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# Delineation of Oil – Polluted Sites in Ibeno LGA, Nigeria, Using Geophysical Techniques

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***Abstract*—**Ibeno, Nigeria hosts the operational base of Mobil Producing Nigeria Unlimited (MPNU), a subsidiary of ExxonMobil and the current highest oil & condensate producer in Nigeria. Besides MPNU, other oil companies operate onshore, on the continental shelf and deep offshore of the Atlantic Ocean in Ibeno, Nigeria. This study was designed to delineate oil polluted sites in Ibeno, Nigeria using geophysical methods of electrical resistivity (ER) and ground penetrating radar (GPR). Results obtained revealed that there have been hydrocarbon contaminations of this environment by past crude oil spills as observed from high resistivity values and GPR profiles which clearly show the distribution, thickness and lateral extent of hydrocarbon contamination as represented on the radargram reflector tones. Contaminations were of varying degrees, ranging from slight to high, indicating levels of substantial attenuation of crude oil contamination over time. Moreover, the display of relatively lower resistivities of locations outside the impacted areas compared to resistivity values within the impacted areas and the 3-D Cartesian images of oil contaminant plume depicted by red, light brown and magenta for high, low and very low oil impacted areas, respectively confirmed significant recent pollution of the study area with crude oil.

***Keywords*—**Electrical resistivity, geophysical investigations, ground penetrating radar, oil-polluted sites.

## I. Introduction

NIGER Delta region, Nigeria is ecologically and economically significant, globally. It is one of the largest wetlands of the world and hosts Nigeria's oil & gas industry. Akwa Ibom State, one of the 9 States of the Niger Delta region is the highest crude oil and condensate producer in Nigeria with Iben LGA hosting Mobil Producing Nigeria Unlimited, MPNU a multinational oil company and a subsidiary of ExxonMobil. In the past, oil discharged into Ibeno LGA environment, including oil in process water, oil discharges from tanker washing (ballast water), oil spills from pipelines bursts and road tanker accidents as well as used oil dumped in the environment are huge and enormous. In addition, oil spills that occurred during the Nigeria civil war of 1970, when many oil installations were either bombed or sabotaged were not cleaned up. Oil spills, oily sludge / wastes dumping and gas flaring are endemic in this region [1].

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An agency, the National Oil Spill Detection and Response Agency (NOSDRA) [2] which was established in 2006 identified approximately 2,000 crude oil polluted sites needing remediation in the Niger Delta, with majority of these sites being SPDC sites [3]. Different methods can be used in delineating oil polluted sites [4]. This research project on the delineation of oil polluted sites in Ibeno LGA using geophysical techniques is the first step to addressing the environmental pollution and its consequent damages due to oil & gas exploration and production (E&P) activities in the area.

## II. Materials and Methods

### *A. Study Area*

The study area (Ibeno LGA) is located in the coastal area of Akwa Ibom State, Nigeria. It lies between Latitude 4º 30'N and 4º 36'N and Longitude 7º 48'E and 8º 18'E [4].

### *B. Delineation of Oil Impacted Sites*

The Direct Current Electrical Resistivity and Ground Penetrating Radar (GPR) methods of geophysical prospecting were adopted [5]. Field data acquisition consisted of 1185 metres of GPR traverse and seven (7) Vertical Electrical Sounding (VES) stations.

1. Electrical Resistivity (ER) Method

The oil polluted area identified by the field guide was the sand beach around Qua Iboe River estuary called Itak Abasi. The VES locations in the designated areas at Itak-Abasi were positioned as shown in Table I.

The (VES) technique was adopted for the resistivity survey, using the Schlumberger field configuration (array). Seven (7) VES stations (VES 1 - VES 7) were occupied at Itak-Abasi which is situated on the shoreline, about 61 Km south of Uyo, the Akwa Ibom State capital. VES 1 to VES 7 were occupied on the beach proximal to the Atlantic Ocean was obtained using Garmin GPS 60 Global Positioning System.

