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Geophysical investigation for base metal mineralization in Karoi-Rajpura area, Bhilwara district, Rajasthan

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ABSTRACT
Today, there is a challenge before geoscientists to discover new mineral deposits by an exploration technique, which should have low risk, consume less time and also cost effective. Towards reaching this goal, Geophysical methods with the phenomenal improvement in the design and development of equipment, methods and precision of data acquisition, processing and interpretation, play an indispensable role. A combination of SP, IP, Resistivity and Magnetic methods was attempted in Karoi-Rajpura area of Bhilwara District of Rajasthan for locating base metal occurrence. The integrated interpretation of the geophysical response of the different geophysical methods, revealed more precise information about the subsurface configuration and mineral distribution in the prospect area. Strong geophysical anomalies were observed in the northern, southern, central and eastern parts of the study area. The low resistivity zones (200 Ohm-m) and high chargeability zones (>24 mV/V) are situated in the southern and eastern parts of the investigated area. However, to strengthen the reliability of the results, the resistivity map is compared with chargeability map; those who have intersection area between low resistivity and high chargeability (> 24 mV/V), are considered to be the prospective zones of base metal mineralization. However, these low resistivity zones may have been influenced by the presence of clay or weathered soil. In this case, the high chargeability zones will help in confirming the prospective zones caused by base metal mineralization. Recent deep drilling by Hindustan Zinc Limited (HZL) in this area has intersected rich ore lodes, thereby confirming depth wise continuity of ore zones at some places.

Key words: Aravalli craton, Bhilwara Super Group, Polymetallic sulphide belt, Rajpura-Dariba Group.

INTRODUCTION

Rajasthan is endowed with a continuous geological sequence of rocks from the oldest Archaeans represented by Bhilwara Super Group (Bundelkhand gneiss and the banded gneissic complex) to sub-recent, that are exposed chiefly in the central plains, existing between the Aravalli and Vindhyan range (Yadav and Avadich, 2010). The sedimentary rock includes the rocks of Aravalli Super Group, Delhi Super Group and Upper Vindhyan Super Group. The south-eastern extremity of the state is occupied by a pile of basaltic flows of Deccan traps. Several mineral deposits of economic importance occur in association with the above rock units. In Rajasthan, the base metal mineralization is found to be confined to the three successive geological time domains, which are identified as the three geo-synclinal basins namely, Bhilwara basin, Aravalli basin and Delhi basin (Ametha and Sharma, 2008). The area exhibits three phases of deformation, giving rise to complicated structural geometry to the lithology and mineralized zones. The rocks exposed in the study area shows surface indication of mineralization in the form of malachite staining and presence of primary copper minerals. Old workings in South Rajasthan (Bhilwara district) by M/S Hindustan Zinc Ltd. (HZL) include:

Aravalli Supergroup Udaipur Group	Zawar lead-zinc belt.
Bhilwara Supergroup Rajpura Group	Rajpura-Dariba-Bethumni belt. Pur-Banera lead-zinc-copper belt.

Base-metal potential recognition criteria in study area is based on knowledge-driven and data-driven Fuzzy models for predictive mineral potential mapping (Porwal et al., 2003a) as well as tectonostratigraphy and base-metal mineralization controls (Porwal et al., 2006b). These findings prompted to conduct geophysical survey in small patch e.g. Karoi-Rajpura area, Bhilwara district to assess the mineralization. Integrated geophysical surveys comprising Self Potential (SP), Induced Polarization (IP) cum resistivity and magnetic surveys have been carried out in Karoi-Rajpura area, Bhilwara district, Rajasthan for delineating the mineralized zones (Figure 1).

GEOLOGY OF THE STUDY AREA

The NE-SW trending Proterozoic Pur-Banera metasedimentary belt in south-east Rajasthan is metallogenetically important. The Karoi-Rajpura area forms a part of the Pur-Banera belt in Bhilwara district, Rajasthan. Regionally, the Karoi-Rajpura area forms a

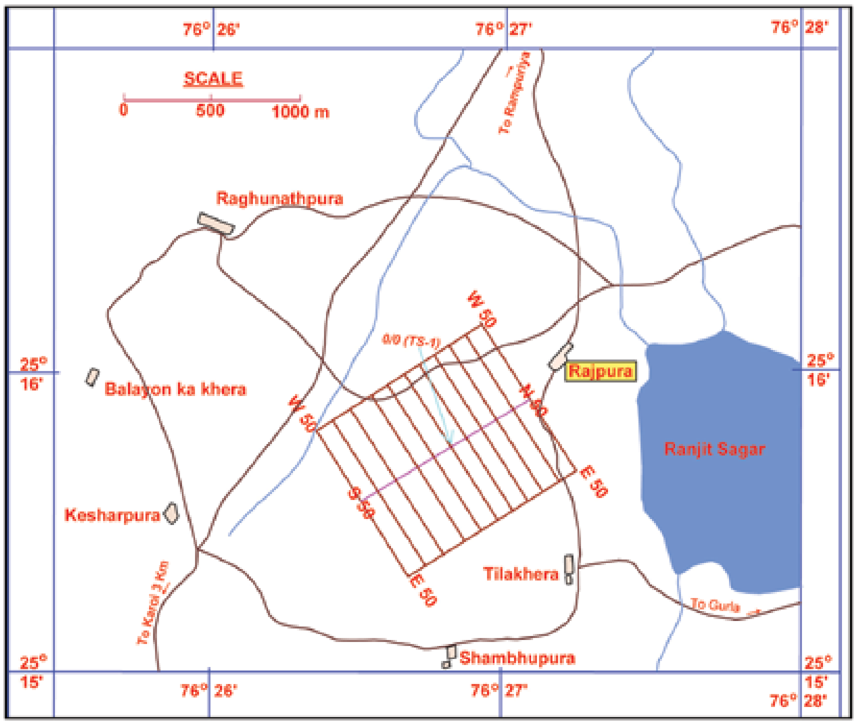

Figure 1. Location Map of the Karoi-Rajpura area, Bhilwara Districts, Rajasthan. 0/0 indicates traverse 1 (TS-1).

