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DISCONTINUITY ANALYSIS AT RUSCHITA MARBLE QUARRY USING TELEVIEWER AND SCANLINE TECHNIQUES

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Abstract: *Stone blocks, such as marble, granite, and sandstone, are natural materials with excellent properties. The most important dimension stone in Romania is Ruschita marble, a natural stone known for its resistance to wear and ability to maintain its natural beauty, regardless of its colour. Regarding colour palette, Ruschita marble stands out for its excellent quality to suit even the most demanding requirements. It is available in shades such as yellowish, orange, pale pink or pink, with a compact structure and characteristic veining. Ruschita is Romania's most famous marble deposit, exploited since the end of the 19th century. The quarry exploitation is conditioned by naturally occurring fractures and discontinuities, such as faults, joints, and fissures, precluding larger blocks excavating with more significant commercial value. This paper describes two largely used techniques for discontinuity investigation, namely the televiewer and scanline methods used at the Ruschita marble quarry.*

Keywords: *quarry, marble, discontinuity, joints, televiewer, scanline*

1. Introduction

All rock masses contain bedding planes, fissures, fractures, joints, and other mechanical defects, referred to as "discontinuities".

A discontinuity is any significant mechanical break or fracture of negligible tensile strength in a rock. The term discontinuity makes no distinctions concerning the feature's age, geometry or mode of origin.

In many cases, it is helpful to distinguish between natural discontinuities, which are of geological or geomorphological origin, and artificial discontinuities created by such activities as drilling, blasting and excavation.

The complex three-dimensional structure of discontinuities in a rock is termed the discontinuity network or the rock structure. Elements of intact, unfractured rock are referred to as the rock material, which, together with the discontinuity network, form the in-situ rock mass.

2. Ruschita Marble Quarry Topography and Geology

2.1. Topography

Ruschita Quarry is a marble deposit located in the northern part of Caras-Severin County, in the village of Ruschita, on the border with Hunedoara County (Fig. 1). The nearest populated centres are Ruschita (1 km) and Rusca Montana (10 km).

Access to the area is from DN68 Caransebes - Hateg, from the locality of Voislova, which it crosses, then on DJ684 Voislova - Rusca Montana – Ruschita - Cosava, partially modernised, from which at approximately 19 km from Voislova, in the locality of Ruschita, an industrial road branches off, providing access to the mining area.

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Geographically, the Ruschita marble quarry belongs to the Poiana Rusca mountains, characterised by a prominent landscape with deep valleys and steep slopes.

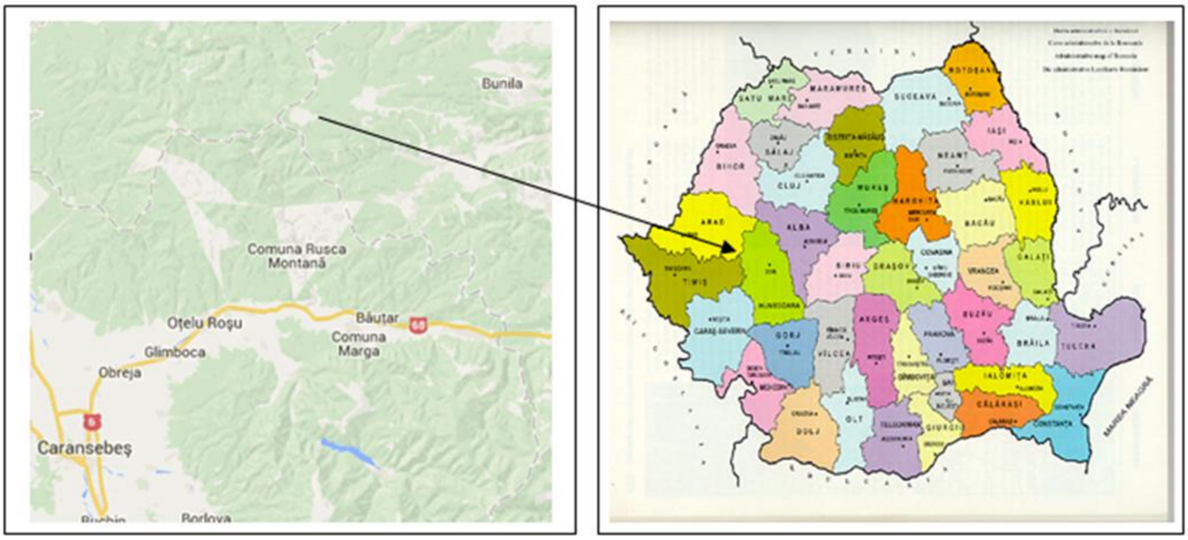

Figure 1. Ruschita Marble Quarry Location

The geographical coordinates which define the localisation of the Ruschita marble quarry are:

- N 45°38'54";
- E 22°24'20";
- 600 - 850 m altitude.

2.2. Geology

The metamorphosis of reefs formed Ruschita marble and Devonian peri reef limestones, developed on a submarine relief composed of basic volcanic rocks.

The Ruschita marble deposit is located in the epimetamorphic unit of the Poiana Rusca massif.

The epimetamorphic formations of Poiana Rusca are represented by three series of crystalline rocks:

- lower terrigenous series;
- basic volcanogenic series;
- superior terrigenous series.

The age of the epimetamorphic formations is Upper Proterozoic, Paleozoic. The crystalline formations are traversed by dykes and phyllodes of banatitic eruptive rocks intruded in the Laramian phase of the Upper Cretaceous-Paleogene magmatism. The banatitic dykes caused thermal metamorphism in contact with the crystalline rocks, and hydrothermal solutions caused a series of alteration processes and the emplacement of complex sulphide mineralisation.The Quaternary is represented in the area by alluvial deposits consisting of boulders, pebbles, coarse sand, and sandy clays.The geology at the site is shown in Fig. 2, its legend is shown in Fig. 3, and a cross-section can be seen in Fig. 4.

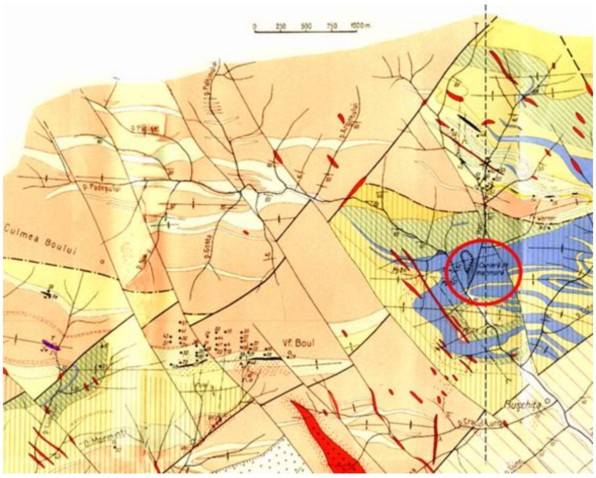
Figure 2. Geology on site

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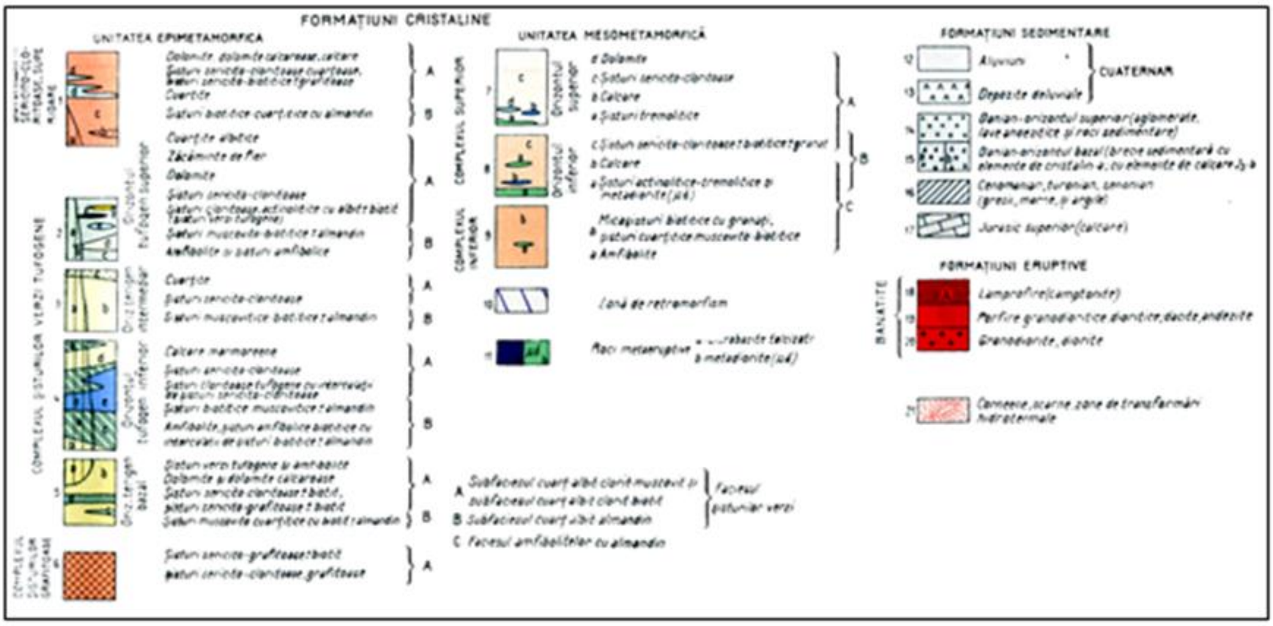

