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RESERVES ESTIMATION OF A MARBLE QUARRY USING QUALITY INDICATORS

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Abstract

The use of standard estimation and modelling software tools in estimating marble quarry reserves poses a number of challenges. Marble quarry reserves are based on marble quality categories, almost unique for each quarry/deposit considered. These categories represent visual and physical aspects of marble such as colour, texture and fractures. Classification of marble 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 available information is, also, mostly qualitative leading to further complications in the application of geomathematical estimation methods. The estimation of marble reserves described in this paper is based on interpolating quality indicator values from drillhole and quarry face samples to blocks in three dimensions. The procedure is applied in all working quarries of Iktinos Hellas SA and is based on Maptek Vulcan Quarry Modeller, a mine planning package adapted for quarrying. Its application and results is demonstrated using a case study from one of the quarries in NE Greece.

Key words: inverse distance weighting, quality indicators, reserves estimation, marble quarrying.

Περίληψη

Η χρήση τυπικών εργαλείων λογισμικού εκτίμησης και μοντελοποίησης στην εκτίμηση αποθεμάτων λατομείων μαρμάρου παρουσιάζει κάποιες προκλήσεις. Τα αποθέματα λατομείων μαρμάρου βασίζονται σε κατηγορίες ποιότητας μαρμάρου, σχεδόν μοναδικές για κάθε εξεταζόμενο λατομείο/κοίτασμα. Οι κατηγορίες αυτές αποδίδουν οπτικές και φυσικές ιδιότητες του μαρμάρου όπως το χρώμα, την υφή και τα ραγίσματα. Η ταξινόμηση του μαρμάρου σε μια από τις κατηγορίες γίνεται από έμπειρο προσωπικό και βασίζεται σε δείγματα κατά πολύ μικρότερα σε εμβαδό από τα μπλοκ μαρμάρου που ενδεχομένως εκμεταλλεύονται. Οι διαθέσιμες πληροφορίες είναι, επίσης, κυρίως ποιοτικές γεγονός που οδηγεί σε επιπρόσθετες δυσκολίες στην εφαρμογή γεωμαθηματικών μεθόδων εκτίμησης. Η εκτίμηση αποθεμάτων μαρμάρου που περιγράφεται σε αυτή την εργασία βασίζεται στην παρεμβολή τιμών δεικτών ποιότητας από γεωτρητικά δείγματα και τομές στα μέτωπα του λατομείο σε μπλοκ τριών διαστάσεων. Η διαδικασία εφαρμόζεται σε όλα τα ενεργά λατομεία της Ικτίνος Ελλάς ΑΕ και βασίζεται στο Maptek Vulcan Quarry Modeller, ένα πακέτο μεταλλευτικού σχεδιασμού προσαρμοσμένου για λατομεία. Η εφαρμογή και τα αποτελέσματα της παρουσιάζονται μέσω ενός παραδείγματος εφαρμογής σε ένα από τα λατομεία στη ΒΑ Ελλάδα.

Λέξεις κλειδιά: ζύγιση αντιστρόφου αποστάσεως, ποιοτικοί δείκτες, εκτίμηση αποθεμάτων, λατομεία μαρμάρου.

1. Introduction

The reserves estimation procedure discussed in this paper concerns the Platanotopos quarry of Iktinos Hellas SA (Figure 1) – similar procedures are applied to the other quarries of the company. Specialised mine planning software (Maptek Vulcan Quarry Modeller) was used in all estimation and reporting stages. Data was provided by Iktinos Hellas SA personnel, including samples quality characterisation. A technical report was issued on behalf of Iktinos Hellas SA (Kapageridis, 2015). Similar computerised estimation efforts are reported by Forlani *et al.* (2000), Careddu *et al.* (2010), and Abdollahisharif *et al.* (2012).

1.1. Location

The quarry area is located in the Municipal District of Platanotopos of the Piereon Municipality of Kavala Prefecture, approximately 1.5km NNE of the Platanotopos village and 2km SW of the Mesoropi village (Figure 1). The quarry area under exploration is 88.649m^2. The quarry area is in public forest land between 380 and 540m elevation covered by bushes, and administered by Kavala Prefecture Authorities and Kavala Forest Inspection Authorities.

Figure 1: Location of Platanotopos quarry near Platanotopos village.

