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Limestone Resources Estimation using Standard Facies Belt as Domain Constraint, Banten, Indonesia

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Abstract. There was scarce literature discussing the estimation of limestone quarry using carbonate platform components as domain constraints. Many estimation studies heavily focus on geostatistical methods. This study offers a new perspective on raw material resource estimation. Carbonate deposits from Pamubulan area are divided into three carbonate platform elements, namely platform interior, platform margin, and platform slope. Twelve different limestone domains were constructed. These solid model act as constraints in further estimation stages. The bimodal nature of CaO and MgO grade from the entire limestone edifice is successfully separated by the domains. Using inverse distance weighting as an estimator, 220 million tons of limestone suitable for cement raw material can be calculated. Only limestone with more than 40% CaO and less than 5% MgO is included in the calculations. Another notable feature is high-grade limestone bisected by low-grade material. Leaving complex and challenging environment for mining production.

Keywords: *3D solid model; carbonate platform; inverse distance weighting; Pamubulan.*

1 Introduction

Our government led by President Joko Widodo has increased the budget for developing mass infrastructure. This step is believed to be one of the fundamental elements that can raise economic growth. Better infrastructure can speed things up and reduce distribution costs, leading to a better price for the community. Population, in general, will benefit greatly from this situation and finally improve national welfare.

Infrastructure like toll roads, airports, terminals, bridges, and seaports require a large number of materials, one of which is cement. Cement production uses natural resources as raw materials, including limestone, sandstone, and claystone. Comprehensive infrastructure development requires support from high profile cement industry. Detail records of the potential and resources of these raw materials, especially limestone, are very important. This can only be achieved by sound mineral resource estimation.

Mineral resources estimation is a series of activities intended to build a mineral deposits model, whether as an exploration target, base for a feasibility study or optimize mining process in Glacken and Trueman [1]. The core step of estimation is geological modeling, practitioners often limit this activity because of the complexity and significant amount of time required. In addition, mining producers often prefer more express decisions.

Suggestions came from Mackenzie and Wilson in [2], and Cowan in [3], who encourage regarding geological concepts as essentials in geological modeling. Models that comply with geological principles are more appropriate as a basis for domaining and interpretation at the estimation stage. This is good practice and will not change, although various methods of analysis and interpretation continue to evolve.

The research area is located in Pamubulan area, Banten Province. It is part of PT. Gama Group exploration mining license. Area extent from 3.5 km WE to 1.2 km NS in size or around 4.2 km^2.

2 Geological Setting

Physiographically research area can be included in Central Depression Ridge Zone in Van Bemmelen in [4]. According to Sujatmiko and Santosa in [5], research location is part of the Limestone Member of Citarete Formation (Tmtl) consisting of limestone, marl, and sandstone. This formation lies unconformably above the Sandstone Member of Cijengkol Formation (Toj), dominated by sandstone, conglomerate, breccia, tuff, and coal. It overlies by Tuff Member of Citarete Formation (Tmt) that constitutes of tuff breccia, sandstone, conglomerate, limestone, and tuff.

Those formations stretch from WNW to ESE direction with relatively homoclinal structure. Two medium size anticline occurs in the northwest area. Strike-slip fault dissects the study location in a relatively north-south manner. While one large reverse fault limits southern boundary of limestone formation (**Figure 1**).

Cijengkol Formation was recognized to have ranged in age from Early to Late Oligocene and interpreted to have been deposited in deltaic to marine environment, according to Sukarna *et al.* in [6]. An unconformity rest in the upper boundary of this formation, separating it from the later Neogene Formation represented by Citarete Formation, which has Late Oligocene to Early Miocene in age. The eruption of Old Andesite Volcano at this time makes this carbonate deposit has an interfingering relationship with its volcanic counterpart. This formation indicates a shallow marine deposition such as littoral that shows a deeper sequence upward and was derived from southern source area.

