Scientific Research Publishing

World Journal of Engineering and Technology, 2023, 11, 424-433
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Reconnaissance Geophysical Study on the Southeastern Part of Al-Qashah Aera, KSA

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How to cite this paper: Al-Bakri, A.Y. and Sazid, M. (2023) Reconnaissance Geophysical Study on the Southeastern Part of Al-Qashah Aera, KSA. *World Journal of Engineering and Technology*, **11**, 424-433.
https://doi.org/10.4236/wjet.2023.113031

Received: May 11, 2023
Accepted: July 3, 2023
Published: July 6, 2023

Abstract

The investigated study area locates about 72 km from Jeddah City, Makkah District, Kingdom of Saudi Arabia. The study mainly aimed to define the most significant zones of possible mineralization and outline their subsurface parameters (location and strike) in the southeast of Jabal Al-Qashah. Several geophysical methods have been conducted to carry out the goal, including ground magnetic, self-potential (SP), and induced polarization (IP) methods. Integrating these methods aims to help delineate the possible mineralization in the study area. The magnetic survey was conducted along 17 profiles where these profiles were chosen to be perpendicular to the strike of the quartz shear zone. Self-potential was applied along with five profiles covering the study area. At the same time, induced polarization was used along with one profile located at the western side of the study area corresponding to some magnetic and SP profiles. The most interesting zones of mineralization were successfully determined by comparing the results of residual magnetic profile (3), SP profile (1), and IP profile, where geological structures control some mineralization.

Keywords

Geophysical Methods, Magnetic Method, Self-Potential (SP), Induced Polarization (IP), Jabal Al-Qashah

1. Introduction

Geophysical methods are practical tools to provide helpful subsurface information [1] [2]. They have a wide range of applications in geoscience, oil, mining, and civil fields [3] [4]. The magnetic geophysical exploration method is considered one of the oldest techniques used for subsurface geophysical exploration. It is an inexpensive and prevalent approach for near-surface metal detection [5].

Site engineering and environmental characterization projects often begin with a magnetometer survey as a method of rapidly illustrating a layer of information for the location of various utilities and buried concerns. The principle of operation is quite simple. When a ferrous material is placed within the Earth's magnetic field, it develops an induced magnetic field. The induced field is superimposed on the Earth's field at that location, creating a magnetic anomaly. Detection depends on the amount of magnetic material present and its distance from the sensor. The anomalies are typically illustrated on color contour maps.

Most rocks are not magnetic; however, certain rocks contain enough minerals to originate significant magnetic anomalies. The data interpretation that reflects differences in local magnetization abundance is beneficial for locating faults and geologic contacts [6]. The series of changes in the lithology, variations in the magnetized bodies' thickness, faulting, pleats, and topographical relief can create magnetic anomalies. A significant quantity of information can leave a qualitative revision of the residual magnetic anomalies map of the total magnetic field. In this sense, we can say that the value of the survey does not finish with the first interpretation, but rather it increases as more geology is known.

The self-potential method (SP) is also one of the oldest exploration geophysical methods [7]. Inside the ground, the difference in the natural potential between two points plays a significant role in SP measurements. This potential, which is partly varying irregularly and somewhat constant, is associated within the Earth with the electric currents. This potential is generated due to action that occurred electrochemically in subsurface rocks or bodies. It can be divided into two types; positive or negative small background potentials (millivolt to a few millivolts) and negative enormous mineralization potentials (hundreds of millivolts) [8]. The second type is the most important in this study. The determined mineralization potentials are associated with sulfide mineralization. Therefore, a self-potential survey will be conducted to determine the expected mineralized zones under the selected profiles. In the past few years, the SP method was used in a wide range of geological investigations: mineral exploration, thermal sources detection and delineation in volcanic and geothermal areas, and groundwater investigations for hydrogeological studies [9] [10].

