5^0 and variogram value for ash content (%), P1 seam, Sin Pun area.

Lag no.	Pair (no.)	Avg. distance (m)	Estimate
1	9	185.249	21.117
2	24	398.774	74.991
3	31	689.91	120.31
4	13	978.584	133.457
5	5	1247.529	201.813

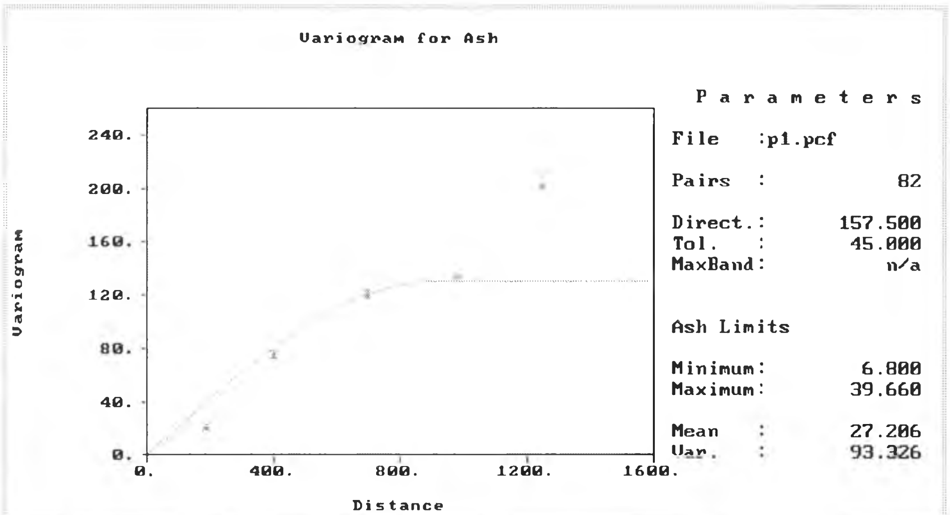


Fig. 4.15. Variogram spherical model of ash content (%), P1 seam, Nong Wa deposit, Sin Pun area.

Table 4.18. Selected lag results of ash content (%) at 157.5 orientation for P1 seam Nong Wa deposit, Sin Pun area, using Geo_EAS software.

Lag 1 for ash content (%)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
15:10	26.33	27.9	113.136	148.233	2.465
15:13	26.33	28.07	205.549	356.601	3.028
13:01	28.07	29.96	149.668	133.917	3.572
10:01	27.9	29.96	200.827	10.345	4.244
9:08	19.07	16.25	170.66	310.961	7.952
14:01	35.23	29.96	134.492	318.353	27.773
8:06	16.25	10.95	212.701	177.508	28.09
12:01	36.6	29.96	200.572	181.536	44.09
8:04	16.25	32.34	279.639	2.177	258.888

Lag 2 for ash content (%)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
4:02	32.34	37.78	303.259	359.563	29.594
15:04	26.33	32.34	435.41	117.113	36.12
14:13	35.23	28.07	283.948	316.017	51.266
12:10	36.6	27.9	400.213	185.943	75.69
11:01	39.66	29.96	518.268	168.198	94.09
14:03	35.23	25.34	510.922	11.13	97.812
15:12	26.33	36.6	318.323	18.499	105.473
13:11	28.07	39.66	403.504	0.257	134.328
10:08	27.9	16.25	496.399	140.256	135.722
3:02	25.34	37.78	410.164	165.655	154.754

Lag 2 for ash content (%) (cont.)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
9:04	19.07	32.34	408.789	343.186	176.093
14:08	35.23	16.25	515.792	158.153	360.24
15:05	26.33	6.8	526.74	159.228	381.421
10:05	27.9	6.8	416.241	162.199	445.21
6:04	10.95	32.34	491.939	0.16	457.532
14:05	35.23	6.8	493.378	179.789	808.265
13:10	28.07	27.9	309.798	166.609	0.029
12:02	36.6	37.78	345.878	124.732	1.392
14:12	35.23	36.6	312.501	344.407	1.877
4:01	32.34	29.96	418.467	315.762	5.664
14:04	35.23	32.34	284.178	134.537	8.352
12:11	36.6	39.66	326.402	340.049	9.364
7:04	35.81	32.34	359.151	303.696	12.041
6:05	10.95	6.8	280.9	314.784	17.222

Lag 3 for ash content (%)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
11:10	39.66	27.9	708.336	174.334	138.298
13:08	28.07	16.25	786.125	150.331	139.712
15:11	26.33	39.66	608.776	359.023	177.689
8:01	16.25	29.96	643.947	334.096	187.964
15:06	26.33	10.95	791.049	150.778	236.544
14:09	35.23	19.07	672.13	151.49	261.146
10:06	27.9	10.95	678.043	151.202	287.303

Lag 3 for ash content (%) (cont.)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
9:02	19.07	37.78	704.948	350.153	350.064
12:08	36.6	16.25	827.135	160.512	414.122
13:05	28.07	6.8	725.513	164.08	452.413
8:02	16.25	37.78	582.747	0.817	463.541
5:01	6.8	29.96	600.835	351.271	536.386
14:06	35.23	10.95	719.933	163.772	589.518
6:02	10.95	37.78	795.188	359.932	719.849
12:05	36.6	6.8	798.997	173.835	888.04
5:02	6.8	37.78	629.412	18.377	959.76
14:07	35.23	35.81	640.491	128.483	0.336
11:02	39.66	37.78	640.632	141.862	3.534
7:02	35.81	37.78	585.818	329.068	3.881
10:03	27.9	25.34	638.95	20.529	6.554
12:04	36.6	32.34	576.568	150.197	18.148
13:04	28.07	32.34	568.078	135.276	18.233
14:11	35.23	39.66	638.441	342.181	19.625
7:01	35.81	29.96	773.336	310.191	34.223
4:03	32.34	25.34	708.293	351.562	49
15:09	26.33	19.07	776.95	139.381	52.708
10:07	27.9	35.81	695.555	115.688	62.568
10:09	27.9	19.07	665.389	137.882	77.969
15:07	26.33	35.81	793.263	120.088	89.87
15:08	26.33	16.25	608.643	141.734	101.606
9:01	19.07	29.96	803.684	329.311	118.592

Lag 4 for ash content (%)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
12:07	36.6	35.81	912.169	140.078	0.624
9:03	19.07	25.34	1114.314	348.498	39.313
11:04	39.66	32.34	899.892	153.755	53.582
13:07	28.07	35.81	922.739	130.795	59.908
13:09	28.07	19.07	948.815	146.911	81
8:03	16.25	25.34	984.495	354.561	82.628
7:03	35.81	25.34	985.892	335.889	109.621
13:06	28.07	10.95	980.171	156.019	293.094
12:09	36.6	19.07	979.218	155.581	307.301
5:03	6.8	25.34	999.388	5.559	343.732
6:01	10.95	29.96	843.383	339.847	361.38
12:06	36.6	10.95	1032.42	163.965	657.922
11:05	39.66	6.8	1118.703	169.848	1079.78

Lag 5 for ash content (%)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
11:07	39.66	35.81	1224.031	145.304	14.822
6:03	10.95	25.34	1196.965	355.085	207.072
11:09	39.66	19.07	1304.876	156.698	423.948
11:08	39.66	16.25	1153.529	160.381	548.028
11:06	39.66	10.95	1358.243	163.024	824.264

Table 4.19. Cross validation for ash content (%) at 157.5^{0} , P1 seam, Nong Wa deposit, Sin Pun area, tested using Geo_EAS program.

Ash content (%)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	6.8	13.868	-9.600	5.974	-.840
25th %tile	16.25	21.520	-5.785	6.471	-.751
Median	27.9	27.297	-2.876	7.278	-.444
75th %tile	35.23	31.518	2.918	8.972	.368
Maximum	39.66	38.426	14.720	11.425	1.505
Mean	27.206	27.244	.038	8.173	.000
Std. Dev.	10	6.477	7.059	1.737	.745

Table 4.20. Results of lag spacing, numbers of pair average distance at direction 90^{0} and variogram value for ash content (%), S1 seam, Saba Yoi area.

Lag no.	Pair (no.)	Avg. distance (m)	Estimate
1	1	186.733	4.440
2	6	377.978	5.137
3	7	609.168	5.308
4	3	790.860	4.841
5	2	1082.398	18.989

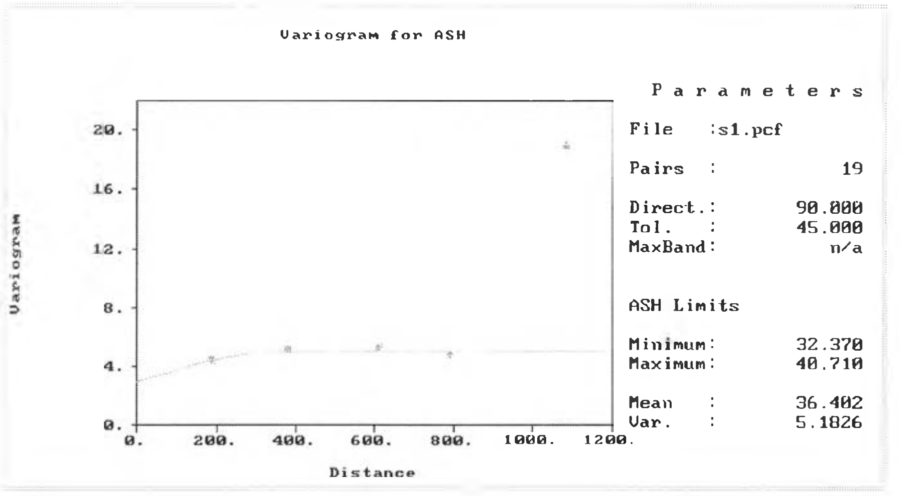


Fig. 4.16. Variogram spherical model of ash content (%), S1 seam, Ban Khok Tok deposit, Saba Yoi area.

