RESISTIVITY STUDY REGARDING THE ALTERATION ZONES OF MARBLE, TRAVERTINE AND ANDESITE QUARRIES

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Abstract. The main objective of the work is to analyse the areas of alteration susceptible to cracks in the test areas of the marble, travertine and andesite quarries in Romania, based on investigations using the resistivity method. The test areas chosen within the ERA-MIN project entitled "Artificial intelligence and combined survey techniques for the optimization of stone quarries" were in the Ruschita, Carpinis and Pietroasa quarries. The data were collected on equidistant profiles at 5-10m, the distance between the electrodes being 2m. The location of the profiles was chosen according to the size, position of the quarry, visible natural discontinuities and their orientation. The acquisition, processing and interpretation of resistivity data were performed with Super Sting R8/IP+64 system and Earth Imager software. After performing the interpretation of the resistivity electrometric tomography, it was possible to underline that the maximum resistivity was associated with unaltered areas, without fractures of circulated fluids. Also, the resistivity minima were associated with altered areas susceptible to deep fractures. These qualitative considerations were corroborated with information from other geophysical and geotechnical measurements as well as with direct information from quarry investigations. The resistivity information is a deliverable of the project that will be used in the future to complete a complex informational table that will serve to identify the optimal cutting directions in the stone blocks to increase the unaltered and uncracked volumes of the stone as well as, implicitly, the increase of their commercial value.

Keywords: Marble Quarry, Resistivity Method, Electric Tomography, Exploitation in Quarries.

Rezumat. Studiu rezistivimetric privind zonele de alterație din carierele de marmură, travertin și andezit. Obiectivul principal al lucrărilor este de a analiza zonele de alterare susceptibile de fisuri din zonele de testare a carierelor de marmură, travertin și andezit din România, pe baza investigațiilor prin metoda rezistivităților. Zonele de testare alese în cadrul proiectului ERA-MIN intitulat „Inteligența artificială și tehnici combinate de sondaj pentru optimizarea carierelor de piatră", au fost în carierele Rușchita, Cărpinis și Pietroasa. Datele au fost colectate pe profile echidistantate la 5-10m, distanța dintre electrozi fiind de 2m. Localizarea profilelor a fost aleasă în funcție de dimensiuni, de poziția carierei, de discontinuități naturale vizibile și orientarea acestora. Achiziția, prelucrarea și interpretarea datelor de rezistivitate au fost efectuate cu Super Sting R8/IP+64 system si Earth Imager software. După efectuarea interpretării tomografiei electrometrice de rezistivitate, s-a putut sublinia faptul că rezistivitatea maximă a fost asociată cu zonele nealterate, fără fracturi de fluide circulate. De asemenea, minimele de rezistivitate au fost asociate cu zonele alterate susceptibile fracturi în adancime. Aceste considerații calitative au fost coroborate cu informații provenite din alte masurători geofizice, geotehnice precum și cu informații directe de investigare a carierelor. Informațiile rezistivimetrice reprezintă un livrabil al proiectului ce va fi folosit în continuare pentru completarea unui tabel informațional complex ce va servi pentru identificarea direcțiilor optime de tăiere în blocurile de piatră pentru creșterea volumelor nealterate și nefisurate de piatră precum și implicit, creșterea valorii comerciale a acestora.

Cuvinte cheie: cariera de marmură, metoda rezitivităților, tomografie electrică, exploatarea în cariere.

INTRODUCTION

In marble quarries, there are several types of alteration that can occur in the rock, including:

- Hydrothermal alteration - this type of alteration occurs when the rock is subjected to high temperatures and high pressures, caused by volcanic activity or tectonic processes. This can lead to increased porosity and permeability of the rock, as well as the formation of cracks and brittle zones.
- Metasomatic alteration - this type of alteration occurs when the rock is subjected to solutions of chemical substances, which change the composition of the rock by replacing or adding chemical elements. This process can increase or decrease the resistivity of the rock.
- Oxidative weathering - this type of weathering occurs when rock is exposed to oxygen and water, which can lead to the formation of metal oxides and loss of material.
- Biological weathering - this type of weathering occurs when rock is exposed to the activity of microorganisms and plants, which can lead to the formation of soil and changes in the texture and composition of the rock.
- Physical weathering - this type of weathering occurs when rock is exposed to physical factors such as extreme temperatures, freeze-thaw cycles and vibrations. This can lead to cracking and disaggregation of the rock.

