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Evaluation of Iron Ore Deposit Using 2D Resistivity Imaging and Induced Polarization Technique At Fakarau Potiskum, Northeastern Nigeria

Aliyu Mohammed Lawan [1] Usman Ahmed[2]
Abubakar Sadiq Lawal[3]

[1]Department of Geology,
Skyline University Nigeria

[2]Department of Physics,
Kebbi State University of Science and Technology Aliero

[3]AG Vision mining Ltd. Utako Abuja

Email: aliyulawan99@gmail.com

Abstract
2D Electric resistivity imaging and Induced polarization (IP) techniques were used to evaluate Iron Ore deposit at Potiskum area of Yobe State, Northeastern Nigeria. The area lies between latitudes 11⁰ 40' 00'' and 11⁰ 50' 00'' N, and longitude 11⁰ 00' 00'' and 11⁰ 10' 00'' E. The survey was targeted at determining resistivity and chargeability values that are associated with the iron ore deposit. The dipole-dipole array was used for 2D resistivity and induced polarization imaging. Data processing and interpretation were done using RES2DINV software. This research had characterized the study area into two portions: the alluvium deposit that is highly enriched of iron ore and alluvium deposit with disseminated iron ore. The portion of the iron rich alluvium, characterized by low resistivity and chargeability of 32 Ωm to 734 Ωm and 0.403 msec to 3.400 msec are inferred as alluvium that is highly enrich with iron ore, while the portion that are respectively characterized by resistivity and chargeability values of 734 Ωm to 1418 Ωm and 1.90 msec to 6.40 msec are inferred as alluvium with disseminated iron ore. It can be concluded that the occurrence of iron ore deposit is probably more at northeast part of the survey area. The iron ore deposit strikes in the Northeast-Southwest direction.

Keywords: Iron ore, Chargeability, Electrical Resistivity Imaging, Induced polarization.

INTRODUCTION
Electrical resistivity imaging (tomography) is a method by which 2D images of subsurface resistivity distribution are generated (Batayneh, 2006). With this method, features with resistivity properties that differ from those of the surrounding material may be located and characterized in terms of electrical resistivity, and depth of burial. The electrical resistivity tomography is carried out by using computer-controlled measurement systems connected to multi-electrode arrays.

Induced Polarization (IP) is the most useful geophysical methods in mineral exploration due to its ability to detect disseminated minerals. The basic concept/principle is overvoltage effect. This effect occurs due to characteristic of ground which acts as capacitor when DC

**Author for Correspondence*

current is switched off. Voltage measured with two potential electrodes does not suddenly drop to zero but takes finite time to decay with time (Milsom, 2003). This overvoltage effect is contributed by minerals, which are good conductors, where its magnitude depends on both magnitude of impressed voltage and mineral concentration. It is most pronounced when the mineral is disseminated throughout the host rock as the surface area available for ionic–electronic interchange is then at a maximum. This work is aimed at using 2D resistivity and induced polarization (IP) imaging to evaluate the iron ore deposit in the study area and also to determine lateral extent of the iron ore deposit. 2D electrical resistivity imaging and induced polarization was employed in this research. This was chosen because it is proven successful in identifying iron ore deposit, on the basis of resistivity contrast and chargeability that exist between iron ore deposit and surrounding formation within the Diddaye-Potiskum environ (Lawan *et al*., 2021) The work of Francis *et al*. (2014) reveals that the apparent resistivity of the iron ore mine tailings range from 11Ωm for a very dense state to 19Ωm for a very loose state in dry condition; while for the fully saturated condition, the resistivity range from 20 to 31Ωm for very dense state to very loose state, respectively. Their results also suggest that this method can be applied to evaluate iron ore deposit in the study area.

Location and Geology of Study Area

The study area falls within Yobe State in northeastern Nigeria, which is located between latitudes $11^{0}40'$ and $11^{0}50'$N and longitudes $11^{0}00'$ and $11^{0}10'$E. The study area is underlain by the sediments of Kerri-Kerri Formation that is predominantly iron rich sandstone and clay with plinth of laterite which is Paleocene in age and has thickness of 130m (Carter *et al*., 1963; Avbovbo *et al*., 1986) which is an elevated plain land located in Yobe State, Nigeria. The Kerri-Kerri Formation comprises medium coarse sandstones, sands, sandy gravel and sandy clay, although fine sands, siltstone and clay stones are well developed (Dike and Dan-Hassan, 1992). The Kerri-Kerri Formation form part of the stratigraphic sequence in the Chad basin which started in the crateceous with the deposition of Bima sandstone which lies un-conformably on the Precambrian Basement rocks. In turonian time an extensive transgression resulted in the deposition of Gongola formation which is a transitional sequence of mixed limestone and shale. However, the condition changed to entirely marine in the senonian during which the marine Fika shales were deposited. Toward the end of cretaceous, probably during the maestrictian, an estuarine-deltaic environment prevailed resulting in the deposition of the Gombe formation (Adegoke, et al., 1978). The Kerri-Kerri Formation outcrops in a number of places particularly in the Alkaleri, Dukku and Potiskum areas respectively. Figure 1 below shows the geological map of the study area and it reveals linear feature traversing northeastern direction and is inferred as fault/fractures.

