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Induced polarization interpretation for subsurface characterisation: A case study of Obadore, Lagos State

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ABSTRACT

Induced polarization (IP) imaging was conducted at Obadore in Ojo Local Government, Lagos State, to evaluate the potential of the method when structural properties of the subsurface are required. It addresses one of the potential near-surface applications of the IP method, namely lithological characterization. The study shows that IP imaging is a promising tool for mapping lithological contrasts in unconsolidated sediments and to clarify difficulties in lithological interpretation observed in other geophysical methods. The profiles obtained in the study area depicted two layers; the first layer with consistent and considerable high chargeability signatures at depth of 20m indicates sand formation. The second layer predicted to be clay with low IP effects was observed at various depths for all the profiles.

Keywords: Lithological characterization, Induced polarization, frequency-domain, time-domain, chargeability.

INTRODUCTION

The investigation undertaken at Obadore in Ojo Local Government area of Lagos State is aimed at determining the value of IP in resolving lithological variability.

Induced polarization (IP) is a geophysical method that has been well known technique for many decades. It has proved to be of significant value for various environmental and hydrogeological investigations of the subsurface. It has been demonstrated in field applications that IP has the potential to distinguish between sediments of different lithological composition [19, 5]

However, most of the underlying core-scale investigations [2, 27, 9, 20, 24, 16]were performed on saturated media, which restrict the applicability of the results to vadose zone studies. Moreover, the influence of vadose zone parameters and state variables on IP measurements is not clear because of the lack of corresponding petrophysical data.

Induced Polarization (IP) phenomena are of electrochemical origin, and depend mainly on the surface characteristics of the pore structure. The method measures the chargeability of the ground, i.e. how well materials tend to retain electrical charges.. The chargeability parameter is dependent upon both surface polarization mechanisms and bulk (volumetric) conduction mechanisms. Consequently, the parameter that quantifies the magnitude of surface polarization is the normalized chargeability, defined as the chargeability divided by the resistivity magnitude. Normalized chargeability and clay content are extended to the interpretation of 1-D and 2-D field-IP surveys. In the 2-D survey, the apparent conductivity and normalized chargeability data are used to segment the images into relatively clay-free and clay-rich zones. A similar approach can eventually be used to predict relative variations in the subsurface clay content, salinity and, perhaps, contaminant concentrations [21]. A strong IP effect is observed in sediments containing clays disseminated on the surface of larger grains. Hence, shaly sand/silt and shaly sandstone typically display large IP effects [6, 22]. In contrast, compacted clays are usually associated with low IP effects, as ohmic conduction dominates current flow. Small but measurable IP effects are associated with clean sand and gravel [27].Lithological mapping using pulled-array DC-resistivity and electromagnetic methods has met with considerable success [3,15] However, resolution of clayey sediments from clean sand and gravel has been complicated by the strong dependence of earth resistivity on fluid chemistry and saturation, in addition to lithology. The presence or absence of clayey layers also exerts a fundamental control on the engineering properties of these subsurface sediments.

Geology of Study Area

The study area, Obadore falls within Lagos State and is a few kilometres from the Lagos Lagoon. Lagos State lies approximately between longitudes $2^{0}42'$ East and $3^{0}42'$ East and latitudes $6^{0}22'$ North to $6^{0}52'$ North. The southern boundary of the state lies along the Atlantic coastline while its northern and eastern boundaries are shared with Ogun State. On the western side the boundary is bordered by the republic of Benin. Its size is about 3,577 square kilometre which accommodate over nine millions of the national population (2006, Nigeria population census figures). Lagos state is the most urbanized state in the Country [12],though there are still many rural areas within the state which are still very poorly connected with urban places and thus remain undeveloped. Lagos State is located within the low lying coastal zone of south-western Nigeria.

Lagos State lies in South-western Nigeria and the formations found here occur within the sedimentary series. According to Jones and Hockey, [4] the geology of South-western Nigeria reveals a sedimentary basin which is classified under five major formations. The state overlies the Dahomey basin which extends almost from Accra in Ghana, through the Republic of Togo and Benin to Nigeria where it is separated from the Niger Delta basin by the Okitipupa ridge at the Benin hinge flank. According to their geological formation age the five formations include: the Littoral and the Lagoon deposits, Coastal Plain sands, the Ilaro formation, the Ewekoro formation and the Abeokuta formation overlying the crystalline basement complex with their ages ranging from Recent to Cretaceous. Four of these formations, excluding Ilaro, constitute aquifers in the Dahomey Basin, from which the geological section of Lagos was drawn. The Ilaro formation is composed predominantly of shaley clay (argillaceous sediments). Limestone forms the aquifer material in the Ewekoro formation while sands and gravels constitute the materials in aquifers of the recent sediments, Coastal plain sands and Abeokuta formations contain brackish water.

