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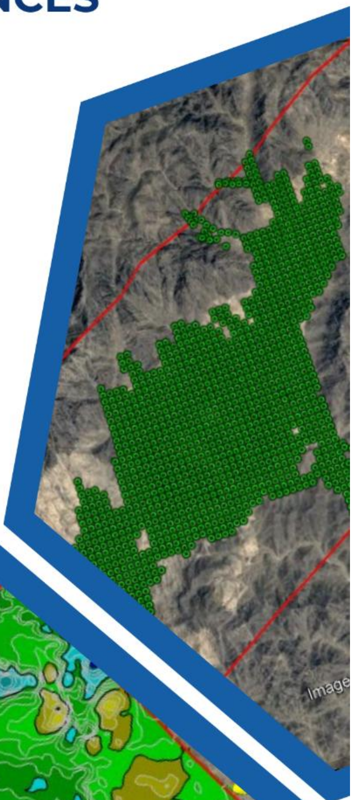

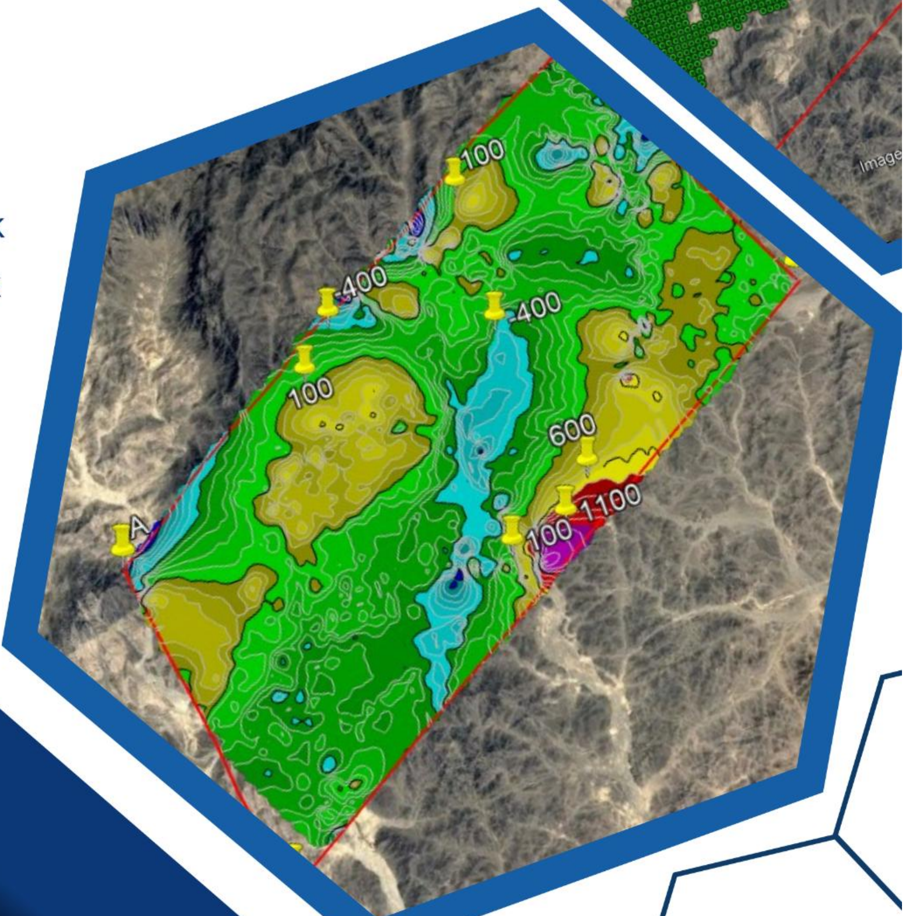

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Integrated Geophysical Investigations (Magnetic, IP & Resistivity) of Aeromagnetic Anomaly No.47 for Exploration of Metallic Minerals in the Chagai Magmatic Arc, Ziarat Balanosh Area, Southwest Pakistan

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ABSTRACT

The Geological Survey of Pakistan conducted a geophysical investigation as part of its research and development program in 2023-24. The focus was on exploring metallic minerals on recommended Aeromagnetic Anomalies (AMAs), especially Anomaly No.47 in the Chagai area of Chagai District, Balochistan. The investigation employed Ground Magnetic and IP/Resistivity Wenner methods to uncover valuable insights. The operation was carried out using the above-mentioned technique for exploring subsurface properties, to thoroughly cover the identified area of interest already proved auspicious in previous expeditions in Siah-Dik and Mashki Chah at AMA No.19 & 18 respectively. Upon the project's completion, noteworthy discoveries were made in the area of AMA No.47. Within this anomaly, two distinct zones were identified and earmarked, exhibiting low magnetic properties but with a high chargeability. Additionally, a third zone was identified in the western part of the area with high magnetic properties. Further, investigations expanded this area from Northern towards southern direction, aiming to encompass the entire anomalous zone. The site is recommended for base metal targets in the Chagai belt with B-type magnetic anomaly, i.e. zones of reduced magnetization are suggestive of an environment that may involve porphyry-type mineralization. A high priority is given to the anomalies in the periphery of the Balanosh intrusive. These findings suggest promising prospects for mineral exploration in the region, especially in terms of sulphide mineralization like copper deposits within the marked zones. Anomalies with varying magnetic and chargeability characteristics hint at diverse mineral compositions, motivating further exploration and detailed assessments in the western zone.

Keywords: Aeromagnetic Anomaly No.47, Iron, Copper, Chagai, Pakistan

INTRODUCTION

Chagai has served as a primary hub for field parties operating in the region for an extensive duration. Ziarat Balanosh is an ancient and historic area in Chagai. Historical records have highlighted the existence of copper and marble (Onex) deposits encircling the Ziarat Balanosh area. An aero-magnetic anomaly has unveiled a promising zone for a porphyry system, along with multiple shallow mines extracting iron and marble. Furthermore, an extensive survey of the region, involving 2314 magnetic points and 29 Wenner profiles, has indicated the likelihood existence of porphyry type copper mineralization. Notably, the chargeability assessment during this phase has depicted the consistent characteristics of the sulphide mineralization like copper deposits located at the western extremity of the map.

The following report outlines the data interpretations derived from comprehensive ground magnetic and IP/resistivity surveys conducted at the site of Aeromagnetic Anomaly-47. These surveys, comprising ground magnetic data points 2314 and geoelectric data numbered 1 to 13, were carried out from August to

October 2023 and 14 to 29 in July 2024 as part of ongoing R&D investigations. The primary aim of this endeavor is to examine the expansion of lineaments situated in the northwest to southeast region. Notably, the analysis of IP/resistivity data within the preview of this study indicates the probability of the presence of sulfide mineralization.

Geo-electric properties are exploited commercially in the search for valuable ore bodies which may be located by their anomalous properties (Lowrie 2011). The IP surveys aim to detect and map possible sulfide mineralization as it is known that gold in this area is associated with pyritization. The IP method is widely used for detecting possible sulfide mineralization (usually an indicator for gold occurrence) that is expected to give a high chargeability response. There are two main mechanisms of rock polarization which are grain polarization and membrane polarization (Milsom, 2003). The overvoltage effect is caused by minerals which are good conductors whose magnitude depends on both the magnitude of impressed voltage and mineral concentration.

The data were processed and interpreted using standard techniques at that time, and all interpretation products and deliveries were mapped. However, with today's state-of-the- art processing and visualization software, it is now possible to identify more subtle anomaly patterns, and interpretation products are digital and connected to databases. Additionally, it is now much easier to make integrated interpretations and simultaneously view details in different datasets. This work will present the AMA-47 data and interpretation products in the same format as corresponding data from the site investigations at the Siahdik copper discovery.

Individual interpretations of lineaments in the magnetic, geoelectric, and topographic data are presented, primarily identified as topographic lows, magnetic and resistivity lows, and chargeability highs. The project area displays various magnetic signatures, with high anomalies of 1500 nT and low anomalies of 900 nT and 950 nT at two prominent geophysical features. These areas were further investigated, and depth sections were prepared. The current exploration program aims to map the copper-bearing deposits based on their MAG and IP signatures, while also assuming that the delineated structures may host gold and silver-bearing mineralization. The deposit extends from approximately 50 meters to 300 meters below the surface and has a maximum width of approximately 800 meters.

