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Exploration of the Cu-Pb-Zn deposit via using IP/Resistivity methods in Kavşut (Göksun-Kahramanmaraş)

Cihan Yalçın [*1], **Hurşit Canlı** [2], **Kıvanç Haznedaroğlu** [2], **Filiz Akbulut** [3]

[1]*Ministry of Industry and Technology, World Bank Project Implementation Unit, Ankara, Türkiye, cihan.yalcin@sanayi.gov.tr*
[2]*Haliç Mineral Exploration and Drilling, İstanbul, Türkiye, hursitcanli@gmail.com, gmhaznedaroglu@gmail.com*
[3]*Filizi Mühendislik, Ankara, Türkiye, akbulut@filizimuhendislik.com.tr*

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Abstract

In the domain of mineral exploration, the identification and characterization of economically viable ore deposits are fundamental challenges. Copper (Cu), lead (Pb), and zinc (Zn) deposits play a crucial role in global metal supply chains, and their exploration demands innovative and reliable methodologies. In this scientific article, we present an inclusive study on the exploration of Cu-Pb-Zn deposits using the induced polarization (IP) and resistivity methods. By combining these geophysical techniques, we aim to enhance the accuracy and efficiency of mineral resource assessment, ultimately contributing to sustainable mining practices and resource management. Türkiye, with its tectonic structure, encompasses significant orogenic belts, and notable ore deposits are found along the well-known Tethys metallogenic belt. Cu-Zn-Pb (polymetallic) mineralization can be found in various areas along this tectonic belt. One such occurrence of polymetallic enrichment is observed southeast of Kavşut (Göksun, Kahramanmaraş-Türkiye), which is also situated within the Tethys metallogenic belt. In this region, the Goksun ophiolites form the basement, overlain by the Malatya Metamorphites with a tectonic contact. The mineralization is predominantly observed in fracture cracks and karstic gaps within carbonate rocks. To investigate the geometry and distribution of this mineralization underground, IP/Resistivity studies were conducted. The results indicate that the sulfide mineralization exhibit a high rechargeability character. Cross-sections, two-dimensional level maps, and 3D maps were generated based on the electrical data acquired, enabling effective planning and coordination for mining operations in the area. This visual information proves invaluable for the mining activities conducted in the region.

1. Introduction

The geological community has long been actively seeking reliable methods for detecting and evaluating mineral deposits. Traditional techniques such as geological mapping and drilling have limitations in terms of coverage, cost, and potential environmental impact. Consequently, geophysical methods have garnered significant attention as valuable tools for mineral exploration. Among these methods, induced polarization (IP) and resistivity techniques have demonstrated their effectiveness in identifying and characterizing mineral deposits below the Earth's surface.

The exploration of Cu-Pb-Zn ore systems is of great importance due to their economic value and widespread occurrence. Copper, lead, and zinc are essential elements used in various industries including electronics, construction, and transportation. Therefore, the development of efficient techniques for locating and assessing these deposits is crucial to meet global demand and optimize the utilization of resources.

Electrical methods, which have been in use since the 1920s and have undergone significant advancements in recent years, have proven to be highly valuable in the exploration of both metallic and non-metallic mineral deposits [1-2].

Electrical resistivity tomography is widely employed for characterizing subsurface structures and understanding geological settings [3-4]. The induced polarization (IP) technique can provide valuable information about small conductive rocks that may no longer exist in the subsurface. Resistivity models derived from both resistivity and IP studies can also help identify the presence of sulfur in minerals, mineral deposits, and soils [5].

In the exploration of sulfide mineral deposits, such as Cu-Pb-Zn deposits, combined geophysical surveys involving electrical and electromagnetic methods have been widely utilized [6-7]. Electrical resistivity and induced polarization (IP) are two significant geophysical techniques employed to map the location of sulfide minerals [8-9]. Geological structures associated with sulfide mineralization typically exhibit low resistivity and high chargeability responses [10-11]. High chargeability and high resistivity anomalies have also been linked to the presence of disseminated sulfides [12]. These geophysical methods have been successfully applied in mineral exploration, and numerous studies by various authors have utilized resistivity and induced polarization techniques in Cu-Pb-Zn exploration [13-14].

The Tethyan Eurasian Metallogenic Belt is a major metallogenic belt that extends from Western Europe to Anatolia and Iran [15-16]. It is home to a wide variety of metallic mineral deposits, including lead, zinc, copper, gold, and silver. The Göksun (Kahramanmaraş) region is located in the heart of this belt and hosts some of the most important metallic deposits in Türkiye.

In this study, geophysical investigations were conducted to assess the ore potential of the Cu-Pb-Zn deposit located in the southeast of Kavşut (Göksun, Kahramanmaraş, Türkiye). The aim of the study was to provide a regional-scale assessment and recommendations regarding the suitability of the area for polymetallic (Cu-Pb-Zn) mineral formation and exploration. Furthermore, the study aimed to identify target areas for exploration and select appropriate exploration methods. The research combined a literature review with observational geological data and subsequently applied geophysical methods to support the findings.

2. Material and Method

The IP/Resistivity method is based on the principle that certain rocks behave like capacitors, retaining a portion of the electric current for a specific duration after the current is turned off. The distribution of metallic mineral particles within rocks leads to IP anomalies. Increasing concentrations of polarizable sulfide minerals result in higher chargeability values, indicating a direct relationship between mineralization and chargeability.

True chargeability, denoted as (M"), is defined as the ratio of the voltage measured after the current is discontinued to the voltage measured during the current supply. It is expressed in millivolts per volt (mV/V) and typically ranges between 0 and 1000 mV/V.

In resistivity (electrical resistivity) method applications, an electric current is injected into the ground using a stainless metal-steel electrode driven into the ground. The voltage difference within the ground is then measured using two electrodes placed at different locations. The applied current is measured in amperes (usually milliamperes), and the measured voltage is recorded in volts (usually millivolts). Using these values and the geometric factor K (array factor) of the electrode array employed, the apparent resistivity (in ohm-m) is calculated for the specific measurement location. The calculated value is assigned beneath the midpoint of the electrode array system.

In the study area, an AGI brand, 8-channel, 84-electrode resistivity, and IP measurement device with 84 electrodes was utilized. The Dipole-Dipole Gradient method was employed, and a total of 32 profiles were generated with electrode spacing ranging between 20-10-7 meters. The collected data were analyzed using the EarthImager 2D evaluation program. For this study, data from 6 profiles are presented.

Following the geophysical measurements, two-dimensional level maps were prepared to enhance the understanding of the region's geological structure. Finally, the 2D maps obtained from the geophysical studies were combined and merged to create a 3D-level map. This 3D map allowed for the modeling of karstic voids in both the X and Y directions. This was done considering the potential presence of ore deposits within these karstic voids. By incorporating the information from the geophysical surveys into the 3D map, it was possible to gain a better understanding of the spatial distribution and characteristics of the karstic voids and their potential as ore-bearing structures.

The study area encompasses the southeastern part of Kavşut in the Göksun-Kahramanmaraş region. The specific point locations and profiles of the geophysical investigations conducted in this area are depicted in Figure 1 using Google Earth.

In the elevation color contour map of the study area (Figure 2), dark blue and light blue tones predominantly represent low-lying or flat areas, while green, yellow, orange, red, and white tones indicate steep slopes and high elevations such as hills or mountains. The geophysical surveys were conducted at an average elevation of 1700-1900 meters, as indicated on the map (Figure 2) and the points represent the coordinates of the IP/Resistivity of the study area.