Table 4.21. Selected lag results of ash content (%) at 90 orientation for S1 seam Ban Khok Tok deposit, Saba Yoi area, using Geo_EAS software.

lag 1 for ash content (%)

Pair *	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
9:06	37.75	34.77	186.733	86.45	8.88

lag 2 for ash content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
3:02	35.82	35.62	287.887	132.959	0.04
7:03	37.79	35.82	415.161	255.261	3.881
2:01	35.62	37.89	444.395	117.253	5.153
7:05	37.79	40.71	406.596	77.446	8.526
9:05	37.75	40.71	434.534	112.593	8.762
6:05	34.77	40.71	279.297	129.725	35.284

lag 3 for ash content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
4:02	34.9	35.62	590.011	270.352	0.518
6:03	34.77	35.82	692.316	237.449	1.102
9:03	37.75	35.82	536.688	227.738	3.725
8:06	32.37	34.77	701.353	110.206	5.76
7:04	37.79	34.9	502.636	127.421	8.352
5:02	40.71	35.62	705.424	236.418	25.908
9:08	37.75	32.37	535.75	298.278	28.944

lag 4 for ash content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
4:03	34.9	35.82	825.243	284.012	0.846
3:01	35.82	37.89	725.729	123.418	4.285
5:03	40.71	35.82	821.607	256.342	23.912

lag 5 for ash content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
8:04	32.37	34.9	1195.694	132.941	6.401
8:05	32.37	40.71	969.102	115.732	69.556

Table 4.22. Cross validation for ash content (%) at 90° , S1 seam, Ban Khok Tok deposit, Saba Yoi area, tested using Geo_EAS program.

Ash Content (%)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	32.37	34.77	-5.94	2.661	-1.863
25th %tile	34.77	34.9	-2.99	2.712	-0.939
Median	35.62	35.82	-0.2	3.183	-0.063
75th %tile	37.75	37.75	0.2	3.188	0.063
Maximum	40.71	39.157	4.387	3.19	1.617
Mean	36.402	36.525	-0.382	3.051	-0.101
Std. Dev.	2.415	1.576	3.239	0.227	1.074

4.4.2 Variogram Analysis of Calorific Value (kcal/kg)

The example of calorific value is made by using P2 seam as a representative for the ***Sin Pun*** area (see Table 4.15). After simulation it is discovered that lag no. 1 is assigned at a distance between 0 and 240 m, lag no. 2 (the second lag spacing) is from 240 to 480 m, lag no. 3 from 480 to 720 m, lag no. 4 from 720 to 960 m, lag no. 5 from 960 to 1,200 m, and lag no. 6 from 1,200 to 1,440 m (see Table 4.24). These ranges of lag spacing are applied to variogram analysis in this study. As shown in Table 4.23, lag no. 1 consists of 6 numbers of pair with the average distance of 185.249 m (computed from distance-column 4 in Table 4.24). The variogram value as estimated based upon these parameters is 279064.400. It is also noted that the orientation used in this study is based upon the direction or trend, another word N-S orientation means samples being concerned are aligned more or less in the N-S trend. Therefore, the orientation of related samples at 90^{o} is automatically applied to 270^{o} for computer calculation. The analysis of P2-seam ash content shows mostly mutual relationships in the N-S direction (90^{o}) at the tolerance angel of 45^{o} and with lag spacing of 240 m. These variogram values of parameters are then applied for variogram-model construction as shown in Table 4.23.

In this model, the nugget effect (Co) equals 0, sill (C) equals 675000, and range is 600 m. Table 4.23 shows a result of variogram parameter values plotted as variogram in Fig. 4.17. Spherical model variogram is obtained from this analysis and it may occur as a result of relationship among samples, shown in Tables 4.23 and 4.24. It is noted that on Table 4.24, pair means relationship between the first and the second data sample points (as 7 : 06 in the first row in the table, respectively). The 1^{st} value of the second column means value of calorific value of the first sample, the 2^{nd} value of the third column indicates value of the second sample, distance in the forth column is length between two given samples, direction in the fifth column is orientation of the second sample as viewed from the first, and difference^{2} of the last column means square of difference in values [(1^{st} - 2^{nd} values)^{2}] (see also equation 4.1).

It is noted that the value in the last column (difference ^{2}, in Table 4.24) are arranged in an increasing order from the top row. Result from Table 4.24 reveals that selected lag results can give rise to the orientation with maximum related sample values at 90° and its opposite direction, as compared with those of the other orientations (not shown herein). Parameters obtained from variogarm model were then tested by cross validation method (see Table 4.25). Since after estimation, the mean of P2 seam calorific value (2501.000) is different from the mean from the analysis (2488.024), giving rise to the value of difference (-0.032). Except for the Zscores of the minimum value (-13.446) and the maximum value (0.949), the other Zscores show rather good result, i.e., close to zero (see Table 4.25). Furthermore, the result of cross validation (Table 4.25) can indicate the search distance used for estimation, since values of the mean of difference and Zscore can be changed basically upon the change in search values. For the ash content of Nong Wa P2 seam, the most appropriate search distance after simulation is 250 m.

For the ***Saba Yoi*** *area*, calorific value is made by using S2 seam as a representative for the Saba Yoi area (see also Table 4.16). It is discovered that lag no.1 is between 0 and 180 m, lag no. 2 is between 180 and 360 m, lag no. 3 is between 360 and 540 m, and lag no. 4 is between 540 and 620 m. It is observed, after simulation, that the analysis of S2 seam calorific value shows mostly mutual relationships in the SW-NE direction (45°) at the tolerance angle of 45° and with lag spacing 180 m. These variogram values of parameters are then applied for variogram model construction.

Fig. 4.18 shows a spherical model simulated from 4 lags and 20 concerned pairs, and average distance and variogram values shown in Table 4.26. In this model, the nugget effect (Co) equals 4000, sill (C) equals 6200, range is 400 m. Table 4.26 shows result of variogram parameters values plotted as variogram in Fig. 4.18 occur as a result of relationship among samples, shown in Tables 4.26 and 4.27. Result from Table 4.27 reveals that selected lag result can give rise to the maximum related sample value at 45 direction (and its opposite direction), compared to those of the other orientations. Parameters obtained from variogarm model were then tested by cross validation method.

After estimation, the mean of S2 seam calorific value (2225.000) is different from the mean from the analysis (2214.804), giving rise to the value of difference (-14.196). For the calorific value of Ban Khok Ok S2 seam, the most appropriate search distance after simulation is 260 m.

Table 4.23. Result of lag spacing, number of pair average distance at direction 90^0 and variogram value for calorific value (kcal/kg), P2 seam, Sin Pun area.

Lag no.	Pair (no.)	Avg. distance (m)	Estimate
1	6	185.249	279064.400
2	27	178.210	561594.600
3	31	610.446	680836.400
4	15	840.604	1235443.000
5	15	1072.767	788247.200
6	8	1300.370	144180.400

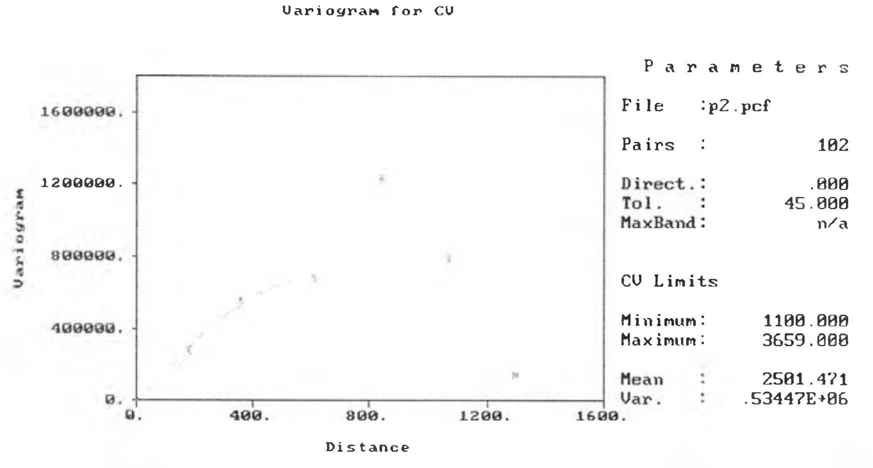


Fig. 4.17. Variogram spherical model of calorific value (kcal/kg), P2 seam, Nong Wa deposit, Sin Pun area.

Table 4.24. Selected lag results of calorific value (kcal/kg) at 90 orientation for P2 seam, Nong Wa deposit, Sin Pun area, using Geo_EAS software.

Lag 1 for calorific value (kcal/kg)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
7:06	3556	3659	149.852	136.842	10609
13:03	2892	2435	222.743	26.263	208849
10:08	2592	3291	212.701	177.508	488601
13:06	2892	3659	203.625	179.912	588289
17:04	1831	2787	128.553	155.591	913936
10:06	2592	3659	151.785	215.261	1138489

Lag 2 for calorific value (kcal/kg)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
17:15	1831	1100	312.501	344.407	534361
7:04	3556	2787	379.795	7.765	591361
15:02	1100	1888	271.066	42.355	620944
4:01	2787	1976	265.493	33.653	657721
11:09	3124	2279	263.611	43.232	714025
17:13	1831	2892	412.392	165.393	1125721
7:03	3556	2435	356.052	34.32	1256641
13:12	2892	1761	379.27	322.775	1279161
6:03	3659	2435	415.168	13.689	1498176
16:04	1398	2787	407.355	142.086	1929321
16:05	1398	2835	407.219	345.785	2064969
15:04	1100	2787	439.977	161.84	2845969
16:14	1398	3121	403.504	0.257	2968729
15:05	1100	2835	366.456	324.426	3010225
12:07	1761	3556	416.241	162.199	3222025
15:14	1100	3121	326.402	340.049	4084441
2:01	1888	1976	410.164	165.655	7744
13:04	2892	2787	286.552	349.773	11025
10:03	2592	2435	279.639	2.177	24649
10:04	2592	2787	387.41	339.004	38025
16:12	1398	1761	309.798	166.609	131769
13:08	2892	3291	307.927	161.602	159201
17:16	1831	1398	283.948	316.017	187489
3:01	2435	1976	303.259	359.563	210681
16:02	1398	1888	419.183	44.885	240100
15:12	1100	1761	400.213	185.943	436921
11:03	3124	2435	408.789	343.186	474721

lag 3 for calorific value (kcal/kg)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
12:05	1761	2835	716.999	346.141	1153476
14:01	3121	1976	640.632	141.862	1311025
11:01	3124	1976	704.948	350.153	1317904
17:14	1831	3121	638.441	342.181	1664100
17:11	1831	3124	672.13	151.49	1671849
15:03	1100	2435	576.568	150.197	1782225
14:12	3121	1761	708.336	174.334	1849600
12:11	1761	3124	665.389	137.882	1857769
17:08	1831	3291	719.933	163.772	2131600
16:13	1398	2892	674.37	153.473	2232036
12:08	1761	3291	678.043	151.202	2340900
7:01	3556	1976	629.412	18.377	2496400
6:01	3659	1976	713.108	7.732	2832489
17:07	1831	3556	493.378	179.789	2975625
17:06	1831	3659	611.648	170.181	3341584
12:06	1761	3659	555.375	155.564	3602404
17:02	1831	1888	510.922	11.13	3249
12:02	1761	1888	638.95	20.529	16129
9:01	2279	1976	585.818	329.068	91809
11:04	3124	2787	543.984	330.522	113569
8:04	3291	2787	592.97	345.54	254016
3:02	2435	1888	708.293	351.562	299209
10:01	2592	1976	582.747	0.817	379456
17:10	1831	2592	515.792	158.153	579121
12:10	1761	2592	496.399	140.256	690561
8:03	3291	2435	491.939	0.16	732736
6:04	3659	2787	488.315	353.983	760384

lag 3 for calorific value (kcal/kg) (cont.)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
4:02	2787	1888	620.047	4.208	808201
13:01	2892	1976	512.126	10.833	839056
17:05	1831	2835	668.727	333.615	1008016
16:03	1398	2435	568.078	135.276	1075369
12:05	1761	2835	716.999	346.141	1153476