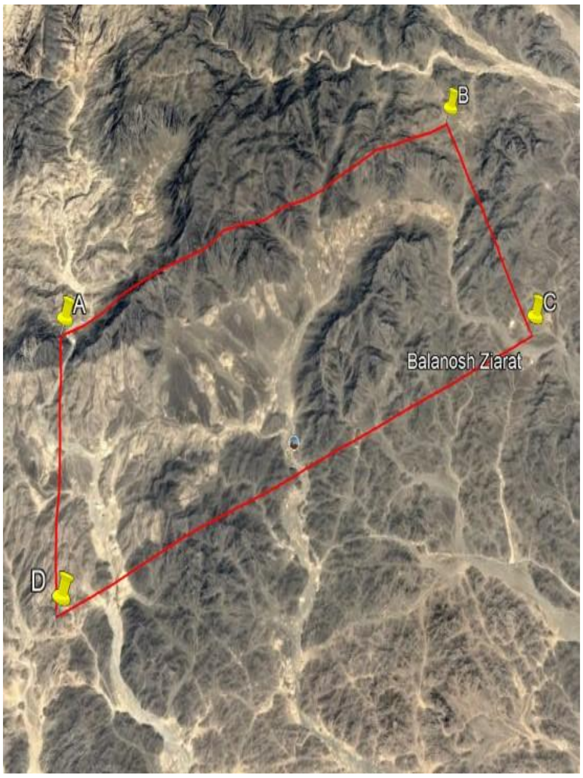


Figure No. 1: Google Map showing Aeromagnetic Anomaly-47

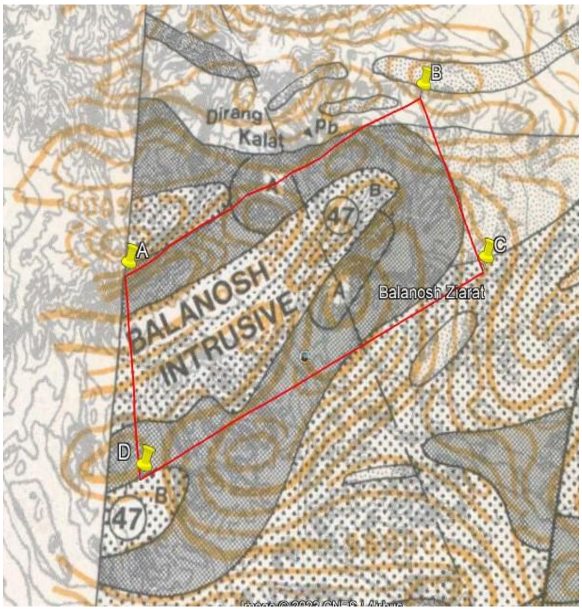


Figure No. 2: Project Area Map on Aeromagnetic Interpretation Map.

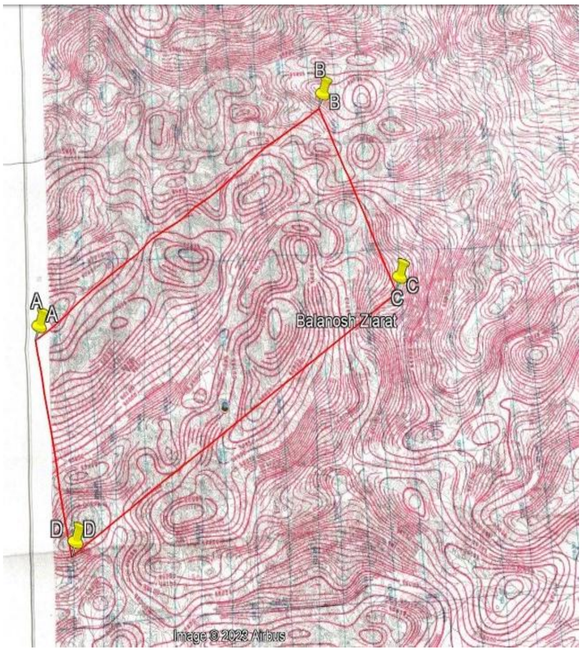


Figure No. 3: Project Area on Aeromagnetic TMI toposheet No.34-C/11

The sulfide mineralization is often a significant source of copper worldwide and can be found using various exploration techniques. These methods include analyzing alteration zones in geology, utilizing high-precision magnetic and electrical techniques in geophysics, conducting stream sediment and soil geochemical surveys in geochemistry, and identifying alteration anomalies through remote sensing (Sillitoe, 2010;). It's essential to locate the true hydrothermal and/or mineralization center of the porphyry system to identify the porphyry copper deposits accurately.

Research on Copper Deposits has shown that the depth of the ore body starts nearly 100 meters and mineralization gradually becomes more intense with increasing temperature, pressure, and salinity. The studies suggest that the PCD may belong to the same porphyry system as the Siahdik system.

Porphyry Copper Deposits (PCDs) are comprised of disseminated copper minerals and copper minerals in veins and breccia that are relatively distributed in a vast volume of rock-forming high tonnage (greater than 100 million tons) low-moderate grade (0.3%- 2.0% copper) ores. Host rocks are altered and genetically related to granitoid porphyry intrusions and adjacent wall rocks.

Lineaments on the site are primarily identified as topographic lows, intermediate magnetic, low resistivity, and chargeability highs. The Ziarat Balanosh copper deposit is covered by 0- to 50-meter-thick alluvium and was not explored before October 2023.

This report describes the characteristics of mineralization and its host sequence, investigates the source of the "discovery" IP anomaly, and examines the properties' implications for deposit exploration. The magnetic susceptibility of rocks is often low in strongly deformed, fractured, altered, or porous bedrock. This is due to the destruction of ferromagnetic minerals, which forms a basis for magnetic lineament interpretation. Linear topographic lows can indicate depressions in the bedrock related to brittle deformation zones along which the bedrock is more easily eroded, due to decreased mechanical strength.

Project Location and Access

The project site is situated close to Ziarat Balanosh, a shrine and village situated approximately 20 km west of Chagai City and roughly 425 km southwest of the capital city of Quetta. To reach this location, one must travel along dirt tracks from Chagai city towards the west.

Figure No. 4: Project Area on Goolge Earth showing locations of project area Ziarat Balanosh and Chagai

General Geology of the Area

The current geological setting of the region shows a northward-inclined oceanic subduction zone, followed by an active accretionary prism and a magmatic arc (Chagai-Raskh) that consists of subduction-related magmatic activity, indicating an Andean-type continental margin setting. Many previous researchers have also supported this tectonic setup for the volcanic rocks, both old and new, including the Late Cretaceous (Sillitoe, 1978; Dykstra, 1978; Arthurton, et. al., 1982; Kazmi, and Jan 1997). However, Siddiqui (1996) contradicts this viewpoint and suggests an oceanic island arc setting for the Late Cretaceous to Paleocene volcanic rocks of the Chagai arc (see Figure- 5).

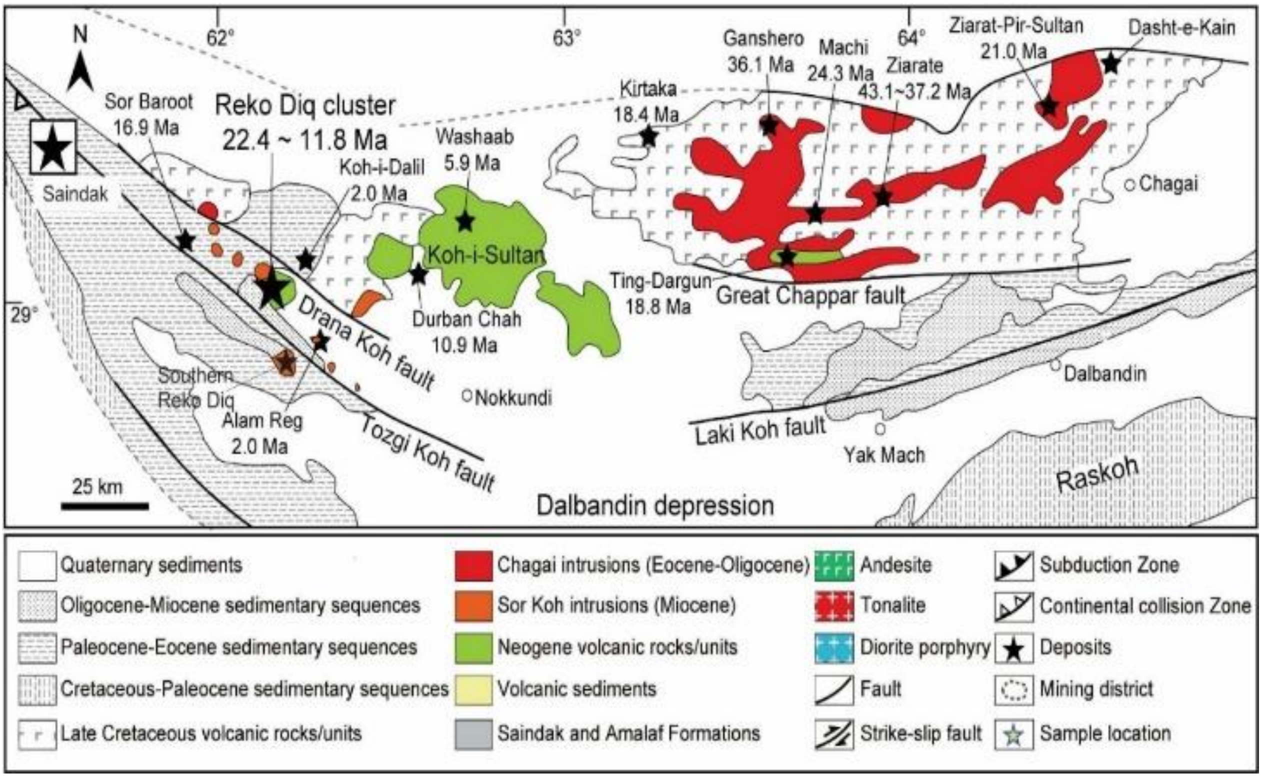


Figure No. 5: Simplified geological map of Chagai metallogenic belt, Pakistan, with geochronological data of the Chagai metallogenic belt showing the location of porphyry systems (Modified from Arthurton et al., 1982; Perello ´ et al., 2008).