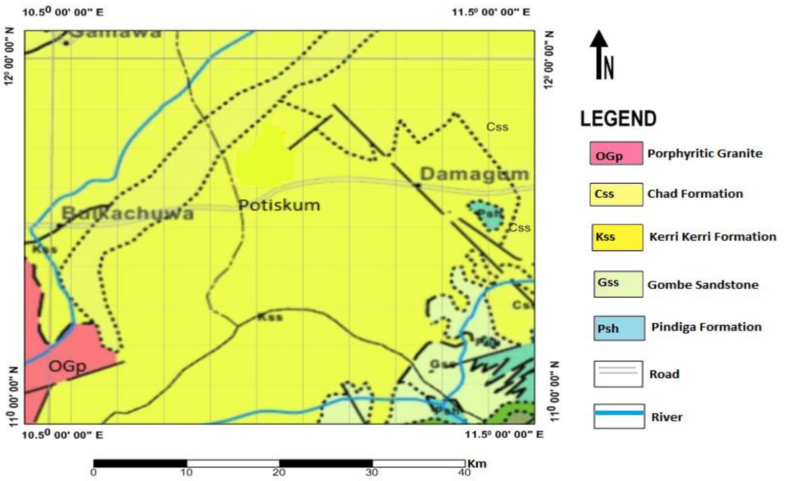


Figure 1: Geological map of study area (Courtesy Nigeria Geological Survey, 2004)

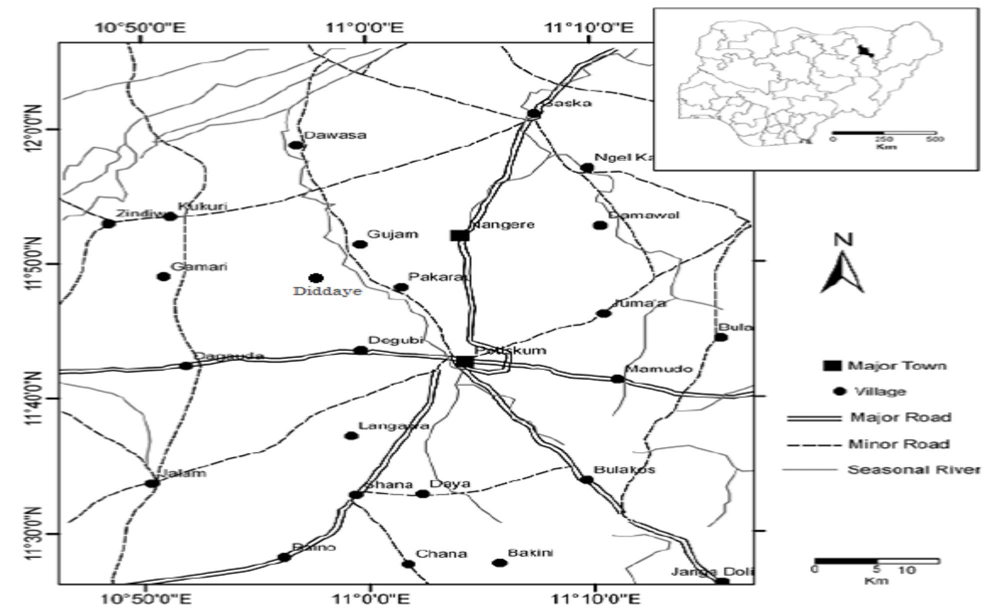


Figure 2: Location map showing the study area (Naibbi *et al.*, 2014)

METHODOLOGY

Materials

The following materials were used in this work; Terrameter, Global positioning system (GPS), ABEM Lund imaging system, stainless steel electrode, cable and reels, compass, hammers, measuring tape, Pieces of peg and UPS Battery and its charger.