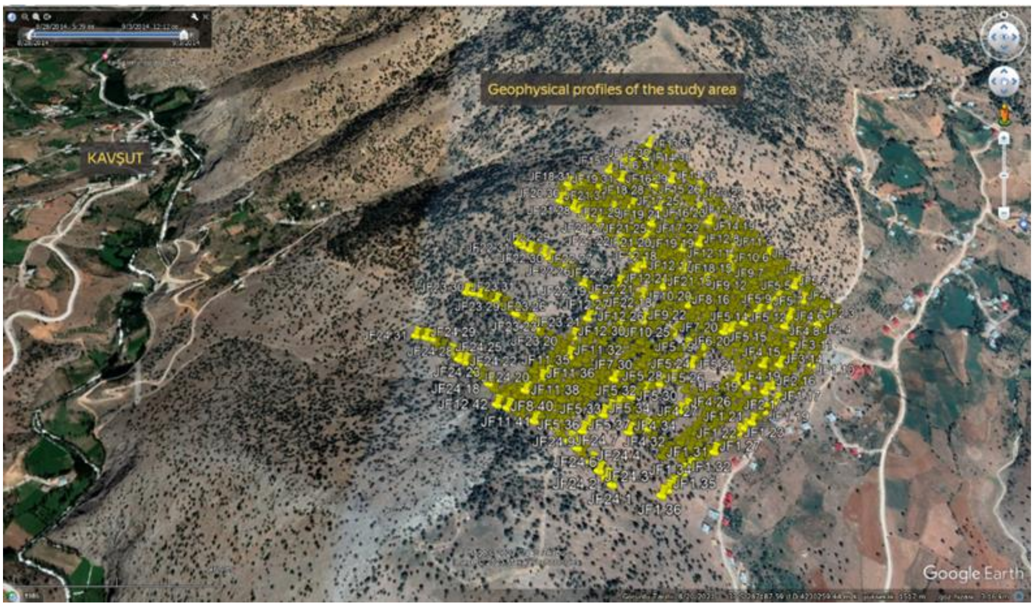

Figure 1. IP / Resistivity coordinates of the study area.

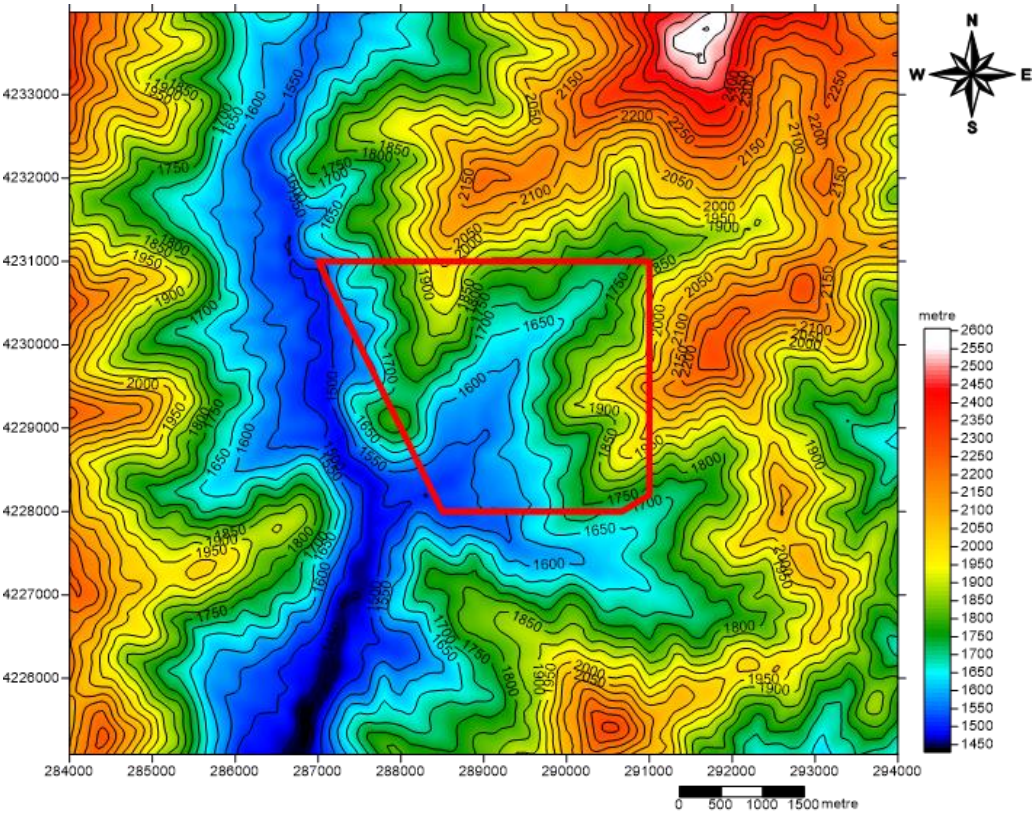

Figure 2. Color, contour (topography) map of the study area and its surroundings with elevation data, and Geophysical profiles of the study area.

2.1. Geological framework and mineralization

The study area is situated in the western part of the Eastern Taurus Mountains, which is part of the larger Taurus orogenic belt. This region is characterized by the presence of allochthonous (foreign) and autochthonous (native) rock units of various ages, bound together by tectonic contacts. The Göksun ophiolitic rocks are located at the base of the region, overlain by the Malatya metamorphics with a tectonic contact [17-18]. Additionally, the Esence granitoids intrude on both of these units [17]. The entire geological sequence is covered by Tertiary-aged sediments with angular discordance.

Geochemical studies conducted in and around the region revealed various anomalies [19]. Tüfekçi and Dumanlılar [20] reported mineralization in alteration zones and karstic gaps. The ore paragenesis consisted of chalcopyrite, sphalerite, galenite, pyrite, malachite, and azurite.

3. IP-Resistivity Applications

The resistivity and chargeability data were inverted to obtain a more realistic geologic representation. The results show that there are high resistivity inclusions at 60 meters, 160 meters, 240 meters, 320 meters, and 580 meters along the 1st profile (Figure 3). These inclusions are thought to be karstic sinkholes. High chargeability inclusions are also observed at 60 meters, 280 meters, 380 meters, and 460 meters. These inclusions are thought to be probable sulfide ores.

