CHROMITE EXPLORATION USING ELECTRICAL RESISTIVITY TOMOGRAPHY IN INGESSANA HILL, BLUE NILE STATE, SUDAN

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Abstract - The Ingessana hills in the southern Blue Nile of Sudan are part of the southern sector of the ophiolithic belt of the Arab-Nubian Shield with mid-neoproterozoic age. The rocks are mainly serpentinized and in parts highly silicified dunites especially towards the contact with the intruding Bau granite. A promising chromite mineralization zones in the area are generally associated with NE-SW trending shear-zones. A detailed geophysical survey employing electrical resistivity tomography (ERT) at 34 lines were carried out over zones of known chromite mineralization to test feasibility of detecting and delineating the ore (if exist) and to facilitate consequently the positioning of exploratory drill holes. ERT sections were inverted with smooth constraints inversion code where the contacts between the granite and the ultramafics are showing up clearly. The continuity of mineralization along the contact is not well confirmed. However, the low-resistivity anomalies are probably recognized as potential chromite mineralization zones. The resistivity anomalies represent prime targets for further exploration by drilling, trenching or shallow pits. If the results of the drilling or excavations are positive, small open pit exploitations may produce important tonnages of chromite.

Keywords - Chromite exploration, ERT, Ingessana Hills, Inversion.

I. CHROMITE EXPLORATION

Geophysical exploration methods could produce good results to outlining “anomalies”, which in turn represent hidden ore bodies. Chromite is a high density metallic mineral and it is often associated with mafic/ultramafic rock. Due to its high density, gravity is the best approach for its investigation. However, due to non-uniqueness in the interpretation of gravity alone cannot be fully reliable. Since chromite is a metallic mineral, it possesses good conductivity. Electrical and EM methods that deal with electrical conductivity of the subsurface are used in integrated study for chromite investigation. In mineral exploration, chromite itself has a very high resistivity, but strong induced polarization (IP) anomalies have been reported over chromite masses in Jancovic (1963) and Parasnis (1963) addressed some aspects of geophysical prospecting for chromite. Resistivity surveys showed that chromite-bearing serpentinite generally has a higher dry resistivity than ordinary serpentinite, but saturated resistivity values are primarily dependent on porosity, which is not related to percentage of chromite (Johnson et al., 1980). Bayrak (2002) have integrated interpretation of very low frequency-electromagnetic (VLF-EM), induced polarization (IP), gravity, magnetic and self potential (SP) for exploration of chrome ore deposits. He showed that resistivities values (<100 Ohm.m) correlated with the extension of known chrome occurrences in the field. Very low frequency (VLF) and DC-resistivity methods in Tangarparha in India suggested that chromite occurs in the form of a small disseminated body within a mafic/ultramafic rock matrix (Mahanty et al., 2010).

The current study is a contribution in the approach of chromite exploration using 2D electrical resistivity tomography survey, which can resolve the geological structures laterally (profiling) and vertically (sounding). The theoretical principles of these methods besides the physical properties of the geologic materials pertinent to the methods, as well as the physical phenomena involved are outlined in (Telford et al. 1991). The ERT data are processed and modelled using 2D & 3D inversion codes (Loke& Barker, 1996), and visualized as electrical resistivity pseudosection and real sections. The inversion process consists in a series of rectangular blocks, in which the disposition of the blocks is connected to the distribution of the field points in the pseudosection, which is the section generated by the field data in theoretical depth (Loke, 2002). The depth of the lower line of the blocks is defined to be approximately equal to the equivalent investigation depth of the points with greatest space among electrodes.

II. GEOLOGY AND MINERALIZATION

The chromite ore bodies occur in general within dunites, as banded bodies of disseminated chromite with irregular shapes and variable sizes, veins lenses and pods. Two main types of ore bodies are recognized: 1.) Orthomagmaticstratiform bodies whose contacts tend to be less well defined, due to their disseminated character of mineralization, 2) Late Magmatic lenticular, vein or podiform bodies of compact to massive mineralization, which occur asveins, lenses or lumps, in sharp contact with the country rock. The Ingessana massif is the largest

mafic ultramafic complex in the Sudan. It represents the central part of the Ingessana—Kurmuk Ophiolite Belt.