Method

Dipole-Dipole was used in both 2D resistivity imaging and IP techniques for this research. The terrameter SAS 1000 and the ES 464 were placed at the center of the layout. The two cables were connected to the Electrode selector (ES 464) at the centre of the layout. Take-out 1 and take-out 21 were made to overlap at the cable ends and at the layout centre. The serial port of the Terrameter was connected to the electrode selector and the electrodes connected to all the take-outs at the intervals of 2m on the electrode cables using cable jumpers. Electrodes were drived into ground by hand. However, hammering and wetting were done on dry and hard ground. The terrameter was then connected to an external 12 volts battery and switched on, which automatically switches on the Electrode Selector and the system set-up echoed on the screen. The instrument was set to resistivity mode and LUND Imaging and IP mode for Dipole-Dipole measurement (ABEM instruction manual, 2010). The programmes automatically continue to measure using the two electrode cables. The apparent resistivity/chargeability values are echoed on the screen. When measurements on each layout were finished, the programme stopped and the Terrameter switched off. The instruments were then transferred to a new profile and the entire process repeated until all the profiles were completed (Albert et al., 2012). Five profiles were taken along north-east to south-west direction of the survey area, this is because the deposit is trending in the north-south direction.

RESULTS AND DISCUSSION

The Figures 1 to 7 shows the electrical resistivity images and Induced polarization of the earth's subsurface along the profiles obtained in the study area. Five profiles were taken from the study area for this work. The inversion result for each profile is shown depicting the images of the geo-electric sections obtained from the processed data. The results show two images for each profile, resistivity model and chargeability model of induced polarization, both obtained after iteration of the inversion programme.

Profile One

Resistivity model (figure 3 below) reveals that the thick layer with resistivity values of 97 Ωm to 633 Ωm occurred at the depth of 0.5 m to 9.6 m. underlying is high resistivity layer with resistivity values ranges from 1611 Ωm to 67439 Ωm. Chargeability model reveal that, chargeability of 0.403 msec to 3.4 msec dominated the model except at the middle between the distance of 22 m to 38 m at a depth of 5.88 m to 10.1 m there appears chargeability values of 4.9msec to 7.9msec. The area with resistivity value ranges from 32 Ωm to 734 Ωm and chargeability values 0.403 msec to 1.90 msec indicated highly enriched iron ore.