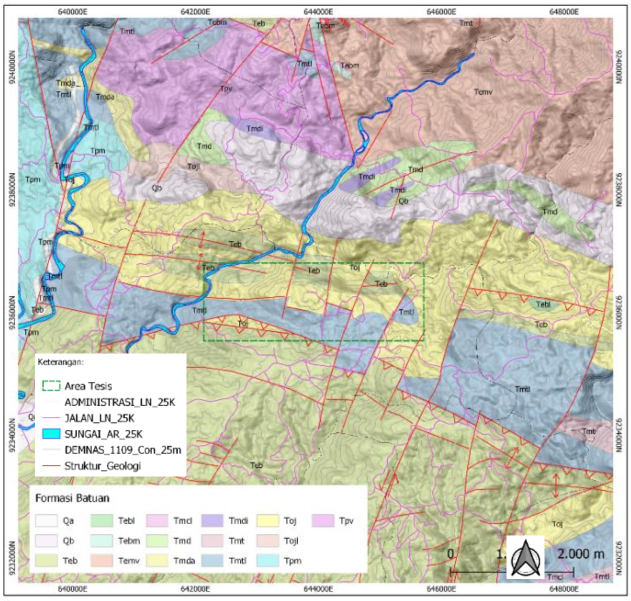

Figure 1 Map showing regional geology from the researched area. Rocks spreading were controlled by the WNW-ESE folds axis and relatively north-south strike-slip faults.

3 Data and Method

Data comes from detailed rocks description originating from 15 drill hole points complemented by 67 surface geological observation locations. Total depth as a whole reached 1697.5 meters. Topographic surveys were carried out throughout the study area accompanied by collar coordinate data from all drill points. There were 538 rock sample intercepts sent to the laboratory. XRF analysis was carried out to determine the levels of CaO and MgO from the samples. The average length of samples was about 2.7 meters with a minimum of 50 cm and a maximum of 4.5 m.

Estimation begins with the development of a conceptual geological model of the site area. This conceptual model is the basis for making solid models (domain). This is an interpretation and correlation between rocks. Philosophically, similar rock sequences with similar geochemical properties with equivalent strike/dip or position, are interpreted as the same unit and will be combined and correlated. In this study, the rock sequences were analyzed, interpreted, and classified according to the standard facies belt from Wilson (1975) in Schlager (2005) [7]. Standard facies belt range from marine to land namely: 1) basin; 2) deep shelf; 3) toe of slope; 4) slope; 5) reef margin; 6) sand shoals; 7) normal platform interior; 8) restricted platform interior, and 9) platform evaporate. To simplify the model created, facies belts are combined to platform margin (belts 5 and 6/PM), platform interior (belts 7 and 8/PI), and platform slope (belts 3 and 4/PS).

In practice, to create a domain is to select several cross-sections between drilled points. These 2-dimensional sections act as canvas to draw the upper, lower, and lateral boundaries of each intercept of the previously interpreted facies belt type. Once they are formed, the lines are connected between sections, thus forming a three-dimensional shape. The next step is to close or triangulate each side of the shapes that have been created and combined. The result is a 3D shape of a limestone body (single facies belt feature) that is closed on each side and so it is called a solid model which has a volume unit.

The next stage is the creation of the blocks model. This model takes the form of many blocks that occupy three-dimensional space, have volume, and their bodies are bound to the x, y, and z-axis. Each unit can be filled with various kinds of data, such as the estimated value of mineral/element grade, density, rocks name, or resource category. The size of the blocks model used is 100 x 60 x 3 meters. The blocks extend west-east following regional rocks spreading. There are 26,516 blocks built into the model.

The result of the main estimation work is a model consisting of a set of blocks whose center point (centroid) has an estimation value. One of the methods that are widely used to process estimation is the inverse distance weighting. IDW method with an exponent of 2 as suggested by Babak and Deutsch in [8] was implemented to estimate the CaO and MgO content of the study area. The minimum number of samples used in the calculation is 3 and can be up to a maximum of 15.

Mineral resources of this area will be divided into several levels, according to their area's proximity to the drill hole points. Corresponding to JORC in [9], resources from highest (nearest) to lowest (farthest) status are divided into measured, indicated, and inferred. The distance of the area of influence will refer to Mucha *et al.* in [10], that probably a development from Snowden in [11], by looking at the level of continuity of the variable or sill. The relationship between variables is reflected in the sill value of a variogram, beyond this, it can be said that the relationship/continuity is no longer present.

4 Result and Discussion

Field data analysis recognized four rock units with relatively west-east distribution and alluvial deposits. Bayah Formation is dominating the south-southeast region. While Cijengkol Formation is mainly located in the north-northeast area, Citarete Limestone Member is generally found in the central part of the study area. All formations extend relatively northwest to the southeast. Tuff unit (probably Tmt or Tuf Member of the Citarete Formation) intercalates south of Citarete Limestone Member and is bounded by a large reverse fault, before meeting Bayah Formation further to the south (**Figure 2**).

