

## GEOPHYSICAL STUDY OF THE BLOCK STRUCTURE IN A RHYOLITE STONE QUARRY

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### Abstract

The main purpose in the extraction of dimension stone is the efficient detachment and preservation of large, intact rock blocks from the active working in quarries. Achieving high extraction efficiency requires a comprehensive understanding of the structural discontinuities within the geological massif. The characterization of fracture networks and the assessment of rock mass integrity at depth are critical for optimizing natural resource utilization. To increase yield, improve operational efficiency, and minimize losses of non-renewable resources, geophysical survey was conducted at quarry for extraction of igneous rocks – rhyolite. The main method used in the study was Electrical Resistivity Tomography (ERT), a non-invasive geophysical technique for mapping the sub-surface geological structure. This method enables the spatial analysis of electrical resistivity variations within rock formations, providing high-resolution data on lithological composition, fracturing patterns, and groundwater saturation, all of which are essential for informed decision-making in quarrying operations. The study confirms the effectiveness of Electrical Resistivity Tomography (ERT) as a geophysical exploration method for quarrying igneous rock blocks, specifically rhyolites. The obtained data can serve as a valuable resource for future extraction planning of the quarries and geological assessments of the area.

**Key words:** open-pit mining of dimension stones, geophysical survey, discontinuity of the rock mass, yield, quarry

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**Introduction.** Geophysical methods are one of the primary approaches for gathering information about subsurface structures. Measurements are typically conducted in a strict sequence of instrument operations and along profile lines. The results are widely used in open pit mining, geology, and increasingly in engineering applications [1]. According to GRIGOROVA [2] preliminary research works have great impact on mining productivity. They are pointed as a key element in resource extraction. The incorporation of any prior geological and geophysical information available can significantly improve the quality of the result, to reduce the expenses, and to reduce damage from future mining activities, which is one of the main factors in the extraction of dimension stone blocks. Prior information from boreholes, direct measurements or such from structural imaging techniques as electrical resistivity tomography proved to be very efficient in the production process [2].

For investigating the characteristics of a mining field and detailed mapping of rock variations, geophysical methods offer a practical and relatively easy-to-apply alternative to time-consuming and more expensive exploratory drilling. The applicability of each method depends on the differentiation of rock types, geological composition, and the specific physical parameter defining the investigated field. The data on the physical properties of the target objects and their surrounding medium serve as the fundamental prerequisite for evaluating the suitability of various geophysical methods. Among the most effective techniques are electrical resistivity methods, which stand out as the most suitable in similar situations. As TOMOVA and KISYOV [3] stated this geophysical technique works by measuring the electrical resistivity of subsurface materials. This is a non-invasive approach, allowing high accuracy in determining the distribution of different lithological units within a section. Electrical Resistivity Tomography (ERT) is a powerful modern tool for studying the near-surface geological structure. In recent years, it has seen increasing application in solving various challenges related to improving efficiency in open-pit mining operations. A major advantage of this method is that it does not disturb the integrity or surface of the studied object, which is particularly important in dimension stone extraction. Another benefit is its ability to obtain continuous data over specified intervals, spatial volumes, or time periods, providing a comprehensive understanding of both the characteristics of the near-surface geological structure and the degree of water saturation in the medium.

**Methodology of electrical surveying (Electrotomography).** In electrotomography, the measured electrical resistivity values reflect the electrical properties of the medium directly beneath the surveyed profile. Variations in electrical resistivity typically correlate with changes in lithology, water saturation, fluid conductivity, porosity, and permeability, which can be utilized for mapping geological structures, fractures, groundwater, and other subsurface features [4].

The ERT method is an important geophysical technique used to generate

high-resolution imaging of the upper Earth's crust [5]. This non-invasive geophysical technique proved itself as very productive when it comes to determine the subsurface resistivity distribution by making measurements generally on the ground surface [6]. In electrotomography, an electric current is injected into the ground through a pair of electrodes, while the resulting potential field distribution in the subsurface is recorded using another pair of electrodes. As noted by NASSAR et al. [7], the fundamental principle of electrotomography is based on the differential electrical conductivity of the rock formations that constitute the surveyed section. The electrical conductivity of rocks depends on numerous factors, including rock type, degree of fracturing, porosity, permeability, pore connectivity, temperature, salinity, cation exchange capacity, clay content, and the nature of the fluid/water filling the pores [7].

ERT is typically conducted using a large number of electrodes (96 or more), connected via a multi-core cable. The appropriate electrodes for each measurement are selected using a mechanical or electronic switching device. The collected data is recorded in a text file or on paper for subsequent input into a computer for further processing and analysis.

As a final result, the RES2DINV software produces three vertical maps (profiles): a pseudo-section displaying the measured apparent resistivities; a pseudo-section showing the modelled apparent resistivities; and a section depicting the actual resistivities calculated by the model. Comparing the first two sections demonstrates the reliability of the model solution, while the third section reveals the actual distribution of electrical resistivities within the subsurface.

