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Integrated ERT and Magnetic Surveys in a Mineralization Zone in Erkowit - Red Sea State - Sudan

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ABSTRACT
The present study focus on integrated geophysical surveys carried out in the mineralization zone in Erkowit region, Eastern Sudan to determine the extensions of the potential ore deposits on the topographically high hilly area and under the cover of alluvium along the nearby wadi and to locate other occurrences if any. The magnetic method (MAG) and the electrical resistivity tomography (ERT) were employed for the survey. Eleven traverses were aligned approximately at right angles to the general strike of the rock formations. The disseminated sulfides are located on the alteration shear zone which is composed of granitic and dioritic highly ferruginated rock occupying the southwestern and central parts of the area, this was confirmed using thin and polished sections mineralogical analysis. The magnetic data indicates low magnetic values for wadi sedimentary deposits in its southern part of the area, and high anomalies which are suspected as gossans due to magnetite formed during wall rock alteration consequent to mineralization. The significant ERT imagesdefinelow resistivity zone as traced as sheared zones which may associated with the main loci of ore deposition. The study designates that correlation of magnetic and ERT anomalies with lithology are extremely useful in mineral exploration due to variations in some specific physical properties of rocks.
Keyword: ERT, Magnetic, Mineralization, Red Sea, Sudan

I. INTRODUCTION

By itself, no geophysical anomaly can simply be correlated with lithology (Lyatsky, 2004). The integration of the geophysical methods became the main tool for successful prospecting in the complex environments of mountainous ore regions with rugged topography, intense tectonics and multitude of rock classes or other factors that make the interpretation of the geophysical anomalies rather difficult. Subsurface models of the earth obtained from a combination of two or more geophysical methods are also likely to be more reliable than those obtained from a single method. Such integration is increasingly being used in the recent years to reduce the ambiguity in interpretation. The ambiguity in geophysical data interpretation is comprehensively dealt with in a classic paper by Roy (1962), an integrated approach involving two or more techniques is recommended (Sill et al., 1977; Bahr, 1983; Stanica and Stanica, 1993; Wang, et.al, 1993, Oldenburg et.al, 1994; Hering et al., 1995; etc). Similar to other geophysical methods, electrical (E) method suffers from ambiguity in interpretation dueto the phenomena of the 'principle of equivalence', especially for thin middle layer problems(PatraandMallick,1980;ZhdanovandKeller,1994). The effectiveness of resistivity data inversion and the quality of tomographic interpretation is highly dependent on accuracy, resolution and equivalence, a description of which is provided in Hauck (2001).

This study focus on the potentiality of gold mineralization zone and mapping the extension of the ore deposits and their associated structural features in Erkowit region (Fig.1) in Eastern Sudanusing magnetic (MAG) and electric resistivity tomography (ERT) methods. However, the specific objective of the study is to provide an idea on both the magnetic field susceptibility and the geo-electric anomalies of the underlying rocks. Based on these integrated anomalies, maps showing the vertical and lateral extensions of the ore deposits layers are generated with the potential mineralization zones for satisfactory core drilling borehole.

The aim of the magnetic survey is to investigate subsurface geology on the basis of base-metal anomalies in the earth magnetic field resulting from the magnetic properties of the underlying rocks. Although most rock forming minerals are effectively non-magnetic certain rock types contain sufficient magnetic minerals to produce significant magnetic anomalies.The magnetic (MAG) measurements are made easily and cheaply than most geophysical measurements and corrections are practically unnecessary. The magnetic field variations are often diagnostic of mineral structures as well as regional structures, but this method is the most versatile of geophysical prospecting techniques. However, like all potential methods, magnetic method lack of uniqueness of interpretation (Telford et.al, 1990).

A more accurate model of the subsurface can be produced using a two-dimensional (2-D) electrical resistivity tomography, where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line (Loke, 2000). The ERT method was chosen in the current study to provide some redundancy to the MAG data and to improve the quality of the conductivity/resistivity responses. Each ERT profile was inverted applying a cell based inversion routine; it subdivided the subsurface into a number of rectangular cells whose positions and sizes are fixed, then it is used to determine the resistivity of cells that provides a model response which agrees with the observed data (Loke et al., 2003).

II. GEOLOGY OF THE STUDY AREA

Erkowit region represents the study area which lies in the eastern part of the Red Sea state (Fig.1) and characterized by a tropical arid climate. However, the region has its own peculiarities due to the presence of the Red Sea as an adjacent water body, the Red Sea Hills as an effective physical barrier and the coastal plain as a narrow flat surface. Erkowit region lie within the heights peak in the Red Sea Hills, with 20^oC as an average temperature. Geomorphological, the study area represents part of the high rugged Red Sea Hills Terrain, sloping rapidly to the east towards the Red Sea relatively and gently to the west towards the Nile, and El Sit Mountain as the highest peak ~ 1808m (Fig.1). This high terrain is an integral part of the upper Eocene uplift of the African-Arabian swell (Mohr, 1971). This swell was later divided by the East African Rift system into an eastern Arabian and a western Nubian part. The Red Sea Hills Terrane is intensively dissected by a complex drainage network which is highly controlled by the prevailing structural elements of the region. Other physiographic features of the area include the coastal strip and the Red Sea.