The induced polarization method (IP) is mainly utilized to explore subsurface disseminated sulfide [11]. For many years, IP phenomena have been known by solid-state physicists as the existence of the over-voltage effect at the surface between a metallic ore's deposits and an ionic solution. This voltage drop is over and above the voltage drop in the materials to either side of the surface. Generally, IP can be conducted either in the time domain or in the frequency domain. However, the time domain will be discussed because it is the domain that has been carried out during this study. The chargeability (IP effect) manifests itself as a residual voltage following the termination of an applied current (time-domain measurement) or as a frequency-dependent resistivity (frequency-domain measurement). In simple terms, the IP response reflects the degree to which the subsurface can store electrical charge, analogous to a capacitor.

This study mainly aimed to define the most significant zones of possible mineralization and outline their subsurface parameters (location and strike) in the southeast of Jabal Al-Qashah, where several geophysical methods have been conducted to carry out the goal, including ground magnetic, self-potential (SP), and induced polarization (IP) methods.

2. Geological Setting

The geological setting of the study area can be shown in Figure 1 and can be summarized as follow:

1) Unassigned meta-gabbro and gabbro (xgb) bodies are scattered throughout the western two-thirds of the quadrangle; most are probably contemporaneous and represent the oldest plutonic rocks preserved in the quadrangle. In the southeastern part of Jabal Al Kashah, the meta-gabbro is highly ferruginated and intruded by quartz veins containing disseminated pyrite and chalcopyrite along a shear zone trending nearly NE, dipping to the north and extends for a few km and attains a variable thickness.

2) The Milh complex (mdg, mdq), named hereafter Wadi al Milh, occurs as large to small masses enclosed by younger plutons within a broad zone of rugged, mountainous places a country that extends northeastward from the south-central boundary to the northeastern corner of the quadrangle.

3) The Ju'ranah complex (kutg), named hereafter wadi Ju'ranah, is well exposed in 1700 km^2 in the center of the quadrangle, where it forms high, in places, mountainous, country.

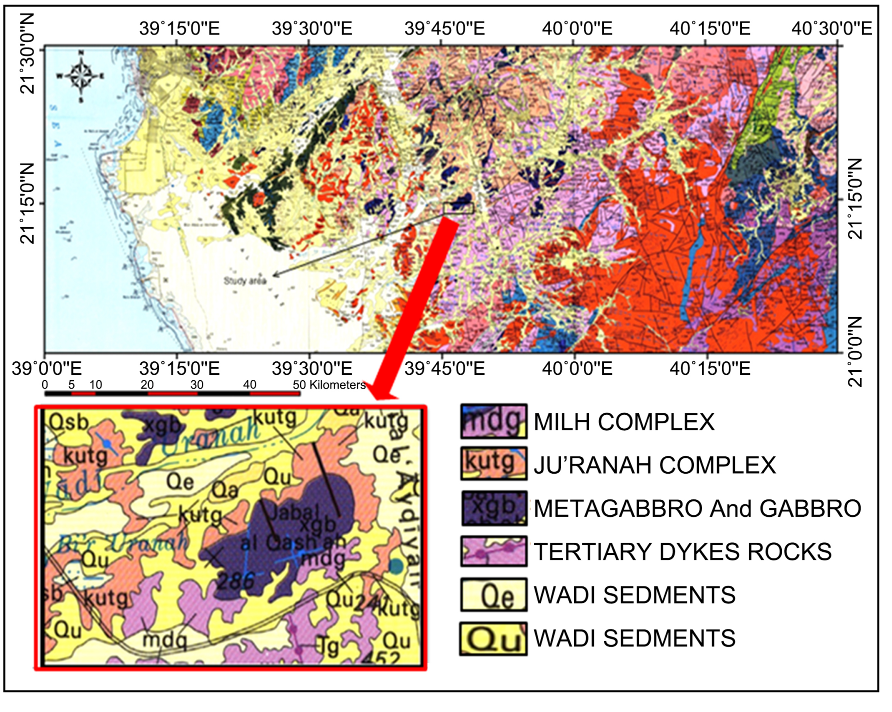

Figure 1. Geologic map of the study area [11].

