Geophysical Investigations for Locating Buried Iron Slag at Lejja, Enugu State, Nigeria

Article · February 2014

1 author:

Gabriel Z. Ugwu
Enugu State University of Science and Technology

Geophysical Investigations for Locating Buried Iron Slag at Lejja, Enugu State, Nigeria

***Ugwu GZ, Ezema PO.**
Department of Industrial Physics, Enugu State University of Science and Technology, Enugu, Nigeria

Keywords: 2D Resistivity imaging, induced polarization, iron slag, pseudosections, inversion, apparent resistivity and chargeability.

Abstract

Archaeological geophysics involving the use of resistivity imaging and induced polarization (IP) techniques were used to locate buried iron slag and furnaces at Lejja, Southeastern Nigeria. The instrument used was the ABEM Lung measuring meter system, employing the Wenner electrode configuration. The acquired resistivity and IP data were processed and interpreted using Res2DINV software. The inverse resistivity models revealed the presence of relatively high resistivity materials of about 1090-2600Ωm buried at depths of 2.55-3.70m at different locations within the survey area. The inverse chargeability models are consistent with the inverse resistivity models in terms of the spatial locations of the buried materials. Materials of relatively high chargeability values of 2.09 – 3.09ms were also shown to have been buried at depths of 2.55-3.70m. These relatively high resistivity and chargeability materials were interpreted to be iron slag or burnt bricks used for the furnace by the iron smelting workers many years ago. Determination of the spatial distribution of the buried iron slag and furnaces helped to identify the most suitable locations, outside the region of the buried materials, where hand-dug wells can be sited.

* Corresponding author: ugwugz@yahoo.com

Introduction

Iron slag is the waste material which remain after useful iron has been extracted from the original rock material or iron ore. At Otobo-Dunoka Village of Lejja, the slag blocks of different sizes and shapes are visibly noticeable (Figure 1), indicating the extent of iron smelting activities carried out in the area many years ago. This has turned the area into an archeological site. The abundance of the iron slag with a density of 3-4 slag blocks per square metre (Anozie,1979; Eze-Uzoamaka,2009) confirms the area as a previous iron smelting site. Most of the blocks look alike but are of different sizes. Their diameter ranges from 31-56cm, with one of the ends either conical or spherical in shape.

The quantity of the iron slag and furnaces buried beneath the earth surface at Otobo-Dunoka village has become a source of concern to the inhabitants. The buried materials have direct effect on the groundwater resources of the area such as contamination with iron oxide through seepage. To harness the groundwater in the area, one has to drill through the buried materials. Harte (1985) opined that the excavation of a smelting site would be extremely difficult because the excavation equipment would be damaged by the strong iron slag.

This research is an example of archaeological geophysics. The purpose of the research is to determine the spatial locations of the buried slag or furnaces, as well as their depth of burial. This is with a view to recommending for their excavation and determining the best locations where hand-dug wells can be sited in order to solve the problem of acute scarcity of water in the area.

The paper reports on the use of two dimensional (2D) electrical resistivity imaging (ERI) and induced polarization (IP) techniques to determine the locations of the buried materials in the survey area. Geophysical investigations employing electrical resistivity imaging and induced polarization techniques have been used to address a wide variety of environmental issues. The 2D electrical resistivity imaging has been used for delineating archaeological features, waste site characterization, geotechnical

Received Manuscript 05-01-2014 Accepted Manuscript --/--/----

investigations of buildings, locating subsurface utilities and for monitoring pollution seepage through the earth's subsurface (Griffiths and Barker, 1993; Dahlin, 1996; Colangelo, 2008; Andrews et al, 2013; Ugwu and Ezema, 2013). Applications of IP method to environmental issues include the works of Seigel (1970) and Zhang and Luo (1990).
The techniques involve the use of necessary equipment and software for processing and interpreting the acquired data.