1.2 Geological Background and Production History

The area belongs to the Rodopi Metamorphic Mass, extending from Thrace to part of Central Macedonia, with characteristic metamorphic geological formations and in particular marble horizons (metamorphic limestones) with gneissic background. Generally, the wider area is characterised by horizons and outcrops of white – semi-white and grey marbles, locally subject to quarrying. In the quarry area we meet calcitic and dolomitic marbles, gneiss and gneissic schists. Calcitic marbles, gneiss and gneissic schists have no use and are not targeted for quarrying.

Interest is focused on dolomitic marbles which are enclosed and protected as a lens by alternating gneissic schist layers and calcitic marbles. The horizons orientation is constant with a bearing NNW-SSE and dipping between 25º - 30º ESE. As already mentioned, marbles in the area are lens-like white dolomitic microcrystallic rocks (marbles). They are characterised as solid white fine grained, with evident spider net fractures which are red-yellow as they are filled with iron oxides and hydroxides.

This rare combination of white fine grained marble which is fractured and filled with secondary material which gives back the cohesion to the marble, constitutes this dolomitic appearance particularly interesting for quarrying. Marbles are solid and allow recovery of large healthy volumes, raising the level of recovery of the quarry and limiting the production of waste material. Close to the surface, the marble deposit is covered by a weathered layer of marble, 1-2m thick, which has a low recovery factor for marketable marble.

Given the geological, mineralogical, and climate characteristics and the quarrying equipment of the quarry, production is scheduled for 7000-10000m^3 per annum and at this rate, the life of the quarry is estimated at 15 years. Marbles extracted are known as Golden Spider and are characterised as fine grain white dolomitic marble with spider net red-yellow fractures, filled with iron oxides and hydroxides (Figure 2). They present very good physical and mechanical properties and can take very fine polishing (Table 1). Historical production of the quarry is given in Table 2.

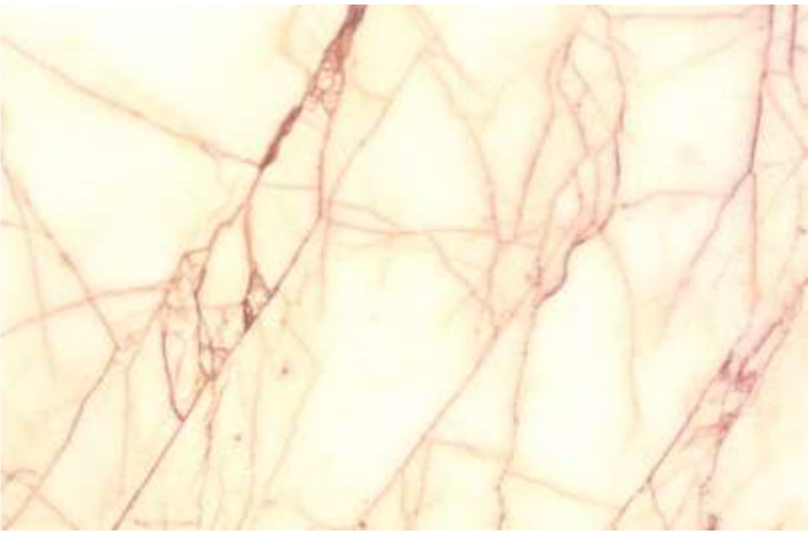

Figure 2: Appearance of marble volumes of Platanotopos quarry.

Table 1: **Physical and chemical properties of marble from Platanotopos quarry.**

Specific gravity	2.850	Bending strength (dry condition) DIN 52112	11.31
Open porosity factor wt% DIN 52102	0.60	Bending strength Mpa** (wet condition) DIN 52112	8.25
Absorption factor wt% DIN 52103	0.21	Compressive strength after freezing and thaw cycles N/mm2** DIN 52104 & 52105	81.25
Elasticity Gpa ASTM C-170	42	Abrasion wearing mm DIN 52108	2.06
Compressive strength N/mm^2** (dry condition)DIN 52105	120.6	Impact strength cm UNI-U 32.07.248.0	29
Compressive strength N/mm^2** (wet condition) DIN 52105	146.3	**1MPa=1N/mm^2 = 10.2kp/cm^2	

2. Marble Blocks Quality Characterisation

2.1. Colour and Texture

Quality grading of Golden Spider marble is initially based on colour and in the following categories: G - Golden, Y - Yellow, R - Red. Grading based on spider texture is in one of 4 categories as described in the following table. Colour and texture combinations are presented in Figure 3.