4) Thick, northwest-to-north-northwest trending gabbro dykes occur throughout the western coastal region of Saudi Arabia. Jabal Al Kashah is traversed by an N-S trending fresh gabbroic dyke with a high content of opaque minerals (magnetite and ilmenite), 100 m thick, and extends a few km along with the strike.

3. Methodology

In this study, the magnetic survey has been conducted along 17 S-N profiles across the strike of mafic and ultramafic rocks (layered Gabbro), suggested by the geologist team, to delineate the possible significant mineralized zones and structures. Frequency analysis techniques are applied on each profile where the total magnetic intensity curve is divided into regional and residual components. Utilizing frequency analysis allows us to estimate the depths of shallow and deep causative targets [12]. The frequency analysis along the profiles is most appropriate since it provides better resolution of shallow sources. The method was applied to digitized magnetic data, in profile form, to obtain the average depth to the subsurface geological sources and to obtain the differential magnetic response of each source ensemble that lying at a certain depth. The magnetic data along each profile, regarded as a set of equally spaced potential intensity data, were transformed into the frequency domain using the Fourier transformation. The Fourier transform integral of the function is expressed as

$$F(q)=\int_{-\infty}^{\infty} F(x)\cdot \mathrm{e}^{-iqx}dx \tag{1}$$

where:

$F(x)$ = the value of the function at a point *x*, and

$F(q)$ = is the transform at a wave number *q*.

SP survey has been conducted along five profiles taking the same direction, covering the area of study. The expected mineralized zone will respond to the negative anomaly. The copper sulfate non-polarized electrodes were utilized in this study. An electrode was positioned at a fixed station, and the second one was used for field measurements of natural self-potential in millivolts. The SP survey shows negative anomalies; most of these anomalies occupy the shear, silicified zones, alterations, and rock contacts. Location and the extension of sulfides are detected as a result of SP. Also, the depth of the mineralized body and its polarization can be found. The determined mineralization potentials are associated with sulfide mineralization. Thus, the self-potential survey will be implemented to find out the expected mineralized zones under the selected profiles.

Moreover, we record the results of resistivity/induced polarization (IP) investigations of the subsurface mineralized zones along one profile selected across the quartz shear zone. The geological studies, magnetic, and SP data interpretation results recommended the profile. The IP measurements are carried out automatically (output voltage, stacking number, quality factor) after selecting limit values by the operator and are stored in the internal memory. Along with the selected profile for the IP survey, a small hole was prepared every 10 m through the profile at each station. These holes were saturated with water and some salt, and one stainless-steel electrode was driven in the hole. For the connection of current electrodes, several cables were used, and each one was connected to the electrode, which, known in the system, arranged the mutual connection between current electrodes (A and B) and potential electrodes (M and N). High-accurate GPS instruments define the locations of all stations of observation.

4. Results Discussion

The main target of the survey in this area is the quartz shear zone that extends east-west trending across the study area. At the interesting area, the total magnetic, regional, and residual maps (**Figures 2-4**), delineate the subsurface extension of the quartz dyke. The regional magnetic map (**Figure 3**) and residual magnetic map (**Figure 4**) show that there is a certain regional structure (fault or dyke) cutting across the quartz dyke.

And to outline the mineralization characters beneath the area, five SP profiles are conducted. The ranges of the measured SP values are relatively low **Table 1**. Therefore, they most probably do not indicate any occurrence of sulfides mineralization. Through the distribution of negative SP anomalies in the area and compared to the magnetic anomalies and location of the quartz dyke outcrops, the SP contour map indicates that the sulfide mineralization content may occur in the subsurface structural zone (**Figure 5**).