Geology of the Area

Lejja is a small community located about 14km south of Nsukka town in Nsukka Local Government Area of Enugu State, Nigeria (Figure 2). It lies at latitude 6°45'N and longitude 7°22'E. The site under investigation is at Otobo-Dunoka village and spans an area of about $500m^2$.
The geology of the area is characteristic of the Eastern Nigeria sedimentary basin which is within the southern portion of the Benue Trough of Nigeria. The rocks range in age from Coniacian to Paleocene and are grouped into three major formations (Figure 3): Mamu Formation, Ajali Formation and Nssukka Formation (Reyment, 1965; Murat, 1972; Nwachukwu, 1972). The Mamu Formation consists of fine–medium grained white to grey sandstones, sandy shale, grey mudstones, shale and coal seams. The thickness is about 450m and conformably underlies the Ajali Formation. The Ajali Formation consists of thick friable, poorly sorted sandstones. They are typically white in colour but sometimes iron-stained. The thickness averages 300m and is often overlain by considerable thickness of red earth, which consists of red, earthy sands, formed by weathering and ferruginisation of the formation. The Nsukka Formation lies conformably on the Ajali sandstones. The lithology is very similar to that of Mamu Formation and consists of an alternating succession of sandstones, dark shale and sandy shale, with thin coal seams at various horizons. The Nsukka Formation is more than 300m thick and has the general effect of confining the aquifers of the Ajali Formation (Ofodile, 2002).

Materials and method

The multielectrode ABEM Lung meter aided with the electrode selector ES464 was used for the resistivity and induced polarization measurements, employing the Wenner electrode configuration. The electrodes were arranged linearly with a constant spacing between adjacent electrodes. The electrodes were then connected to the multicore cable which was connected to the selector and then to the resistivity meter. The continuous vertical electrical sounding (CVES) method which combines lateral average with the vertical sounding was employed in the data acquisition process. Figure 4 shows the electrode arrangement and the sequence of measurements for building the pseudosections for the 2D electrical resistivity imaging and the induced polarization techniques carried out at the field (Edwards, 1997; Loke, 2001). The minimum electrode spacing used in the field was 4km. Two profiles were taken at the survey site in a cross pattern. Profile 1 was taken in the North-South direction covering a distance of 130m while Profile 2 was taken in the East-West direction through a horizontal extent of 200m. Along each profile, measurements of apparent resistivity and induced polarization were made. The time domain IP measures the apparent chargeability.
The acquired electrical resistivity and induced polarization was processed using the Res2DINV software (Geotomo, 2008). Elevation corrections were not carried out because the survey area was fairly flat. The data was filtered to remove bad data points whose resistivity values were clearly wrong compared to the neighbouring data points. The Res2DINV software was used to generate the 2D resistivity and chargeability models by inverting the resistivity and IP data sets. The inversion routine used by the program is based on the smoothness – constrained least – squares method (deGroot – Hedlin and Constable, 1990; Sasaki, 1992). The Least – squares optimization techniques (Loke and Barker, 1996) tries to minimize the difference between the measured and calculated apparent resistivity or chargeability values by adjusting the resistivity or chargeability values of the model earth subsurface blocks. A measure of this difference is often given after 3-5 iterations by the root – mean – square

Received Manuscript 05-01-2014 Accepted Manuscript --/--/----
www.journal-of-natural-sciences.darsgah-e-ahlebait.com

(RMS) error. Thus the smaller the RMS error after the iterations, the closer the fit between the measured and the calculated data.

Results

Figures 5 and 6 show the electrical resistivity images of the earth subsurface at the survey area as inverse resistivity models while figures 7 and 8 show the induced polarization images as inverse chargeability models. The models were obtained by the optimization techniques of the Res2DINV software after minimizing the difference between the measured and the calculated pseudosections of the apparent resistivity and induced polarization data sets. The models show the unit electrode spacing as 2.0m because the model refinement "option" of the inversion "menu" was used to take care of the large variations of apparent resistivity and induced polarization near the ground surface. With this option, the program automatically reduced the unit electrode spacing of 4m used in the field to half (Loke 2001). The RMS error after 3 iterations for the inverse resistivity models were given as 15.2% and 9.0% for profiles 1 and 2 respectively while the inverse chargeability models have RMS error of 0.20% and 0.12% for profiles 1 and 2 respectively.

