Greek Statistical Institute
Proceedings of the 36th Panhellenic & 2nd International Stat Conf (2024), pp.000-000

SPATIAL DECLUSTERING OF EXPLORATION DATA IN MARBLE RESOURCE ESTIMATION FROM IRREGULAR DRILLING PATTERNS

Ioannis Kapageridis[1], Evangelos Gialamas[1], Charalampos Albanopoulos[2], and Georgios Anastasiadis[1]
[1]Laboratory of Mining Informatics and Machine Learning Applications, Department of Mineral Resources Engineering, University of Western Macedonia
[2]Iktinos Hellas SA
ikapageridis@uowm.gr

ABSTRACT

Resource estimation of a marble deposit is commonly based on sample data from surface and/or underground drillholes, characterized as to several visual, physical, and mechanical properties [Kapageridis et al. (2018)]. Drilling campaigns in marble quarries tend to be highly irregular as to their spatial density and drillhole orientation, as drilling is driven by the progress of extraction, and the need to expose good quality marble. This process introduces bias to resource estimation and can lead to overestimation of resources, if samples are not treated first for their spatial clustering. The clustered distribution of samples means that areas of good marble quality are potentially oversampled, while areas of poor quality have fewer to no samples leading to a sample distribution that is not representative of the resource that is to be estimated. Several sample declustering methods exist and have been applied to mineral resources estimation [Isaaks and Srivastava (1989); Deutsch and Journel (1998)]. The procedure described in this paper is based on cell declustering to derive sample weights that can reduce the effect of bias caused by irregularly spaced sampling during resource estimation of a marble deposit.

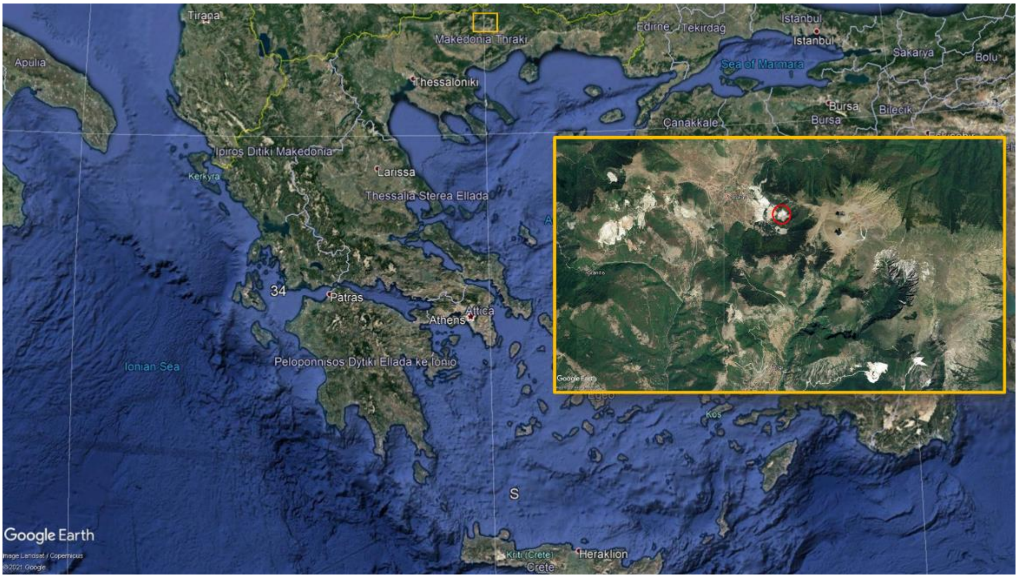
Keywords: geostatistics, mineral resource estimation, marble deposits, sampling, declustering.