MATERIALS AND METHODS

Methodology

Induced polarization is the capacitance effect, or chargeability, exhibited by electrically conductive materials. A 4-pointlight hp, a high power induced polarization earth resistivity meter was used. Measurement of I.P. was done by pulse an electric current into the earth at one or two second intervals through metal electrodes. Disseminated conductive minerals in the ground discharged the stored electrical energy during the pause cycle. The decay rate of the discharge was measured by the IP receiver. The decay voltage was zero when there were no polarizable materials present. Generally, both IP and resistivity measurements were taken simultaneously during the survey. Survey depth is determined by electrode spacing.

Theory of Induced Polarization

If in a homogenous medium we introduce current at two or more points (sources and sinks) then the primary potential drop between two other electrodes serving as potential electrodes will, in the absence of volume polarization effects, be given by

$$V = \frac{I}{\sigma}.F(s,g)$$

Where *F(s,g)* is a function of the size and shape of the body, and of the geometry of the various electrodes, and σ is the electrical conductivity of the medium.

In the presence of polarization the potential drop between the voltage electrodes will be increased to

$$V_0 = \frac{I}{\sigma(1-m)}.F(s,g)$$

The increase in voltage, i.e. the secondary voltage V_s, is given by

$$V_S = V_0 - V = I.\frac{F(s,g)}{\sigma}\frac{m}{1-m}$$

and the ratio of peak secondary voltage to the observed steady state voltage is

$$\frac{V_S}{V_0} = \frac{(V_0 - V)}{V_0} = m$$

We now call *m* the chargeability of the medium. The expression for m contains no geometrical factor so that ideally, true chargeability is a volume effect. Thus the ratio $\frac{V_S}{V_0}$ should be independent of topography and, for homogenous isotropic samples (as used in the laboratory, for instance) independent of the electrode geometry, specimen size and shape.

In time-domain IP, several indices have been used to define the polarizability of the medium [17] defined "chargeability" (in seconds) as the ratio of the area under the decay curve (in millivolt-seconds, mV-s) to the potential difference (in mV) measured before switching the current off. Komarov, et al., [7] defined "polarizability" as the ratio of the potential difference after a given time from switching the current off to the potential difference before switching the current off. Polarizability is expressed as a percentage.

Seigel [17] showed that over a heterogeneous medium comprised of *n* different materials, apparent chargeability η_a is approximately related to apparent resistivity by

$$\eta_a = \sum_{i=1}^{n} \eta_i \frac{\partial \log \rho_a}{\partial \log \rho_i} \qquad (1)$$

where η_i = chargeability of the ith material,
ρ_i = resistivity of the ith material.

Seigel provided the validity of

$$\sum_{i=1}^{n} \frac{\partial \log \rho_a}{\partial \log \rho_i} = 1 \qquad (2)$$

Equations 1 and 2 yield the useful formula:

$$\frac{\eta_a}{\eta_1} = 1 + \sum_{i=2}^{n} \frac{\partial \log \rho_a}{\partial \log \rho_i} \left[\frac{\eta_i}{\eta_1} - 1 \right] \qquad (3)$$

If the theoretical expression for apparent resistivity ρ_a is known, then the corresponding expression for the reduced apparent chargeability η_a/η_i can be derived.

RESULTS AND DISCUSSION

IP measurements were conducted to determine the value of IP in resolving lithological variability in the study area and with a view to reducing the ambiguity in interpretation inherent in other geophysical methods such as resistivity and electromagnetic methods.

The chargeability data obtained were plotted against the values of electrode separation. The results of 1-D IP sounding imaging are presented as chargeability curves in figure 1.0 (a-h).

The 1-D sounding does not have sufficient resolution to distinguish the numerous sediment layers; however, the chargeability values plotted can be related based on the general shapes of the signature displayed.

A strong IP effect is observed in sediments containing clays disseminated on the surface of larger grains. Hence, clayey-sand and sandy-clay typically display large IP effects [6;22]. In contrast, compacted clays are usually associated with low IP effects, as ohmic conduction dominates current flow. Small but measurable IP effects are associated with clean sand and gravel [27].