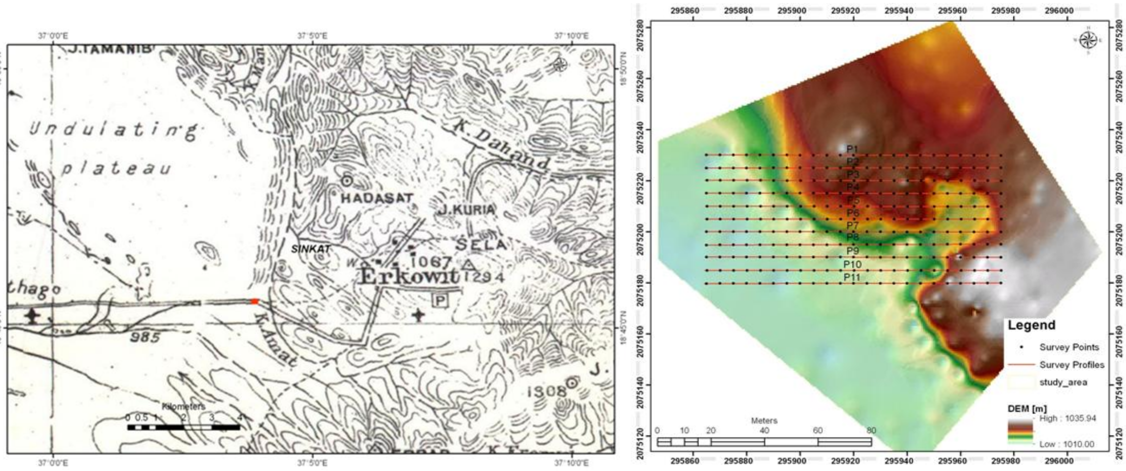


Fig.1: Location map of the study area and a digital elevation model (DEM) map shows the general topography, overlapped by the selected locations of the eleven ERT profiles.

Topographically the target area slopes towards the southwest with highest elevations of 1035m at its southeastern limits and lowest elevation of 1010m on the eastern limits towards the wadi. This gives a topographic gradient of 0.9% in a SE direction or at a drop of 9 m/km. The regional geology of the study area being a part of the Red Sea Hills lies entirely within Erkowit Terrain comprises different lithological units (Krorner, et.al, 1991) overlain the Pre-Cambrian Basement complex which is comprises of high-grade gneisses (Kashabib Series), the low-grade Volcano-sedimentary group intruded by igneous assemblages. The lithological sequence is followed upwards by Tertiary coastal sedimentary sequences, overlain by Tertiary volcanic and finally surficial Quaternary Sediments

III. MINERALOGICAL ANALYSES

The occurrences of gold and disseminated sulfides lie as a part of the shearing fault zone that extends from the northeast to the southwest of the study area for a length of about 250 m. The gold and disseminated sulfides are located on the alteration shear zone which is composed of granitic and dioritic highly ferruginated rock occupying the southwestern and central parts of the area (Fig.2). Using thin and polish sections mineralogical analyses that were done on bedrock samples of the oxidized and alteration zones, few indications are found.