1. INTRODUCTION

The company that provided our study data is Iktinos Hellas, one of many marble quarrying companies active in Northeastern Greece. It is among the leading companies in the field of marble in the country. Iktinos is a vertically integrated company with four privately owned marble quarries, three cutting and processing factories, a local sales network and an ever-growing sales network abroad. The Laboratory of Mining Informatics and Machine Learning Applications of the University of Western

Macedonia has been supporting Iktinos in developing and implementing solutions for marble resources estimation and quarry design and modelling since 2014. The marble deposit used in the present study, is in the Volakas area near the city of Drama (Figure 1). Volakas is hosting several significant marble quarries, each with different marble qualities.

Figure 1. *Location of the Volakas quarry.*



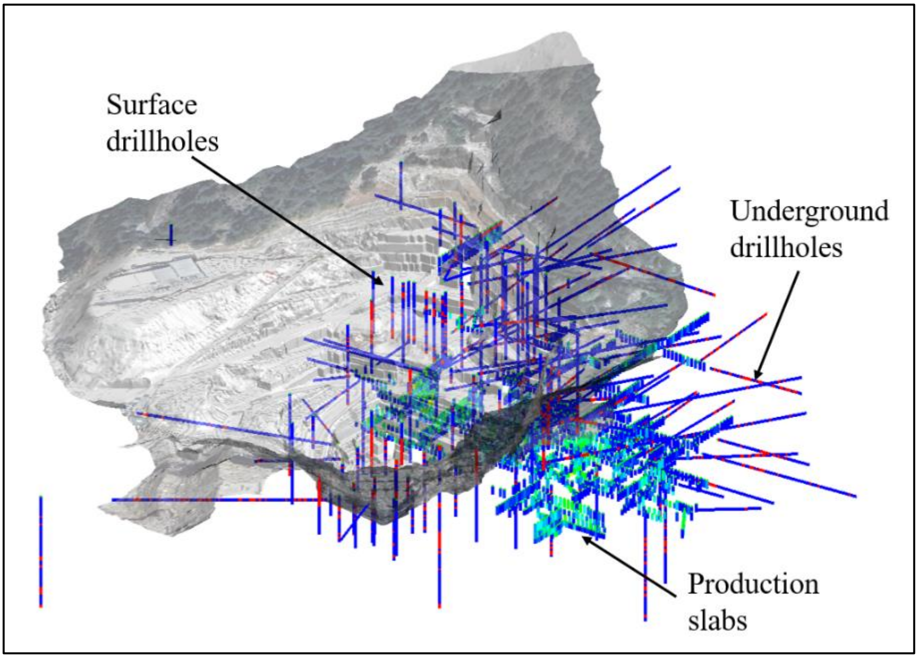
Depending on the actual marble products produced and market needs, some general categories are commonly used, such as A1, A2, AB, B, C, and waste. These general categories or classifications reflect marble mass visual and structural parameters which can also be different from one quarry to another. These parameters include marble characteristics such as background colour and appearance, texture, presence of veins, discolouration, and discontinuities of different scale. Parametrisation of marble samples and classification to one of the categories is performed by experienced personnel and is based on samples much smaller in area than the blocks of marble which are potentially exploited. The use of standard estimation and modelling software tools in estimating marble quarry reserves poses a few challenges, as the available information is mostly qualitative. Generalisation of qualities was also considered necessary, focusing on 3 products (A, AB, and B), as the limited sampling does not allow for a more detailed analysis of resources and reserves to the original quality categories produced by the quarry. Reported waste quantities are the remaining bench volume, which cannot be estimated using the available sampling and the limitations set by the reserve categories.