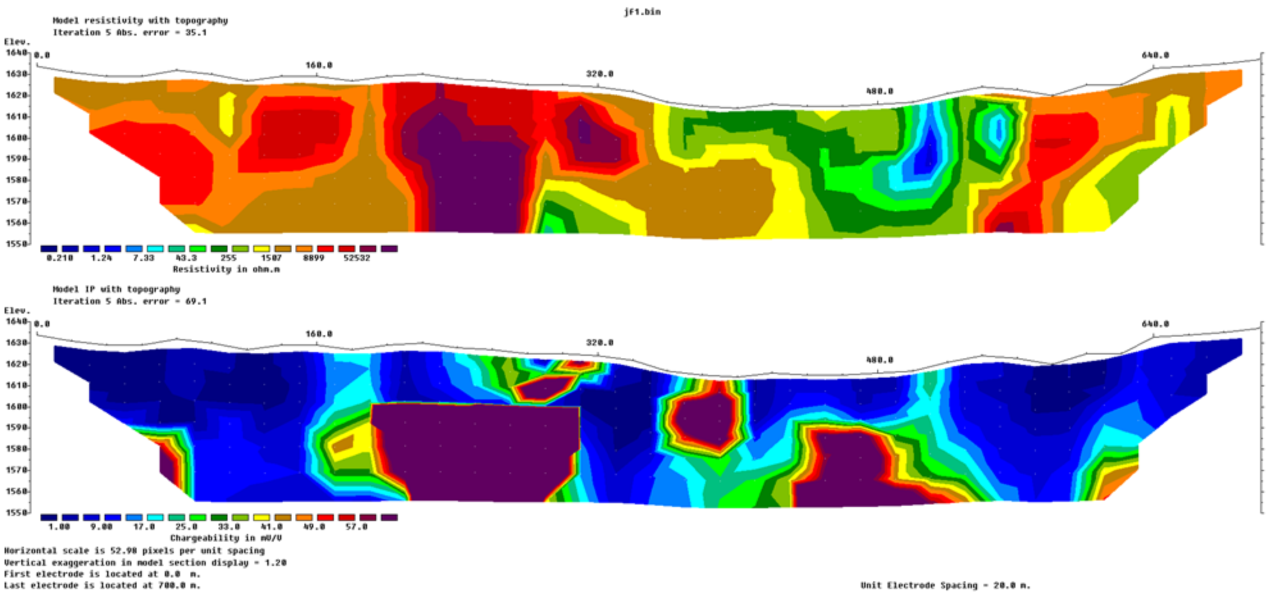

Figure 3. The inverted resistivity and IP sections of the 1st profile.

Along the 2nd profile, high resistivity inclusions are found to be more widespread at 160 meters and 220 meters (Figure 4). This is due to the development of karstic gaps and fracture-crack system below this profile. The chargeability is not as widespread as the high resistivity, but it is concentrated in a narrower area at 270, 370 and 480 meters.

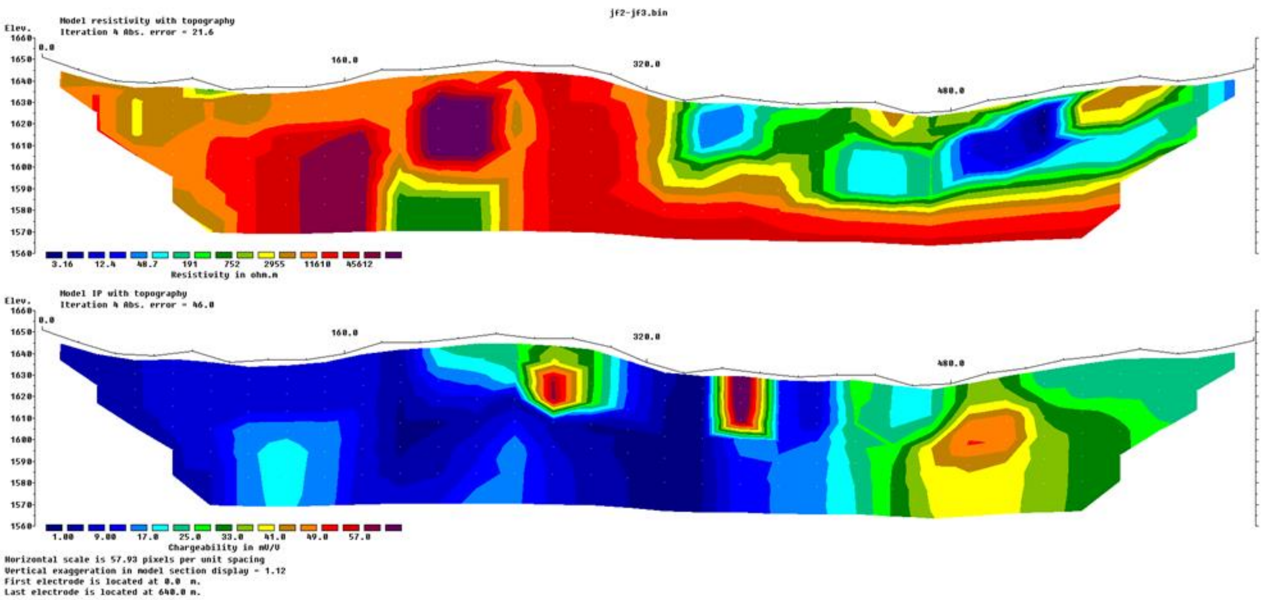

Figure 4. The inverted resistivity and IP sections of the 2nd profile.

The results of this study suggest that there are karstic sinkholes and sulphide ores in the area. Further investigation is needed to confirm these findings.

Here are some additional points to note:

-The warm red-purple colors in the graphs represent high chargeability and resistivity values, while the cool colors such as green and blue represent low values.

-The important targets in this study are the areas showing high resistivity (karstic sinkholes).
-Normal chargeability values were observed in most of the profiles measured in the field.
-Probable sulphide ores are thought to be the cause of the high chargeability values obtained.

On the third profile (Figure 5), there are notable observations regarding resistivity and chargeability. High resistivity inclusions are observed at depths of 60 meters, 140 meters, 220 meters, and 300 meters. These high resistivity zones indicate the presence of less conductive or resistive materials compared to the surrounding rocks.

Additionally, high chargeability anomalies are observed at depths of 280 meters, 370 meters, and 480 meters. These high chargeability values suggest the presence of materials with enhanced polarizability, which can be indicative of the presence of mineralization or potential ore bodies.

These observations of high resistivity and high chargeability along the third profile provide valuable insights into the subsurface characteristics and the potential presence of mineral deposits in the study area.

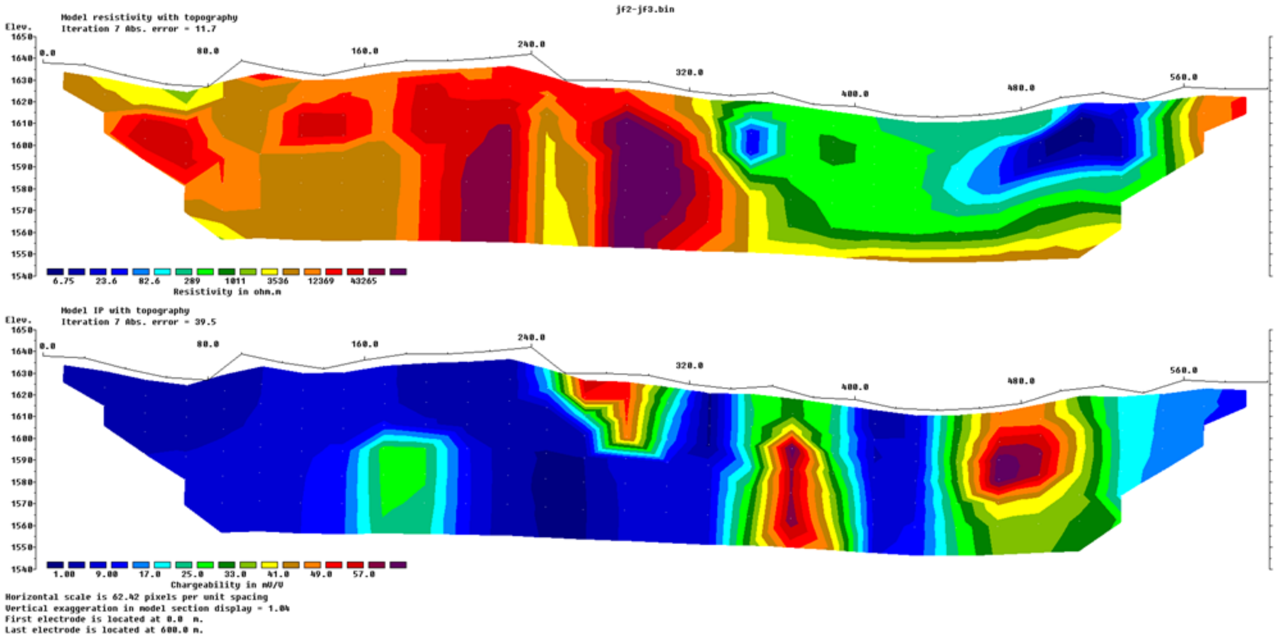

Figure 5. The inverted resistivity and IP sections of the 3rd profile.