In the study area, all the Profiles depicted two layers; the first layer is modelled with consistent signatures at depth (AB/2) between 1-25 m except for Profile 1. Above 25 m, the model also predicts considerable high chargeability, indicating clay free sediments. An increase in IP effect or chargeability value was observed at depth (AB/2) of 32m and 100m in profile 2. At profile 3, IP increase was observed at depth range between 50–160 m, although there was a sudden drop at 100m and 200m, this may be due to settlement of the formation. Profile 4 depicts increase IP at depth range of 50-250 m and 100m in Profile 5. At depth from 50m above, there was strong IP for Profiles 6, 7 and 8 respectively. Basing our interpretation on the chargeability signatures in the study area, the curves depict sand sediment predicted at 20m with indication of clayey-sand and sandy-clay sediments. Profile 1 shows strong IP effect at various depths. Low IP effects indicating clayey sediment is predicted at various depths for all the profiles.

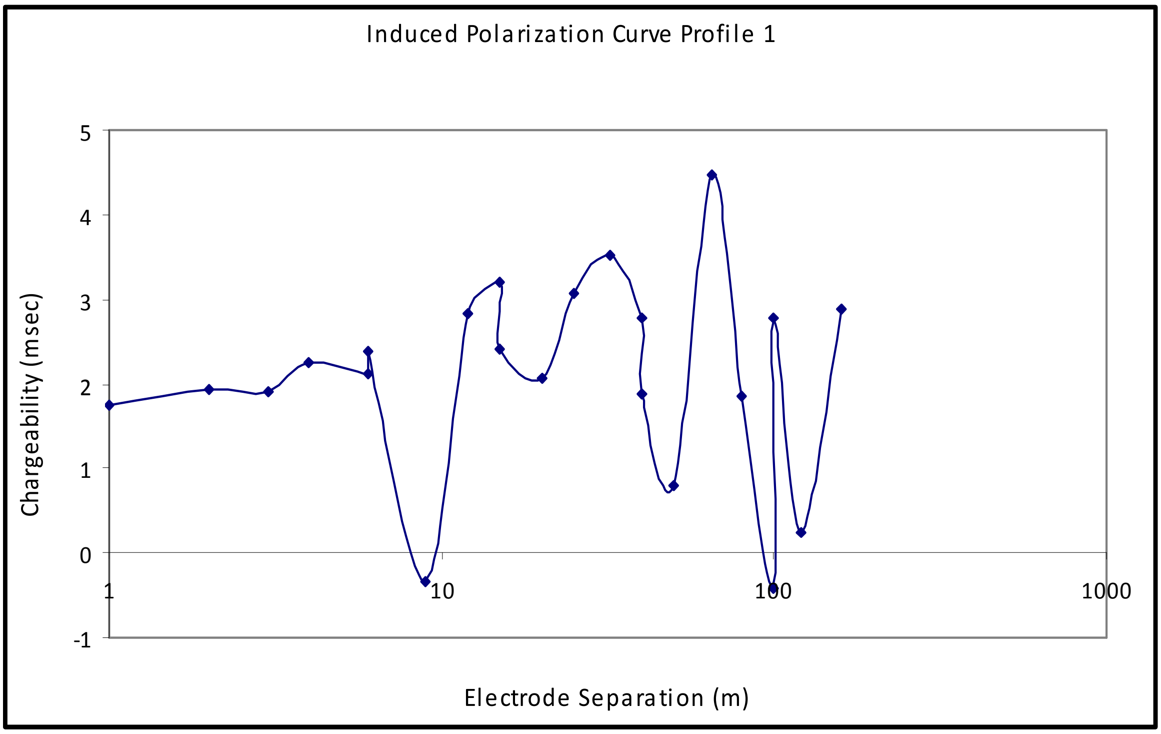


Figure: 1a chargeability curves

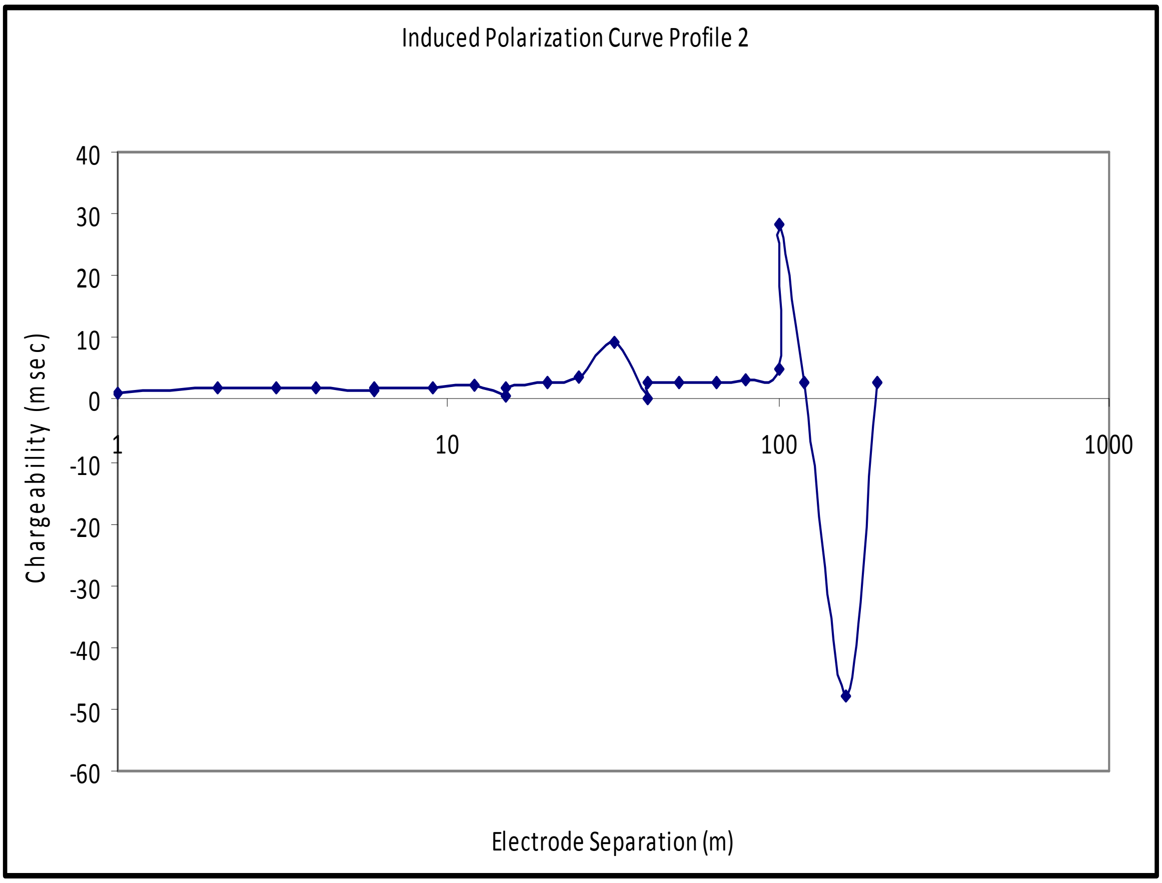


Figure: 1b

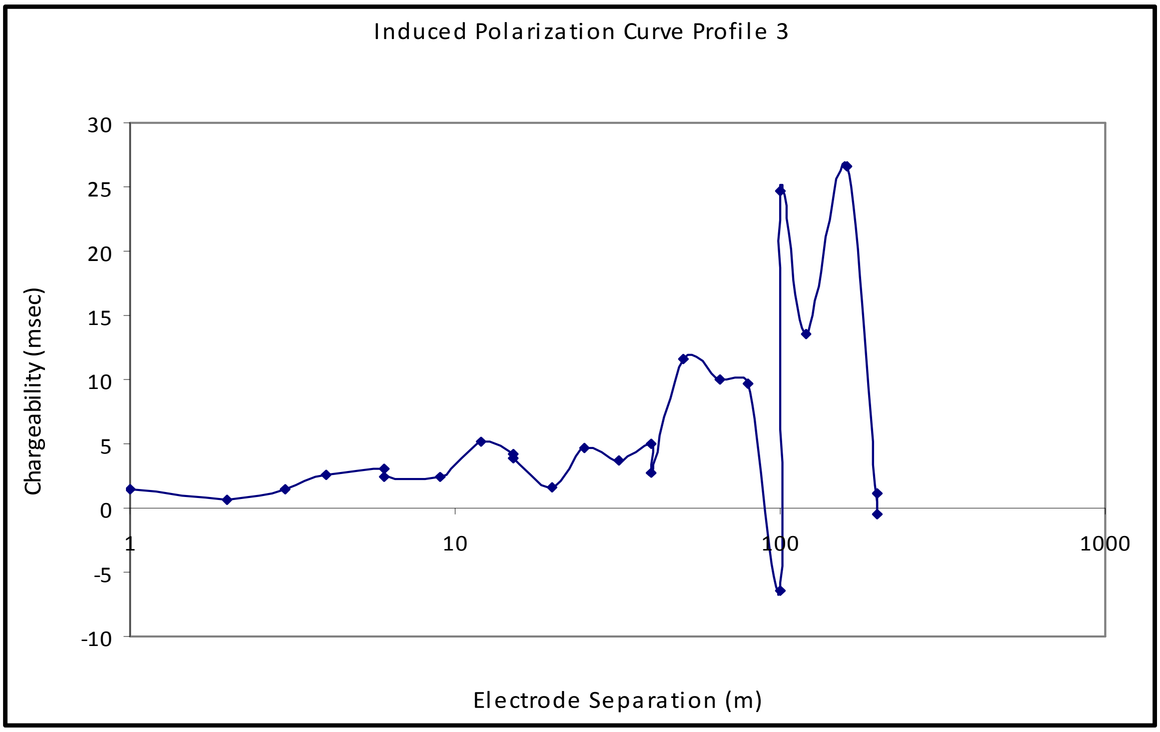


Figure: 1c

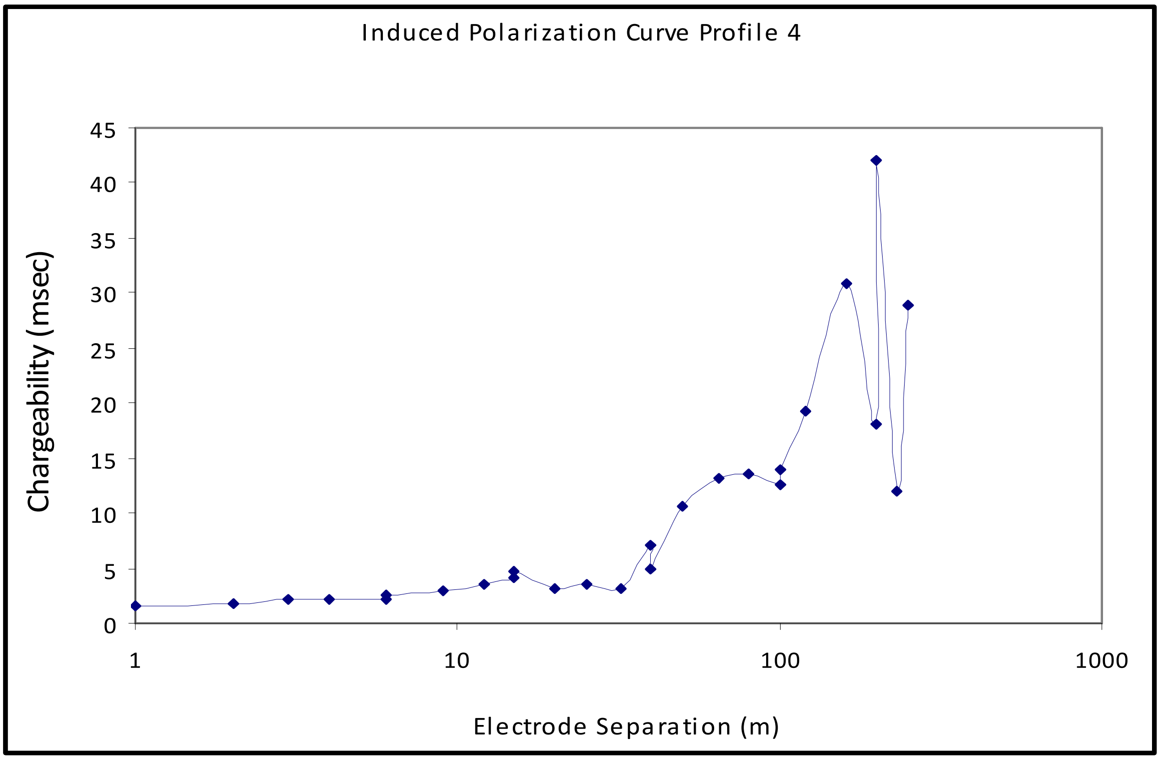
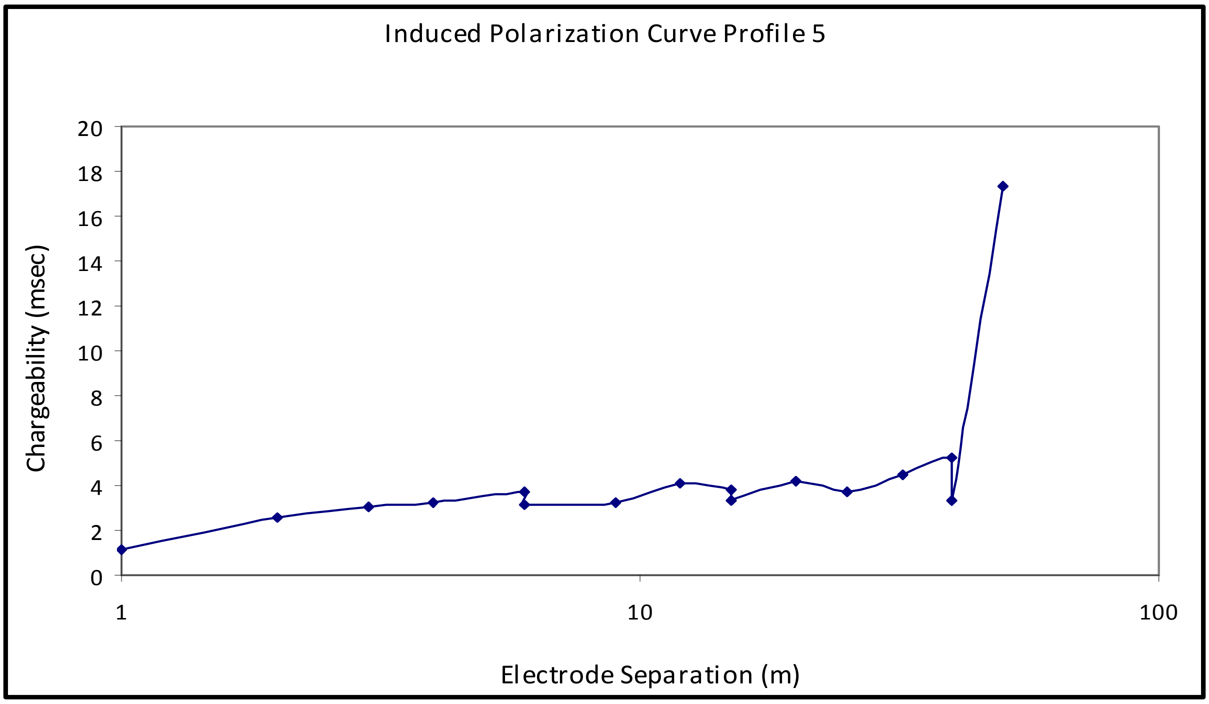


