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Effectiveness of Induced Polarisation Method in Identifying the Presence of Minerals: 2-Dimensional Interpretation Modeling of Crossing Lines

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Abstract

This study evaluates the effectiveness of the Induced Polarization (IP) method in identifying mineral presence within the Pacitan region through a detailed case study utilizing 2-dimensional (2D) interpretation of crossing lines. The Pacitan region, with its diverse geological structures, offers an ideal test site for assessing the IP method's capabilities in mineral exploration. By conducting extensive IP surveys and integrating the data with geological and geophysical information, distinct anomalies indicative of mineralization were identified. The results demonstrate that the IP method is highly effective in detecting subsurface minerals, providing a reliable tool for exploration. The 2D interpretation of crossing lines significantly improved the accuracy of anomaly detection and offered detailed insights into the spatial distribution of mineral deposits. Based on the IP survey results, a large resistivity anomaly is located at a distance of 40 metres from the starting point of measurement with a depth of 2-20 metres and a diameter of about 40 metres. Meanwhile, the chargeability anomaly is at a distance of 30 metres from the starting point with a depth of 4-24 metres and a diameter of about 30 metres. When observed from each analysis of line 1 and 2, the cross results can identify resistivity and chargeability anomalies very accurately. This research highlights the potential of the IP method as a non-invasive, cost-effective approach for mineral exploration, particularly in geologically complex regions like Pacitan. The findings underscore the method's utility in enhancing mineral prospecting efforts and contributing to more efficient exploration strategies.

Keywords: induced polarization; mineral; 2-dimensional; crossing lines; pacitan

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INTRODUCTION

The identification and exploration of mineral deposits are critical components of the mining industry and economic development. Traditional methods of mineral exploration, such as geological mapping and drilling, often involve significant costs and environmental impacts (McNeill J. D. and Labson V. F, 1991). As a result, there is a growing interest in non-invasive geophysical techniques that can enhance the efficiency and accuracy of mineral exploration (Idroes et al., 2019).

One such technique is the Induced Polarization (IP) method, which has gained prominence for its ability to detect subsurface mineralization. The IP method measures the capacitive properties of subsurface materials, providing valuable information about the presence and concentration of metallic minerals. The Induced Polarization (IP) method is a widely used geophysical technique for identifying the electrical properties of subsurface materials. Originally discovered during resistivity surveys, IP measures the delayed voltage response of materials when an external electric field is applied. This method is particularly effective in detecting disseminated sulfide minerals and other conductive phases, making it invaluable in mineral exploration. IP surveys can be conducted in both time-domain and frequency-domain modes. In the time-domain mode, the voltage response is measured as a function of time after the injected current is switched off. In the frequency-domain mode, an alternating current (AC) is injected at different frequencies, and the resulting voltage phase-shifts are measured. These measurements provide insights into the capacitive properties and spatial variation of subsurface materials. The IP method has applications beyond mineral exploration, including hydrogeological studies and environmental investigations. By combining IP data with other geophysical methods, researchers can create comprehensive models of subsurface structures and properties. This geophysical technique is particularly useful in regions with complex geological settings, where traditional methods may be less effective (Playà et al., 2010; Saparun et al., 2022).

The Pacitan region, located in East Java, Indonesia, is characterized by its diverse geological formations and potential for mineral resources. However, the region's complex geology presents challenges for traditional mineral exploration methods. This study aims to evaluate the effectiveness of the IP method in identifying the presence of minerals in the Pacitan region. By employing a 2-dimensional interpretation of crossing lines, we aim to enhance the accuracy and reliability of the IP method in detecting subsurface mineralization (Daffaedra et al., 2023; Nugraha et al., 2019; Saparun et al., 2022).

Through comprehensive geophysical surveys and data analysis, this research seeks to provide insights into the capabilities of the IP method in complex geological environments. The findings of this study have significant implications for the exploration and sustainable management of mineral resources in the Pacitan region and beyond.

Geological Setting

The Pacitan region, located in East Java, Indonesia, is characterized by its diverse and complex geological formations. This area is part of the southern mountain range of Java, which is known for its tectonic activity and rich mineral resources. The geology of Pacitan plays a crucial role in influencing the distribution and characteristics of mineral deposits, making it a significant area for geophysical studies and mineral exploration (Nishimura et al., 1986).

