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Use of Non-Destructive Methods in Structural Analysis of Petrous Materials - Ultrasonic Testing and Ground Penetrating Radar (GPR)

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Abstract. In the extractive and transformation processing industry of ornamental rocks, the presence of discontinuities, grain size, porosity and textural anisotropies in the explored blocks is an economic risk factor. This study aims the identification and possible quantification of these elements. The existence of a low-cost, non-intrusive and fast inspection method for the evaluation of blocks would facilitate their use avoiding their wastage. For this purpose, two non-destructive methods ("P" Wave Ultrasonic Testing and the Ground Penetration Radar (GPR)) were tested on a limestone rock block and compared the models obtained. The portable ultrasound equipment used was a Proceq Pundit Lab (Portable Ultrasonic Non-Destructive Digital Indicating Tester) which is based on the pulse rate method with 54 KHz to provide information about the uniformity, cavities, cracks and defects of the material concerned by the measurement of the ultrasonic wave time and the measurement of the pulse rate. The equipment used for the GPR data acquisition was a PULSEEKKO GPR (SENSORS & SOFTWARE), with a system of two bistatic antennas (transmitter and receiver) with a frequency of 1 GHz, using the reflection method with a common offset and with an antenna separation of 0,15 meters [m]. To make a comparison of the results valid and representative, both tests were performed with 0,10 m spacing between measurements, according to a pre-defined and common grid. In the case of the ultrasonic test, velocity color maps were created based on the results of the measurements, and through this colors differences it was possible to detect and locate some of the individual and visible fractures, but also not visible fractures on the surface of the tested face. By increasing the distance between transducers, the measurement depth also increases, creating maps of the same face at different depths. This method allows us to create several GPR profiles (radargrams) were obtained because of the processing, and were used to create 2, 2,5 and 3D models to identify the existing structures, their vertical and horizontal limits and spatial relationships between them.

1.Introduction

In the ornamental rock industry, the first phase of the process is the rock extraction in the form of blocks, which are subsequently transformed and traded in different types of products (blocks, sawn-off plates and in construction material). In this sector, all petrous material types are partly extracted and processed in different dimensions and shapes. The extraction of ornamental rocks is made by cutting blocks with a volume of 3 to 5 cubic meters, which after the processing originates plates of various thicknesses, depending on their use [1].

The presence of discontinuities in the rock mass is an economic risk factor, which must be identified in advance, determining the technical and economic viability of the exploration. Detecting hidden characteristics is generally not possible except by intrusive techniques. For extractive and transforming industries, a non-destructive diagnostic procedure used for the quality control of blocks would be an added value [2], [3].

It is true that there are several standards to indicate which tests shall be done on rocks, usually physical-chemical characterization tests are carried out at a stage of exploration or transformation, but there is still an increasing need for more specific test to facilitate the professionals of this sector the recognition of factors that enable the implementation of the exploration or minimization of the risks associated with the transformation.

This study is about the latest thematic, being of great relevance and competitive advantage, maximizing the quality of the products, avoiding as much as possible their waste and consequently the costs related to it. If at the beginning it was possible to know a discontinuity, three-dimensional gaps hidden inside the block [4], the variety of sedimentary rock types and textures [5] as well as its horizontal and vertical development, although it is not visible to surface, it would allow to have a different cutting approach according to its location and size, achieving greater use of this and a lower cost for the owner.

Taking in consideration the difficulties in obtaining information on the quality of the ornamental rock blocks, it was the main objective of this work to detect and if possible to locate any internal discontinuities through non-destructive techniques such as Ultrasound technique and Ground Penetration Radar (GPR).

2. Methods and methodologies

For the accomplishment of this work two equipment were used according to the methods:

- Ultrasound Method - Proceq Portable Pundit Lab (Portable Ultrasonic Non-Destructive Digital Indicating Tester);
- GPR Method - SENSORS & SOFTWARE PULSEEKKO GPR equipment.

The ultrasound method is based on the pulse rate method, to provide information about the uniformity, cavities, cracks and defects of the material in question. This equipment allows the measurement of ultrasonic wave travel time and pulse rate measurement [6]. According to the operating instructions manual of this equipment, three types of transmission are normally used, being the direct, semi-direct and indirect or surface method [6]. In this way, only contact tests were carried out to transmit longitudinal waves in the sample, and the transducers were also used as contacts, with a frequency of 54 kHz, chosen to be able to penetrate both fine grain and coarse grain materials at major penetration depths. In these tests, it is essential to use a coupling substance between the faces of the transducers and the sample to be tested to facilitate the transmission of ultrasonic energy, in this case, petroleum jelly.