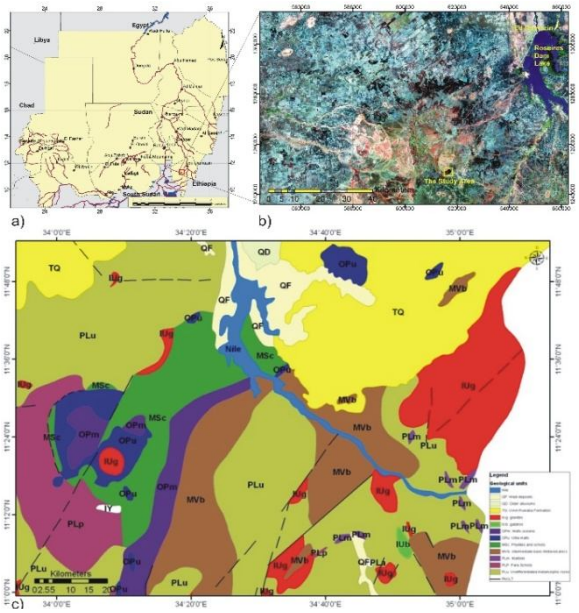

Fig. 1. Location map of the study, a) Location of the study area in the geographic map of Sudan map, b) Landsat satellite map showing different rock-type and mineralization, c) Location of ERT lines in the studied area (coordinates were removed for confidential purposes)

The massif comprises a highly serpentinizeddunite—harzburgite lower fades overlain by peridotite, minor pyroxenite chromite occurrences in the Ingessana massif hosted by the lower dunite—harzburgite fades. Other occurrences had been reported at Hamissana-sol Hamed in the northern Red Sea Hills, the Nuba Mountains in southern Kordofan, JabalRahib northwest Sudan and Jabal El Tawil in central Butana. However, the Ingassana chromite ore is considered as one of largest chromite ore deposits in Sudan [Adli, 1998; Seifelnassr&Tamam 2011].

The study area is located southwest of Ad Damazin, the Capital of Blue Nile State, Sudan (Fig. 1). It represents an inner part of the Ingessana ring complex. It is accessible by ≈ 63 km gravel road from Ed Damazin to the Deran locality and from there approximately 9 km dirt road accessible even in the rainy season. The area is a typical of savannah grassland with black cotton soil and wide spread trees and bushes.

The Ingessana hills (Fig. 1c) are part of the southern sector of the NE-SW trending ophiolithic belt, of the Arab-Nubian Shield with mid-neoproterozoic age. They are made (Fig. 2b & c) up by ultramafic rocks such as dunites and hartzburgites intruding the metagabros outcropping in the central parts and creating the western-north-western semicircular ultramafic complex, as well as by duniteshartzburgites, which in turn have been intruded at a later stage by the so called Bau granite. As the Bau granite intruded the ultramafic complex in the eastern-south-eastern parts, it created a second circular structure, referred to as the south-eastern ultramafic masses. These ultramafic circular structures have been separated by a NE-SW structure line, the so called KhorFeri Shear zone which in turn runs sub-parallel to the western contact between Bau granite and the adjacent ultramafic rocks of the Ingessanacomplex.The mineralization tends to be generally associated with NE-SW trending shear-zones. The ultramafic rocks have been subjected to serpentinization, carbonatization and are in places strongly silicified. The central part of this ring structure consists of a relatively flat plain containing the so called Bau granite.Topographically the area under investigation is a roughly E-W oriented ridge of approximately 1,5 km length, rising about 30m above the plain at the center of the study area and about 100m at the to NW corner. This ridge is about 250m wide at its narrowest and over 400m at its widest.