On the fourth profile (Figure 6), significant observations can be made regarding resistivity and chargeability. High resistivity inclusions are detected at various depths, particularly at 160 meters, indicating the presence of less conductive or resistive materials in those areas. Additionally, a smaller inclusion is observed at 280 meters.

Furthermore, high rechargeability values are observed at depths of 190 meters, 360 meters, and 620 meters. These elevated chargeability values suggest the presence of materials with enhanced polarizability, which could be associated with mineralization or potential ore deposits.

These findings along the fourth profile provide valuable information about the subsurface characteristics and potential mineralization in the study area.

On the fifth profile (Figure 7), notable observations can be made regarding resistivity and chargeability. High resistivity inclusions are observed at depths of 180 meters and 400 meters, indicating the presence of less conductive or resistive materials in those regions. Additionally, smaller inclusions are observed at a shallower depth of 40 meters.

Moreover, high chargeability inclusions are observed at depths of 100 meters, 160 meters, 240 meters, 380 meters, 620 meters, and 680 meters. These elevated chargeability values suggest the presence of materials with enhanced polarizability, which may be associated with mineralization or potential ore deposits.

On the sixth profile (Figure 8), significant observations can be made regarding resistivity and chargeability. High resistivity inclusions are detected at depths of 140 meters and 540 meters, indicating the presence of less conductive or resistive materials in those areas.

Furthermore, high rechargeability values are observed at depths of 140 meters, 260 meters, 440 meters, and 620 meters. These elevated chargeability values suggest the presence of materials with enhanced polarizability, which could be associated with mineralization or potential ore deposits.

The preparation of visual cross-sections and maps can provide significant advantages for planning and coordination.

The two-dimensional level maps that you mentioned are a valuable tool for visualizing the subsurface geology. These maps can help to identify areas of potential mineralization and to plan future drilling campaigns.

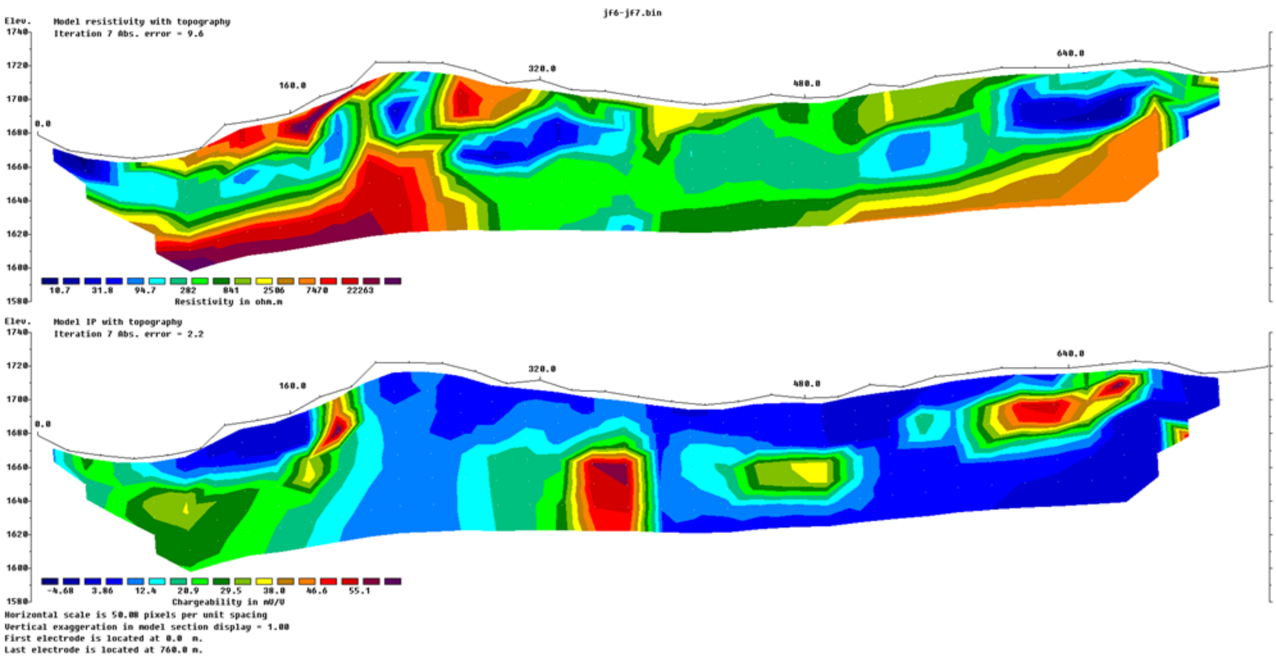

Figure 6. The inverted resistivity and IP sections of the 4th profile.

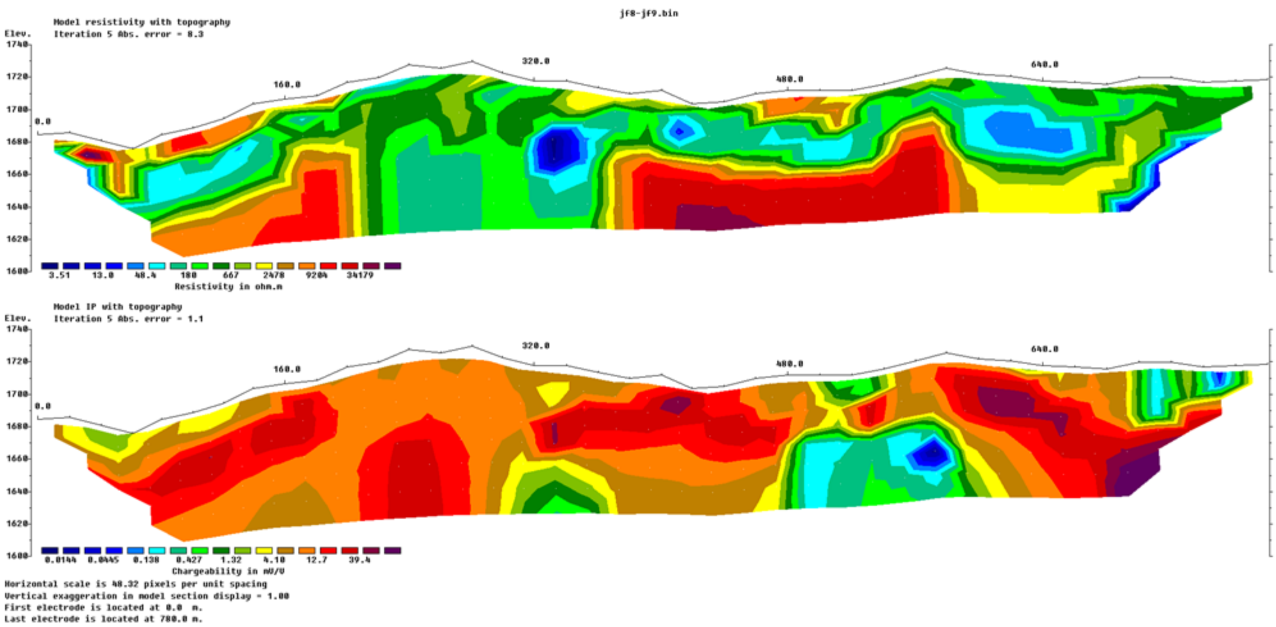

Figure 7. The inverted resistivity and IP sections of the 5th profile.