It was decided to perform only the surface transmission test, with variants in the arrangement of the transducers, applied in a limestone block with dimensions of approximately 1,80 m x 0,80 m x 2,20 m. To facilitate the measurements, a grid with vertical and horizontal lines spaced 0,10 m apart (Figure 1) was drawn and numbered on each of the four faces of the block.

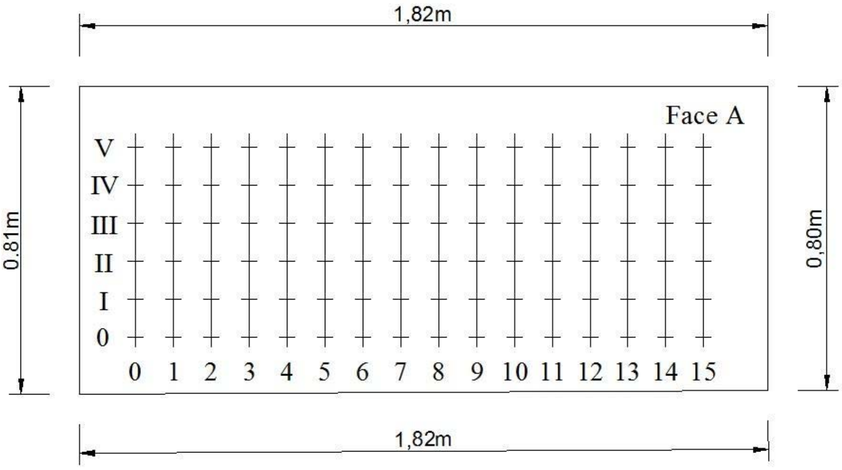

Figure 1. Schematics of the pre-defined grid with a spacing of 0,10 m (face A of the block).

The Surface Transmission Contact - Mapping Test was performed on each of the vertical lines with a constant spacing of 0,10 m. By increasing the distance between transducers, the measurements depth inside the block also increases, giving origin to maps of the same face but with different depths of investigation (Figure 2). The data was processed in the Golden Surfer V 8.01 software, using the Kriging interpolation mathematical algorithm to create the color map corresponding to the measured velocities.

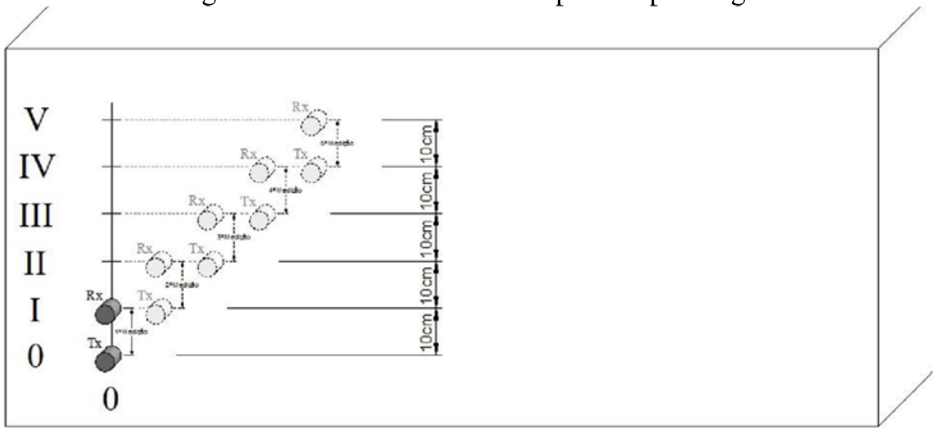

Figure 2. Acquisition scheme with 0,10 m spacing between lines in one of the columns.

In the GPR method, the data were acquired by reflection, with a common offset of 0,10 m spacing between measurements (points corresponding to measurements made with ultrasound (Figure 1), using two shielded bi-static antennas (transmitter and receiver) of 1000 MHz with 0,15 m fixed distance between them. For a limestone block, the standard electromagnetic (EM) wave propagation velocity indicated for this material by the equipment is 0.12 m/ns. A time window of 22 ns has been defined and a stacking number of 32. With these parameters of acquisition and after processing the data (adjustment to time zero, dewow filter, DC-shift, background subtraction and gain function) were obtained radargrams with a depth of investigation of 1.17 meters. The radargrams obtained for each face were combined to create an in-depth slice view model for each face of the block. The acquisition data were processed in the REFLEXW ver 7.5.9 software, of the SANDMEIER-GEO [7]

The data processing performed in this case was just the basics, trying to have as much information as possible without changing too much the original data acquired.