Table 2: **Production history of Platanotopos quarry between 2010-2014.**

	2014		**2013**		**2012**		**2011**		**2010**	
	m^3	**%**	**m^3**	**%**	**m^3**	**%**	**m^3**	**%**	**m^3**	**%**
Extraction	77,617		92,668		89,929		73,533		34,618	
Production	13,494	17	20,657	22	19,905	22	21,151	29	13,409	39
A1	353	3	915	5	1,014	5	1,367	6	1,290	10
A2	1,835	14	2,136	10						
AB	3,423	25	3,981	19	4,684	24	5,135	24	4,100	31
B	7,246	54	11,509	56	10,011	50	8,833	42	5,630	42
BB	636	5	2,116	10	4,196	21	5,816	27	2,390	18

Table 3: **Volume texture categories of Platanotopos marbles.**

1	Classic Spider, even net, clear background (classic type)
2	Relatively even spider with local strong concentrations (logs), or unclearly constructed net (fuzzy spider) or uneven zones of dense/coarse net, (standard type)
3	Dense spider, or many continuous brown lines, (heavy type).
4	Absence of spider, many white parts or with minimum net, (white type)

2.2 Volume Defects

Based on defects (fractures, dendrite zones, brown lines, discolourings or marks etc.) each volume is classified using the 4 categories in Table 4 and final volume quality is assigned according to Table 5.

Table 4: **Categories based on defects of Platanotopos marble.**

1	Solid volume with no evident defects or defects to less than 10% of each slab which is handled with a -3% or -6% discount
2	One or two defects up to 20-25% of each slab
3	Defects up to 30-35% of each slab
4	Defects up to 50% of each slab

Table 5: **Platanotopos marble quality based on defects and texture/colour categories.**

Rectangular (Length >180, Height > 120)	**1** - No defects	**2** - Defects 25-35% of each slab	**3** - Defects 25-35% of each slab	**4** - Defects 35-50% of each slab
Classic type 1	1-1=A1	1-2=A2	1-3=AB	1-4=B
Standard type 2	2-1=A2	2-2=AB	2-3=B	2-4=BB
Heavy type 3	3-1=AB	3-2=B	3-3=BB	3-4=BB
White type 4	4-1=B	4-2=BB	4-3=BB	4-3=BB

1	Classic Spider, even net, clear background (classic type)
	
2	Relatively even spider with local strong concentrations (logs), or unclearly constructed net (fuzzy spider) or uneven zones of dense/coarse net, (standard type)
	
3	Dense spider, or many continuous brown lines, (heavy type).
	
4	Absence of spider, many white parts or with minimum net, (white type)
	

Figure 3: **Colour and texture categories of Platanotopos marbles.**

3. Reserves Estimation Data

Data used in the reserves estimation of each quarry includes the original as well as the current topography of the quarry area based on the quarrying activities up to the date of the study. It also includes diamond drillhole samples and sections on quarry faces, which are analysed per meter as to the marble quality characteristics. A separate data folder was created for quarry with a separate database for topographical/vector data and one for drillhole/section data. An effort was made to maintain a systematic naming of all files of databases and models created during modelling and estimation. Topographical data were provided in AutoCAD™ (DWG, DXF) file format and were imported to Maptek Vulcan Quarry Modeller software and stored to appropriate layers. Drillhole data were provided in Microsoft Excel™ file format and were imported to specialised samples databases in Maptek Vulcan Quarry Modeller. In the following paragraphs we discuss briefly the data provided for each quarry.

3.1 Topographical Data

For the Platanotopos quarry, two layers were provided with the minor and major contours every 4 and 20 meters respectively. The exploitation limits were given as a separate layer as shown in Figure 4. The contours covered an area much larger than the quarry area and had very good detail, suitable for reserves estimation. The current morphology of the quarry was also provided in two separate layers for crests and toes.