part of the western limb of the Pur-Syncline and all the rocks of the area have a generalized NE-SW to NNE-SSW trend (Fig. 2). The main rock types exposed in the area belong to Mangalwar Complex of Bhilwara Supergroup and metasediments of Pur-Banera Group. The rocks of Mangalwar Complex are represented by biotite + garnet + staurolite + kyanite schist along with arenaceous and amphibolite bands. Schist, quartzite, conglomerate, calc-silicate and metavolcanic represent the rocks of Pur-Banera Group. Profuse malachite staining and primary chalcopyrite, pyrrhotites are observed in the western part of the area. Sulphide mineralization has been observed at several locations and the host rock for the mineralization is mostly calc-silicate dolomite and graphite mica schist of Rajpura-Dariba Group (Ametha and Sharma, 2008; Haldar, 2001; Haldar and Deb, 2001). The lead-zinc mineralization occurs in the form of galena and sphalarite (Mishra, 2000). Structures associated with mineralization such as folds, faults, veins and shear zones highlight the importance of a changing history of brittle and ductile deformation for economic mineralization. The Dariba-Rajpura part of the area show very narrow basin elongated for a strike length of 3 km. In this part, the mineralized loads are concentrated along two faults. These two faults are parallel to each other and the regional strike of the area, thus almost N-S. Among two faults, eastern fault has accumulated metals to form a load called east load. In the western fault there are two loads, named north load and south load. It is very clear that the mineralization is faulting controlled (Nawal, 2017). Stratigraphy of the study area (Gandhi, 2001) is given below:

Intrusive	Quartz vein Granite
Rajpura-Dariba Group	*Upper Unit:* Interbanded quartzite and mica-schist/ash bed/ tuffaceous mica-schist/graphite mica-schist. *Middle Unit:* Limonitised graphite mica-schist, silicified/ gossanised ferruginous chert breccia. Garnetiferous-magnetite quartzite. Graphite±garnet±staurolite±kyanite±a ndalusite, mica-schist, micaceous cherty dolomite, acid-basic volcanics, tuffaceous/ carbonaceous/mica-schist. *Lower Unit:* Marble, amphibolite, metamarl, quartzite and conglomerate.
Unconformity	
Mangalwar Complex	Migmatites Gneisses and schist.

MINERALIZATION

India has a geological and metallogenic history similar to the mineral-rich shield areas of Antarctica, Australia, South Africa and South America. Its geological domains are well endowed with mineral resources; however, they are yet to

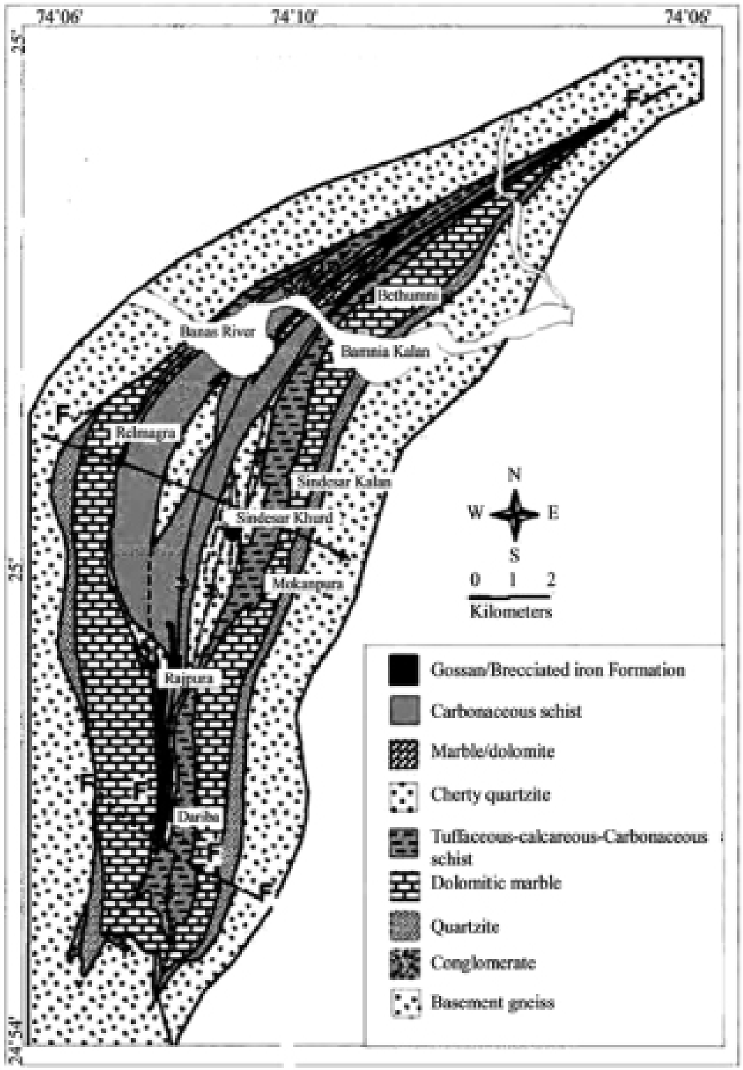

Figure 2. Geological map of the study area (after Ametha et al., 1999).

