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Oil Sands Exploration Using 2-D Electrical Imaging Technique

Geraldine Anukwu[1*], Kola Odunaike[2] and Olusola Fasunwon[3]
1. Department of Geosciences, University of Lagos, Akoka, Lagos
2. Department of Physics, Olabisi Onabanjo University, Ago-Iwoye, Ogun State
3. Department of Physics, University of Regina, Saskatchewan, Canada
*E-mail of the corresponding Author: ganukwu@unilag.edu.ng or chibzdine@yahoo.com

Abstract
This study describes the use of two-dimensional electrical imaging technique in defining regions of oil sand deposits and determining the geometry of such deposits in Imeri, South Western Nigeria. Three field survey lines were acquired in different orientations in the study area with one of the lines above the oil sand outcrop observed in the area. The Gradient electrode Configuration was employed to obtain apparent resistivity and chargeability of the subsurface. Very high resistivity value greater than 3000 ohm-m and pronounced induced polarization effects were associated with the region were the outcrop was observed. These electrical characteristics were used in delineating oil sand zones in the study area.
Keywords: Oil sand, electrical imaging, resistivity and induced polarization

1. Introduction

Oil sand is known to occur in Nigeria and according to Adegoke et al. 1981, the country has a reserve estimate of 30-40 billion barrels (bbls) with potential recovery of 3654×10^6bbls (Adegoke et al, 1981). The significant benefits that may result from the exploitation of this resource (MMSD, 2010) makes its delineation an important concern. Several investigations have documented the use of electrical methods in characterizing of oil sands deposits. The application of this method is based on the fact that it is expected that the effect of bitumen saturation on the conductivity of various types of rocks should be negative i. e. increased resistivity (McCollen and Glenn, 2008; Paul Bauman, 2005) and also show pronounced IP effects (Vekeen et al., 2009). In Nigeria, various authors have employed electrical methods in the exploration of oil sands. Ako et. al. (1983) applied resistivity sounding in the exploration for oil sand in Agbabu, Ondo State. In their work, they were able demonstrate the effectiveness of electrical resistivity method in delimiting bitumen saturated sediments from the overburden material. Odunaike et al, (2010) also reported the use of Vertical Electric Sounding techniques to map the occurrence of shallow oil sands in Okitipupa area, Ondo State. With results obtained they were able to identify possible bitumen saturated zones based on the analysis of the electrical response of the subsurface. In another similar study carried out by Odunaike et al. (2009) in Ijebu-Imushin, Ogun State, they reported the use of magnetic and electrical resistivity techniques in mapping the oil sands. They were able to identify the presence of oil sands and recommended that further geophysical investigations be carried out in the area. Amigun et al. (2012) integrated electrical resistivity and Magnetic method to explore for oil sand in Agbabu, Southwestern Nigeria, while Akinmosin et. al. (2011) applied electrical resistivity survey to investigate the role of fault as a barrier or conduit for bitumen seepages found in Imeri, Southwestern Nigeria. The electrical method was also applied by Akimosin et. al. (2013) to determine the nature and depth of occurrence of tar sand unit in Ogun state. These investigations clearly indicate the feasibility of the use of electrical techniques in characterizing oil sands deposits. The advances in field equipment design for 2-D electrical imaging and development of computer algorithms capable of effectively interpreting such data has made the technique attractive than the conventional resistivity survey. This motivated this current research which aims at characterizing the oil sands deposits in Imeri, Ogun state, Southwestern Nigeria an area with visible oil sand outcrop with the use of automated 2-D electrical resistivity imaging.

This work describes the results of the application of 2-D electrical method in the exploration of oil sands with the major objectives of (i) identifying the oil sand regions (ii) determining the geometry of the oil sand.

2. Physiographical and geological setting of the study area

The study area, Imeri (Figure 1) is located at $06^0 46'53''$N and $003^0 58'23''$E. Imeri is a rural village in Ijebu-Imushin located in Ijebu-East Local Government Area of Ogun State, Southwestern Nigeria. The study area falls in the rain forest region of Nigeria and is covered by thick vegetation of scrubs and tall wood-trees with a mean annual rainfall of 105cm and an average monthly temperature ranging from 23°C in July to 32°C in February.

