Use of Ground Penetration Radar (GPR) in the Evaluation of Geological-Structural Elements of Ornamental Carbonated Rocks - Case Study in Valinho De Fatima, Portugal

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Abstract. In the extractive industry of carbonated ornamental rocks, the presence of discontinuities, size of grain, colour, textural anisotropy and porosity are factors that determine the extraction planning and their economic viability. This characterization is important for the planning and scaling of the exploitation. The objective of this work was in first, using the penetration radar in the soil (GPR), to identify and determine the spatial distribution of these elements. The choice of this non-destructive geophysical method to perform the work was because it is a fast method of inspection, having a good horizontal and vertical resolution, and relative precision. For this purpose, a PULSEEKKO GPR (SENSORS & SOFTWARE) acquisition equipment was used, with a system of two bi-static antennas (transmitter and receiver), unshielded, with a frequency of 100 MHz, using the reflection method with a common offset and with an antenna separation of 1.00 meter (m), at the pre-defined locations at each level of the quarry. The acquired data were subsequently processed in the REFLEXW® vers. Software. 7.5.9, from SANDMEIER-GEO®. The multiple profiles obtained (radargrams) [1], [2], which were compared with the corresponding exploitation fronts. This comparison allows validating the methodology used in the identification of existing structures, their vertical and horizontal limits and spatial relations between them.

1. Introduction

In the ornamental rock industry, the first stage of the exploitation process is the exploration of stone materials with certain characteristics that give them commercial value [3]. For an industrial stone extraction unit to be economically viable, it is necessary to comply with some requirements regarding the presence of discontinuities, grain size or presence, textural anisotropy and porosity of materials [4].

The presence or not of these elements in the rock massif is an economic risk factor, which must be identified in advance [5], determining the technical and economic viability of the exploitation. Pre-detection is usually difficult, and intrusive and costly techniques are common. It considers these limitations, this preliminary work intends with the use of a non-destructive geophysical method, to develop a methodology, that allows to reduce costs and with rigor, to detect, quantify and modelling these hidden characteristics (discontinuity [6], [7], [8], [9], the variety of types and textures of rocks and horizontal and vertical development [10]).

The objective of this study is the development of a methodology using non-destructive techniques, in this case, the ground penetration radar method (GPR), which allows the professionals involved in
the sector to identify and quantify the risk factors that allow the implementation of the exploitation or minimization of associated risks. This is objectively a competitive advantage, maximizing the quality of the products, avoiding to the maximum its wastes and consequently the costs related to it, through the proper planning of the exploitation.

2. Location and Geology
This work was carried out in the centre of Portugal, in Valinho de Fátima, Fátima, Ourém, Santarém, according to the location indicated in figure 1. Geologically the outcrop limestones are stratigraphically located in the middle Jurassic - Caloviano Formation of Santo António - Candeeiros - Member of Moleanos) [6], formed by oolitic, biocalciclastic and sparritic limestones.

3.Methods and methodologies
To perform this work, the geophysical method used was the GPR, and the data acquisition was done using the SENSORS & SOFTWARE PULSEKKO GPR equipment (Fig.2).

For the results to be satisfactory and to reach the proposed objectives, the equipment was configured according to the parameters presented in table 1.

With these acquisition parameters and after data processing (DC-Shift, zero-time adjustment, subtract-mean (Dewow filter), background removal, bandpass frequency, gain adjustments, diffraction stack and correct 3D topography), radar radars? with the depth of investigation of ±14.00 meters were obtained. The radargrams obtained for each bench allowed a comparison with the fronts and a block extracted, to make an evaluation of the existing structures, discontinuities and textures. The acquisition data were processed in the REFLEXW software, vers. 7.5.9, of the SANDMEIER-GEO [11].
In order to make a valid and representative comparison of the results, the GPR profile coincided significantly with the exploitation front of the quarry, to match the radargram with the horizontal and vertical distribution of the structures and the spatial relations between them.