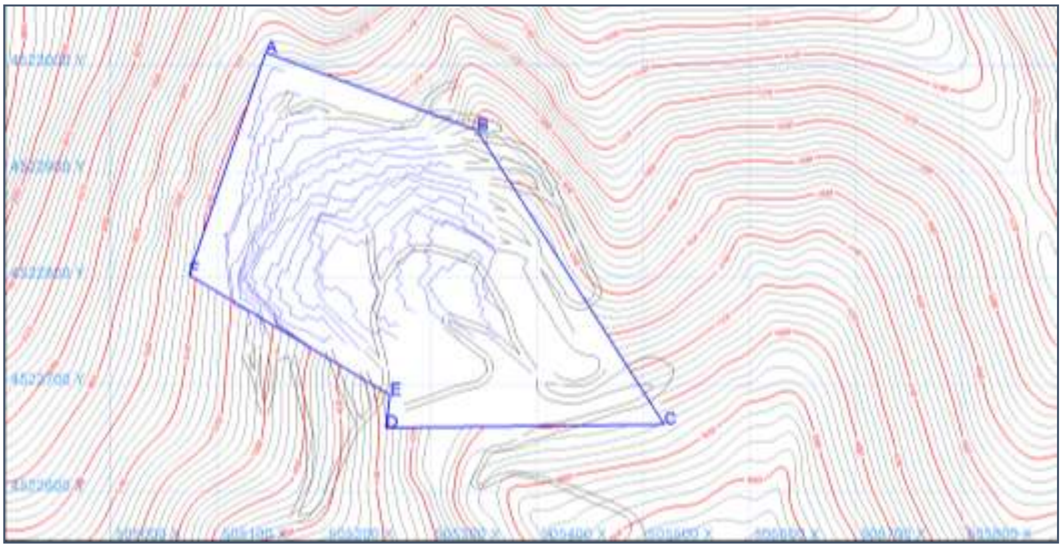

Figure 4: Original topography contours, current pit and exploitation limits of the Platanotopos quarry.

3.2 Drillholes and Quarry Face Sections

A total of 92 drillholes and sections were provided for the Platanotopos quarry (47 sections and 45 drillholes), giving a total of 1,684 one-meter samples used in reserves estimation of the quarry. This data covers sufficiently the space of the estimated final excavation as show in the following figure. The data was validated using the software for collar location and overlapping intervals.

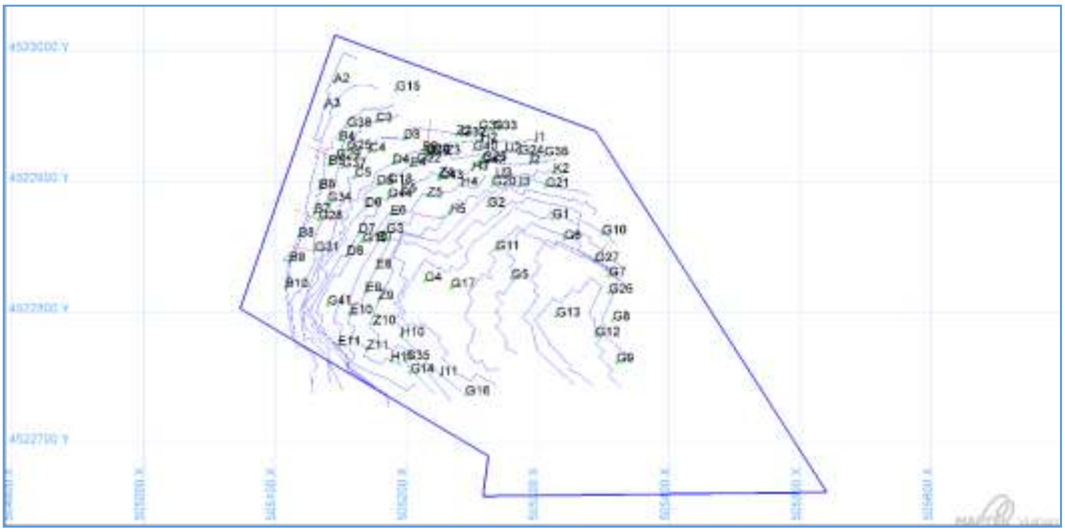

Figure 5: Plan view of drillhole and face section locations.