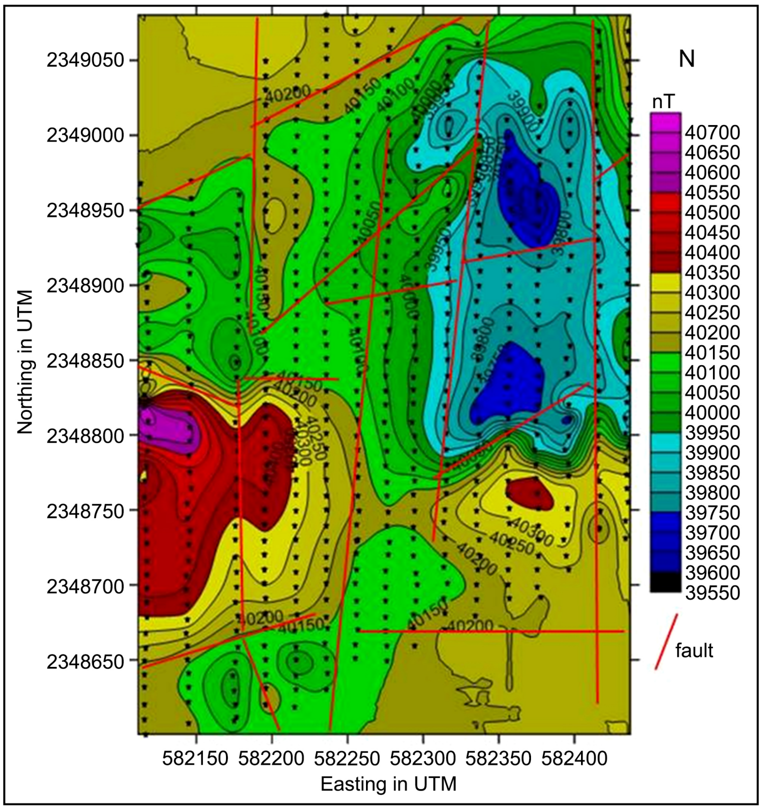

Figure 2. Total magnetic intensity contour map of the study area.

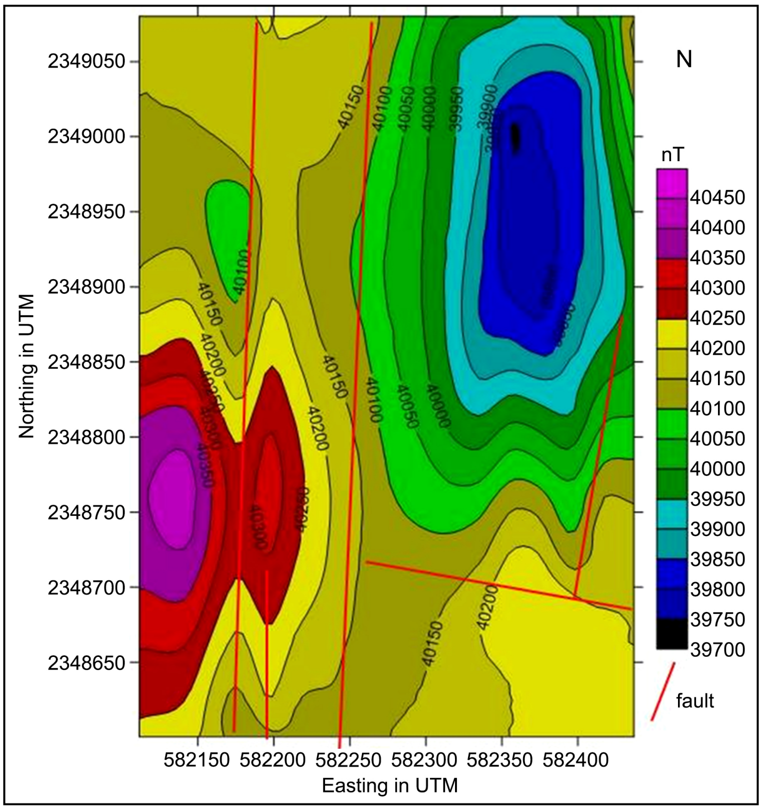

Figure 3. Regional magnetic component contour map of the study area.