Discussion

The two inverse resistivity models showed increase in resistivity with depth. The inverse resistivity model of profile1 (Figure 5) revealed the presence of a high resistivity material of about 1095Ωm at the 15-21m mark along the profile buried 2.55m deep. This high resistivity material could be buried iron slag. Another high resistivity and relatively larger material buried 3.70m deep and between the 78-94m mark along the profile was also revealed in Figure 5. This larger material has a resistivity range of 1090-2600Ωm and was also interpreted to be iron slag or the burnt bricks used for the furnaces. In between these high resistivity sections is a stretch of moderate resistivity section of about 500 - 700Ωm and up to a depth of 4-6m. This section probably contains alluvium and sand, in view of the resistivity range of sedimentary rocks shown in Table1. This formation could be a perched aquifer. Bellow this water bearing stratum is a high resistivity section of 1095-2672Ωm, characteristic of consolidated shale.

The inverse resistivity model of profile 2 (Figure 6) did not reveal the presence of the buried materials but rather showed long patches of low resistivity near-surface formation of about 100- 300Ωm, characteristics of clayey sand of top to depth of 3.70m. Below this depth is the water bearing formation of alluvium and sand which is also underlain by a higher resistivity material of consolidated shale.

The inverse chargeability model of profile 1 (Figure 7) is consistent with the inverse resistivity model of Figure 5. High chargeability value of 2.70 – 3.01ms was depicted around the 16-20m mark along the profile, and up to a depth of 2.55m. Another fairly high chargeability range of 2.09-3.09ms was equally recorded between the 78-94m and from 106 - 120m mark along the profile. These high chargeability bodies are likely to be the buried slag or the furnace.

The inverse chargeability model of profile 2 (Figure 8) shows the presence of iron slag along the profile at the 20, 66, 82, 94, and 140m marks. The brick furnace is likely to be at the 174m mark along the profile and with a width of 12m. The blue section with chargeability of 0.94-1.30ms is the saturated clayey sand .

Conclusion

Electrical resistivity imaging and induced polarization techniques have been used to investigate the subsurface structures at Lejja. The ABEM Lung meter system was used to acquire the 2D resistivity and induced polarization data, employing the Wenner electrode configuration. Interpretation of the acquired field data using Res2DIV software enabled the spatial determination of the buried iron slag and furnaces at the survey area. This information in conjunction with the local geology of the study area helped to identify the most suitable area, outside the section of the buried materials, where hand-dug wells can be sited in order to harness the groundwater. However, the aquifer identified by this study is the perched aquifer, considering the subsurface depth sampled by this method of investigation.

Although Figure 6 did not show any signature in apparent resistivity arising from the buried materials, strong chargeability signature was recorded using IP (Figure 8). This shows the advantage of using IP method over resistivity method in locating buried metal bodies (Zhang and Luo, 1990).
The success achieved in this study has shown the combination of ERI and IP techniques as a powerful tool for imaging areas with complex geology.

References

Andews N.D., A.A. Aning, S.K. Danvor and R.M. Noye, 2013. Geophysical investigations at the proposed site of the KNUST teaching hospital building using 2D and 3D resistivity imaging techniques. Int. Res. Jour. Geol. Min. 3(3), 113-123.

Anozie F.N, 1979. Early iron technology in Igboland (Lejja and Umundu). West African Journal of Archaeology, 9, 119-134.

Colangelo G., V. Lapenna, A. Loperte, A. Perrone and L. Telesca, 2008. 2D electrical resistivity tomographies for investigating recent activation landslides in Basilicata region (Southern Italy). Annals of Geophysics, 51(1), 12 – 21.

Dahlin T, 1996. 2D resistivity surveying for environmental and engineering applications, First Break, 275-284.

deGroot-Hedlin C and S. Constable, 1990. Occam's inversion to generate smooth, two –dimensional models for magnetotelluric data. Geophysics, 55, 1613-1624.

Edwards S. A, 1997. Modified pseudosection for resistivity and induced polarization. Geophysics, 42, 1020 – 1036.

Eze C.C. and G.Z. Ugwu, 2010. Geoelectrical sounding for estimating groundwater potentials in Nsukka LGA, Enugu State, Nigeria. Int. Journal of Physical Sciences, 3(1), 58-61.

Eze-Uzoamaka P.I, 2009. Iron Age Archaeology in Lejja. In Pwiti C.R. and S. Macamo (eds). Studies in African Past. 7, 41-51.

