# EVALUATION OF CRACKS IN THE CĂRPINIȘ TRAVERTINE QUARRY USING GROUND PENETRATING RADAR

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**Abstract.** The purpose of this work is to analyse the cracks in a test area of the Cărpiniș travertine quarry, based on investigations by the Ground Penetration Radar method. These analyses are part of an ERA-MIN project entitled "Artificial Intelligence and combined survey techniques for the optimization of stone quarries", acronym AI-COSTSQO, ongoing with partners from Turkey, Italy, Slovenia and Romania. Data collection was carried out with AKULA 9000C equipment, on profiles with 1m equidistant, both longitudinally and transversely. The data were collected on the Cărpiniș quarry, in three sites that were chosen according to dimensions, quarry position and geotechnical rock properties. Also, data were collected according to visible natural discontinuities, including their orientation, spacing, span and length. The data were processed to calculate the orientation and position of natural discontinuities in depth. This information will be used to identify the optimal cutting directions in the marble blocks. Mathematical model development, based on cracks detected in the quarry, will take into account the minimum and maximum limits of the cuboids, the polyhedrons and commercial volumes, but also joints and cracks in the rock.

**Keywords:** Travertine quarry, Ground penetration radar, Rock cracking, Risk in exploitation.

**Rezumat. Evaluarea fisurațiilor în cariera de travertin Cărpiniș folosind radarul de penetrare în subsol.** Scopul acestei lucrări este de a analiza fisurile dintr-o zonă de testare a carierei de travertin Cărpiniș, pe baza investigațiilor prin metoda Ground Penetration Radar. Aceste analize fac parte dintr-un proiect ERA-MIN, aflat în derulare cu parteneri din Turcia, Italia, Slovenia și România, care are ca scop principal realizarea Rețelei Discrete de Fracturi (DFN), care caracterizează fiecare dintre depozitele de pietre pentru a genera. un model geologic realist 3D. Colectarea datelor s-a realizat cu echipament AKULA 9000C, pe profile cu 1m echidistant, atât longitudinal cât și transversal. Datele au fost colectate din cariera Cărpiniș, în trei situri care au fost alese în funcție de dimensiuni, poziția carierei și proprietățile geotehnice ale stâncii. De asemenea, au fost colectate în funcție de discontinuități naturale vizibile, inclusiv orientarea, distanța și lungimea lor. Datele au fost prelucrate pentru a calcula orientarea și poziția discontinuităților naturale la adâncime. Aceste informații vor fi folosite pentru a identifica direcțiile optime de tăiere în blocurile de travertin. Elaborarea modelului matematic, pe baza fisurilor depistate în carieră, va ține cont de limitele minime și maxime ale cuboidelor, poliedrelor și volumelor comerciale, precum și rosturilor și fisurilor din rocă.

**Cuvinte cheie:** cariera de travertin, radar de penetrare la sol, fisurația rocilor, riscul în exploatare.

## INTRODUCTION

Travertine as a construction material and ornamental rock has been exploited for at least two thousand years, mentioned in classical texts for various edifices in the world.

Although there are many definitions that have been given about travertine, we will state the definition given by PENTECOST (2005): "Travertine is a chemically-precipitated continental limestone formed around seepages, springs and along streams and rivers, occasionally in lakes and consisting of calcite or aragonite, of low to moderate intracrystalline porosity and often high mold or framework porosity within a vadose or occasionally shallow phreatic environment. Precipitation results primarily through the transfer (evasion or invasion) of carbon dioxide from or to a groundwater source leading to calcium carbonate supersaturation, with nucleation/crystal growth occurring upon a submerged surface".

The chemical processes responsible for almost all travertine formation on Earth are in relations with the degassing of surfacing carbon dioxide-rich groundwaters containing minimum 80 ppm calcium. Groundwater capable of depositing travertine is produced when dissolved carbon dioxide ('carbonic acid') attacks carbonate rocks to form a solution containing calcium and bicarbonate ions ('calcium bicarbonate').