The Chagai arc spans across the western region of Pakistan and extends a small portion towards the north in Afghanistan and the west in Iran. Its length is approximately 500 km, its width is 150 km, and it appears to trend in an east-west direction. The Chagai arc is identified as the rear arc of the Chagai-Raskoh arc system, as noted by Siddiqui in 1996. The northern edge of the Chagai arc is concealed by Quaternary alluvium and dunes, while its southern margin is shaped in a convex manner and is bordered by the Dalbadin trough, which is an abrupt deep synclinal trough. The Chaman and Harirud fault zones mark the eastern and western boundaries of the arc, respectively.

The Plio-Pleistocene volcanic rocks occur about 30 km N and NE of Nokundi. The oldest rock unit of the Chagai arc is the Late Cretaceous Sinjrani Volcanic Group, composed mainly of submarine stratified intercalations of basaltic to andesitic flows and pyroclastic rocks including agglomerate, volcanic breccia, volcanic conglomerate and tuff (Jones, 1960: Arthurton et. al., 1979) assigned a Senonian age to the group, based on Maastrichtian fauna present in the overlying Humai Formation and suggested a total thickness of about 10,000 m. The Sinjrani Volcanic Group was invaded by the Chagai Intrusions during the Late Cretaceous to Miocene including a variety of rock types such as granite, adamellite, granodiorite, tonalite, diorite, and gabbro. The main sedimentary rock formations developed in the area include limestone and conglomerate of the Humai Formation (Late Cretaceous), shale, sandstone, siltstone, and limestone intercalated with mafic lava flows and pyroclastic rocks of the Juzzak Formation (PaleoEocene) and Saindak Formation (Eocene). Shale, siltstone, sandstone, and limestone sequence of Amalaf Formation (Oligocene to Miocene), multicolored conglomerate, sandstone, gritstone, and clays of Dalbadin Formation (Miocene Pliocene), mottled clays, sandstone, and conglomerate represent Quaternary deposits. Plio Pleistocene lava flows and pyroclastic are known as the Koh-e-Sultan Volcanic Group. In the Chagai arc several episodes of volcanism were identified during the Late Cretaceous to Pleistocene (Jones, 1960). The Late Cretaceous volcanic activity is most widespread and is represented by the Sinjrani Volcanic Group (Jones, 1960). Later substantial volcanism occurred during the Paleocene, Eocene, Oligocene, Miocene, Pliocene, and Pleistocene.

Data Set & Methodology

Survey Grids

The project site spans 11km x 05km in a rectangle shape. Magnetic mapping led to the implementation of 29 IP profiles of 300meter depth. The magnetic map includes grids with N/S lines every profile with 100 meters of space and the station interval is also 100 meters, surveyed using a GPS receiver. The IP lines were numbered and positioned accordingly.

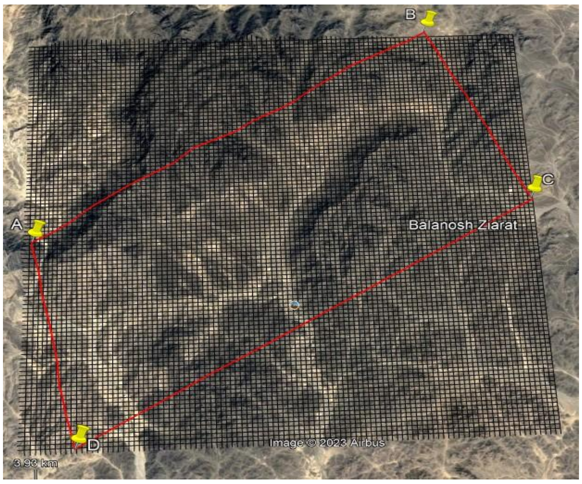


Figure No.6: Location of Project Area with Magnetic Grid Lines

Magnetic Data Acquisition and Data Processing

In magnetic survey, Total Magnetic Intensity measurements are taken along regularly spaced traverses to identify magnetic materials such as magnetite and/or pyrrhotite that are usually associated with metallic mineralization. These measurements also serve as a mapping tool to differentiate rock types and to pinpoint faults, bedding, structure, and alteration zones. The magnetic data is available in digital format and as stacked profile and color contour displays of the total field data, after being corrected for diurnal and Normal variations. Additionally, the magnetic data has undergone processing through a reduction to the pole filter, which modifies the observed responses to mimic the responses recorded if the survey was conducted at the magnetic north pole, where the earth's magnetic field is vertically inclined.

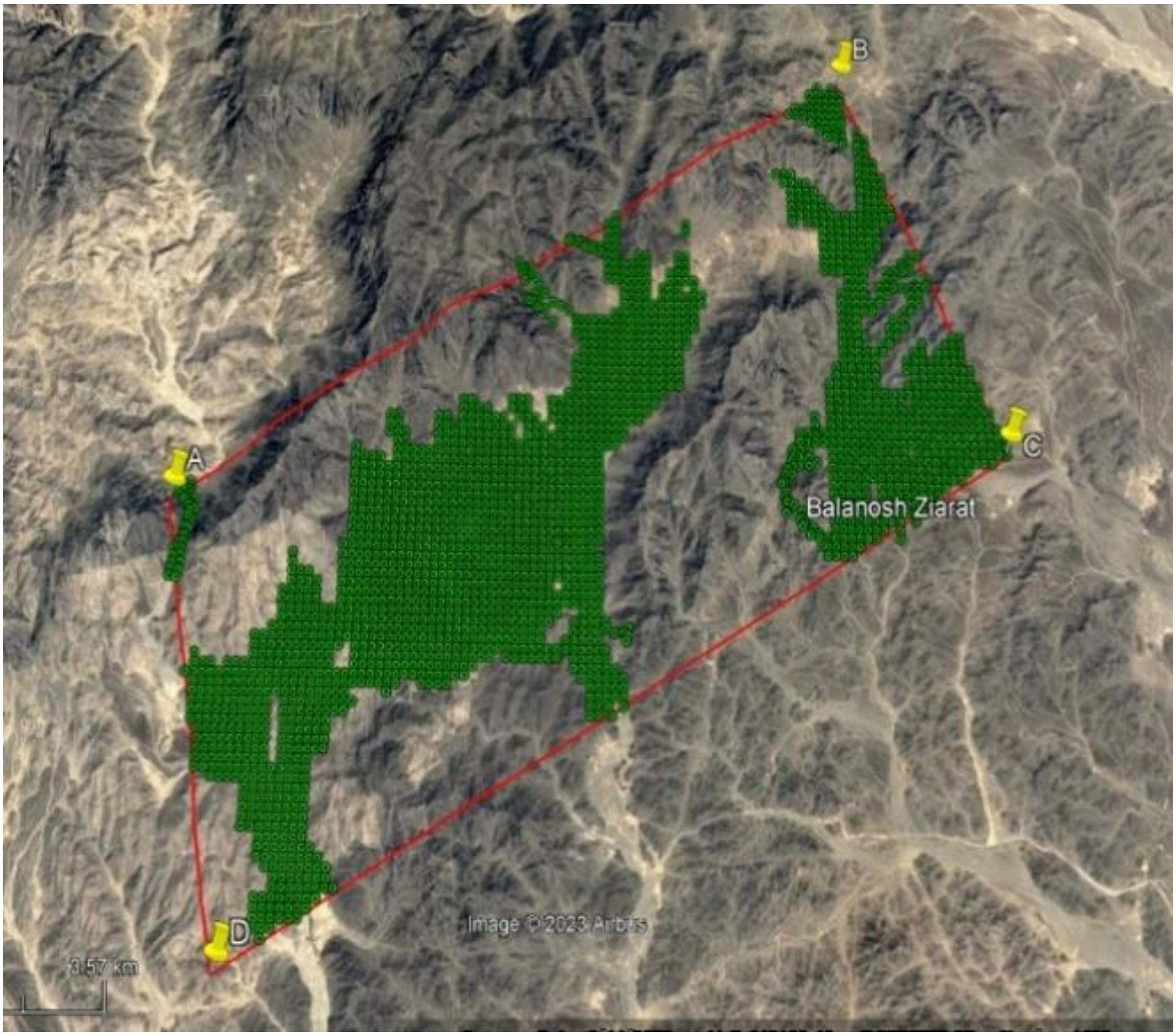


Figure No. 7: Magnetic acquired points in the project area.