Lag 4 for calorific value (kcal/kg)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
5:04	2835	2787	797.216	153.933	2304
14:04	3121	2787	766.287	161.077	111556
5:03	2835	2435	941.888	147.955	160000
14:03	3121	2435	899.892	153.755	470596
13:02	2892	1888	900.391	359.658	1008016
15:09	1100	2279	912.169	140.078	1390041
16:10	1398	2592	786.125	150.331	1425636
8:01	3291	1976	795.188	359.932	1729225
15:10	1100	2592	827.135	160.512	2226064
16:11	1398	3124	948.815	146.911	2979076
15:13	1100	2892	724.867	164.968	3211264
16:07	1398	3556	725.513	164.08	4656964
16:06	1398	3659	861.482	159.514	5112121
15:07	1100	3556	798.997	173.835	6031936
15:06	1100	3659	923.099	168.229	6548481

Lag 5 for calorific value (kcal/kg)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
13:05	2892	2835	1075.735	338.103	3249
14:13	3121	2892	1050.439	163.441	52441
10:05	2592	2835	1183.606	335.591	59049
9:02	2279	1888	985.892	335.889	152881
14:07	3121	3556	1118.703	169.848	189225
14:10	3121	2592	1153.529	160.381	279841
10:02	2592	1888	984.495	354.561	495616
7:05	3556	2835	1132.617	344.693	519841
11:02	3124	1888	1114.314	348.498	1527696
8:02	3291	1888	1196.965	355.085	1968409
7:02	3556	1888	999.388	5.559	2782224
6:02	3659	1888	1104.015	359.705	3136441
16:08	1398	3291	980.171	156.019	3583449
15:11	1100	3124	979.218	155.581	4096576
15:08	1100	3291	1032.42	163.965	4800481

Lag 6 for calorific value (kcal/kg)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
14:11	3121	3124	1304.876	156.698	9
14:08	3121	3291	1358.243	163.024	28900
11:05	3124	2835	1340.627	332.55	83521
8:05	3291	2835	1383.215	338.881	207936
14:06	3121	3659	1247.046	166.095	289444
9:05	2279	2835	1277.872	321.324	309136
6:05	3659	2835	1267.046	341.526	678976
14:09	3121	2279	1224.031	145.304	708964

Table 4.25. Cross validation for calorific value (kcal/kg) at 90°, P2 seam, Nong Wa deposit, Sin Pun area, tested using Geo_EAS program.

Calorific value (kcal/kg)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	1100	1639.002	-970.625	590.402	-1.272
25th %tile	1831	1918.116	-482.823	621.723	-0.773
Median	2435	2268.661	-146.979	759.91	-0.217
75th %tile	2892	2968.329	334.813	797.559	0.567
Maximum	3659	3226.813	845	1125.591	0.949
Mean	2501	2488.024	-13.446	753.657	-0.032
Std. Dev	753.578	542.7	519.159	136.825	0.692

Table 4.26. Results of lag spacing, numbers of pair average distance at direction 45° and variogram value for calorific value (kcal/kg), S2 seam, Saba Yoi area.

Lag no.	Pair (no.)	Avg. distance (m)	Estimate
1	3	126.7.7	65142.670
2	6	265.607	92681.340
3	6	461.921	102521.500
4	5	620.738	13366.500

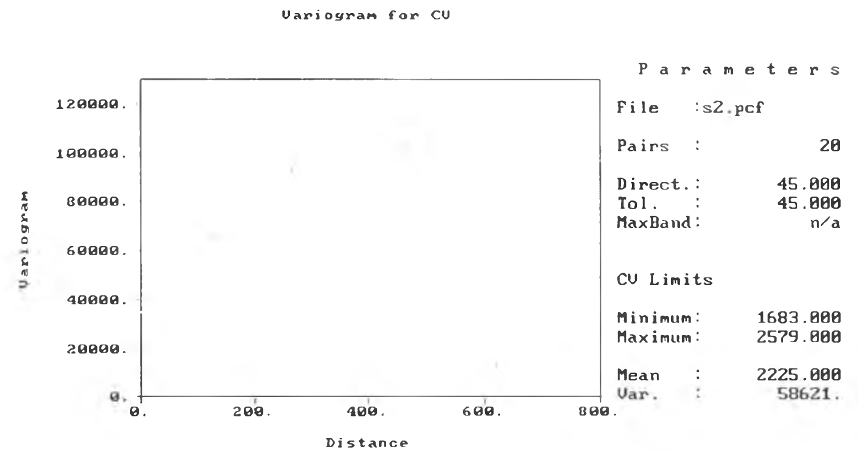


Fig. 4.18. Variogram spherical model of calorific value (kcal/kg), S2 seam, Ban Khok Ok deposit, Saba Yoi area.

Table 4.27. Selected lag results of calorific value (kcal/kg) at 45 orientation for S2 seam, Ban Khok Ok deposit, Saba Yoi area, using Geo_EAS software.

lag 1 for calorific value (kcal/kg)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
6:05	2323	2341	121.048	83.954	324
5:04	2341	2307	108.283	190.947	1156
4:01	2307	1683	150.88	235.395	389376

lag 2 for calorific value (kcal/kg)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
7:03	2112	2167	266.047	217.613	3025
7:04	2112	2307	359.122	63.854	38025

lag 2 for calorific value (kcal/kg) (cont.)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
7:06	2112	2323	336.071	41.472	44521
7:01	2112	1683	211.054	69.891	184041
6:01	2323	1683	180.9	187.744	409600
5:01	2341	1683	240.451	217.013	432964

lag 3 for calorific value (kcal/kg)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
6:02	2323	2288	473.799	261.473	1225
7:05	2112	2341	433.128	52.351	52441
8:06	2579	2323	535.722	23.224	65536
8:04	2579	2307	505.729	37.958	73984
3:01	2167	1683	458.553	51.841	234256
8:01	2579	1683	364.596	30.834	802816

lag 4 for calorific value (kcal/kg)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
5:02	2341	2288	594.757	261.978	2809
4:03	2307	2167	609.216	232.721	19600
6:03	2323	2167	601.781	219.767	24336
5:03	2341	2167	693.731	226.752	30276
8:05	2579	2341	604.205	33.289	56644

Table 4.28. Cross validation for calorific value (kcal/kg) at 45°, S2 seam, Ban Khok Ok deposit, Saba Yoi area, tested using Geo_EAS program.

Calorific Value (kcal/kg)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	1683	2021.234	-557.766	932.835	-0.507
25th %tile	2112	2021.234	-557.766	932.835	-0.507
Median	2288	2161.012	-145.988	990.465	-0.156
75th %tile	2323	2246.145	134.145	1083.494	0.124
Maximum	2579	2362.603	633.170	1211.865	0.616
Mean	2225	2201.804	-14.196	1047.997	-0.018
Std. Dev	258.834	112.880	378.723	92.525	0.359

4.4.3 Variogram Analysis of Moisture Contents (%)

The example of moisture content is made by using P4 seam as a representative for the *Sin Pun* area (see Table 4.15). After simulation it is discovered that the lag no. 1 is assigned at a distance between 0 and 310 m, lag no. 2 (the second lag spacing) is from 310 to 620 m, lag no. 3 from 620 to 930 m, lag no. 4 from 930 to 1,240 m, lag no. 5 from 1,240 to 1,550 m, and lag no. 6 from 1,550 to 1,860 m. These ranges of lag spacing are applied to variogram analysis in this study. As shown in Table 4.29, lag no. 1 consists of 20 numbers of pair with the average distance of 219.096 m (computed from distance-column 4 in Table 4.30). The variogram value as estimated based upon these parameters is 18.459. It is also noted that the orientation used in this study is based upon the direction or trend, another word E-W orientation means samples being concerned are aligned more or less in the E-W trend. Therefore, the orientation of related samples at 0^{o} is automatically applied to 180^{o} for computer calculation. The analysis of P4-seam moisture content shows mostly mutual relationships in the WSW - ENE direction (157.5^{o}) at the tolerance angel of 45^{o} and with lag spacing of 310 m. These variogram values of parameters are then applied for variogram-model construction and shown in Table 4.29. In this model, the nugget effect (Co) equals 5, sill (C) equals 22.5, and range is 550 m. Table 4.29 shows a result of variogram parameter values plotted as variogram in Fig. 4.19. Spherical model variogram is encountered using these parameter and occur as a result of relationship among samples, shown in Tables 4.29 and 4.30. It is noted that on the Table 4.30, pair means relationship between the first and the second data sample points (as 17 : 04 in the first row in the table, respectively). The 1^{st} value of the second column means value of moisture content of the first sample, the 2^{nd} value of the third column indicates value of the second sample, distance in the forth column is length between two given samples, direction in the fifth column is orientation of the second sample as viewed from the first, and $difference^{2}$ of the last column means square of difference in values [(1^{st} - 2^{nd} values $)^{2}$] (see also equation 4.1).

