

## SPATIAL ANALYSIS 3D GEOLOGY NICKEL USING ORDINARY KRIGING METHOD

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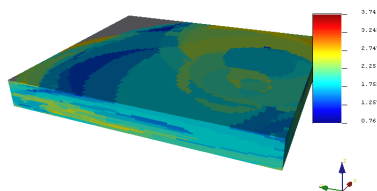
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### Graphical abstract



### Abstract

Utilization of minerals to supply raw materials in various fields, causing diminishing reserves of the mine. Nickel is one of mine production are widely used today are in various applications and industries, such as coating steel, coating copper, industrial batteries, electronics, aerospace applications, the textile industry, and a variety of other functions. The activities to obtain continuous nickel had to be done by the mining industry. Therefore, it need to conduct nickel resources exploration to obtain optimum results. To obtain complete and accurate information accosiated with mineral resource and geological conditions of nickel mine in exploration activities, 3D spatial analysis is needed. This paper discusses the general process of 3D nickel geological modeling and also discuse spatial analysis results have been obtained on each layer. Analysis of the ferro (Fe) content is also considering because Fe is a material that greatly affects nickel content in a layer of soil. The analysis result shown, that show each layer has different characteristics. Layer 1 has a nearly 60% saprolite layer characteristics, while at layer 2, has nearly 70% saprolite.

Keywords: Nickel, geological modelling, spatial, ordinary Kriging

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## 1.0 INTRODUCTION

In mining industry there are several steps that must be done, which includes prospecting, exploration, evaluation (feasibility study), mine plant design and finance (plant design and cost), development (preparation), exploitation (mining) and processing (processing). Exploration is a basic stages that determine the successful of a mining activity. Exploration is the stage to estimate the location and amount of the mineral reserves.

Nickel is important mine that widely used today. Nickel are used in various applications and industries, such as coatings of steel, coatings of copper, industrial batteries, electronics, aerospace applications, the textile industry, turbine power plant, a maker of powerful magnets, manufacture of laboratory equipment (nichrome) wire electric lamps, and various other functions. The effort to get a continuous resource of nickel must be done in the mining industry with optimum results.

To obtain optimum results, the exploration activities need modeling and resource computation. A model of mineral resources resulting from the modeling phase will determine mining method that will be perform. While the resource computation is very important in the mining evaluation activity both at the stage of feasibility studies as well as for the implementation of the mining activities. Modeling and resource computation can be done by various methods that are based on empirical and theoretical considerations.

The remaining chapter of this paper is organized as follows: in the chapter literature review, will be presented recently research related to nickel exploration process. In Chapter of modeling process, will be described in detail the process of experimental semivariogram calculation stage until the prediction and visualization of nickel content. experimental result chapter contains an analysis of the experimental results that have been obtained. Finally, in the conclusion chapter, delivered

important summaries of the results of the analysis that has been done.

## 2.0 LITERATURE REVIEW

In nickel exploration activities, there are a few studies have been done within the last 10 years. Lightfoot companies in their research have identified eight key features that are required in development of large nickel sulphide system[1]. These key features would have important benefit in nickel mining activities, however Lightfoot could not provide details description of every large Ni system. Other related studies with description of every large Ni system, carried out by Sahiti *et al.* [2]. Based on the results of 3D structural modeling, some important points of research among others Factors that have contributed to the re-grouping of chemical elements and the formation of new minerals, Classification of nickel deposit in three group, and ore bodies' morphology consists of layered composition character with horizontal zonality.

Sutisna *et al.* make exploration planning in the eastern Halmahera as a model Nickel laterite exploration in Indonesia[3]. Planning is done in three area categories, namely sector area A (very high prospective area), sector B (relative prospective areas), and sector C (minor prospective area). In another similar study, Hill and Mccarthy utilize results of nickel modeling in western Tasmania region to make the prospectivity Modelling of Granite-Related Nickel Deposits Throughout Eastern Australia[4]. In this research, Hill and Mccarthy use the weights of evidence (WOE) spatial data modelling technique to evaluate the wealth of geological data available over the study area. In another study, the performance of the method weights of evidence (WOE) for spatial modeling of data then improved by He *et al.* using case-based reasoning (CBR)[5]. The Kriging is an interpolation technique that gives the best linear unbiased prediction of the intermediate values[6]. However, the uncertainty factor is still appear in the prediction process. 3D nickel geological modeling uncertainty can be analyzed from several factors. Choi *et al.* propose a new method for analyzing the uncertainty factor predictions using Kriging variance[6].