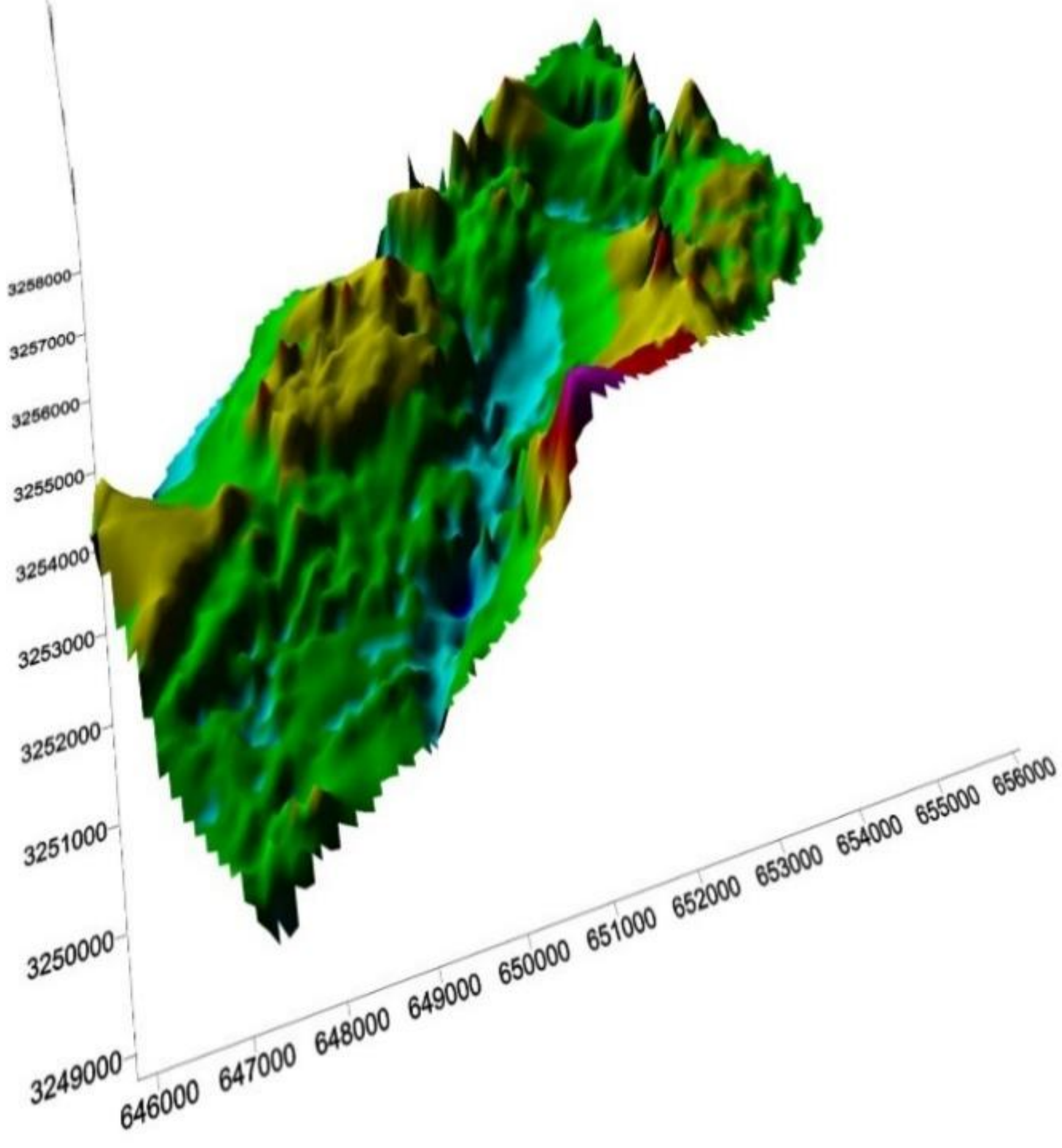


Figure No. 8: 3D Surface Total Magnetic Intensity Anomaly Map

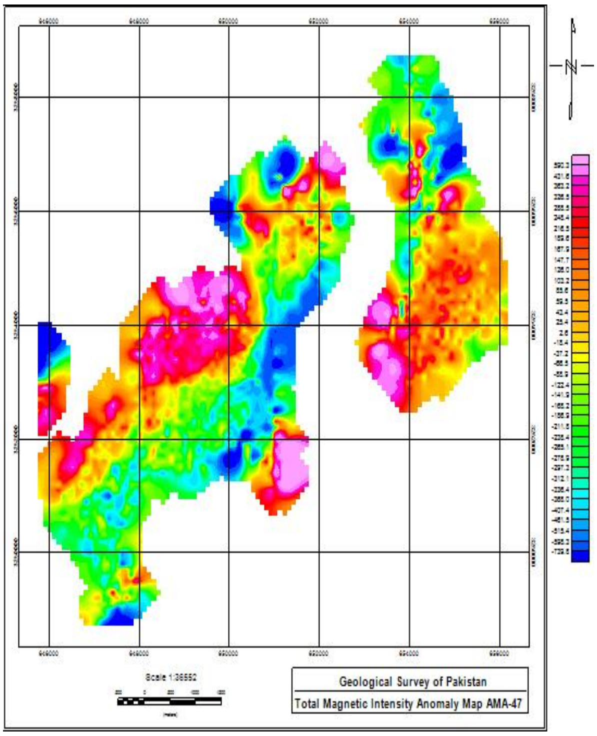
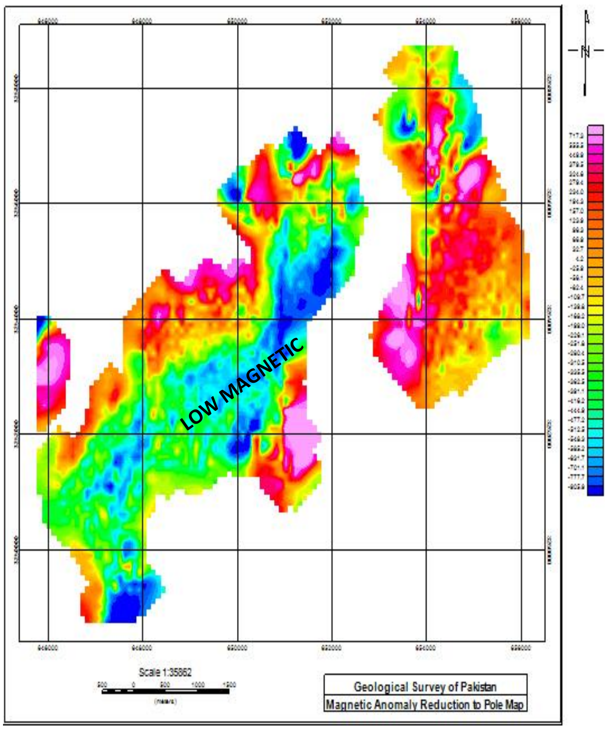


Figure No. 9: Total Magnetic Intensity Anomaly Map showing low magnetic zone.



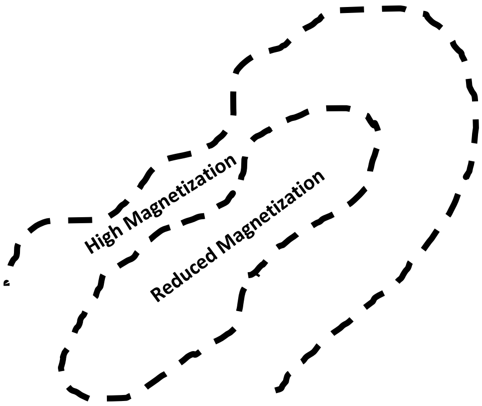


Figure No. 10: Total Magnetic Intensity Anomaly Reduction to Pole Map.