Geotomo Software, 2008. Res2DINV Ver. 3.57 www.geoeletrical.com.

Griffiths D.H. and R.D. Barker, 1993. Two dimensional resistivity imaging and modeling in areas of complex geology. Jour. Appl. Geophysics. 29, 211-226.

Harte D.D, 1985. Archaeology in the Nsukka Area. In Ofomata G.E.K. (ed). The Nsukka Environment.

Loke M.H. and R.D. Barker, 1996. Rapid least-squares inversion of apparent resistivity pseudosections by quasi – Newton method. Geophysical prospecting, 44, 131-152.

Loke M.H, 2001. Tutorial: 2D and 3D electrical imaging survey, Geotomo software, Malaysia.

Loke M.H., I. Acworth and T. Dahlin, 2003. A comparison of smooth and blocky inversion methods in 2D electrical imaging surveys. Exploration Geophysics, 34, 183-187.

Murat A.C, 1972. Stratigraphic and paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In Dessauvagie T.F. and A.J. Whiteman (eds). African Geology, Ibadan University Press.

Nwachukwu S.O, 1972. The tectonic evolution of the southern portion of the Benue Trough, Nigeria. Geol. Magazine, 109, 411-419.

Ofodile M.E, 2002. Groundwater study and Development in Nigeria. Ibadan University Press, Ibadan.

Reyment R.A, 1965. Aspects of geology of Nigeria. Ibadan University Press, Ibadan.

Sasaki Y, 1992. Resolution of resistivity tomography inferred from numerical simulation. Geophysical prospecting, 40, 453-464.

Seigel H.O, 1970. The induced polarization method in mining and groundwater geophysics. Geological survey of Canada. Economic Geology Report 26.

Telford W.M., L.P. Geldart, R.E. Sheriff and D.A. Keys, 1976. Applied Geophysics. Cambridge University Press, Cambridge.

Received Manuscript 05-01-2014 Accepted Manuscript --/--/----
www.journal-of-natural-sciences.darsgah-e-ahlebait.com

Ugwu G.Z. and P.O. Ezema, 2013. 2D electrical resistivity imaging for the investigation of the subsurface structures at the proposed site for Kauridan Estate at Ibagwa – Nike, Southeastern Nigeria. Int. Journal of Scientific Research in Knowledge, 1(12), 528-535.

Zhang G. and Y. Luo, 1990. The applications of IP and Resistivity methods to detect underground metal pipes and cables. Geotechnical and Environmental Geophysics, Society of exploration Geophysicists, 3, 239-248.

Figure 1. Iron slag visibly scattered at Otubo-Dunoka village square.