## 3.0 MODELLING PROCESS

This study proposed a system that able to provide estimates of mineral content at new point to determine the position of the new drilling that used in the exploration stage. The system is integrated system designed ranging from spatial data input, modeling, model validation until output issued both in numbers prediction and visualization. Design of Nickel modeling system that developed can be seen in Figure 1.

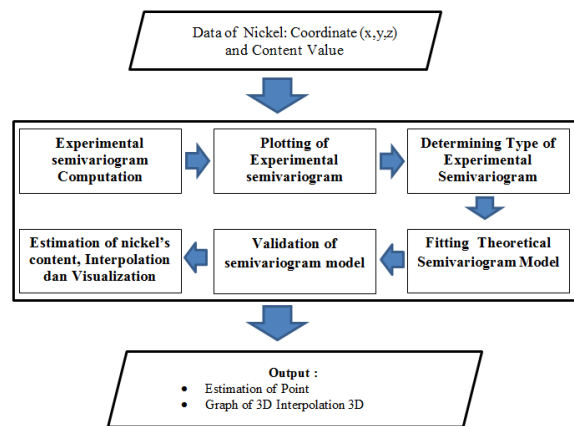


Figure 1 Design of 3D Nickel Modelling System

### 3.1 Experimental Semivariogram Computation

Development of a model for the 3D experimental semivariogram computation based on 2D experimental semivariogram models. This process includes computation of horizontal experimental semivariogram and computation of vertical experimental semivariogram.

#### 3.1.1 Horizontal Experimental Semivariogram

The horizontal experimental semivariogram measure the spatial correlation in the error variance form at locations with a distance h. In general, the models developed will be used for irregular or regular data. There are 4 direction is defined in the horizontal plane for the computation of Horizontal Experimental semivariogram ie North-South (N-S), East-West (E-W), North West-South East (NW-SE), and South West-North East (SW-NE). Illustration of four horizontal direction can be seen in Figure 2.

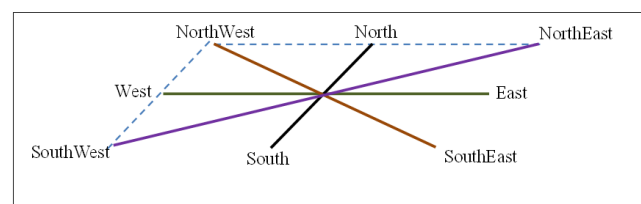


Figure 2 Four Directional of Horizontal Semivariogram

#### 3.1.2 The formula for Direction and Tolerance

Determination of two points A and B into one direction is based on angle between two points. In the real data, the angle that occurs between two points is not always appropriate four cardinal directions have been determined. Angle tolerance is required to solve this problem. If  $\theta$  is the real angle between points A and B, then the formula to

determine Direction (A, B) with a tolerance t can be written as follows:

$$Direction(A, B) = \begin{cases} N-S, & 90^\circ - \frac{t}{2} \leq \theta \leq 90^\circ + \frac{a}{2} \quad OR \quad 270^\circ - \frac{t}{2} \leq \theta \leq 270^\circ + \frac{t}{2} \\ W-E, & 360^\circ - \frac{t}{2} \leq \theta \leq 0^\circ + \frac{a}{2} \quad OR \quad 180^\circ - \frac{t}{2} \leq \theta \leq 180^\circ + \frac{t}{2} \\ NE-WS, & 45^\circ - \frac{t}{2} \leq \theta \leq 45^\circ + \frac{a}{2} \quad OR \quad 225^\circ - \frac{t}{2} \leq \theta \leq 225^\circ + \frac{t}{2} \\ NE-SE, & 135^\circ - \frac{t}{2} \leq \theta \leq 135^\circ + \frac{a}{2} \quad OR \quad 315^\circ - \frac{t}{2} \leq \theta \leq 315^\circ + \frac{t}{2} \end{cases}$$