The main rocks outcropping in this ridge are ultramafic rocks such as serpentinized and partly highly silicified dunites and Bau granite exhibiting characteristic granitic weathering, quite soft on the surface and hard when fresh. Hydrothermally altered surfaces are present in the center of the ridge, which contain in places intense quartz-vein stockworks. Parts of chromite veins, at two positions shown in the image above artisanal excavations have been exposed (Plate 1). They seem to pinch out and swell laterally as well as down dip, have an E-W trend and are nearly vertical. Further artisanal excavations are visible between the two main positions, some with traces of mineralization and some “sterile”. Due to the fact that most of the surface is covered by topsoil, talus scree and rock fragments of various sizes, this mineralized zone is very hard to trace. It is thus only possible by means of manual or mechanical excavation along the vein trend to trace it further.

At this point the importance of this mineralized contact zone between the Bau granite and the dunites was recognized. It seems that the granite emplacement is the main controlling factor of this type of mineralization.

It was thus decided to employ the geophysical electrical exploratory method to trace the contact between the Bau granite and the dunites and investigate this contact for possible chromite mineralization.

III. ERT FIELD DATA & ANALYSIS:

A detailed geophysical survey employing electrical resistivity tomography were carried out over a zone of a known chromite mineralization in the study area (Fig. 2a) to test feasibility of detecting and delineating the ore and accordingly facilitate the

positioning of exploratory drill holes. Electrical Resistivity Tomography (ERT) survey with multi-electrode system (Tigre32, Allied-UK) was carried out in this study. The electrode configurations, 2m & 5m were used for data collection and the spacing between electrodes were selected based on the target of ERT survey.

34 electrical resistivity tomography (ERT) lines (Fig. 2b) were measured in the study area. About 30 separate lines over a E-W trending ridge of over 1500 m length. The aim was to follow laterally as well as down dip the continuation of a 1-1.5 m wide chromite vein emplaced between ultra basic rocks (Dunites) and granite bodies. The suitable field procedure was selected based on the nature and mode of occurrence of the Chromite ore body, and the field conditions, therefore high resolution ERT profiles using Wenner and dipole-dipole configuration with electrode spacing of 5 m was preferred for resolving the target shallow subsurface relatively small Chromite ore body.

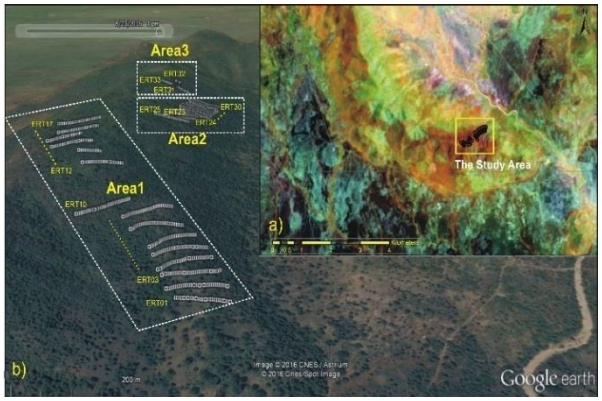

Fig. 2. Locations of ERT lines in the study area

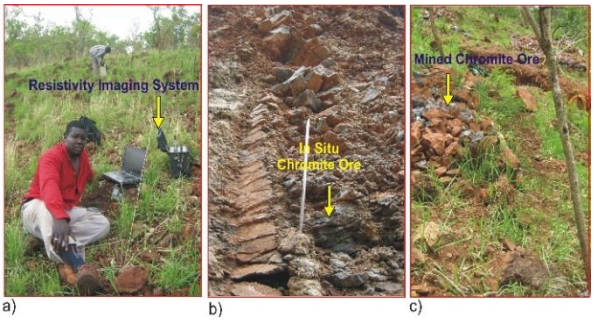

Plate 1. Fieldwork plate showing geophysical work and conditions, a) Electrical resistivity tomography data acquisition , b) Outcropping chromite ore in shear and alteration zone, c) Production of chromite ore by artisanal miners in the study area.

Area 1 (Fig. 2b) is located in the eastern part of the study area, where 17 ERT lines were carried out with north-south trend, the offset between the lines started with 20 meters and increased gradually westwards.