The main chemical reactions that take place for the formation of travertine are:

$$CaCO_3+CO_2+H_2O=Ca^{2+}+2(HCO_3)^-$$

A few travertines are formed by the reaction between atmospheric carbon dioxide and hyperalkaline groundwater:

$$Ca(OH)_2+CO_2= CaCO_3+H_2O^-$$

The following chemical reaction can also take place, in the case of saline lakes where the OH- concentration is increased as a result of geochemical processes.

$$Ca(HCO_3)_2+OH^-= CaCO_3+(HCO_3)^-+H_2O^-$$

In Romania, there are exploitable resources in travertine quarries in two important locations, Cărpiniș and Geoagiu.

The textural appearance of travertine is given by the density, size and spatial arrangement of the vacuoles. Sometimes, travertine can look like breccia or weathered wood. Travertine quarries are susceptible to cracking, making it difficult to extract large uncracked blocks. Several methods can be used to evaluate the cracks in the Carpinis travertine quarry, including:

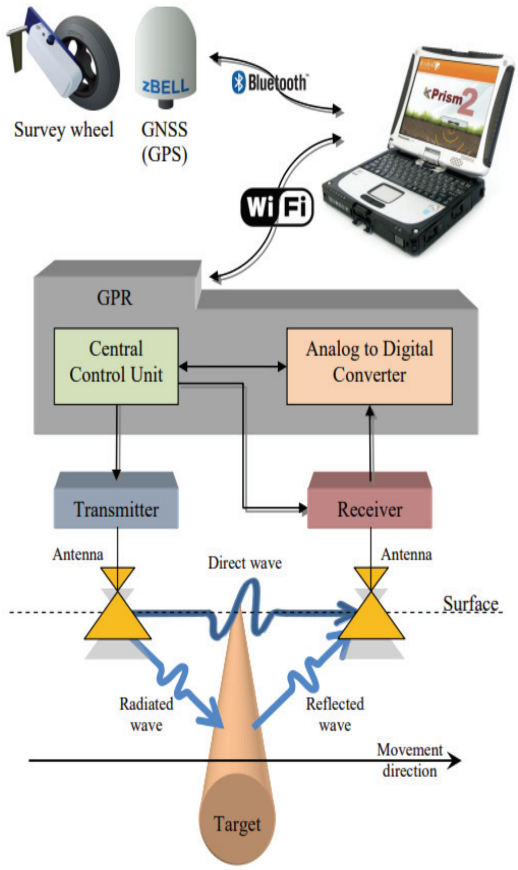


Figure 1. Simplified block diagram of GPR (RADAR SYSTEM INC. 2022).

- Visual inspection: a simple and accessible method, which involves inspecting the areas of the quarry where there are suspicions of cracking. This method can provide preliminary information, but is not accurate enough to determine the extent and severity of cracks.
- Geophysical methods, such as Ground Penetration Radar (GPR) or the resistivity method, can be used to detect underground cracks and estimate their depth. These methods can be more effective than visual inspection, because they allow the evaluation of cracks at greater depths and without the need to enter the quarry.
- Image analysis: the use of digital images of the Cărpiniș travertine quarry can help identify cracks and quantify the degree of cracking. This method can be achieved through laser scanning technologies or aerial photography.
- Mineralogical analysis such as the evaluation of the composition of the travertine minerals can provide information regarding its stability and its propensity to crack.

Depending on the specific needs of the Cărpiniș travertine quarry, one may have to use a combination of methods to assess the cracks and determine the risks associated with its exploitation. In the present study, we used the GPR method in a test area of the Cărpiniș quarry to highlight the cracks in the travertine blocks. GPR is an active method, which transmits radar waves into the ground and then records the waves that are received back at the surface. The variables that are measured in this method are the time elapsed between sending and receiving a wave, the amplitude of the recorded waves, and also data about the frequencies of the waves that are recorded (Conyers 2013). These characteristics of the GPR method recommend it as very effective for detecting cracks in rocks from quarries that are currently in operation or that will be exploited in the future.