3.3 Quarry Volumetric Model

The estimated volume of the final excavation was designed per bench (level) starting from the existing quarry morphology. The design of each of the 16 benches was modelled as a solid triangulation which was used in reserves estimation (Figure 6). These solids were visually checked and validated using triangulation topology checks (self-crossing, opening, inconsistencies) to ensure that they can be used for valid volumetric calculations.

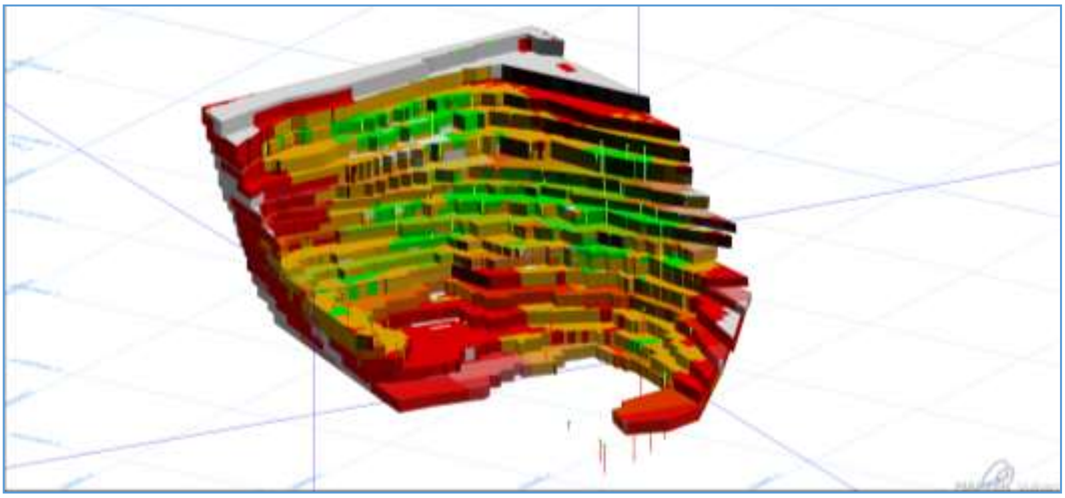

Figure 6: Solid triangulation models of the final excavation benches of the Platanotopos quarry coloured by reserves classification (green = proved reserves, orange = probable reserves, red = inferred resources).

4. Methodology

4.1. Samples Database Processing

The drillhole and section samples database was configured with extra fields to allow the interpolation of arithmetic values in space. Specifically, fields were added which represent the different marble qualities based on original colour, texture, fracture and tectonism fields. These fields take only two values, 0 or 1, based on if whether the specific sample belongs or not to the particular marble quality, which is based on criteria which are specific for each quarry. As shown in Figure 7, at the Platanotopos quarry, if a sample has lithology value LITHO = "SPIDER" and spider type SPTYP = 1 and fractures BACKRO = 1 then it belongs to quality A1. This logic leaves out of the definition of initial quality the large scale tectonism (represented by a solidity field called SYNOXH), which affects the final quality after it is estimated separately with its own class fields. In other words, as with the different initial quality classes (A1, A2, etc.), a number of fields are defined for the different tectonism categories. The reason for handling tectonism separately is the different orientation of large scale tectonism requiring a different search ellipsoid orientation during estimation to the one used for all other fields. It is combined with initial qualities to derive the final ones with degrading wherever necessary based on the estimated value of this field.

In other words, if the original field SYNOXH (solidity) has a value of 1, then the field SN1_PR receives the value of 1, if it has a value of 2, then field SN2_PR receives the value of 1 and so on. The original quality class fields and the additional tectonism field are combined after interpolation in space to receive the final qualities. The need to interpolate tectonism separately is due to its different spatial distribution, i.e. the different orientation of this parameter in space compared to other parameters.

Condition	Field	Equation
LITHO == "SPIDER" AND SPTYP == 1 AND BACKRO == 1	A1_PR	1
LITHO == "SPIDER" AND ((SPTYP + BACKRO) == 3) AND A1_PR == 0	A2_PR	1
LITHO == "SPIDER" AND SPTYP == 2 AND BACKRO == 2 AND (A1_PR + A2_PR == 0)	AB_PR	1
LITHO == "SPIDER" AND (SPTYP == 3 OR SPTYP == 4) AND BACKRO == 1 AND (A1_PR + A2_PR + AB_PR == 0)	B_PR	1
LITHO == "SPIDER" AND BACKRO < 4 AND SPTYP < 5 AND (A1_PR + A2_PR + AB_PR + B_PR == 0)	BB_PR	1
	W_PR	1 - A1_PR - A2_PR - AB_PR - B_PR - BB_PR

Figure 7: Quality class fields calculation based on original colour, texture and fracture fields for the Platanotopos quarry.