The first three ERT lines were used for calibration and for testing reliability of ERT to explore the Chromite ore body which was confirmed by the nearby open pits. These lines were laid out in such way so that they crossed over the granite body, the chromite vein and the ultra-mafic rocks (partially serpentinizeddunites). Area2 (Fig. 2b) is located in the western part of the study area, where 13 ERT lines were carried out, namely; ERT18 up to ERT30. The survey in this part started by ERT18 and ERT19, which were carried out in such way to cross the granite body, the chromite vein and the ultra-mafic rocks (partially serpentinizeddunites). The offset between the lines started with 20 meters and increased gradually eastwards. Area3 shows a recent excavation, where fresh chromite was produced (Plate 2b). Three ERT lines (ERT31, ERT32 & ERT33) were carried, two of them laid out in East-West trend crossing the trench and accordingly the suspected ore body and zone of mineralization (Fig. 7), a third one was carried out in a perpendicular trend to the former two ones. A higher resolution profile (ERT34) with electrode spacing of 2 m was carried out along the same location of line ERT18. The centre of this line coincides with the Chromite body presents in the old excavation in this part (Plate 2) and coincides with the centre of line ERT18. A selected sections from this study will be presented and discussed in the following section showing the most important anomalies and findings.

IV. ERT RESULTS AND INTERPRETATION

The presented sections show some anomalies in the pseudosections sometimes match and sometimes mismatch with the ones in inverse sections. The resistivity values in all sections are displayed with a common colour scale for an easy correlation. The inverse sections are displayed with topographical elevation data, which were measured using Triumple Differential GPS System.

Line ERT 1 (N-S direction):

This line was laid out in such way to cross over the granite body, the chromite vein and the ultra-mafic rocks (partially serpentinizeddunites). It was thus used as calibration. In the Wenner array profile (Fig. 3) the chromite mineralization shows clearly a low resistivity of a range between 25 and 90 Ωm and is well defined against the granite, which is in this area exhibits a resistivity of between 90 and over 1500 Ωm. The chromite body does not seem to be continuous below 10m depth. In this section the granite is shown as a body clearly dipping to the south.

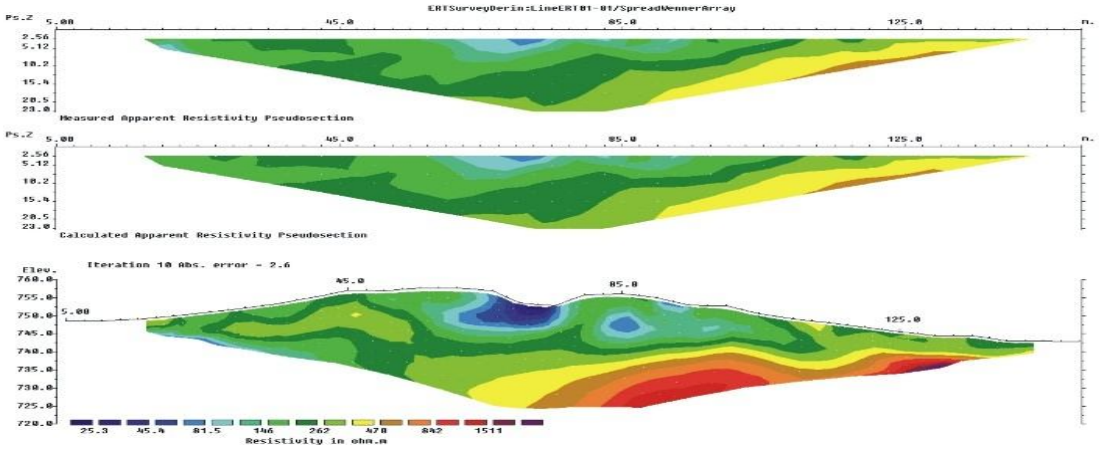

Fig. 3. The measured, calculated and inverse sections of ERT01 (Wenner array).