It is noted that the value in the last column (difference ^{2}, in Table 4.31) are arranged in an increasing order from the top row. Result from Table 4.31 reveals that selected lag results can give rise to the orientation with maximum related sample values at 157.5^{o} and its opposite direction, as compared with those of the other orientations (not shown herein). Parameters obtained from variogarm model were then tested by cross validation method (see Table 4.31).in order to check values obtained from kriging estimation (column3; estimate, Table 4.31). Since after estimation, the mean of P4 seam moisture content (28.266) is different from the mean from the analysis (28.315), giving rise to the value of difference (0.064). However, for the maximum and minimum values, it is figured out that the cross-validation analysis reveals the rather high Zscores (i.e., 2.271 and -2.361, respectively, quite large), compared to those of the median and mean values (-0.373 and 0.007, respectively). Furthermore, the result of cross validation (Table 4.31) can indicate the search distance used for estimation, since values of the mean of difference and Zscore can be changed based upon the change in search values. For the moisture content of Nong Wa P4 seam, the most appropriate search distance after simulation is 150 m.

For the ***Saba Yoi*** moisture content is made by using S3 seam as a representative for the Saba Yoi area (see also Table 4.16). After simulation it is discovered that the lag no. 1 is assigned at a distance between 0 and 330 m, lag no. 2 is from 330 to 660 m, lag no. 3 from 660 to 990 m, lag no. 4 from 990 to 1,320 m, lag no. 5 from 1,320 to 1,650 m, lag no. 6 from 1,650 to 1,980 m, and lag no. 7 from 1,980 to 2,310 m.

It is observed, after simulation, that the analysis of S3 seam moisture content shows mostly mutual relationships in the SSW-NNE direction (112.5^{o}) at the tolerance angle of 45^{o} and with lag spacing 330 m. These variogram values of parameters are then applied for variogram model construction. Fig. 4.20 show a spherical model simulated from 7 lags and 42 concerned pairs, and average distance and variogram values shown in Table 4.32.

In this model, the nugget effect (Co) equals 0, sill (C) equals 26, range is 1400 m. Table 4.32 shows result of variogram parameters values plotted as variogram in Fig. 4.20. After simulation, it is observed that the most appropriate model is gaussian which may occur as a result of relationship among samples, shown in Tables 4.32 and 4.33. Result from Table 4.33 reveals that selected lag result can give rise to the maximum related sample value at 112.5 direction (and its opposite direction), compared to those of the other orientations. Parameters obtained from variogarm model were then tested by cross validation method.

After estimation, the mean of S3 seam moisture content (27.520) is different from the mean from the analysis (27.890), giving rise to the value of difference (0.37). Moreover, the result of cross validation can indicate the search distance used for estimation, since values of the mean of difference and Zscore can be changed based upon the change in search values. It is important to note that the Zscore of the minimum and maximum value are quite high (much deviating from zero).

This gives rise to the high Zscore of the standard deviation (Table 4.34). For the moisture content of Ban Sao S3 seam, the most appropriate search distance after simulation is 150 m.

Table 4.29. Result of lag spacing, number of pair average distance at direction 157.5^0 and variogram value for moisture content (%), P4 seam, Sin Pun area.

Lag no.	Pair (no.)	Avg. distance (m)	Estimate
1	20	219.096	18.459
2	29	501.354	26.497
3	39	749.776	42.393
4	10	1032.843	28.169
5	15	1339.982	24.162
6	1	1553.327	65.437

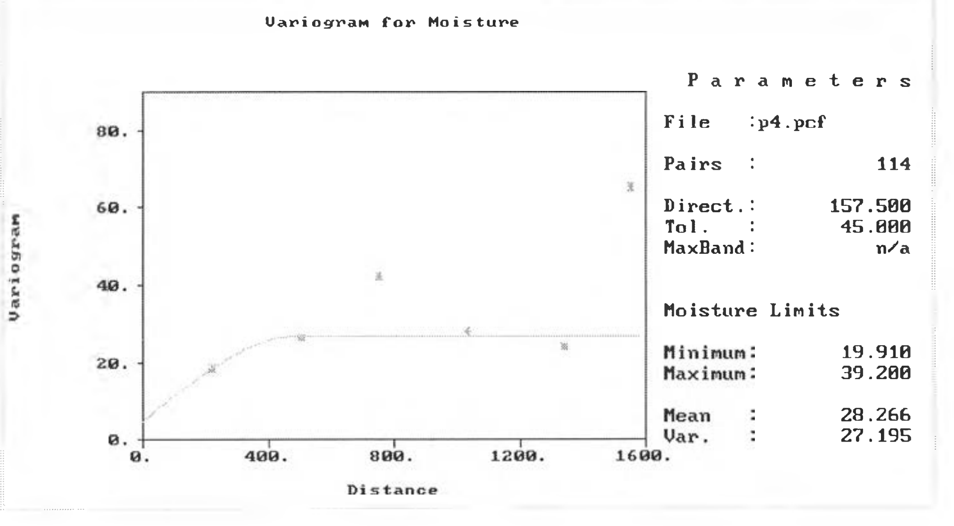


Fig. 4.19. Variogram spherical model of moisture content (%), P4 seam, Nong Wa deposit, Sin Pun area.

Table 4.30. Selected lag results of moisture content (%) at 157.5 orientation for P4 seam, Nong Wa deposit, Sin Pun area, using Geo_EAS software.

Lag 1 for moisture content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
17:04	27.97	26.51	264.959	116.009	2.132
4:01	26.51	24.91	260.076	326.776	2.56
7:06	37.25	35.07	131.256	312.433	4.752
11:09	26.11	28.41	289.316	131.462	5.29
15:01	27.28	24.91	149.668	133.917	5.617
10:01	21.96	24.91	200.827	10.345	8.703
16:01	19.91	24.91	134.492	318.353	25
15:10	27.28	21.96	309.798	166.609	28.302
17:10	27.97	21.96	113.136	148.233	36.12
16:04	19.91	26.51	128.553	155.591	43.56
16:03	19.91	26.85	284.178	134.537	48.164
16:15	19.91	27.28	283.948	316.017	54.317
11:06	26.11	35.07	203.625	179.912	80.282
14:12	35.25	25.81	152.376	316.895	89.114
11:07	26.11	37.25	307.927	161.602	124.1
13:12	39.2	25.81	201.846	358.953	179.292
4:03	26.51	26.85	170.577	118.828	0.116
11:04	26.11	26.51	286.552	349.773	0.16
3:02	26.85	26.3	303.259	359.563	0.303
17:15	27.97	27.28	205.549	356.601	0.476

Lag 2 for moisture content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
8:02	28.51	26.3	585.818	329.068	4.884
15:05	27.28	23.23	407.219	345.785	16.403
11:10	26.11	21.96	379.27	322.775	17.223
17:05	27.97	23.23	610.337	349.408	22.468
16:11	19.91	26.11	412.392	165.393	38.44
15:14	27.28	35.25	504.532	11.693	63.521
6:03	35.07	26.85	415.168	13.689	67.568
6:04	35.07	26.51	488.315	353.983	73.274
14:01	35.25	24.91	597.901	179.467	106.916
7:03	37.25	26.85	491.939	0.16	108.16
7:04	37.25	26.51	592.97	345.54	115.348
17:13	27.97	39.2	608.776	359.023	126.113
15:13	27.28	39.2	403.504	0.257	142.086
10:06	21.96	35.07	555.375	155.564	171.872
13:01	39.2	24.91	518.268	168.198	204.204
16:06	19.91	35.07	611.648	170.181	229.826
11:02	26.11	26.3	512.126	10.833	0.036
15:03	27.28	26.85	568.078	135.276	0.185
15:04	27.28	26.51	407.355	142.086	0.593
17:03	27.97	26.85	435.41	117.113	1.254
11:01	26.11	24.91	535.683	338.839	1.44
15:12	27.28	25.81	605.315	359.823	2.161
9:03	28.41	26.85	408.789	343.186	2.434
8:03	28.51	26.85	359.151	303.696	2.756
5:01	23.23	24.91	540.139	157.372	2.822
17:11	27.97	26.11	492.01	144.028	3.46
9:04	28.41	26.51	543.984	330.522	3.61
3:01	26.85	24.91	418.467	315.762	3.764
8:04	28.51	26.51	529.311	302.129	4

Lag 3 for moisture content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
14:04	35.25	26.51	828.771	169.709	76.388
6:02	35.07	26.3	713.108	7.732	76.913
14:02	35.25	26.3	663.695	153.592	80.103
17:07	27.97	37.25	791.049	150.778	86.118
6:01	35.07	24.91	729.375	344.6	103.226
7:02	37.25	26.3	795.188	359.932	119.903
7:01	37.25	24.91	843.383	339.847	152.276
13:03	39.2	26.85	899.892	153.755	152.523
13:04	39.2	26.51	766.287	161.077	161.036
13:02	39.2	26.3	640.632	141.862	166.41
14:10	35.25	21.96	796.022	182.196	176.624
10:07	21.96	37.25	678.043	151.202	233.784
16:14	19.91	35.25	704.798	352.259	235.316
13:10	39.2	21.96	708.336	174.334	297.218
16:07	19.91	37.25	719.933	163.772	300.676
16:13	19.91	39.2	638.441	342.181	372.104
9:02	28.41	26.3	704.948	350.153	4.452
17:12	27.97	25.81	810.622	359.006	4.666
5:02	23.23	26.3	701.85	134.867	9.425
5:04	23.23	26.51	797.216	153.933	10.758
16:05	19.91	23.23	668.727	333.615	11.022
9:01	28.41	24.91	803.684	329.311	12.25
8:01	28.51	24.91	773.336	310.191	12.96
12:10	25.81	21.96	909.672	175.358	14.823
16:12	19.91	25.81	833.738	346.187	34.81
10:09	21.96	28.41	665.389	137.882	41.603
10:08	21.96	28.51	695.555	115.688	42.903
17:06	27.97	35.07	667.742	154.325	50.41
17:14	27.97	35.25	705.026	7.339	52.998
15:06	27.28	35.07	861.482	159.514	60.684

Lag 3 for moisture content (%) (cont.)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
16:09	19.91	28.41	672.13	151.49	72.25
16:08	19.91	28.51	640.491	128.483	73.96
17:09	27.97	28.41	776.95	139.381	0.194
12:02	25.81	26.3	810.83	150.497	0.24
17:08	27.97	28.51	793.263	120.088	0.292
12:01	25.81	24.91	717.558	171.207	0.81
15:11	27.28	26.11	674.37	153.473	1.369
15:08	27.28	28.51	922.739	130.795	1.513
10:05	21.96	23.23	716.999	346.141	1.613