Figure 3 shows a photogrammetric model of the block, with an indication of the dimensions and faces on which the tests was performed. This set of tests was only applied to the face represented as A.

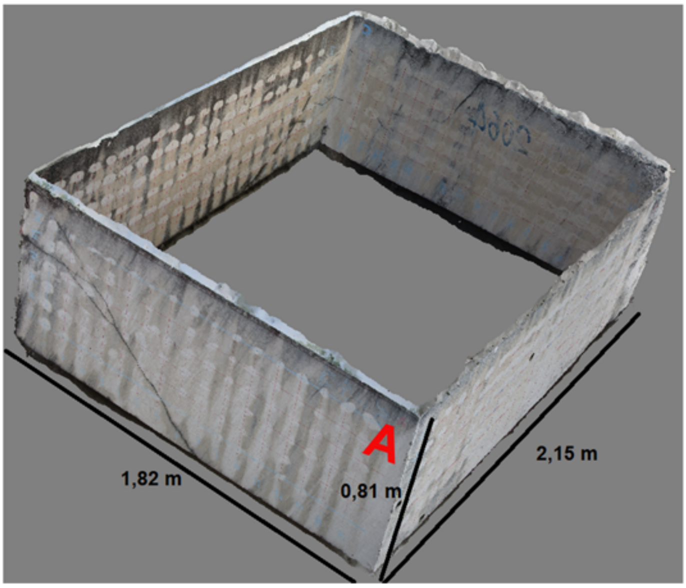

Figure 3. Photogrammetric model of the Block nr.4 (block ref.2064), of the Eduardo Marques & Rosa Lda quarry.

To make a valid and representative comparison of the results, both tests were performed with 0,10 m spacing between transducers and antennas, according to the pre-defined grid and equal for both (Figure 1).

In the case of the ultrasound test, a colour velocity map (Figure 4) was developed based on measurements. It was possible, through colour differences, to detect and locate some of the individualized visible fractures, but also fractures that are not visible on the surface of the face tested. By increasing the distance between transducers, the measurement depth inside the block also increases, allowing us to create maps of the same face, but at different depths. From these results, a time / distance chart can be traced where it was possible to locate and sometimes determine the depth of internal discontinuities.

For the GPR, several GPR profiles (radargrams) were obtained because of the processing (Figure 5), which with the 2, 2.5 and 3D models created based on them, we can identify the existing structures, their vertical and horizontal limits and spatial relations between them.

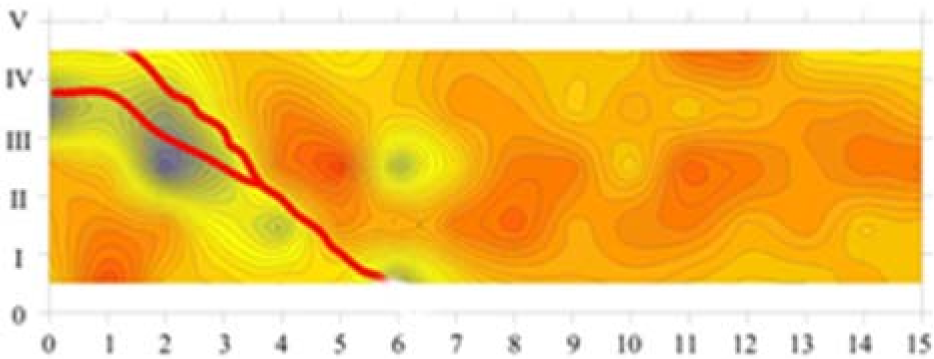

Figure 4. Coloured map of velocities based on the measurement values determined by the ultrasonic test on face A.

