Topographic effect to the prediction of nickel deposit

La Ode Ngkoimani, and Edi Cahyono

Abstract**—**Predicting nickel ore content inside the soil under a given area/region is considered. This is very important for exploitation activity from economic point of view. So far, the prediction is based on the data from the drilling activity at several „points" which yield information of the nickel concentration at every point. Current methods applied in industries only provide nickel concentration in the whole region. Moreover, in drilling activity the effect of topographic surface does not taken into account. This paper discusses the prediction of total nickel content in the whole region by considering the topographic surface. The total content is approximated by integral of the nickel concentration over the surface. Whereas the nickel concentration under the surface is approximated by applying linear interpolation of the data obtained from drilling. The total nickel content in the whole region is more desirable for deciding exploitation activity from economic point of view. An example of the effect of surface topography which gives an error in prediction is also presented.

Keywords**—**Interpolation, nickel ore, nickel deposit, prediction, topographic surface.

I. Introduction

THIS paper is motivated by the limited study on the nickel mining activity in Indonesia, some of them are given in [1,2]. Whereas recently the nickel mining industries in Indonesia grow very rapidly which need to be done effectively and efficiently, both from exploration and exploitation points of views.

Many ways have been done to make exploration more efficient, including to obtain information of nickel reserves underneath the earth surface. The information may be collected by applying the geochemical exploration techniques from soil samples [3, 4, 5, 6, 7, 8, 9], or by combining soil samples and some data from plants in the biogeochemical techniques [10, 11]. These are exploration activity to know the indicators of the existence of nickel ore. To know the information of the nickel deposit, however, it needs a detail exploration, such as predicting the deposit from drilling data [12, 13].

Basically, exploitation is just taking out (mining) mineral ores, and carried out only if it is economically feasible [14]. Exploration such as to know the predicted nickel deposit, must guarantee that the exploitation is profitable. Unfortunately, the nickel deposit cannot be measured directly. It is calculated indirectly based on the existing data that are collected from drilling samples at several points. Recently economic feasibility should also consider the future prices in derivative trading. In this case predicting economic recession such [15] should be considered. The impact of mining such as chemical mineral to the environment is not less important. Hence a method presented in [16] is also important to be considered in studying the impact of the mining to the environment.

II. Problem Formulation

Economic feasibility of mining industries requires the knowledge of nickel deposit in the areas where the mining process will be carried out. However, the amount of nickel in this area cannot be measured directly. It should be calculated based on the existing data from drilling at several points using a prediction method.

In the drilling activity, the drilling depth is up to 30 meter. Mining nickel more than 30 meter below the surface is dangerous and not economically profitable. Sometimes, the drilling is less than 30 meter of depth if it reaches the fresh rock. Nickel and other minerals are deposited in the upper layers, see Figure 1 for an illustration. Those mineral cannot penetrate into the fresh rock layer.

La Ode Ngkoimani is Associate Professor of Physics at *Universitas Halu Oleo*, Kampus Bumi Tridharma Anduonohu Kendari 93232 Indonesia (e-mail: ld.ngkoimani@uho.ac.id or laodem@yahoo.com).

Edi Cahyono is with Department of Mathematics *Universitas Halu Oleo*, Kampus Bumi Tridharma Anduonohu Kendari 93232 Indonesia (corresponding author phone: +62 819-4321-5989; fax: +62 401-319-0006; e-mail: edi.cahyono@uho.ac.id or edi_cahyono@innov-center.com).

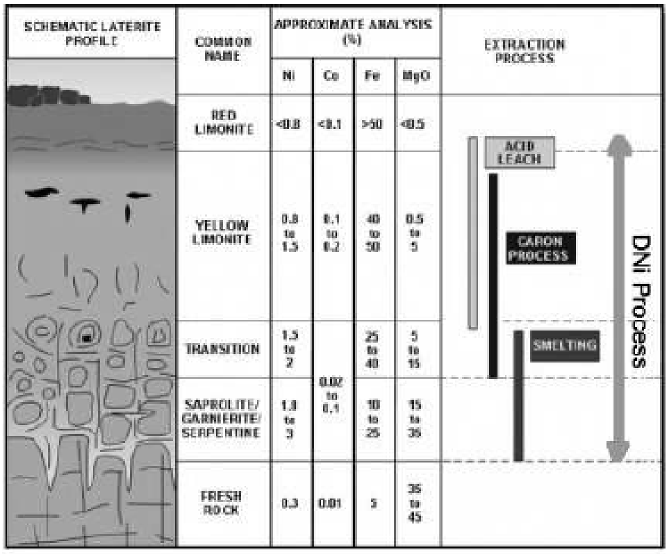

Figure 1. Illustration of soil layers contain nickel (and other metals).