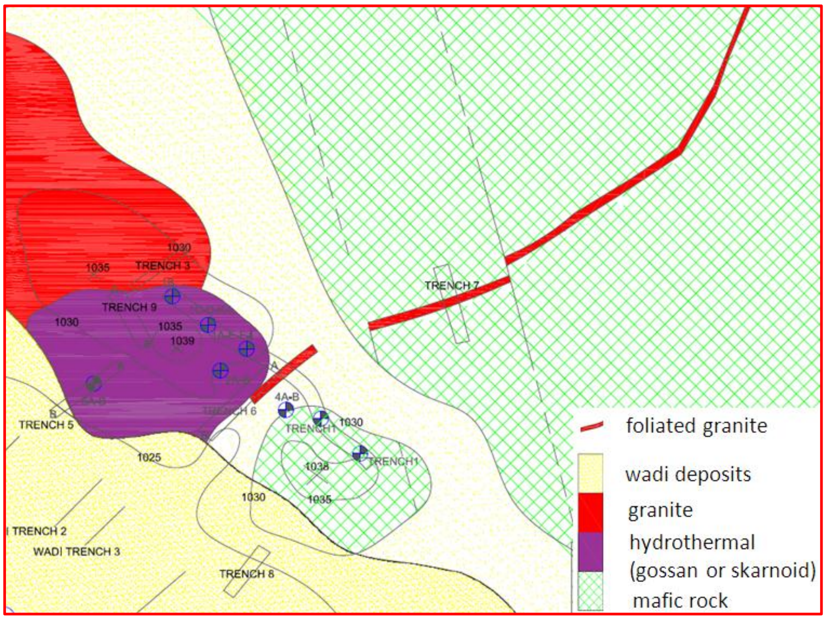
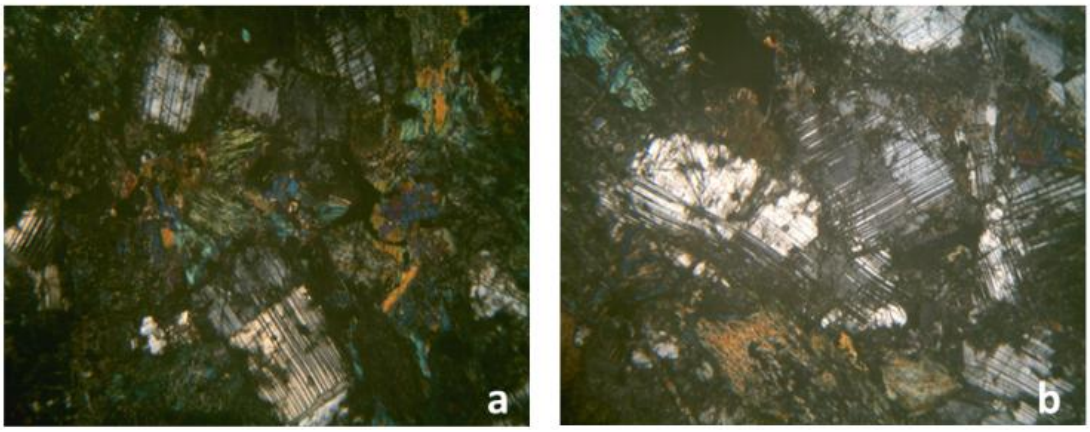
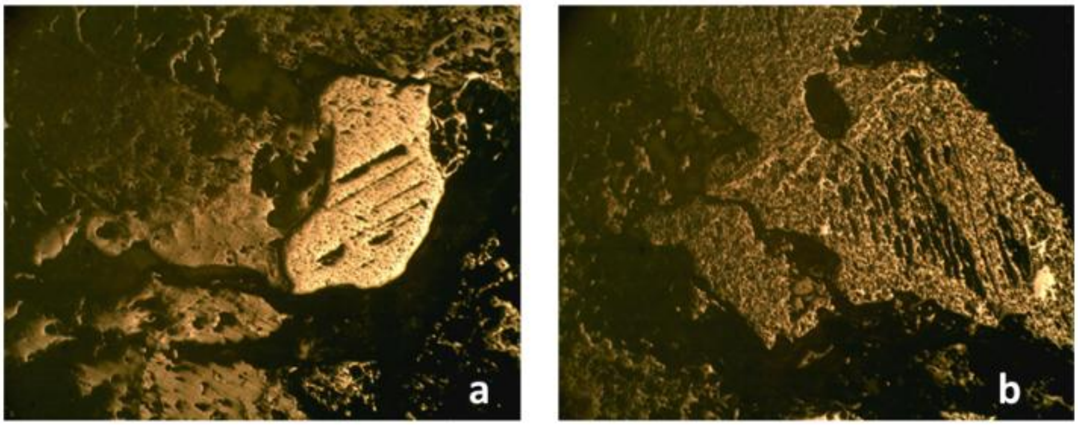


Fig.2. Detailed Geology of the study area

The prepared thin sections show that the rock type is mainly Diorite; it is a coarse-grained, intrusive igneous rock that is intermediate in composition between granite and gabbro. Diorite is composed primarily of plagioclase feldspar, amphibole, and pyroxine minerals with small amounts of biotite mica (Photomicrograph No. 1a). Generally the rock is deformed as it is obvious in the affected plagioclase feldspar (Photomicrograph No. 1b).The Polish sectionsare composed mainly of brecciated rock, and the fragments and cavities field by Iron oxides minerals mainly Hematite and Magnetite occurred both as primary and secondary minerals. (Photomicrograph No. 2a and Photomicrograph No. 2b).



Photomicrograph 1:The prepared thin sections show that the rock type is mainly Diorite. (a) It is primarily composed of plagioclase feldspar, amphibole, and pyroxine minerals with small amounts of biotite mica, (b) Deformed plagioclase.



Photomicrograph 2: The Polish sections are composed mainly of brecciated rock, and the fragments and cavities field by Iron oxides minerals mainly Hematite in (a) and Magnetite in (b) occurred both as primary and secondary minerals.

IV. GEOPHYSICAL DATA ACQUISITION AND PROCESSING

Magnetic (MAG)

Magnetic surveys were carried out using a Geoscan Fluxgate Gradiometer (FM36), a number of eleven profiles were collected in zig-zagmode, 5 m apart with measuring point interval of 5 m. These profiles were joined together to form a grid pattern (55m E-W, 155m N-S). The MAG data were processed with the OsaisMontajV.7.2. The measured data have been corrected, including diurnal correction and normal correction. Then, the processed data are used to produce the isoline plan and check point distribution in order to guide the production and monitor the quality; the results of each magnetic profile are presented in vertical plots aligned with the corresponding ERT profiletocorrelate and assess data reliability.

Electrical Resistivity Tomography (ERT)

Electrical Resistivity Tomography (ERT) surveywas acquired using Tigre resistivity imaging system. The ERT profiles; along the same points surveyed by the magnetic survey; were carried out using both Wennerarray and dipole-diploe arrays and sometimes using Wenner-Schlumberger, see Loke (2000)for field procedure of these arrays, with electrode spacing of 5m.