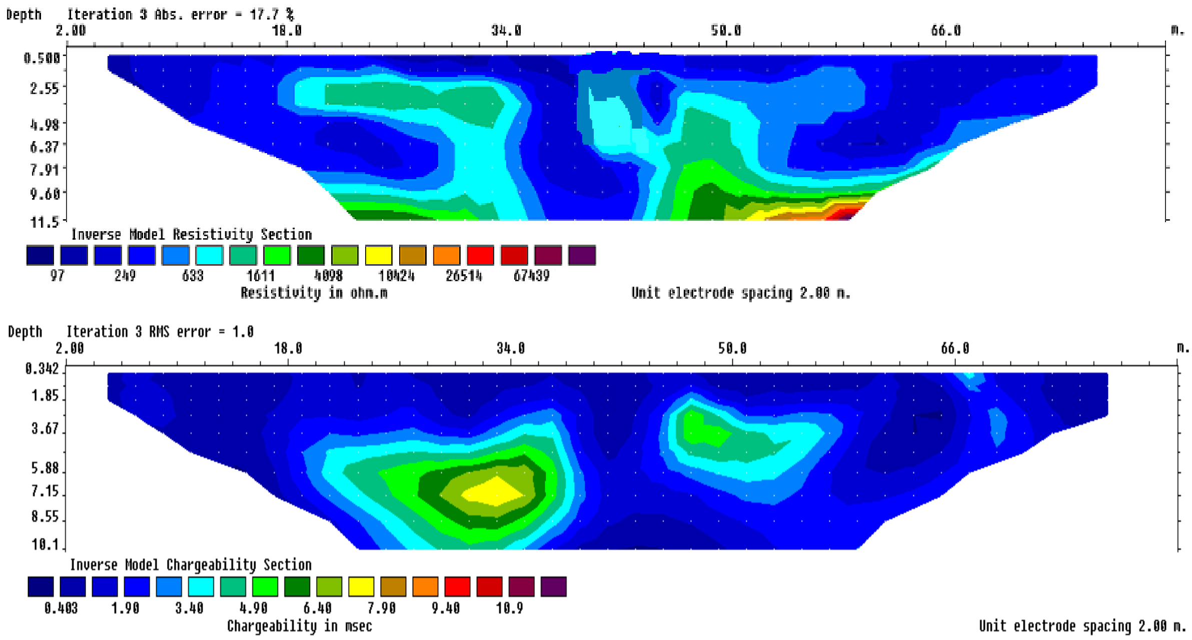


Figure 3: Result of 2D resistivity inversion and IP inversion along profile one

Profile Two

Figure 4 below shows resistivity and chargeability models of profile. Resistivity model reveals that the profile comprises alluvium deposit that has resistivity values ranging from 33 Ωm to 1138 Ωm. From the depth of 0.5 m to 4.98 m at the distance between 2m to 20m, low resistivity of 33 Ωm to 352 Ωm occurred; underlying is the relative high resistivity of 355 Ωm to 1138 Ωm. Chargeability model reveals low chargeability values ranges from 0.43 msec to 3.4 msec except in small portion at the middle of the model where chargeability value reached 4.9 msec. The area with resistivity 33 Ωm to 1138 Ωm and low chargeability ranges from 0.403 to 3.4msec indicates portion of highly enrich iron ore.

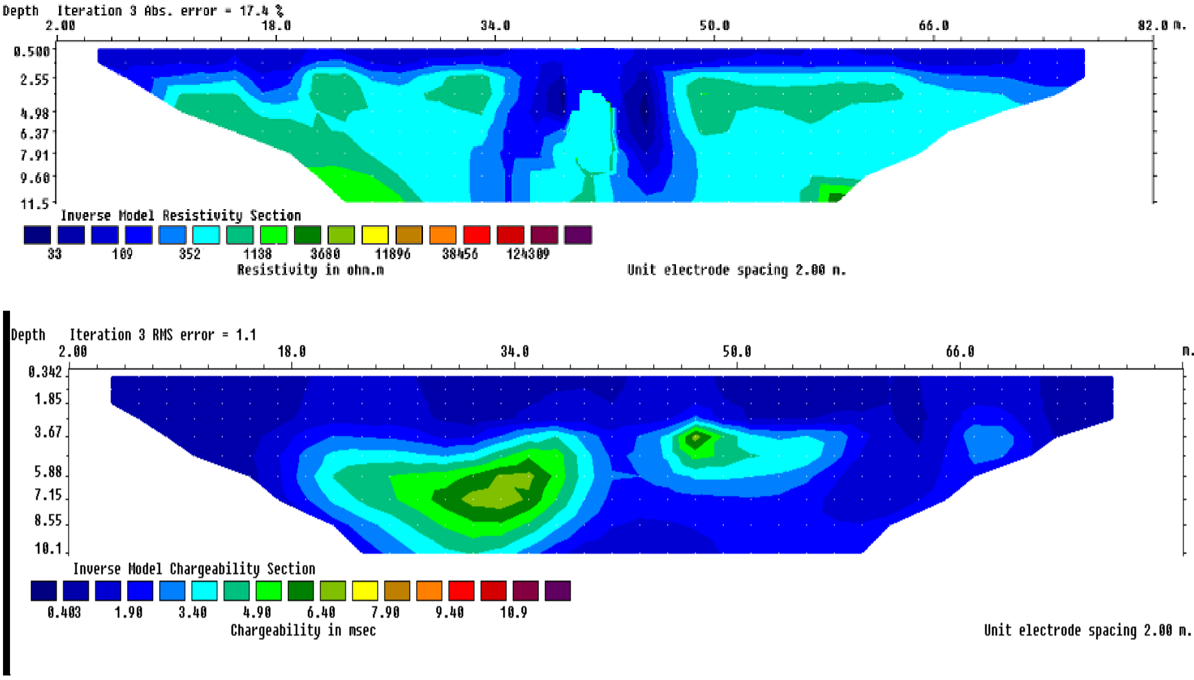
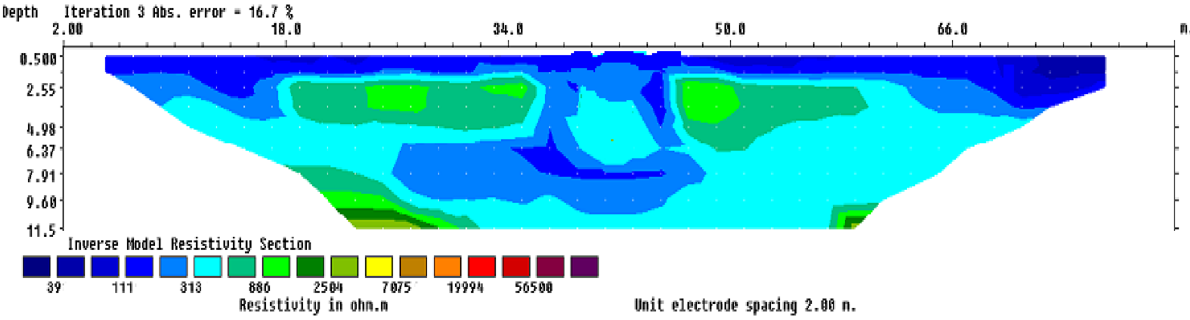


Figure 4: Result of 2D resistivity inversion and IP inversion along profile two.

