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Application of Induced Polarization and Electrical Resistivity Tomography for Subsurface Targeting in Underground Polymetallic Mines

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Summary
This study explores the application of Induced Polarization (IP) and Electrical Resistivity Tomography (ERT) in underground mining environments for the identification of zones with elevated chargeability, which may correspond to mineralized structures. The IP method, which measures the delayed electrical response of the subsurface, is particularly effective in detecting disseminated sulfide mineralization. The research focuses on overcoming the logistical and technical challenges inherent in underground IP surveys—such as limited space, electromagnetic noise, and grounding issues—while leveraging the advantage of proximity to target zones. By integrating geophysical data with geological and lithological observations, the study assesses the potential of IP for delineating mineralized zones and improving the effectiveness of mine planning and resource targeting.

Introduction

This study investigates the application of Induced Polarization (IP) for delineating zones within an underground mine that exhibit elevated chargeability, potentially corresponding to mineralized structures. The general aspect of this research involves conducting an examination of underground conditions and object detection using Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) methods. The Induced Polarization (IP) method is a geophysical technique that measures the delayed response of the ground to the passage of electrical current (Dimovski 2010). It is particularly effective for identifying subsurface zones containing disseminated sulfide minerals, clays, and other polarizable materials. The method relies on the principle that certain geological materials temporarily store electrical energy when exposed to an external electric field.

The goal is to identify areas with higher likelihood of mineralization based on geoelectrical contrasts. Induced Polarization (IP) can be used to delineate sections of an underground mine that exhibit higher chargeability responses, which may indicate zones with increased potential for mineralization, particularly in the presence of disseminated sulfides or conductive ore minerals. ERT is a versatile geophysical tool that provides valuable subsurface information essential for effective underground mine planning, resource optimization, and environmental management. Integrating ERT and IP data with other geological, geotechnical, and hydrological information enhances the understanding of subsurface conditions, leading to safer and more efficient mining operations.

In this study, we explore the adaptation of IP measurements within an underground mining environment, with the objective of delineating zones that exhibit elevated chargeability. These zones are interpreted as having a higher potential for mineralization, particularly in cases where sulfide-bearing minerals or associated alteration zones are present. Although the underground application of IP presents logistical and technical challenges — including limited space for electrode deployment, potential electromagnetic noise from mining infrastructure, and grounding difficulties — it also offers the advantage of proximity to the mineralization target. By correlating IP anomalies with geological observations, lithological data, and known ore zones, we aim to evaluate the viability of IP as a tool for subsurface targeting in confined mine settings.

Method

The Induced Polarization (IP) method, a geophysical technique sensitive to the electrical chargeability of subsurface materials, has traditionally been employed in surface and borehole surveys to detect disseminated sulfide mineralization. As noted by Revil, disseminated ores within porous or fractured media can become polarized under the influence of an external electric field, a process described by the dimensionless parameter known as chargeability. The Induced Polarization (IP) method is a non-invasive geophysical technique capable

of imaging both electrical conductivity and chargeability, along with the characteristic relaxation time of the medium (Rivil et al. 2022).

In this study, a two-dimensional (2D) Induced Polarization (IP) survey was conducted within an active underground mine to identify zones with elevated chargeability potentially associated with sulfide mineralization. As stated by Prastowo when an electric current is injected into the subsurface through current electrodes, the resulting voltage is measured at potential electrodes (Prastowo et al. 2019). Ideally, if the electric current is interrupted abruptly, the measured voltage should instantly drop to zero. However, in practice, the voltage decays gradually in an exponential manner and approaches zero over a time interval of several seconds to minutes. This delayed voltage decay is known as the Induced Polarization (IP) effect (Siregar & Kurniawan 2018).

Field measurements were performed in polymetallic underground mining conditions in Central Bulgaria. IP measurements are acquired using the same four-electrode geometry that is conventionally used for electrical resistivity surveys, although IP surveys typically employ nonpolarizing electrodes. Surveys are conducted in the time domain. The current is injected and the decay of the voltage over time is measured (Hubbard & Linde 2011). The survey was carried out along accessible shafts and crosscuts using a Schlumberger array, selected for its balance between depth penetration and resolution in confined geometries. Electrodes were deployed at regular intervals along the tunnel walls, ensuring optimal contact resistance despite challenging grounding conditions. A multi-channel IP receiver was used to record time-domain IP responses, and each survey line was georeferenced relative to mine infrastructure and geological mapping data.