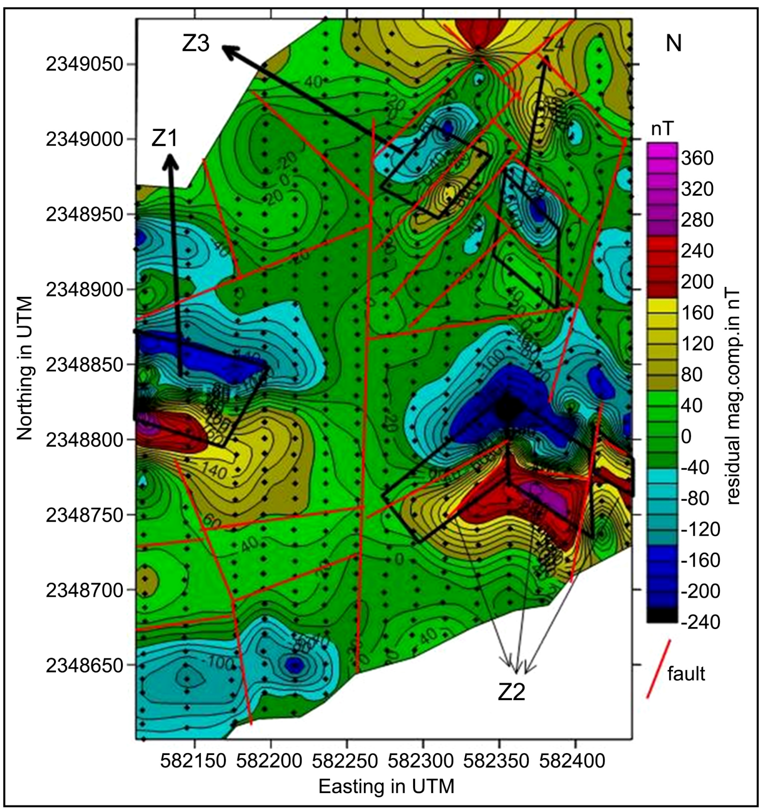

Figure 4. Residual magnetic component contour map of the study area.

Table 1. Measured SP values for five conducted profiles.

Profile NO.	Number of Reading Values	Minimum (mv)	Maximum (mv)	Range (mv)	Length (mv)
1	36	−32	9	41	349.9
2	35	−31	0	31	240.4
3	25	−20	0	20	243.1
4	26	−25	25	25	248.4
5	24	−24	0	24	217.0