Results and Discussion

The magnetic survey was conducted, capturing data along continuous N/S lines, and ensuring a comprehensive assessment of the area. This method involved taking total field intensity readings at intervals of 100 meters along the survey profiles and 100-meter station interval, resulting in an extensive magnetic database with over 2314 readings. This rich dataset offers a remarkably high information density, enabling the creation of detailed, high-resolution maps. The increased granularity facilitates a superior delineation of subtle and short-wavelength anomalies that might otherwise be overlooked.

This is B-type magnetic anomaly with high magnetic with high signature at the periphery and reduced magnetization at the center. This type of set up is prospective for the presence of porphyry system along the Balanosh intrusive. In the southern section of the grid, the underlying geological formations appear notably distinct. The transition from one lithological domain to another aligns predominantly along ENE to E/W striking contacts. Notably, a significant NW to SE contact is more prominently evident in the IP maps. The reduced-to-pole total field map reveals a regional gradient that intensifies toward the north. However, this impact is mitigated in the first vertical derivative map, resulting in a clearer delineation of magnetic anomalies. These anomalies generally exhibit elliptical shapes with reduced magnetic zone at center is generally trending in NW-SE direction encircled with high magnetization. The wavelengths associated with these anomalies suggest the presence of shallow targets, indicating prospects for further ground mapping and exploration endeavors in these areas (Allan Spector, 1981).

Specifically, the most robust anomalies, measuring approximately 1500 nanoteslas (nT), are situated are situated at the periphery of the grid. These signatures are understood to primarily arise from lithological variations, particularly the prospective reduced magnetization with Balanosh Intrusive, a leading indication for conduction Res/IP to confirm the presence of sulphide mineralization. The regions exhibiting low magnetic signatures at the center of the magnetic data have piqued further interest. This curiosity has led to an in-depth exploration utilizing detailed IP profiles, a methodology that had been recommended based on preceding aeromagnetic survey. The aim is to gain a comprehensive understanding of the characteristics and potential mineralization in this area displaying diminished magnetic signatures.

Induced Polarization Survey (Wenner Method)

We keenly assessed the data quality, meticulously storing pertinent information in distinct databases dedicated to each survey line. These databases were formatted in Excel/Surfer and Geosoft Oasis Montaj, allowing for comprehensive data organization and management. To ensure meticulous quality control and to identify any potential inaccuracies, we conducted multiple readings often three times for each data point in the field.

Following data collection, specific details from these databases were later transferred to file formats compatible with Surfer software. The 2D models employed in our analysis comprise multiple blocks, and their distribution and size are automatically determined by the program based on the points' distribution within the sections, a function intricately linked to the electrode array used during the surveys.

The Induced Polarization (IP) technique, a method employed to measure two key physical properties of the ground chargeability and resistivity was instrumental in our investigations. Our primary objective in setting up the IP survey was to locate a concealed porphyry system. Our focus primarily centered on identifying higher chargeabilities associated with metallic mineralization (specifically sulfide) and high resistivities. Additionally, we also considered secondary targets encompassing variations in both parameters, aiming to identify potential geological structures and lithological variations within the surveyed area. These secondary targets served as additional indicators to guide our exploration efforts.

IP Wenner Method Electrode Array

The Wenner array was used for the induced polarization survey, with 50 to 300-meter separations. The profile spacing was between 250 to 300 meters. The Wenner four-pin method, developed by Dr. Frank Wenner of the US Bureau of Standards in 1915, was utilized in this process.

This technique involves four electrodes, two for current injection and two for voltage measurement. The four electrodes are placed in a straight line in the ground, with the outer ones serving as current electrodes and the inner ones measuring voltage drop due to the soil's resistance as current passes between the outer electrodes. The resistivity values are then processed and plotted as a contour map at a specific depth (Wenner, 1915). The current dipole distance between electrodes A and B and the potential M and N distance remains constant, with the depth of penetration being the same as that of the current and potential electrodes.

IP Contour Maps

The values of chargeability and resistivity (Wenner electrode configuration) extracted at 50 to 300 meters of vertical depth were used to create 2D maps.

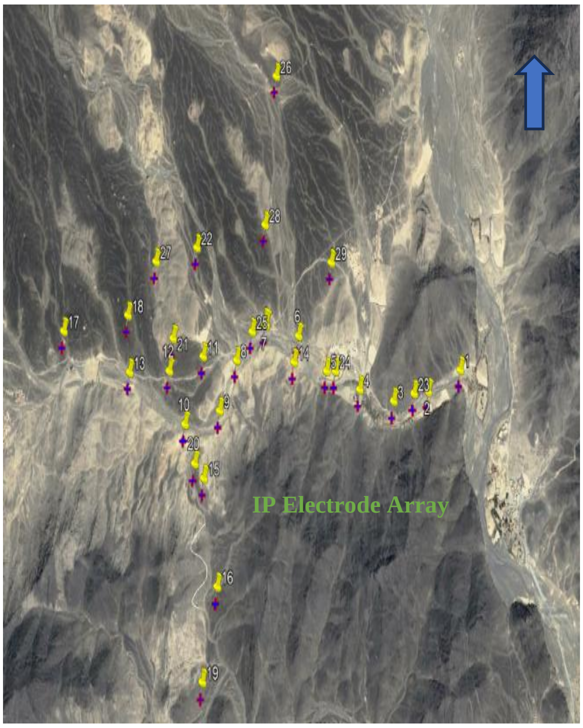


Figure No. 11: Locations of IP Survey Profiles

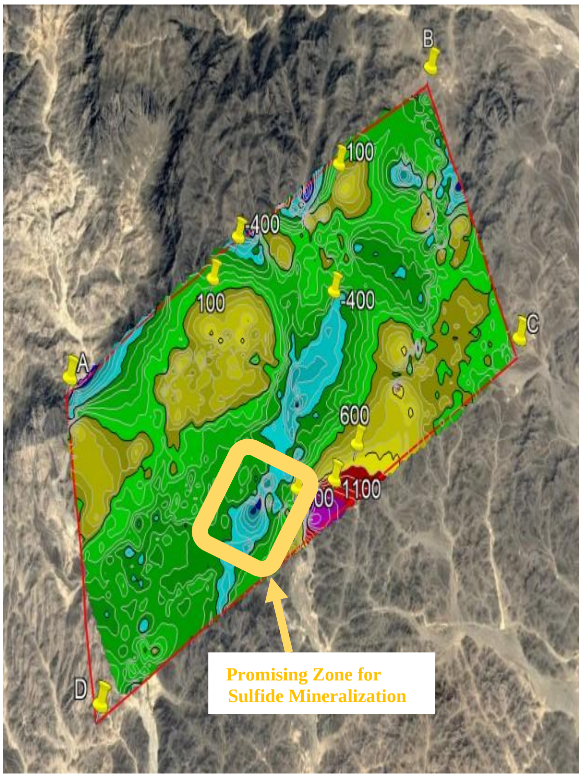


Figure No. 12: Potential Zone marked for IP Survey to be conducted.