Figure 3. Geological legend

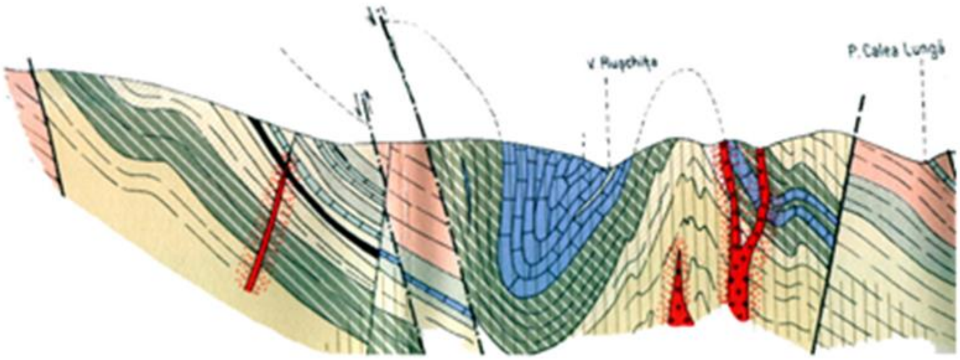

Figure 4. Geological cross-section

The Marmorean crystalline limestones are in the middle of the green tuffaceous schist complex, forming the lower part of the Poiana-Rusca massif series.

The band of crystalline limestones develops over a width of 400 m and a distance of 800 m between Paraul Morii to the east and Cracul Poiana Plumbului to the west.

Stratigraphically it is formed by three levels forming parallel strips in the plane:

- the level of grey marble;
- level of white marble;
- the pink marble level.

3. Optical borehole survey

3.1. Technique

An optical borehole inspection has been performed to identify the fracture, discontinuity, and other material changes.

The discontinuity depth has been recorded, and the inclination (dip) and dip direction have been identified in the post-processing phase.

3.2. Instrument

The tool is a portable borehole camera with digital recording for inspection - micro CA-330 RIDGID (Figure 5). This digital platform allows the inspection and recording of images and videos in inaccessible areas, such as wells and cavities.

It is possible to adjust the image parameters, rotation, and digital zoom for detailed and accurate visual inspection.

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Figure 5. Inspection camera Micro CA-330

The instrument can record images on external memory and output them to the TV system.
Technical specifications are presented in Table 1.