The drilling is to provide data of nickel concentration and other minerals such as iron, cobalt at the drilling points. It also gives information about of the depth of the mineral concentrations below the surface. Tabel 1 is an example of data recorded from a drilling point, [12].

Tabel 1. An example of mineral concentration data recorded at a drilling point.

SampNo	EASCO	NORCO	ELEV	Level		Ni	Co	Fe	SiO2	CaO	MGO
60	-5675	-5909.6	133.9	17	16	1.26	0.12	27.70	29.38	1.17	11.80
60	-5675	-5910.2	133.9	18	17	1.35	0.03	10.22	39.31	1.27	30.36
60	-5675	-5910.8	133.9	19	18	1.25	0.04	19.53	33.34	0.70	25.41
60	-5675	-5911.4	133.9	20	19	0.92	0.04	15.92	51.63	0.57	16.46

SampNo	EASCO	NORCO	ELEV	Level		S/M	Fe/Ni	BC	LP	TAMB
60	-5675	-5909.6	133.9	17	16	2.49	21.98	0.43	625	0
60	-5675	-5910.2	133.9	18	17	1.29	7.57	0.79	625	0
60	-5675	-5910.8	133.9	19	18	1.31	15.62	0.78	625	0
60	-5675	-5911.4	133.9	20	19	2.53	17.30	0.41	625	0

In the detail exploration, sample data is collected from drilling at corners of rectangular shape mining area. The distance of two adjacent points is 25 meter. The number of points to drill may reach hundreds. The larger the number of points, the more expensive the drilling. Figure 2 shows an illustration of the drilling points. The nickel concentration under the rectangular surfaces is predicted by applying interpolation method from the drilling data at those points.

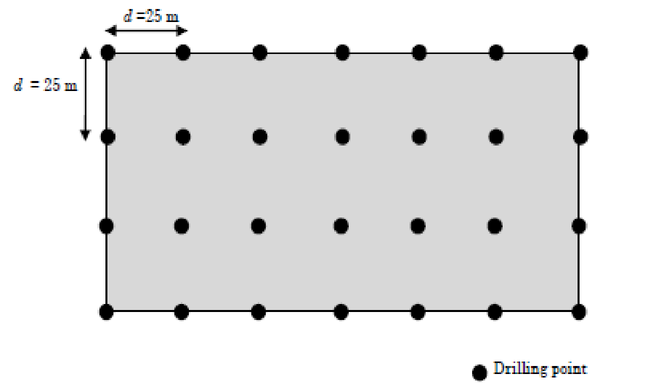

Figure 2. Illustration of drilling points on rectangle-shaped mining area.

Several current methods have been applied to predict nickel concentration under a given surface area based on data from drilling point. A prediction in three-dimensional representation provides nickel concentration information. Figure 3 shows a schematic plot of information about nickel concentration above 1% in a mining block in Sulawesi, Indonesia. It is plotted based on more than a hundred drilling points. The same block may give a different schematic plot for concentration above 2%, a minimum concentration that is required by industries.