The generated resistivity model is further refined and adapted to the subsurface conditions specific to the study area based on:

- General information about the surface topography, as well as the lithological, facies, tectonic, and hydrogeological conditions of the region;
- Data on the specific electrical resistivities of various rock types;
- Information from exploratory drilling.

Surface topography is typically determined through orthophoto surveying using modern aerial platforms (drones) or electronic geodetic instruments such as LiDAR. In the present study, measurements were conducted on a working bench in the quarry, which is practically horizontal due to the rock block extraction technology. Because of this characteristic, as well as the relatively small area of the site, the influence of surface topography on the results is minor.

Data on the lithological, facies, tectonic, and hydrogeological conditions in the region are presented in the geological reports for the deposit.

Thereby, the obtained results can be used for the development of 3D models, applicable both for slope stability assessment and for planning the development of mining operations in open-pit mines and quarries [8].

**Results of the geoelectrical measurements.** In this study, one profile was measured using electrical tomography with a length of 130 m. Two slanted 48-core cables were used with a distance of 3 m between the electrodes (a total of 96 electrodes in the setup, with 43 electrodes used in this particular case) (Fig. 1).



Fig. 1. Field survey view – electrodes



Fig. 2. Field survey view – equipment ZZ Universal 96-Channel Resistivity/IP Meter

As KISYOV et al. [9] mentioned Electrical Resistivity Tomography (ERT) is a geophysical technique used to image subsurface structures and variations in electrical resistivity. The measurements were conducted using a 4-electrode Wenner–Schlumberger configuration. The field measurement data were interpreted using the RES2DINV computer program, determining the distribution of true resistivities in the subsurface. The resulting geoelectrical section was performed using the Australian equipment ZZ Universal 96-Channel Resistivity/IP Meter.

The ZZ Universal 96-Channel Resistivity/IP Meter (Fig. 2) is manufactured by the Australian company ZZ Resistivity Imaging Pty Ltd. The equipment enables the measurement of the medium's specific electrical resistance and is also successfully used to measure both natural and induced potentials. The ZZ Universal 96 is the only device in the world featuring the FlashRES-UNIVERSAL 96 system, which allows for all electrodes to be used simultaneously, thus gathering more data for the section. This enhances the flexibility of electrode arrangement along a profile and makes the results of electrical tomography much more accurate and reliable. FlashRES-UNIVERSAL 96 has 93 channels and can collect data from 93 points simultaneously with each current pulse along the profile.

In this way, the equipment can collect significantly more data than conventional systems, thereby creating a tomographic image with higher quality and resolution. A major advantage of the system is its ability to display data quality in real time, while simultaneously allowing the operator to filter out any noise (background, contact, or instrumental) on the spot. This helps the operator assess the collected data in the field and, if the signal deteriorates, take corrective action to eliminate interference when possible.

**Analysis and interpretation.** In the present study, one geoelectrical cross-section was measured, processed, and analyzed in the territory of a rhyolite stone quarry in Pazardzhik region (Fig. 3). Data processing and interpretation includes the following sections:

- A pseudo-section with the measured apparent resistivities;
- A pseudo-section with the model-calculated apparent resistivities;
- A section with the actual resistivities calculated by the model.

In the first section (Pseudo-section with measured apparent resistivities), the real apparent resistivities measured in the field are shown, with each point representing a measurement. The filtered points are shown in a lighter gray colour.

In the second section (Pseudo-section with model-calculated apparent resistivities), the section generated by the software according to the given constraints and geometry is shown.

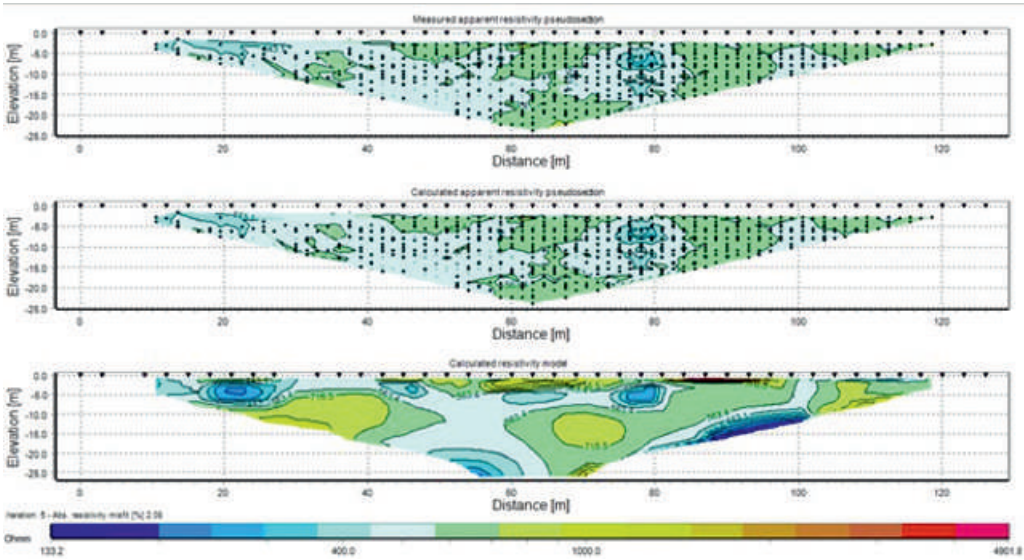


Fig. 3. Pseudo-section with measured apparent resistivities; pseudo-section with model-calculated apparent resistivities; and final ERT-1 section with model-calculated real resistivities

In the third section (Final ERT-1 section with model-calculated real resistivities), the actual distribution of specific electrical resistivity along the profile is shown. These are created based on five iterations, through which the difference between the Pseudo-section with measured apparent resistivities and the Pseudo-section with model-calculated apparent resistivities is minimized.