These types of alteration can have a significant impact on the physical properties of the rock, as well as the cost and efficiency of mining. Therefore, it is important to identify and assess the types of alteration in marble quarries in order to make informed decisions about exploitation and environmental protection. During mining, there are several changes that can occur in marble quarries, including:

- Changing the composition and texture of the rock - during mining, layers of marble with different compositions and textures can be found than in other areas of the quarry. Also, due to the exposure of the rock to different conditions of pressure and temperature, it can undergo changes in composition and texture.

- Rock movement and loading - during mining, rock movement can occur, which can lead to the collapse of part of the quarry. Also, rock loading can lead to cracks and brittle areas.
- Changes to the topography - mining operations can change the topography of the area, by raising or lowering the level of the land, or by changing water courses.
- Pollution - mining operations can cause air and water pollution in the area by releasing dust and chemicals into the environment.

These changes can have a negative impact on the environment, by changing the composition of soil and water, changing habitats and destroying vegetation areas. It is therefore important to take measures to minimize the impact of mining on the environment and to protect the affected areas. The resistivity of the altered zone in marble quarries can vary depending on the degree of alteration and the composition of the rock. In general, areas of alteration may have lower resistivity than areas of intact rock because alteration can lead to an increase in porosity and a reduction in density. In addition, weathering can lead to an increase in the water content of the rock, which can decrease resistivity.

However, it is important to keep in mind that the electrical properties of rock can also be influenced by other factors, such as temperature, pressure, humidity, salinity, and the chemical composition of groundwater. Also, the resistivity measurement method can influence the obtained values. If it is desired to determine the resistivity values of the rock in the marble quarries, geophysical methods such as the electrical resistance tomography method can be used, which allows the determination of the subsoil resistivity profile by measuring the electrical potentials at the soil surface. Methods such as the vertical electrical survey method or the contact electrode resistivity measurement method can also be used.

METHODOLOGIES

The used equipment, the SuperSting R8/IP+64 system, is produced by the American company Advanced Geosciences, Inc, Austin, Texas and uses a pulsating direct current for emission with the duration of the pulse equal to the duration of the pause. Compensation of the natural potential is done automatically, throughout the measurement. The resistivity is calculated by entering the coordinates of the device and the system generating images of resistivity and induced polarization uses the EarthImager software. The acquisition system has 8 channels and is used with multi-electrode passive leads.

It uses a pulsed direct current for emission with the duration of the pulse equal to the duration of the pause. Compensation of the natural potential is done automatically, throughout the measurement. The resistivity is calculated by entering the coordinates of the device. Noise attenuation is at least 100 dB at frequencies higher than 20 Hz and at least 120 dB at frequencies of 16, 20, 50, 60 Hz from the transmission line, ensuring a clean signal.

EarthImager inversion software are programmes that interpret the recorded resistivity data (the inversion process) and produce images in the form of sections that reflect the geological structure of the subsurface. The inversion of the resistivity data is a combination of forward simulation and inverse simulation with the final result being the production of the structural model of the basement (the image of the basement obtained on the basis of the resistivity data measured on the surface of the land). First, direct simulation or modeling is performed (virtual prospecting, an application from model to data, from cause to effect), on a model built on the basis of some a priori known information (distribution of apparent resistivity in the basement, electrode configuration) or assumed information (the average resistivity of a sector, the user's hypothesis or the structure of the basement), obtaining a set of synthetic data. Direct modeling (direct solution) is obtained by solving the equation with partial derivatives in the domain of the Fourier transform.

$$\frac{\partial}{\partial x}\left(\sigma\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial z}\left(\sigma\frac{\partial V}{\partial z}\right)-k^2\sigma V=-I\cdot\delta(x)\cdot\delta(z),$$

Where: V is the scalar electric potential in the Fourier transform domain,
I is the intensity of the electric current of the source,
σ is the electrical conductivity, a quantity depending on (x,y).