The top of the granite body with resistivity of between 90 and 400 Ωm is similar to the resistivity of the ultra-mafics. This fact makes the distinction between granite and ultra-mafics difficult. In the dipole-dipole array profile (Fig. 4), a fracture zone is shown in the granite at 95 to 105 m.

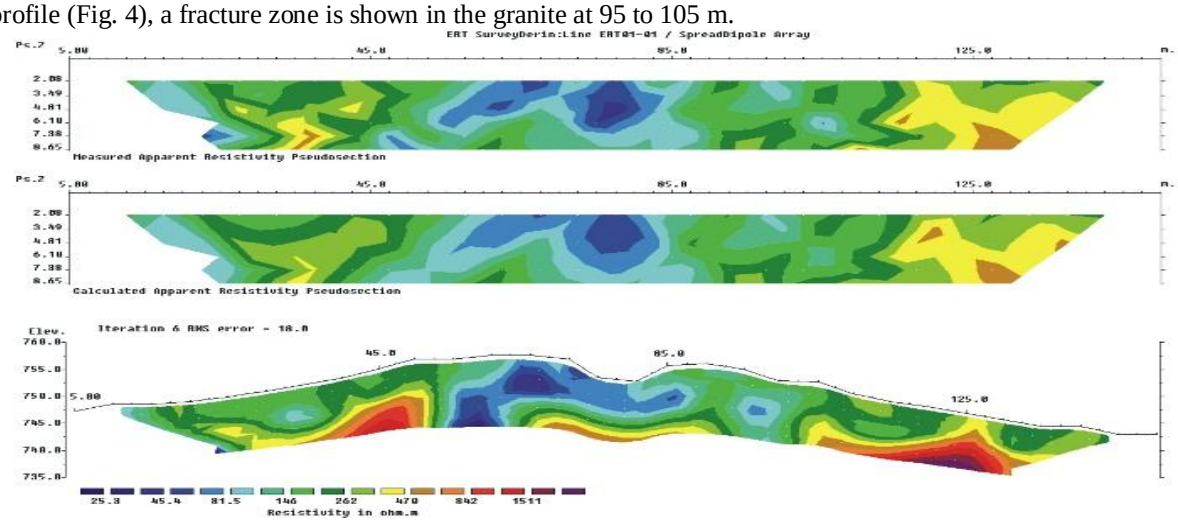

Fig. 4. The measured, calculated & inverse sections of ERT01 (dipole-dipole array).

Line ERT 7 (NNE-SSW):

In the dipole-dipole array section (Fig. 5) there is a low resistivity anomaly at 40-45m. This anomaly is dipping gently to the south and is connected with another one lower down, which is dipping to the opposite direction.