Table 1. Technical specifications

Specifications	Parameter
Suggested use	indoor
Visualisation distance	From 0.4" (10 mm) a ∞
Display	3.5" (90 mm) Color TFT (Resolution 320 x 240)
Cam diameter	3/4" (17 mm)
Lights	4 LED dimmable
Cable	3' (0,9 m), up to a 30' (9 m)
Minimum curve radius	5" (13 cm)
Waterproof	Up to 10'(3 m), IP67
Foto file format	JPEG
Image resolution	640 x 480
Video resolution del video	320 x 240
Video format	MP4
Frequency	30 FPS
Digital zoom	2X
Output TV	PAL/NTSC
Protection	IP65
Integrated memory	235 MB
External memory	SD™ 32 GB max
Data output	USB cable, SD™ and Wi-Fi.
Wi-Fi range	33' (10 m)
Bluetooth range	16.4' (5 m)
Temperature range	from 32 to 113° F (from 0 to 45° C)
Alimentation	battery Li-Ion o
Weight	5.5 lbs (2,5 kg)

For this particular analysis, the camera has been positioned in a metallic structure, with two disk plates of 70 mm diameter, with holes connected by four flexible metallic arches.

The camera has been inserted by hand in the borehole, with rods of 1.5 m each.

The operator can see the images in real-time, while the other operator can record the dip and video time of the fracture, discontinuity, or cavities.

Fig. 6 represents the equipment used for the camera in the borehole and the horizontal hole logging.

3.3 Methods

Images and video have been recorded to preserve the north direction on the top-centre part of the image, both for horizontal and vertical boreholes.

Additional data was recorded during image acquisition when the camera encountered a structure of particular relevance. The rods of the instrument are marked every 10 cm to identify the structures' depth.

Figure 6. Equipment used for the camera in the borehole and the horizontal hole logging

3.4. Ruschita Quarry Measurements

In the Ruschita marble quarry, two boreholes have been inspected. The first is a horizontal borehole positioned in a vertical wall in a north-south direction. The second one is vertical, about 10 m in depth. Both holes have a diameter of 89 mm.

The examined bench is almost near the north-south direction, with a height of about 7.5 m. A horizontal borehole is located at a height of around 1.80 m from the base of the bench. The length of the hole is 11.5 m, est-west direction, with a diameter of 89 mm. At the top of the bench is a vertical borehole of 9.80 m depth, located at 1.5 m from the wall bench. The vertical borehole is orthogonal to the horizontal hole at a distance of approximately 2 m.

Boreholes' positions are presented in Fig. 7, where the wall face is shown with the exact position of the horizontal borehole and the approximate position of the vertical borehole drilled vertically on the top bench.

Also, Fig.7 shows the compass used to determine the azimuth of the face and bench structures, as well as the steel rod introduced into the boreholes.

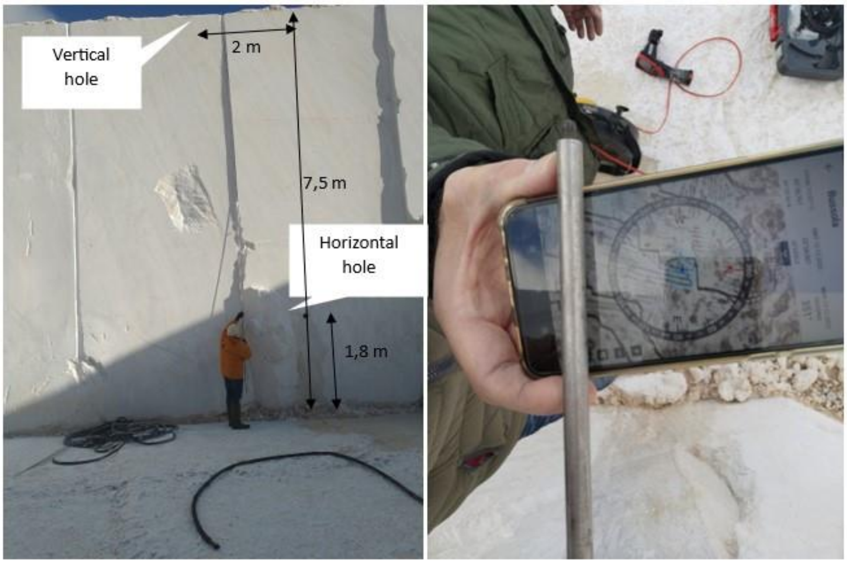

Figure 7. Picture of the horizontal hole in the bench and the vertical hole at the top of the bench

3.5. Ruschita Qualitative Characterization

The rock mass is compact with discontinuities that can be classified into two classes.