The oil sands occurrence in Nigeria is restricted to the eastern part of the Dahomey Basin (MMSD, 2010) which is one of the several sedimentary basins in Nigeria. The basin's onshore portion covers a broad arc shaped profile of about 600 km^2 in extent, attaining a maximum width, along its N-S axis, some 130 km around the Nigerian–Republic of Benin border. It narrows to about 50 km on the eastern side where the basement assumes a convex upwards outline with concomitant thinning of sediments (Akinmosin and Shoyemi, 2010). The Dahomey Basin falls within an area bordered approximately by latitude 6°00´N to 8°30’N and longitude 0°15´E, extending from the Volta delta (Ghana) to the Okutipupa ridge end of Lagos. Various researchers have worked on the stratigraphy of the Dahomey basin (Russ, 1924; Jones and Hockey, 1964; Reyment, 1965 and Agagu, 1985) with most part of the basin dominated by an alternation of sand and shale with varying minor proportion of limestone and clays. The stratigraphy of the basin entails the Neocomian – Maastrichtian Abeokuta group, Paleocene Imo group, Eocene Ilaro formation, Pleistocene-Oligocene Coastal plain sands and Recent Alluvium (Omatsola and Adegoke, 1981). The oil sands occur in the Abeokuta group which consists of conglomerates, sandstones, sandy siltstone, clay, shale and thin limestone beds.

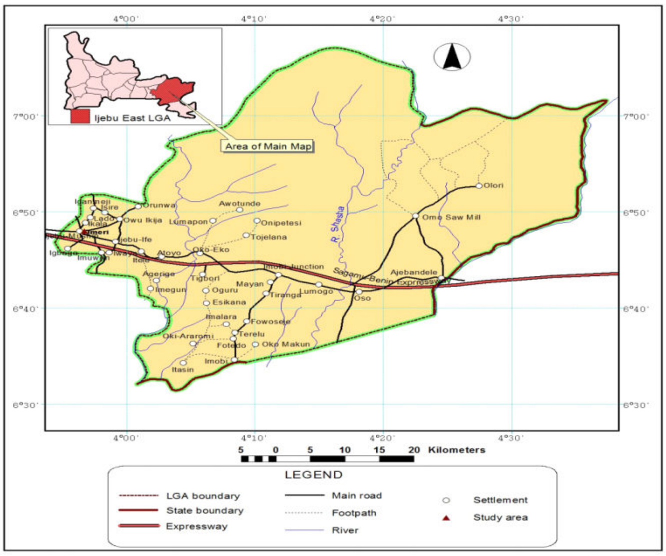

Figure 1: Location Map of the Study Area

3. Data Acquisition and Processing

Electrical Resistivity and Induced polarization method were taken along three established lines in the study area (Figure 2). The ABEM SAS 1000 Terrameter and ABEM System Electrode Selector ES 10-64C was used to obtain the measurements. A total of 64 steel electrodes were used for the study with a spacing of 5m between each electrode on the ground. The Gradient electrode configurations were used to take the apparent resistivity and chargeability readings. The individual inversion scheme of both the resistivity and IP data was done with the use of the Advanced Geosciences, Inc. (AGI) EarthImager 2D Inversion software to calculate the inverted resistivity and IP sections.