After calculation of initial quality class fields and tectonism categories, a secondary process of the database is performed in order to calculate the location of each sample (XYZ coordinates at the centre of each sample) and assign a weighting factor to the samples. This factor takes the value of 1 if the sample is from a section on the face of the quarry, and 0.5 if the sample comes from a drillhole. Essentially, more weight is given to face sections as their quality assessment is performed on a surface larger than the drillholes and therefore better approaches the actual quality of the marble in the specific location. These weight factors are used to further weight samples during interpolation.

4.2 Qualities Estimation

Interpolation of quality class field values was performed using the inverse distance squared method as implemented by Maptek Vulcan Quarry Modeller software on the basis of a block model. The estimated volume is divided in blocks of the same size. For Platanotopos quarry, a block model with rotation around Z axis was constructed that covered the entire quarry volume and current sampling. The model specifications are given in Table 6. Block dimensions were configured based on the marble volumes that are extracted separately at the given quarry. In each block, the percentage of each marble quality was estimated using the method analysed earlier using neighbouring samples. These samples are selected around each block using search ellipsoids which are oriented according to the geological features of the particular deposit. Ellipsoid parameters are given in Table 7.

Table 6: Block model specifications of the Platanotopos quarry.

Origin	X	505,460
	Y	4,522,340
	Z	290.5
Model dimensions	X	582
	Y	728
	Z	350
Block dimensions	X	6
	Y	2.8
	Z	7
Orientation	X-axis azimuth	28
	X-axis rotation arount Y-axis	0
	Y-axis rotation arount X-axis	0
Block count		1,261,000

Block estimation in Platanotopos quarry was different to the other quarries as the ellipsoids had different orientation in each block due to the folding of the deposit. Thus, a special function of the software was used before estimation that calculates the appropriate ellipsoid orientation for each block, taking in to account reference surfaces that define folding (Figure 8). In the case of Iktinos Hellas SA quarries, the modifying factors for converting marble resources to reserves include the limitation of resources inside a technicallly feasible excavation as designed by the company's personnel (mining and legal factors), inside the exploitation license limits (legal, environmental and governmental factors). Classification based on the three categories of mineral resources was performed during three stages of block estimation, using ellipsoids of different dimensions and different sample count requirements (Table 7).

Table 7: Platanotopos quarry estimation parameters.

	Measured (Proved) Reserves	Indicated (Probable) Reserves	Inferred In-Pit Resources	SYNOXH
Major Axis (m)	15	30	50	50
Semi-major Axis (m)	15	30	50	50
Minor Axis (m)	5	10	15	10
Azimuth	Variable	Variable	Variable	330
Plunge	Variable	Variable	Variable	0
Dip	Variable	Variable	Variable	70
Minimum Number of Samples	8	8	4	4
Maximum Number of Samples	20	20	20	20
Maximum Samples per Drillhole	4	4	4	4
Blocks estimated	1342	9754	26259	37355