The first class have thin discontinuity (Fig. 8), with a thickness lower than 1 mm, dark, probably for the presence of pyrite without a visible opening. The second class shows ochre oxidations that probably are due to a water flow, with thicknesses, in some cases, greater than 1 mm (see Fig. 9).

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Figure 8. Ruschita Quarry, borehole 2 - Image taken at 3 m depth

Figure 9. Ruschita Quarry, borehole 1 - Image taken at 4.8 m depth

3.6. Discontinuity analysis

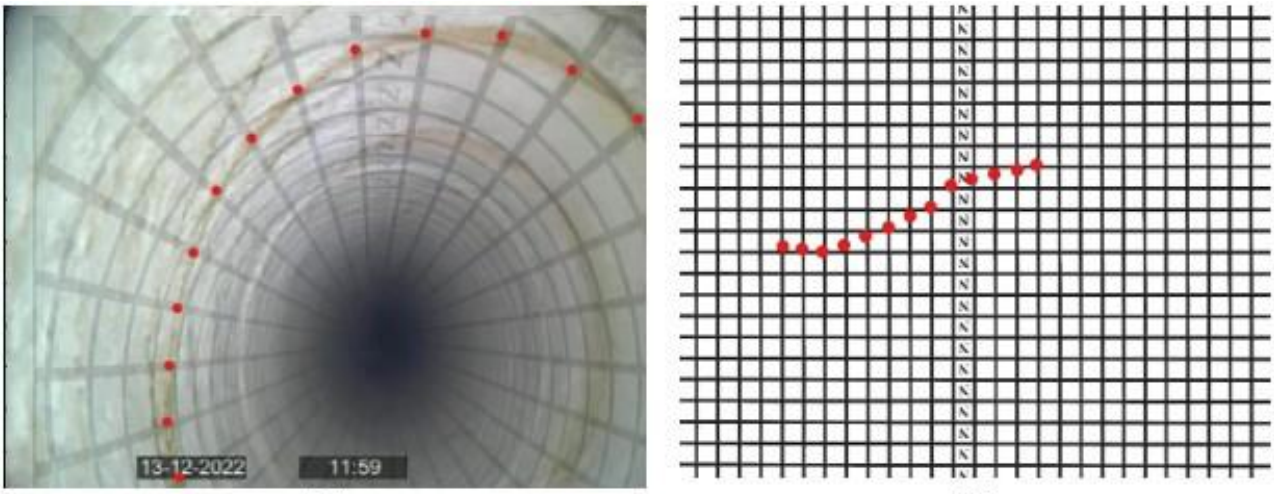
Using IrfanView Software, each discontinuity was superimposed to a grid in a transparent layer, and a calibration image was obtained using the same camera - with a calibrated mesh of dimension 1 cm x 1 cm.

The calibration image has been acquired in a borehole of the same size as the in-situ holes. The fracture has been characterised by the visual inspection of the trace of the fracture against the reference mesh. The intersection between a plane and a solid cylinder will generate an ellipse.

By unrolling the ellipse into a 2D plane, the fracture trace can be represented by a sinusoid.

An Excel worksheet allows interpolating the fracture with a plane of known dip and dip direction.

Fig. 10a shows hole 1 horizontally, at a depth of 4.8 m - image with the fracture and calibration mesh and Fig. 10b the interpolating sinusoid.



(a) (b)

Fig.10a. Hole 1 horizontally, at a depth of 4.8 m - image with the fracture and calibration mesh
Fig.10b. The interpolating sinusoid

3.7. Discontinuity characterisation

The trace of the sinusoid has been inserted in the Excel graph for parameter interpolation (inclination and deep direction) to characterise the space's discontinuity.

Results are summarised in Table 2 and Table 3.

Borehole No. 1, horizontal - X coordinate is in the north-south direction, Y in the hole direction (along the borehole), and Z is constant at 1.7 m from the base of the bench.

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Table 2. Results from Hole No. 1

Fracture N.	Position (x y z)(m)	Inclination/ Dip (deg)	Dip Direction (deg)	Note
1	Y 1.0	65	125	
2	Y 2.0	72	101	
3	Y 3.0	175	130	
4	Y 3.9	155	70	
5	Y 4.7	172	28	
6	Y 4.8	140	22	
7	Y 4.9	160	35	
8	Y 5.0	160	30	
9	Y 5.2	155	73	
10	Y 8.7	110	85	
11	Y 9.0	155	76	

Borehole No. 2, vertical - X direction is along the wall north-south, Y is in the east-west direction and Z is the depth of the borehole.