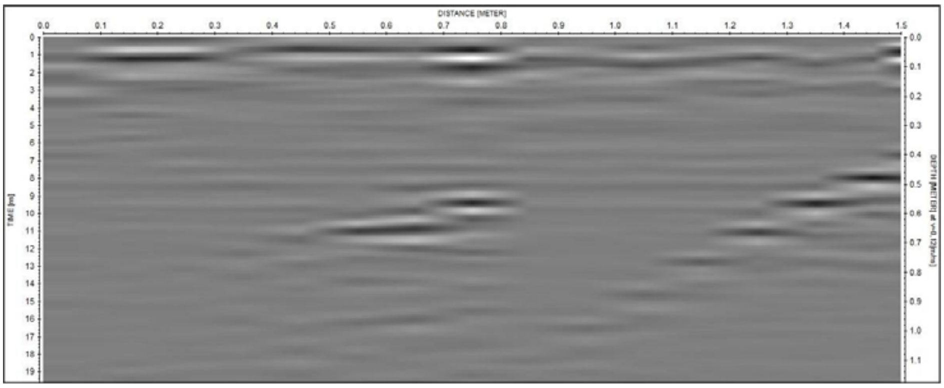

Figure 5. Face A Radargram obtained by the GPR (coordinates x=0; y=2).

3. Results and discussions

In the Surface Transfer Test (ultrasound) the values of propagation speeds between 7500 and 6500 m/s were obtained in areas with coarser grain with a fine matrix, between 6000 and 5000 m/s in areas of finer and homogeneous grain and between 4500 and 3500 m/s in fracture zones, distinguishing areas of granulometric anisotropy (Figure 6A).

In the GPR survey the values obtained have a similar signal reflection amplitude distribution. In void zones the range varies from -590 to -398, in areas with coarser grain between -334 to -79, in areas of finer grain and more homogeneous between -15 to +176 and in areas with fluids (water) between +176 to +432, making able to distinguish areas of granulometric anisotropy.

The presence of discontinuities is identified by observing the abrupt change in reflection amplitude values, which cuts an existing structure and presents a linear arrangement. If there is infiltration and percolation of fluids the values presented are identical to those indicated for this case, they vary between +176 to +432 (Figure 6B).

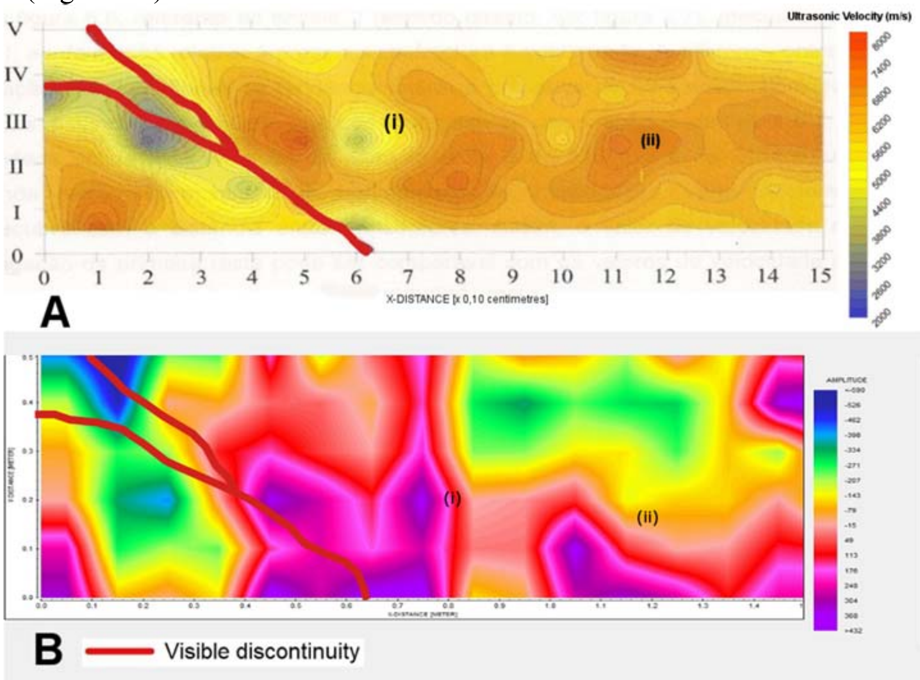

Figure 6. GPR slice view (A) and Ultrasound slice view (B) from the same block side, both at 5 cm depth. (i) Fine grain, (ii) Coarse grain.

The comparison of the results obtained by the two methods, associated with their validation by the visual observation of the block face (Figure 7), allowed us to identify the correspondences between them and to determine which source is responsible for the measured values (Table 1), as well as their spatial dispersion, which is closely related to existing structures.