The preparation of these maps requires a careful evaluation of the resistivity and chargeability data. The data from the different profiles must be combined and interpreted in order to create a comprehensive picture of the subsurface geology.

The preparation of visual cross-sections and maps can be a time-consuming and challenging process. However, the benefits of these tools can be significant. By providing a clear and concise visualization of the subsurface geology, these tools can help to improve the efficiency and effectiveness of mineral exploration campaigns.

Two-dimensional level maps were generated by integrating and analyzing the data from various profiles, including the profiles mentioned earlier. These maps provide visual representations of different elevation ranges, offering insights into subsurface geology.

Figure 9 represents the 5–10-meter elevation range, highlighting the geological features and anomalies within this depth interval. It provides a detailed view of the subsurface geology in this specific range.

Figure 10 displays the 15–22-meter elevation range, providing further information about the geological characteristics within this depth interval. This map offers a comprehensive visualization of the subsurface features in this specific range.

Figure 11 represents the 50–61-meter elevation range, focusing on the geological attributes and anomalies present within this depth interval. It provides a detailed depiction of the subsurface geology within this specific range.

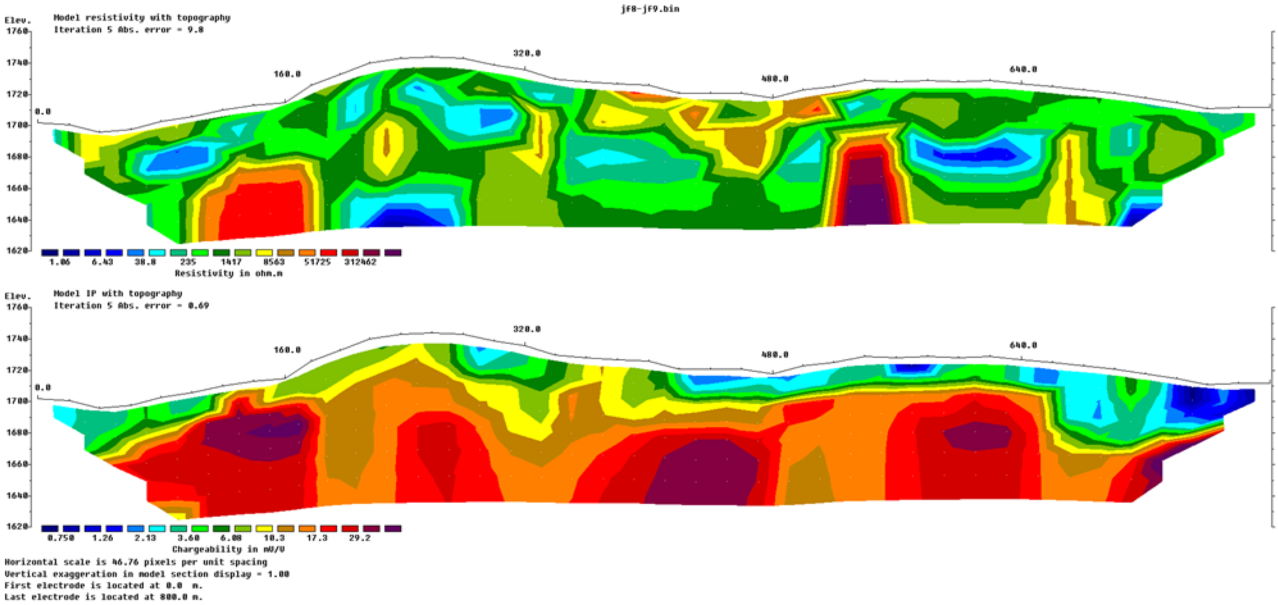

Figure 8. The inverted resistivity and IP sections of the 6th profile.

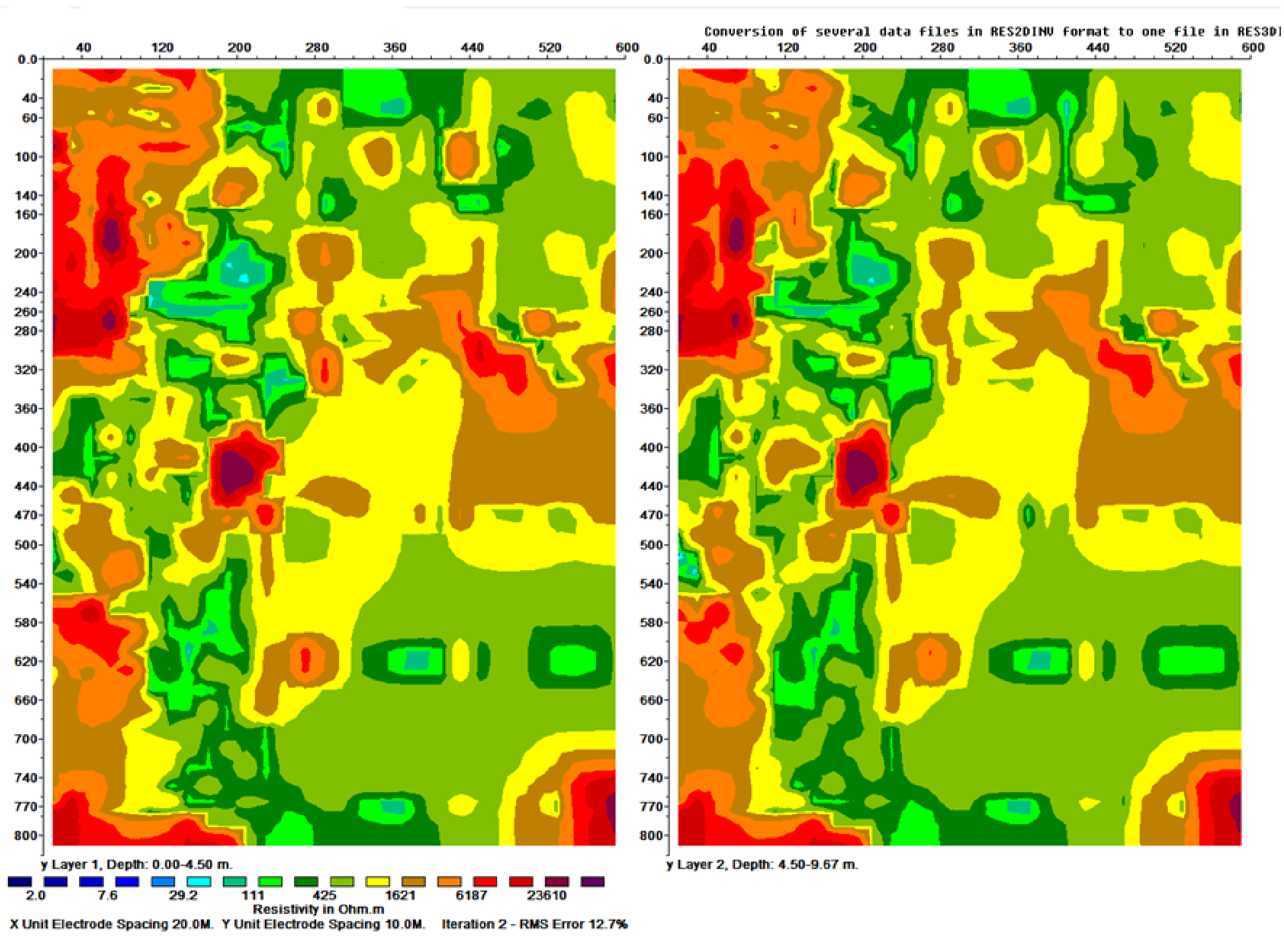

Figure 9. Two-dimensional level maps (Resistivity) of 5–10-meter range.

