Resource and Reserve estimation for a marble quarry using quality indicators

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Synopsis

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, which are unique for each quarry/deposit considered. These categories represent visual and physical aspects of marble such as colour, texture, and fractures. Classification of marble in one of the categories is performed by experienced personnel and is based on samples much smaller in area than the slabs of marble that would be produced. Furthermore, the available information is mostly qualitative, leading to further complications in the application of geomathematical estimation methods. The method of estimating marble reserves described in this paper is based on interpolating quality indicator values from drill-hole 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 are demonstrated using a case study from a quarry in northeastern Greece.

Keywords
inverse distance weighting, quality indicators, Reserve estimation, marble quarrying.

Introduction

The reserve 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. Specialized mine planning software (Maptek Vulcan Quarry Modeller) was used in all estimation and reporting stages. Data was provided by Iktinos Hellas SA personnel, including sample quality characterization. A technical report was issued on behalf of Iktinos Hellas SA (Kapageridis, 2015). Similar computerized estimation efforts are reported by Forlani and Pinto (2000), Careddu, Siotto, and Tuveri (2010), and Abdollahisharif *et al.* (2012).

Location

The quarry area is located in the Municipal District of Platanotopos of the Piereon Municipality of Kavala Prefecture, approximately 1.5 km NNE of Platanotopos village and 2 km SW of Mesoropi village (Figure 1). The quarry area under exploration is 88 649 m². The quarry area is in public forest land covered by bushes, between 380

Figure 1—Location of Platanotopos quarry near Platanotopos village

and 540 m elevation and administered by Kavala Prefecture Authorities and Kavala Forest Inspection Authorities.

Geological background and production history

The area is part of the Rodopi metamorphic massif, which extends from Thrace to part of Central Macedonia, with characteristic metamorphic geological formations and in particular marble horizons (metamorphosed limestones) in gneissic country rocks. Generally, the wider area is characterized by horizons and outcrops of white to semi-white and grey marbles, which are quarried locally. The quarry area contains calcitic and dolomitic marbles, gneiss, and gneissic schists. The calcitic marbles, gneiss, and gneissic schists have no commercial value and are not exploited.

Interest is focused on the dolomitic marbles, which occur as lenses enclosed by alternating gneissic schist layers and calcitic marbles. The marble-bearing horizon has a regular strike of NNW-SSE and dips between 25° and 30°° ESE. The lensoid white dolomitic

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Resource and Reserve estimation for a marble quarry using quality indicators

Figure 2—Appearance of 'Golden Spider' marble from Platanotopos quarry

microcrystalline marbles are massive, white, fine-grained, and traversed by red-yellow 'spider-web' fractures filled with iron oxides and hydroxides.

This rare combination of white fine-grained fractured marble and fractures filled with secondary material results in a massive, cohesive rock mass with an interesting appearance (Figure 2). Because the marbles are massive, large slabs can be recovered with minimal production of waste material. The top 1–2 m of the marble deposit consist of a weathered layer which has a low recovery factor for marketable marble.

Production from the quarry is scheduled for 7 000–10 000 m³ per annum and at this rate, the life of the operation is estimated at 15 years. The marble, which is known as 'Golden Spider', has very good physical and mechanical properties and can take a very high polish (Table I).

Table I

Physical and chemical properties of marble from Platanotopos quarry

Specific gravity (g/cm³)	2.850	Flexural strength (dry condition) MPa** DIN 52112	11.31
Open porosity factor wt% DIN 52102	0.60	Flexural strength MPa** (wet condition) DIN 52112	8.25
Absorption factor wt% DIN 52103	0.21	Compressive strength after freeze and thaw cycles N/mm²** DIN 52104 and 52105	81.25
Elasticity GPa ASTM C-170	42	Abrasion wearing mm DIN 52108	2.06
Compressive strength N/mm²** (dry condition) DIN 52105	120.6	Impact strength cm UNI-U 32.07.248.0	29
Compressive strength N/mm²** (wet condition) DIN 52105	146.3		

**1 MPa = 1 N/mm² = 10.2 kp/cm²

Table II

Production history of Platanotopos quarry between 2010–2014

	2014		2013		2012		2011		2010	
	m³	%	m³	%	m³	%	m³	%	m³	%
Extraction*	77 617		92 668		89 929		73 533		34 618	
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
Total production	13 494	17	20 657	22	19 905	22	21 151	29	13 409	39

*Extraction refers to total quantities mined (including waste), while total production refers to final marble products extracted (the sum of A1, A2, AB, B, and BB).