Profile Three

Figure 5 below shows Resistivity model and Chargeability model. Resistivity model reveals a top soil layer that has resistivity value of 39 Ωm and depth of 2 m. Underlying the top soil is alluvium deposit with high resistivity ranging from 111 Ωm to 886 Ωm and it has thickness of 8.3 m. Chargeability model reveals low chargeability value ranges from 0.403 msec to 1.98 msec, and at the middle of the model, chargeability of 3.40 msec to 6.40 msec occurred. The area with resistivity values ranges from 17 Ωm to 763 Ωm and chargeability values from 0.403 msec to 1.90 msec indicates the occurrence of alluvial with highly enriched iron ore.



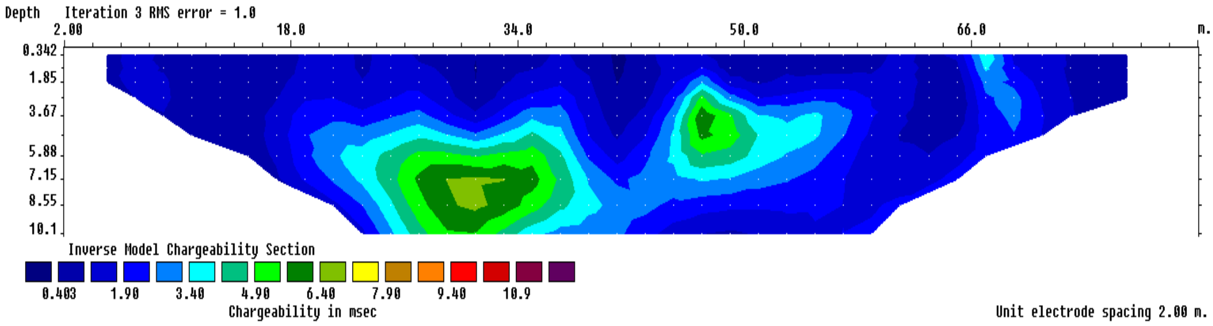


Figure 5: Result of 2D resistivity inversion and IP inversion along profile three.

Profile Four

Figure 6 below shows resistivity and chargeability models of profile four. Resistivity model reveals that the profile is of alluvium deposit with resistivity values ranging from 32 Ω m to 734 Ωm and depth of 7.91 m. There is occurrence of high resistive coarse grain sandstone with resistivity values ranging from 2077 Ωm to 46991 Ωm, at depth ranging from 7.91 m to 11.50 m. Chargeability model reveals low chargeability values of 0.433 msec to 2.26 msec, at the depth of 0.34 m to 5.88 m and also chargeability values ranges from 4.09 msec to 5.92 msec occurred at depth of 6 m to 10.1 m. The area with resistivity values ranges from 74 Ωm to 508 Ωm and low chargeability values ranges from 0.433 msec to 2.26 msec shows the occurrence of iron ore with disseminated ore.