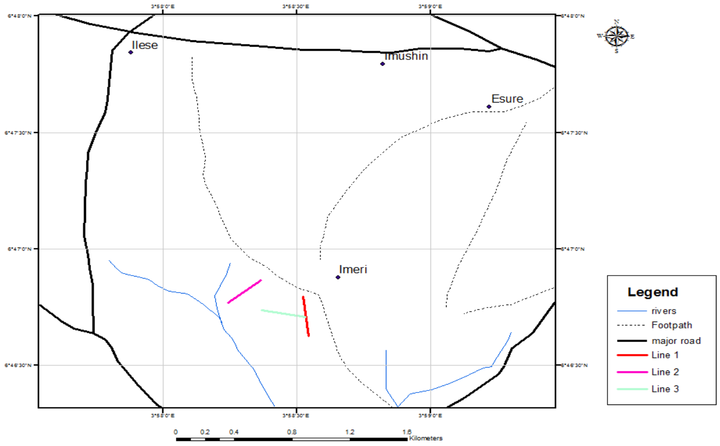

Figure 2: Base map of the study area, showing the electrical imaging lines

4. Results and Discussion

The inverted resistivity and IP sections, which gives a picture of the resistivity and chargeability distribution of the subsurface are presented in figures 3 to 5. Generally, a change in the resistivity and Induced Polarization (IP) response of the subsurface indicates a change in mineralogy, fluid chemistry and saturation of the earth materials (Olhoeft, 1985; Klein and Sill, 1982 and Ulrich and Slater, 2004).

Line 1

The result of the inverted resistivity and IP sections using the gradient configuration is presented in Figure 3. The resistivity distribution as seen across the line is not homogeneous and three lithologic units can generally be inferred:

- A top layer with resistivity value in the range of 275 ohm-m (green) occurring at a depth 0-7.5m across the line, a probable indication of clayey sand. Patches of high resistivity zones, greater than about 2000 ohm-m (yellow-red), which is suggestive of a compact or well cemented sand, conglomerate or lateritic pan can be seen to occur in this defined unit.
- The above unit is followed by a second litholigic unit with a resistivity value in the range of 16.6 ohm-m (blue) and with varying thickness. This unit has been interpreted as being possibly composed of clay. It is worth noting that this unit is seen to extend to a depth of 59m from line position 60 – 110m, a possible indication of a fault zone.
- The third layer has a higher resistivity also of about 275 Ωm (green) and is delineated as a layer of sand. Worth mentioning is the high resistivity value indicated from line position of 180m to 230m from a depth of 22m to 59m (yellow), indicating probably the compaction of the sandy layer to sandstone or possible thin lens layer of oil sand.

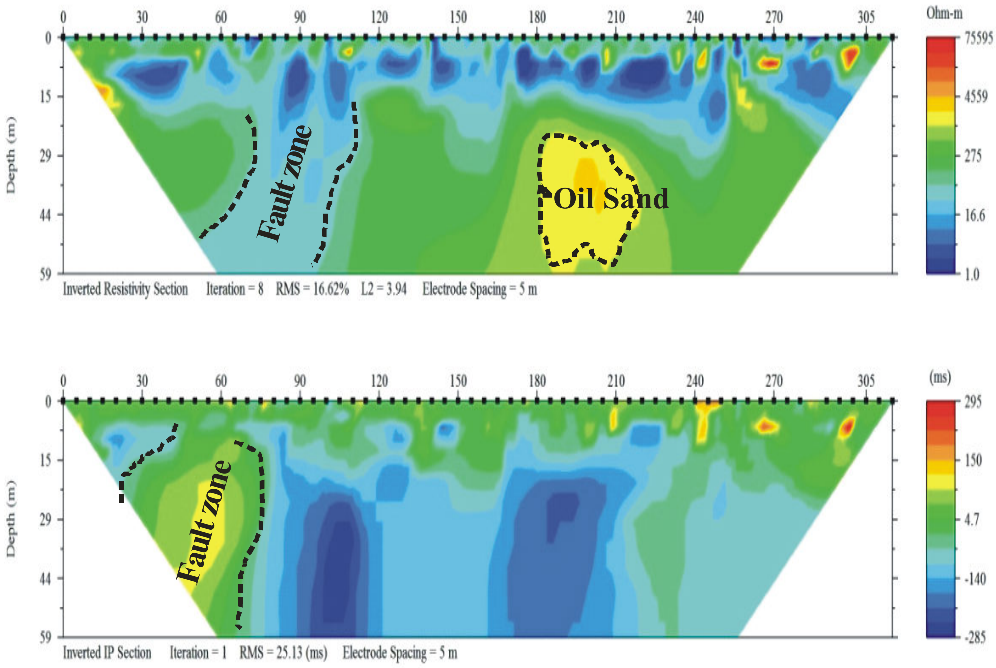

Figure 3: Electrical Section of line 1 showing the Inverted Resistivity and IP Sections.