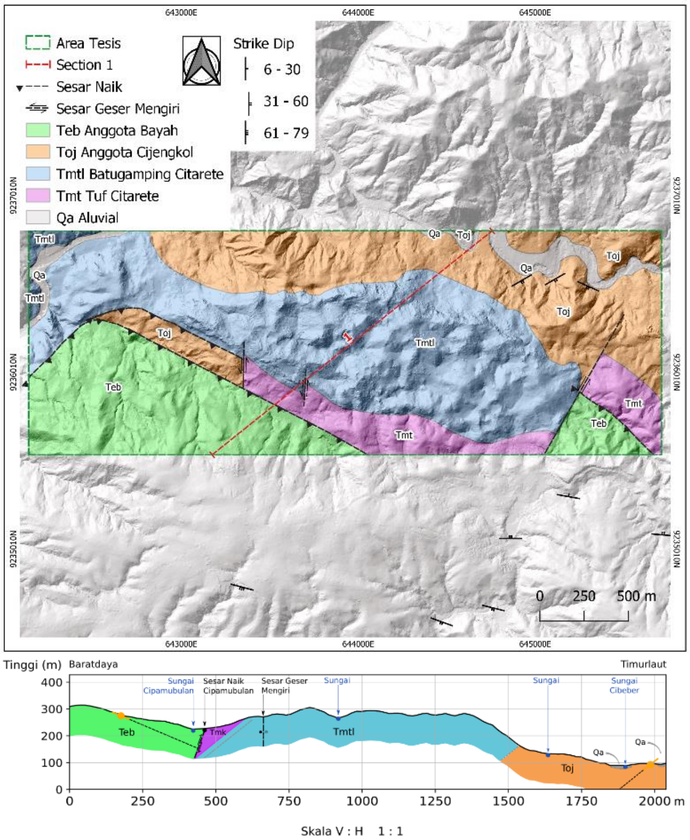

Figure 2 Map showing local geology from the researched area. The section shows that limestone member dive into the southwest with N120°E/35° strike/dip.

Several fold wings were observed in a relatively northwest-southeast elongation, but no fold axis was found specifically in the study area. Cijengkol Formation, followed by Citarete Members form a structurally homoclinal fold with southwest dipping. Average local azimuth or strike/dip angle of formation equal to N120°E/35°. Bayah Formation forms a similar homoclinal fold with north-east dipping flanks. There is a reverse fault that separates Bayah in the south from the Cijengkol and Citarete Members in the north. A sinistral strike-slip fault limits limestone spreading to the east before meeting with Bayah Formation.

4.1 Facies Belt Domain and Geometry

There were 12 limestone solid bodies perceived from the analysis (**Table 1**), each of them having its own geometric, physical, and geochemical characteristics (**Figure 3**). PM has a relatively thin elongated shape which is divided into three cycles/repeating deposits but has variations of up to 10 different features. PI covers the entire PM body and becomes the "background" of all solid bodies. PS is found in the northeast. The lowest PM model, the first cycle, bisected into 1A-1B. The second cycle of the PM model dismembered into five branches with code 2A-2E. The youngest PM cycle is segregated into three splits namely 3A-3B. PM models tend to have a thin, elongated shape like in 1A. Its body stretches up to 1.1 km with a width of 470 m. The thickness of the model reaches 169 meters. Another body has lenses feature with short and thin shapes like 2E. It has only 161 meters long and 86 meters wide with only 71 m thick, the thinnest of all solid bodies. PI model shape is very long and wide, as it spreads by enveloping the PM model. It has more than 2 km long and almost 750 m wide. The model is about 209 meters tall, the thickest of all bodies. PS solid is only found in the northeast. Secluded point location with a relatively low elevation compared to the population of other drill points, causes this model to be correlated thicker and larger than it should be. This model has a fairly high thickness, about 176 m with over 1 km long, and almost 400 m wide.

Table 1 List of facies belt domain and geometry in the Pamubulan area.

