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Research Paper

Geophysical Modeling of Electrical Resistivity and Induced Polarization Data to Determine the Potential of Gold Mineralization in East Azerbaijan

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Abstract: The exploratory region, covering an area of 20 square kilometers, is located in the northern part of East Azerbaijan. This region is characterized by diverse geological formations such as marl, sandstone, limestone, sedimentary volcanic rocks, tuff, and sheared tuff from the Cretaceous period, quartzdiorite and granite intrusive masses from the Oligocene period, and quaternary basalts. A geoelectrical survey was conducted using the pole-dipole method along 9 parallel profiles, each 200 meters in length, perpendicular to a silica dyke visible in some parts of the region. Following data acquisition and processing, 2D inversion modelling of electrical resistivity and induced polarization data was carried out, and the inversion sections were displayed in both 2D and 3D formats. By having drilling information aligned with the geoelectrical profiles, the correlation between gold grade, electrical resistivity, and induced polarization was examined. The results of this research demonstrated that the geoelectrical method can be useful for exploring low-sulphide epithermal gold deposits. Additionally, a 3D representation of the inversion modelling results for all 9 profiles was prepared. Finally, by analyzing and comparing anomalies in electrical resistivity and induced polarization and utilizing drilling data, it was found that the gold veins in the exploratory region exhibit relatively predictable behavior in terms of geophysical parameters. The sulphide-rich sections of the gold vein exhibited low electrical resistivity and high induced polarization, while sections of the vein with lower sulphide content, located within the silica, displayed higher resistivity and polarization.

Keywords: Electrical resistivity, Induced polarization, Inverse modeling, Geological interpretation, Gold deposit.

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INTRODUCTION

Geophysics has evolved into a well-established discipline capable of precisely assessing various physical properties of the Earth, including its electrical characteristics. Among the key techniques utilized in mineral exploration are geoelectrical methods, particularly resistivity and induced polarization (IP), with the IP method being especially prevalent in the search for metallic and sulfide deposits. The inception of geoelectrical studies in Iran can be traced back to 1946, and these methods have since been employed across nearly all identified metallic deposits in the country, encompassing polymetallic and gold deposits. By synthesizing the acquired geoelectrical data with geological, mineralization, alteration, and geochemical insights, optimal drilling sites can be identified [1]. Geoelectrical methods are recognized as effective techniques for the identification of metallic minerals such as pyrite, chalcopyrite, and pyrrhotite. Additionally, in the context of gold exploration within the Alta Floresta Gold Province in Mato Grosso, Brazil, an integrated approach combining magnetic and geoelectrical data was utilized to pinpoint promising gold exploration targets. This multifaceted interpretation of geophysical data has the potential to greatly advance the understanding and effectiveness of gold exploration initiatives [2]. Gold is an exceptionally valuable metal that finds applications across multiple sectors, such as jewellery, electronics, and finance. It functions not only as a store of value and a safeguard against inflation but also as collateral for loans. Recently, there has been a surge in demand for gold in developing nations, where it is viewed as a tool for wealth enhancement and economic advancement. This growing interest has prompted a rise in global gold exploration and extraction efforts, alongside the innovation of new technologies aimed at improving the efficiency and sustainability of these processes [3].

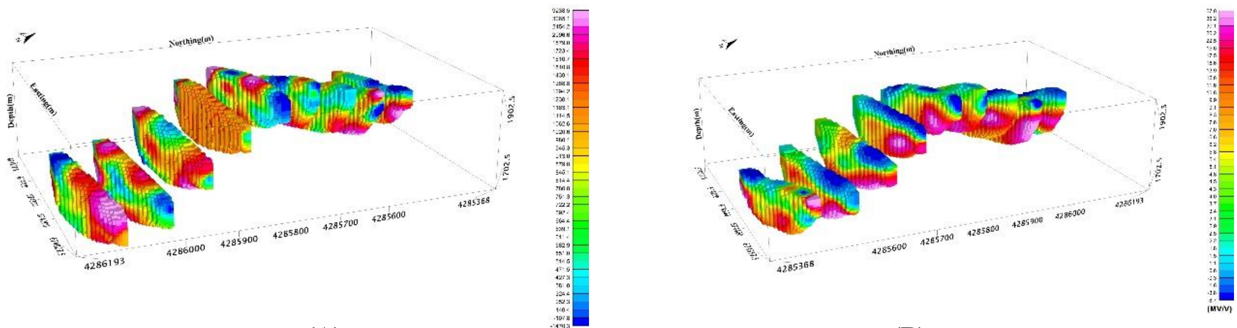
The northern region of East Azerbaijan province exhibits significant lithological diversity, featuring various geological units such as marl, sandstone, limestone, and volcano sedimentary rocks. This area also contains aplite veins and silica veins, both characterized by white coloration and iron oxide staining, which indicate the presence of iron oxide and sulfide mineralization. Notably, it is identified as a gold mineralization zone associated with low-sulfidation epithermal deposits, suggesting that gold formation occurs predominantly in low-temperature, low-sulfidation conditions. The study employed a range of tools to develop comprehensive geoelectrical and geological models of gold deposits in the region. These models were assessed using drilling data, and significant correlations between the geophysical models and findings from other exploration efforts were analyzed. Ultimately, the objective was to enhance the accuracy and utility of geological models for generating gold maps in the investigated area.