The synthetic data set is then subjected to inverse simulation (model parameterization process, a data-to-model, effect-to-cause application) to reconstruct the subsurface resistivity distribution based on the measured V and I data on the surface (KAUFMAM & EATON, 2001; KAUFMAM, 1994). A model of the basement is thus obtained which is compared with the initial synthetic model and modified through successive iterations until the difference between them falls below a set threshold. The mean squared error (RMS Error, Rooth Mean Squared Error) characterizes the agreement between the data measured in the field and the calculated data of the model

$$\mathrm{RMS}=\sqrt{\frac{\sum_{i=1}^{N}\left(\frac{d_i^{\mathrm{Pred}}-d_i^{\mathrm{Meas}}}{d_i^{\mathrm{Meas}}}\right)^2}{N}}\times 100\%,$$

:

Where: N is number of measurements; d^{pred} is the predicted data; d^{meas} is the measured data.

The resistivity method is based on the interdependence between the electrical properties (resistivity) and the geotechnical and physical parameters of the land, on the contrasts of resistivity between the different rocks and formations that participate in the geological composition of an area, therefore on the contrast of resistivity between the tracked object and the surrounding environment (LOWRIE, 2007; ZHDANOV, 2009). In the case of sedimentary rocks, which are characterized by ionic conductivity, the nature of the mineralogical components does not influence the resistivity, its size depending exclusively on the value of the porosity, the geometry of the pores, the nature and concentration of fluids in the pores of the rock and their degree of filling. The resistivity of the main types of rocks found in the area, measured in laboratory conditions on samples, varies within the limits of Table 1:

Table 1. Resistivity of the main types of rocks.

Rock type	**Resistivity measured on samples in the laboratory (Ohm*meter)**	**The resistivity established by Vertical Electrical Surveys (SEV) or in the gradient version (Ohm*meter)**	
		rock saturated with demineralized water	**rock saturated with salt water**
clay	10^3 - 10^5	10 – 100	1 - 10
porous sandstone, sand	10^5 - 10^6	30 – 200	1 - 10
compact sandstone	10^5 - 10^6	100 – 1000	5 - 100
conglomerate, gravel	10^5 - 10^6	100 – 1000	5 - 100
marl	10^4 - 10^5	100 – 1000	10 - 100
salt	10^{12} - 10^{14}		
oil	10^9 - 10^{16}		

Measured in the field, where there are large volumes of different rocks located both along the direction of the measuring device and laterally, the resistivity contrasts between the rocks are attenuated, but the ratio between them is preserved. From the analysis of this table, a first criterion for the interpretation of the geoelectric data is outlined. Maximum resistivity anomalies can be generated by the presence of marl, compact rocks, dry or impregnated with petroleum products, as well as salt, which produces characteristic anomalies of extremely high values. The minimum anomalies may reflect the presence of clay or water in the rock pores, while salt water produces the most intense minimum anomalies. The notion of apparent resistivity, ρa, refers to the fact that the value of the resistivity recorded at a point on the land surface represents a weighted average of the resistivities of all the rocks located in the space crossed by the current lines between the emission electrodes (a hemisphere with a diameter equal to this distance), value in which the resistivity corresponding to the length of the respective emission line has the largest weight.

The determination of the apparent resistivity in the field is done with a quadripolar measuring device made up of 2 emission electrodes A, B through which a direct current with intensity I is injected into the soil and 2 reception electrodes M, N through which the potential difference ΔV is measured produced by the passage of the current through the resistance represented by the basement. The depth of penetration of the current into the basement, so the depth from which the geophysical information comes (investigation depth), is directly proportional to the length of the measuring device AB. By keeping the constant distance MN between the receiving electrodes and progressively increasing the distance AB, the current lines will penetrate deeper into the subsoil, so the information will come from a greater and greater depth, thus recording the variation of resistivity with depth for the same point from the surface of the land. This is the principle of vertical surveying (SEV).

The finesse of the investigation is achieved horizontally by using a distance MN as small as possible and by reducing the interval between SEV locations, and vertically by increasing the number of AB lengths (Fig. 1).

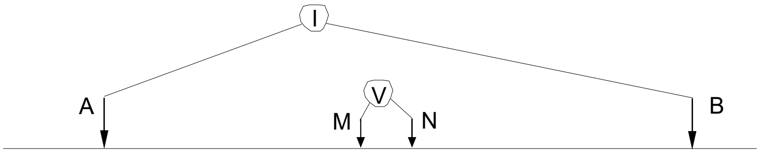

Figure 1. Simplified diagram of SEV.

The apparent resistivity value is calculated according to Ohm's Law in a homogeneous medium (CONSTANTINESCU, 1965; GEORGESCU, 1982)

$\rho a = K \times \Delta V / I$, where K is a coefficient that depends on the geometric configuration of the electrodes:

$K = 1/AM - 1/AN - 1/BM + 1/BN$.