Table 3. Results from Hole No. 2

Fracture N.	Position (x y z) (m)	Inclination/ Dip (deg)	Dip Direction (deg)	Note
1	Z 1.3	155	80	
2	Z 2.2	100	67	
3	Z 2.7	98	53	
4	Z 2.9	55	117	
5	Z 3.7	50	80	
6	Z 5.2	40	355	
7	Z 6.2	60	66	
8	Z 8.3	83	125	

Fig. 11 is an example of the applied procedure for determining the dip direction and inclination/ dip of the fracture/ discontinuity, using image dimension (pixels) at borehole diameter.

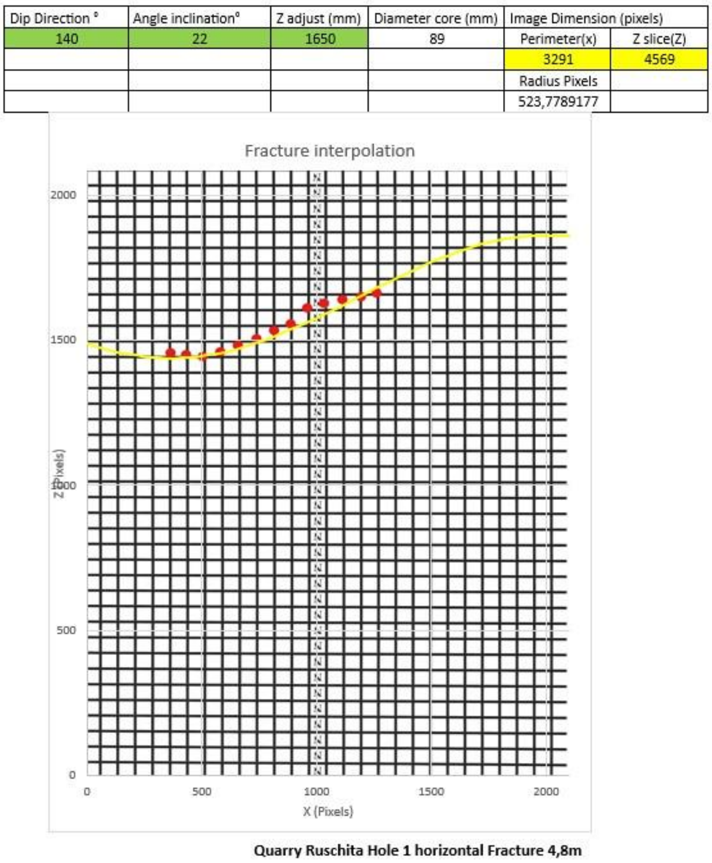

Figure 11. Example of sinusoid fitting for the Ruschita quarry, borehole no. 1, horizontal

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4. Discontinuity Survey using Scanline Method

4.1. Methodology Used for Discontinuity Measurement

We have used the same block face as Borehole No. 1 for joint measurements to correlate measurements from the televiewer and scanline.

The exact location of the block faces is presented in Fig. 12 (position based on Google Earth and GPS localisation from the Fieldmove Clino (www.petex.com) software used for bedding/ joint measurement.

Figure 12. Location of the block faces in Ruschita Quarry

The methodology used for discontinuity measurements (bedding planes, joints) was an adaptation of the scanline / window sampling method described by Priest [1].

An iPhone was used for discontinuity orientation and inclination measurement using Fieldmove Clino software and a Brunton compass for calibration - Fig. 13.

Figure 13. Brunton compass and Schmidt hammer

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Simultaneously, a Schmidt hammer was used to determine the marble's compressive strength.

Fig. 14 presents all the equipment and materials used for in situ measurements: rulers, tape, a geological hammer, laser spirit level, a digital camera and coloured dye for marking joints and distances on the faces.