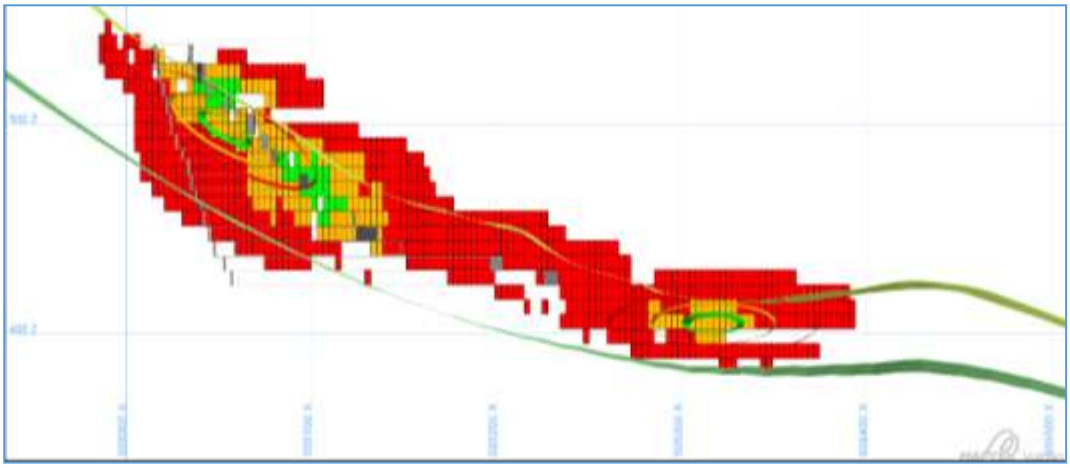

Figure 8: Cross section through block model and resource classification ellipsoids following the deposit folding of the Platanotopos quarry (smaller to larger – measured, indicated, inferred).

5. Results and Conclusions

5.1 Reserves Estimates

Table 8 gives the results of the reserves calculation. For each reserve category, three generalised qualities are reported. Generalising of qualities was considered necessary as the limited sampling does not allow more detailed analysis of reserves to the original A1, A2, AB, B, and BB qualities produced by the particular quarry. Therefore, reported quality A corresponds to quantities A1 and A2, AB is reported on its own, while B quality contains both B and BB. Reported waste quantities are the remaining bench volume which cannot be estimated using the available sampling and the limitations set by the reserve categories as to ellipsoid dimensions and minimum sample count. As a result, a considerable part of the waste and the inferred resources can be upgraded potentially in the future with additional drilling which will provide a clearer picture in areas with no samples currently.

Table 8: Reserves estimation results for the Platanotopos quarry.

		Measured (Proved) Reserves (m^3)			Indicated (Probable) Reserves (m^3)			Inferred In-Pit Resources (m^3)				
Bench	**Elevation**	**A**	**AB**	**B**	**A**	**AB**	**B**	**A**	**AB**	**B**	**Waste**	**Total**
P11	423	296	227	242	2,753	8,229	14,236	4,443	18,843	27,146	130,896	207,312
P10	430	140	128	337	3,942	7,863	12,088	7,094	19,414	41,562	92,659	185,228
P09	437	43	68	51	3,402	11,166	16,313	5,460	21,649	39,272	68,859	166,283
P08	444	28	156	708	2,078	13,171	25,174	4,088	16,381	34,392	59,047	155,222
P07	451	204	1,993	4,101	2,590	12,393	36,991	4,506	11,370	32,786	59,560	166,494
P06	459	336	1,548	4,253	2,444	7,987	24,850	2,485	5,618	12,518	31,392	93,432
P05	464	600	1,718	5,871	2,405	7,263	25,625	2,194	5,335	12,740	26,246	89,998
P04	469	722	2,351	9,020	2,116	7,906	30,162	2,530	6,826	18,035	30,793	110,460
P03	476	771	2,019	8,445	1,059	5,642	28,002	1,554	7,095	20,281	26,147	101,015
P02	483	398	1,031	4,824	465	2,732	18,544	573	5,367	16,006	18,327	68,267
P01	488	227	644	5,839	443	2,927	22,082	277	5,568	23,672	25,995	87,676
P00	495	1	826	5,230	358	2,691	28,704	177	5,356	29,298	38,795	111,435
P-01	505	165	818	3,063	343	2,376	20,618	104	3,624	18,147	22,949	72,207
P-02	513	118	253	2,536	298	2,012	11,791	134	2,634	17,007	14,016	50,801
P-03	520	17	19	192	198	1,022	14,530	82	1,034	10,987	20,008	48,090
P-04	529				-	22	1,240	89	139	8,449	18,125	28,063
Total		**4,068**	**13,801**	**54,713**	**24,894**	**95,402**	**330,951**	**35,790**	**136,251**	**362,299**	**683,814**	**1,741,983**

5.2 Conclusions

This paper discussed a reserves estimation procedure applied at the Platanotopos marble quarry of Iktinos Hellas SA. Reserves estimation was performed using specialised software. Original sample quality values were converted to indicator values to allow interpolation to a block model using inverse distance weighting. This procedure provides Iktinos Hellas SA and potentially other marble quarrying companies with a solid method to produce reliable results according to international standards of resources/reserves reporting.

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