The data has been filtered, and Fig. 4 shows the distribution of the measured values in histograms and the distribution of discrepancies between the measured and calculated data.

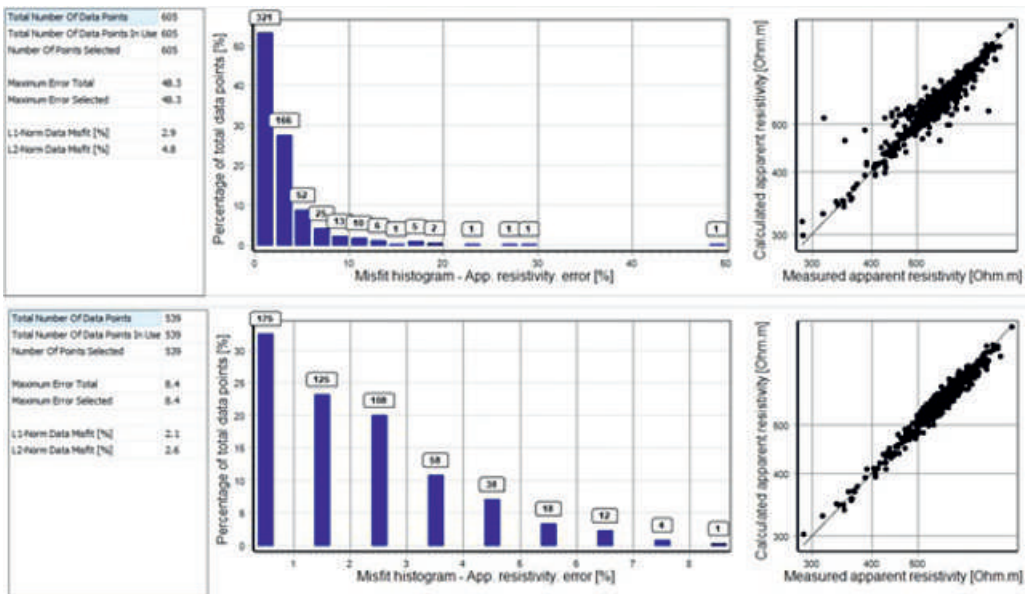


Fig. 4. Data distribution before and after filtering

Figure 4 presents the impact of external noise, which could potentially introduce certain inaccuracies in the results. After filtration, the data distribution becomes compact and all random noise, anthropogenic noise, and interference from quarry mining machines, such as drilling hammers and excavators, are removed. Consequently, the processed data exclusively reflects the influence of the structures in the investigated section.

The analysis and interpretation of the electrical tomography results from the studied rhyolite quarry area lead to the following key conclusions:

1. In the predominant part of the measured geoelectric cross-section, the electrical resistance is well-defined with a clear and smooth character.
2. The electrical resistance of the rock units (environments) that make up the studied cross-sections varies within relatively wide range – from about 130  $\Omega$  to 5000  $\Omega$ , indicating the presence of very robust rock masses.

3. The zones marking the spatial distribution of the medium with increased electrical resistance, most likely due to the presence of solid, bonded rock material, are in the range from  $1000\Omega$  and above, indicating the presence of monolithic rock block reserves.
4. The obtained geoelectric section reaches an average depth of 25 m, providing adequate data for planning future mining operations and expanding extraction horizons.
5. The section with relatively lower electrical resistance values, in the range from 130 to  $500\Omega$ , most likely indicates loosened fractured zones, crack zones, and those with weakly bonded materials.

**Conclusions.** This geophysical study demonstrates the effectiveness of Electrical Resistivity Tomography (ERT) for detailed mapping of the near-surface geological structure in quarry for rhyolite block extraction. The method provides valuable information on the distribution of various lithological units, their structural characteristics, the degree of fracturing, and water saturation – all without the need for invasive and time-consuming drilling. The obtained results can help optimization of extraction activities, development of anthropogenic deposits as integrated facilities for disposal of mining waste, and minimization of risks associated with unstable or water-saturated zones [10]. In the future, similar studies could be widely applied in mining and engineering geology, contributing to more precise planning and the sustainable utilization of non-renewable resources and improved yield in the extraction of dimension stones blocks [11]. Moreover, integrating ERT with other geophysical methods, such as seismic tomography and ground penetrating radar scanning, could further enhance the reliability of interpretations and the efficiency of mining-engineering operations.

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