Table III

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)

Table IV

Marble categories based on defects

1	Solid slab with no evident defects or less than 10% defects, 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 V

Platanotopos marble quality based on defects and texture/colour categories

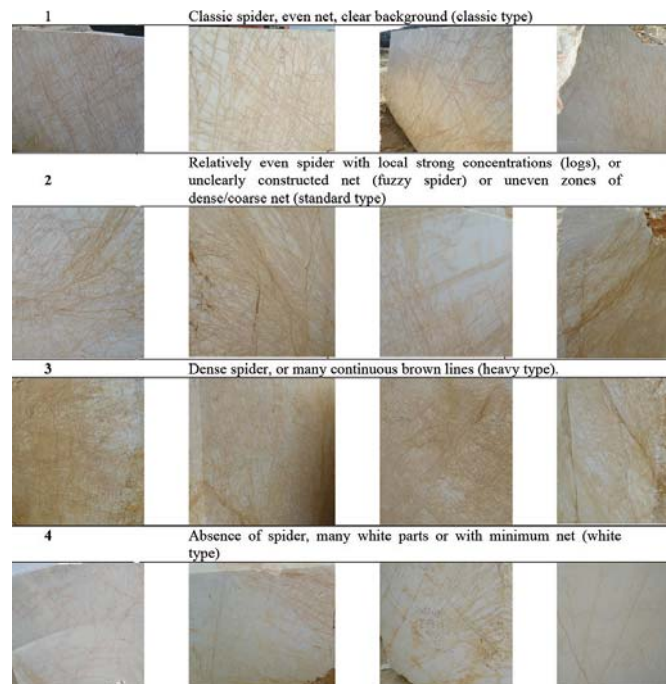| Rectangular (length >180 cm, height > 120 cm)	1 - No defects	2 - Defects 25–35% of each slab	3 - Defects 25–35% of each slab	4 - Defects 35–50% of each slab
Classic type 1	1-1=A1	1-2=A2	1-3=AB	1-4=B
Standard type 2	2-1=A2	2-2=AB	2-3=B	2-4=BB
Heavy type 3	3-1=AB	3-2=B	3-3=BB	3-4=BB
White type 4	4-1=B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

Figure 3—Colour and texture categories of Platanotopos marbles

Historical production from the quarry is given in Table II – the marble quality categories are explained in the following section.

Marble quality characterization

Colour and texture

Quality grading of Golden Spider marble is initially based on colour according to the following categories: G - golden, Y - yellow, R - red. Grading based on the spider-web texture is in one of four categories as described in Table III. Colour and texture combinations are presented in Figure 3.

Defects

Based on defects (fractures, dendrite zones, brown lines, discolourings or marks *etc.*) each slab is classified using the four categories in Table IV, and the final quality is assigned according to Table V. The slabs produced from the Platanotopos quarry are 6 × 2.8 × 7 m (width, depth, height).

Resource and Reserve estimation for a marble quarry using quality indicators

Reserve estimation data

Data used in the reserve estimation for 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, as well as diamond drill-hole samples and sections on quarry faces, which are analysed every metre as to the marble quality. A separate data folder was created for each quarry with a separate database for the topographical/vector data and one for the drill-hole/section data. An effort was made to maintain a systematic naming scheme for all files of databases and models created during modelling and estimation. Topographical data was provided in AutoCAD™ (DWG, DXF) file format and imported to Maptek Vulcan Quarry Modeller software and stored in appropriate layers. Drill-hole data was provided in Microsoft Excel™ file format and imported to the specialized sample databases in Maptek Vulcan Quarry Modeller. In the following paragraphs, we discuss briefly the data provided for each quarry.

Topographical data

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

Drill-holes and quarry face sections

A total of 92 drill-holes and sections were provided for the Platanotopos quarry (47 sections and 45 drill-holes), giving a total of 1684 one-metre samples for use in reserve estimation. This data sufficiently covers the extent of the estimated final pit as show in Figure 5. The data was validated using the software for collar location and overlapping intervals.