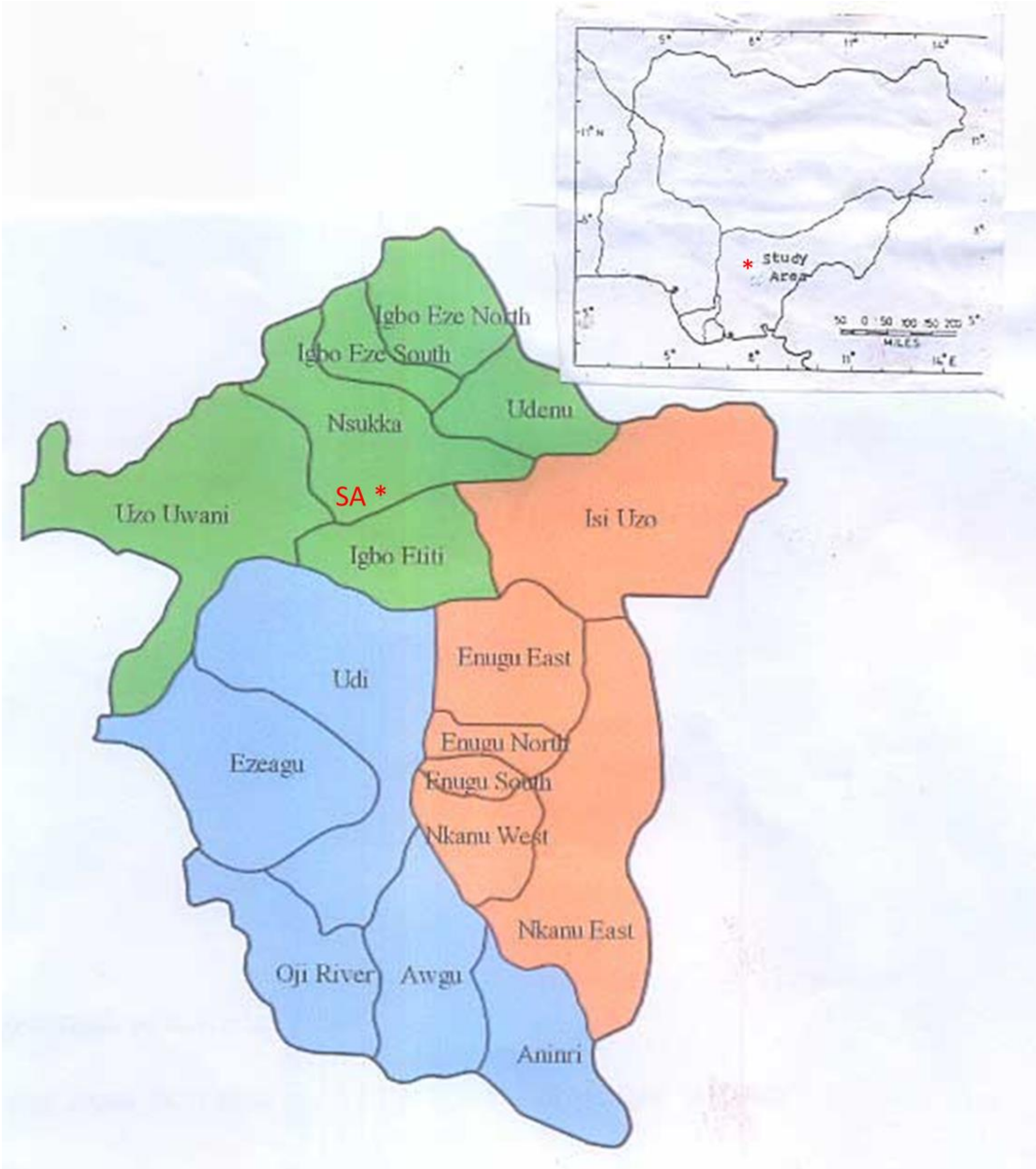


Figure 2. Map of Enugu State of Nigeria showing the study area (SA).

