Estimations of limestone resources using three dimension block kriging method, a case study: limestone sediment at PT Semen Padang

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Abstract. Making of block model was performed by geostatistic approach using kriging method to estimate and modeling of limestone source quality at Karang Putih Hill. Modeling and counting of source were based on three-dimension block model concept which was divided into block units with grid size 100x100x15 m which was appropriate with the size of mining block at location of the study. Variable used for limestone source estimation were CaO, SiO2 and H2O levels, according to conditions of raw material quality which has been specified. The result from variogram analysis showed that spatial characteristic of CaO, SiO2 and H2O levels in limestone had nugget effect percentage of 47.36%, 30.92%, dan 33.3% with range 145 - 230 m and range for vertical direction 21 - 40 m. Percentage (%) error of limestone estimation with confidence level 95% for CaO level were 54.74% ± 0.04%, SiO2: 0.72% ± 0.04% and H2O: 0.36% ± 0.007% respectively. Limestone resource quantity estimation at Karang Putih Hill up to elevation 214 meters above sea level which fulfilled the standard quality of CaO level ≥ 48 %, SiO2 level < 10 %, and H2O level < 6 % was 158.01 million ton, while tonnase in the form of 799,94 thousand ton of silica and 1,17 million ton of basalt.

1. Introduction
Limestone is one of the main and dominant raw materials in the process of making cement which must be used in the right quality to produce a good cement product. PT. Semen Padang uses a standard reference from ISO 9002 to control the quality of the limestone to be mined in the limestone quarry of Bukit Karang Putih. With the discovery such as basalt and silica intrusions be side of limestone in the mining site that are not known for their distribution. This condition has severely hampered of mining operations because the mining boundary targets and pit plans are not appropriate and limestone production targets cannot be absolutely complete.

To controlled the quality and planning of pit designs, the relationship of spatial variables is very important to see. In this journal, we will measure the quality of limestone in Bukit Karang Putih, PT. Semen Padang. The parameters that used to estimates from the variables in limestone deposits are CaO, SiO2, and H2O and use a geostatistical method called kriging. Kriging method works to estimate the average levels of CaO, SiO2, and H2O in a several blocks that have not been known the grade of limestone as well as horizontally and vertical. And it will produce a sedimentary model in the form of
3 (three) dimensional blocks. Block Model was made based on the kriging method that will calculate the volume and tonnage of limestone so that it will generate a resource of limestone based on the quality requirements.

The aim of modeling and estimating of the limestone resources is to describe the geometry and grade of limestone sedimentation and make design of process of the mining and it applications that will be carried out. In the mining industry assessment the quality and quantity of the resources is a very important part that is carried out to determine mine planning, mine life and others.

2. Research Methodology
The location of this research is in Bukit Karang Putih PT. Semen Padang, were located in Indarung Village, Lubuk Kilangan District, Padang City, West Sumatra Province. Mapping area can be seen on the Figure 1 bellow:

![Figure 1. Area of Mining Business License PT. Semen Padang](image)

Carrying out of this research, several work steps were prepared to facilitate and detailed the activities, bellow is the following steps:

2.1. Study of literature
Study literature in this research area was carried out by collecting various references on génèsis from limestone deposits and studying previous research reports with the aim of finding out the research area in general.

2.2. Data collecting
The data obtained in the form of secondary data which is supporting data in the subsequent data processing. Secondary data obtained are: drill log data, assay data, drill point distribution map, topographic map of the study area. The drilling data which were used comes from the exploration results of drilling at Bukit Karang Putih conducted by PT. Gamma Epsilon in 1997 as many as 13 (thirteen) core drill holes BH-01, BH-02, BH-03, BH-04, BH-05, BH-06, BH-08, BH-09, BH-10, BH-11, BH-12, BH-13, BH-14 with an average depth of 100 m. Limestone quality variables tested in the laboratory are assay values of all drill cores for CaO, SiO₂ and H₂O levels (in the form of percentage
weight). Quality requirements for raw materials provided by PT. Semen Padang can be seen in Table 1.