be fully explored, assessed and exploited. Interestingly, the Proterozoic Aravalli-Delhi orogenic complex hosts a large number of economically important strata bound base metal sulphide deposits. Rock samples taken from Outcrop and Underground mines of Sindeskar Kalan, Vedanta Group, Rajpura-Dariba-Bethumni Belt have been petrographicaly by Juned Alam et al., (2015). The chief litho-units of the group which were identified contain sulfide-bearing calc-silicate and graphite mica schist, dolomite marble, calc-biotite schist and quartzite. Important ore minerals like galena and sphalerite, which have been reported in association with the buffer minerals like pyrite and pyrrhotite, occurred in these host rocks (Juned Alam and Farhat Nasim Siddiquie, 2015). Keeping in mind the importance of mineral exploration, geophysical surveys employing SP, magnetic (VF) and IP cum resistivity, were carried out in the study area for delineating sulphide mineralization.

Geophysical Instruments and Survey Layout

The IP unit used in the present survey consists of an 8 HP petrol engine generator, 3 KW transmitters (TSQ-3) and IPR-10A receiver of Scintrex make. The SP measurements were made using NGRI, India, make digital potentiometer. A vertical field conventional Fluxgate Magnetometer was used for magnetic survey. Sensitivity of potentiometer used for SP survey was ± 1 mV, for magnetometer was 10 nT and for IP receiver was ±0.5 mV/V.

Geophysical surveys were carried out with base line trending in N60°E direction. A total of 11 regular traverses (N50, N40………S50), each 1000 m in length were laid orthogonal to base line at 100 m interval and 20 m station interval. All the observations were taken in 100 m X 20 m grid pattern. The unit of distance was kept 10 m for traverses as well as for stations also.

RESULTS AND DISCUSSION

Results of geophysical surveys comprising SP, magnetic, IP chargeability and resistivity methods have been presented in the form of contour maps to identify the significant anomaly zones, which might reveal mineralization. Structures associated with mineralization such as folds, faults, fissures and shear zones highlight the importance of a changing history of brittle and ductile deformation for economic mineralization. The Dariba-Rajpura part of the area show very narrow basin elongated for a strike length of 3 km. In this part, the mineralized loads are concentrated along two faults, which are parallel to each other and the regional strike of the area, thus run almost N-S. Among the two faults, eastern fault has accumulated metals to form a load called east load. In the western fault, there are two loads named north load and south load. Thus it is very clear that the mineralization in this area is fault controlled (Nawal, 2017).

Self Potential (SP) survey

This method makes use of small currents which are naturally produced beneath the Earth's surface. SP method is mainly used for exploration of massive sulphide ore bodies, finding leaks in canal embankments, defining zones and plumes of contaminants, etc. The data in the study area has been presented in the form of contour map as shown in Figure 3. SP value in the surveyed area varies from + 20 to – 50 mV. The map has indicated SP low anomaly zone of about 100 m width, bounded by – 10 mV contour trending in E-W direction. The highest magnitude of SP anomaly is about – 15 mV. This anomaly extends from '0' (traverse 1; TS-1) in the north to traverse S10 in south as indicated in the contour map. The dimension of anomaly zone is about 100 m X 100 m. Another SP low anomaly zone of about 200 m width, bounded by – 5 mV contour trending in N-S direction has the peak anomaly of – 10 mV. This anomaly extends from N15/E40 in the north to traverse S10 in the south. The dimension of this anomaly zone is 200 m X 200 m. The continuous E-W trending SP anomaly zone in the north-east corner beyond north of traverse N40 is indicative of litho contact in the surveyed area.

Magnetic (VF) survey

In the present study area, the magnetic base was chosen at a non-magnetic point and the magnetic observations were taken in 100 m X 20 m grid pattern. All the magnetic data were processed with respect to base and results are shown Figure 4. The magnetic value varies from – 300 nT to + 700 nT in the area. The magnetic survey has delineated few isolated magnetic high anomaly zones of the order of about 500 nT in the north-west part of the area. In this zone, there are five isolated peaks of the order of 650 nT that may be due to the presence of some ferruginous magnetic material. High magnetic responses observed in western part compared to eastern part may be due to the lithological contacts in the area apart from picking up a few dipolar-nature anomalies. These high amplitude dipolar anomalies suggest either emplacement of basic bodies along some fault planes, or the faults/fractures, along which concentration of magnetite is a natural phenomenon.

Induced Polarization (IP) survey

IP survey was carried out in the area using dipole-dipole array with a = 20 m and n = 3, where 'a' is array spacing and 'n' is represented by separation parameter between the current and potential electrode pair (Kearey et al., 2003). Dipole-dipole array was used in the field measurement by considering that even though it has low vertical resolution, it is very sensitive to deeper lateral variations, making it suitable for deeper sounding (Reynolds, 1997). Chargeability and resistivity values were measured at an interval of 20 m. The results of IP chargeability have been presented as a contour map (Figure 5), which revealed four anomaly zones that are favorable for mineralization, as discussed below. These anomaly zones are trending almost in N-S and NE-SW directions. The peak magnitude in these fair anomaly zones is varying from 20-28 mV/V. The chargeability anomaly zones may be due to base metal sulphide mineralization.