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 reserve 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.
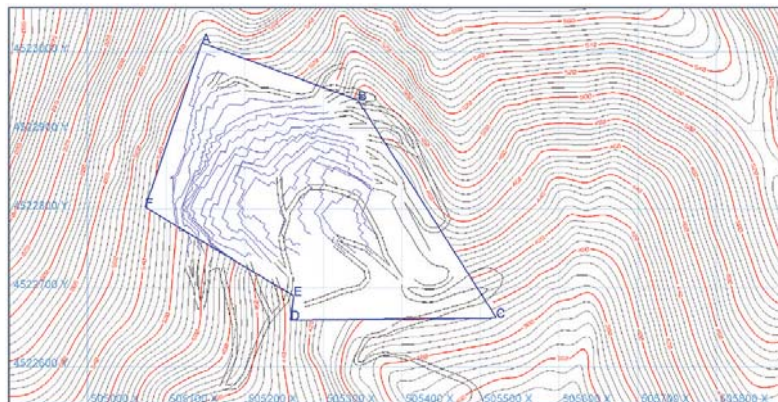

Figure 4—Original topography contours, current pit, and exploitation limits of the Platanotopos quarry
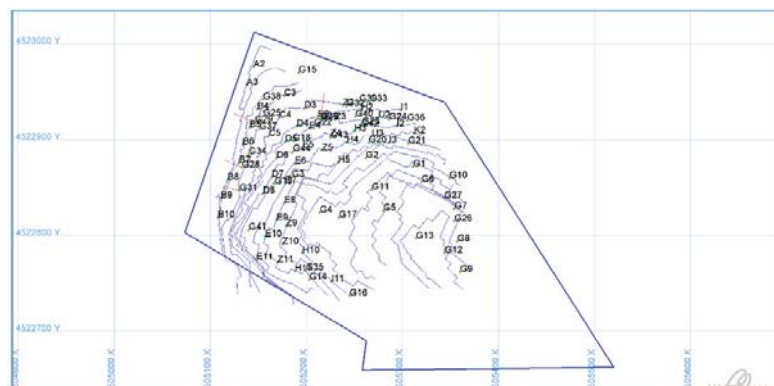

Figure 5 – Plan view of drill-hole and face section locations

Resource and Reserve estimation for a marble quarry using quality indicators
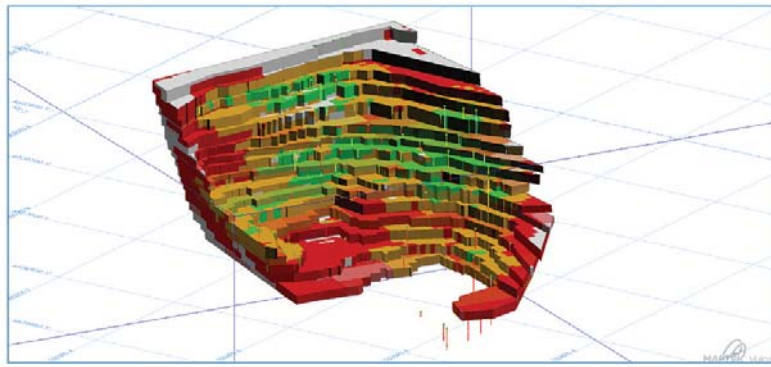

Figure 6—Solid triangulation models of the final excavation benches of the Platanotopos quarry coloured by reserves classification (green = Proved Reserves, orange = Probable Reserves, red = In-pit Inferred Resources)

Methodology

Sample database processing

The drill-hole and section sample 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 whether the specific sample belongs to or does not belong to the particular quality category, which is based on criteria that 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 1. This logic leaves out of the definition of initial quality due to the large-scale tectonism (represented by a solidity field called SYNOXH), which affect the final quality after it is estimated separately, with its own class fields. Thus different tectonism categories are defined for evaluation as for the different initial quality classes (1, 2, *etc.*). The reason for handling tectonism separately is the different orientations of large-scale tectonism, which requires a different search ellipsoid orientation (see Table VII). It is combined with initial qualities to derive the final ones with downgrading 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 indicator field SN1_PR receives the value of 1; if it has a value of 2, then indicator field SN2_PR receives the value of 1 and so on up to SN5_PR. Only one indicator field can have the value of 1 in any case, while the others would be 0. The initial qualities are downgraded based on the SN*x*_PR fields. For example, if the initial quality is A1 and SN1_PR is 1 then the final quality is again A1 – no

downgrading occurs. If the initial quality is A1 and SN3_PR is 1 then the final quality is AB – downgrading to two qualities lower.