Lag 4 for moisture content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
12:04	25.81	26.51	960.39	164.776	0.49
12:03	25.81	26.85	1085.936	158.294	1.082
15:09	27.28	28.41	948.815	146.911	1.277
11:05	26.11	23.23	1075.735	338.103	8.294
5:03	23.23	26.85	941.888	147.955	13.104
14:03	35.25	26.85	945.7	161.664	70.56
14:11	35.25	26.11	1115.323	169.725	83.54
15:07	27.28	37.25	980.171	156.019	99.401
13:08	39.2	28.51	1224.031	145.304	114.276
13:11	39.2	26.11	1050.439	163.441	171.348

Lag 5 for moisture content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
35.25	35.07	1316.231	171.2932	0.180	0.032
25.81	26.11	1246.103	165.924	0.300	0.090
39.2	37.25	1358.243	163.0242	1.950	3.803
35.25	37.25	1420.826	167.9704	2.000	4.000
25.81	28.41	1493.643	159.6314	2.600	6.760
25.81	28.51	1396.542	149.8973	2.700	7.290
39.2	35.07	1247.046	166.0947	4.130	17.057
28.41	23.23	1340.627	332.5497	5.180	26.83
28.51	23.23	1277.872	321.324	5.280	27.879
35.25	28.51	1248.543	151.4708	6.740	45.428
35.25	28.41	1354.389	162.1236	6.840	46.786
25.81	35.07	1444.529	167.8766	9.260	85.748
39.2	28.41	1304.876	156.6976	10.790	116.424
35.07	23.23	1267.046	341.5257	11.840	140.186
37.25	23.23	1383.215	338.8813	14.020	196.560

Lag 6 for moisture content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
25.81	37.25	1553.327	165.068	11.440	130.874

Table 4.31. Cross validation for moisture content (%) at 157.5^{o} , P4 seam, Nong Wa deposit, Sin Pun area, tested using Geo_EAS program.

Moisture Content (%)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	19.91	22.969	-11.848	4.788	-2.361
25th %tile	24.91	25.361	-3.387	5.018	-0.665
Median	26.51	26.85	-1.919	5.146	-0.373
75th %tile	28.41	30.464	4.446	5.933	0.903
Maximum	39.2	37.892	12.082	6.592	2.271
Mean	28.266	28.315	0.64	5.435	0.007
Std. Dev	5.375	3.958	6.052	0.575	1.147

Table 4.32. Results of lag spacing, numbers of pair average distance at direction 112.5^{0} and variogram value for moisture content (%), S3 seam, Saba Yoi area.

Lag no.	Pair (no.)	Avg. distance (m.)	Estimate
1	2	246.065	3.880
2	9	538.301	4.498
3	8	809.871	16.943
4	11	1160.084	22.731
5	5	1471.897	26.377
6	5	1784.327	24.812
7	2	2112.986	63.128

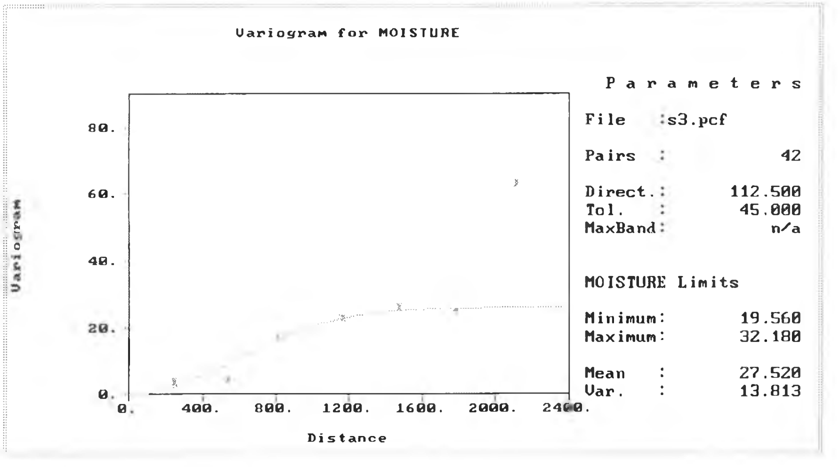


Fig. 4.20. Variogram gaussian model of moisture content (%), S3 seam, Ban Sao deposit, Saba Yoi area.

Table 4.33. Selected lag results of moisture content (%) at 90 orientation for S3 seam, Ban Sao deposit, Saba Yoi area, using Geo_EAS software.

lag 1 for moisture content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
11:06	30.26	32.18	275.721	132.988	3.686
13:03	27.85	31.29	216.409	254.9	11.834

lag 2 for moisture content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
9:08	25.92	26.35	399.191	89.749	0.185
6:03	32.18	31.29	440.787	248.681	0.792
11:07	30.26	31.61	608.5	89.929	1.823
12:05	24.2	22.69	508.143	307.142	2.28
12:09	24.2	25.92	548.376	337.108	2.958
13:09	27.85	25.92	632.157	142.015	3.725

lag 3 for moisture content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
8:05	26.35	22.69	623.905	251.291	13.396
4:02	30.01	25.56	530.89	130.522	19.803
2:01	25.56	19.56	552.755	134.139	36
13:08	27.85	26.35	931.585	122.206	2.25
11:09	30.26	25.92	880.72	153.784	18.836
10:09	30.28	25.92	811.737	104	19.01
9:03	25.92	31.29	743.544	306.461	28.837
8:06	26.35	32.18	839.348	315.667	33.989
7:02	31.61	25.56	799.003	90.161	36.603
10:05	30.28	22.69	714.769	123.523	57.608
5:03	22.69	31.29	758.261	327.604	73.96
11:04	30.26	30.01	1061.056	71.115	0.063
13:12	27.85	24.2	1170.36	149.023	13.322
11:08	30.26	26.35	1114.842	135.005	15.288

lag 4 for moisture content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
10:08	30.28	26.35	1202.665	99.313	15.445
8:03	26.35	31.29	1089.997	293.815	24.404
12:10	24.2	30.28	1222.32	305.027	36.966
6:02	32.18	25.56	1220.15	81.208	43.824
8:01	26.35	19.56	1092.558	68.415	46.104
12:03	24.2	31.29	1247.059	319.415	50.268
4:01	30.01	19.56	1083.105	132.367	109.203
7:01	31.61	19.56	1256.815	107.943	145.203

lag 5 for moisture content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
13:02	27.85	25.56	1437.141	78.343	5.244
11:02	30.26	25.56	1407.501	90.061	22.09
12:11	24.2	30.26	1428.527	335.06	36.724
9:01	25.92	19.56	1471.578	74.078	40.45
6:01	32.18	19.56	1614.74	97.059	159.264

lag 6 for moisture content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
5:01	22.69	19.56	1715.962	69.46	9.797
10:02	30.28	25.56	1900.69	71.844	22.278
3:02	31.29	25.56	1653.211	77.893	32.833
13:01	27.85	19.56	1806.664	93	68.724
11:01	30.26	19.56	1845.109	102.089	114.49

lag 7 for moisture content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
10:01	30.28	19.56	2212.484	84.623	114.918
3:01	31.29	19.56	2013.487	91.087	137.593

Table 4.34. Cross validation for moisture content (%) at 112.5° , S3 seam, Ban Sao deposit, Saba Yoi area, tested using Geo_EAS program.

Moisture Content (%)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	19.56	25.415	-4.66	1.474	-1.906
25th %tile	24.2	26.503	-2.314	2.417	-0.643
Median	26.35	27.25	-0.145	3.404	-0.028
75th %tile	30.26	28.036	0.811	4.525	0.294
Maximum	32.181	30.773	8.476	5.615	1.87
Mean	27.52	27.89	0.37	3.629	0.023
Std. Dev.	3.868	1.672	3.452	1.352	1.122

4.4.4 Variogram Analysis of Sulphur Contents (%)

The example of sulphur content is made by using P3 seam as a representative for the ***Sin Pun*** area (see Table 4.15). After simulation six lag numbers are recognized and it is discovered that the lag no. 1 is assigned at a distance between 0 and 210 m, lag no. 2 (the second lag spacing) is from 210 to 420 m, lag no. 3 from 420 to 630 m, lag no. 4 from 630 to 840 m, lag no. 5 from 840 to 1,050 m, lag no. 6 from 1,050 to 1,260 m, lag no. 7 from 1,260 to 1,470 m, lag no. 8 from 1,470 to 1,680 m, lag no. 9 from 1,680 to 1,890 m, lag no. 10 from 1,890 to 2,100 m, and lag no. 11 from 2,100 to 2,310 m. These ranges of lag spacing are applied to variogram analysis in this study. As shown in Table 4.35, lag no. 1 consists of 11 numbers of pair with the average distance of 164.630 m (computed from distance-column 4 in Table 4.36).

The variogram value as estimated based upon these parameters is 3.957. It is also noted that the orientation used in this study is based upon the direction or trend, another word E-W orientation means samples being concerned are aligned more or less in the E-W trend. Therefore, the orientation of related samples at 0° is automatically applied to 180° for computer calculation. The analysis of P3-seam sulphur content show mostly mutual relationships in the WSW - ENE direction (157.5°) at the tolerance angel of 45° and with lag spacing 310 m. These variogram values of parameters are then applied for variogram-model construction.

As shown in Table 4.35. In this model, the nugget effect (Co) equals 2.3, sill (C) equals 3, and range is 650 m. Table 4.35 shows a result of variogram parameter values plotted as variogram in Fig. 4.21. Spherical model is considered to be the most appropriate and may occur as a result of relationship among samples, shown in Tables 4.35 and 4.36. It is noted that on Table 4.36, pair means relationship between the first and the second data sample points (as 6 : 05 in the first row in the table, respectively). The 1^{st} value of the second column means value of sulphur content of the first sample, the 2^{nd} value of the third column indicates value of the second sample, distance in the forth column is length between two given samples, direction in the fifth column is orientation of the second sample as viewed from the first, and difference^2 of the last column means square of difference in values [(1^{st} - 2^{nd} values $)^2$] (see also equation 4.1). It is noted that the value in the last column (difference ^{2}, in Table 4.37) are arranged in an increasing order from the top row. Result from Table 4.37 reveals that selected lag results can give rise to the orientation with maximum related sample values at 157.5^o and its opposite direction, as compared with those of the other orientations (not shown herein). Parameters obtained from variogarm model were then tested by cross validation method. Since after estimation, the mean of P3 seam sulphur content (4.81) is different from the mean from the analysis (4.57), giving rise to the value of difference (-0.087). Furthermore, the result of cross validation (Table 4.37) can indicate the search distance used for estimation, since values of the mean of difference and Zscore can be changed based upon the change in search values. For the sulphur content of Nong Wa P3 seam, the most appropriate search distance after simulation is 200 m.