![Figure 2. a) Equipment of GPR. b) Local of acquisition inside the quarry.](image)

### Table 1. Equipment Configuration Parameters

| Profile A-A’ |  |
|---------------|-----------------|
| Data Collected | 2018-Out-02 |
| Survey Type   | Reflection |
| Acquisition mode and trigger | Continuous, odometer |
| Antenna type  | Bi-static, unshielded |
| Frequency (Mhz) | 100.00 |
| Time Window (ns) | 250.00 |
| Speed of the environment | 0.100 m/ns |
| Step Size (m) | 0.050 |
| Antenna Separation (m) | 1.00 |
| Dynamic Stacking (medium value) | 13 |
| Maximum depth of investigation (m) | ±14,00 |

### 4. Results and discussions

The profile was executed in the quarry at the location marked by Profile A-A' (Fig.3). The corresponding front consists almost entirely of Oolitic limestone with cross-stratification. Due to security and technical issues, the proximity of the verticality (boundary condition of Dirichlet [12]), the profile was made more recessed, not coinciding with the front, to mitigate this effect (Fig.3). Because of this retreat, the radargram obtained presents in its upper part (between 1.5 and 2 meters) a structural pattern different from the rest of the radargram (Fig.4).

In figure 5, which corresponds to the same radargram, the interpretive structures were drawn, based on the interpretation of the radargram and observation of the front of the quarry.

Thus, it was identified in its upper part what would correspond to the oolitic limestone, structures and discontinuity’s above the blue line. The presence of this type of lithology in the radargram is because of the retreat of the profile, which makes it not coinciding with the lithology observed at the front top of the quarry.

As the stratification in the predicate presents a strike of 8ºE, the retreat distance was enough to register the line of contact between the two lithologies (oolitic limestone / oolitic limestone with cross-stratification).
Figure 3. Location of the profile A-A’. Red line - height and location of limestone types. Yellow dashed line – Discontinuity. Icon – Stratification attitude.

Below this line, which corresponds to the stratification, it is possible to identify layers of oolitic limestone with cross-stratification, indicated in figure 5. Near the point A of the profile, approximately 1.5 meters there is a discontinuity in the trace of the radargram, marked with the yellow dashed line. This discontinuity is identifiable in figure 3.

Figure 4. Radargram of the profile A-A’, without interpretation.

The bench front was disassembled later in blocks with commercial sizes of 2.85 x 1.5 x 1.7 meters (Fig. 6).

The block shown in the figure was withdrawn substantially at the location of the profile. From its observation, it is possible to correlate some of the existing structures in the radargram, the cross stratification.
Figure 5. Radargram of the profile, with interpretation. Red line - height and location of limestone types. Yellow dashed line – Discontinuity.

Figure 6. Removed block, with an exposed face. It is possible identified the structures observed in the radargram of figures 4 and 5.

5. Conclusions
The main objective of the present work was to evaluate an exploitation front using a non-destructive geophysical method, GPR. This preliminary study aimed at evaluating characteristics such as the alteration state of rocks, texture and sedimentary structures, to detect and to locate any discontinuities that were not perceptible in the massif and that could condition the quality of the extracted blocks as well as the mining planning.
With the use of the GPR method, it was observed that the reflection amplitudes of the EM signal are directly related to the textural and structural variations visible in the exploitation front, as well as in the later extracted block. It can be concluded from this preliminary work that:

1. The grain size and texture, the sedimentary structures present, the presence of discontinuities are factors that influence the amplitude of signal reflection;
2. The method requires critical sense and attention because there are more external factors to consider that influence the results (e.g., saturation of rocks in water).
3. In terms of data acquisition and processing it turns to be a fast method, with high depth of penetration and resolution, that allow us a very reliable visualization of the existing textures, structures and discontinuities.

In the future, it is important to use other antennas with better resolution, allowing better identification of the parameters and correlating the data collected, such as grain size, porosity, grain compaction and calibration, presence of fluids (water) and other elements existing and likely to be taken as a reference. This correlation is important to determine with some rigour the lithological type present, mainly in places where it is not possible to visually identify the material or inactive mining zones, for its planning.

The proposed methodology was validated by the observation of the fronts and blocks extracted, and the objective of the preliminary study was reached. The elements described above were identified with considerable resolution and precision. The GPR method proved to be versatile, without the need for large preparations of the chosen acquisition place, allows to vary the acquisition parameters in an expedited way and to visualize in real time the result of the acquisition.

It will be very important in the future make a data acquisition that allows the 2D and 3D modelling of the rocky massif, aiming at the visualization and the horizontal and vertical determination, as well as the correlation of the mentioned elements.

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