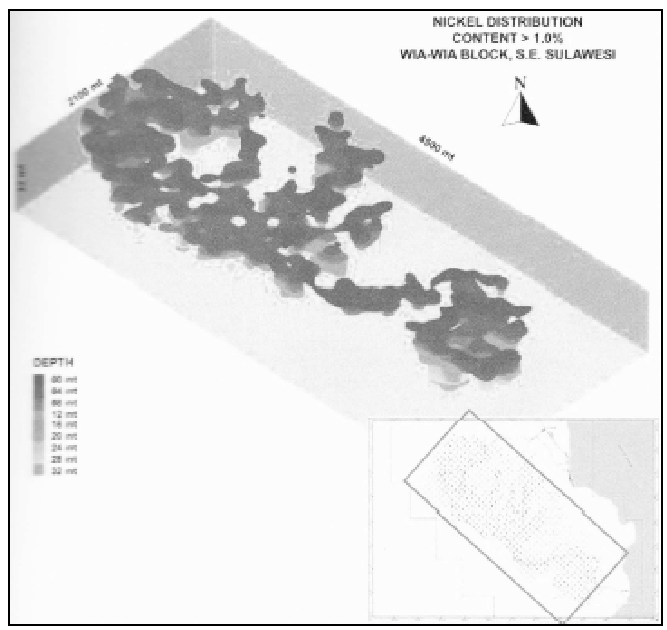

Figure 3. Prediction of nickel concentration based on data from drilling points.

For economic feasibility studies, the knowledge of nickel deposit is more preferable than nickel concentration. The interest is the total nickel deposit. Hence, we need to introduce a terminology nickel concentration per unit surface area ρ, measured in kg.m^{-2}. At every drilling points ρ can be computed, namely the total nickel in the pipe taken from that drilling divided by the area of the pipe of drilling.

III. Mathematical Formulation

Let the nickel content over unit surface area at point (x, y) denoted by $\rho(x, y)$. Hence, the total nickel deposit in a surface area A is given by double integral

$$T = \int_A \rho(x, y) dA . \quad (1)$$

The function $\rho(x, y)$ is still unknown. Hence, the integral (1) is also unknown.

Suppose A be union of A_i $A = \bigcup_{i=1,n} A_i$. A_i is a 'rectangle' on a surface where the drillings are conducted at the corners. Integral (1) is equivalent to

$$T = \sum_{i=1}^{n} \int_{A_i} \rho(x, y) dA . \quad (2)$$

We now focus on every the surface area A_i, without loss of generality we consider only A_1. Therefore, we focus on

$$T_1 = \int_{A_1} \rho(x, y) dA . \quad (3)$$

Assuming that A_1 is on a flat surface, then A_1 is a rectangle where the edges are 25 m. Suppose the nickel concentration per unit surface area at the corners of A_1 be ρ_{1i} for i = 1, 2, 3, 4. Applying linear interpolation for $\rho(x, y)$ in the rectangle A_1, integral (3) can be approximated by

$$T_1 = \frac{L_{A_1}}{4} \left(\rho_{11} + \rho_{12} + \rho_{13} + \rho_{14} \right). \quad (4)$$

where L_{A_1} is the area of rectangle A_1. For the flat surface $L_{A_1} = 25 \times 25\, m^2 = 225\, m^2$.

In general, the surface is not flat. It follows the topography of earth surface. In this general condition, formula (4) cannot be applied.

IV. Proposes Method

In general we have surface area A_1 with drilling points $P_{11}(x_1, y_1, 0)$, $P_{12}(x_2, y_2, z_2)$, $P_{13}(x_3, y_3, z_3)$ and $P_{14}(x_4, y_4, z_4)$ as illustrated in Figure 4. The curve lengths P_{11}, P_{12}, P_{13}, and P_{14}, are 25 m. The total nickel deposit under the surface A_1 is the total nickel inside the soil up to 30 m taken vertically. Hence, the integral (3) and the approximation (4) overestimate the nickel deposit below the surface A_1.

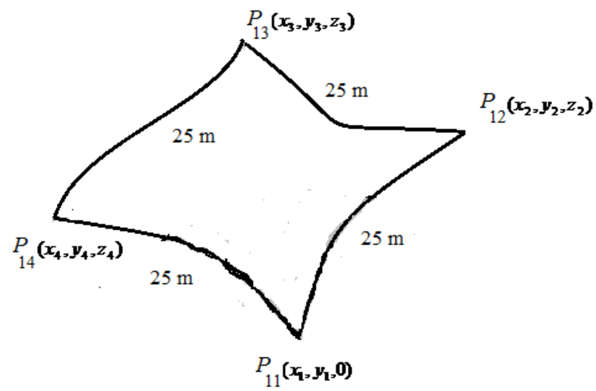

Figure 4. Surface area A_1 in general is not flat.