No.	Facies Belt	Validated	Status	X min	X max	Y min	Y max	Z min	Z max	X	Y	Z	Surface Area (m2)	Volume (m3)
	Platform Margin													
1	1A	TRUE	Solid	643.856	644.985	9.236.028	9.236.501	108	277	1.128	473	169	556.750	8.298.429
2	1B	TRUE	Solid	644.696	644.985	9.236.028	9.236.258	149	272	288	230	123	95.881	1.476.240
3	2A	TRUE	Solid	643.356	643.923	9.236.267	9.236.469	114	295	567	203	181	192.405	2.224.806
4	2B	TRUE	Solid	643.953	644.327	9.236.044	9.236.357	143	298	374	313	155	143.732	2.433.583
5	2C	TRUE	Solid	643.982	644.198	9.236.071	9.236.227	215	297	215	156	82	47.199	281.747
6	2D	TRUE	Solid	643.259	643.469	9.236.268	9.236.402	114	237	210	134	123	55.382	636.490
7	2E	TRUE	Solid	643.715	643.876	9.236.375	9.236.461	199	270	161	86	71	20.598	104.926
8	3A	TRUE	Solid	643.743	644.705	9.235.752	9.236.219	128	295	962	467	168	374.160	4.460.851
9	3B	TRUE	Solid	643.186	643.496	9.236.138	9.236.273	186	283	310	135	97	70.299	666.496
10	3C	TRUE	Solid	643.359	643.628	9.236.105	9.236.267	174	288	269	162	115	67.528	684.041
	Platform Interior													
11	PI	TRUE	Solid	643.186	645.278	9.235.738	9.236.484	100	309	2.092	746	209	2.536.958	69.461.026
	Platform Slope													
12	PS	TRUE	Solid	643.923	644.968	9.236.155	9.236.544	79	255	1.045	389	176	521.372	13.485.871

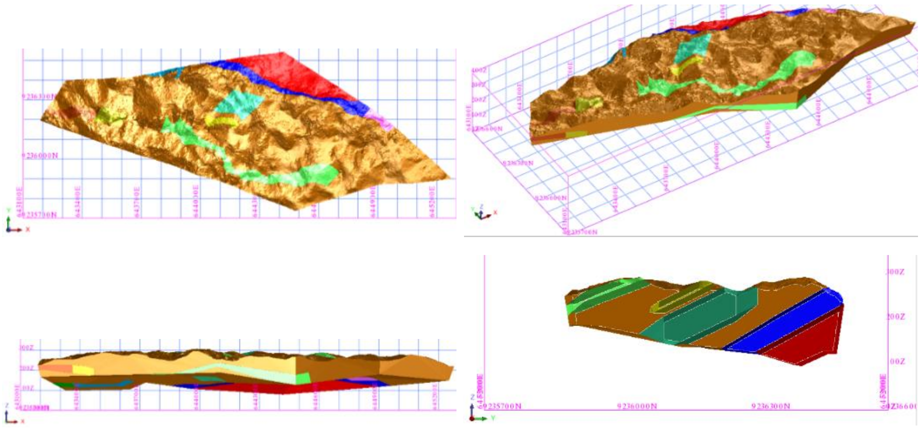

Figure 3 Solid model map from every facies belt. PI envelops other PM bodies, while PS body lies in the northeast part. Map view (upper left), perspective (upper right), W-E section (lower left), S-N section (lower right).

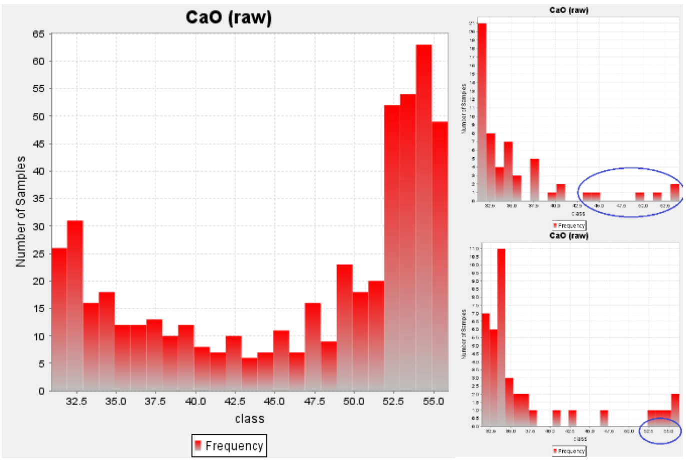

Figure 4 Bimodal CaO grade histogram from all solid models (left). Unimodal histogram from solid model 1A (upper right) and solid model 3A (lower right). Outliers need grade cutting (blue circle).