Zone-I: This zone is reflected by an anomaly having a peak magnitude of 28 mV/V over background of 14 mV/V. This anomaly zone is trending almost in a NE-SW direction and is occurring between traverses S15 in north and S45 in the south. The extent of this anomaly zone is about 200 m and width is about 50 m (between E5 and E10). This zone has indicated two isolated anomalies of 2 to 6 mV/V near station E5 on traverse S20, and E10 on traverse S40 respectively.

Zone-II: This zone is trending almost in a NE-SW direction having peak magnitude 20 mV/V over a background of 14 mV/V, which is localized in nature near station E35 on traverse '0' (TS-1). The background contour 14 mV/V extends over wider area and is open towards north and is still continuing as reflected from contour map. The extent of this anomaly zone is about 150 m. This zone is also supported by the occurrence of SP anomaly.

Zone-III: This zone is characterized by an anomaly of the order 20 mV/V over a 14 mV/V background. This zone is trending almost in a NE-SW direction and is occurring between traverses N50 in the north and N40 in the south.

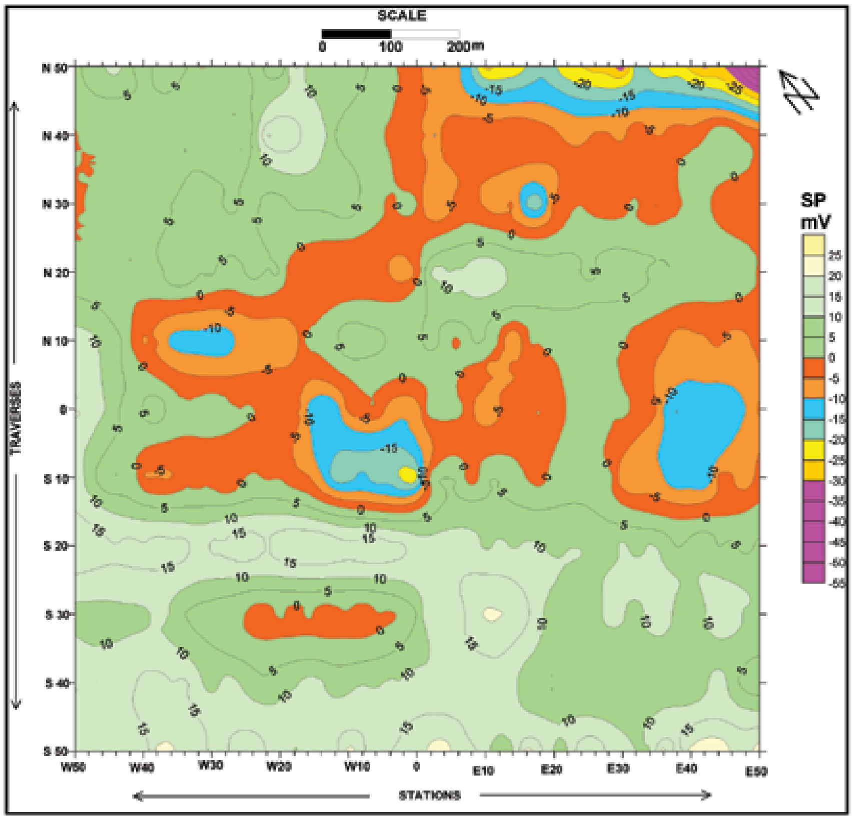

Figure 3. SP contour map of Karoi-Rajpura area, Bhilwara district, Rajasthan. '0' indicates traverse 1 (TS-1).

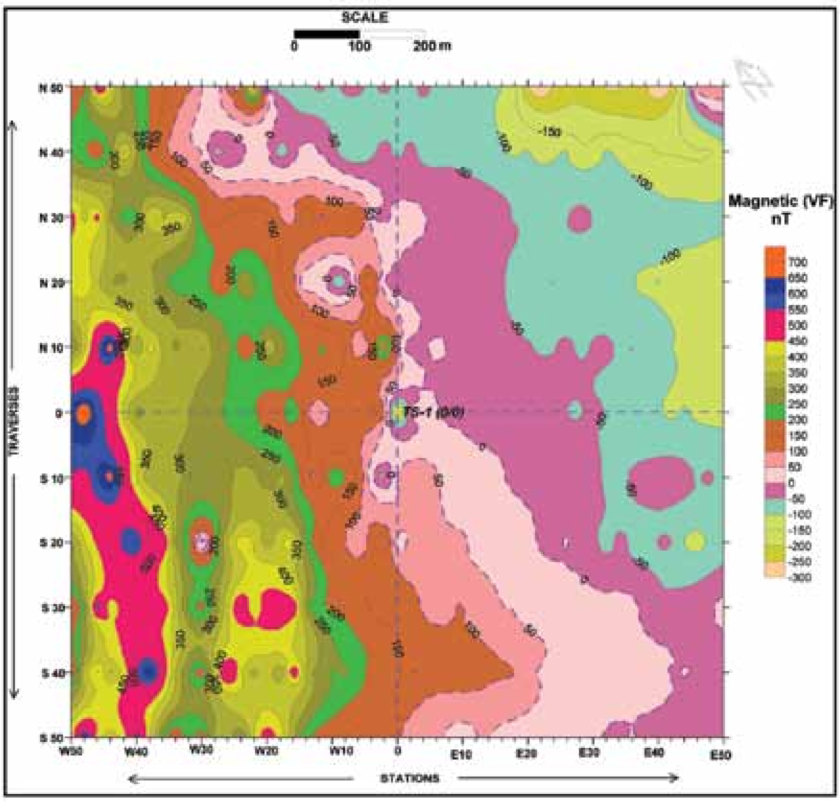

Figure 4. Magnetic (VF) contour map of Karoi-Rajpura area, Bhilwara district, Rajasthan.