Received Manuscript 05-01-2014 Accepted Manuscript --/--/----

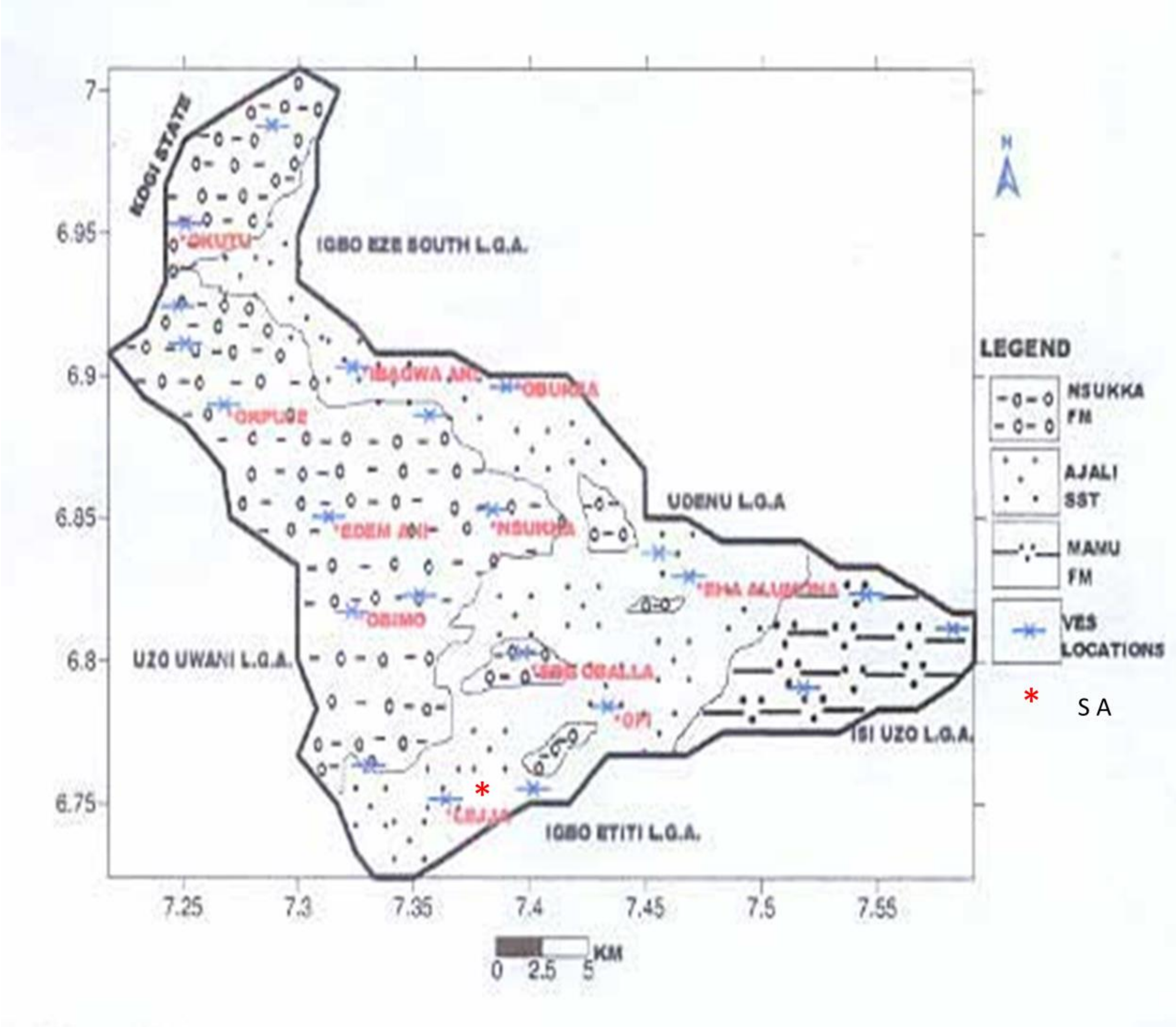


Figure 3. Geologic map of Nsukka showing the study area (Eze and Ugwu, 2010).

Received Manuscript 05-01-2014 Accepted Manuscript --/--/----
www.journal-of-natural-sciences.darsgah-e-ahlebait.com