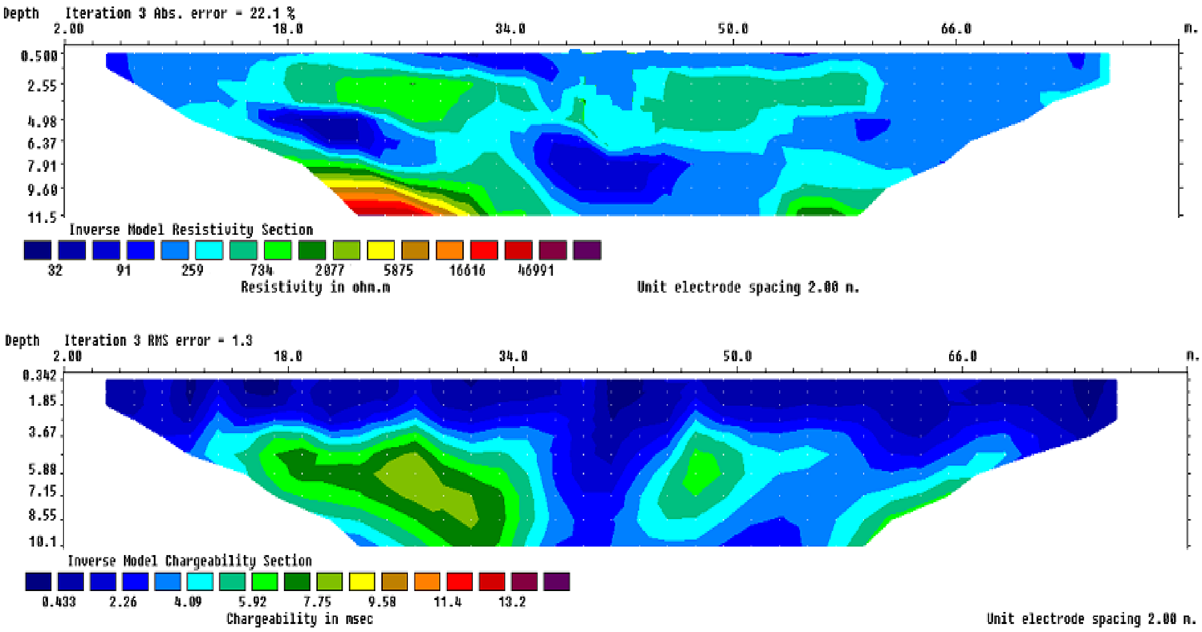


Figure 6: Result of 2D resistivity inversion and IP inversion along profile four.

Profile Five

Figure 7 below shows Resistivity model and Chargeability model. Resistivity model reveals that the profile comprises alluvium deposit with resistivity values ranges from 14 Ωm to 568 Ωm at a depth of 11.5m. Chargeability model reveal the low chargeability values ranges from 0.468 msec to 2.29 msec. From the depth 5.88 m to 10.1 m there is occurrence the chargeability values ranges from 4.12 msec to 7.77 msec. The portion that has resistivity values ranges from 10 Ωm to 323 Ωm and low chargeability shows the occurrence of disseminated iron ore deposit.

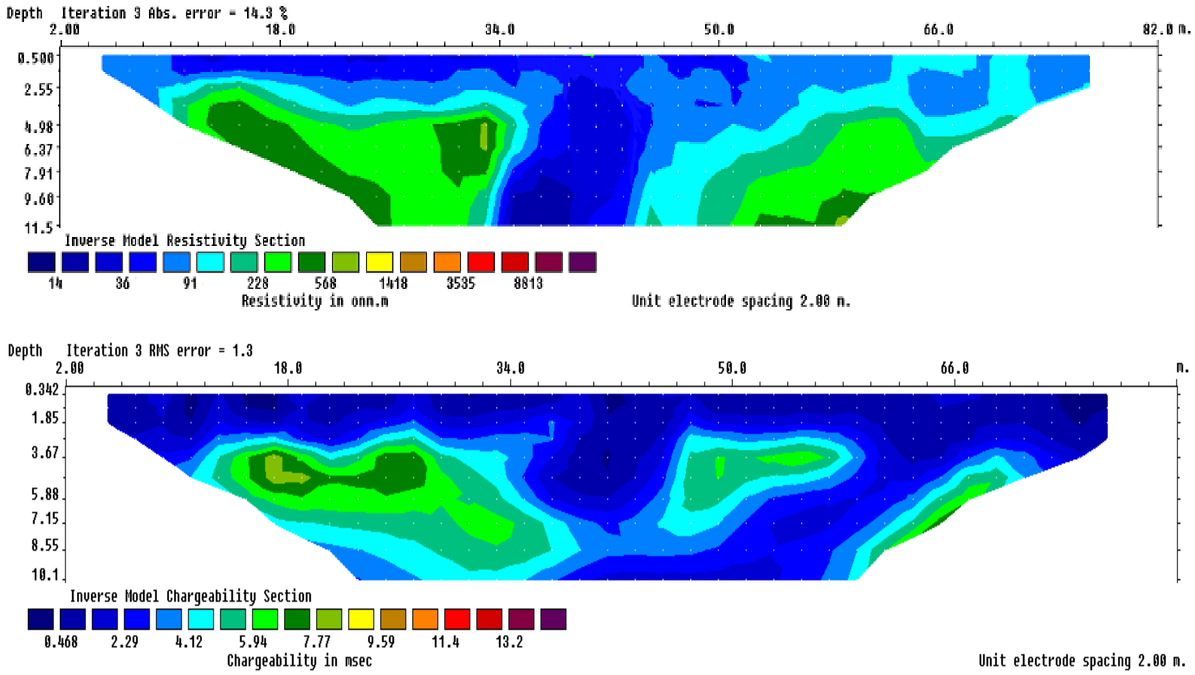


Figure 7: Result of 2D resistivity inversion and IP inversion along profile five.