2. EXPLORATION AND PRODUCTION DATA CHARACTERISTICS

2.1 Exploration Data

The provided dataset consists of 150 surface and underground exploration drillholes (vertical and horizontal) and 1899 production slabs giving a total of 3344 6m composite samples (Figure 2). In the marble deposit of the present study, the following parameters were identified and used to characterise the marble features that are significant to its quality classification:

Figure 2. *3D view of exploration and production data overlayed by a model of the surface Volakas quarry.*



- Lithology (dolomitic or calcite)
- Type (flower-like or diagonal vein features)
- Background (presence of visible defects)
- Tectonic features at different observation scales (number of discontinuities per 1m drillhole core sample)

__Figure 3.__ Examples of Volakas marble type and background categories.

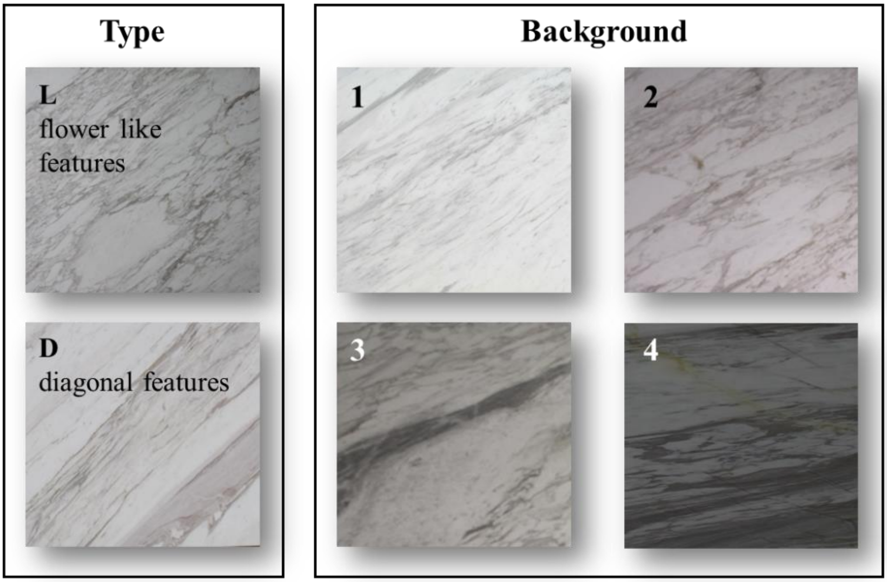


__Table 1.__ Tectonic parameters and values.

Parameter	**TECTO1**	**TECTO2**	**TECTO3**	**TECTO4**
Orientation	40/40	210/70	320/55	20/80
Parameter value	**1**	**2**	**3**	**4**
Discontinuities	0	1	2	3 or more

2.2 Production Data

Marble slabs extracted from the quarry are georeferenced and recorded as to the percentages of each quality produced (A, AB, B, Waste). Slabs are represented as vertical drillholes with a single interval (sample). This data is used as a reference distribution for normal score transformation and a benchmark for block estimates. Production data is combined with exploration composite samples during block estimation.

3. MARBLE RESOURCE ESTIMATION

Interpolation of marble quality indicator values is normally performed using ordinary kriging on the basis of a block model. Similar computerised estimation efforts are reported by [Forlani et al. (2000)], [Careddu et al. (2010)], and [Abdollahisharif et al. (2012)]. The estimated volume is divided into blocks of the same size. Block dimensions are configured based on the marble volumes (slabs) that are extracted separately at the given quarry. Samples are selected around each block using search ellipsoids which are oriented according to the geological features of the particular deposit.

Declustering weights calculated with cell declustering are stored in the composite samples database. These weights are combined with ordinary kriging weights during block model estimation:

- Without the application of declustered weights, the estimated grade is:

$$(OK\_weight1 \times grade1) + (OK\_weight2 \times grade2) + \ldots \quad (1)$$

- With the application of declustered weights, the estimated grade is:

$$[(OK\_weight1 \times DC\_weight1 \times grade1) + (OK\_weight2 \times DC\_weight2 \times grade2) + \ldots] / [(OK\_weight1 \times DC\_weight1) + (OK\_weight2 \times DC\_weight2) + \ldots] \quad (2)$$

4. DECLUSTERING

Drilling campaigns in marble quarries tend to be highly irregular as to spatial density and drillhole orientation, as drilling is driven by the progress of extraction, and the need to expose good quality marble. This process introduces bias to resource estimation and can lead to overestimation of resources, if samples are not treated first for their spatial clustering. The clustered distribution of samples means that areas of good marble quality are potentially oversampled, while areas of poor quality have fewer to no samples leading to a sample distribution that is not representative of the resource that is to be estimated.