### 3.1.3 Formula of Horizontal Semivariogram

For each horizontal direction, experimental semivariogram is calculated using the formula:

$$\gamma(h_s, 0) = \frac{1}{2 \|N(h)\|} \sum_{N(h_s)} [W(s+h, v) - W(s, v)]^2$$

### 3.1.4 Computation of Vertical Semivariogram

Computation of Vertical semivariogram use identical formula with horizontal semivariogram formula, but the vertical semivariogram formula is simpler. There is no angle tolerance and there is only one direction.

### 3.2 Plotting of Experimental Semivariogram

This is a process to display result of experimental semivariogram computation in the two-dimensional plane to see Experimental semivariogram distribution pattern in four different directions, namely: North-South (N-S), East-West (E-W), NorthWest-SouthEast (NW-SE), and SouthWest-NorthEast (SW-NE). To facilitate the validation process, the Grid is made. Plotting the data will be visualized in the horizontal plane with a certain grid size.

### 3.3 Determining Type of Experimental Semivariogram

Horizontal experimental semivariogram types are unisotropy or isotropy. Type un-isotropy occurs when patterns of experimental semivariogram appear in certain direction. The strongest pattern in certain direction will be chosen, along with minor value range and range-related major. When all the patterns are random, then experimental semivariogram types is isotropy. In isotropy type, four directions semivariogram are combined by calculating the average.

### 3.4 Fitting Theoretical Semivariogram Model

This is the matching process between theoretical semivariogram and experimental semivariogram. This process is done visually where the user selects the parameters (range, sill) and choose best theoretical semivariogram models based on visual observation.

### 3.5 Validation of Semivariogram Model

This process is used to validate each semivariogram theoretical models. The model with the smallest Root

Mean Square Error (RMSE) value, was chosen as the best model.

### 3.6 Estimation of nickel's content, Interpolation dan Visualization

This is the nickel content estimation process on a number of new points. The estimation results then are used in the interpolation process, i.e. the prediction process on a very large number points. This will make the quality of image visualization will be high. Kriging estimation formula at the point v is given by:

$$\hat{W}(v) = \sum_{i=1}^n \lambda_i W(v_i) \tag{1}$$

where W (vi) is the nickel content at i-th neighboring point and λi is the weight of the i-th point. Neighboring point is the point which lies inside ellipsoid with radius : minor range, major range and vertical range. The ellipsoid based on the following models:

$$\frac{x^2}{Major\ range^2} + \frac{y^2}{Minor\ range^2} + \frac{z^2}{Vertical\ range^2} = 1$$

while λi is the solution of linear equation system:

$$\begin{bmatrix} \gamma_{11} & \gamma_{12} & \dots & \gamma_{1N} & 1 \\ \gamma_{21} & \gamma_{22} & \dots & \gamma_{2N} & 1 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ \gamma_{N1} & \gamma_{N2} & \dots & \gamma_{NN} & 1 \\ 1 & 1 & \dots & 1 & 0 \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_N \\ \mu \end{bmatrix} = \begin{bmatrix} \gamma_{1,v} \\ \gamma_{2,v} \\ \vdots \\ \gamma_{N,v} \\ 1 \end{bmatrix}$$

where γiv defined as the distance between the point i and v.

2D plane interpolation process use kriging interpolation with Least Square method while 3D surface interpolation uses the B-Spline method.

## 4.0 RESULTS AND DISCUSSION

The data used in this study is a real geological data of nickel and Fe in a mine. The information used is the location coordinates (x, y), z elevation from sea level, the levels of nickel, and the level of Fe and Nickel profile (saprolit and limonit).

### 4.1 Type of Experimental Semivariogram

The first stage should be done to estimated levels of nickel, is to calculate the experimental semivariogram based on the distance and direction of the observational data. The characteristics of 3D semivariogram is anisotropy. 3D semivariogram is a combination of horizontal and vertical, characterized by the three range, namely major range, minor range and vertical range. Table 1 and Table 2 is the result of matching between semivariogram theoretical and experimental semivariogram. Model

matching result is then used in the estimation process by the method of ordinary kriging.