For the ***Saba Yoi*** , sulphur content data is made by using S1 seam as a representative for the Saba Yoi area (see also Table 4.16). It is observed, after simulation, that the analysis of S4 seam sulphur content shows mostly mutual relationships in the SSW-NNE direction (112.5^o) at the tolerance angle of 45^o and with lag spacing 160 m. These variogram values of parameters are then applied for variogram model construction. Fig. 4.20 shows a spherical model simulated from 5 lags and 15 concerned pairs, and average distance and variogram values shown in Table 4.32. In this model, the nugget effect (Co) equals 0.21, sill (C) equals 0.02, range is 610 m. Table 4.38 shows result of variogram parameters values plotted as variogram in Fig. 4.22. After simulation, the spherical model is encountered and may occur as a result of relationship among samples, shown in Tables 4.38 and 4.39. Result from Table 4.38 reveals that selected lag result can give rise to the maximum related sample value at 90 direction (and opposite), compared to those of the other orientations.

Parameters obtained from variogarm model were then tested by cross validation method. After estimation, the mean of S4 seam sulphur content (4.810) is different from the mean from the analysis (4.570), giving rise to the value of difference (-0.240). For the sulphur content of Ban Khok Ok S4 seam, the most appropriate search distance after simulation is 150 m.

Table 4.35. Result of lag spacing, number of pair average distance at direction 157.5^0 and variogram value for sulphur content (%), P3 seam, Sin Pun area.

Lag no.	Pair (no.)	Avg. distance (m)	Estimate
1	11	164.630	3.957
2	22	339.374	4.844
3	20	541.101	6.053
4	23	726.172	5.116
5	8	932.530	10.800
6	7	1160.827	6.516
7	6	1361.497	5.494
8	2	1523.485	.934

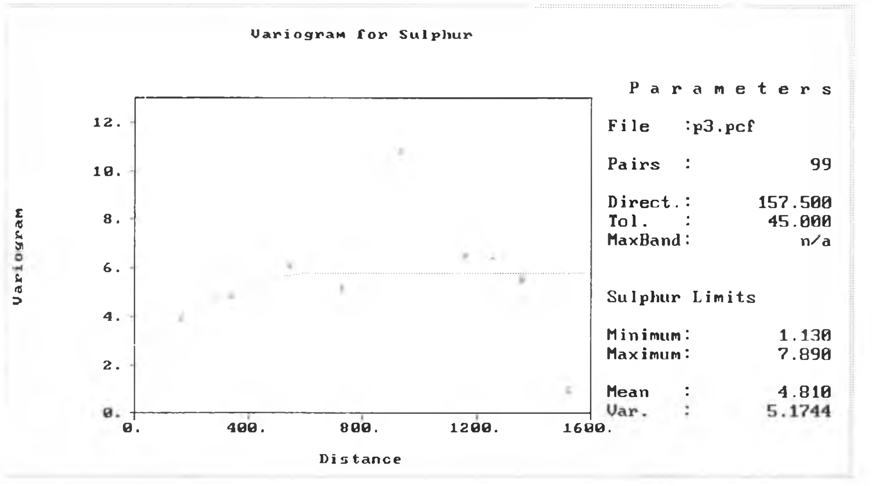


Fig. 4.21. Variogram spherical model of sulphur content (%), P3 seam, Nong Wa deposit, Sin Pun area.

Table 4.36. Selected lag results of sulphur content (%) at 157.5 orientation for P3 seam, Nong Wa deposit, Sin Pun area, using Geo_EAS software.

Lag 1 for sulphur content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
6:05	7.89	7.59	149.852	136.842	0.09
11:01	3.4	3.73	200.827	10.345	0.109
7:05	7.16	7.59	131.256	312.433	0.185
12:09	2.01	2.94	118.672	132.182	0.865
4:03	5.09	6.99	170.577	118.828	3.61
16:01	1.8	3.73	134.492	318.353	3.725
15:01	1.13	3.73	200.572	181.536	6.76
16:04	1.8	5.09	128.553	155.591	10.824
14:13	2.09	5.72	201.846	358.953	13.177
10:09	7.01	2.94	170.66	310.961	16.565
12:05	2.01	7.59	203.625	179.912	31.136

Lag 2 for sulphur content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
15:14	1.13	2.09	326.402	340.049	0.922
4:01	5.09	3.73	260.076	326.776	1.85
12:11	2.01	3.4	379.27	322.775	1.932
8:03	5.44	6.99	359.151	303.696	2.402
9:04	2.94	5.09	387.41	339.004	4.623
15:11	1.13	3.4	400.213	185.943	5.153
6:04	7.89	5.09	379.795	7.765	7.84
12:04	2.01	5.09	286.552	349.773	9.486
3:01	6.99	3.73	418.467	315.762	10.628
9:03	2.94	6.99	279.639	2.177	16.402
9:07	2.94	7.16	212.701	177.508	17.808
11:06	3.4	7.89	416.241	162.199	20.16
12:10	2.01	7.01	289.316	131.462	25
12:07	2.01	7.16	307.927	161.602	26.522
16:03	1.8	6.99	284.178	134.537	26.936
15:02	1.13	6.97	345.878	124.732	34.106
3:02	6.99	6.97	303.259	359.563	0
10:03	7.01	6.99	408.789	343.186	0
16:12	1.8	2.01	412.392	165.393	0.044
5:03	7.59	6.99	415.168	13.689	0.36
16:15	1.8	1.13	312.501	344.407	0.449
7:06	7.16	7.89	280.9	314.784	0.533

Lag 3 for sulphur content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
16:09	1.8	2.94	515.792	158.153	1.3
8:02	5.44	6.97	585.818	329.068	2.341
14:01	2.09	3.73	518.268	168.198	2.69
12:01	2.01	3.73	535.683	338.839	2.958
10:04	7.01	5.09	543.984	330.522	3.686
7:04	7.16	5.09	592.97	345.54	4.285
5:04	7.59	5.09	488.315	353.983	6.25
15:04	1.13	5.09	439.977	161.84	15.682
9:02	2.94	6.97	582.747	0.817	16.241
6:01	7.89	3.73	600.835	351.271	17.306
11:05	3.4	7.59	555.375	155.564	17.556
15:13	1.13	5.72	521.477	347.253	21.068
12:02	2.01	6.97	512.126	10.833	24.602
16:05	1.8	7.59	611.648	170.181	33.524
15:03	1.13	6.99	576.568	150.197	34.34
16:06	1.8	7.89	493.378	179.789	37.088
7:03	7.16	6.99	491.939	0.16	0.029
8:04	5.44	5.09	529.311	302.129	0.122
11:09	3.4	2.94	496.399	140.256	0.212
6:02	7.89	6.97	629.412	18.377	0.846

Lag 4 for sulphur content (%)

Pair*	1st Value	2nd Value	Distance	Direction	Difference^2
14:11	2.09	3.4	708.336	174.334	1.716
8:01	5.44	3.73	773.336	310.191	2.924
15:09	1.13	2.94	827.135	160.512	3.276
13:01	5.72	3.73	717.558	171.207	3.96
11:08	3.4	5.44	695.555	115.688	4.162
14:04	2.09	5.09	766.287	161.077	9
10:01	7.01	3.73	803.684	329.311	10.758
11:10	3.4	7.01	665.389	137.882	13.032
16:08	1.8	5.44	640.491	128.483	13.25
11:07	3.4	7.16	678.043	151.202	14.138
5:01	7.59	3.73	729.375	344.6	14.9
16:13	1.8	5.72	833.738	346.187	15.366
14:02	2.09	6.97	640.632	141.862	23.814
16:10	1.8	7.01	672.13	151.49	27.144
16:07	1.8	7.16	719.933	163.772	28.73
15:06	1.13	7.89	798.997	173.835	45.698
10:02	7.01	6.97	704.948	350.153	0.002
7:02	7.16	6.97	795.188	359.932	0.036
16:14	1.8	2.09	638.441	342.181	0.084
5:02	7.59	6.97	713.108	7.732	0.384
9:01	2.94	3.73	643.947	334.096	0.624
15:12	1.13	2.01	724.867	164.968	0.774
13:02	5.72	6.97	810.83	150.497	1.563

Lag 5 for sulphur content (%)

Pair*	1^{st} Value	2^{nd} Value	Distance	Direction	$Difference^2$
13:04	5.72	5.09	960.39	164.776	0.397
13:11	5.72	3.4	909.672	175.358	5.382
7:01	7.16	3.73	843.383	339.847	11.765
15:08	1.13	5.44	912.169	140.078	18.576
14:03	2.09	6.99	899.892	153.755	24.01
15:10	1.13	7.01	979.218	155.581	34.574
15:07	1.13	7.16	1032.42	163.965	36.361
15:05	1.13	7.59	923.099	168.229	41.732

Lag 6 for sulphur content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
14:12	2.09	2.01	1050.439	163.441	0.006
14:09	2.09	2.94	1153.529	160.381	0.723
13:03	5.72	6.99	1085.936	158.294	1.613
14:08	2.09	5.44	1224.031	145.304	11.223
13:12	5.72	2.01	1246.103	165.924	13.764
14:05	2.09	7.59	1247.046	166.095	30.25
14:06	2.09	7.89	1118.703	169.848	33.64

Lag 7 for sulphur content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
13:08	5.72	5.44	1396.542	149.897	0.078
13:05	5.72	7.59	1444.529	167.877	3.497
13:06	5.72	7.89	1318.393	171.236	4.709
13:09	5.72	2.94	1346.399	163.118	7.728

Lag 7 for sulphur content (%) (cont.)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
14:10	2.09	7.01	1304.876	156.698	24.206
14:07	2.09	7.16	1358.243	163.024	25.705

Lag 8 for sulphur content (%)

Pair*	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
13:10	5.72	7.01	1493.643	159.631	1.664
13:07	5.72	7.16	1553.327	165.068	2.074

Table 4.37 Cross validation for sulphur content (%) at 157.5° , P3 seam, Nong Wa deposit, Sin Pun area, tested using Geo_EAS program.