The Pacitan region is situated within the Sunda-Banda Arc, an active tectonic zone resulting from the subduction of the Indo-Australian Plate beneath the Eurasian Plate. This tectonic setting has given rise to a series of volcanic and plutonic activities, contributing to the formation of mineral-rich deposits. The region's geology is marked by the presence of volcanic arcs, fault lines, and fracture zones, which provide pathways for hydrothermal fluids and mineralization processes (Deon et al., 2015; Maryanto, 2017; Purnomo et al., 2016; Rizki et al., 2022). The geological formations in Pacitan comprise a variety of lithological units, including: Volcanic Rocks: Predominantly andesitic to basaltic lavas and pyroclastic deposits from past volcanic activity; Sedimentary Rocks: Including limestone, shale, and sandstone, which are often interbedded with volcanic materials; Intrusive Rocks: Granitic and dioritic intrusions that have contributed to the region's mineralization through hydrothermal processes (Hariyono & S, 2018; Saparun et al., 2022).

The interaction between tectonic activity and hydrothermal processes has led to significant mineralization in Pacitan. Hydrothermal fluids, rich in minerals, circulate through fractures and faults, depositing economically valuable minerals such as gold, copper, lead, and zinc. The presence of alteration zones and mineral veins further indicates active hydrothermal systems (Hanuš et al., 1996).

The Pacitan region exhibits distinct geophysical characteristics that are conducive to the application of the Induced Polarization (IP) method. The varying conductivity and resistivity of different rock types and mineralized zones can be effectively mapped using IP surveys. The complex geology, with its mixture of volcanic, sedimentary, and intrusive rocks, provides a challenging yet promising environment for geophysical exploration. The geological setting of the Pacitan region, with its active tectonic framework, diverse lithological units, and significant hydrothermal activity, makes it an ideal location for studying the effectiveness of the IP method in identifying mineral deposits. This understanding of the regional geology is essential for interpreting geophysical data and enhancing the accuracy of mineral exploration efforts (Saparun et al., 2022).

METHOD

Data Acquisition

To evaluate the effectiveness of the Induced Polarization (IP) method in identifying the presence of minerals in the Pacitan region, extensive geophysical surveys were conducted across selected sites (**Figure 1**). The surveys involved the deployment of IP equipment along strategically chosen lines that crossed geological features of interest. The crossing lines allowed for a comprehensive 2-dimensional interpretation of the subsurface characteristics.

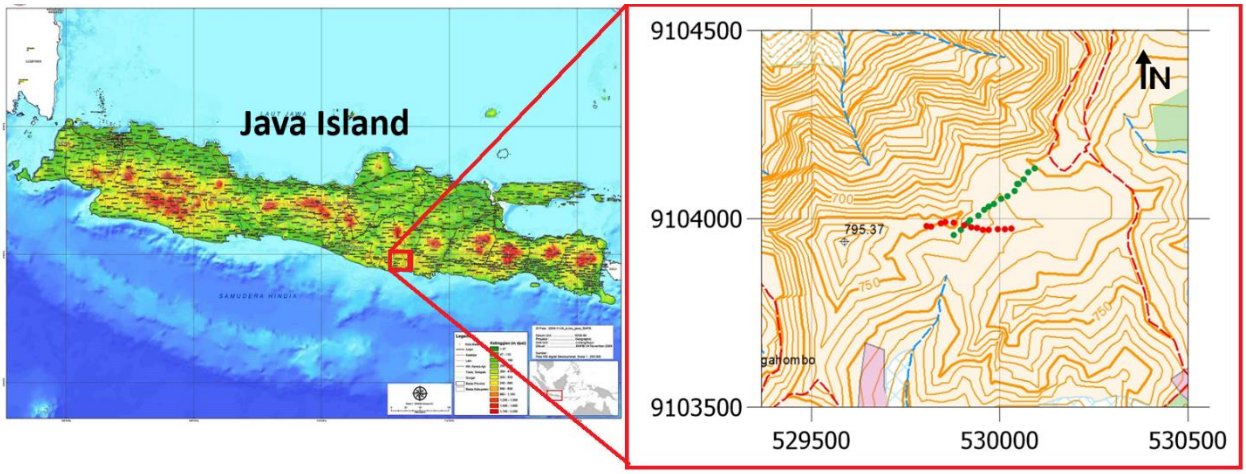

Figure 1. Map of the study area. Red colour is line 1, Green colour line 2, Distance between electrodes and porospots 20 meters.