Profile one to five (figure 3 to 7) reveals alluvium of highly enriched iron ore and disseminated iron ore with resistivity and chargeability values of 14 Ωm to 1418 Ωm. The portion of the iron rich alluvium, characterized by low resistivity and chargeability of 32 Ωm to 734 Ωm and 0.403 msec to 3.400 msec are inferred as alluvium that is highly enrich with iron ore, while the portion that are respectively characterized by resistivity and chargeability values of 734 Ωm to 1418 Ωm and 1.90 msec to 6.40 msec are inferred as alluvium with disseminated iron ore. This inference was made based on surface geology, standard resistivity and chargeability values of rocks and minerals used as control, and on the basis that iron rich layer which is characterized by low resistivity and chargeability values (Lawan *et al.*, 2021). The thickness of alluvium highly enriched with iron ore ranges from 3 m to value that extends beyond the probe limit of the electrode spacing of the survey which is 11.5 m. Spatial display of resistivity and chargeability models of all the profiles have been shown in figure 8 and 9. The maximum depth displayed by the figures is 8 m and previous studies of the area were used as control, the depth suggest that the investigation is limited to deposit of alluvial in the stratigraphic sequence of the chad basin where the study area lies upon.

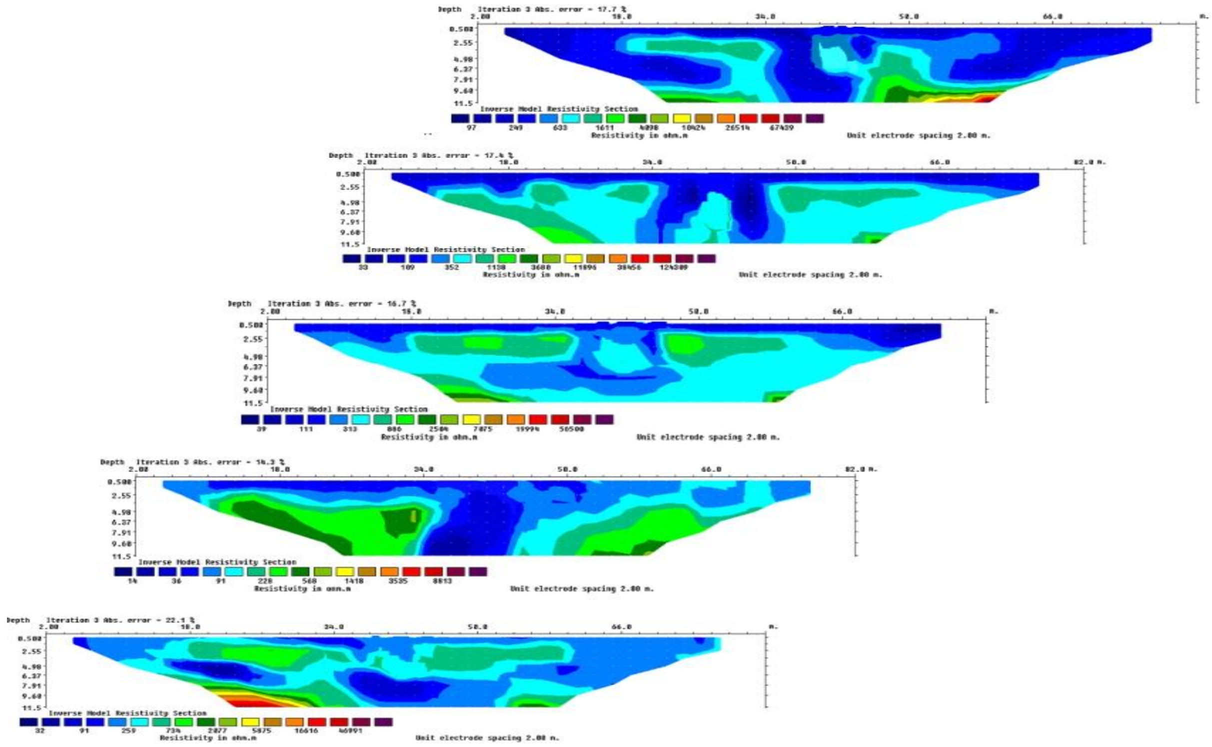