The inversion process applied Res2Dinv code by which forward modeling subroutine was used to calculate the apparent resistivity values, the standard least-squares optimization technique was used for the inversion routine. The routine used constraints to minimize the square of the difference between the observed and the calculated apparent resistivity values, the effect of the side block were reduced, so that the calculated value not unreliably exaggerated. Since there are very large resistivity variations near the ground surface, a model of width half the unit spacing was used to give the optimum inversion results. The standard least-squares optimization technique converged after 5 to 10 iterations with a RMS misfit between 10% and 40%.

V. GEOPHYSICAL DATA INTERPRETATION

Magnetic Results

The magnetic map (Fig.3) indicates that the investigated area has low magnetic values for wadi sedimentary deposits in its southern part, the high magnetic anomalies in the area of the suspected gossans are probably due to magnetites formed during wall rock alteration consequent to mineralization. A part of the magnetic anomaly is possibly associated with pyrrhotite, as it is usually primary constituents of the sulphide ores. Non-sulfide metallic minerals with high susceptibility values, such as magnetite, are common in the deposits and contribute to the strong positive magnetic anomalies.

The magnetic map is presented with a contour interval 50 nT/m and represents anomalies from the entire vertical and lateral magnetic susceptibility variation with the earth and may be used to qualitatively deduce mineralization zone. The magnetic of the study area is characterized by a broad high anomaly trending NE/SW caused by hydrothermal vent. These smaller anomalies which vary in their lateral extent and amplitude reflect the spatial variability of the alteration zone. The width of these anomalies is in the range of 20-30 m, the magnetic anomalies are in the range 32 to 2047 nT/m.

The quantitative interpretation of magnetic data was carried out using Euler deconvolution. The results of the magnetic interpretation indicated that the depths of such ore deposits range from 26 to 115 m and the half width ranged from 20 to 35 m (Fig.4).

Electrical Resistivity Tomography Results

From ERT, the observed low-resistivity zones coincide geologically with the altered and sheared zones. The quantitative interpretation technique determined the conductive bodies' extension where the depth to the top of the ore body ranged from 2 to 62 m while the maximum width ranged from 100-150 m, which may be in most locations are associated with the main loci of ore deposition (Fig.5).