ISSN 2308-5061

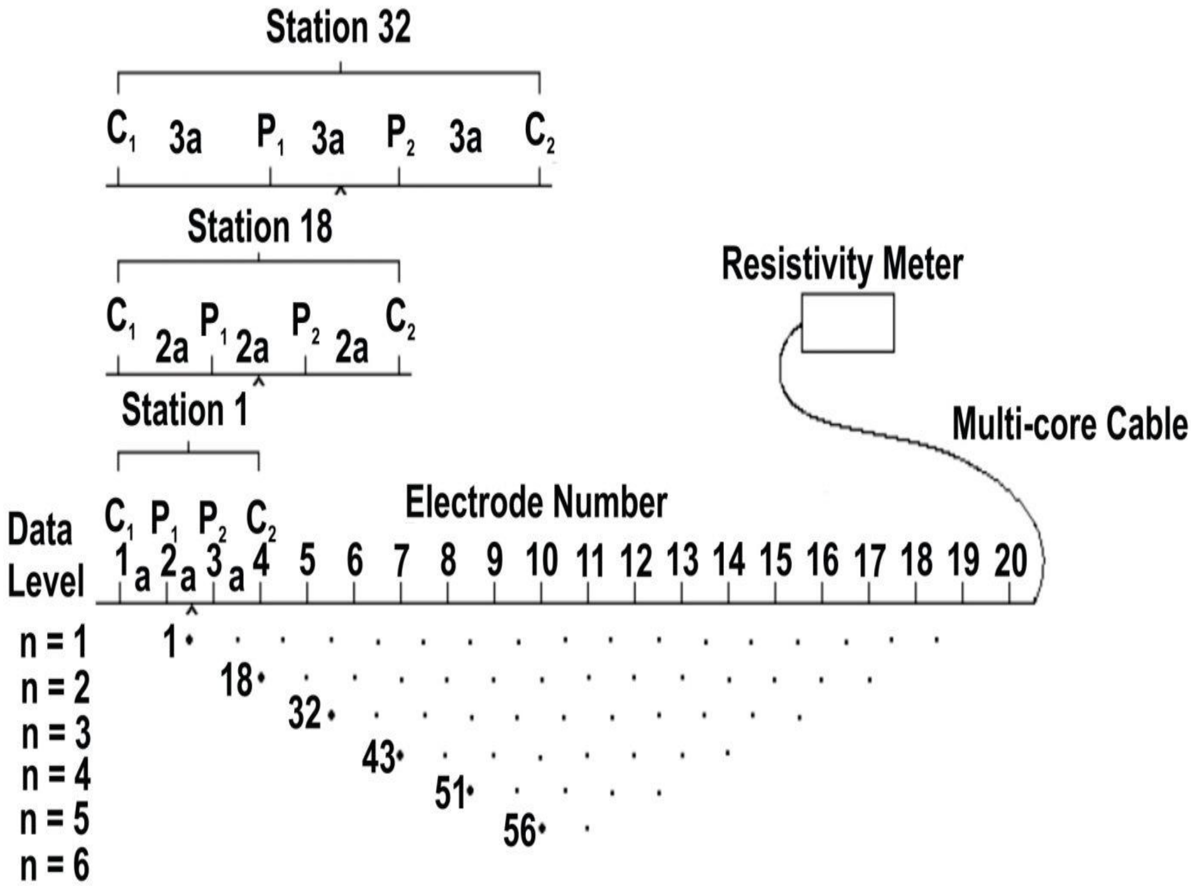


Figure 4. Electrode arrangement and the sequence of measurements for building the pseudosections in 2D ERI and IP survey (Loke, 2001).

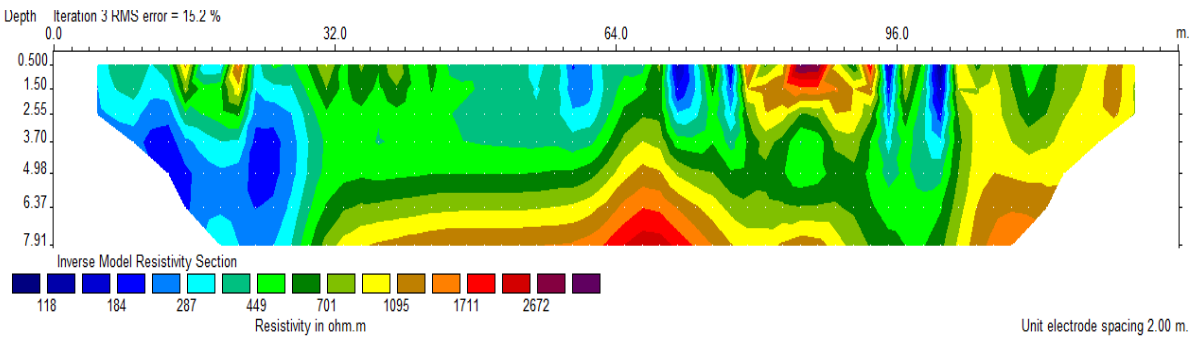
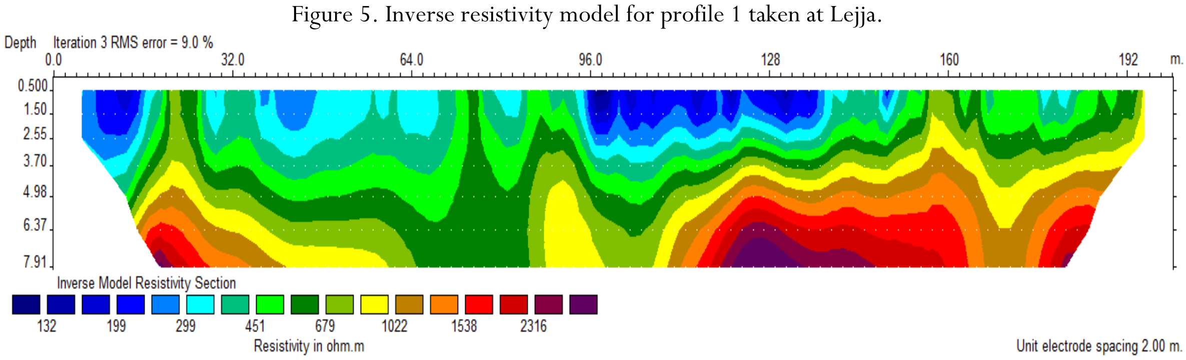