Field Measurements

The IP method involves the injection of a controlled electrical current into the ground using electrode arrays (**Figure 2**). For this study, a dipole-dipole electrode configuration was employed due to its effectiveness in resolving subsurface anomalies. The field measurements included Chargeability (mV/V): Measurements of the induced polarization effect, reflecting the ability of the subsurface materials to temporarily store electrical charge; and Resistivity (Ω·m): Measurements of the subsurface's resistance to electrical current flow, providing insights into the distribution of conductive and resistive materials (Playà et al., 2010; Saparun et al., 2022).

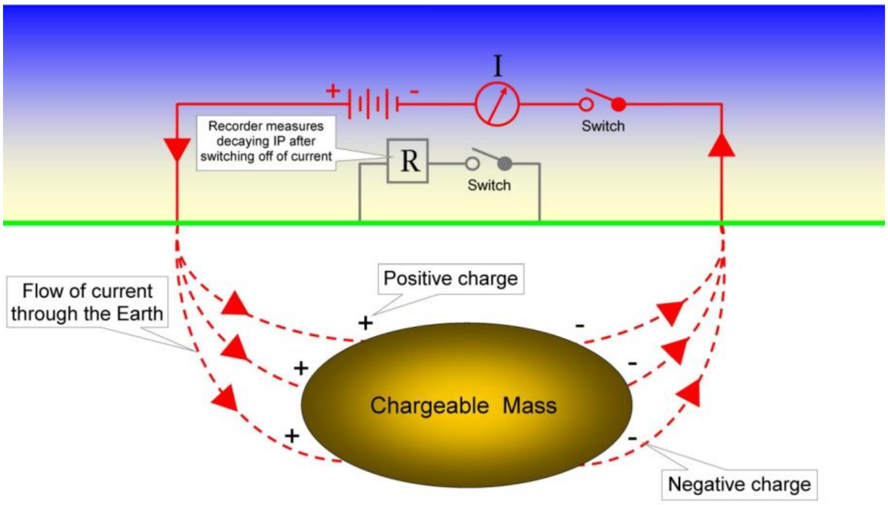

Figure 2. Induced Polarisation Method Ilustration. The Figure Adapted from (Playà et al., 2010)

Analytical Data and Equations

The Induced Polarization (IP) method involves measuring the delayed response (or polarization) of the subsurface materials to an applied electrical current. The key equations used in the IP method are related to chargeability and resistivity. Chargeability (M): Chargeability is a measure of the IP effect and is defined as the ratio of the secondary voltage (Vs) to the primary voltage (Vp) after the current is turned off. It is given by equation (1) (Martinho, 2023):

$$M = Vs/Vp \qquad \dots (1)$$

where: M is the chargeability; Vs is the secondary voltage and Vp is the primary voltage.

For Resistivity (ρ): Resistivity is a measure of how strongly the subsurface material opposes the flow of electrical current. It is calculated using Ohm's law (equation (2)), which relates the voltage (V), current (I), and resistance (R) (Martinho, 2023; Panwar et al., 2021):

$$\rho = \frac{R \times A}{L} = \frac{V}{I} \times \frac{A}{L} \qquad \dots (2)$$

where: ρ is the resistivity; R is the resistance; A is the cross-sectional area through which the current flows; L is the length of the current path; V is the voltage; and I is the current.

Cole-Cole Model: The Cole-Cole model is often used to describe the frequency dependence of the IP effect. It is given by equation (3) (Martinho, 2023; Panwar et al., 2021):

$$Z(\omega) = R_0 \left[1 + \frac{M}{(1+(j\omega\tau)^c)}\right] \qquad \dots (3)$$

where: $Z(\omega)$ is the complex impedance; R_0 is the DC resistivity; M is the chargeability; ω is the angular frequency; τ is the time constant; c is the frequency dependence parameter; j is the imaginary unit.