| Raw material | Composition of Chemical Quality Standards |
|--------------|------------------------------------------|
|              | SiO\(_2\) (%) | Al\(_2\)O\(_3\) (%) | CaO (%) | H\(_2\)O (%) |
| Limestone    | <10          | -                | ≥ 48     | <6          |
| Silica       | ≥ 65         | -                | -        | <10         |
| Clay         | -            | ≥ 27             | -        | <37         |

2.3. Data processing

Based on the results of the analysis of secondary data that has been collected, the drill hole data is recapitulated as a database which will be used for further data processing, where the initial data processing is doing geological modeling and continued using descriptive statistical methods. In addition, calculations such as variogram studies, determination of estimation parameters, estimation by kriging method were then followed by modeling in 3 (three) dimensions of limestone deposits. The data base processing process uses the SGeMS program (Stanford Geostatistical Earth Modeling Software) version 2.0 where in this program will produce an estimated level in the block model.

2.3.1. Data processing is done by statistical analysis. Statistical analysis is used to see the tendency of the distribution pattern of a data set. Based on this statistical analysis can be explained the relationship/correlation and trend of the data so that it can be determined the assessment method that is suitable with the pattern of data distribution [2].

2.3.2. Import Data and Data Interpolation. Import data is the data base entry process assay (drill hole, drill hole coordinates, and the assay data CaO, SiO\(_2\), and H\(_2\)O) into SGeMS program. The result of import data is the output file in the form of a three-dimensional (3D) drill hole distribution display. Data interpolation of CaO, SiO\(_2\), and H\(_2\)O levels was carried out on the block model that had been made based on the existing content data for every 5 (five) meters of drill hole depth interval. Interpolation is carried out on each grid which has not known the value or the grid that has a grade value from the drill assay results, in various directions in three dimensions. In this case the geostatistical method is used in the form of block kriging with attention to the distribution of the surrounding data that are interconnected with a certain radius obtained from the variogram analysis. The variable made to get the kriging parameter in this study is the three-dimensional variogram, because it takes into account spatial aspects in terms of x, y, and z [3].

2.3.3. Experimental Variogram and Fitting Variogram. Variogram can be used to analyze the level of similarity or variability between each data level CaO, SiO\(_2\), and H\(_2\)O. To determine the appropriate variogram, it is necessary to make an experimental variogram. The experimental variogram was made based on each level data in limestones so that there would be 6 (six) experimental variograms. The process of making an experimental variogram is done with the SGeMS program, which requires first selection of variogram parameters. The selection of these parameters is done by observing the data patterns and sample data used, because the selection of good parameters will produce a good experimental variogram so that it can facilitate the variogram fitting process to produce variogram models. There are 2 (two) methods commonly used in fitting variogram, namely: visual method and least square method. Geostatistics experts use more visual (manual) methods for variogram fittings because the results are satisfactory [4].

2.3.4. Geological Modeling. Geological modeling is the activity of making a geological model of a deposit of quarry material, in this case limestone deposits, based on data taken in the field to obtain a representative model. From the resulting model can be calculated resources. Limestone resource
modeling Bukit Karang Putih, PT. Semen Padang is done using a program mining. Resource modeling and estimation is an activity that is the basis for mine planning. Resource modeling and estimation must be carried out before mining activities begin [5]. The data needed as input for the basic modeling material are as follows [6]:

1. Topographic map of Bukit Karang Putih.
2. Coordinate data (X, Y, Z) position of each core drilling point.
3. Lithological data from core drilling results.

Core drilling data becomes input for making drillhole files. The drillhole file contains information [6]:

1. Collar data, contains information on coordinates (X, Y, Z) surface position of each core drilling point, total depth, drill ID,
2. Survey data, contains bearing, dip and drill ID information.
3. Sample data, contains information of penetration (from, to) and data content and drill ID
4. Geological data, contains information containing information, drill ID, Depth (from, to) and lithology.

![Diagram](image_url)

**Figure 2.** Cross Section Directions West-East [6]

2.3.5. *Estimation with Kriging*. Value estimation of the smaller block model units (grid) is done by geostatistical method in the form of kriging, where the type of kriging method used in this case is ordinary block kriging. In this study estimates were made of limestone as ore, while silica and basalt were considered as waste. The process of calculation by the kriging method to get the estimated values of CaO, SiO₂, and H₂O uses SGeMS program [7].