Let the projection of $P_{12}(x_2, y_2, z_2)$, $P_{13}(x_3, y_3, z_3)$ and $P_{14}(x_4, y_4, z_4)$ on horizontal plane be $P'_{12}(x'_2, y'_2, 0)$, $P'_{13}(x'_3, y'_3, 0)$ and $P'_{14}(x'_4, y'_4, 0)$, respectively. The length of P_{11} P'_{12}, P_{11} P'_{14}, P'_{12} P'_{13} and P'_{13} P'_{14} are less or equal to 25 m. Suppose the projection of A_1 be A'_1 with corners $P_{11}P'_{12}P'_{13}P'_{14}$, the nickel deposit below the general surface A_1 (not necessarily flat surface) is

$$T_1 = \iint_{A'_1} \rho(x, y) dx dy . \quad (5)$$

This can be approximated by

$$T_1 = \frac{L_{A'_1}}{4} \left(\rho_{11} + \rho_{12} + \rho_{13} + \rho_{14} \right). \quad (6)$$

Example: Let $P_{11}(0,0,0)$, $P_{12}(25,0,0)$, $P_{13}(25, y', 5)$ and $P_{14}(0, y', 5)$ form a rectangle where the edges are 25 m. Therefore, P_{11} P_{12} P_{13} P_{14} is not on the horizontal plane. To have its projection on the horizontal plane, we compute

$$y' = \sqrt{25^2 - 5^2} \approx 24.5 .$$

The projection of $P_{11}\, P_{12}\, P_{13}\, P_{14}$ on the horizontal plane is P_{11} P'_{12} P'_{13} P'_{14} where $P'_{12}(25,0,0)$, $P'_{13}(25,24.5,0)$ and $P'_{14}(0,24.5,0)$. Hence, $L_{A'_1} \approx 612.5$, but $L_{A_1} = 625$. For this example, the relative error if one applies

$$E_{\text{Rel}} = \frac{L_{A_1} - L_{A'_1}}{L_{A_1}} = 2\% .$$

For the case $P_{11}(0,0,0)$, $P_{12}(25,0,0)$, $P_{13}(25, y',10)$ and $P_{14}(0, y',10)$, $E_{\text{Rel}} = 8.4\%$.

For general surface area $A = \bigcup_{i=1,n} A_i$, the total nickel deposit should not be computed using (2). Rather, it must be computed by applying formula

$$T_1 = \sum_{i=1}^{n} \iint_{A'i} \rho(x, y)dxdy . \tag{7}$$

Equation (7) can be approximated by

$$T_1 = \frac{1}{4}\sum_{i=1}^{n}\left(L_{A'i}\left(\rho_{i1} + \rho_{i2} + \rho_{i3} + \rho_{i4}\right)\right). \tag{8}$$

The error depends on the topography of the surface as shown in the example.

V. Conclusion and Further Research

Predicting nickel deposit is important for nickel mining industries, it will be more important than merely the information of nickel concentration. Nickel deposit gives more direct information to the economic calculation of mining process. It can also be obtained from similar data from drilling taken for predicting nickel deposit.

In predicting nickel concentration, often the effect of surface topography is not taken into account. This may yield prediction error, especially enlarge the error. In predicting the nickel deposit, the effect of topography is responsible in overestimating the total deposit. It is because the total deposit is the integral of nickel concentration per unit area. If the integral is taken over the surface area, it overestimates the deposit. It should be taken over the projection of the surface on the horizontal plane.

The result of predicting nickel concentration often presented graphically that is more interesting, especially for investors of industries. The same data from drilling activity yield information about nickel concentration at every level below the surface and the nickel concentration per unit surface area. The former information results in Figure 3 about nickel concentration below the whole surface area. Following the idea [17] to reproduce image from rather similar information, the graphical plot will be the future work.

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La Ode Ngkoimani was born in Nihi, Indonesia in 1971. He has Master and Doctor in Physics from ITB, Indonesia. He is an associate professor at *Universitas Halu Oleo* (UHO), Kendari, Indonesia. Currently he works in the field of geophysics, especially related to the mining industries which have collaboration with UHO.

Edi Cahyono was born in Malang, Indonesia in 1968. He has Master in Mathematics from ITB, Indonesia and Doctor in Applied Mathematics from University of Twente, the Netherlands. Currently, he is professor of applied and industrial mathematics at *Universitas Halu Oleo*, Kendari, Indonesia.