## METHODOLOGIES

GPR is a geophysical technique that uses electromagnetic waves to detect natural discontinuities and other features of soil or rock below the surface. This technique is often used in marble quarrying to identify natural discontinuities and plan the cutting direction of marble blocks. To detect natural discontinuities with GPR, a transmitter that generates electromagnetic waves of a certain frequency and a receiver antenna that receives the reflected waves from different layers of the rock are used. These signals are then digitally processed to create an image of the subsurface that can be used to identify discontinuities and other rock features. There are several software programmes available on the market that allow analysing GPR data and identifying natural discontinuities in marble blocks. Such software can be used to plan the cutting direction of marble blocks so as to minimize the risk of breaking or cracking the blocks and maximize the yield of marble quarrying. GPR is a geophysical method that uses radar pulses to image the subsurface discontinuities of resistivities. It is a non-intrusive method of investigating the underground. GPR uses electromagnetic radiation in the microwave band (UHF/VHF frequencies; the range 10 MHz to 2.6 GHz) of the radio spectrum, and detects the reflected signals from subsurface structures that can have applications in a variety of media, including rock, soil and pavements. In our study, we used GPR to detect changes in material properties (marble, andesite, travertine), voids and cracks. A GPR simplified block diagram (Fig. 1), allows to imagine the general idea of its operation principle.

The transmitter excites the transmitting antenna with very short electrical pulses. The transmitting antenna radiates ultra-wideband one-and-half-period electromagnetic waves. The electromagnetic waves propagate in the underground medium, through the antenna. The reflected signal is received and registered by the GPR receiver. But in addition to the reflected wave, there is also a direct wave that goes directly from the transmitting antenna to the receiving antenna along the shortest path. Therefore, the output of the receiver provides a signal, which is a sum of the transmitter pulse (as in Fig. 2) and the reflected pulses following it.

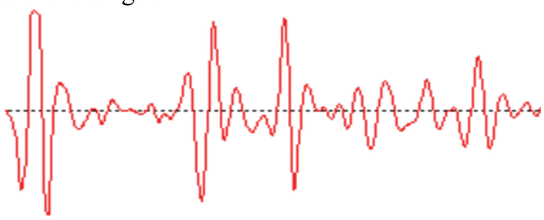

Figure 2. Received signal example The transmitter pulse is clearly visible on the left (RADAR SYSTEM INC. - 2022).

The time difference between the transmitter pulse and the reflected signals from the target surface determines the depth of the target in the medium. Signals characteristics depend on the antenna, transmitter power (Tx), environmental conditions and receiver parameters (Rx) from the moment the transmitting antenna is excited until the reflected signal reception. All of these parameters affect the overall dynamic range of the entire system.

There have been various methods for digitizing analog signals since the advent of digital technologies. One of the main methods used in pulsed georadars are the stroboscopic method and the Real Time Sampling method, or their symbiosis (KELLY et al., 2021; SRIVASTAV et al., 2020; PIRO et al., 2003).

Also, the structure of the GPR itself and of antenna systems used with it, or rather, the choice of an analog-to-digital converter (ADC), as the main element for converting an analog signal to digital, depends on the chosen method of digital conversion.

The stroboscopic method is based on the thesis that the GPR and its antenna are in the same place for a relatively ultra-short millisecond time interval (CAMPANA & PIRO, 2009; CONYERS, 2016).

GPR will receive 512 identical signals for 512 launches of the transmitter and take only one corresponding sample from each signal, and then build them all up into one trace, restoring the complete signal. At the same time, the georadar needs a transmitter with a trigger frequency of hundreds of kHz, a stroboscopic converter and a receiver with a sampling and storage device, the output of which will be fed to the ADC input with a trigger frequency of the transmitter.

Processing data is to extract useful signals and suppress noise and interference. Therefore, before processing, we need to define parameters that are different for the signals and interference. This may be amplitude, trajectory or spectral characteristics. The software Prism 2 contains all tools required for analysis of the said characteristics (GAFFNEY et al., 2004; GOODMAN & PIRO, 2009).

The steps of processing procedures used:

• Background removal is used under some conditions, when signal happens to have “background” which may be seen on the profile as horizontal lines that do not change their intensity and time position and may mask the real reflected signals. In these cases, this procedure can ensure efficient background suppression.

• Automatic gain control was used for automatic signal gain within the width of the window in each separate trace.