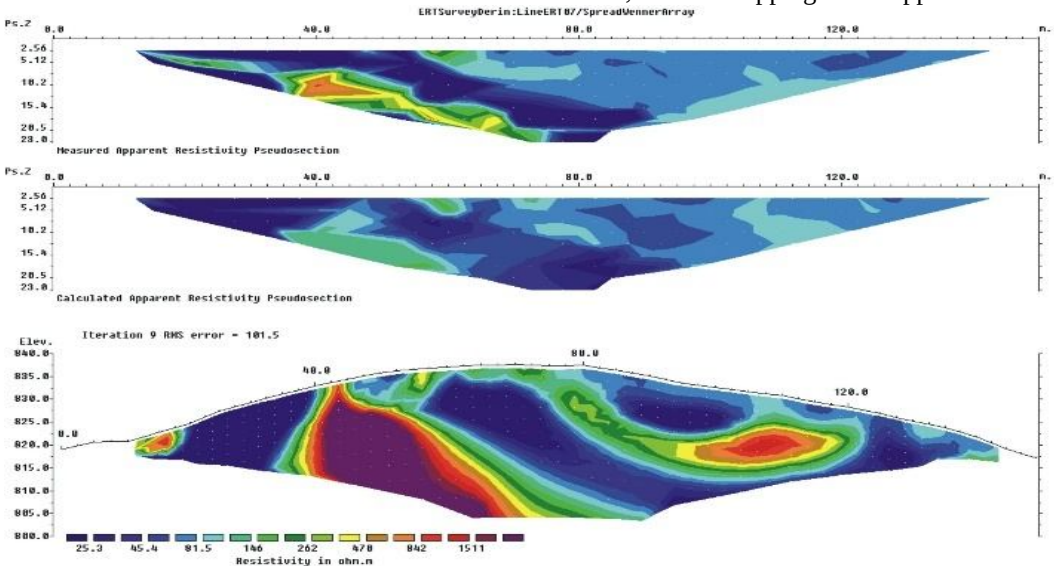

Fig. 5. The measured, calculated and inverse sections of ERT07 (Wenner array).

Line ERT 9 (NNE-SSW):
Two overlapping lines (ERT 9 & Line ERT 10) were measured, where the surface geology along the line is characterized by surface debris from the north-eastern-most part of the line up to about 160 m. From about 135m to 160m we find ultra-mafic rocks outcropping. At the contact of the ultra mafics up to the end of the line there is an intense low resistivity zone (Fig. 6) attributed to water saturated superficial deposits containing silicified boulders. At the end of the line, stock-worked silicified rocks are outcropping. The anomalous values in the center of the line are attributed to a granitic block observed at this point on surface.

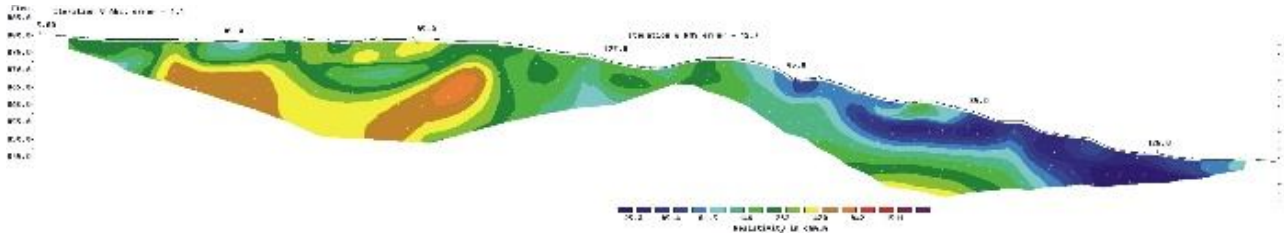

Fig. 6. The combined inverse sections of ERT09 and ERT10 (Wenner a rray).

Line ERT 10 (NNE-SSW):
It is the south-westerly continuation of line 9 (Fig. 6). Intense red hydrothermal alteration characterizes the surface along this line. This line resembles, structurally at least, line ERT 6. Both the Wenner and the dipole-dipole model of this line are very reliable. Two anomalous zones with sharp vertical contacts are the characteristic features of this line. One at 30m, which seems the most promising one for chromite mineralization, possibly the contact of the granite with the ultra-mafic rocks. The second is at 100m and is a lower priority target.

Line ERT 12 (NNE-SSW):
The area of line 12 is characterized by very intense silification shown in the sections as very high resistivity values. A rooted siliceous body occupies the south-western part of the Wenner array section. Very high resistivity value anomalies cover the surface of this section. Below this "silica cap" three distinct low resistivity bodies are showing up at various depths. The first anomaly is below the point at 45m and at an estimated depth of 2m. This anomaly which is inclined to the northeast. The second anomaly is below point 75m, is sub horizontal and is at a depth of about 20m. The third anomaly is expressed as a low resistivity zone at about 107m, is attributed to altered ultra mafic rocks on the surface, and is underlain by a lower resistivity area. All three anomalies, which are aligned and seem to be parts of a broken up mineralized body.