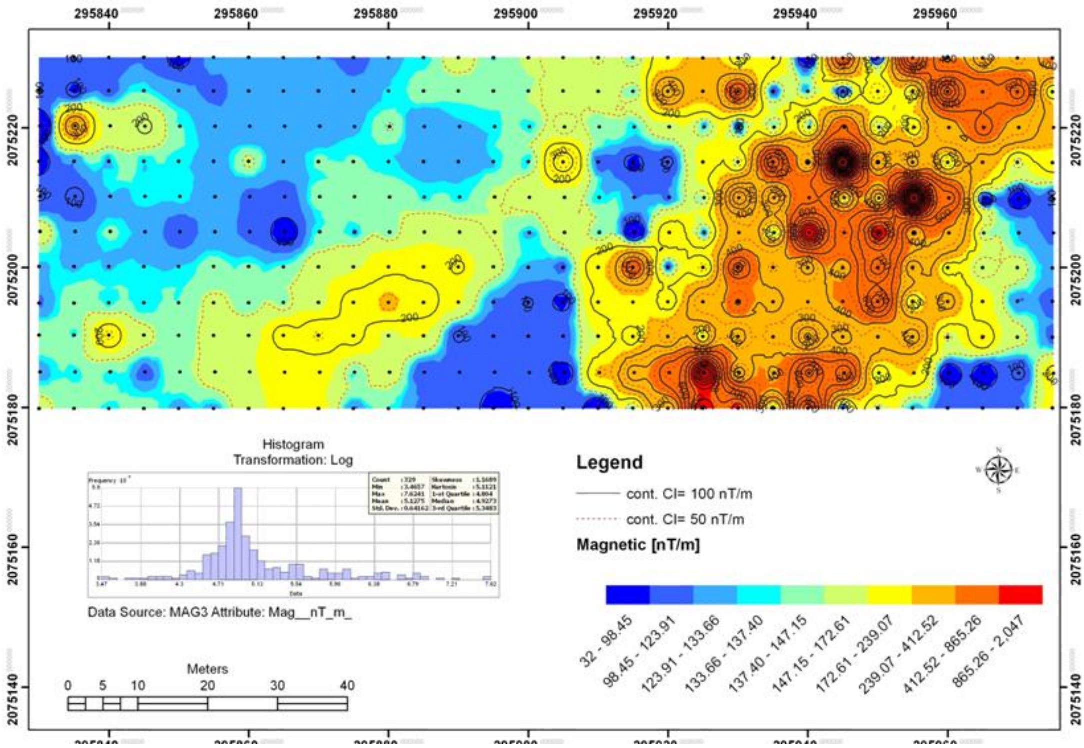


Fig.3. Magnetic contour map of the study area

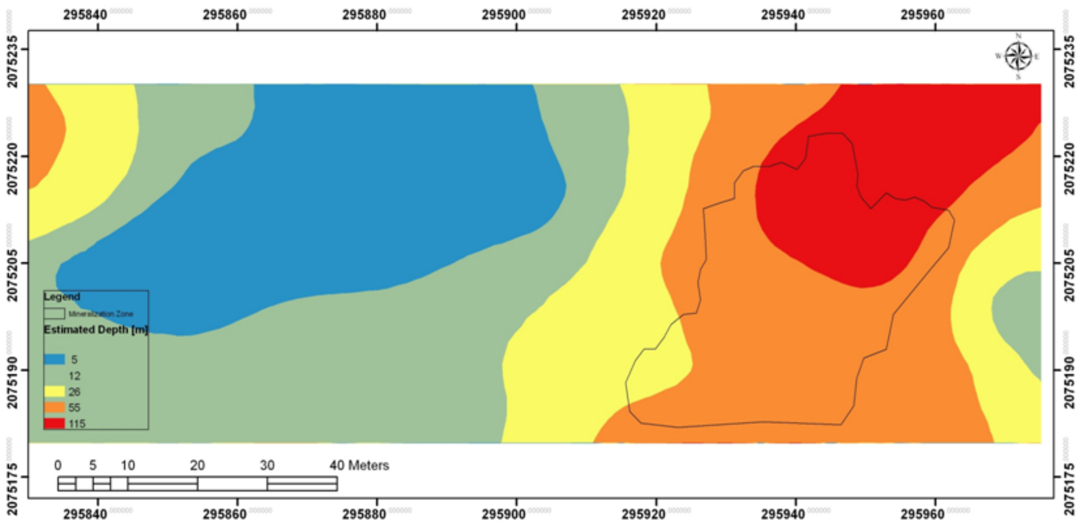


Fig.4. Depth mapestimated from magnetic data using Euler Deconvolution

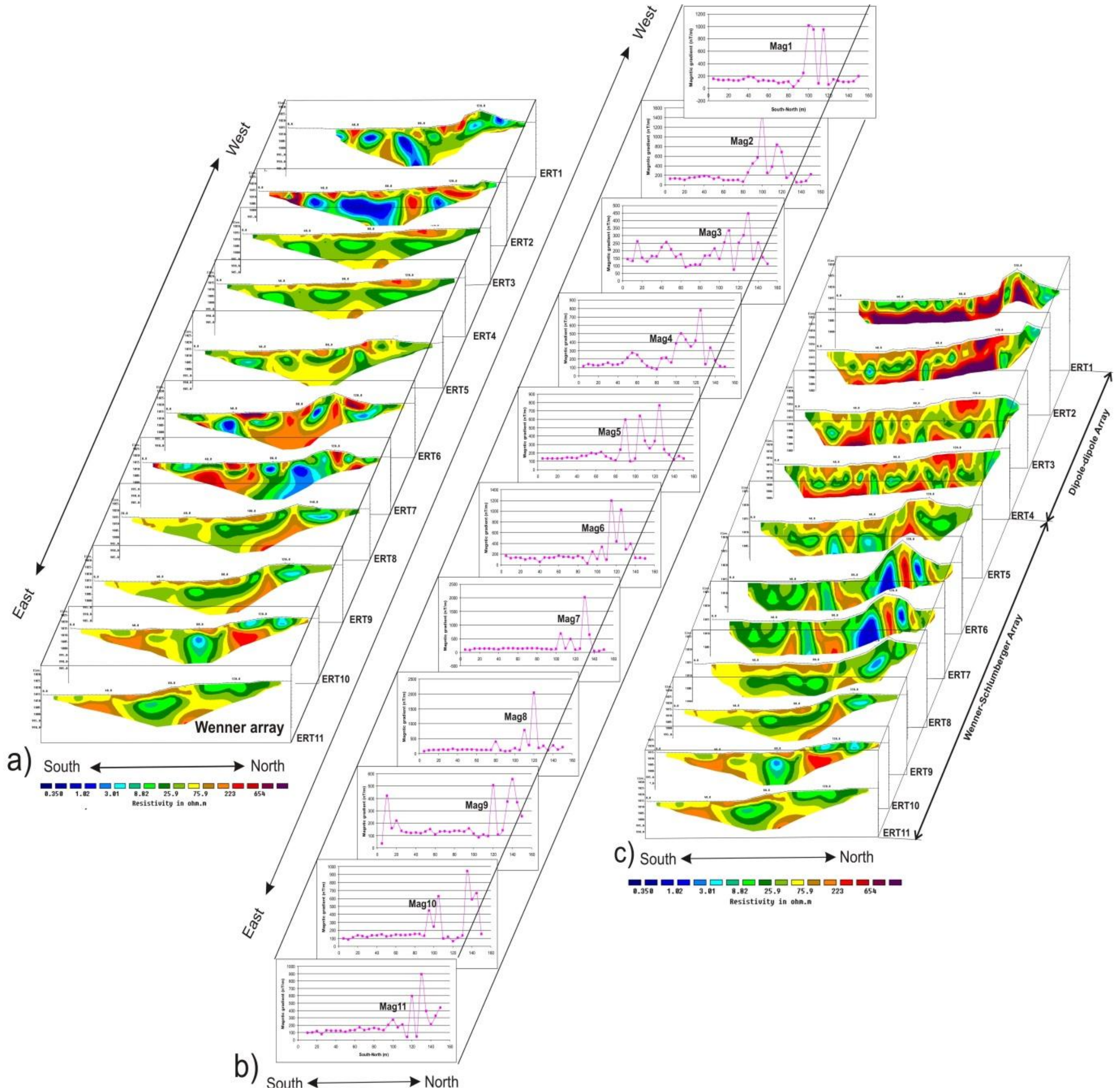


Fig.5: The eleven geophysical profiles collected using MAG and ERT survey in the study area, a) magnetic data; b) inverted ERT using Wenner array, c) inverted ERT using dipole-dipole andWenner-Schlumberger arrays.

VI. INTEGRATION OF THE RESULTS

The magnetic anomaly as an example in figure (6) extend from 80m up to 110m coincides with the target topographically elevated area which may be due to the existence of pyrhotite and magnetite content in the rock. This gives the prospect that these rocks containmagnetite disseminations. The peak value (>1000 nT) exactly at the excavated heap containing both basalt and the material of the assumed gossans. The excavated materials show high magnetic positive values, but they are sometimes