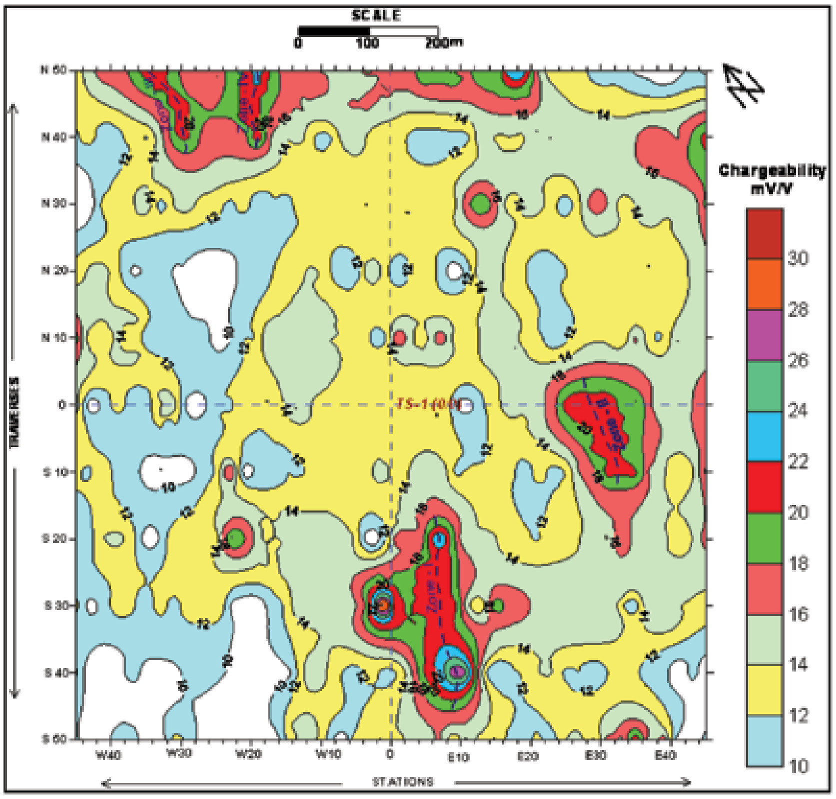

Figure 5. Chargeability contour map (a=20m & n=3) of Karoi-Rajpura area, Bhilwara district, Rajasthan.

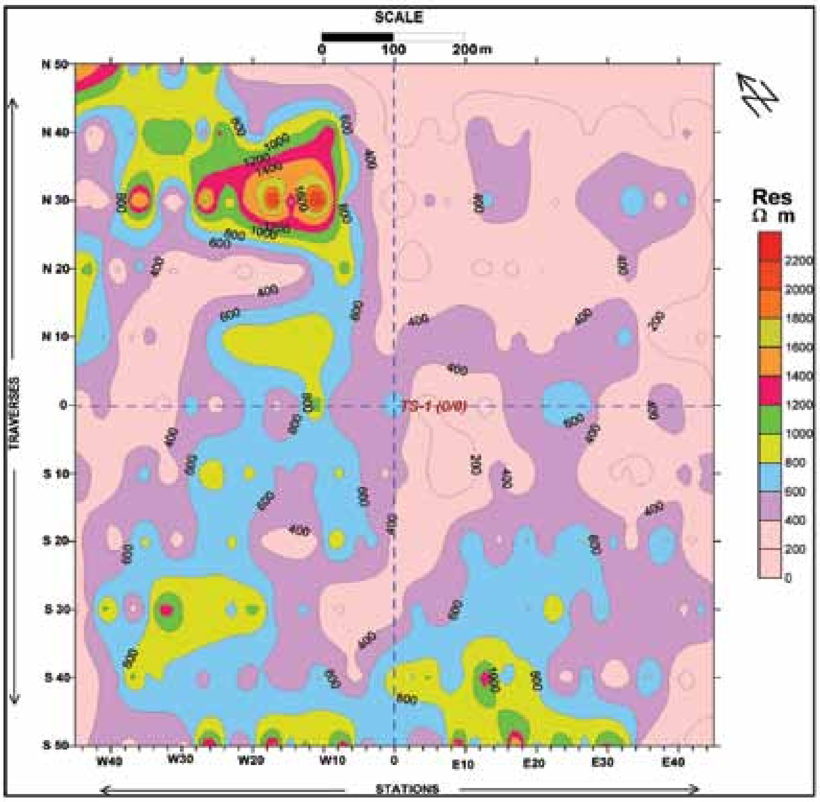

Figure 6. Resistivity contour map (a=20m and n=3) of Karoi-Rajpura area, Bhilwara district, Rajasthan.