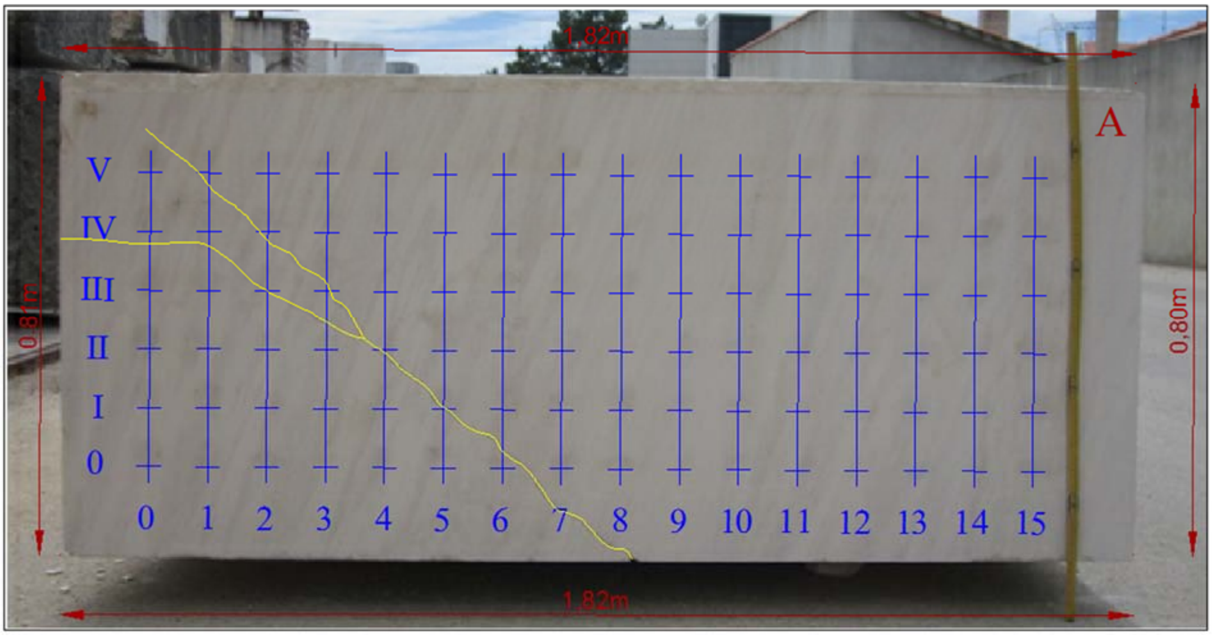

Figure 7. Face A of the block used for this study.

Table 1. Table of correspondence between the measured values and the interpreted structures.

Ultrasonic velocity (m/s)	GPR Amplitude	Type of structure interpreted
3500 to 4500	+432 to +176	Discontinuities / Fluids
4500 to 6500	+176 to -15	Fine grain
6500 to 7500	-79 to -334	Coarse grain
< 3500	-398 to -590	Voids