2.3.6. *Estimation with Kriging*. The block model that has been estimated with kriging contains information about the values of CaO, SiO₂, and H₂O levels estimation results. This information is very important for the next process, namely estimating limestone resources in the study area. Estimated levels using the kriging method with certain cut-off values in accordance with limestone quality requirements of PT. Semen Padang. Before calculating resources, the model must be corrected to the topographic value of the calculation area, the elevation of the bottom borehole, the silica and basalt boundary because the existing model is a solid block [8].

The correction of the model cannot be done with the SGeMS program, so it must be done with a separate program. Where, the correction material is the output value of the model, which in the value of the correction results will be modeled again to represent the distribution of quality and limestone resources resulting in 3 (three) dimensional kriging blocks [9].
Figure 3. Block estimation model for CaO levels and SiO$_2$ levels in limestone with kriging which has been corrected to the topography and bottom borehole.

2.3.7. Calculation of Resources. Limestone resource calculation is done using a grid model. Where each grid is 100 x 100 x 15 m corresponds to the smallest units in the block model system. In this study the distribution of limestone quality and estimation is adjusted to the quality requirements of raw materials at PT. Semen Padang. Resource calculation is done based on the results of estimation of levels in limestone by block 3 (three) dimensional kriging method as shown in Figure 4.

Figure 4. Map outline of resource calculation

Resource modeling is carried out based on the block modeling framework. With the dimensions of each block adjusted to the dimensions of mining. The principle of volume calculation is the volume of one cell block multiplied by the number of existing block cells, which are defined as follows[10]:

\[ \text{Volume} = \text{length} \times \text{width} \times \text{height} \times \text{number of block cells} \]
Tonnage = Vol. one block Number of Blocks density (\( \rho \))

\[
\sum_{i=1}^{n} x_i y_i z_i \times \text{density}(\rho)
\]

(1)

\[
\text{Tonnage limestones} = \text{total tonnage} - (\text{Geological Losses} \times \text{Total tonnage})
\]

(2)

The tonnage of Bukit Karang Putih limestone resources is calculated by the parameters:
1. Density (\( \rho \)) limestone used is 2.6 tons/m\(^3\).
2. Geological losses in limestone deposits are 10%.
3. Limestone resource estimates are carried out up to level 214.
4. In modeling the silica rock boundary has been localized, and the basaltic rock intrusion boundary. The area within the boundaries in the estimation is not counted as limestone resources at the study site.

At this stage, data analysis is carried out both qualitatively and quantitatively. Qualitative analysis is carried out based on a limestone sediment model made from secondary data. Whereas quantitative analysis is carried out based on statistical analysis, variogram studies, and parameters that are determined in the process of estimation of limestone deposits in the study area.

3. Result and Discussion

3.1. Database Assay

The assay database is the initial data that contains information about the results of drilling and sampling activities, which can later be used in various activities, such as resource calculations. This assay database can be obtained from exploration drilling, test pit, or channel sampling activities. In this study, the assay database used was obtained from exploration drilling activities. Database used in this study include the coordinates of the drilling location, the depth of drilling, the content of the elements consisting of levels of CaO, SiO\(_2\), and H\(_2\)O.

The basic information of the assay database for this study was obtained from exploration drilling activities with depths ranging from 84 meters to 100 m, while the level analysis of samples obtained from drilling was carried out on average every 5 (five) meters of the sample depth.

This assay database was made for the purpose of importing data into the SGeMS (Stanford Geostatistical Earth Modeling Software) program, which is software or programs for processing data in geostatistics using the kriging method on a geometry support in the form of 3 (three) dimensional blocks which are models from processed data. The assay database used in this study is divided into 2 (two) parts, namely: Drill hole data, which contains the position/coordinate data of drill holes in the form of Northing, Easting, and elevation. Level data that contains information about the levels at each specific depth interval according to assay or analysis of the levels carried out.