In the practice of field investigations, different electrode layout configurations (devices) can be used for different geological situations. The most common devices are:

- Wenner device (equal spacing between electrodes), characterized by a strong signal, poor lateral resolution and an investigation depth of 30% of the length of the AB emission line. It is used in particular for measuring by the profiling process (Fig. 2).

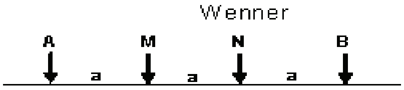

Figure 2. Wenner device.

- Schlumberger device (AB ≥ 5MN), with reasonable lateral resolution and the investigation depth of 20% of the AB length. It is the most used device in vertical electrical surveys (SEV), due to the fact that the MN reception line remains fixed, so it requires little staff (Fig. 3).

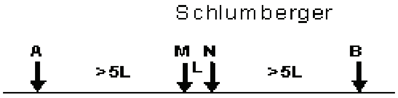

Figure 3. Schlumberger device.

- dipole-dipole device, with good lateral resolution and the depth of investigation of 15% of the length of the AB emission line. Especially applied to multi-channel recording instruments, to reduce working time (Fig. 4).

Figure 4. Dipole-dipole device.

- pole-pole device, with the greatest depth of investigation, but generating fewer clear images. It is especially applied to 3D recordings (Fig. 5).

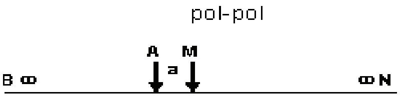

Figure 5. Pole-pole device.

CASE STUDY AND RESULTS

In figure 2 are photos from measurements in the Ruschita quarry (general view, profile, marble wall)

a) **Image from Google Earth**

b) **Original photo**

c) **Original photo**

Figure 6. Ruschita quarry (general view from global mapper, photo on profile, photo of marble wall).

In figures 7, 8 and 9 we can find 9 sections of resistivities on the performed electrometric profiles in the quarries of Ruschita, Carpinis and Pietroasa. The areas of minimum values, outlined in blue, represent alteration zones and fissures in the quarry rock mass. Also, the areas of increased gradient (quick transitions from minimum-blue to maximum-red) highlight the change in the geological and microtectonic characteristics of the rock mass.