negative due to the dipole nature of bodies of small size. The area from 110 to 150m shows a low magnetic field of granitic rock outcropping there. The inverted section of ERT1 using dipole-dipole and Wenner arrays in (Fig.6) respectively. That shows a low resistivity (< 1 Ω.m) in the upper layers, underlain by high resistivity layer in this profile has. It is expectable that this inconspicuous resistivity low bodies corresponding to the mineralization are too shallow for sulphide mineralization and is probably related to the assumed gossans.

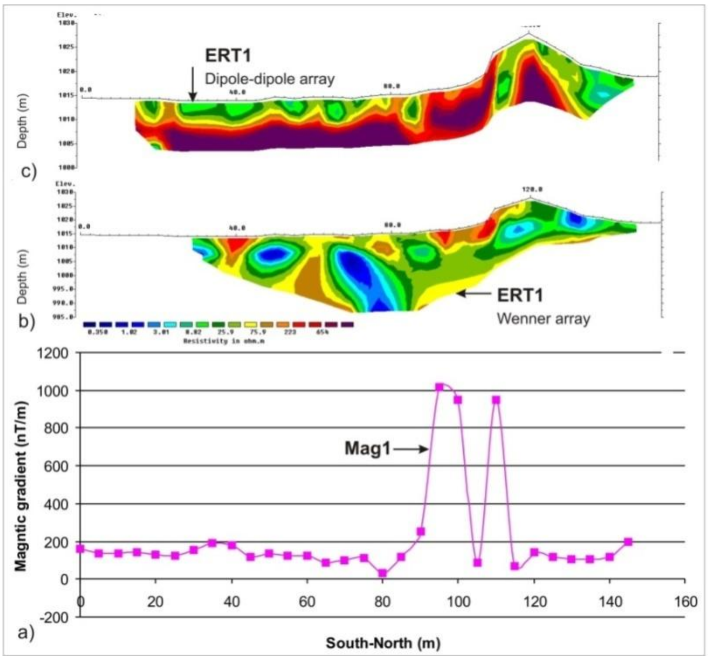


Fig.6. Geophysical result of profile-1; a) magnetic data (nT); b) inversion results of ERT1 using wenner array; c) Inversion results of ERT1 using dipole-dipole array.

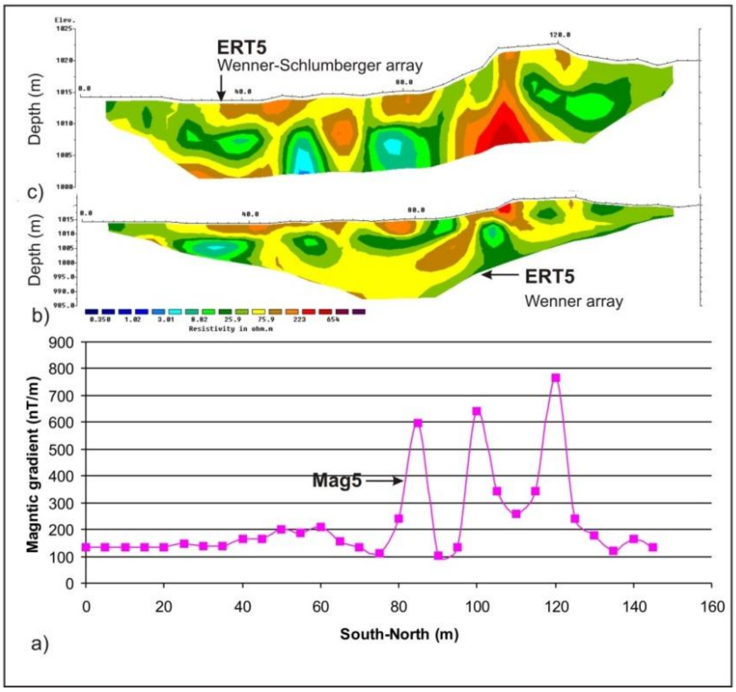


Fig.7. Geophysical result of profile-5; a) magnetic data (nT); b) inversion results of ERT5 using wenner array; c) Inversion results of ERT5 using wenner-schulmberger array.