4.1 Purpose and Methods

There are different methods available to treat the spatial clustering of data, with the most common ones being the following:

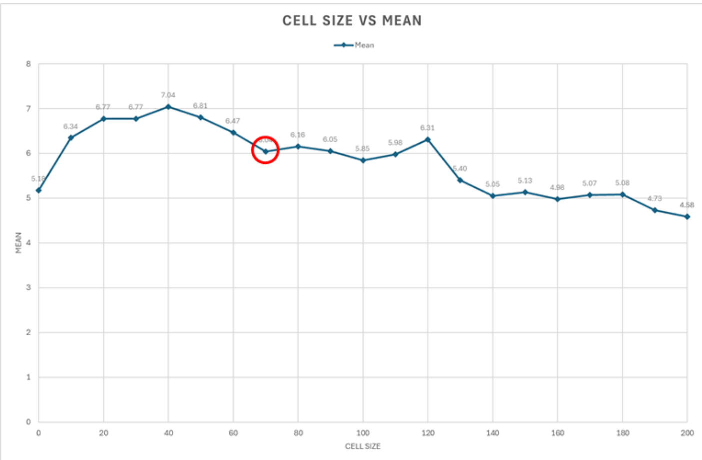
- **Cell declustering**: it is the most common method applied in geostatistics. It is insensitive to the boundary locations and for this reason is seen as more robust than polygonal declustering.
- **Polygonal declustering**: it is based on the construction of polygons of influence around each of the sample data. These polygons of influence are described by all midpoints between each neighbouring sample data.
- **Kriging weight declustering**: kriging of the area of interest is performed and the weights applied to each conditioning data are summed and then standardised.

4.2 Cell Declustering

The volume covered by the sample data is divided into 3D rectangular sections for declustering called cells. Each sample selected for declustering receives a weight inversely proportional to the number of samples that fall within the same cell. Therefore, closely spaced samples are assigned lower weights and sparse samples are assigned higher weights. The calculated global mean from cell declustering depends on the size of the cells.

If the cells are very small, then each sample will fall into its own group and all samples will receive equal weights. If the cells are as large as the global area, then all samples will fall into one group and will again receive equal weights. Somewhere between these two extremes is the appropriate cell size. A range of different cell sizes are examined and a graph of the declustered mean vs. cell size is produced to aid the selection of the cell size (Figure 4).

Figure 4. *Selection of appropriate cell size using a graph of the declustered mean vs. cell size.*



Anisotropy in the data can be accounted for when calculating declustering weights. In the case of cell declustering, this is achieved using different aspect ratios between X, Y and Z directions, i.e. cells are 3D blocks of different size along X, Y and Z. The appropriate ratios might not be obvious (particularly for the Z axis) and experiment with multiple configurations is usually required.

Table 2. *Comparison statistics between original (clustered) and declustered marble quality percentages.*

	A% clustered	A% declustered	AB% clustered	AB% declustered	B% clustered	B% declustered
Mean	6.11	5.18	17.14	14.35	10.71	10.11
Standard deviation	16.32	14.10	25.93	21.06	20.95	16.21
Variance	266.26	198.91	672.57	443.32	438.88	262.85
CV	2.67	2.72	1.51	1.47	1.96	1.60
Max	100.00	100.00	100.00	100.00	100.00	100.00
Min	0.00	0.00	0.00	0.00	0.00	0.00
Skewness	3.32	3.90	1.66	2.02	2.67	2.77
Kurtosis	11.67	17.30	2.01	4.32	7.43	10.08
Range	100.00	100.00	100.00	100.00	100.00	100.00

5. CONCLUSIONS

Preferential sampling commonly leads to sample distributions not representative of the underlying phenomenon. Declustering methods can be applied to address this issue. Cell declustering is one of the more robust methods available. Multiple tests might be necessary to decide the “optimum” cell size for the calculation of declustering weights. The effects of applying declustering weights to the original samples for resource estimation need to be carefully examined. Standardisation of quality assignment to drillhole core samples and production marble slabs is also an area where significant improvement is required.