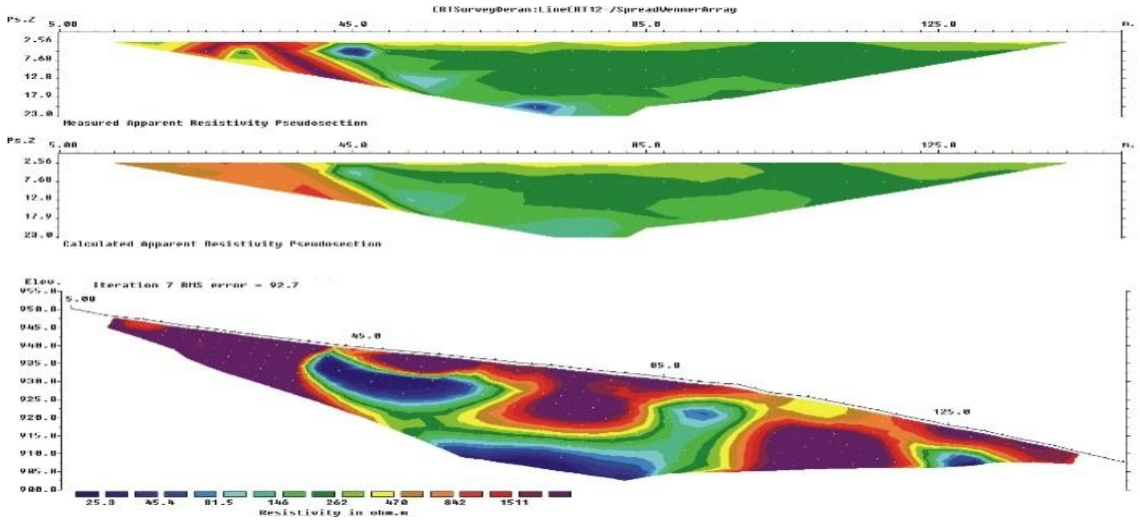

Fig. 7. The measured, calculated and inverse sections of ERT12 (Wenner array)

Line ERT 21 (NNE-SSW):
The granite body in this section in both Wennersection and dipole-dipole section, it is well defined at point 40-45m in Wenner section (Fig. 8) showing a sharp contact with the ultra-mafics.

It correlates with surface observations. This contact contains a low resistivity anomaly which is interpreted as a possible chromite mineralization. A second anomalous zone is present within the granite body between 85 and 100m, which cannot be explained.

Explanatory note for ERT 31, 32 and 33:

In this area (area3 see Fig. 2b) a fresh artisanal excavation was discovered. This excavation has a N 20° direction and is about 20 m long and about 2m wide. Around this excavation, 9 stockpiles of very massive and heavy chromite have been created. This chromite looks like high grade material.

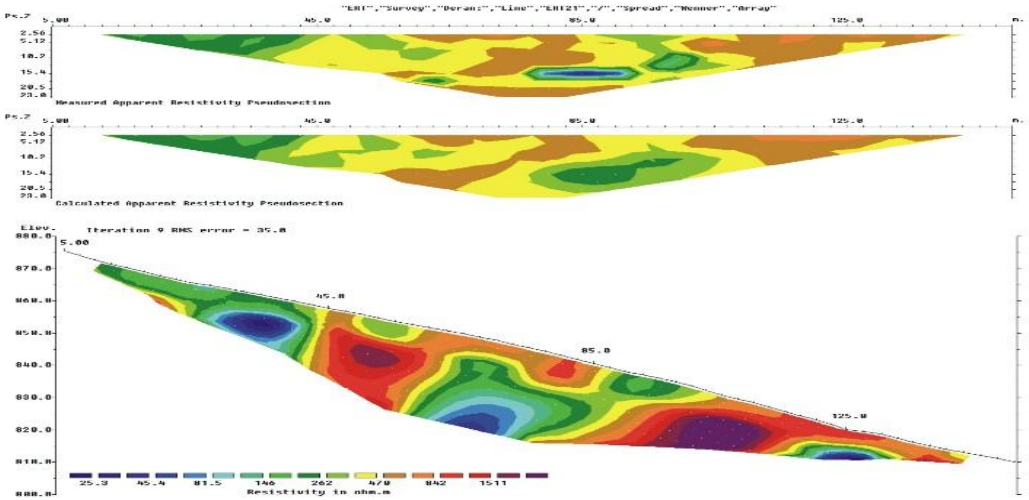

Fig. 8. Measured, calculated and inverse sections of ERT21 (Wenner array).