• The reverse procedure was used for back-to-front trace rearrangement, i.e., the first trace becomes the last one, the second trace becomes next to last, and so on. For convenience of subsequent analysis and interpretation of sounding data, the procedure may be used before each even (or odd) profile.

• Time-depth conversion was used for restructuring the initial time profile into a depth profile in compliance with the velocity areas as set in annotations.

• Processing flow was used for the sequence of creating procedures for several data files processing under the same algorithm.

Each processing was applied to the active profile or to all opened profiles by pressing on buttons Apply or Apply To All correspondingly. Sometimes it was necessary to consequently apply several processing procedures to achieve the desired result.

## CASE STUDY AND RESULTS

The location of the perimeters investigated by GPR in the Cărpiniș Quarry is presented in figure 3. We used equipment AKULA 9000C and two FLB 390 and GCB 200 antennas.

The software supplied with the Akula 9000C radar control units is universal for all Geoscanner control units, making switching between control units simple and quick. FLB antennas have a relatively small footprint on the air-ground interface, given that they operate in the VHF band, and therefore a substantial amount of energy is successfully delivered to the ground. GCB antennas have the best performance in their antenna category on the market and are fully shielded, providing excellent results even in the most polluted EM survey sites.

To obtain a 3D block diagram with fracture interpretation, GPRSoft™ Professional version software is required. If this software is not purchased, the PRISM 2 trial version can be used, which offers sufficient interpretation facilities.

Of course, for very detailed analysis, MATLAB, the image processing with wavelet modules can be used. In the following we will present the profiles processed and interpreted with PRISM2 and at the end of this chapter (figure 8) an example of image decomposition in approximations and details, the 2$^{nd}$ order decomposition tree, the Morlet function.

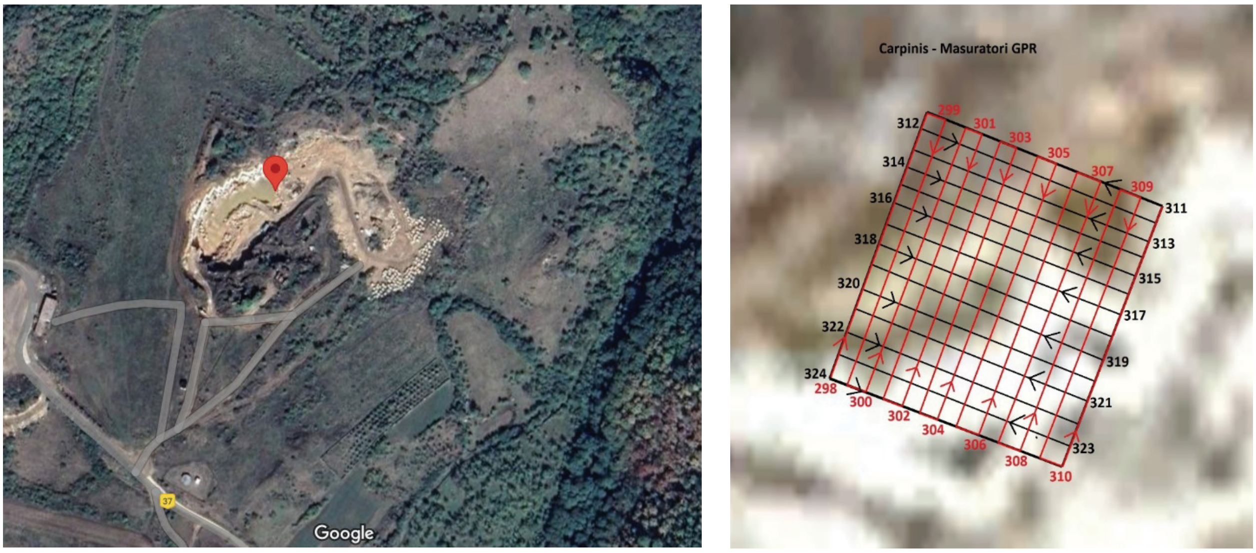


Figure 3. Top view of the Cărpiniș quarry (Google Maps); Detail of GPR measurements – site 1 (“original”).