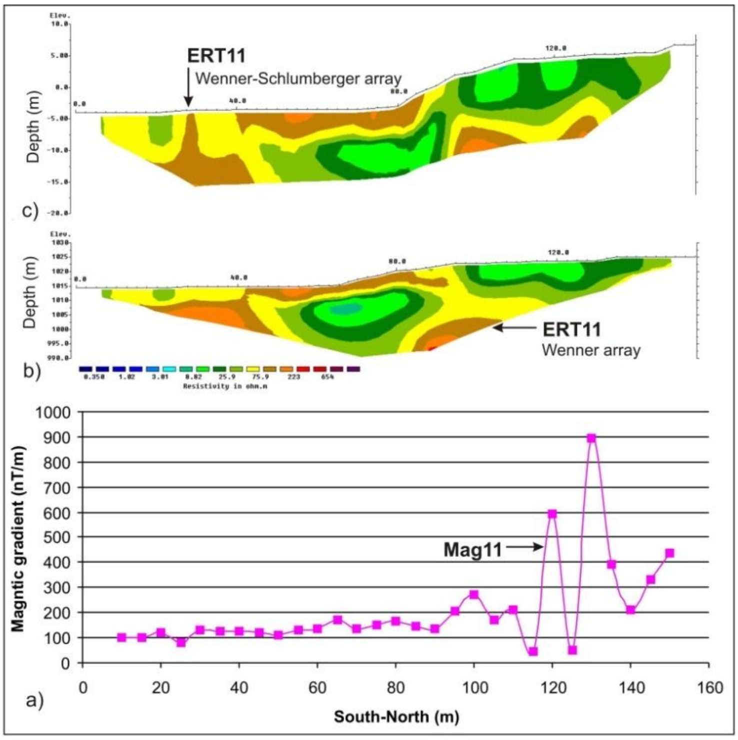


Fig8. Geophysical result of profile-11; a) magnetic data (nT); b) inversion results of ERT11 using wenner array; c) Inversion results of ERT11 using wenner-schulmberger array.

Average magnetic signal from wadi deposits is ranging between 132 nT to 167 nT as shown in figure (7), where laterally the magnetic anomalies from 135m to 140m are due to basalt/gabbro. A peak of 767 is attributed to the assumed gossan, the following magnetic values ranging between 250 nT to 640 nT in the distance between 100m and 115m are due to the excavated magnetic susceptible material, which contain materials look like pyroxene. The inverted section ERT5 using Wenner-Schlumberger and Wenner arrays (Fig.7) show relatively higher resistivity, it may be attributed to the solid intact humid rock there. A small body of low resistivity at distance between 100m and 110m may correspond with the sulphide mineralization zone or fractured rock with water and humidity contents and is probably related to the gossans. Whereas the elongated separated low resistivity zones may due to wet wadi deposits.

Some profiles show the magnetic anomalies of dipole nature (Fig.8) varying from 120m to 135 m, and granitic rocks are recognized on a center distance aroundthis magnetic anomaly. The conductive body in the target zone is typically observed in this profile, in addition to another detected conductive body at a distance between 50m and 80m, which is in the field, coincides with Wadi deposits.

VII. CONCLUSION

As the main objective of this study is to delineate the various structural aspects in the area in addition to pilot prospecting work to pin point the gold deposits which could be related to mineralization zones. The gold and disseminated sulfides are located on the alteration shear zone which is composed of granitic and dioritic highly ferruginated rock occupying the southwestern and central parts of the area.

Average magnetic signal for wadi deposits is 140 nT as shown in figure (7), where a peak of average magnetic anomaly ~700 nT is attributed to the assumed gossan structure, other magnetic values ranging between 250 nT to 600 nT in the distance between 100m and 120m are due to the excavated magnetic susceptible material, which contain materials look like pyroxene.

The significant ERT resultsare the resistivity low zones as traced the sheared zones, which are shown distances between 100-150m. These zones areobserved in most locations and are associated with the main loci of ore deposition. The interpretation indicates the occurrence of gossans, which lies between 80m and 150m in the geophysical profiles. From ERT, these low-resistivity zones which coincide geologically with the altered and sheared zoneshave depths to the top of the ore body range from 2 to 62 m while the maximum width range from 100-150 m. Thus, based on the integrated geophysical results, four suggested borehole sites were selected in the study area (Fig.9)