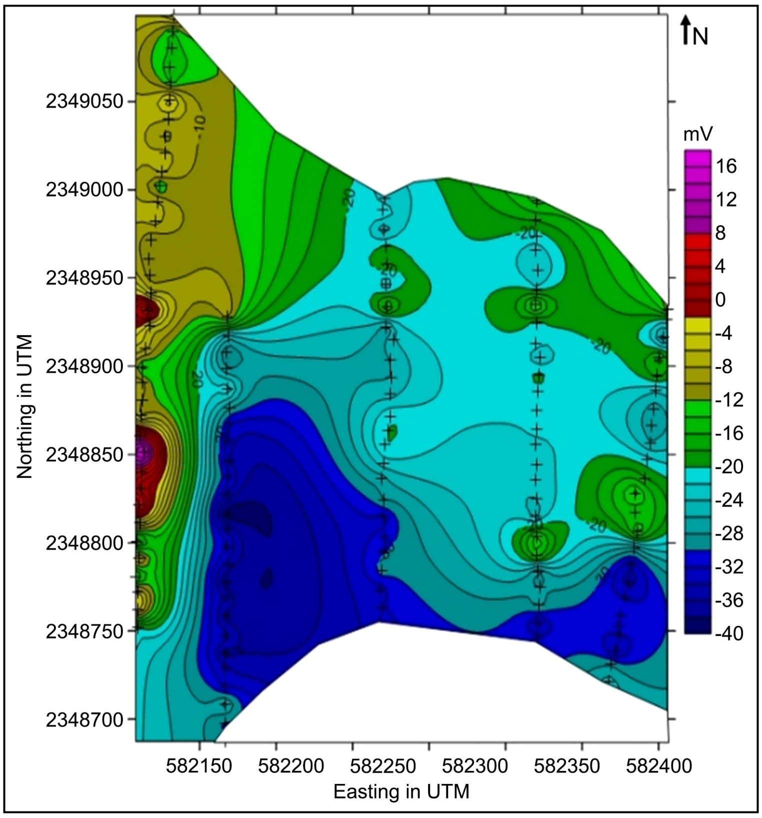

Figure 5. Self-potential contour map of the study area.

And to prove the previous information obtained from both magnetic and SP surveys, induced polarization (IP) survey is applied along with one profile cutting across near the western quartz dyke outcrop (along with magnetic profile number 3 and SP profile number (1). The constructed resistivity, chargeability, and metal factor pseudo-sections delineate the distribution of the mineralized zones beneath the ground surface of the profile, particularly near the western quartz dyke outcrop. These results are shown clearly in the metal factor pseudo-section and the resistivity, chargeability, and metal factor curves constructed based on Frazer filter (**Figure 6**).

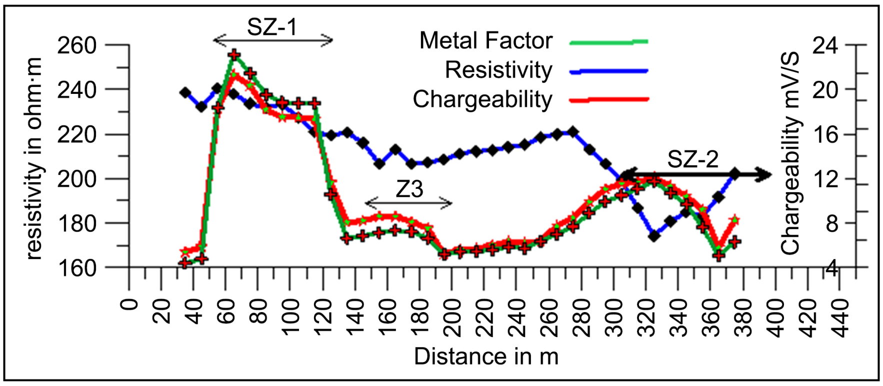

Figure 6. Relation between the resistivity, chargeability, and metal factor curves.