Figure: 1d



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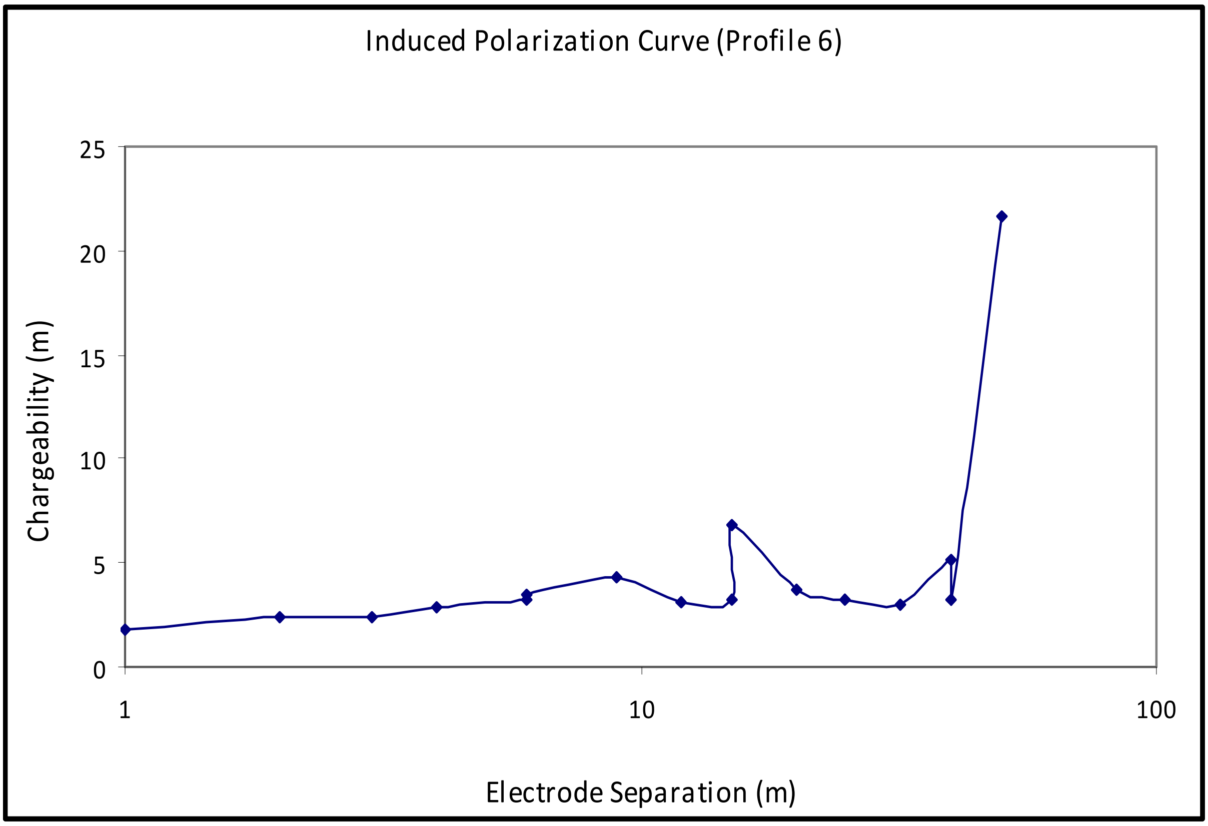

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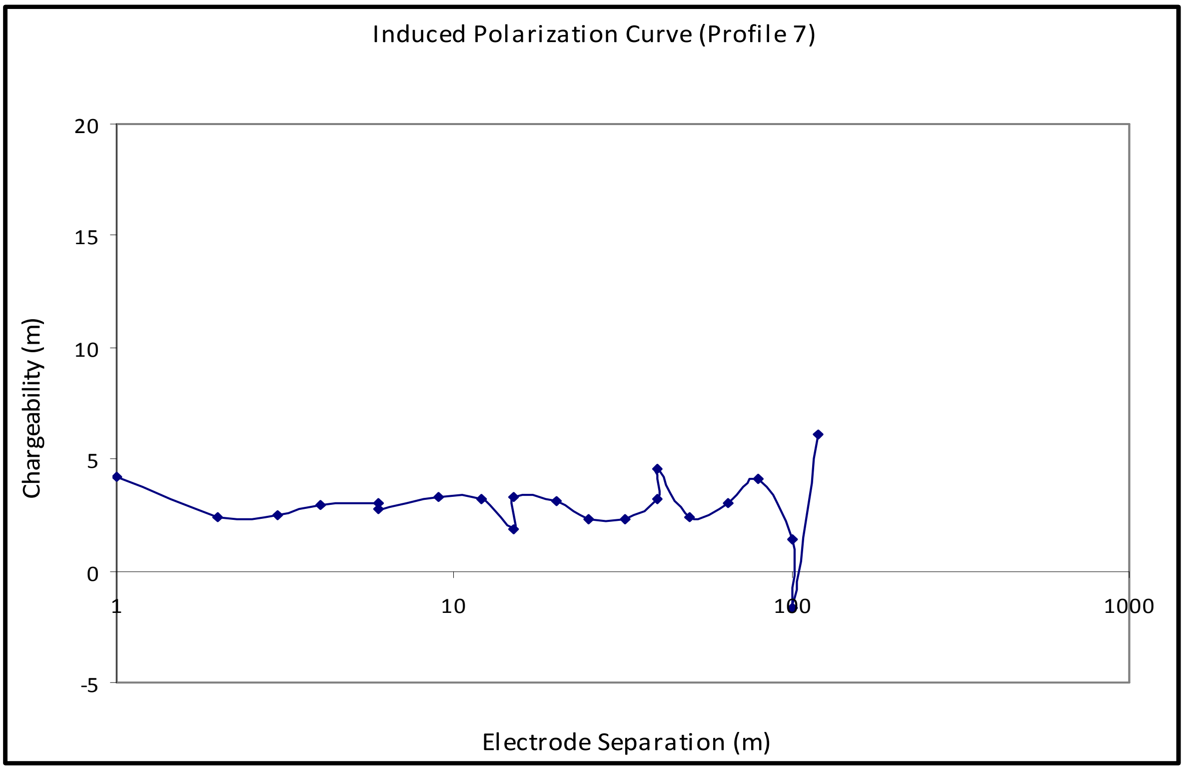