Figure 4. Cărpiniș Quarry and images of cracks. (“original”).

Figure 5 shows profile 299, recorded on the system laptop in a *.gsf file, with the GPRsoft software.

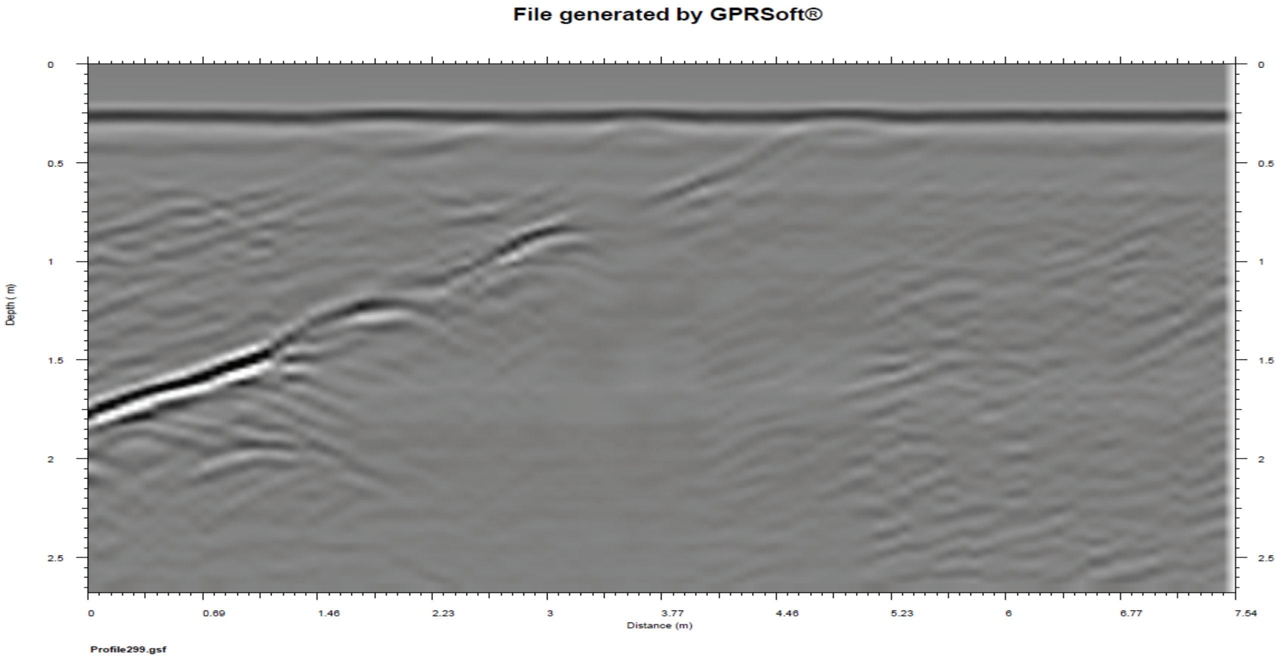


Figure 5. Profile 299, recorded with GPRsoft at Cărpiniş Quarry, site 1. ("original").

Figure 6 shows the same profile 299, after we converted the *.gsf file into another *.sgy format, which we were able to process and interpret with the PRISM 2 software.