A standard four-electrode configuration, labeled A, B, M, and N, is used in IP surveys. Electrodes A and B act as current electrodes, injecting electrical current into the ground, while M and N are potential electrodes that measure the resulting voltage difference. When current is applied, part of the energy is stored in the medium in the form of mechanical, electrical, or chemical energy (Maryanto 2017). Upon sudden interruption of the current, this stored energy is released gradually, producing a decaying voltage response. This delayed voltage decay is the basis of the IP effect and is quantified by the parameter known as chargeability. The principle is demonstrated in Fig. 1.

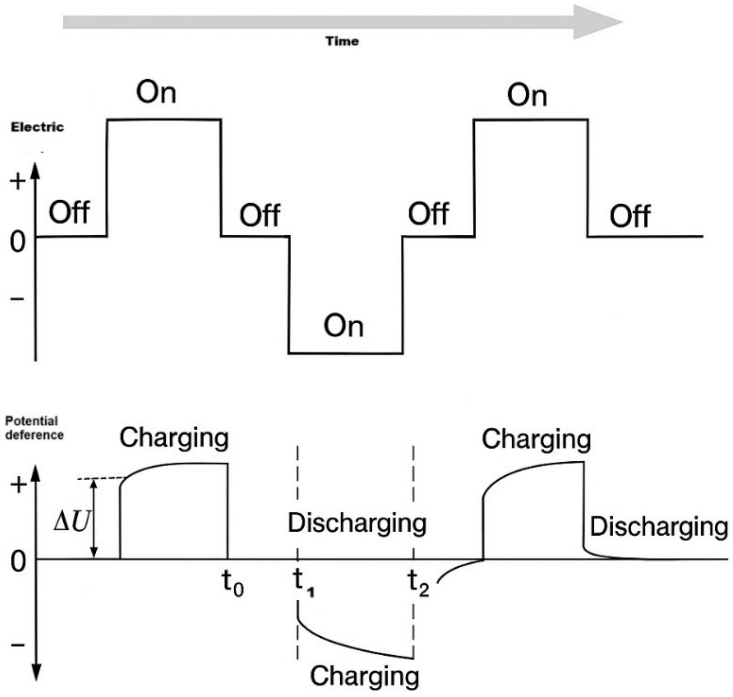


Figure 1. Dependence of the potential difference ΔU in the receiving circuit on the time t after switching on and off the current in the supply circuit

The acquired IP data were processed and inverted using a the Res2DInv software package based on smoothness-constrained least squares minimization. The inversion model accounted for the tunnel geometry and heterogeneous resistivity distribution typical of fractured rock masses in underground environments. The resulting 2D models of resistivity and chargeability were interpreted in conjunction with geological data and

known mineralized zones. Areas showing anomalously high chargeability were considered as potential targets for further exploration, with particular emphasis on correlating IP anomalies with sulfide-bearing structures and hydrothermal alteration zones. This approach allowed the integration of geophysical and geological information to improve subsurface targeting within the constraints of underground conditions.

The usefulness of the proposed technology is demonstrated with an example field study where ERT line and IP line are interpreted simultaneously (Fig. 2). From the obtained geoelectrical sections by electrical resistivity tomography (ERT) and induced polarization (IP), two zones can be very separated. One from 0 to the 38th meter along the profile, and the other from the 39th meter to the end of the profile. As it can be observed on Fig. 1 it is well distinguished geoelectrical contrast between several different types of media. The lowest values here mark spatial distribution of an environment with presence of mylonitized, clayey areas, very likely hydrated, part of the active fault system.

Elevated resistivity values are interpreted as indicative of rock units in contact with the fault system associated with the Trans-Balkan Deep Fault.

In the current study, ERT survey is used to help delineate the extent, geometry, and continuity of structures underground. By identifying the distribution of high resistivity zones associated with ore bodies, it can be optimized the design of mining operations, including excavation planning and potential hazards. ERT surveys can provide valuable information about the geological structures within the mine area, such as faults, fractures, and bedding planes. Mapping these structures helps in understanding the ore deposition and designing mining layouts that minimize the risk of encountering geological hazards.