3.2. Preparation of Database Assay

The assay database is an important data or information that forms the basis of the process of modeling and estimating resources obtained from the results of the sampling activities and the results of the level analysis of the sample. In this study, the data collected to obtain information about the characteristics of the data and the population of subsurface limestone deposits were obtained based on drilling activities by PT. Semen Padang.

The spatial characteristics of this initial data population can be known from the results of the variogram analysis of these data. Assay spacing carried out every 5 m for limestone deposits is not representative
enough to produce preliminary data in resource modeling and estimation activities, because it will get little or limited initial data although generally limestone deposits have a spread with relatively homogeneous continuity laterally, but constraints the existing data contained in the Bukit Karang Putih is only limited to 13 (thirteen) drill holes.

3.3. Distribution and Drill Hole Intervals
Regular distribution and drill hole intervals will be crucial for getting good initial data in resource modeling and calculation. In general, for limestone deposits there is no convention regarding drilling intervals to state the classification of resources and deposits of limestone, it is different for coal deposits that have been clearly formulated regarding the classification of resources in SNI (Indonesian National Standard). However, based on the reality in the field and exploration activities regarding the previous limestone sediments stated that the average drilling interval of 100 m was representative enough to do the modeling and calculation of resources.

Judging from the data in the form of a base map and drill hole distribution map for exploration of limestone deposits in the Bukit Karang Putih research area, PT. Semen Padang, it can be seen that the distribution of data is not good enough, where drilling is done with a grid that is not regular. Likewise, the assay data space should be done every 1 m interval so that the estimation of limestone quality distribution is better. However, with the increasingly tight data assay samples taken, the costs to be incurred will be even greater.

3.4. Variogram Analysis
Variograms for levels in limestones are made in various directions, namely horizontal direction and vertical direction with omnidirectional. The goal is to determine the continuity of data in three dimensions and get a representative estimation parameter for subsequent data processing, namely estimation using 3-dimensional block kriging method.

3.4.1. Variogram in Limestone
The variogram model used for the data levels of CaO, SiO$_2$ and H$_2$O is a spherical model where the data behaves linearly near the starting point stating that the data has moderate / moderate continuity. In addition, the CaO variogram in these limestones has a percentage Nugget effect is 47.36%, SiO$_2$: 30.92% and H$_2$O: 33.33%, and for CaO levels in the vertical direction is 15.62%, SiO$_2$: 45%, and H$_2$O: 35.29%. The nugget effect data values of CaO, SiO$_2$ and H$_2$O in various directions are included in the medium nugget effect, except for CaO levels for vertical direction included in the classification of low nugget effect. However, in general, the levels of limestone deposits are relatively uniform, and the tendency of erratic data is almost non-existent. Total value sill obtained for CaO content data on limestone is 3.80%, SiO$_2$: 4.85% and for H$_2$O: 0.12% data, while for vertical direction on total CaO data sill of 3.20%, SiO$_2$: 3.37% and H$_2$O: 0.08%. Percentase Nugget effect 25-50 % is included in the medium nugget effect[11].

However, the range (a) value is different for the data of CaO, SiO$_2$ and H$_2$O levels, namely the range variogram value for the data of CaO, SiO$_2$ and H$_2$O levels in limestone of 150 m, 230 m, and 145 and the variogram range value for vertical direction for levels of CaO, SiO$_2$ and H$_2$O for 40 m, 40 m, 21 m. Range values state the extent to which a data relates or has a correlation with other data. The level of SiO$_2$ has a relatively low variability or high continuity from the data of CaO and H$_2$O levels in limestones which can be seen with a large range value.