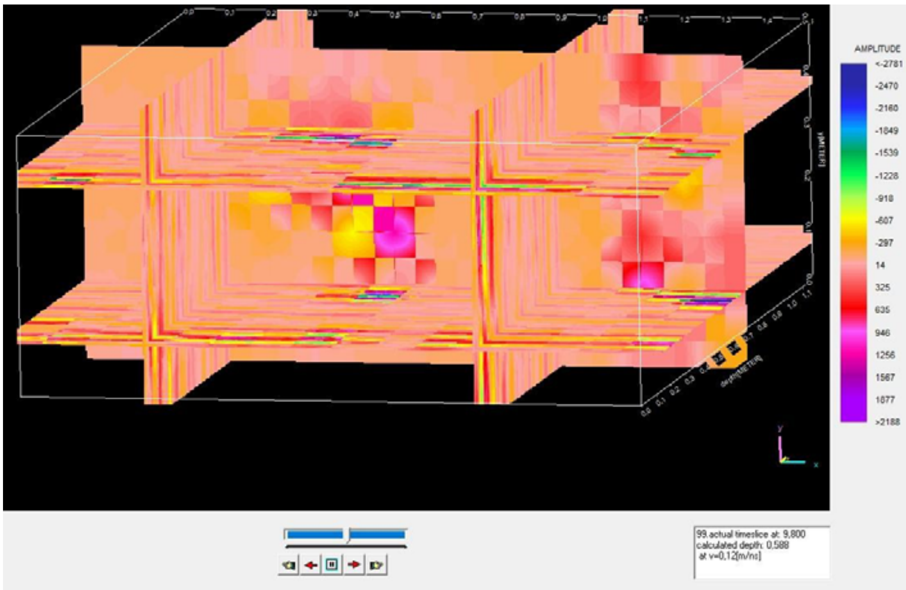

Figure 8 - 3D modelling of the block created through the spatial combination of the acquired GPR profiles.

4. Conclusions

The main objective of the present work consisted on the evaluation of an ornamental rock block by using a non-destructive test, ultrasonic test and GPR survey. This study aimed to evaluate characteristics such as the state of rock alteration, texture and grain size differences on the block, detect and locate any discontinuities within the block.

The results obtained from the application of this methods on this single block of limestone allowed to conclude that the distribution of propagation velocity values has a direct relation with what is observed on the block face, essentially when the spacing between transducers is 0,10 m. In this, it was possible to detect and locate visible and non-visible fractures on the face of the block and variations in grain size. Considering the objectives of this study and the results presented for the ultrasound test, the following conclusions can be drawn:

- The transducers at 0,10 m provided the easier results to interpret and establish a closer relationship with what is observed on the faces of the block.
- In areas with a larger grain size, the signal attenuation should be greater, and by that decreasing the propagation speed of the waves. From the tests performed, this was not observed, it was found that the propagation speed increased, which can be justified by the finer matrix intercalation in these zones of the block, making this zone more compact.
- The high degree of roughness of the surfaces is a characteristic that does not helped the realization of the tests, because the surface of contact with the transducers is reduced.
- Regarding the orientation of the discontinuities, it was verified that, despite their orientation in relation to the soundwave beam, it is possible to detect them using reflected and non-direct waves.

About the GPR method that was used later, the results and their interpretations could be refuted by observing the faces of the block used for this study. As in the ultrasonic method, it has been observed that the reflection amplitudes of the EM signal are directly related to the textural and structural variations visible on the faces of the block. In this way, it was concluded that:

- The porosity of the grain is a factor to be considered and influences the signal reflection amplitude. The amplitude values that were obtained for the coarser grain are more approached to the value of the voids / pores (negative values). Although this correlation between the methods seems contradictory, we suspect that this is due to the presence of fluids (water), in so far as the negative amplitude values for the coarser grain are related to the grain being more compact, and therefore the water has no ability to penetrate and migrate through the rock, as opposed to the finer grain, which shows more positive values (closer to the values of the fluids), which suggests that there is a greater presence of water in this zone, due to the higher porosity and lower compaction and grain calibration.

- Based on the previous point, we consider that the analysis of the results obtained by this method requires a greater critical sense and attention than in the ultrasound method, since there are more external factors to consider that influence the results (for example, rock saturation in water).
- In terms of data acquisition and modelling, it has been revealed to be a fast, clean method and the one in which more information is obtained in less time. Instead of ultrasound, in which for each transducer spacing we have only one slice view at a determined depth, in the GPR method we have the possibility to create several slice views from the surface to the maximum depth of penetration, keeping the initial parameters of the acquisition (Figure 8).

In further, the block will be cut in slabs, to allow us correlating the detected and actual discontinuities, and to relate the data obtained with the altered state of the material inside and the texture variations.

It can be concluded that the proposed methodologies are valid, that the study aim was reached and that the existing structures were identified with considerable resolution and precision. Comparing the two methods in relation to this study, we consider that ultrasound is the method that offers us more viable results and the one that has less influence of external factors that influence the properties of the rock and consequently the data of the acquisition, but it is a method which requires further preparation of the surface of the block to couple the equipment, and which gives the least number of data to analyse. The GPR method has proved to be more versatile, without the need to pre-prepare the surface of the block to make the acquisition, and it is the data-based method that gives us more information per acquisition, which give us the way to do a more complete and continuous modelling along the volume of the block. Nevertheless, it is what requires more care in terms of use and interpretation of results due to the greater influence of external factors previously mentioned. In this way and considering the virtues and limitations of each of the methods used, we consider that the use of GPR proved to be the best method for the proposed objective.

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