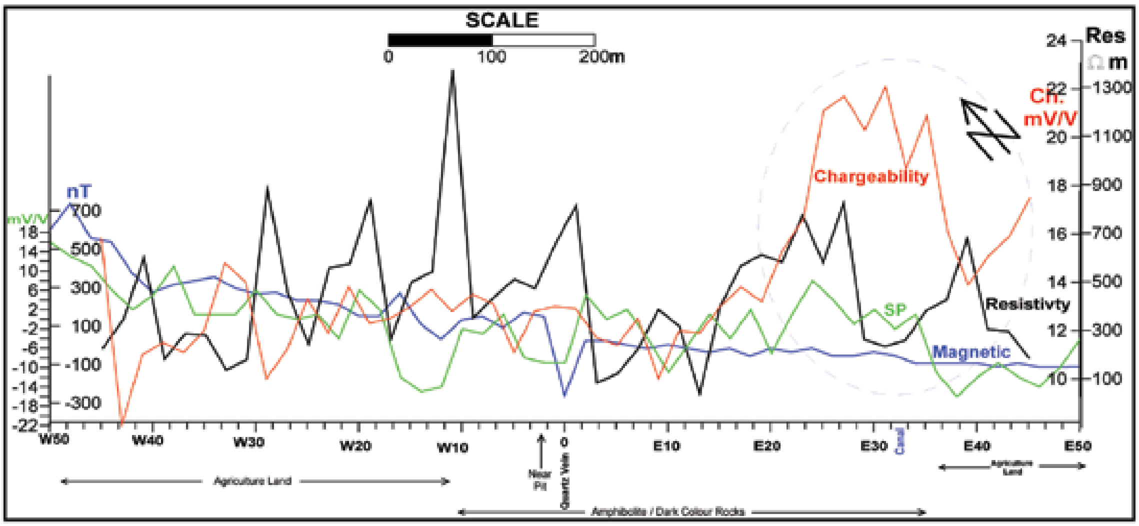

Figure 7a. SP, magnetic, IP cum resistivity profiles along traverse '0' (TS-1) of Karoi-Rajpura area, Bhilwara district, Rajasthan.

The extent of this anomaly zone is about 100 m and width about 40 m (between W35 and W30).

Zone-IV: This zone is characterized by an anomaly of the order 20 mV/V over a 14 mV/V background and is trending almost in a N-S direction. This zone is occurring between traverses N50 in north and N40 in the south like in Zone-III. The extent of this anomaly zone is about 100 m and width is about 50 m (between stations W25 and W30). The continuous high chargeability value between stations W10 to E25 of traverses N45 and N50 corroborated with low SP trend has been recorded in the surveyed area.

Resistivity survey

The result of resistivity survey has been presented in the form of a contour map (Figure 6). Almost throughout the map, resistivity values range between 200 and 400 Ohm-m, which is considerably low from overall perspective. This feature may be attributed to the presence of base metal mineralization and/or clay matrix or rocks with low bulk resistivity. The rocks with mineralization content are interpreted to have resistivity < 600 Ohm-m. However, to strengthen the reliability of the results, the resistivity sections are compared with chargeability sections, those who have intersection area between low resistivity and high chargeability (> 24 mV/V) are considered to be the prospective zones of mineralization. The low resistivity closure in the central and eastern portion of the surveyed area is corroborated with high chargeability zone. These zones may strongly correlate to the presence of base metal mineralization. These low resistivity zones may have been influenced by the presence of clay or weathered soil. In this case, the high chargeability zones will help in confirming the prospective zones caused by sulphide mineralization. However, several isolated zone of high resistivity of the order of 800 Ohm-m have been picked on traverse S50. This anomaly may be due to presence of hard rock in subsurface.

Representative profile

Representative anomaly profiles 0 (Figure 7a), N50 (Figure 7b), S30 (Figure 7c) and S40 (Figure 7d) are presented in order to quick look of described anomalous zones in the study area.

Representative anomaly profile '0' (traverse-1; TS-1) has been shown for easy comprehension. High chargeability value of magnitude 22 mV/V is corroborated with low resistivity value (300 Ohm-m) with a flat magnetic response at station E30 (Figure 7a). Another geophysical anomaly having low SP of – 16 mV, is well corroborated with high chargeability (18 mV/V) and low resistivity (200 Ohm-m) along with high magnetic response (300 nT) at station W32.

Representative anomaly profile 'N50' has shown high chargeability value of 30 mV/V (Fig. 7b) is associated with low resistivity, flat magnetic response and high SP values around station -60 (60 m towards west from center). Another high chargeability value of 25 mV/v is observed around station 200 (200 m towards east from center) which is associated with low resistivity, low magnetic and low SP values. In between station, -60 to 200 moderate chargeability values have been observed. High amplitude magnetic response is observed around station -220, (220 m towards west from center) which is, associated with high chargeability values (22 mV/V).