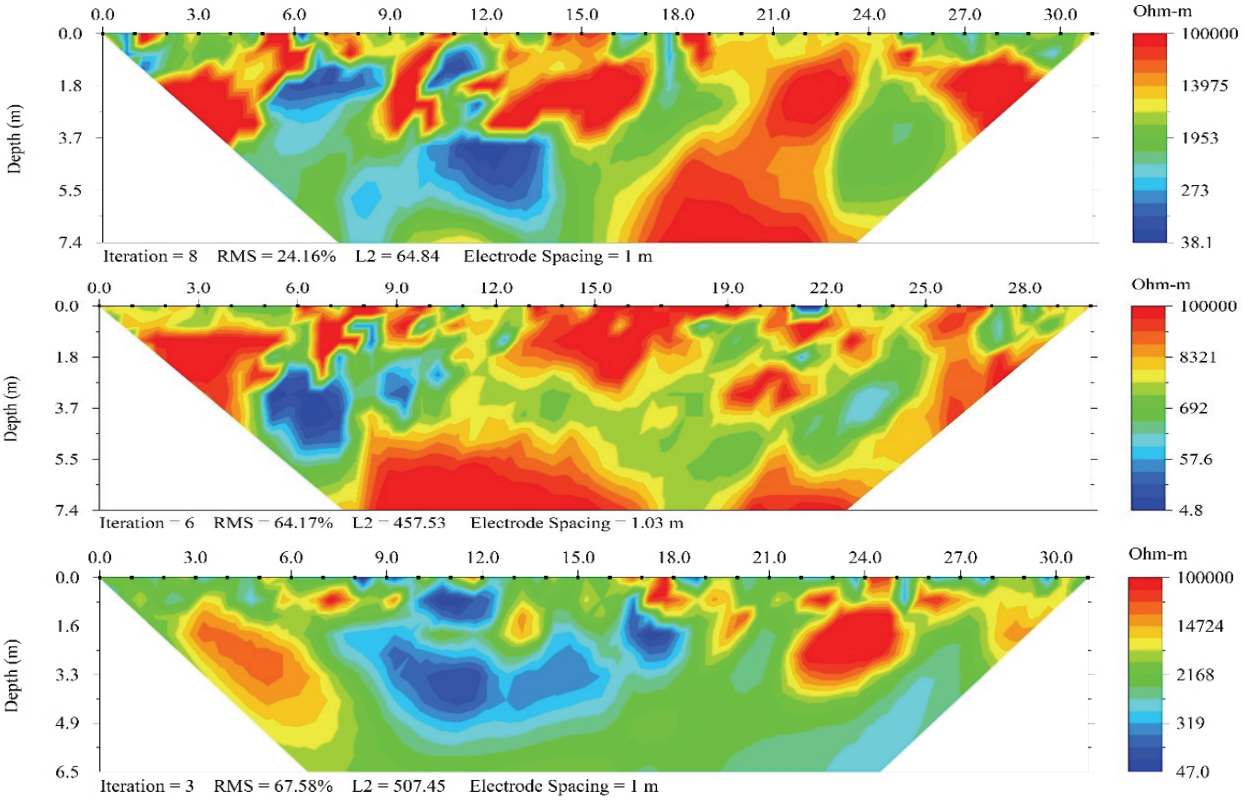

Figure 7. Three profiles at the Ruschita Quarry.

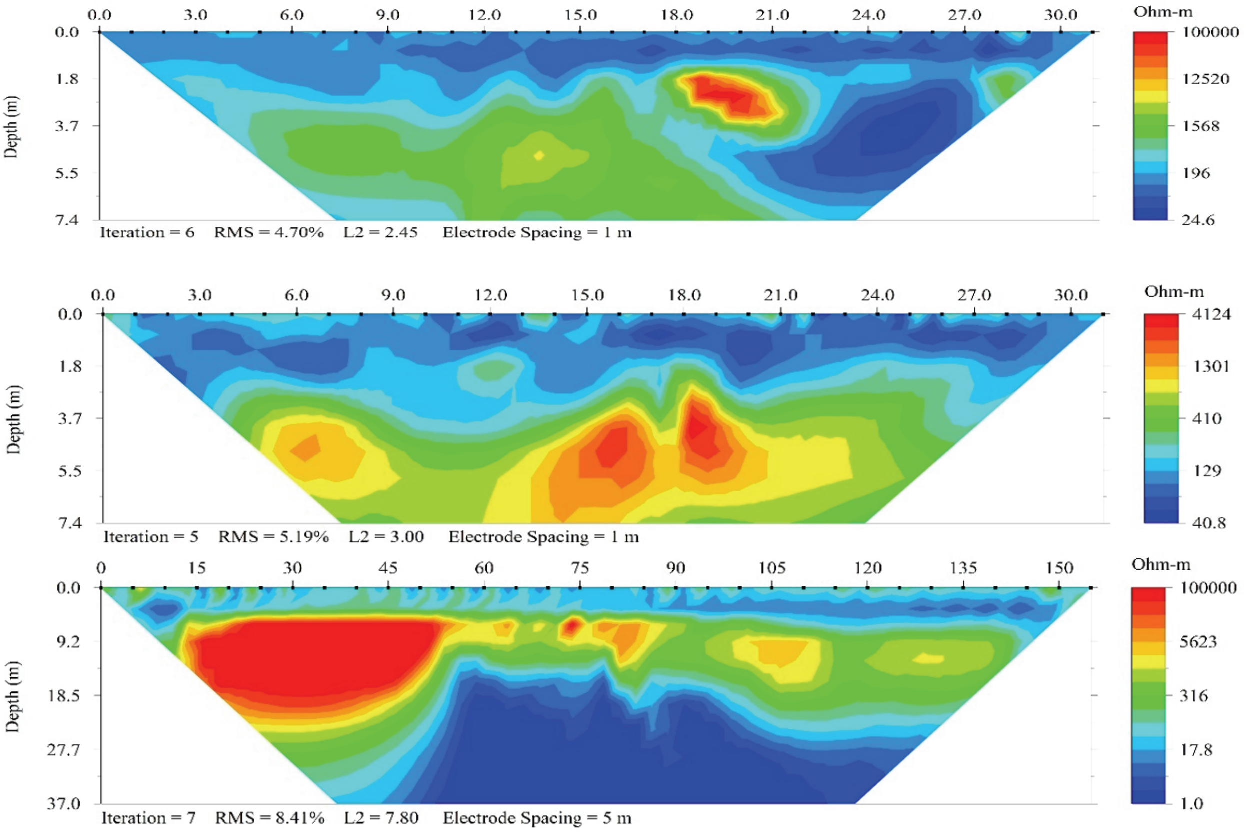

Figure 8. Three profiles at the Cărpiniş Quarry.