**Table 1** The best characteristic in Experiment: Nugget, Sill, major range and minor range

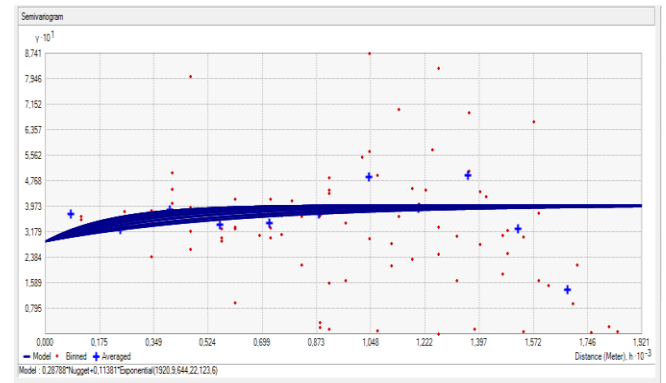
Layer	Mine	Model	Nugget	Sill	major range	minor range
1	Nickel	Spherical	0,303	0,101	1920,94	644,22
		Exponential	0,29	0,114	1920,94	644,26
		Gaussian	0,32	0,092	1920,94	644,22
	Fe	Spherical	127,76	16,73	1920,94	644,22
		Exponential	128,39	14,25	1920,94	644,26
		Gaussian	128,67	19,46	1920,94	644,26
2	Nickel	Spherical	0,46	0,14	344,33	194,03
		Exponential	0,35	0,26	344,33	194,03
		Gaussian	0,50	0,10	344,33	214,14
	Fe	Spherical	158,68	56,40	1760,81	589,57
		Exponential	146,84	67,64	1760,81	589,57
		Gaussian	168,39	52,37	1760,81	589,57

Table 2 shows that data is anisotropy, which indicated the presence of a range of major, minor range and vertical range in different values. The best theoretical semivariogram elected to Nickel layer 1 and layer 2 are respectively Exponential and Gaussian, with RMSE values of 0.17 and 0.77. While the best theoretical semivariogram elected to the iron layer 1 and layer 2 are respectively Gaussian and spherical with RMSE values of 12.75 and 14.45. These two cases show that the theoretical semivariogram models of each mineral in different layers tend to be different. It is also in accordance with the geological characteristics of the nickel and Fe are likely to tend to different.

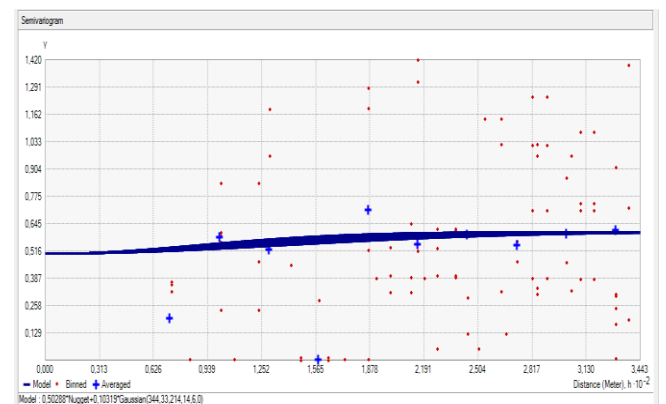
**Table 2** The best characteristic in Experiment: vertical range, direction (Dir), factor of anisotropy and RMSE

Layer	Mine	Model	vertical range	Dir	Factor of an	RMSE
1	Nickel	Spherical	3,07	121,113	2,98	0,618
		Exponential	3,07	123,57	2,98	0,617
		Gaussian	3,07	119,179	2,98	0,618
	Fe	Spherical	143,72	126,035	2,98	12,77
		Exponential	143,72	126,035	2,98	12,76
		Gaussian	143,72	126,035	2,98	12,75
2	Nickel	Spherical	4,10	142,48	1,77	0,81
		Exponential	3,07	144,92	1,77	0,82
		Gaussian	4,10	5,98	1,60	0,77
	Fe	Spherical	143,72	133,07	2,99	14,45
		Exponential	143,72	133,42	2,99	14,45
		Gaussian	143,72	132,54	2,99	14,46

The distribution pattern of horizontal semivariogram values for nickel mine material in each layer is shown in Figure 3 and Figure 4.