Figure 8: Composite display of Resistivity model of all the profiles

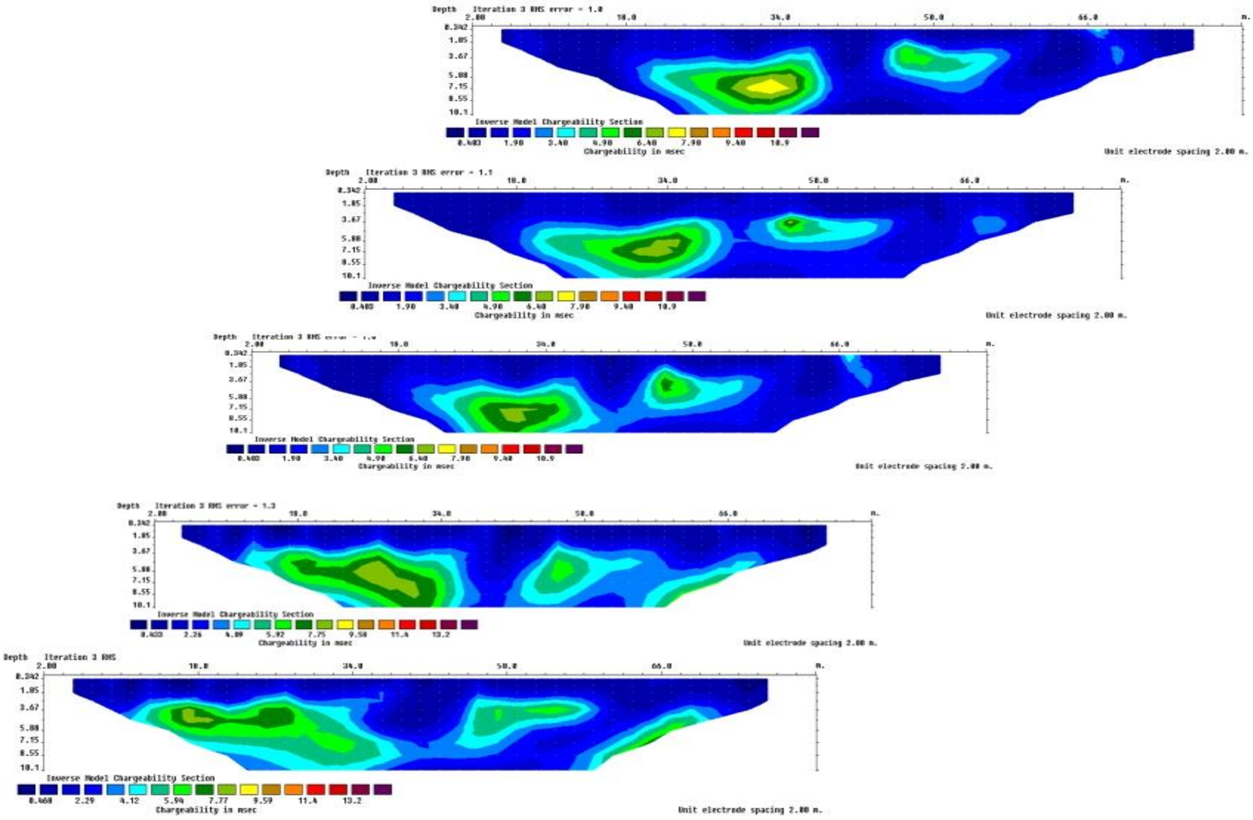


Figure 9: Composite display of IP (Chargeability) model of all the profiles.

CONCLUSION

Electrical resistivity imaging and induced polarization were carried out at Karau-Karau Potiskum environ, Northeastern Nigeria, have successfully addressed the aim of the investigation. The study evaluated the iron rich alluvium into two, thus; the portion of alluvium that is highly enriched iron ore with resistivity and chargeability values of 32 Ωm to 734 Ωm and 0.403 msec to 2.4 msec respectively. The portion with highly iron ore occurred at an average depth of 5.88 m and the thickness ranges from 0.5 m to depth beyond the probe limit of the electrode spacing of the equipment used for this investigation. At the other portion of alluvium with disseminated iron ore, the range of resistivity and chargeability values of this portion are respectively 734 Ωm to 1418 Ωm and 1.28 msec to 12.11 msec. The maximum depth of this portion is 11.5 m but the thickness could not be provided because of the probe limit of the electrode spacing of the equipment used for investigation.

RECOMMENDATIONS

Based on the result of this research it is recommended that, further investigation using magnetic and seismic geophysical methods can also be used so as to compliment the results obtained from resistivity and IP investigations.

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