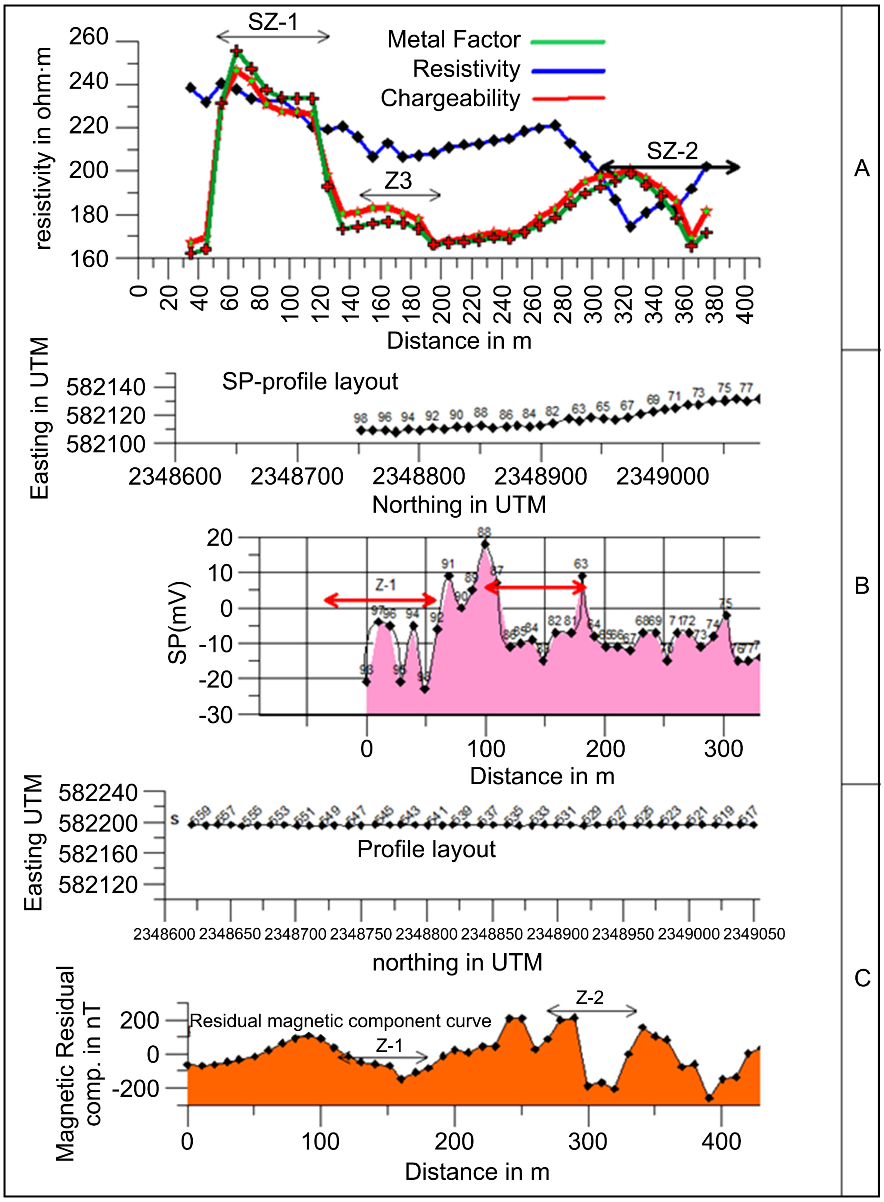

Figure 7. The correlation between (A) IP, using Frazer filter curves, (B) SP curve, and (C) magnetic curve, along profile (SP1).

These curves delineate three distinctive anomalous zones with different characters: The western zone (Z1) is characterized by high resistivity, chargeability, and metal factor, indicating the occurrence of the disseminated mineralizing body; zone (Z3) is characterized by relatively low chargeability, and high resistivity at depth reaches up to 80 m related to massive rocks without mineralization. Zone (Z2) has low resistivity and high chargeability, indicating a conductive zone attributed to the expected mineralized body beneath this zone at the eastern part. Also, Figure 7 shows that the IP anomaly zone is related to the negative SP and the low magnetic anomaly. These results recommend following up with detailed geological and geophysical exploration methods.

5. Conclusions

The primary purpose of this study is to delineate the potential mineralization within the mafic and ultramafic rocks (layered gabbro) at the quartz shear zone, which is in the study area. The results of magnetic data processing showed that the area of study has shallow depth extracted from the residual component of the causative body and deeper depths extracted from the regional component. Magnetic contacts have been delineated, which may be related to geological structures such as faults.

Self-potential was applied along with five profiles, covering the study area. It showed that a range of negative values related to the presence of clay or may be related to sulfide mineralization.

Induced polarization was applied along with one profile. Chargeability and resistivity pseudo sections have been constructed, and hence metal factor pseudo-section was computed and constructed. The results show the distribution of possible mineralization along with this profile.

There are mainly three scenarios for the presence of mineralization along with this profile:

- Mineralization is characterized by high resistivity, high chargeability, and high metal factor, interpreted as disseminated sulfide mineralization.
- Mineralization is characterized by low resistivity, high chargeability, and high metal factor, which can be interpreted as massive sulfide mineralization.
- Mineralization is characterized by relatively moderate resistivity values, relatively low chargeability, and metal factor values, which may be interpreted as a lesser amount of disseminated sulfides mineralization zone.

Comparison between residual magnetic along with the profile (3) and SP profile (1) and IP results are constructed where they show the most interesting zones of mineralization, where geological structures control some mineralization.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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