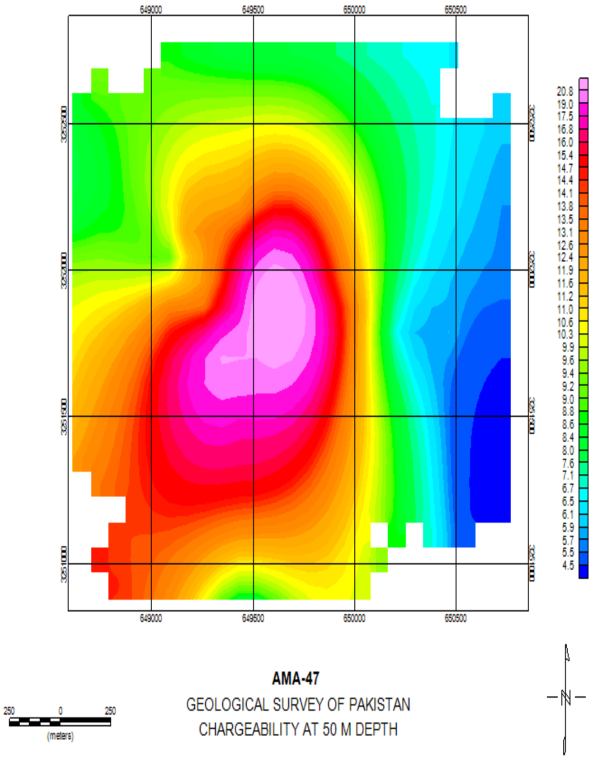


Figure No. 13: IP Survey Chargeability model at 50m depth

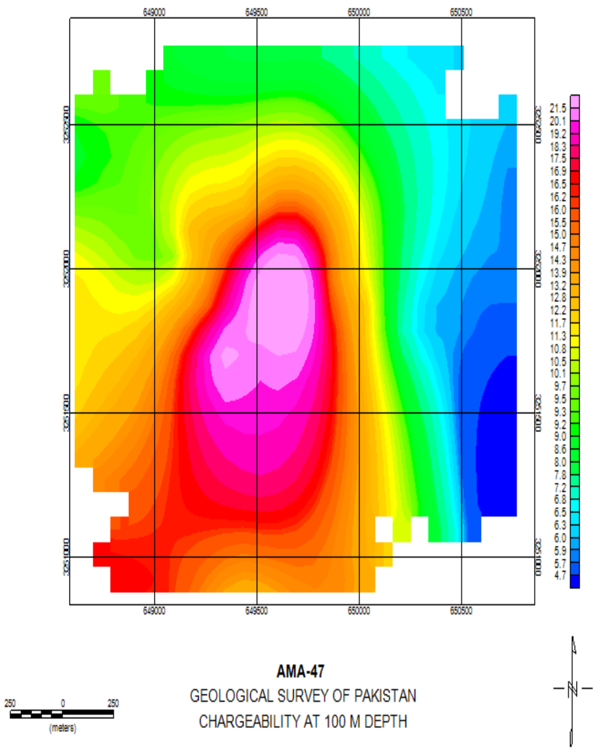


Figure No. 14: IP Survey Chargeability model at 100m depth

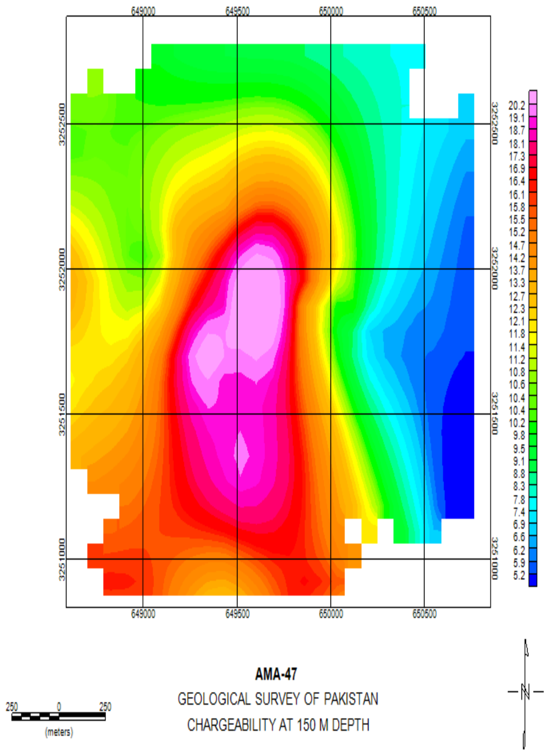


Figure No. 15: IP Survey Chargeability model at 150m depth

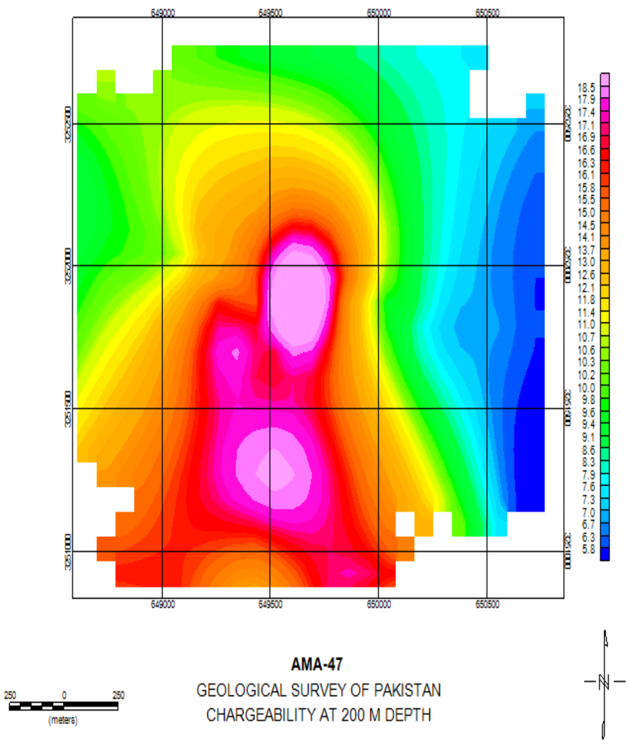


Figure No. 16: IP Survey Chargeability model at 200m depth

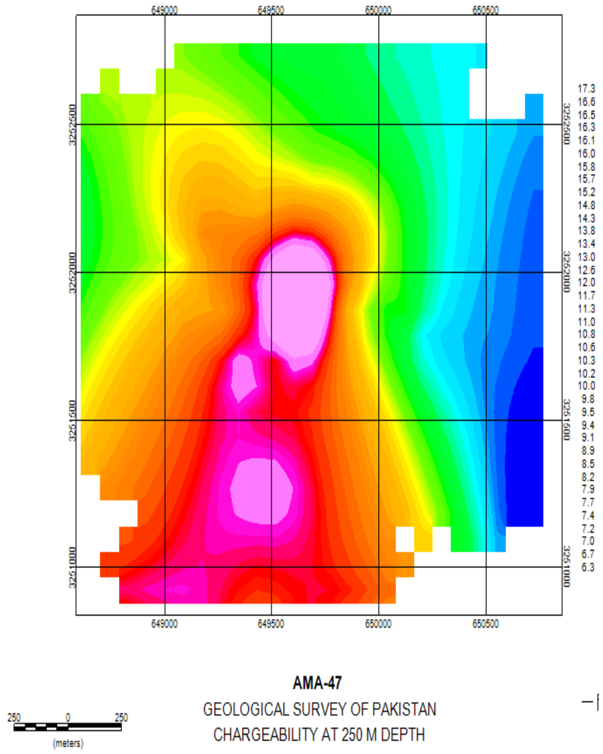


Figure No. 17: IP Survey Chargeability model at 250m depth

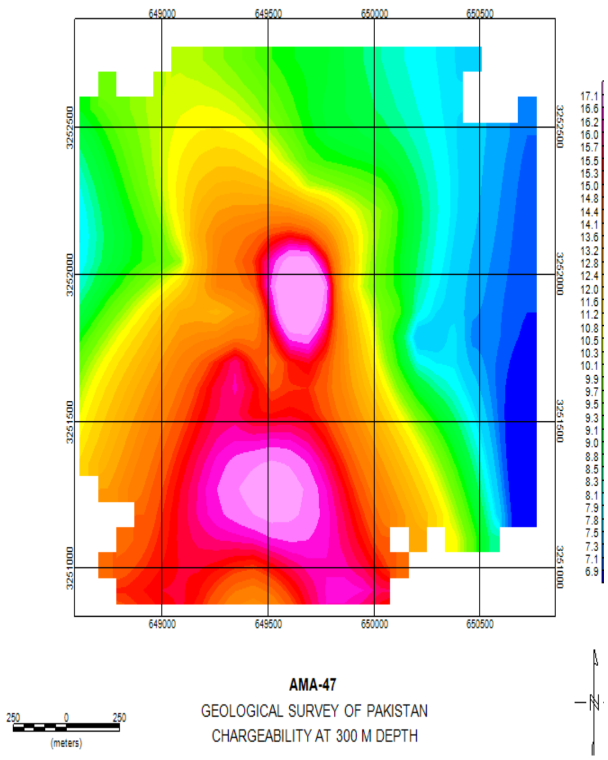


Figure No. 18: IP Survey Chargeability model at 300m depth

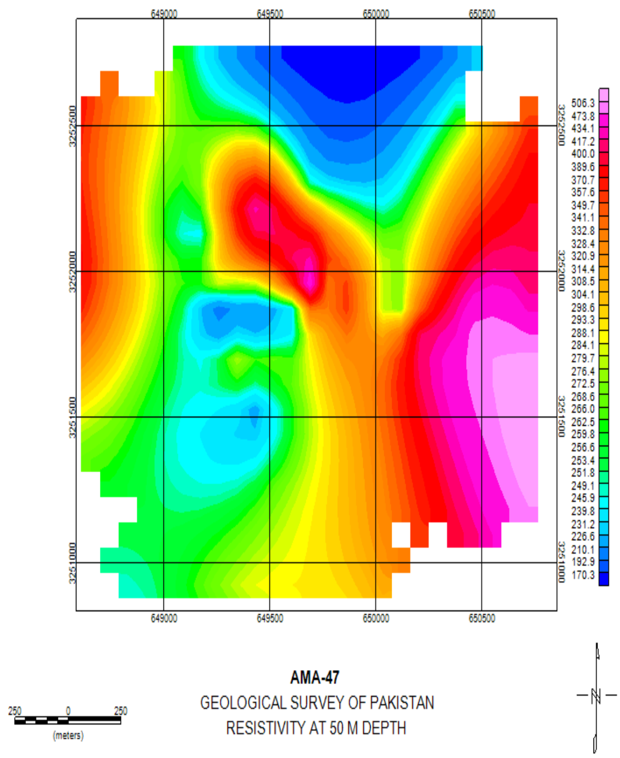


Figure No. 19: Resistivity Survey Model at 50m depth

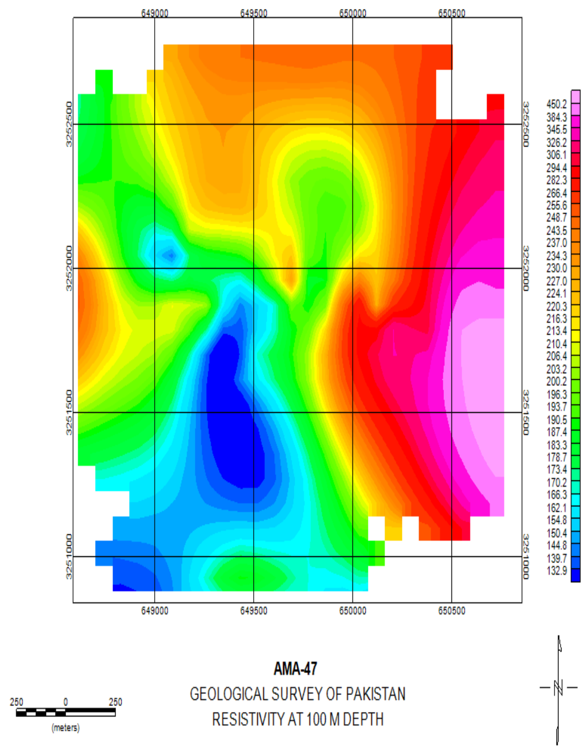


Figure No. 20: Resistivity Survey Model at 100m depth

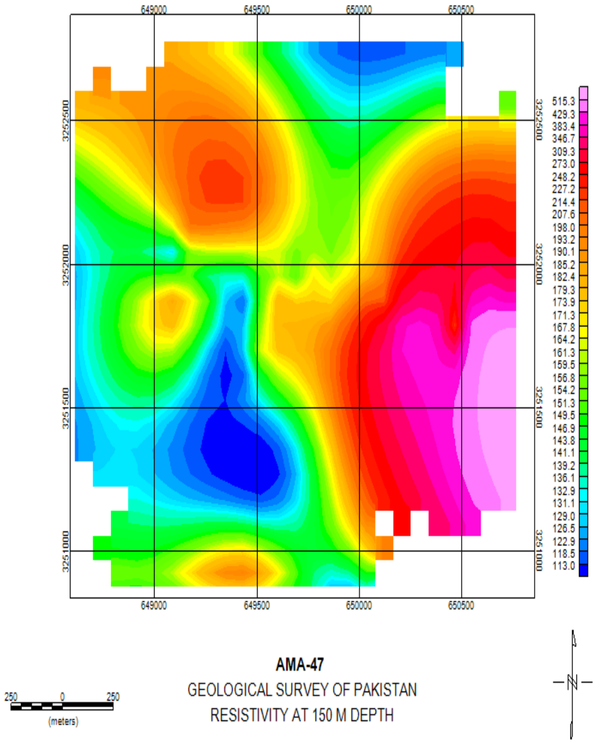


Figure No. 21: Resistivity Survey Model at 150m depth

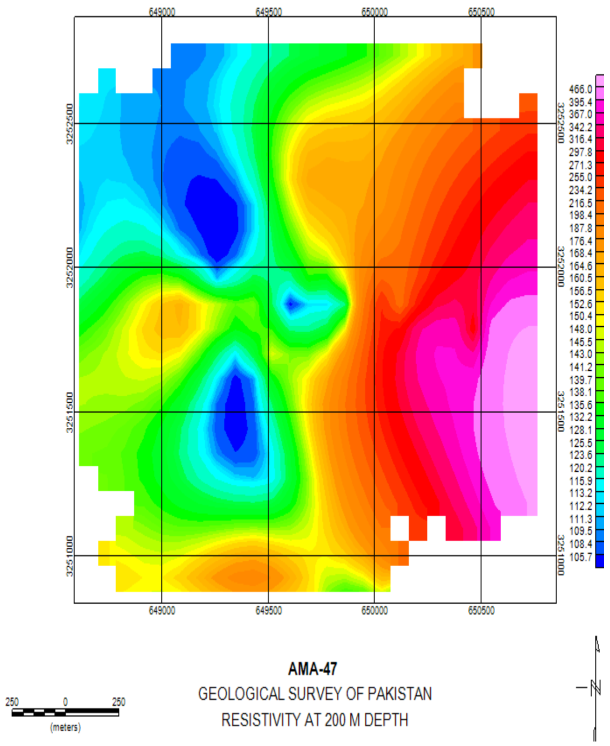


Figure No. 22: Resistivity Survey Model at 200m depth

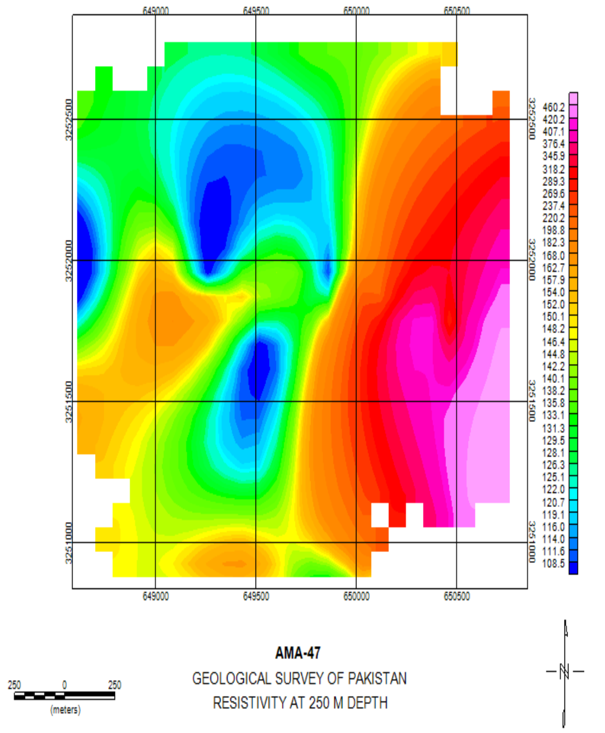