Figure: 1g

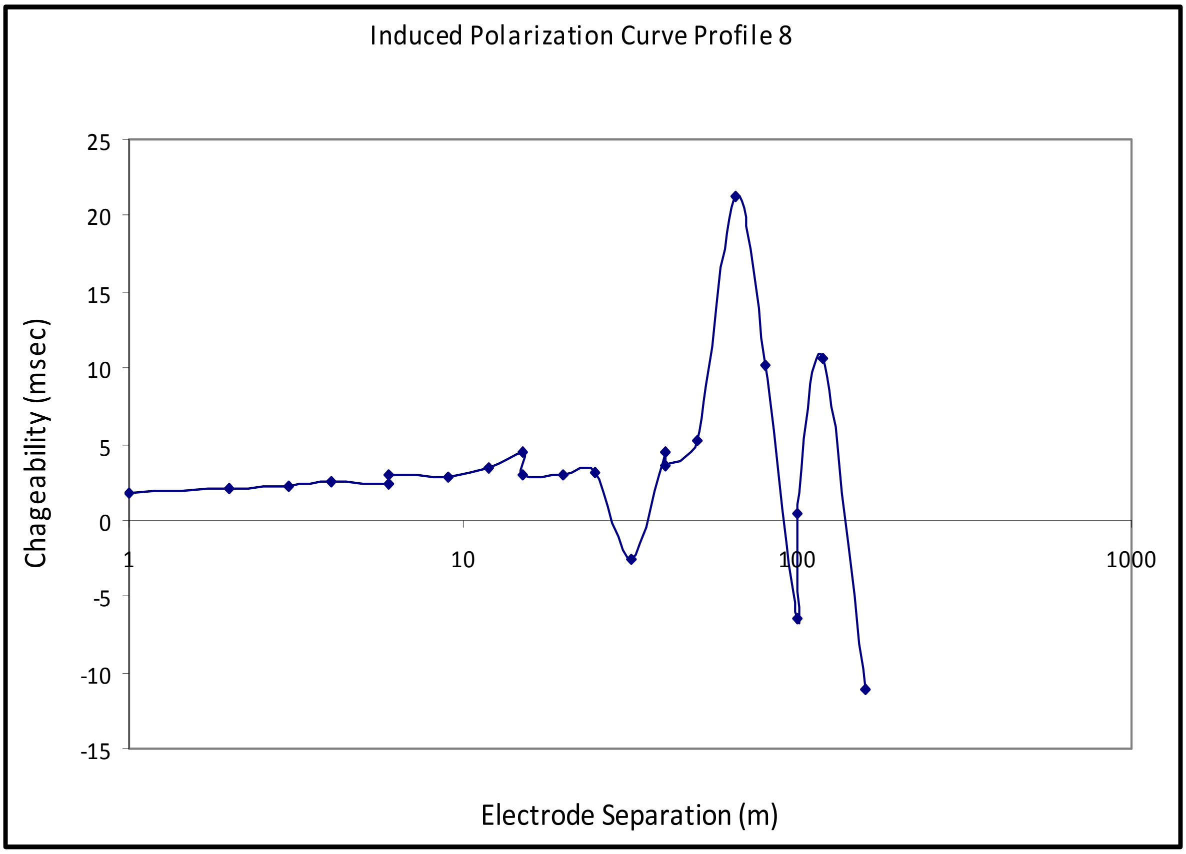

Figure: 1h

CONCLUSION

Geophysical techniques have made, and continue to make, a major contribution to subsurface investigations. This study provides a qualitative assessment of the utility of the Induced Polarization a geophysical technique for resolving lithology. It was found that with careful interpretation, IP imaging can improve understanding of the properties of the subsurface. The profiles obtained in the study area depicted two layers; the first layer with consistent and considerable high chargeability signatures at depth of 20m indicates sand formation. The second layer predicted to be clay with low IP effects was observed at various depths for all the profiles.

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