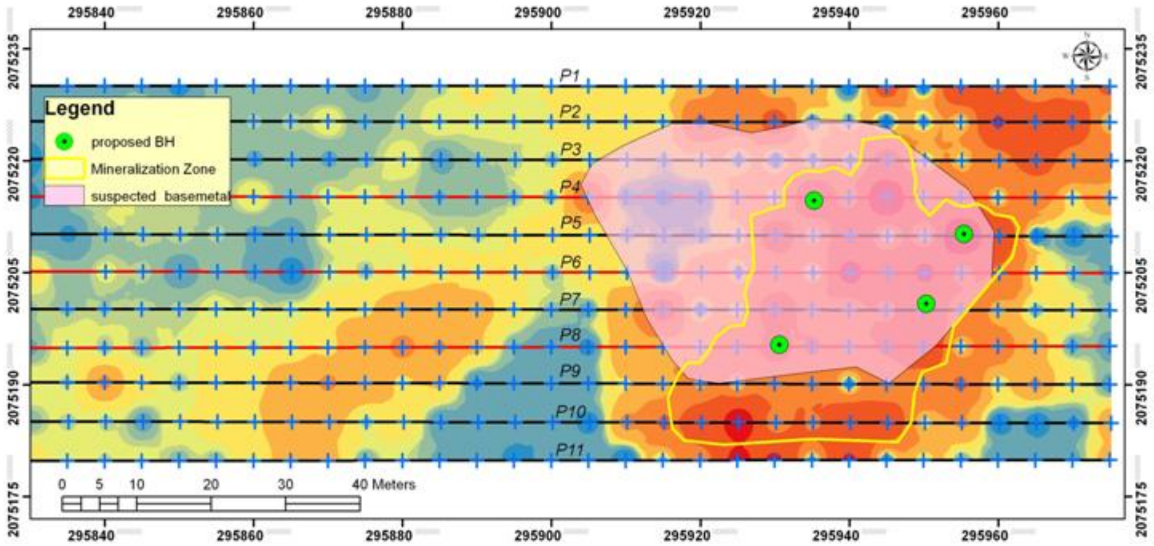


Fig.9. Locations of four proposed boreholes as new targets of mineralizationbased on the integrated geophysical results in this study.

REFERNCES

[1] Bahr, K., 1983.*Joint interpretation of magnetotelluric and geomagnetic data and local telluric distortions*, J. of Geomag. Geoelec. 35: 555–566.

[2] Hauck, C., 2001.*Geophysical methods for detecting permafrost in high mountains*. PhD thesis, ETH Zurich.

[3] Hering, A., Misiek, R., Gyulai, A., Ormos, T., Dobroka, M., and Dresen, L., 1995.*A joint inversion algorithm to process geoelectric and surface wave seismic data*; Part I, Basic ideas, Geophys. Pros. 43: 135–156.

[4] Krorner, A., Linnebacher R.J., Stern, Reischmann T., Manton, W. and Hussein, I.M., 1991.*Evolution of Pan-African island arc assemblages in the southern Red Sea Hills, Sudan, and in southwestern Arabia as exemplified by geochemistry and geochronology*. Elsevier Science Publishers B.V., Amsterdam. Precambrian Research, 53: 99-118.

[5] Loke, M., 2000.*Electrical imaging surveys for environmental and engineering studies. A practical guide to 2-D and 3-D surveys*.

[6] Loke, M., Acworth, I., Dahkin, T., 2003.*A comparison of the smooth and blocky inversion methods in 2d electrical imaging surveys*. Exploration Geophysics 34: 182-187.

[7] Mohr, P., 1971. Smithson. Astrophys.Obs. Spec. Rep. 339: 1−85.

[8] Oldenburg, D.W., Li, Y., and Ellis, R.G.. 1994, *Joint interpretation of DC, IP, magnetic, airborne EM, geological, and mineralization data*; a case history from Mt. Milligan, SEG Annual Meeting Expanded Technical Program Abstracts with Biographies 64: 512–515.

[9] Patra, H.P. and Mallick, K., 1980.*Geosounding principles, 2: Time varying geoelectric soundings*, Elsevier, Amsterdam, 419pp.

[10] Roy, A., 1962.*Ambiguity in geophysical interpretation*, Geophysics 27: 90–99.

[11] Sill, W.R., Bostick, F.X., Hohmann,G.W., Petrick,W., Phillips R.J., Stodt, J., Swift C.M., Tripp, A., and Ward, S.H.,1977.*Resistivity structure in southwestern Utah based on magnetotelluric and deep resistivity measurements'*, Geophysics 42: 1539.

[12] Stanica, D. and Stanica, M., 1993.*An electrical resistivity lithospheric model in the Carpathian Orogen from Romania*, in: The V.R.S. Hutton symposium; Electromagnetic studies of the continents, Phy. of the Earth and Plan. Int. 81: 99–105.

[13] Telford, W.M., Geldart, L. P., Sheriff, R.E., 1990.*Applied Geophysics*, Cambridge University Press; 2nd edition, 792 pp.

[14] Wang, H., Zhang, W., and Xie, J., 1993.*Iterative algorithm for joint inversion of gravimetric and seismic data in layered medium*, ShiyouDiqiuWuliKantan, Oil Geophys. Pros. 28: 153–165.

[15] Zhdanov, M.S. and Keller, G.V.,1994.*The geoelectrical methods in geophysical exploration*, Methods in Geochemistry and Geophysics 31: 873pp.