**Figure 3** The distribution pattern of horizontal semivariogram values for nickel material in first layer



**Figure 4** The distribution pattern of horizontal semivariogram values for nickel material in 2nd layer

Based on Figure 3 and 4, it appears that the trend towards of nickel in layer 1 and layer 2 are different. At layer 1, the slope is 123.570 so that the distribution of the data tend towards the Northwest - Southeast. While at layer 2, the slope of 5.980 with a data distribution tends to the north - south. distribution pattern semivariogram values tend to be different in each layer. on the 1st nickel layer semivariogram values tend to gather closer to the average, while the nickel layer 2nd, semivariogram value tends to spread away from the average. Figure 5 shows the distribution pattern of horizontal semivariogram values for Fe material in first layer while Figure 6 demonstrates the distribution pattern of horizontal semivariogram values for Fe material in 2nd layer.

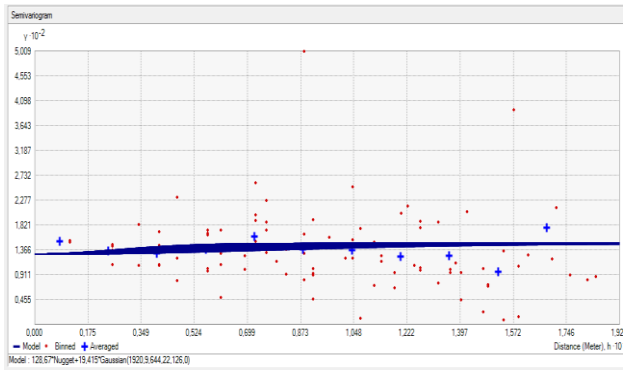


Figure 5 The distribution pattern of horizontal semivariogram values for Fe material in first layer

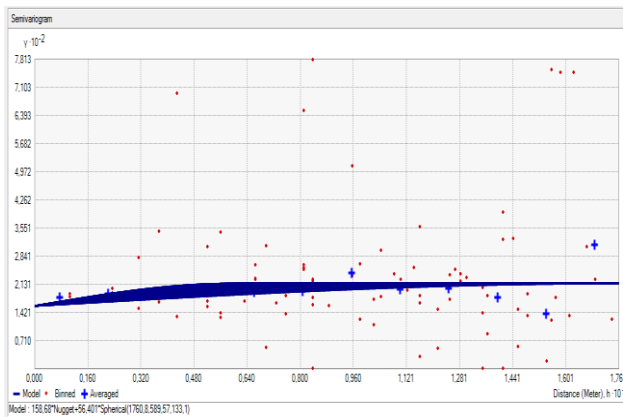


Figure 6 The distribution pattern of horizontal semivariogram values for Fe material in 2nd layer

### 4.2 Prediction, Interpolation and Visualization Levels of Nickel and Fe

By using the best semivariogram models that have been obtained from the previous process and its parameters, then the prediction process is done using Ordinary Kriging method. The interpolation process then also carried out on other points based on points predicted results that have been obtained.

Distribution pattern nickel and Fe content that describes the overall geology of minerals in each layer are then presented in a pattern of colored regions. The shades start from dark blue that express the lowest levels of the value, up to the red color of the declared value greatest levels. Distribution pattern of nickel content in each layer can be seen in Figure 7 and 8, while the distribution pattern of the Fe content in each layer can be seen in Figure 9 and 10.