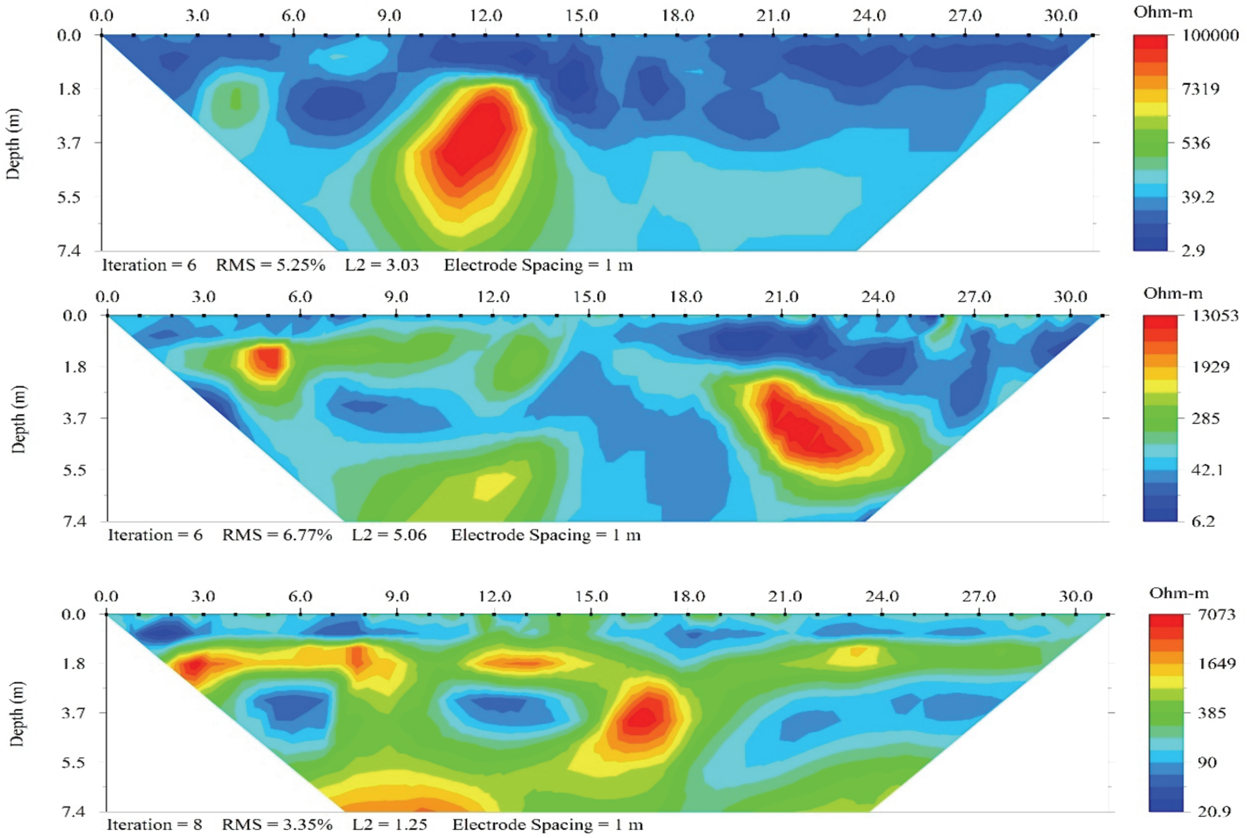

Figure 9. Three profiles at the Pietroasa Quarry.

Figure 10 depicts three modes of representation of 3D block diagram from the Pietroasa quarry.