After calculation of initial quality class fields and tectonism categories, a second procedure is carried out on the database by which the location of each sample (XYZ coordinates at the centre of each sample) is calculated and a weighting factor is assigned 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 drill-hole. Essentially, more weight is given to face sections as quality assessment is performed on a surface larger than the drill core and therefore better approaches the actual quality of the marble in that specific location. These weighting factors are used to further assess samples during interpolation.

Quality estimation

Quality class field values were interpolated 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 into blocks of the same size. For Platanotopos quarry, a block model with rotation around the Z axis was constructed that covered the entire quarry volume and current sampling. The model specifications are given in Table VI. Block dimensions were configured based on the marble volumes that are extracted separately at the Platanotopos quarry (slab dimensions). 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 that are oriented according to the geological features of the particular deposit. Ellipsoid parameters are given in Table VII.

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 Platanotopos marble

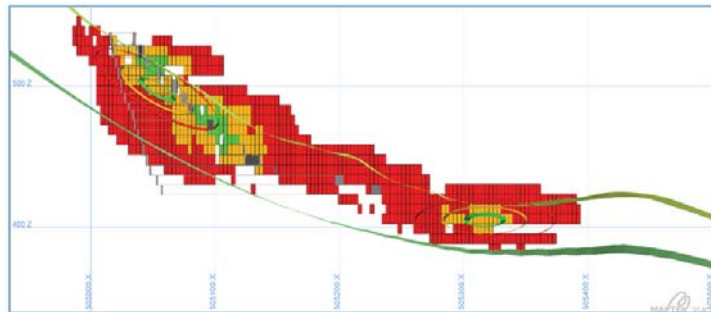| Table VI			
Block model specifications of the Platanotopos quarry			
Origin	X		505 460
	Y		4 522 340
	Z		290.5
Model dimensions	X		582 m
	Y		728 m
	Z		350 m
Block dimensions	X		6 m
	Y		2.8 m
	Z		7 m
Orientation	X-axis azimuth		28ᶜ
	X-axis rotation around Y-axis		0°
	Y-axis rotation around X-axis		0°
Block count			1 261 000

Figure 8—Cross-section through block model and resource classification ellipsoids following the folding of the deposit in the Platanotopos quarry (smaller to larger – Measured, Indicated, Inferred)

Table VII				
Plantanotopos quarry estimation parameters				
	Measured Resources	Indicated Resources	Inferred Resources	SYNOXH parameter
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 drill-hole	4	4	4	4
Blocks estimated	1 342	9 754	26 259	37 355

Resource and Reserve estimation for a marble quarry using quality indicators

Table VIII

Reserves estimation results for the Platanotopos quarry

Bench	Elevation	Proved Reserves (m³)			Probable Reserves (m³)			Inferred In-Pit Resources (m³)			Waste	Total
		A	AB	B	A	AB	B	A	AB	B		
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

Block estimation in Platanotopos quarry was different to that for the other quarries as the ellipsoids had a 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 technically 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 VI).

Results and conclusions

Reserve estimates

Table VIII gives the results of the reserve estimation. For each reserve category, three generalized qualities are reported. Generalizing of qualities was considered necessary as the limited sampling does not allow for a more detailed analysis of reserves to the original A1, A2, AB, B, and BB quality categories 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 with reference ellipsoid dimensions and minimum sample count. As a result, a considerable part of the waste and the Inferred Resources can potentially be upgraded in the future with additional drilling, which will provide a clearer and more detailed picture in areas where there are currently no samples.

Conclusions and future work

A Resource and Reserve estimation procedure applied at the Platanotopos marble quarry of Iktinos Hellas SA was performed using specialized 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 method of producing reliable results according to international standards of Resources/Reserves reporting.

Future work will include integration of historical production data with the quality estimation process and implementation of an appropriate production quality control system that will produce the necessary data to improve the current quality models and reserve classification. As is evident in Figure 6, there is room to improve the Resource and Reserve classification of exposed marble – most of the exposed quarry face blocks are not classified as Proved. Standardization of quality assignment to drill core samples and production marble slabs is also an area where significant improvement is required.

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