Based on the available data, it shows that the drilling spacing distance conducted at the Bukit Karang Putih research site is an average of 100 m where this distance is smaller than the range obtained from the variogram analysis. To get the data that has a spatial correlation and the same characteristics, based on the CaO level the drilling should be carried out at a distance of 150 m, SiO$_2$: 230 m, while the H$_2$O 145 m, but the overall data content, then the drilling space should be performed with a distance 145 m follow kontiniutas levels of H$_2$O which is the lowest, while the vertical direction seen from the data content of the entire sample taking should be done at a distance of 21 m follow kontiniutas H$_2$O which is the lowest.
3.5. Kriging estimates

The estimation process with the kriging method is part of the procedure for modeling and estimating limestone sediment resources. Kriging will estimate each value in the block model units (grids) that have been made using the initial data, namely the assay results in the drill hole. The estimation grid is 100 x 100 x 15 m. This dimension corresponds to the size of the mining block and high level at PT. Semen Padang. Although on some grids there are CaO, SiO₂ and H₂O levels from the assay results, but kriging will re-estimate each level of CaO, SiO₂ and H₂O in the grid. Because it has been explained in the previous chapter that the data collected from the drill hole does not necessarily represent the actual values of CaO, SiO₂ and H₂O from the grid / block represented by the drill hole. The estimation with this kriging method uses the following parameters:

- The maximum data used is 15 data, where the data used is in the search area which is generally the closest data to the data that will be estimated at a certain distance.
- The area of the search area is in the form of "Ellipsoid 3D" which is stated by the axis parameter, namely: r max = 300 meters, r med = 300 meters, and r min = 50 meters, and the angular parameters are α, β, and θ which are all 0 angles made of 0 °.

The ellipse field in the search area will be located in the horizontal plane and there is no subduction because all the angles are made 0 °, this is based on the characteristics of limestone deposits which have a high homogeneity and lateral dispersal, in contrast to deposits in the form of veins that have a specific orientation. In the figure below shows a level map of the estimation results with kriging on the levels of CaO and SiO₂ at the elevation of basalt and silica intrusions at the study site.

![Figure 5. Map of Isograde: (a) CaO and (b) SiO₂ at an elevation of 281.5 meters above sea level.](image1)

![Figure 6. Map of Isograde: (a) CaO and (b) SiO₂ at an elevation of 296.50 meters above sea level](image2)

The presence of basalt intrusion will inhibit the mining activity process, therefore it is necessary to know the position and elevation of its density. From Figure 5 through 6 above it can be seen that the basalt intrusion is at the elevation of 281.5 m and 296.5 m, and this can be seen from the decreasing...
levels of CaO and increasing SiO\textsubscript{2} levels to direction of intrusion. Likewise, the presence of silica in the study location is at an elevation of 386.5 m, and 401.5 m. Breakthrough rocks found in the research location are igneous rocks with basaltic composition consisting of mafic minerals. Limestone as a side rock will experience quality changes towards intrusion with reduced levels of CaO and increased SiO\textsubscript{2} levels.

4. Presentation and Tabulation of Resource Calculations

Presentation and tabulation of the results of resource calculation is a very important step in the assessment and modeling of a quarry and to display a model of resources that are considered potential value and calculate the number of deposits based on the model that has been made taking into account certain aspects. The resource calculation block model system contains the smallest block units that function as geometry support for estimated values of CaO, SiO\textsubscript{2} and H\textsubscript{2}O. The size of the block model units is 100 x 100 x 15 m as described earlier. The size of the block model units considers the dimensions of the mining block in the study area.

**Table 2.** Tabulation of Limestone Resources at Bukit Karang Putih PT. Semen Padang Up to Elevation 214 Meters Above Sea Level

| Category                      | Total            |
|-------------------------------|-----------------|
| Resources (\textit{insitu}) Limestone (Ton) | 175,566,800     |
| \textit{Geological Losses} 10\% (Tons)     | 17,566,800      |
| Resources (Tons)              | 158,010,120     |

Tabulation of results of limestone sediment resources by using 3 (three) dimensional block kriging methods are shown in Tables 2 and 3 where limestone sediment resources are expressed by tonnage and the calculation is based on the size of the mining block. The calculation of the amount of limestone sediment resources in this study has considered aspects of the cut off grade value and limestone density value of 2.68 tons / m\textsuperscript{3}.

**Table 3.** Tabulation of Silica and Basalt Tonnage Bukit Karang Putih PT. Semen Padang Up to Elevation 214 Meters Above Sea Level

| Category                  | Total        |
|---------------------------|--------------|
| Silica Tonnase (Ton)      | 799,949.30   |
| Tonnase Basalt (Tons)     | 1,179,045.40 |

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