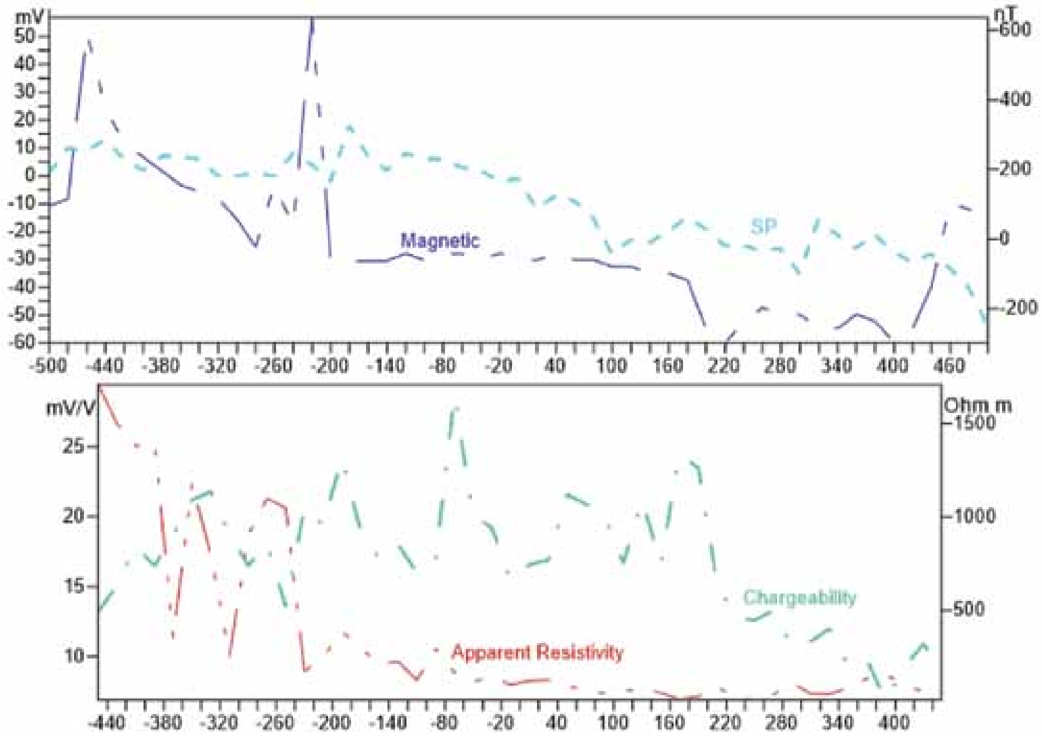

Figure 7b. SP, magnetic, IP cum resistivity profiles along traverse N50 of Karoi-Rajpura area, Bhilwara district, Rajasthan.

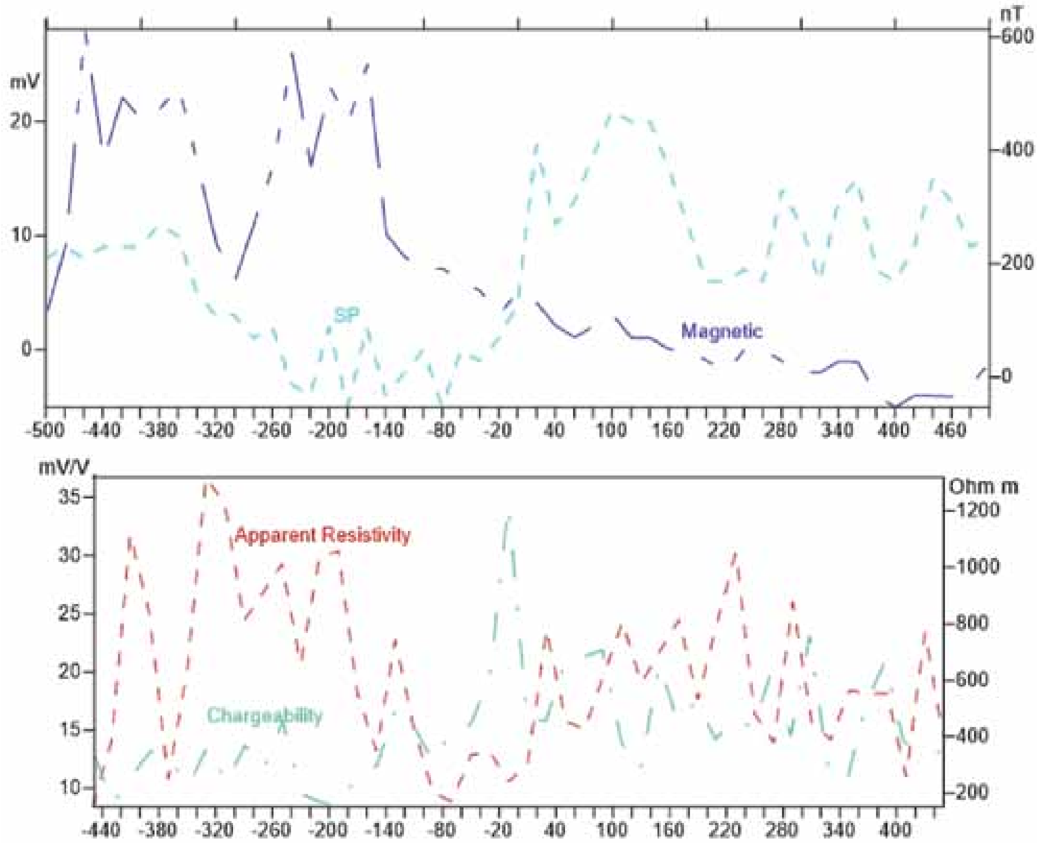

Figure 7c. SP, magnetic, IP cum resistivity profiles along traverse S30 of Karoi-Rajpura area, Bhilwara district, Rajasthan.