The actual excavation has been covered by soil so that it is not possible to see the actual chromite body, nor its shape size and possible down-dip extension. The shape of this excavation points to a body, inclined to the east, possibly a vein. It was thus decided to further investigate this area with the ERT method with a view to evaluating it. Three ERT profiles were carried out (Fig. 2b). Two of them were measured perpendicular to the excavation and one parallel to its eastern side.

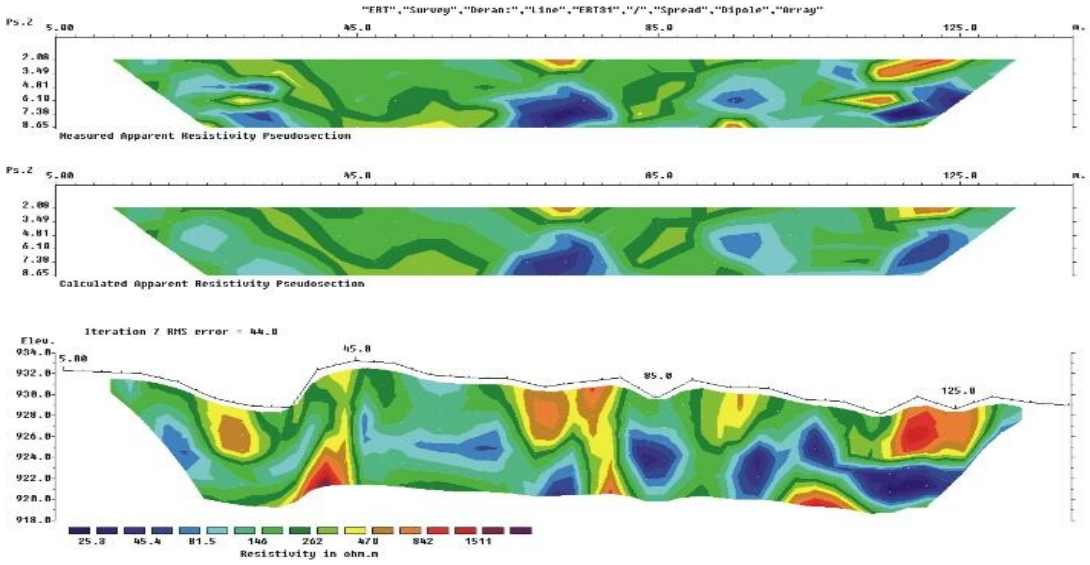

Fig. 9. Measured, calculated & inverse sections of ERT32 (Dipole-dipole array).

Line ERT 32 (E-W)

The inverted Wenner array section (Fig. 9) shows a very clear and sharp low resistivity anomaly at 80m. The model looks very reliable not only based on its very low RMS error but also because it matches the geological observations. It is very possible that the mineralization is widening downwards and is assumed that we deal here with a buried chromite body, and could be a continuation of the third anomaly on line ERT 31.

CONCLUSION AND RECOMMENDATIONS:

1- Chromite exploration using Electrical Resistivity Tomography (ERT) was helpful in the current phase of evaluation that it gives valuable information on the geology and the structures controlling the chromite mineralization in the area.

2- Laying out some ERT lines in such way so that they crossed over the contact zones (between granite rocks and ultrabasic rocks) which are associated with chromite mineralization in the area was helpful and provided calibration for reliability of ERT to explore the already confirmed Chromite in excavated pits.

3- Based on above calibration and results of each line, the current paper summarizes the most interesting anomalies associated with chromite mineralization, giving description of the anomalies in the corresponding details of each lines.

4- It is recommended to ground truthing the discovered anomalies and to update interpretation based on its results.

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