Every solid model will have their grade constraint. Thus, the bimodal nature of grade data will be refined into unimodal shape (**Figure 4**). This feature is more suitable for input data in the later estimation stage of the block model. Grades that are different from other common grade values (outliers) will be cut. Leaving more homogenous and relatively equal values in every individual solid model.

4.2 Spatial Variability and Resource Categorization

The main objective of variogram fitting in this study is to obtain maximum variation and distance values or sill and range. Range values will be used as references to determine the nature of data continuity in various directions or isotropic/anisotropic. Meanwhile, the sill value will be used to determine the area influence radius for mineral resources categorization.

Data shows horizontal range at 220 meters with azimuth N130°E as the major direction and sill value of 78.65 (**Table 2**). A semi-major range that has a perpendicular direction to the major results in the same value. The ratio between major and semi-major is 1:1, or isotropic. While the minor range that is perpendicular to semi-major is around 57 meters. The ratio between semi-major and minor is 220:57 or 1:3.8. Thus, the study area can be said to have an anisotropic condition. Based on the above-mentioned parameters, the measured resource category area of influence is 1/3 of the sill (78.65) or 25.95 or 50 meters radius (**Figure 5**). Indicated resource category rests on 2/3 of the sill or 51.91, which is equivalent to 105 meters radius. Inferred resource category is based on 0.95 from the sill or 74.72 or 180 meters radius.

Table 2 Sill and range adopted for determining the area of influence in resource categorization in the Pamubulan area.

Variogram Pamubulan		78,65	220 m
Resources Category	**Percentage**	***Sill***	***Range (m)***
Measured	0,33	25,95	50
Indicated	0,66	51,91	105
Inferred	0,95	74,72	180

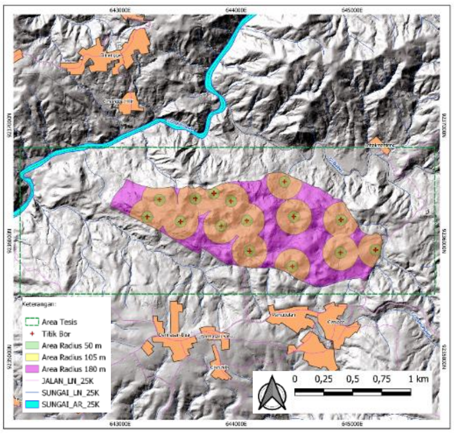

Figure 5 Area of influence map and resource category area.

Blocks model stretched west-east following major formation spreading. Attributes included for estimation are CaO and MgO. No rotational or tilting transformation was applied.

To acquire the tonnage of the deposits, the volume of blocks is multiplied by the density of limestone. Chatterjee [12] studied that the average density of limestone is 2.6 gr/cm^3. Volume and tonnage calculation will only measure blocks with CaO values above 40% and MgO values below 5%. The total volume/tonnage suitable for raw material for cement is around 220 million tonnes or 84 million cubic meters (**Table 3**).

High-grade limestone with a good level of CaO content is concentrated in the east-southeast and northwestern parts of the study area (**Figure 6**). This grade seems to be bisected in the middle by low-grade limestone, stretching from southwest to northeast. A similar aspect is shown in the distribution of MgO (**Figure 7**). High MgO levels tend to gather in the southwestern part extending to the northeast.

Another notable feature is the emergence of high MgO levels in the middle of high-grade limestone in the southeast. Both of these characteristics should handle with care by limestone producers and or company owners. A more sophisticated mining strategy could be needed to achieve desired mining profit. Selective mining operations might be used and concentrated in two different areas.

Table 3 Sill and range adopted for determining the area of influence in resource categorization in the Pamubulan area.

CaO		MgO		Resource	Volume (m^3)	Tonnes	Average	
from	to	from	to	Category			CaO	MgO
40	45	0	5	MEA	720.000	1.872.000	43,32	1,76
				IND	8.370.000	21.762.000	43,22	1,57
				INF	6.048.000	15.724.800	44,09	2,35
45	50	0	5	MEA	1.116.000	2.901.600	47,73	1,29
				IND	15.012.000	39.031.200	46,98	1,66
				INF	6.966.000	18.111.600	47,15	1,45
50	55	0	5	MEA	5.922.000	15.397.200	52,99	0,89
				IND	28.314.000	73.616.400	52,75	0,90
				INF	12.150.000	31.590.000	53,18	0,66
				Grand Total	**84.618.000**	**220.006.800**	**49,64**	**1,23**