These equations form the basis for interpreting IP data and understanding the subsurface properties in geophysical surveys. The combination of chargeability and resistivity measurements provides valuable information about the presence and distribution of minerals.

Data Processing

The raw field data were processed using specialized geophysical software. This involved several steps: 1). Data Filtering: Removal of noise and outliers to ensure the quality and reliability of the data; 2). Inversion Modeling: Transformation of raw measurement data into a subsurface model that represents the distribution of chargeability and resistivity. The inversion process used regularization techniques to stabilize the solutions and enhance the resolution of subsurface features; 3). 2-Dimensional Interpretation: The processed data were used to generate 2-dimensional (2D) geoelectrical sections along the crossing lines. These sections provided a detailed view of the subsurface, highlighting areas of potential mineralization. Key observations from the 2D interpretation are:

1. Anomalies Detection: Identification of distinct chargeability anomalies corresponding to zones of increased mineralization. These anomalies were cross-referenced with known geological features and previous exploration data.
2. Depth Estimation: Estimation of the depth and extent of the identified anomalies, aiding in the assessment of their economic potential.
3. Geological Correlation: Correlation of the geoelectrical sections with geological maps and lithological logs to validate the findings and refine the interpretation.

RESULTS AND DISCUSSION

Chargeability is a measure of a subsurface material's ability to temporarily store electrical charge when an external electric field is applied. It is an important parameter in the IP method as it helps identify materials with high charge resistance, such as sulphide minerals, clay-rich materials and graphite. The presence of these materials can indicate potential mineralisation. Resistivity, on the other hand, is a measure of how strongly a material resists the flow of electric current.

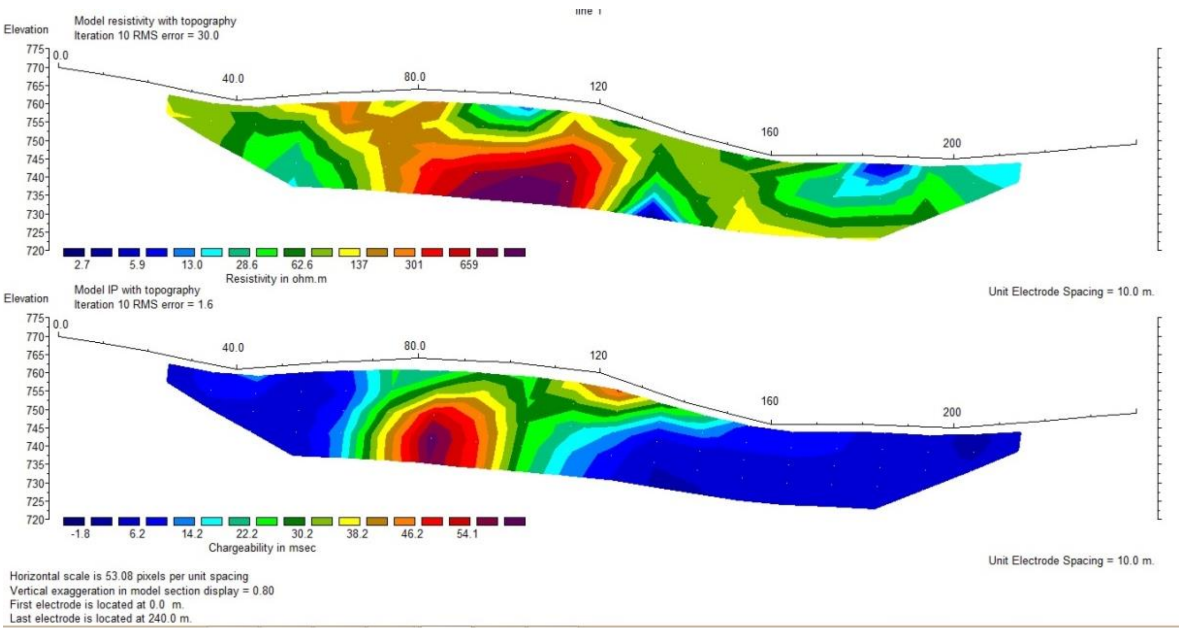

Figure 3. 2D Interpretation in line 1 using induced polarisation method; upper part is resistivities distribution; and lower part is chargeability distribution.