Figure 5. Inverse resistivity model for profile 1 taken at Lejja.



Received Manuscript 05-01-2014 Accepted Manuscript --/--/----

Figure 6. Inverse resistivity model for profile 2 taken at Lejja.

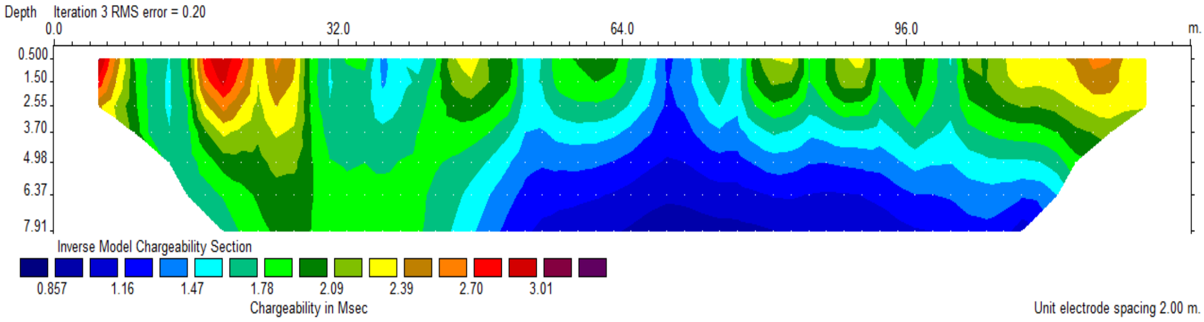


Figure 7. Inverse chargeability model for profile 1 taken at Lejja.

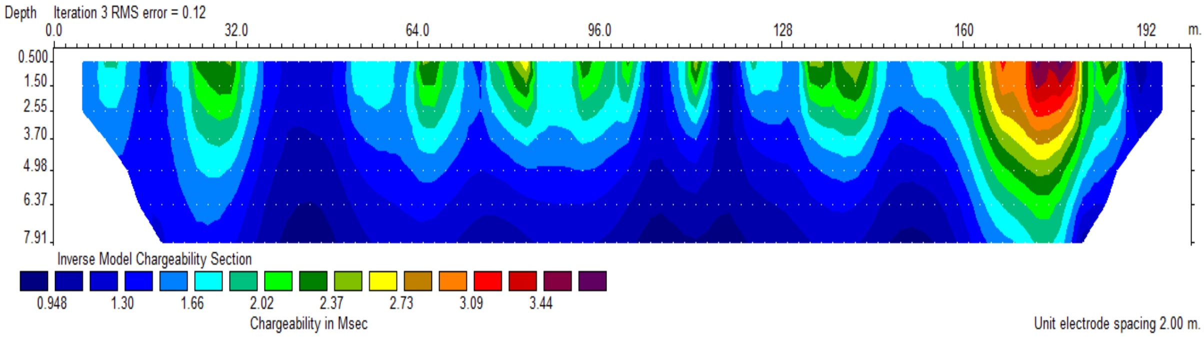


Figure 8. Inverse chargeability model for profile 2 taken at Lejja.

Table 1. Resistivity of rocks and sediments (after Telford *et al.*, 1976)

Rocks and Sediments	Resistivity range (Ωm)
Consolidated shales	20-2000
Argillites	10-800
Conglomerates	2 x 10^3-10^4
Sandstones	1-6.4 x 10^8
Limestones	50- 10^7
Marls	3-70
Clays	1-100
Alluvium and Sands	10-800
Oil Sands	4-800

Received Manuscript 05-01-2014 Accepted Manuscript --/--/----