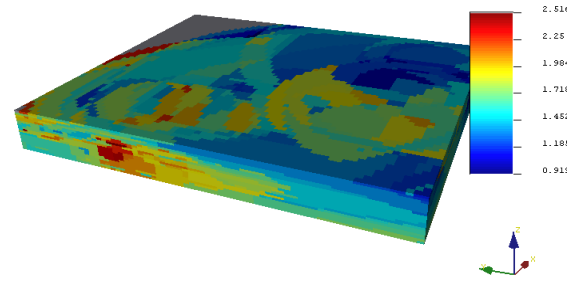


Figure 7 Distribution pattern of Nickel value prediction on the 1st layer

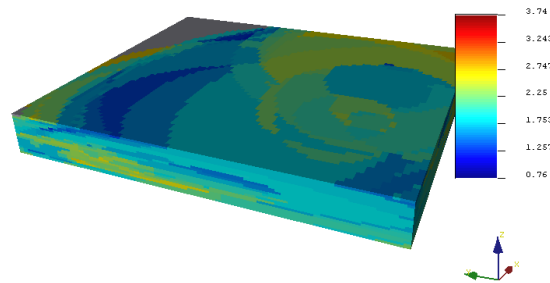


Figure 8 Distribution pattern of Nickel value prediction on the 2nd layer

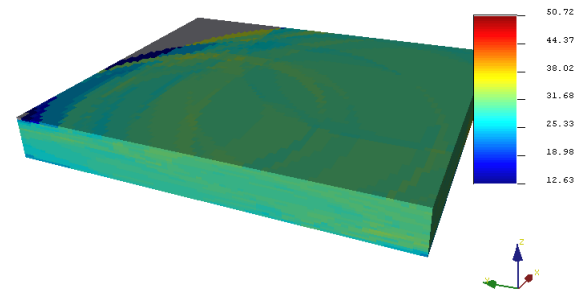


Figure 9 Distribution pattern of Fe value prediction on the 1st layer

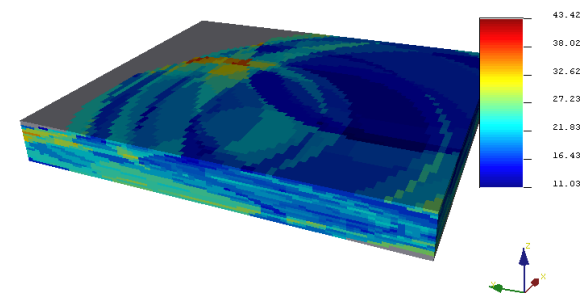


Figure 10 Distribution pattern of Fe value prediction on the 2nd layer



Based on the Figure 7 and 8, it can be concluded that about 40% of nickel content ranges from 0.92 to 1.72, 40% other levels ranged from 1.72 to 2.25, and the remaining ranging from 2.25 to 2.5. Based on the references used, it can be said that most of the estimated levels of nickel in the 1st layer is about 60% of saprolite. While on the 2nd layer, shows that almost 70% of the nickel content distribution is saprolite, because the levels of light blue to yellow dominate the block at intervals of 1.75 to 2.75. This result is also supported by the distribution of the Fe values in the Figure 9 and 10.

### 4.3 Validation of Result Prediction

The accuracy of the prediction results of nickel and Fe that has been obtained from the previous process can be validated based on it's interval predictive value have been obtained. In Figure 11 and Figure 12, the prediction interval of nickel is 0.76 to 3.74. This value interval corresponding to the actual nickel content data. Likewise for data prediction Fe content as shown in Figure 9 and 10. The iron prediction interval is 11.03 to 50.72 value also corresponds to the actual Fe content data.

Another way to validate Result Prediction is based on Kriging variance value. Based on Figure 13 and Figure 14, nearly 95%, the variance of nickel content is in the interval 0.18 to 0.22. While based images 13 and 14, nearly 95%, the variance of the iron content is in the interval from 0.15 to 0.18. these variance values is relatively small so that the prediction results obtained can be quite good.