In the IP survey in **Figure 3**, it can be seen that chargeability and resistivity measurements are essential for identifying mineral deposits. High chargeability often correlates with the presence of metallic minerals, while resistivity helps distinguish different types of geological formations. At the top of **Figure 3** it can be seen that the high anomalies coloured red to dark purple are large resistivities. While at the bottom of **Figure 3** the high anomalies coloured red to dark purple are chargeability. On line 1, the large resistivity anomaly is at a distance of 80 meters from the starting point of measurement with a depth of 10-25 meters and a diameter of about 40 meters. While the chargeability anomaly is at a distance of 70 meters from the starting point of measurement with a depth of 10-25 meters and a diameter of about 30 meters.

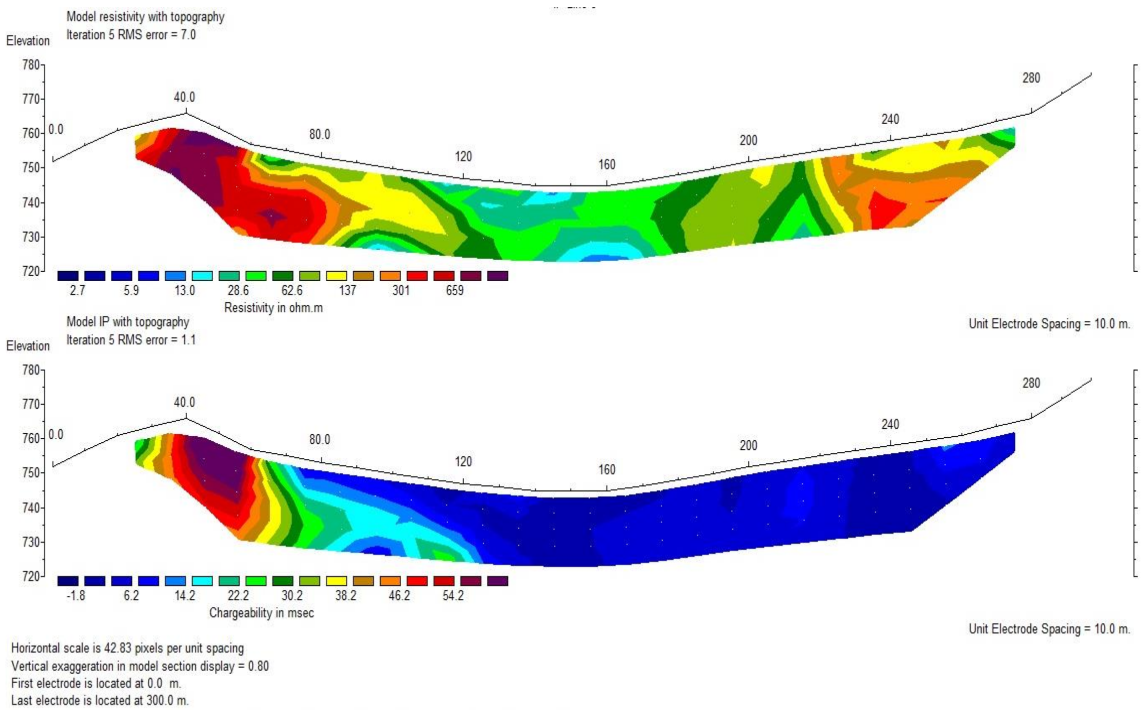

Figure 4. 2D Interpretation in line 2 using induced polarisation method; upper part is resistivities distribution; and lower part is chargeability distribution.

In the context of the IP method, resistivity data provides information about the composition and structure of subsurface materials. Different geological materials show different resistivity values, with conductive materials (e.g., water-saturated zones) showing low resistivity and resistive materials (e.g., solid rock) showing high resistivity. Therefore, high anomalies in resistivity and chargeability can describe the location of mineralised rocks.

In the IP survey in **Figure 4**, the high resistivity anomalies are located at a distance of 40 metres from the starting point of measurement with a depth of 2-20 metres and a diameter of about 40 metres. While the chargeability anomaly is located at a distance of 30 metres from the starting point with a depth of 4-24 metres and a diameter of about 30 metres. If observed from each, it can identify resistivity and chargeability anomalies very accurately.