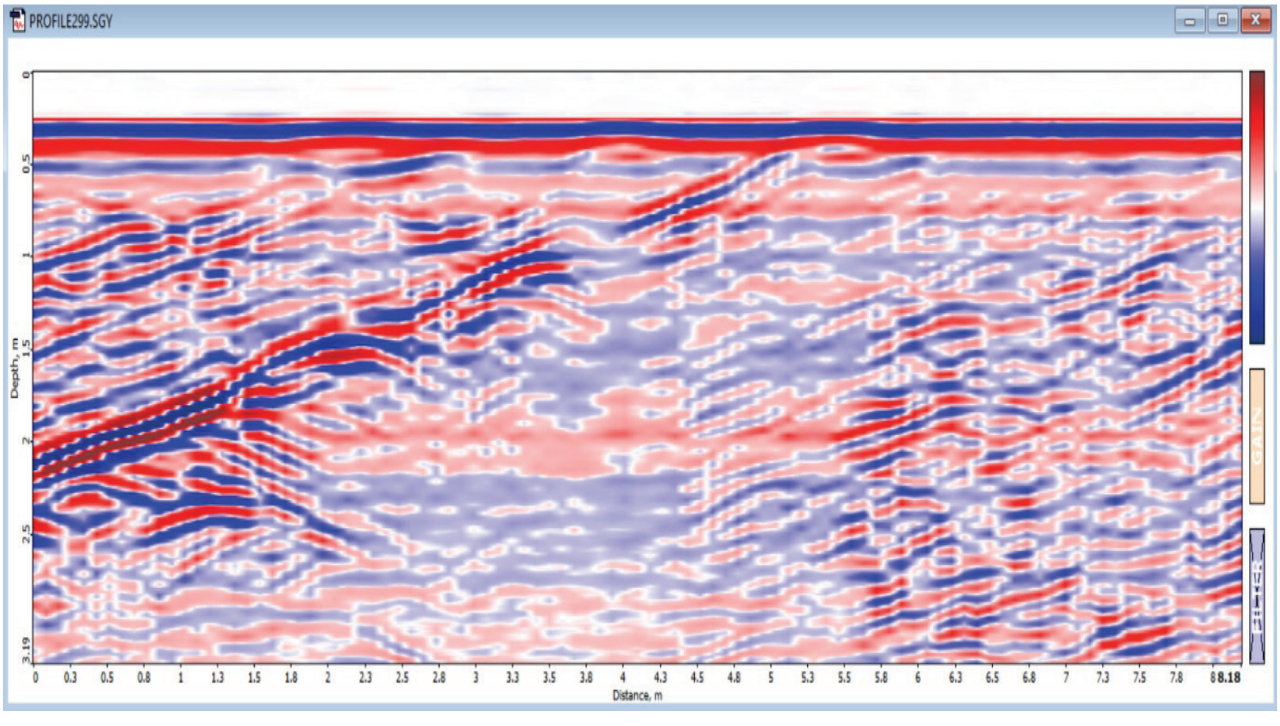


Figure 6. Profile 299, converted from *.gsf file into *.sgy format, procesed with PRISM 2.at Cărpiniş Quarry, site 1 ("original").

We proceeded similarly for all the longitudinal (298-310) and transversal (311-324) profiles performed, presented in site 1 (figure 3 - GPR detail Carpinis quarry). Figure 7 shows 8 longitudinal profiles (298-305) in *.sgy format, which can be viewed in detail - site1 from figure 3, processed and interpreted with the PRISM 2 software.