ΠΕΡΙΛΗΨΗ

Η εκτίμηση αποθεμάτων ενός κοιτάσματος μαρμάρου βασίζεται συνήθως σε δειγματοληπτικά δεδομένα από επιφανειακές ή/και υπόγειες γεωτρήσεις, που χαρακτηρίζονται ως προς διάφορες οπτικές, φυσικές και μηχανικές ιδιότητες [Kapageridis κ.ά. (2018)]. Τα γεωτρητικά προγράμματα σε λατομεία μαρμάρου τείνουν να είναι εξαιρετικά ακανόνιστα ως προς τη χωρική πυκνότητα και τον προσανατολισμό των γεωτρήσεων, καθώς οι γεωτρήσεις καθοδηγούνται από την

πρόοδο της εξόρυξης και την ανάγκη έκθεσης καλής ποιότητας μαρμάρου. Αυτή η διαδικασία εισάγει μεροληψία στην εκτίμηση αποθεμάτων και μπορεί να οδηγήσει σε υπερεκτίμηση τους, εάν τα δείγματα δεν υποβληθούν πρώτα σε επεξεργασία για τη χωρική ομαδοποίηση τους. Η ομαδοποιημένη κατανομή των δειγμάτων σημαίνει ότι γίνεται υπερβολική δειγματοληψία των περιοχών καλής ποιότητας μαρμάρου, ενώ οι περιοχές κακής ποιότητας έχουν λιγότερα έως καθόλου δείγματα, γεγονός που οδηγεί σε κατανομή δειγμάτων που δεν είναι αντιπροσωπευτική του αποθέματος που πρόκειται να εκτιμηθεί. Υπάρχουν αρκετές μέθοδοι αποσυσταδοποίησης δειγμάτων που έχουν εφαρμοστεί στην εκτίμηση ορυκτών πόρων [Isaaks and Srivastava (1989); Deutsch και Journel (1998)]. Η διαδικασία που περιγράφεται στην παρούσα εργασία βασίζεται στην αποσυσταδοποίηση κελιού για την εξαγωγή βαρών δείγματος που μπορούν να μειώσουν την επίδραση της μεροληψίας που προκαλείται από ακανόνιστη δειγματοληψία κατά την εκτίμηση πόρων ενός κοιτάσματος μαρμάρου.

Acknowledgments: The authors gratefully acknowledge the financial support of the University of Western Macedonia and funding of this research.

REFERENCES

Abdollahisharif, J., Bakhtavar, E., Alipour, A., and Mokhtarian, M., (2012). Geological Modeling and Short-term Production Planning of Dimension Stone Quarries Based on Market Demand, Journal of Geological Society of India, Vol. 80, September 2012, pp. 420-428.

Careddu, N., Siotto, G., and Tuveri, A., (2010). Evolution of a Marble Quarry: From Open Cast to Underground Exploitation, Proceedings of Global Stone Congress 2010, Alicante, Spain.

Deutsch CV, Journel AG (1998) GSLIB: geostatistical software library and user’s guide. Oxford University Press, New York, p 340.

Forlani, G., and Pinto, L., (2000). Monitoring Marble Extraction in Open Cast Quarries, International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B4, Amsterdam, 2000, pp. 283-289.

Isaaks EH, Srivastava RM (1989) An introduction to applied geostatistics. Oxford University Press, New York, p 561.

Kapageridis, I., Albanopoulos, C. (2018). Resource and Reserve estimation for a marble quarry using quality indicators. *Journal of the Southern African Institute of Mining and Metallurgy,* **118**, 39-45.