The inverted IP section correlates quite well with the resistivity section and is also useful in properly defining the various lithologic units established by the interpretation of the inverted resistivity section. The IP section does not differentiate between the first two layers as the resistivity section did, this can be attributed to probably the thickness and constituents of the topsoil. The relatively higher chargeability (green) value obtained from the subsurface to a depth of about 22m is an indication of the clayey nature of these layers. The interpreted fault zone is can also be seen on the IP section. There is however a slight displacement of this zone, but it still shows a relatively higher chargeability (green to yellow). Satarugsa et al., (2004) attributed such displacement to probably a strong three-dimensional effect from the subsurface. The third layer interpreted as sand in the inverted resistivity section correlates with the very low chargeability values obtained, with a value of approximately -140ms (blue).

Line 2

This section reveals a distinct top layer with an approximate resistivity value of 1392 ohm-m (green) and an average depth of about 7m from the surface. This has been interpreted as the first lithologic unit and is probably made up of sandstone. Isolated patches of low (blue) and high (red) resistivity can be found in this unit on the resistivity section. A second lithologic unit can also be observed distinctly on the inverted resistivity section for the gradient configuration. It is a very high resistivity zone with resistivity value from 6596 Ωm up to 100,000 Ωm (yellow to red). The thickness of this layer varies extensively across the line but has a maximum thickness of 50m from line position 160m to 240m. The oil sand outcrop found in this area lies below this line and this coincides with the portion of the section with very high resistivity from line position of about 160 m to the end of the line on each of the resistivity section. This high resistivity suggests that the unit is a bitumen saturated zone (oil sands).

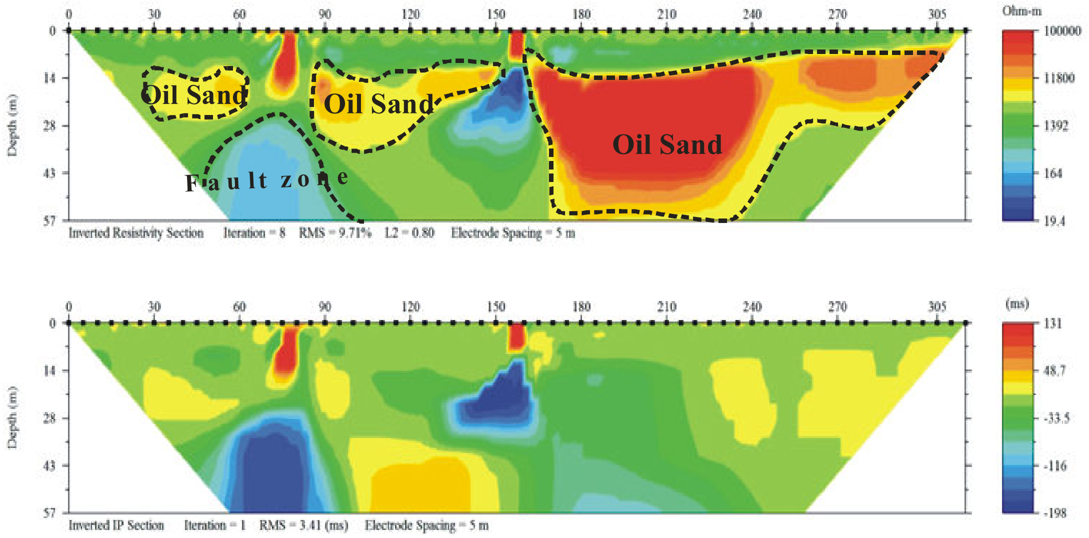

Figure 4: Electrical section of line 2 showing the Inverted Resistivity and IP Sections.

The observed IP effects on this line is seen to vary across the line with areas of high resistivity showing more pronounced chargeability, although not in all cases as some parts of the delineated oil sand zones have low IP values. The IP effects of the delineated fault zone is highly negative an indication of a possible variation in the composition of the geologic materials as to that shown in line 1. Another low resistivity portion is seen to serve as a barriers between two oil sand zones, with similar IP values.