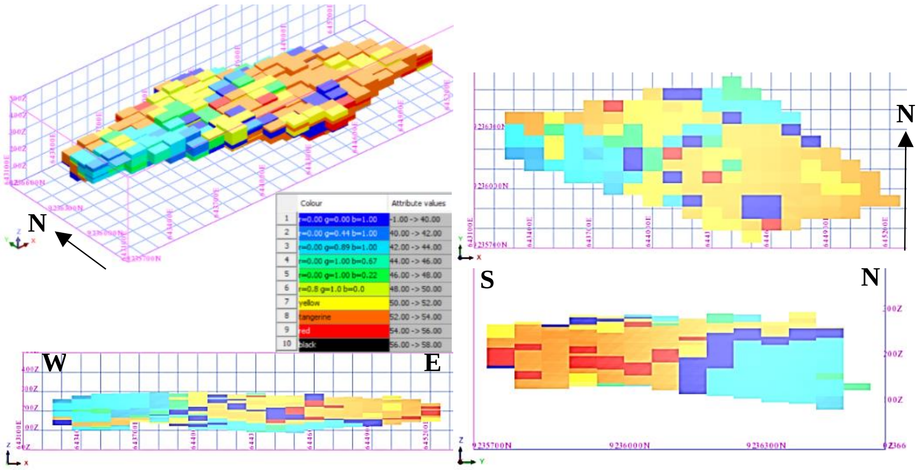

Figure 6 Blocks model representing certain location volume and CaO grade in the researched area. Perspective view (upper left), map view (upper right), W-E section (lower left), S-N section (lower right).

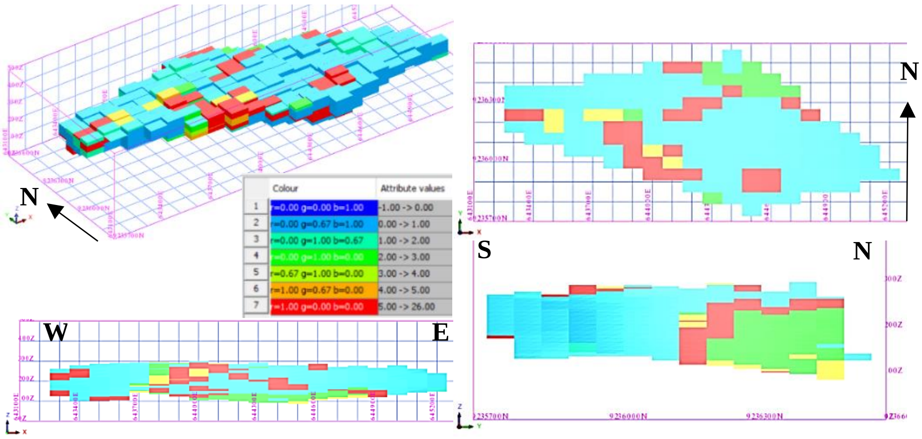

Figure 7 Blocks model representing certain location volume and CaO grade in the researched area. Perspective view (upper left), map view (upper right), W-E section (lower left), S-N section (lower right).

5 Conclusion

Applying estimation directly to the limestone deposits as a whole is common practice in raw material quarries. The entire limestone body is used as an arena for resource estimation without any domains. This is due to the high level of practicality of the geostatistical method and its swift application. Additionally, several methods are claimed to be able to give satisfactory results, even after facing bimodal-grade data. Limestone grade data are generally bimodal although most limestone bodies have a massive, homogenous, uniform edifice.

Limestone estimation using standard facies belt as domain or constraint offers a new perspective in mineral resources evaluation. Estimation should not be carried out directly on the limestone body, as a whole. The nature of limestone grade data, which is generally bimodal, should be separated into domains. Segregation using facies belt as a framework follows the nature of the limestone body.

The author proposes a division of the domain according to the genetics of the limestone deposits, which is based on the architecture of the carbonate platform. This division has been proven to be able to divide the nature of the data into unimodal. Estimation made on a more homogeneous domain will produce better forecasting. Prediction results are more precise. This will reduce uncertainty, and increase efficiency, also possible future loss, which finally leads to company prosperity.

Disclaimer

Resource estimation from this paper is a research product. Results might be different from company products. The distinction is mainly caused by different parameters and levels of completeness of the data used.

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