Figure No. 23: Resistivity Survey Model at 250m depth

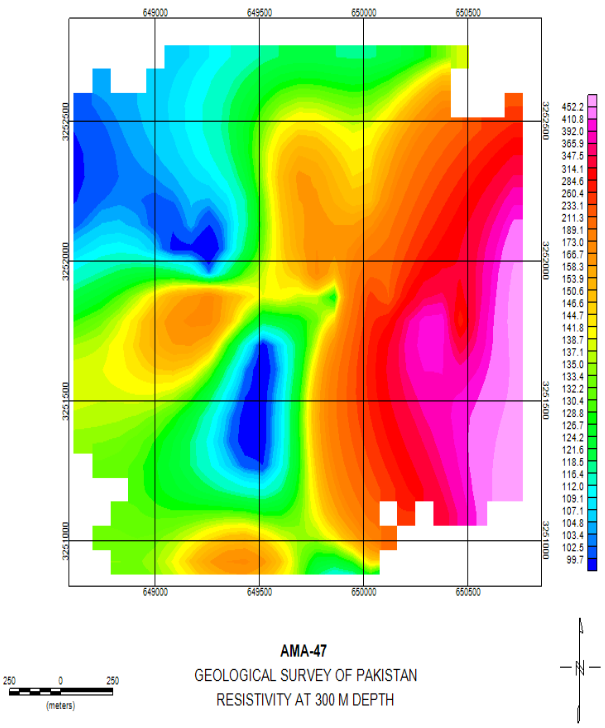


Figure No. 24: Resistivity Survey Model at 300m depth

Interpretation of IP Maps

The site is recommended for exploration of base metal target in Chagai belt with B-type magnetic anomaly i.e. zones of reduced magnetization are suggestive of environment that may involve porphyry type mineralization. A high priority is given to the anomalies in the periphery of Balanosh intrusive.

The IP surveys were conducted on the central part covered by magnetic under exploration of Aeromagnetic Anomaly-47.

The high chargeabilities are also associated with low resistivities at depth although some relatively conductive zones are present near the surface.

The resistivity data marks an important NW-SE trending structure contact on all the extended survey lines. Material on the periphery of this zone is resistive and low chargeability.

Strongly magnetic bodies are concentrated at outer rim of the main chargeability anomalies.

There is a notable decrease in magnetic signature and an increase in IP effect.