Figure 14. Equipment and materials used for joints measurements

Discontinuity orientation measurements were recorded automatically by the Clino software and saved on the iPhone. Files were subsequently transferred on a tablet with the same software, having more data processing capabilities, and exported to Google Earth for visualisation and further processing.

Distances from the origin of the scanline/ window sampling were recorded on a survey logging form similar to the one suggested by Priest [1] and presented in Fig. 15.

SCANLINE SURVEY LOGGING FORM | Page | Of |

Details of scanline:	Details of rock face:	
Label	Location	Rock type ....
Trend	Dip direction	Excavation method ....
Plunge	Dip angle	Condition of exposure
Trimming level ....m	Non-overhanging / Overhanging	Comments
Logged by	Height ....m	
Date logged	Width ....m	

Intersection distance d (m)	Dip Direction (Degrees)	Dip Angle (Degrees)	Semi-trace length *l* (m) above or left of scan	Semi-trace length *l* (m) below or right of scan	Termination I=1, A=2, O=3		Rough-ness *JRC* 1-20	Curv-ature 1-5	Comments (Refer to table of abbreviations and codes)

Figure 15. Survey logging form used for joints measurements

Additional information regarding strength JCS – Joint Compressive Strength (Fig. 16) and Roughness JRC – Joint Roughness Coefficient were collected during the in-situ investigation.

Distances were marked horizontally and vertically on the block face – further south from the horizontal borehole (used for the televiewer) on the West-facing marble block (Fig. 17) and were continued at 90 degrees on the north-facing block marble - see Fig. 18.

This approach has given the possibility to determine joint distribution in a 3D space, as measurements took place on two orthogonal faces/ planes. This, combined with televiewer investigation of 2 orthogonal boreholes, would give a 3D real distribution of the jointing system – a pre-requisite for good conditioning of the Discrete Fracture Network (a step along the line for the project).

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Figure 16. Using Schmidt hammer for Joint Compressive Strength measurements

Figure 17. Main wall of the block marble west-facing for televiewer and scanline measurements

Figure 18. Main wall of the block marble north-facing only for scanline measurements

Fig. 19 presents an overview of the two orthogonally located block marble faces used for joint system measurements and marked with Joint Numbers (F1 to F20) and horizontal distances – from 0 m to 16 m and vertically from 0 m to 2 m.

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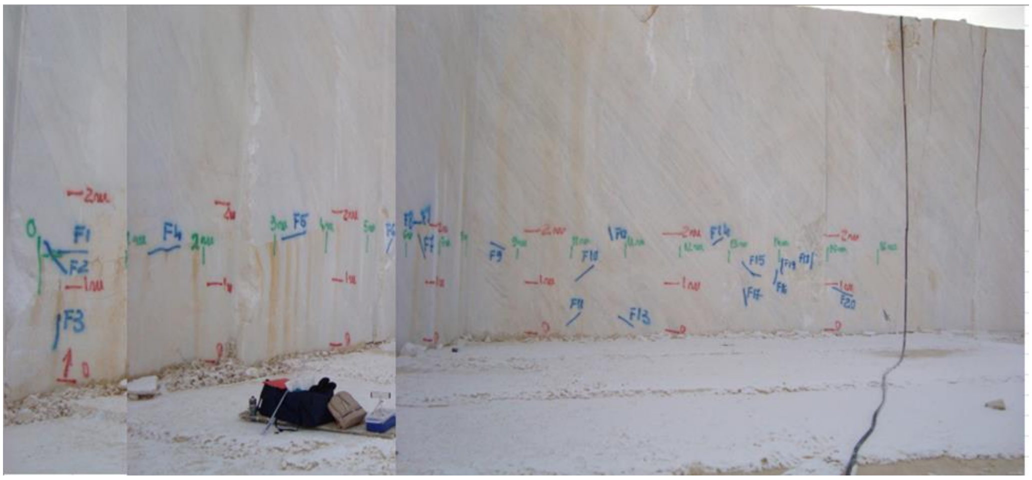

Figure 19. Scanline/ window sampling area of the orthogonal faces of marble blocks west & north-facing

Thus, the in-situ measurements cover the was approximately 32 m^2.

4.2. Processing Data from Discontinuity Measurement

Cluster analysis for each face was processed using DIPS from Rocscience (www.rocscience.com) and the scanline / face plane as a traverse.