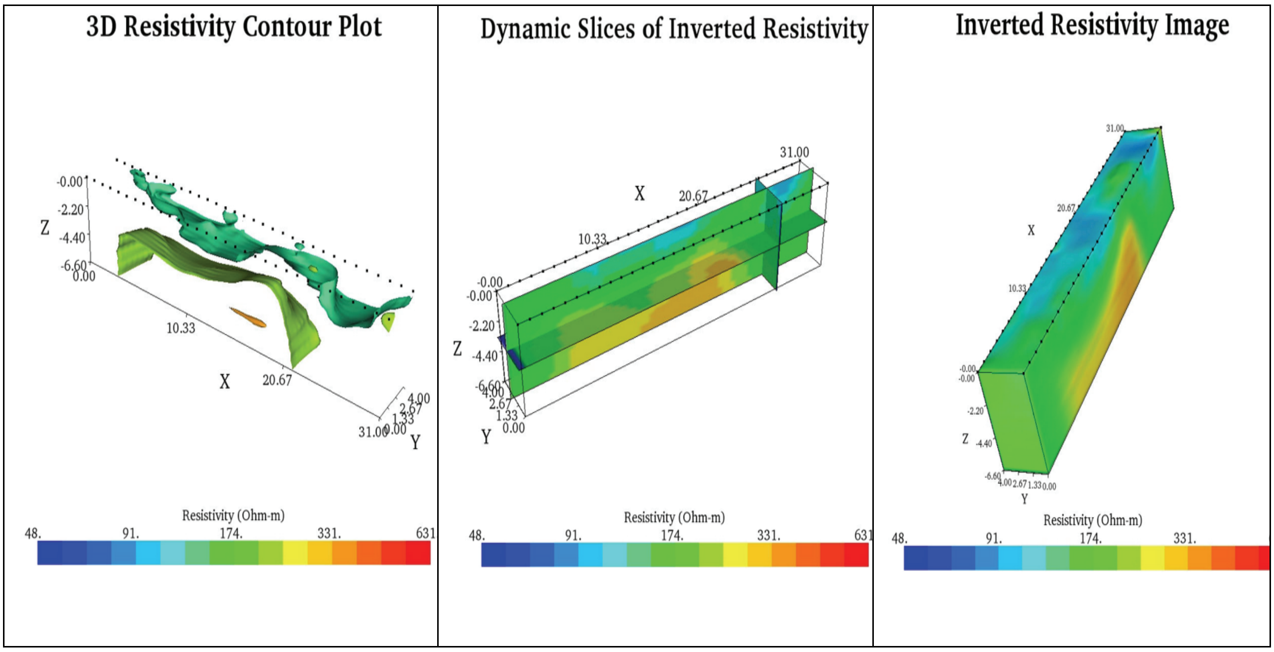

Figure 10. Three images 3D block diagram at the Pietroasa Quarry.

To create the 3D of the subsoil resistivity (Fig. 6), the following steps are taken: Obtaining resistivity data for different layers in the basement. Preprocessing the data into a format suitable for creating the graph. This includes removing outliers or incomplete data and interpolating missing values. Specialized graphics software is used to create the 3D model of the basement can be created, with the base on the horizontal axis and the depth on the vertical axis.

Each resistivity layer can be represented by a different color or by a color scale.

After the model is created, the 3D plot can be viewed and explored from different perspectives to gain a better understanding of the resistivity distribution in the subsurface.

CONCLUSIONS

Resistivity is a physical property of a material that measures how much the material resists electrical flow. This depends on many factors such as crystal structure, chemical composition, degree of hydration, temperature and pressure. Resistivity is measured in ohms per meter (Ω/m). Resistivity values for marble, travertine and andesite can vary depending on certain conditions and specific compositions. In general, the following resistivity values can be found:

- Marble: between 10 and 1000 Ω·m (depending on the degree of crystallinity and water content)
- Travertine: between 50 and 300 Ω·m (depending on porosity and degree of hydration)
- Andesite: between 100 and 1000 Ω·m (depending on chemical composition and degree of hydration).

After performing the resistivity electrometric tomography, we can draw the following conclusions:

- Resistivity maximum may represent unaltered areas, without fluid-circulated fractures. We can consider an electronic conductivity between particles.

- The resistivity minimum may represent altered areas with fluid-circulated fractures. We can consider an electrolytic conductivity between particles. These considerations are qualitative. For a quantitative determination, the electrometric resistivity data must be corroborated with direct investigative information.

To create 2D and 3D graphics, in addition to the Earth Imager software, various other tools and software can be used, such as Surfer, RockWorks, Voxler or Geomodeller.

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