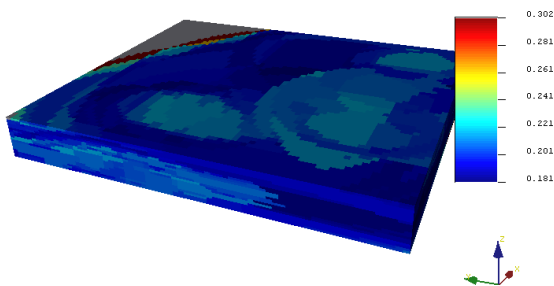


Figure 11 Kriging variance distribution pattern of nickel on the first layer

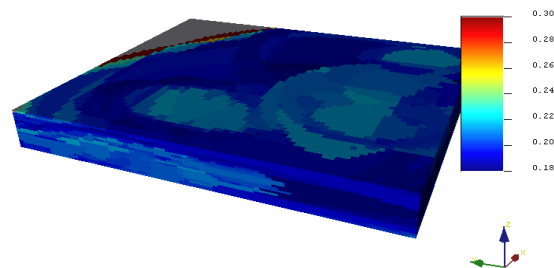


Figure 12 Kriging variance distribution pattern of nickel on the second layer

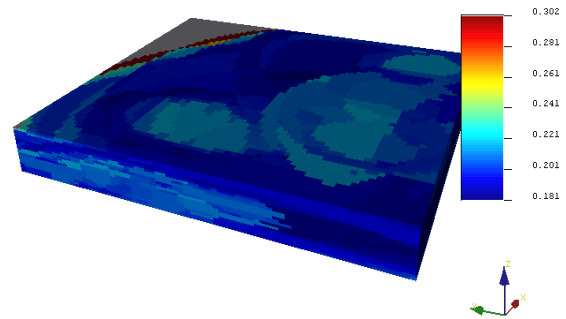


Figure 13 Kriging variance distribution pattern of Fe on the first layer

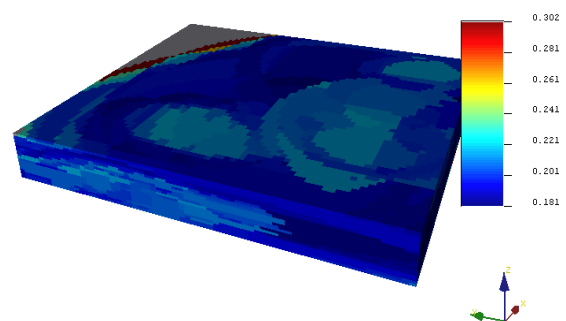


Figure 14 Kriging variance distribution pattern of Fe on the second layer

## 5.0 CONCLUSION

Based on the analysis of experimental results, some conclusions can be drawn related to spatial analysis of geological nickel namely

1. Selected semivariogram theoretical model of nickel and Fe materials in layers 1 and 2 is different, according to the geological characteristics of each mineral
2. The pattern of semivariogram value distribution is indicated by the direction of the ellipse
3. Based on the distribution pattern of nickel and Fe content in the layer 1, almost 60% of its characteristics is saprolite, whereas in the layer 2, almost 70% of characteristics is saprolite.

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## References

- [1] Lighfoot. 2007. Advances in Ni-Cu-PGE Sulphide Deposit Models and Implications for Exploration Technologies. 629-646.
- [2] F. Sahiti, K. Makolli, F. Jusufi, S. Avdullahi, dan I. Fejza. 2013. 3D Structural Modeling And Organization Of Silicate Deposit Of Fe , Ni In Gllavica. 3(4): 99-104.
- [3] D. T. Sutisna, D. N. Sunuhadi, A. Pujobroto, dan D. Z. Herman. 2006. Perencanaan Eksplorasi Cebakan Nikel Laterit di Daerah Wayamli, Teluk Buli, Halmahera Timur sebagai Model Perencanaan Eksplorasi Cebakan Nikel Laterit di Indonesia. *Bul. Sumber Daya Geol.* 1(3): 48-56.
- [4] M. P. Hill dan A. Mccarthy. 2008. Prospectivity Modelling of Granite-Related Nickel Deposits Throughout Eastern Australia. November: 1-6.
- [5] B. He, J. Chen, C. Chen, dan Y. Liu. 2012. Mineral Prospectivity Mapping Method Integrating Multi-Sources Geology Spatial Data Sets and Case-Based Reasoning. April: 77-85.
- [6] Y. Choi, Y. Choi, S. Park, dan J. Um. 2014. Uncertainty Analysis For 3D Geological Modeling Using The Kriging Variance. 16: 10061.