Line 3

The varying resistivity across the line is an indication of a complex subsurface structure. No clearly defined unit can be indentified across the entire line, however, a high resistivity zone (≥ 3000 Ωm) can be observed between the lateral distance of 15-85, 95-165, 170-210, 210-220 and 240-305 m with varying depth distribution. This is suspected to be sand, with possible saturation with bitumen. A low resistivity zone is seen to occur on this section with resistivity values of about 17.8 ohm-m and less, suspected to be a fault zone.

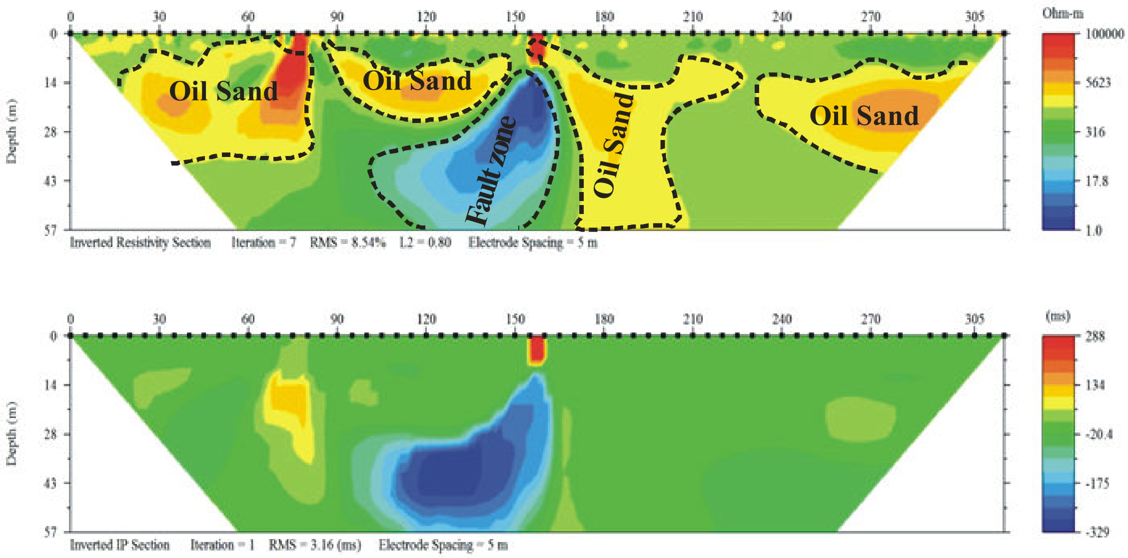

Figure 5: Electrical Section of line 3 showing the Inverted Resistivity and IP Sections.

The IP section show an almost uniform chargeability value across the line except at line position of about 90 – 150 m with a chargeability value that is highly negative, this coincides with the fault zone and a possible indication of a variation in the geologic material that makes up in the zone when compared to the fault zone as noticed on line 1.
Nigerian oil sands is said to have the same effect on resistivity values as water with considerable content of dissolved deposits (Adegoke et al., 1981), and show similar characteristics with those found in Athabasca Canada (Dada, 2005) which have typical resistivity value for oil rich sands ranging from about 110Ωm to 1800Ωm (McConnel and Glenn, 2008). However, the results of this present study is suggestive that the resistivity value of the oil sands in Imeri is relatively high (greater 3000 ohm-m), collaborating the results obtained in a similar work carried out by Odunaike et. al, (2009). This value is well beyond the characteristic resistivity value obtained from earlier studies on Oil Sands in Ondo state Nigeria (Ako et al., 1983; Odunaike et al. 2010).
Furthermore, the results shows that the study area has quite a number of fault zones, which play significant roles in fluid flow (both groundwater and hydrocarbon) and buttresses the work of Akinmosin et. al, 2011 that the oil sand seepages in Imeri is fracture controlled.

5. Conclusion

The electrical method applied in this study has proven to be effective in characterizing the oil sands in the study area. The identified oil sands layer has a resistivity value greater than 3000Ωm and show pronounced IP effects. Line 2 show great concentration of the oil sands deposits especially from line position 160 - 240m with a thickness of about 50m. The oil sand zones of line 3 show varying thickness distribution along the line. Results also indicates that the oil saturation of the oil sands deposits for line 3 is not as high as that for line 2, a possible indication of probable development of the oil sands deposit on this line.

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