The IP method is widely used in mineral exploration due to its effectiveness in detecting subsurface mineralisation. By analysing chargeability and resistivity data, exploration teams can identify areas with high potential for mineral deposits, guiding further exploration efforts and reducing the need for invasive techniques such as drilling. While IP methods are powerful, they also have challenges, such as the influence of noise on data quality and the complexity of interpreting results in geologically diverse areas. Proper data processing and interpretation techniques are essential to ensure accurate results.

2D Cross Modelling

The interpretation results of **Figure 5** show a positive correlation between the two intersecting lines. In this case, the use of induced polarisation method is very effective to ensure the location of minerals or other objects with high resistivity. On the other hand, the nature and working principle of induced polarisation method can also be used as a tracer of the presence of groundwater in water drought areas. Drought conditions and the presence of water are the reasons for the use of induced polarisation method to be very effective because water and rocks have a large difference in resistivity or conductivity.

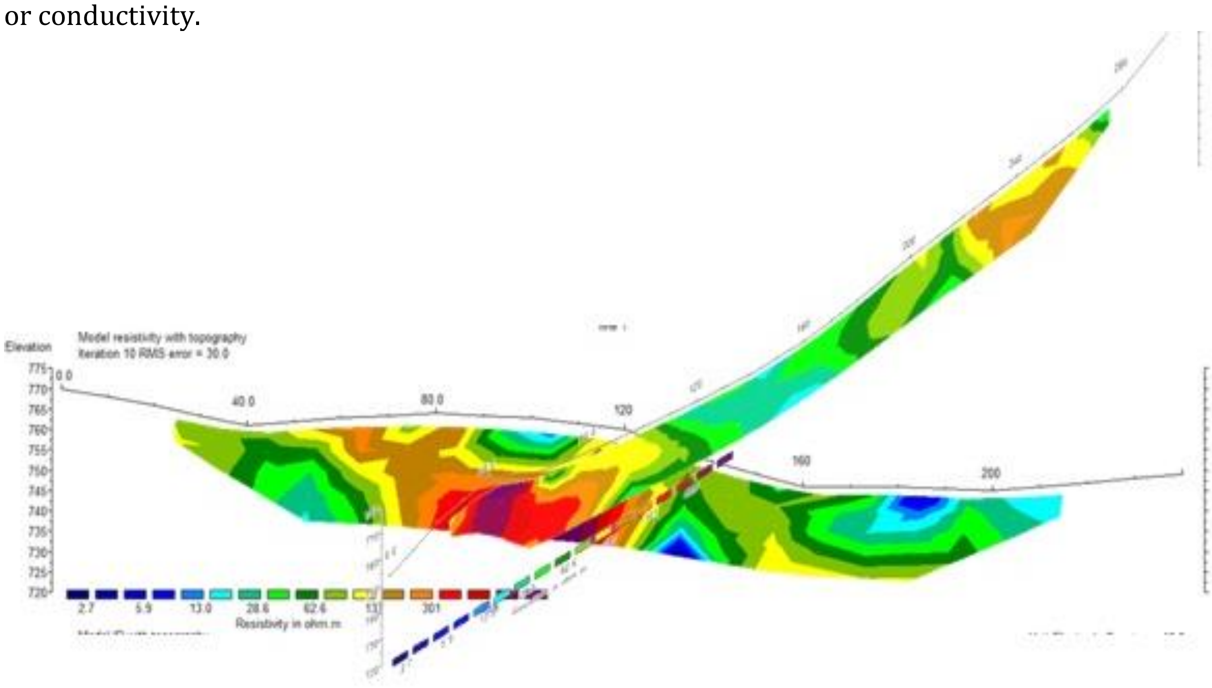

Figure 5. 2D Interpretation of crossing modeling in resistivity using induced polarisation method; upper part is line 2; and lower part is line 1.

The interpretation results of **Figure 6** show a positive correlation between the two intersecting lines. In this case, the use of induced polarisation method is very effective to ensure the location of minerals or other objects with high chargeability. Detecting chargeability in the induced polarisation (IP) method has several important benefits in geophysics and mineral exploration. Chargeability helps identify minerals that have the ability to store electrical charge, such as gold and copper sulphides. This is very useful in mineral exploration. In addition, chargeability provides information about the distribution of material in the subsurface, which helps in geological mapping and identification of potential mineralisation. On the other hand, the use of chargeability detection allows it to be used for environmental monitoring, such as detecting soil and water contaminants.