Sulphur Content (%)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	1.13	1.753	-3.967	2.256	-1.504
25th %tile	2.09	3.911	-2.709	2.319	-1.144
Median	5.09	4.428	-1.185	2.389	-0.525
75th %tile	6.99	5.305	2.053	2.854	0.815
Maximum	7.89	6.97	3.991	3.406	1.765
Mean	4.81	4.57	-0.24	2.499	-0.087
Std. Dev.	2.349	1.403	2.585	0.285	1.068

Table 4.38. Results of lag spacing, numbers of pair average distance at direction 90° variogram value for sulphur content (%), S2 seam, Ban Khok Ok deposit, Saba Yoi area.

Lag no.	Pair (no.)	Avg. distance (m.)	Estimate
1	3	136.246	.016
2	3	231.006	.047
3	5	436.394	.066
4	3	590.942	.077
5	1	693.731	.011

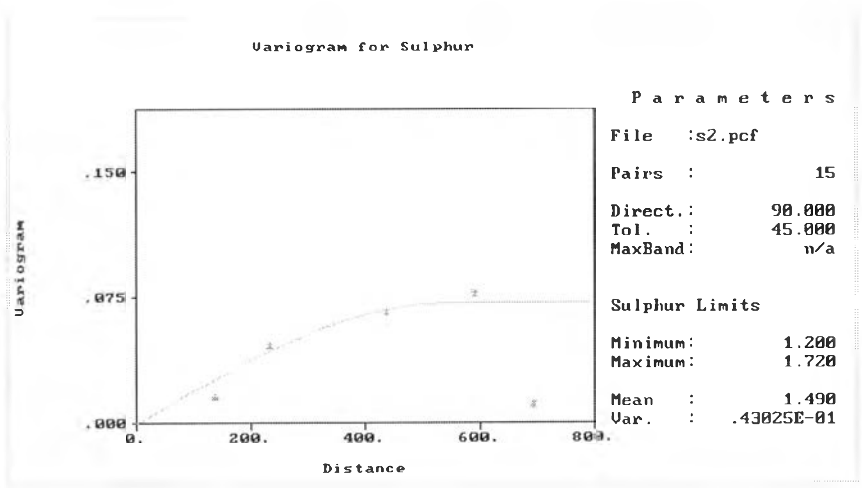


Fig. 4.22. Variogram spherical model of sulphur content (%), S2 seam, Ban Khok Ok deposit, Saba Yoi area.

Table 4.39. Selected lag results of sulphur content (%) at 90 orientation for S2 seam, Ban Khok Ok deposit, Saba Yoi area, using Geo_EAS software.

lag 1 for sulphur content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
6:04	1.720	1.690	136.808	133.149	0.001
4:01	1.690	1.620	150.880	235.395	0.005
6:05	1.720	1.420	121.048	83.954	0.09

lag 2 for sulphur content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
8:03	1.280	1.270	176.217	279.720	0.000
7:01	1.720	1.620	211.054	69.891	0.01
7:02	1.720	1.200	305.747	306.430	0.27

lag 3 for sulphur content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
7:04	1.720	1.690	359.122	63.854	0.001
7:05	1.720	1.420	433.128	52.351	0.090
3:01	1.270	1.620	458.553	51.841	0.123
2:01	1.200	1.620	457.366	103.787	0.176
6:02	1.720	1.200	473.799	261.473	0.27

lag 4 for sulphur content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
5:02	1.420	1.200	594.757	261.978	.048
4:03	1.690	1.270	609.216	232.721	.176
4:02	1.690	1.200	658.853	272.349	.240

lag 5 for sulphur content (%)

Pair*	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
5:03	1.420	1.270	693.731	226.752	.022

Table 4.40. Cross validation for sulphur content (%) at 90^o , S2 seam, Ban Khok Ok deposit, Saba Yoi area, tested using Geo_EAS program.

Sulphur Content (%)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	1.200	1.270	-.236	.191	-.993
25th %tile	1.270	1.280	-.190	.206	-.752
Median	1.420	1.500	-.010	.239	-.027
75th %tile	1.690	1.668	.048	.321	.199
Maximum	1.720	1.695	.492	.368	1.532
Mean	1.490	1.581	.028	.279	.074
Std. Dev	.222	.171	.249	.072	.941

4.4.5 Variogram Analysis of Density (g/cc)

The example of density is made by using M seam as a representative for the ***Sin Pun*** area (see Table 4.15). After simulation it is discovered the lag no. 1 is assigned at a distance between 0 and 190 m, lag no. 2 (the second lag spacing) is from 190 to 380 m, lag no. 3 from 380 to 570 m, lag no. 4 from 570 to 760 m, lag no. 5 from 760 to 950 m, lag no. 6 from 950 to 1,140 m, lag no. 7 from 1,140 to 1,330 m, and lag no. 8 from 1,330 to 1,520 m (see Table 4.41). These ranges of lag spacing are applied to variogram analysis in this study. As shown in Table 4.15, lag no. 1 consists of 1 number of pair with the average distance of 131.256 m (computed from distance-column 4 in Table 4.16).

The variogram value as estimated based upon these parameters is 0.002. It is also noted that the orientation used in this study is based upon the direction or trend, another word E-W orientation means samples being concerned are aligned more or less in the E-W trend. Therefore, the orientation of related samples at 0^{o} is automatically applied to 180^{o} for computer calculation. The analysis of M-seam density show mostly mutual relationships in the WSW - ENE direction (157.5^{o}) at the tolerance angel of 45^{o} and with lag spacing 190 m. These variogram values of parameters are then applied for variogram-model construction. As shown in Table 4.41. In this model, the nugget effect (Co) equals 0, sill (C) equals 0.012, and range is 700 m. Table 4.41 shows a result of variogram parameter values plotted as variogram in Fig. 4.23. Spherical model is recognized from the analysis and the model may occur as a result of relationship among samples, shown in Tables 4.41 and 4.42. It is noted that on the table 4.42, pair means relationship between the first and the second data sample points (as 6 : 05 in the first row in the table, respectively). The 1st value of the second column means value of density of the first sample, 2nd value of the third column indicates value of the second sample, distance in the forth column is length between two given samples, direction in the fifth column is orientation of the second sample as viewed from the first, and difference^2 of the last column means square of difference in values [(1st - 2nd values)^2] (see also equation 4.1). It is noted that the value in the last column (difference ^{2}, in Table 4.43) are arranged in an increasing order from the top row.

Result from Table 4.43 reveals that selected lag results can give rise to the orientation with maximum related sample values at 157.5° and its opposite direction, as compared with those of the other orientations (not shown herein). Parameters obtained from variogarm model were then tested by cross validation method (see Table 4.43). Since after estimation, the mean of M seam density (1.372) is different from the mean from the analysis (1.393), giving rise to the value of difference (0.021). It is also visualized from Table 4.43 that only the Zscore of the maximum value is deviate from zero, the rest of the values are satisfied, giving rise to the more reliable of the analysis. Furthermore, the result of cross validation can indicate the search distance used for estimation, since values of the mean of difference and Zscore can be changed based upon the change in search values. For the density of Nong Wa M seam, the most appropriate search distance after simulation is 420 m.

For the ***Saba Yoi*** density is made by using S4 seam as a representative for the Saba Yoi area (see also Table 4.16). After simulation it is discovered the lag no.1 is between 0 and 320 m, lag no.2 is between 320 and 640 m, lag no. 3 is between 640 and 960 m, lag no. 4 is between 960 and 1,280 m, and lag no. 5 is between 1,280 and 1,600 m. It is observed, after simulation, that the analysis of S4 seam density shows mostly mutual relationships in the N-S direction (90°) at the tolerance angle of 45° and with lag spacing 320 m. These variogram values of parameters are then applied for variogram model construction. Fig. 4.24 shows a spherical model simulated from 5 lags and 10 concerned pairs, and average distance and variogram values shown in Table 4.44.

In this model, the nugget effect (Co) equals 0.0001, sill (C) equals 0.0018, range is 1100 m. Table 4.44 shows result of variogram parameters values plotted as variogram in Fig. 4.24, After simulation, it is found out that the most satisfied model is spherical, which may occur as a result of relationship among samples, shown in Tables 4.44 and 4.45.

Result from Table 4.21 reveals that selected lag result can give rise to the maximum related sample value at 90 direction (and opposite), compared to those of the other orientations. Parameters obtained from variogarm model were then tested by cross validation method. After estimation, the mean of S4 seam density (27.388) is different from the mean from the analysis (27.206), giving rise to the value of difference (0.182). For the density of Ban Sao S4 seam, the most appropriate search distance after simulation is 270 m.

Table 4.41. Result of lag spacing, number of pair average distance at direction 157.5^0 and variogram value for density (g/cc), M seam, Sin Pun area.

Lag no.	Pair (no.)	Avg. distance (m)	Estimate
1	1	131.256	0.002
2	3	340.711	0.015
3	7	444.088	0.009
4	7	665.995	0.011
5	4	844.246	0.012
6	3	1038.869	0.027
7	2	1232.005	0.012
8	1	1383.215	0.014

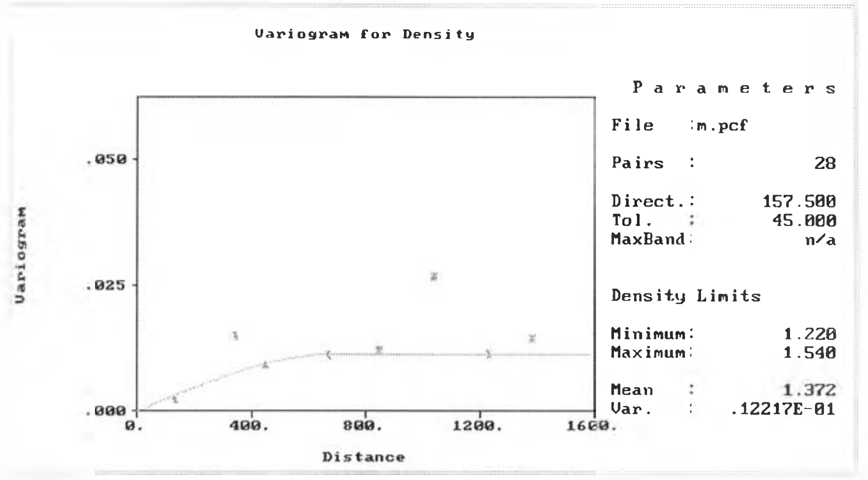


Fig. 4.23. Variogram spherical model of density (g/cc), M seam, Nong Wa deposit, Sin Pun area.