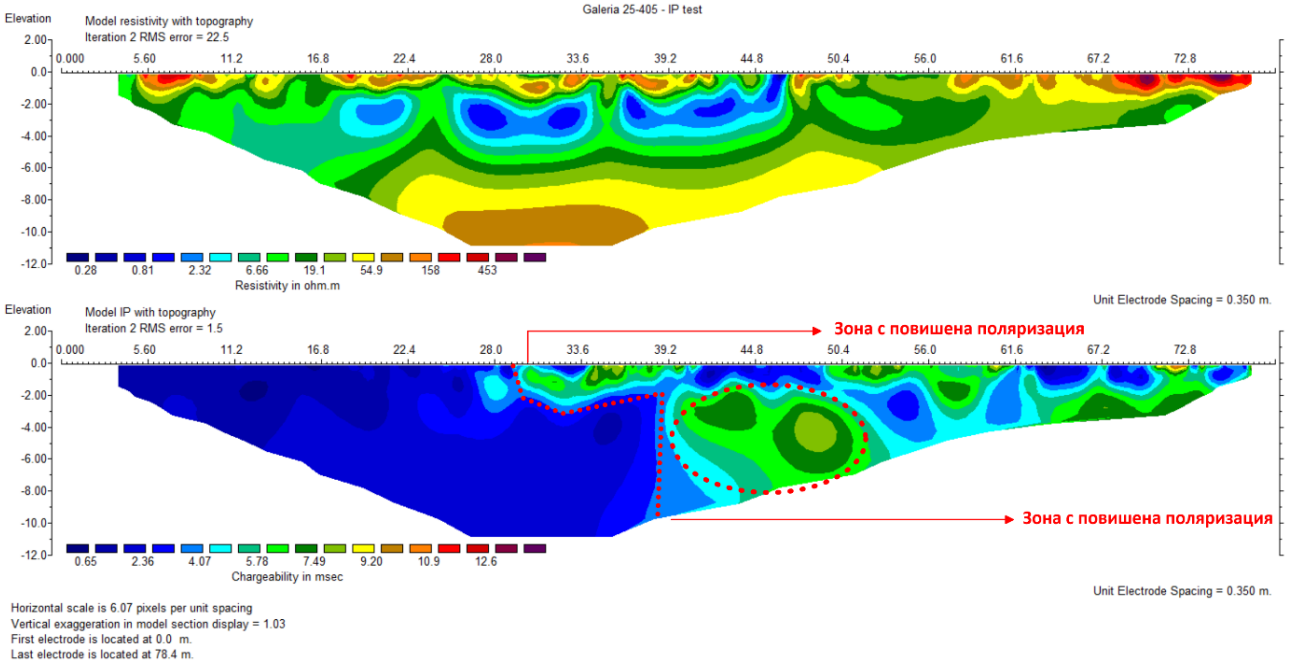


Figure 2. IP Line along mining gallery wall

According to Fig. 2, this study evaluates the feasibility and effectiveness of the Induced Polarization (IP) method for delineating mineralized zones in an underground copper-gold-pyrite mining environment. The resulting 2D resistivity and chargeability models provided insights into the spatial distribution of electrically distinct zones. In these areas elevated chargeability values were interpreted as potential indicators of disseminated sulfide enrichment, consistent with the copper-gold-pyrite mineral assemblage known from lithological mapping. These IP anomalies were cross-referenced with structural features and geological information to validate their geophysical significance and guide further exploration targeting within the mine. The electrical resistivity sections clearly reveal contrasts between different geological environments, enabling more confident differentiation of lithological units and fracture zones, as well as delineation of contact surfaces between distinct rock types. Variations in resistivity observed across the profiles provide a basis for distinguishing water-saturated, mylonitized, and clay-rich zones from more compact and less fractured rock complexes.

According to the data obtained, the induced polarization (IP) values for the host rock, in the absence of mineralization, range between 0 and 5 milliseconds. These lower values dominate the section from 0 to 38 meters along the profile. Beyond the 39th meters, a sharp increase in chargeability is observed, with IP values reaching 7 to 8 milliseconds. This significant change may indicate enhanced mineralization in these sections.

Conclusions

The results demonstrate the applicability of IP for near-mine targeting and mineral exploration under the constraints of confined underground conditions, offering a valuable geophysical tool for optimizing underground exploration strategies. The application of the Induced Polarization (IP) method in underground mining conditions has proven effective for characterizing subsurface geological variations and identifying zones with higher mineralization potential. Using a four-electrode configuration and 2D inversion techniques, the survey successfully differentiated lithological units, fracture zones, and contact surfaces based on their electrical resistivity and chargeability properties. Elevated chargeability values, particularly beyond the 39th meter of the profile, indicate the possible presence of disseminated sulfide mineralization, consistent with the known copper-gold-pyrite assemblage.
The ability of IP to distinguish between compact rock masses and water-saturated zones enhances its value as a tool for mine exploration and geological modeling. Despite the logistical challenges of conducting geophysical surveys in underground settings, the results demonstrate that the IP method, offers reliable insights for subsurface targeting and supports more informed decision-making process in mineral exploration.

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