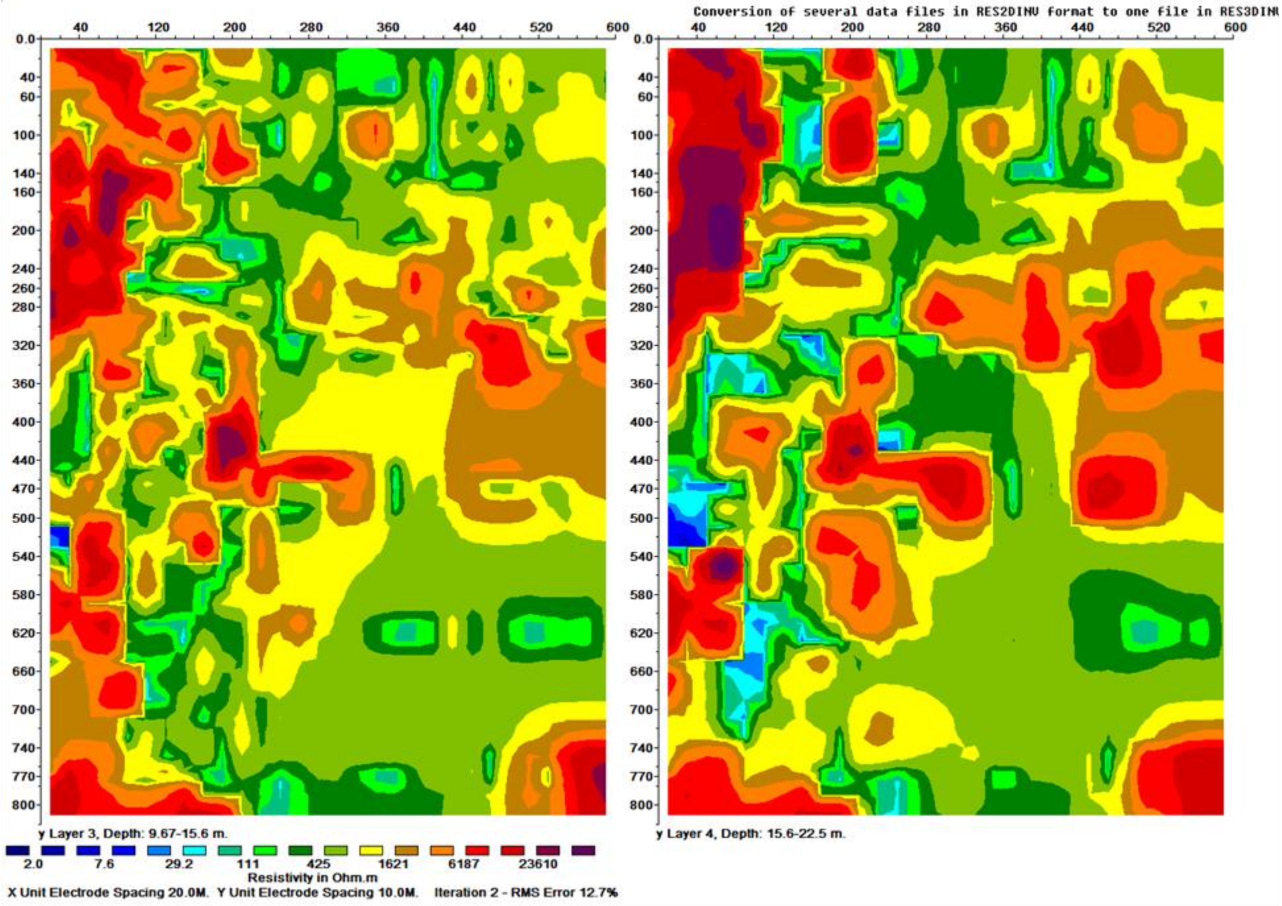

Figure 10. Two-dimensional level maps (Resistivity) of 15–22-meter range.

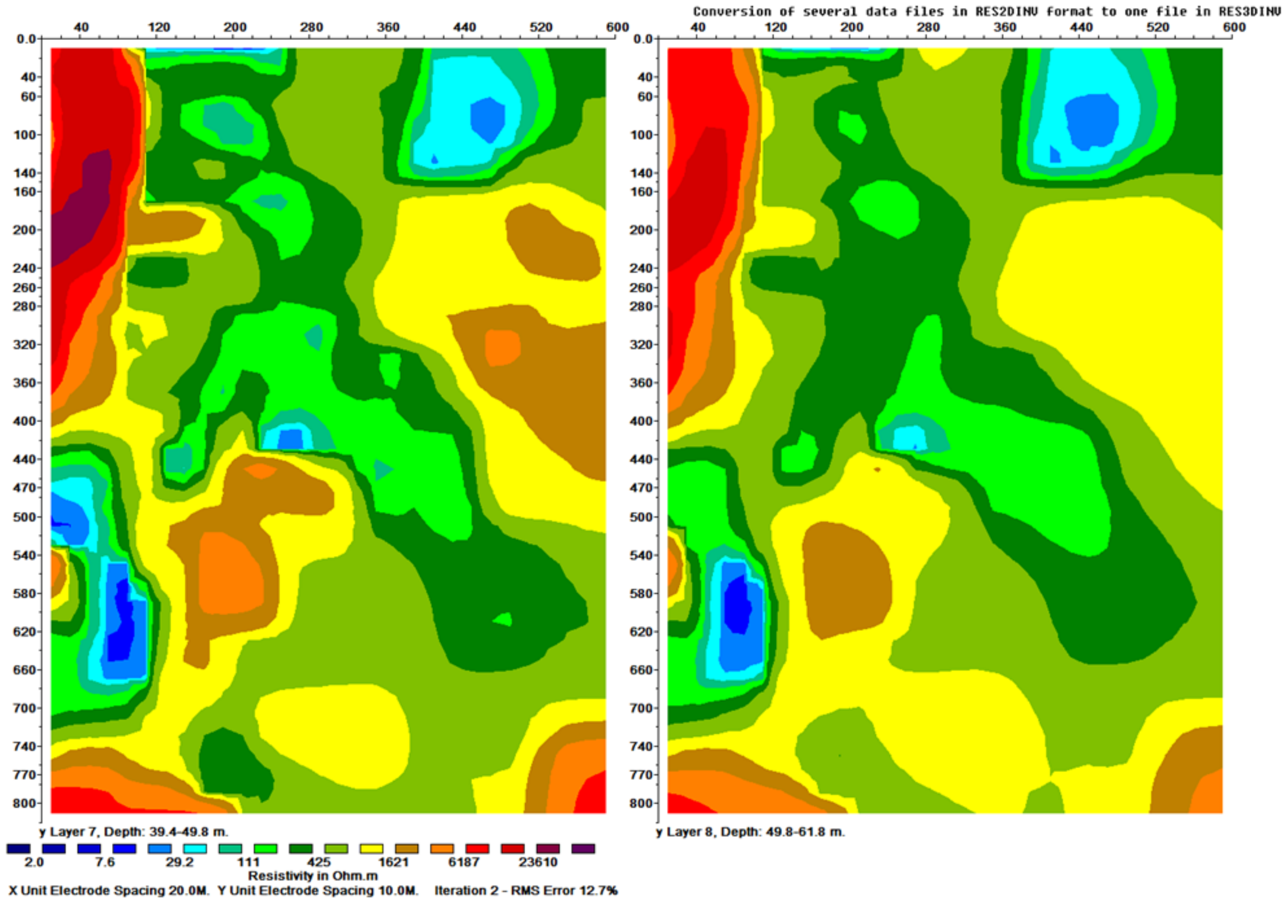

Figure 11. Two-dimensional level maps (Resistivity) of 50–61-meter range.