Table 4.42. Selected lag results of density (g/cc) at 0 orientation for M seam Nong Wa deposit, Sin Pun area, using Geo_EAS software.

Lag 1 for density (g/cc)

Pair *	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	$Difference^2$
6:05	1.220	1.290	131.256	312.433	0.005

Lag 2 for density (g/cc)

Pair *	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	$Difference^2$
8:04	1.430	1.390	366.456	324.426	0.002
9:07	1.540	1.330	309.798	166.609	0.044
8:1	1.430	1.220	345.878	124.732	0.044

Lag 3 for density (g/cc)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
9:03	1.54	1.52	407.355	142.086	0
7:05	1.33	1.29	555.375	155.564	0.002
8:03	1.43	1.52	439.977	161.84	0.008
8:07	1.43	1.33	400.213	185.943	0.01
9:04	1.54	1.39	407.219	345.785	0.022
2:01	1.41	1.22	410.164	165.655	0.036
5:03	1.29	1.52	488.315	353.983	0.053

Lag 4 for density (g/cc)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
7:04	1.33	1.39	716.999	346.141	0.004
7:01	1.29	1.22	713.108	7.732	0.005
7:02	1.33	1.41	638.950	20.529	0.006
7:06	1.33	1.22	678.043	151.202	0.012
3:02	1.52	1.41	620.047	4.208	0.012
4:01	1.39	1.22	701.850	134.867	0.029
6:03	1.22	1.52	592.970	345.540	0.090

Lag 5 for density (g/cc)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
6:01	1.220	1.220	795.188	359.932	0.000
4:03	1.390	1.520	797.216	153.933	0.017
8:05	1.430	1.290	923.099	168.229	0.020
9:09	1.540	1.290	861.482	159.514	0.063

Lag 6 for density (g/cc)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
5:02	1.220	1.410	1104.015	359.932	0.014
8:06	1.430	1.220	1032.420	163.965	0.044
8.06	1.540	1.220	980.171	156.019	0.120

Lag 7 for density (g/cc)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
5:04	1.290	1.390	1267.046	341.526	0.010
6:02	1.220	1.410	196.965	355.085	0.036

Lag 8 for density (g/cc)

Pair *	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
6:04	1.220	1.390	1383.215	338.881	0.029

Table 4.43. Cross validation for density (g/cc) at 0^{o} , M seam, Nong Wa deposit, Sin Pun area, tested using Geo_EAS program.

Density (g/cc)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	1.220	1.281	-.239	.085	-2.566
25th %tile	1.220	1.289	-.163	.086	-1.884
Median	1.330	1.341	-.001	.092	-.014
75th %tile	1.410	1.476	.086	.096	.694
Maximum	1.540	1.498	.265	.124	2.500
Mean	1.372	1.393	.021	.098	.157
Std. Dev	0.117	0.092	.158	.013	1.634

Table 4.44. Results of lag spacing, numbers of pair average distance at direction 112.5^{0} and variogram value for density (g/cc), S4 seam, Saba Yoi area.

Lag no.	Pair (no.)	Avg. distance (m.)	Estimate
1	3	232.840	0.001
2	2	528.237	0.001
3	3	828.838	0.003
4	2	1038.402	0.002

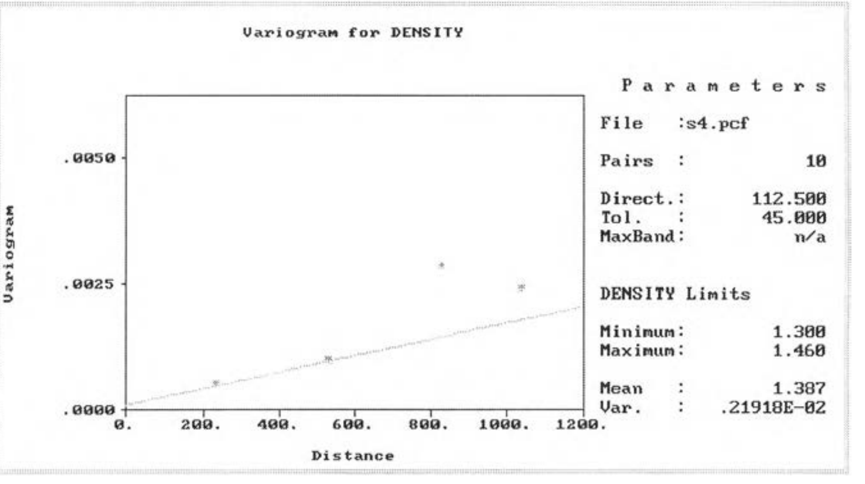


Fig. 4.24. Variogram linear model of density (g/cc), S4 seam, Ban Sao deposit, Saba Yoi area.

Table 4.45. Selected lag results of density (g/cc) at 0 orientation for S4 seam Ban Sao deposit, Saba Yoi area, using Geo_EAS software.

lag 1 for density (g/cc)

Pair	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
6:01	1.410	1.390	216.409	254.900	0.000
5:03	1.390	1.410	275.721	132.988	0.000
4:03	1.460	1.410	206.389	88.438	0.003

lag 2 for density (g/cc)

Pair	1st Value (%)	2nd Value (%)	Distance (m)	Direction (degree)	Difference^2
3:01	1.410	1.390	440.787	248.681	0.000
7:03	1.350	1.410	615.688	281.061	0.004

lag 3 for density (g/cc)

Pair	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
7:05	1.350	1.390	862.118	290.799	0.002
7:06	1.350	1.410	806.063	271.902	0.004
7:04	1.350	1.460	818.332	277.902	0.012

lag 4 for density (g/cc)

Pair	1^{st} Value (%)	2^{nd} Value (%)	Distance (m)	Direction (degree)	$Difference^2$
7:01	1.35	1.39	1015.749	267.623	0.002
5:02	1.39	1.30	1061.056	71.115	0.008

Table 4.46. Cross validation for density (g/cc) at 112.5^o , S4 seam, Ban Sao deposit, Saba Yoi area, tested using Geo_EAS program.

Density (g/cc)

Value	Variable	Estimate	Difference	Kriging Std.	Zscore
Minimum	1.300	1.398	-.057	.019	-3.021
25th %tile	1.300	1.398	-.057	.019	-3.021
Median	1.390	1.407	.028	.027	.659
75th %tile	1.410	1.418	.033	.036	.772
Maximum	1.460	1.443	.057	.073	1.861
Mean	1.387	1.418	.016	.037	.250
Std. Dev	0.051	0.019	.043	.020	1.775

4.5 Summary of the Variogram Result

Based upon the results shown in section 4.4 and the overall results and analyses [including the details of lag results, results from variogram-parameter values, variogram model for the other variables, not shown in section 4.5 in the Appendices B, C, and D, the followings (see Tables 4.47 and 4.48) are the summary of such variogram results.

It is observed that most of the variogram results fit fairly well with the spherical model, particularly those of Sin Pun coal quality data (about 96% of 25 models). However, for the 20 models of Saba Yoi, it is found that about 40% is spherical, 35% is linear, 20% is nugget-effect, and 5% is gaussian.

Table 4.47. Summary of result of Variogram for Sin Pun Area.

Seam	Variable	direction (degree)	tolerance angle	lag spacing (m)	nugget	sill	range (m)	model
P1	Ash	157.5	45	280	0	130	900	Spherical
	CV	157.5	45	280	0	690000	600	Spherical
	Moisture	135	45	150	0	63	800	Spherical
	Sulphur	157.5	45	180	0	4	500	Spherical
	Density	157.5	45	190	0	0.009	700	Spherical
P2	Ash	157.5	45	140	15	72	750	Spherical
	CV	0	45	240	0	675000	600	Spherical
	Moisture	157.5	45	170	12	19	600	Spherical
	Sulphur	157.5	45	350	0.5	-	420	Linear
	Density	157.5	45	260	0.004	0.0045	400	Spherical
P3	Ash	157.5	45	160	0	100	530	Spherical
	CV	157.5	45	160	0	960000	650	Spherical
	Moisture	0	45	190	0	22	350	Spherical
	Sulphur	157.5	45	210	2.8	3	650	Spherical
	Density	22.5	45	280	0.006	0.013	850	Spherical
P4	Ash	157.5	45	300	18	-	500	Linear
	CV	157.5	45	200	250000	280000	450	Spherical
	Moisture	157.5	45	310	8	18.5	550	Spherical
	Sulphur	0	45	280	2.3	2.6	500	Spherical
	Density	157.5	45	150	0	0.021	420	Spherical
M	Ash	157.5	45	170	18	-	550	Linear
	CV	157.5	45	220	0	-	400	Linear
	Moisture	157.5	45	350	0	17	600	Spherical
	Sulphur	157.5	45	300	2.8	4.2	850	Spherical
	Density	157.5	45	190	0	0.0115	700	Spherical

Table 4.48. Summary of result of Variogram for Saba Yoi Area.

Seam	Variable	direction (degree)	tolerance angle	lag spacing (m)	nugget	sill	range (m)	model
S1	Ash	90	45	240	2.2	3	380	Spherical
	CV	90	45	300	2500	-	530	Linear
	Moisture	112.5	45	260	0	9	450	Spherical
	Sulphur	112.5	45	200	0	0.07	600	Spherical
	Density	90	45	260	0	0.007	700	Spherical
S2	Ash	67.5	45	130	3	5	250	Spherical
	CV	45	45	180	40000	62000	400	Spherical
	Moisture	-	45	200	-	2.5	-	Pure nugget
	Sulphur	90	45	160	0	0.072	550	Spherical
	Density	67.5	45	150	0	-	550	Linear
S3	Ash	112.5	45	320	-	40	-	Pure nugget
	CV	112.5	45	330	0	130000	1000	Spherical
	Moisture	112.5	45	330	1	26	1500	Gaussian
	Sulphur	112.5	45	330	0	-	1200	Linear
	Density	112.5	45	400	0.0026	-	1600	Linear
S4	Ash	-	45	-	-	10	-	Pure nugget
	CV	-	45	-	-	190000	-	Pure nugget
	Moisture	-	45	-	-	15	-	Pure nugget
	Sulphur	-	45	-	-	0.3	-	Pure nugget
	Density	112.5	45	350	0.0001	-	1100	Linear