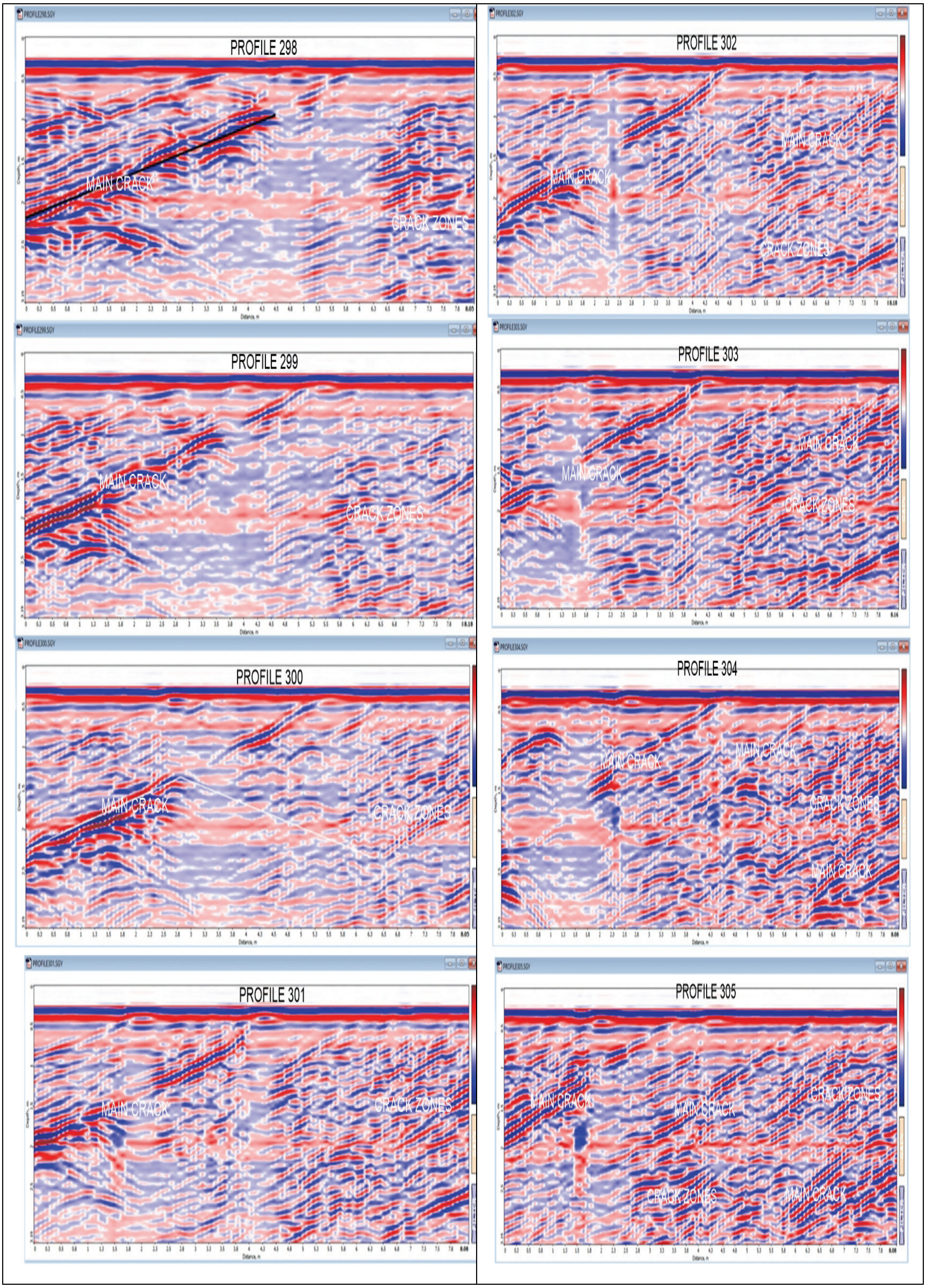


Figure 7. Profiles 298-305 from the Cărpiniș Quarry – site 1 (detailed in figure 3), processed and interpreted with the PRISM 2 software ("original").