The IP / Resistivity cross-sections used in the study area were combined to construct the level maps. Cross sections in the X, Y, and Z directions (depth) were collected at specific meters, and the resulting data were integrated to produce a three-dimensional map (Figure 12). As a block diagram displaying all the data at once, this map was created.

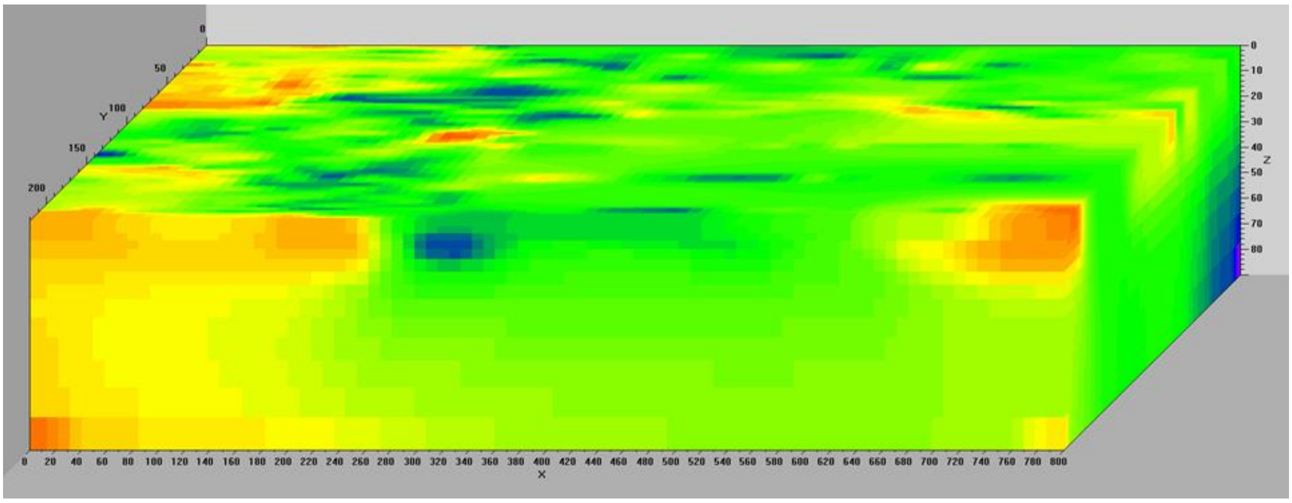

Figure 12. 3D level map of the study area.

The hydrothermal processes associated with Pb-Zn mineralization can result in various types of ore deposition within a mine site. These include the settling of minerals in fracture zones, the precipitation of minerals in the surrounding rocks due to orogeny, and the deposition resulting from the melting of adjacent rocks (cartization). Among these processes, karstic voids have been identified as significant areas for ore concentration and are often targeted during the production process. To better understand and model these karstic voids beneath the ground, Figure 13 and Figure 14 schematize potential voids in the X and Y directions, respectively. These models are based on geophysical data and aim to represent potential ore zones associated with these karstic voids. By incorporating geophysical information and interpreting the data, these models can assist in identifying areas of interest for further exploration and production efforts.

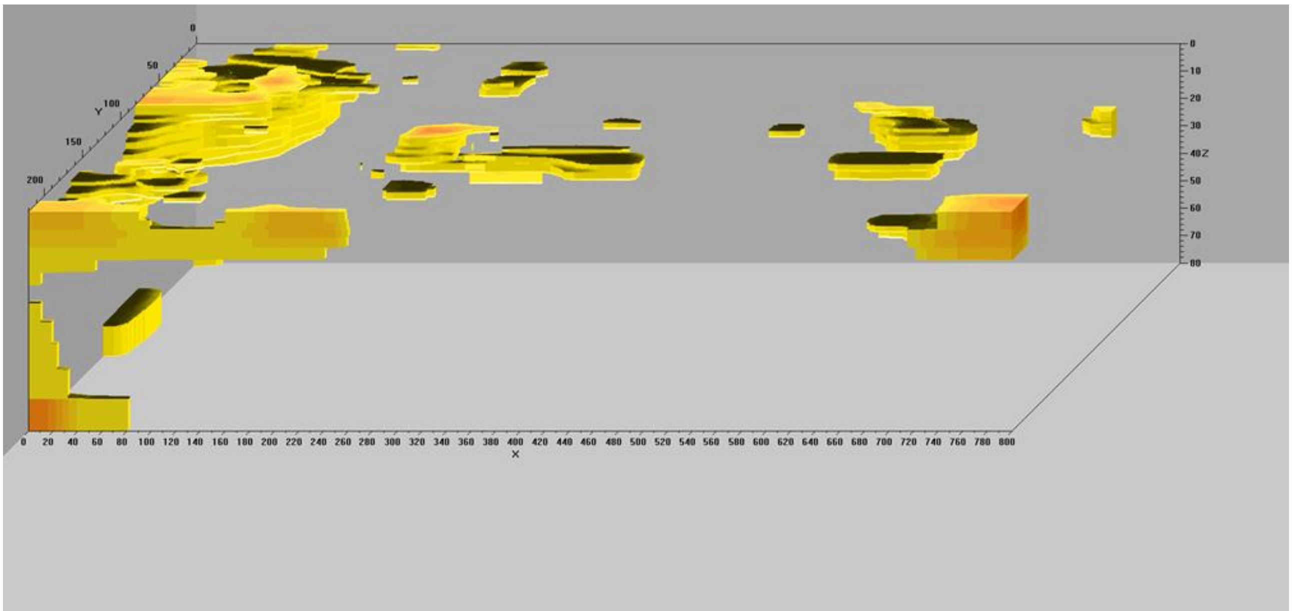

Figure 13. 3D modeling of possible karstic cavities in the X direction.

It is important to note that these models are based on interpretations and assumptions derived from the available geophysical data. Further geological and geophysical investigations, including drilling and sampling, would be necessary to confirm the presence and extent of the karstic voids and associated mineralization.