The geophysical investigations indicate that the principal magnetite event was centered in the periphery closing the low magnetic zone with high chargeability in the center, indicating the presence of sulphide mineralization particularly copper.

The aeromagnetic anomaly-47 is recommended for sulfide mineralization, overall, the high magnetic signatures were encountered on the outer rim of the map. It is also recommended as a Type-B and Priority-1 Aero-magnetic Anomaly (Allan Spector, 1981).

At the potential zone, the total magnetic amplitude is -1400 gammas and the area is about 1000 x 700 meters with a depth estimation is about 100 to 300 meters.

The high resistivity zone shows the exposed hard rock in the area with restively ranging > 100-ohm meters, whereas the low resistivity is marked on the southwestern end of the maps. The magnetic low is associated with Balanosh intrusive.

Review of Maps and Models for IP

According to the information available, the signature of copper-bearing structures will depend on the percentage of certain accessory minerals such as pyrite or clays. Additionally, the percentage content of other minerals like pyrrhotite, arsenopyrite, or magnetite (if present) will indirectly help to identify mineralized structures, layers, or bodies (refer to Table-1). The strength of the anomaly will be determined by the percentage content of sulfide, thickness, lateral, and depth extent of the mineralized structures. As mineralization is expected to be found in altered areas and along faults, chargeability anomalies indicative of this mineralization should also be associated with resistivity lows.

Minerals	**Chargeability (ms*)**
Pyrite	13.4
Chalcocite	13.2
Copper	12.3
Porphyry	22
Chalcopyrite	9.4
Bornite	6.3
Magnetite	2.2

Table No.1: Handbook chargeability values of certain minerals (Chaidir, Fauzi Yul, et al,s 2021).

On the IP maps, areas with high chargeability and low resistivity have been identified and categorized based on their relative strength. The northwest corner of the mapped region of RES/IP shows a clear correlation and alignment among the magnetic, resistivity, and IP contours.

Notably, this area exhibits significant chargeability anomalies. In addition, there are some weak chargeability responses in the eastern and northern portions of the grid, but they cannot be easily linked to form an axis.

Conclusion and Recommendations

Based on the outlined survey objectives and a comprehensive review of the research material, significant conclusions are drawn:

a. <u>Enhanced Mineral Potential for Sulfide Deposits</u>

Data on the geophysical maps has significantly enriched comprehension of the sulfide deposit potential in the central region around the periphery of the Balanosh intrusive. A robust IP anomaly has been detected, exhibiting a correlation with low resistivity and reduced magnetic signature.

Notably, these characteristics are observed to expand further southward, indicating a promising area for potential sulfide deposits.

b. <u>Chargeability Insights in Different Zones</u>

The drill hole data from Siahdik indicates varying chargeabilities ranging from 12 to 25 in the central part of the area suggesting potential mineralization prospects within this area.

The identified prospective copper zone has been determined to initiate at a depth of approximately 50 meters and shows indications of potential continuation beyond depths exceeding 300 meters.

This depth assessment suggests a substantial vertical extent for the copper-bearing zone, implying the likelihood of significant copper mineralization present in this area from 50 meters depth onward, offering promising prospects for further exploration and mining activities.

c. <u>Exploration Findings in the Southern Area:</u>

Extensive exploration in the northern region did not yield prominent chargeabilities, with measurements ranging from 5 to 6 mv/v recorded at the eastern portion of the mapped area.

Based on geophysical surveys and data, the following drill hole is recommended:

<u>Drill Hole Coordinates</u>

For Copper, drill at:

- 649668N 3251970E (UTM)
- 29°23'16.91"N 64°32'32.38"E (Degree Minutes Second) down to a depth of 300m.

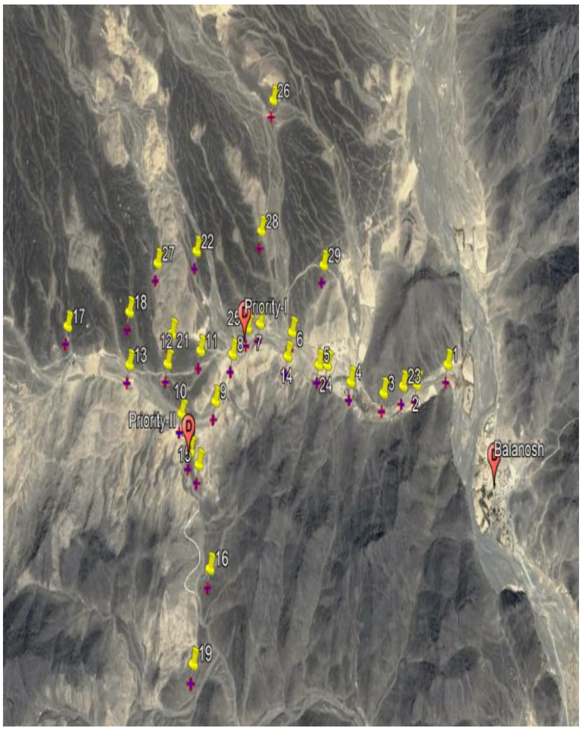


Figure No. 25: Map showing the drill-hole locations and the Wenner profiles

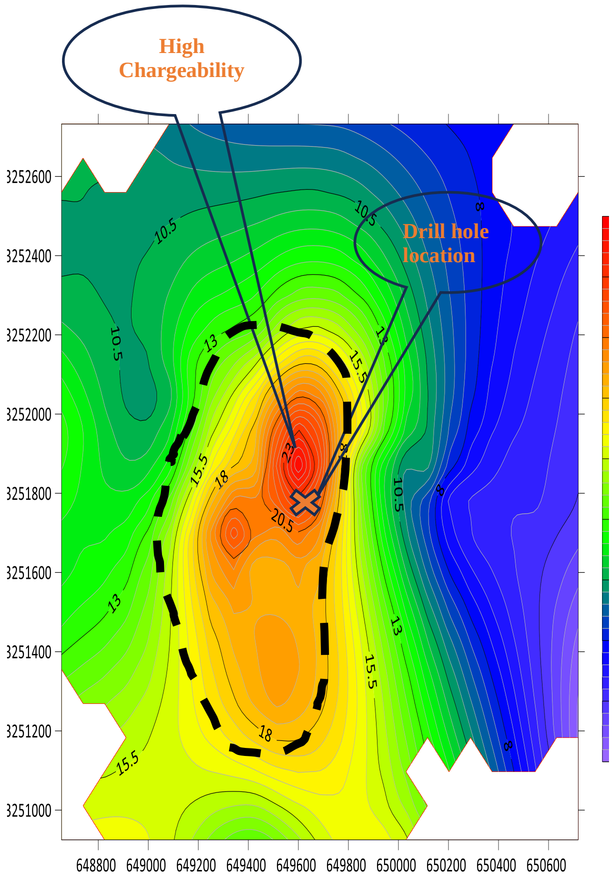


Figure No. 26: Map showing the total area at 150m depth of the anomaly zone (IP >12 mVs/V) showing recommended drill-hole location and HM zone.

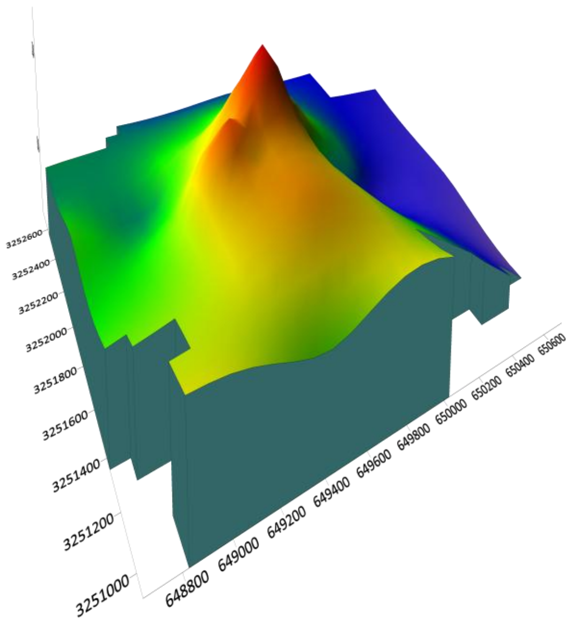


Figure No. 27: 3D Map showing the IP map at 150 meters depth.

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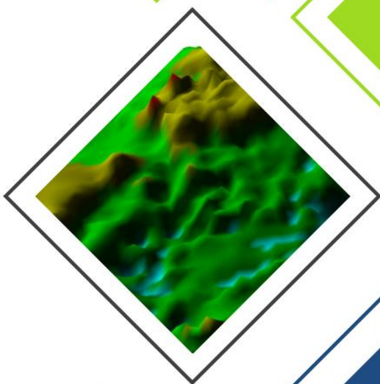

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