MATERIAL AND METHODS

In this research, nine geoelectrical profiles were executed in a NE-SW orientation to gather resistivity and electrical chargeability data. This was achieved using a pole-dipole array with a length of 200 meters and an electrode spacing of 10 meters across 16 intervals per reading in NE Azerbaijan. The data collected often includes various noise types, making direct interpretation unreliable for accurately understanding subsurface layer behavior. Consequently, it is essential to establish the connection between field data and the physical properties of the earth, which involves modelling the data to interpret subsurface behavior effectively. In numerical modelling, physical relationships are articulated through differential and integral equations, and solving these equations enables the determination of parameters and the distribution of the model's physical properties [4]. Geophysicists have historically acknowledged the significance of data inversion; however, past limitations in computational resources restricted even the most advanced inversion algorithms to estimating only a few parameters. As a result, subsurface structures were typically represented as multilayered or simplistic prismatic forms, with parameters fine-tuned to align the modelled data with observed results. Given the often-intricate geometries of geological formations, such simplifications in numerical inversion modelling frequently led to misleading interpretations. In recent years, substantial improvements in computational capabilities and inversion methodologies have facilitated the creation of more accurate inversion models, underscoring the critical role of geophysics in addressing real-world challenges [5]. In this study, the drilling of 11 exploratory boreholes across the profiles has enabled the analysis of geophysical modelling in conjunction with assay data, leading to the discovery of notable correlations. The 3D visualization of resistivity and chargeability data, paired with gold assay charts, has effectively highlighted geophysical anomalies and demonstrated the connection between assay values and geoelectric parameters.

FINDINGS AND ARGUMENTS

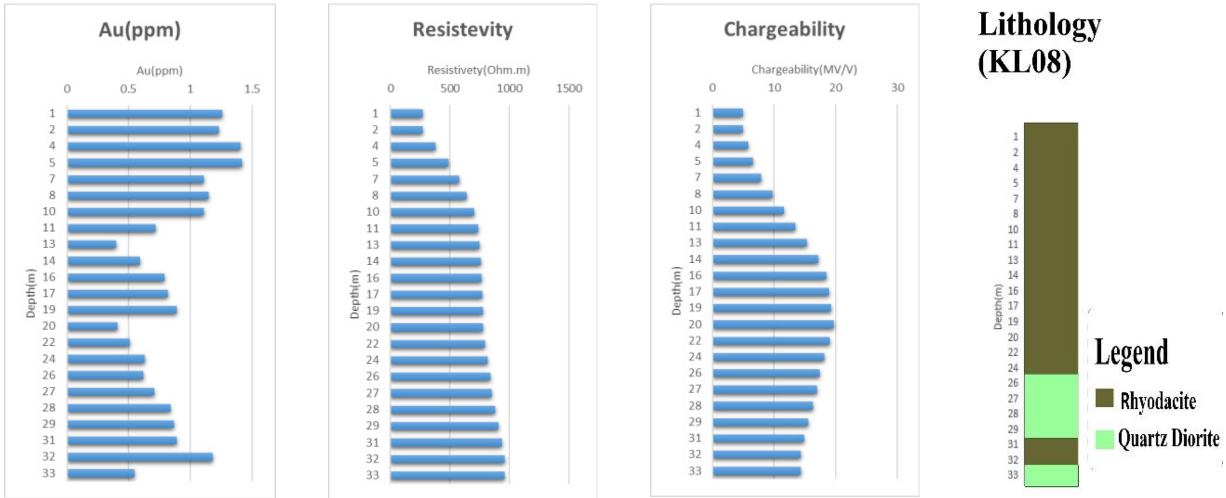
Iran hosts a remarkable array of gold deposits, encompassing orogenic, epithermal, Carlin-type, intrusion-related systems, and gold-rich volcanic sulfides. Each type is uniquely situated across various regions, showcasing distinct characteristics and properties. This geological diversity highlights Iran's prominence in gold mining, emphasizing its vital role in the exploration and extraction of precious gold resources [6]. The thorough analyses and investigations reveal that the northern region of East Azerbaijan is distinguished as a rich zone of gold mineralization, characterized by a vein-type system within a host rock of rhyodacite and tuff. Moreover, the findings from mineralization temperature and fluid inclusion studies indicate that this area corresponds to low-sulfidation epithermal deposits. Beyond gold, the presence of additional elements in this region further elevates its economic and exploratory significance. Inversion modelling of resistivity and induced polarization data was meticulously conducted for each of the nine profiles. The resulting observed and predicted resistivity and induced polarization sections are presented. Each section consists of 215 measurement points employed for the inversion process. The analysis of these inversion results indicates the promising identification of a silica vein infused with sulfides, potentially signalling gold mineralization. A comprehensive review of all 2D modeled sections reveals that anomalies have consistently emerged across the parallel profiles (Figure 1).