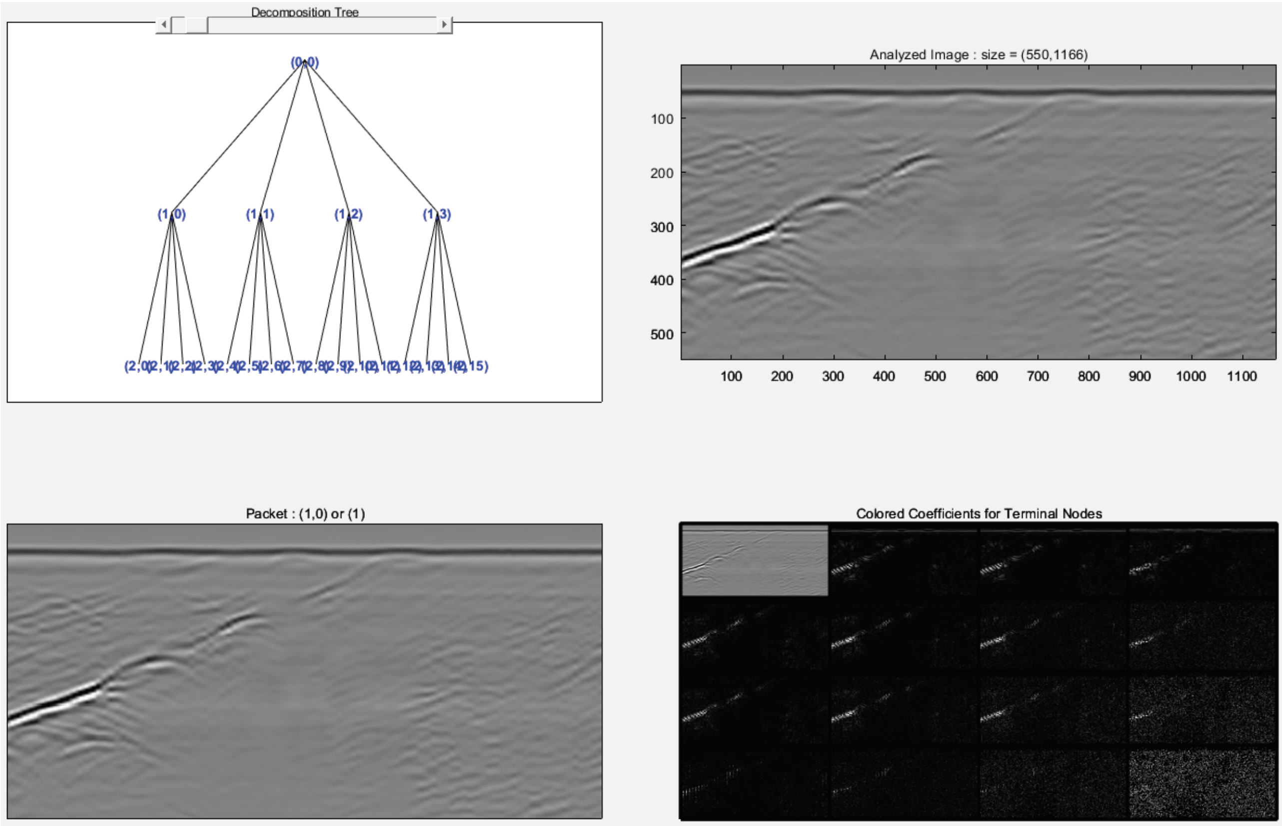


Figure 8. Profile 299, from the Cărpiniş Quarry, site 1, analysed with MATLAB tools (wavelet 2D) (with software from https://www.mathworks.com/). ("original").

Another complex way to analyse rock cracks is to use the 2D wavelet from MATLAB (figure 8). This method, together with the one given by GPR soft and PRISM2, can facilitate the 3D analysis of DFN.

## CONCLUSIONS

Reflection profiles are the basic interpretive tool for GPR and are created as radar antennas move along the ground surface transmitting waves downward into the ground. A sequential stacking of many reflections consisting of reflected waves from different depths in the stone is then produced. In the GPR method all two-dimensional reflection profiles (longitudinally and transversally) are re-sampled in depths and relative amplitudes of reflected waves located at those depths. Then, they are plotted, interpolated and gridded to produce a defined number of cracks in the stone.

With colour differentiation, traces of reflected radar signal, associated with the discontinuity, are visible in the radargrams.

The depth dimensions can be identified, but the resolution of the data does not allow the exact geometrical definition and the determination of the amplitude value of the discontinuity, which in any case is to be considered of minimum size with respect to the limit value that can be determined instrumentally.

The propagation allows to analyse the block up to the depth of -300 cm.

The analysis was conducted by applying digital filters of the type: Band Pass in the time domain with extremes of 200 MHz and 900 MHz, then the Soil Sample, then Back Ground Removal to better define the data and a signal gain of equalizer, with 1 meter step application.

These images can be used in data fusion analyses, where depth-slices are directly compared to maps generated from other geophysical methods. However, when a number of GPR reflection profiles are compared to geophysical (electrometry, magnetic, seismic) profiles and others adjoining it, a direct comparison can be made using these methods. GPR has the ability to define strata that are good indicators of units that were deposited as sediments when conditions were unstable and soils that formed when the ground was stable.

The identification of cracks and areas of cracks in a quarry helps to optimize the exploitation process, starting from the consideration that uncracked blocks of extracted stone have a commercial value proportional to their size.

On the other hand, the optimal cutting direction can be chosen, depending on the direction of the highlighted cracks.

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