For the west-facing marble block, three joint families were identified and presented in Fig. 20 on the Polar equal-angle net and the rosette plot.

Fisher distribution parameters were calculated during joint data processing.

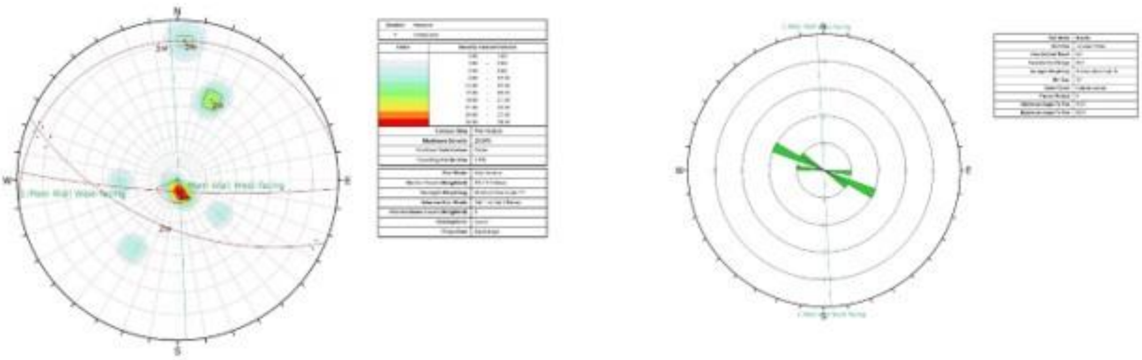

Figure 20. Stereonet and Rosette plots for west-facing marble block

A similar joint cluster analysis was run for the North-facing marble block, identifying four joint families. Results are presented similarly in Fig. 21.

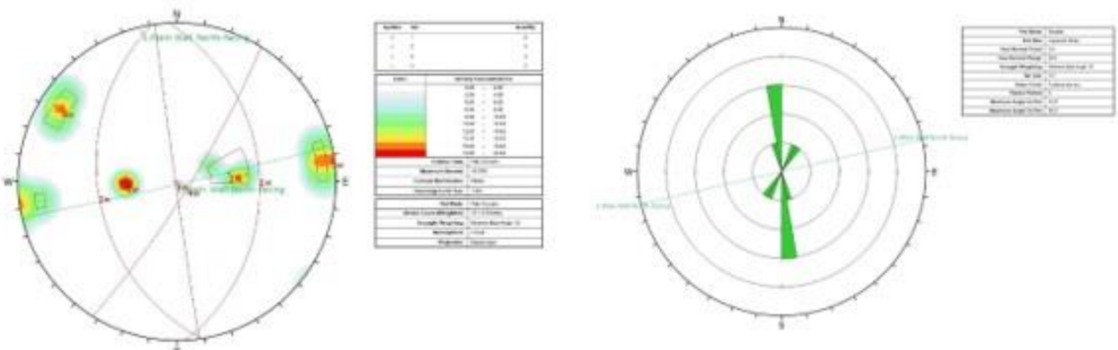

Figure 21. Stereonet and Rosette plots for north-facing marble block

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5. Conclusions

Two investigation techniques, largely used in rock mechanics for discontinuity measurements, were used at Ruschita marble quarry to determine the rock mass jointing system and identify joint clusters/ families.

The first investigation technique is based on recording images inside a borehole using a digital optical televiewer, whereas the second one is based on the classical scanline/ window mapping of the rock mass discontinuities using a digital compass (basically a mobile phone with specialised software).

In situ joint orientation measurements were calibrated using a Brunton compass, following procedures presented in [2].

Televiewer data was processed in accordance with the methodology suggested in [3], and the dip/ dip direction of the encountered fractures was derived.

Scanline, and joint orientation measurements, were processed using DIPS, which is an interactive and graphical software for the analysis of orientation-based data [4]. Cluster analysis shows joint families and their Fisher's distribution for both faces.

The next step would be to run a similar analysis for the televiewer and compare it with the results from the scanline method. Ultimately, all discontinuity information should be processed together for an overall result and used for the conditioning of the DFN – Discrete Fracture Network.

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