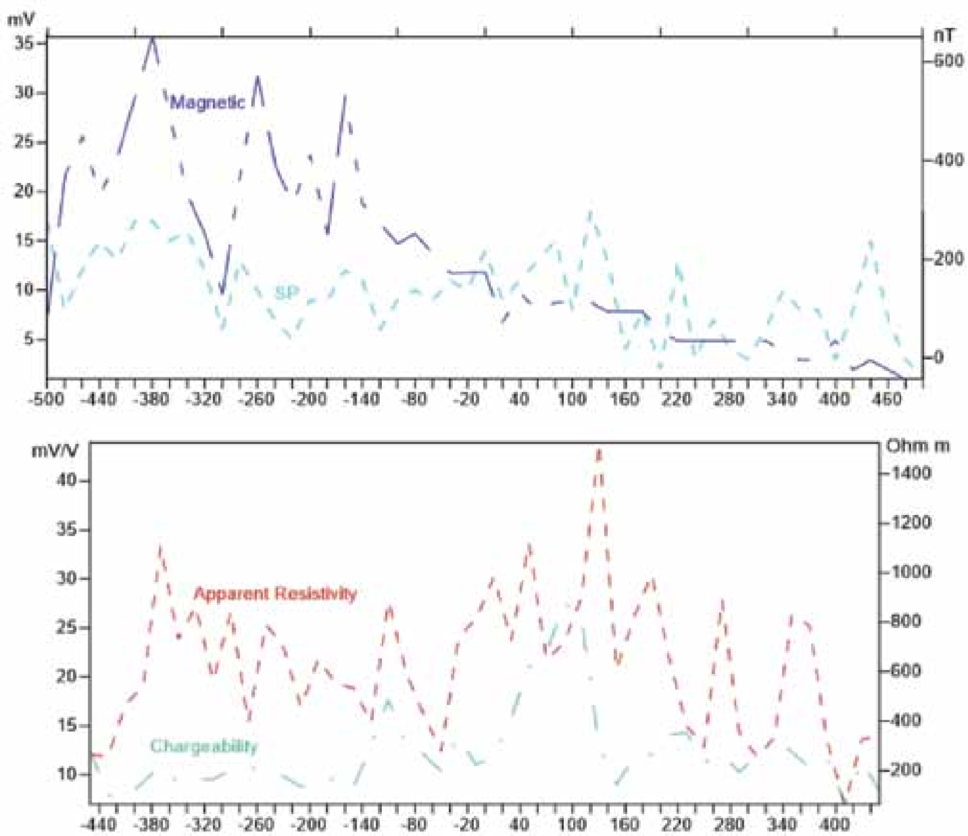

Figure 7d. SP, magnetic, IP cum resistivity profiles along traverse S40 of Karoi-Rajpura area, Bhilwara district, Rajasthan.

Apart from these fluctuating responses are observed throughout the profile.

Representative anomaly profile 'S30' has shown intermediate chargeability value of 15 mV/V, which is associated with high resistivity (Figure 7c), low SP and high amplitude magnetic responses around station in between -140 to -360 (140 m to 360 m towards west from center). High SP value of 20 mV is observed around station in between 80 to 160 (80 m to 160 m towards east from center) and is associated with low magnetic, high resistivity and low chargeability values. Gradual decrease in magnetic response is observed in between station -140 to 500 (140 m from west to 500 m east).

Representative anomaly profile 'S40' has shown high chargeability value of 27 mV/V which is associated with low resistivity, low magnetic and low SP values (Fig. 7d) around station 80 (80 m towards east from center). High resistivity values are corroborated with low chargeability values throughout the profile. High amplitude (300-600 nT) magnetic values are observed in between station -140 to -260 (140 m to 260 m towards west from center), which is associated with low SP values.

EXPLORATION AND DEVELOPMENT

The details of exploration activities conducted by GSI during 2012-13 have been given below:
Agency: GSI; Mineral: Base metal; District: Bhilwara
Location: Karoi & Rajpura
Drilling: No. of boreholes = 8 and Meterage = 1224
Remarks: Reserves/Resources estimated
Prospecting stage investigation (G-3) was carried out for base metals in areas in Pur-Banera belt, to assess the base metal potential of the area. Based on field evidences and ore microscopic studies, it is established that the mineralization is strata bound and evidences of remobilization has been identified. The sulphide mineralization occurs as fracture filling in the form of stringers and veins. The investigation was supplemented by drilling to test the presence of sub surface copper mineralization in this area. The different units intersected in the boreholes are biotite bearing banded calc silicate rock, amphibole bearing banded calc silicate rock and garnet bearing banded calc silicate rock. The sulphide mineralization intersected in the boreholes are in the form of disseminations, stringers and veins of chalcopyrite, bornite, covellite, pyrite and pyrrhotite.

Analytical results of borehole BH-1 have been received. One mineralized zone is intersected in this borehole between depths of 3.00 m and 8.70 m with 0.28 % Cu.

CONCLUSIONS

Geophysical surveys in the area have delineated four anomaly zones favorable for the occurrence of sulphide mineralization. IP survey has brought out four chargeability zones trending N-S and NE-SW directions. Zone-I in NE-SW direction falling in the southern part of the area has moderate order of anomaly. This anomaly zone seems to be favorable for sulphide mineralization and has a dimension of about 200 m X 50 m. Zone-II aligning in NE-SW direction falling in the central portion of surveyed area has a strike length of 150 m. This zone is well corroborated with low SP anomaly. Zone-III trending in N-S and NE-SW directions is lying in northern corner of the area and is extending for 100 m. The opening of 20 mV/V chargeability anomaly contour has indicated its further extension in northern side of surveyed area. Zone-IV aligning in N-S and NE-SW directions is open towards northern side. This zone has strike length of 100 m. The magnetic and SP surveys have picked up lithological variation as well as structural features. State-of-the-art modeling workflows can lead to a better structural insight in already developed and explored mine settings (Vollgger et al., 2015). It may be concluded that the most potential zone of possible mineralization is concentrated in the base metal sulphide deposits and the host rock for the mineralization is mostly calc-silicate dolomite and graphite mica schist of Rajpura-Dariba Group. Based on the present studies structural and lithological controls of base metal mineralization have been recorded and guides for searching new areas and exploration strategy has been suggested here.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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