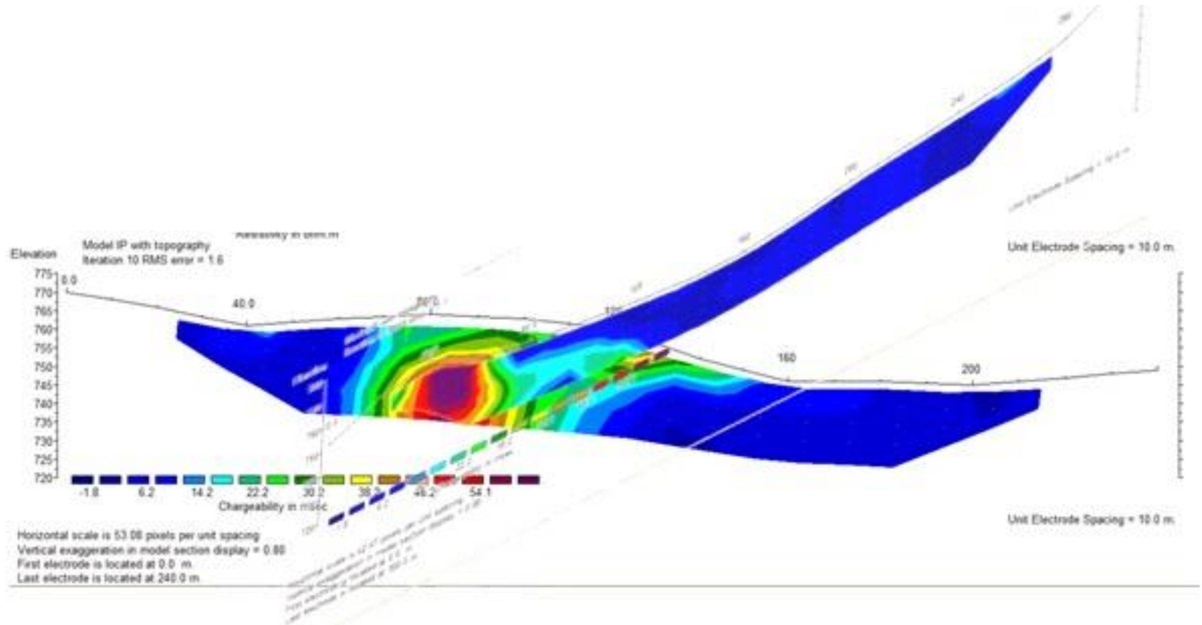

Figure 6. 2D Interpretation of crossing modeling in chargeability using induced polarisation method; upper part is line 2; and lower part is line 1. Data acquisition is carried out with 2 lines that cross each other, namely line 1 which leads east to west and line 2 which leads southwest-northeast, from these 2 lines a fairly high chargeabillity value is obtained between 54.2-64 msec which is found at x = 80-90 m on line 1 and x = 40-60 m, but has a fairly low resistivity, it is estimated that this area has a mineral differentiation zone. If the 2 lines are cross sectioned, there will be an alignment between the mineral zones on lines 1 and 2.

CONCLUSION

he study demonstrates the effectiveness of the Induced Polarization (IP) method in identifying the presence of minerals in the Pacitan region. High resistivity anomalies are located at a distance of 40 metres from the starting point of measurement with a depth of 2-20 metres and a diameter of about 40 metres. While the chargeability anomaly is located at a distance of 30 metres from the starting point with a depth of 4-24 metres and a diameter of about 30 metres. If observed from each, it can identify resistivity and chargeability anomalies very accurately. The 2-dimensional interpretation of crossing lines revealed distinct anomalies in resistivity and chargeability, which correlate with potential mineralization zones. The integration of IP data with geological maps and previous exploration data provided a comprehensive understanding of the subsurface mineral distribution. The findings highlight the potential of the IP method as a reliable and efficient tool for mineral exploration in geologically complex areas. Future research should focus on refining data processing techniques and integrating additional geophysical methods to enhance the accuracy and resolution of IP surveys.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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