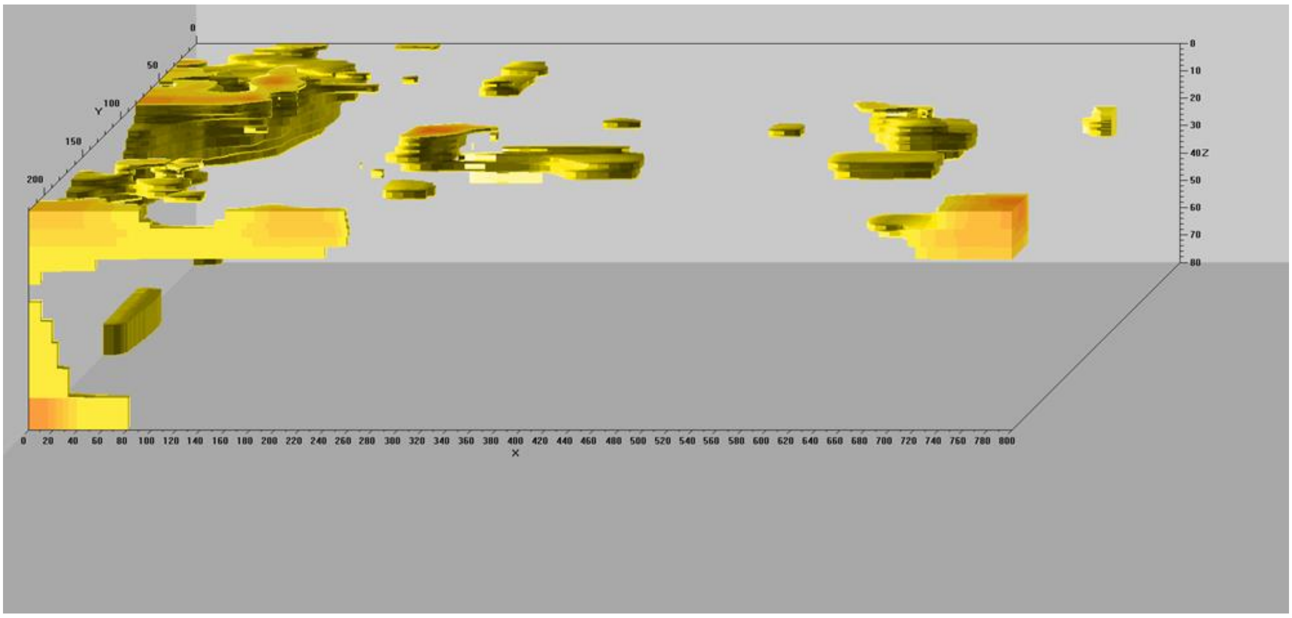

Figure 14. 3D modeling of possible karstic cavities in the Y direction.

4. Discussion

The exploration and confirmation of sulfide deposit occurrences have been effectively carried out using geophysical methods such as resistivity, induced polarization (IP), and self-potential (SP) methods [21-22].

An integrated geoelectrical study utilizing electrical resistivity tomography (ERT) and induced polarization (IP) has been conducted in Umuobuna, Uburu, Ohaozara local government area, southeastern Nigeria. The purpose of this study was to identify and delineate potential zones of Lead-Zinc mineralization in the area [23].

By combining ERT and IP data, the geoelectrical study in Umuobuna aimed to map and delineate areas with potential Lead-Zinc mineralization [23]. These geophysical techniques can help identify areas of interest for further exploration, guide drilling campaigns, and assist in mineral resource assessment.

The integration of ERT and IP data allows for a more comprehensive understanding of the subsurface geology and potential mineralization in the study area. This information can be valuable for mineral exploration and resource evaluation in the southeastern region of Nigeria [23].

The study in Umuobuna is just one example of the many ways that geophysical methods are being used to explore mineral deposits. In recent years, there has been a growing interest in using geophysics to map and characterize mineralization zones, and this trend is likely to continue in the years to come.

In a separate study conducted in the Bolkardağı region of the Central Taurus, geophysical measurements were performed [24] in bauxite-bearing limestone formations that exhibit characteristics suitable for the karst-type model. The aim of the study was to identify potential areas for bauxite mineralization using resistivity and induced polarization (IP) measurements.

The results of the study indicated that areas with low resistivity and high chargeability values were associated with potential bauxite mineralization. This correlation suggests that the combination of IP and resistivity measurements can provide valuable information for locating metallic mineral deposits [24].

The low resistivity values observed in the geophysical measurements can be attributed to the presence of conductive minerals or fluids associated with the bauxite mineralization. On the other hand, the high chargeability values indicate the polarizability of rocks and minerals in the subsurface, which can be indicative of the presence of metallic minerals.

In this case, the combination of resistivity and IP measurements was able to identify potential areas for bauxite mineralization. This is because low resistivity and high chargeability values are typically associated with bauxite deposits.

Yalçın and Canlı's [25] application of these geophysical methods (IP/Resistivity) in the YahyalI (Kayseri-Turkey) region would have most likely aimed to contribute to the understanding of Pb-Zn mineralizations in the area, assisting in resource evaluation and sustainable mining practices. Such studies are critical to the efficient use of mineral resources and the promotion of responsible mining practices.

The use of compatible IP and resistivity values is a powerful tool for mineral exploration, and it is being used in many different parts of the world. As the technology for geophysical surveys continues to improve, we can expect to see even more accurate and detailed maps of the subsurface geology. This will lead to a better understanding of the distribution of mineral deposits, and ultimately to more successful exploration and mining operations. As the technology for geophysical surveys continues to improve, we can expect to see even more accurate and detailed maps of the subsurface geology. This will lead to a better understanding of the distribution of mineral deposits, and ultimately to more successful exploration and mining operations.

5. Conclusion

The high resistivity zones suggest the presence of less conductive or resistive materials compared to the surrounding rocks. These materials could be karstic sinkholes, which are typically composed of limestone or dolomite. Karstic sinkholes are often associated with mineralization, as they can provide a pathway for fluids to flow through the subsurface and concentrate minerals.

The high chargeability anomalies suggest the presence of materials with enhanced polarizability. This means that these materials are more likely to store and release electrical charge than the surrounding rocks. This property is often associated with sulfide minerals, such as pyrite and chalcopyrite. Sulfide minerals are often associated with economic mineral deposits, such as copper, gold, and silver.

The combination of high resistivity and high chargeability is a strong indicator of the potential presence of mineral deposits. The observations along the third profile suggest that there is a potential for mineralization in the area. Further investigation is needed to confirm these findings and to determine the extent of the mineralization.

These two-dimensional level maps enable geologists and exploration teams to visually interpret and analyze the subsurface geology at different elevation intervals. They play a crucial role in identifying potential mineralization zones and assisting in planning and coordination efforts for further exploration activities.

The level maps were created by combining the IP / Resistivity cross-sections applied in the study area. The cross-sections were taken at certain meters in X, Y, and Z directions (depth), and these data were combined to create a three-dimensional map. This map was prepared as a block diagram showing all the data together.

The three-dimensional map is a valuable tool for visualizing subsurface geology in three dimensions. This map can help to identify areas of potential mineralization and to plan future drilling campaigns.

The preparation of the three-dimensional map is a complex process. However, the benefits of this tool can be significant. By providing a clear and concise visualization of the subsurface geology in three dimensions, this tool can help to improve the efficiency and effectiveness of mineral exploration campaigns.

Here are some of the key benefits of using a three-dimensional map:

-It can help to identify areas of potential mineralization that would not be visible in two-dimensional maps.

-It can help to plan future drilling campaigns more effectively.

-It can help to visualize the relationship between different geological features.

-It can help to communicate the results of a mineral exploration campaign to stakeholders.

The Pb-Zn mineralization produced at the mine site can take different forms, depending on the hydrothermal processes. It can be found in fracture zones, in the side rock, or in melted side rock (karstification). Karstic voids are important ore areas because the ore is deposited in these voids during the production process. To model these voids below the ground, possible karstic voids in the X and Y directions are shown in Figure 13 and Figure 14. These voids, which were modeled using geophysical data, represent potential ore zones.

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Author contributions

Cihan Yalçın: Writing-Reviewing and Editing, Geology, Methodology, **Hurşit Canlı:** Editing, IP/Resistivity. **Kıvanç Haznedaroğlu:** Geophysics, **Filiz Akbulut:** Geology.

Conflicts of interest

The authors declare no conflicts of interest.

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