(A) **(B)**

Figure 1. 3D visualization of the 2D inverse modelling of geoelectrical data: **A:** electrical resistivity and **B:** chargeability (Nine profiles have been collected in this area.)

Upon the meticulous processing and modelling of resistivity and induced polarization data, a thorough quantitative and qualitative analysis ensues. This process entails a sophisticated comparison with existing drilling data in the vicinity, aiming to uncover significant correlations between geoelectric and grade data. Generally, gold exploration is a challenging subject due to geological complexities, while interpreting and concluding about areas indicative of gold mineralization require significant precision and attention. The analysis of the results reveals two notable types of correlations. (1) Areas within the profiles exhibiting induced polarization and resistivity values above the background level suggest the existence of a siliceous vein at depths ranging from 25 to 35 meters. In these regions, the gold concentration is roughly 1 ppm, indicating that these sections predominantly reflect gold mineralization associated with the siliceous vein. (2) Depth intervals exhibit an enhancement in grade and electrical chargeability, alongside a reduction in electrical resistivity. The lithological columns suggest that these intervals are predominantly associated with rhyodacite and hornfels. The notable decline in resistivity in these zones points to an elevated concentration of sulfides relative to surrounding areas. Typically, the gold grade in these sections exceeds 1 ppm, indicating the presence of gold mineralization within the sulfide content. Analyzing Figure 2 reveals that the resistivity-grade diagrams show a clustering of high-grade points in regions characterized by low resistivity, indicative of gold mineralization within the sulfide section, while high-grade points are dispersed in areas of high resistivity associated with gold mineralization in the silica vein. Furthermore, the chargeability-grade diagram lacks a significant correlation. The interpretation of chargeability values is inconclusive when considered in isolation due to the influence of the sulfide zone; thus, a combined analysis with electrical resistivity is recommended for enhanced understanding.



(A) **(B)** **(C)** **(D)**

Figure 2. A: Variations in gold grade, **B:** electrical resistivity, and **C:** chargeability **D:** at borehole KL08

CONCLUSIONS

In this research, a 2D analysis of electrical resistivity and chargeability data across nine profiles was conducted, revealing the presence of silica veins enriched with sulfides, potentially indicating gold mineralization. The anomalies identified through modelling imply the existence of low-sulfidation gold veins associated with silica. The consistent occurrence of these anomalies in parallel profiles, along with their strong correlation to gold mineralization characteristics, represents a noteworthy outcome of this investigation. The analysis of geoelectrical data in conjunction with drilling data has identified two distinct relationships in the region: one where gold mineralization occurs in the host silica vein, characterized by elevated resistivity and chargeability, and another where gold mineralization is found in the sulfide zone, marked by reduced resistivity and heightened chargeability. These findings are valuable for enhancing the interpretation and identification of regions that are conducive to gold mineralization. The alignment of the 3D models of resistivity and chargeability data with the silica dyke, as established through geological and lithological data obtained from drilling, represents a crucial finding of this research. A vital component of this study is the interpretation of resistivity and chargeability results, which enhances the utility of this method in the exploration of gold mineralization, alongside the strategic application of drilling data to mitigate uncertainties in the findings. Certain areas do not conform to the established relationships, although these relationships generally apply in most locations. Various factors contribute to these discrepancies, including geological complexities related to gold mineralization, uncertainties in geoelectrical data, errors in data acquisition, and the presence of noise within the data. Naturally, with the completion of exploratory layers in this area and their integration, many ambiguities will be resolved.

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