TABLE I
Co-Ordinate Reference of VES Stations in Itak Abasi

| Station No. | Co-ordinate | | | |
|---|---|---|---|---|
| | UTM | | Longitude & Latitude | |
| | Easting | Northing | N | E |
| VES 1 | 0387593 | 0502103 | 04° 32.538' | 007° 59.205' |
| VES 2 | 0387588 | 0502094 | 04° 32.532' | 007° 59.201' |
| VES 3 | 0387588 | 0502078 | 04° 32.525' | 007° 59.201' |
| VES 4 | 0387573 | 0502109 | 04° 32.540' | 007° 59.195' |
| VES 5 | 0387571 | 0502099 | 04° 32.535' | 007° 59.194' |
| VES 6 | 0387571 | 0502082 | 04° 32.527' | 007° 59.192' |
| VES 7 | 0387546 | 0502098 | 04° 32.535' | 007° 59.177' |

GARMIN GPS 60 Global Positioning System was used to determine the geodetic system of coordinates and approximate altitude above sea level, while a Compass Clinometer was used to measure Whole Circle Bearing (WCB).

The Schlumberger current electrode separation (AB) was varied from a minimum of 2.0 m to a maximum of 30 m at VES 7; 80 m at VES 5 and VES 6; 130 m at VES 1 and VES 2; 200 m at VES 3 and VES 4. Variations of the apparent resistivity with depth were measured. This was achieved by a gradual and systematic increase in the electrode array [5].

2. Ground Penetrating Radar (GPR) Method

Four GPR profile of 1185 m length was occupied at Itak-Abasi beach. The GPR scanning was done by dragging the radar equipment on the ground along established traverses. The subsurface reflections were recorded on the screen of the field laptop and stored digitally in the laptop computer hard disk and a back up with an external drive. The Ramac X3M GPR equipment was used for the GPR investigation. A high frequency, 250 MHz antenna was deployed for field data acquisition and could provide high resolution data at depths up to 15 metres [5].

It is important to note that a radar is, in principle, related to reflection seismic methods. A transmitter emits a signal into the surface of investigation and the reflected signal is detected and registered by a receiver. In contrast to seismic methods, a radar instrument uses electromagnetic waves instead of acoustic waves. EM-waves will not penetrate as deep as acoustic waves but will result in much higher resolution sections and maps. Targets with a contrast in electrical impedance to the surrounding media will be registered and detected. Therefore, surface radar instruments are primarily used for detection and localization of conductive and non-conductive targets down to an approximate depth of 30 m [5].

## III. Results and Discussion

### *A. Electrical Resistivity (ER) of the Oil Polluted Soils*

The result of the geoelectric data interpretation for Itak Abasi is presented on Table II.

TABLE II
SUMMARY OF GEOELECTRIC DATA INTERPRETATION OF ITAK-ABASI

| VES No. | Depths (m) $d_1/d_2/......./d_{n-1}$ | Resistivity (Ω-m) $\rho_1/\rho_2/......../\rho_n$ | Curve Type |
|---|---|---|---|
| 1 | 1.2/6.6 | 1.0/0.8/4.4 | H |
| 2 | 1.0/2.2/14.5 | 1.2/0.6/1.3/21.6 | HA |
| 3 | 0.9/3.6/9.4/21.7 | 1.1/0.9/1.1/5.0/33.2 | HAA |
| 4 | 0.7/1.7/5.0/9.5/15.1/17.9/75.2 | 1.1/1.3/0.9/1.1/2.9/2.0/54.5/4.9 | KHAKHK |
| 5 | o.8/3.8/11.8 | 1.3/1.0/1.3/14.4 | HA |
| 6 | 0.8/1.8/4.3/10.1 | 1.1/1.4/0.9/1.4/9.8 | KHA |
| 7 | 1.1/13.5 | 727/8.8/20.2 | H |

The field data for geo-electric soundings are represented as curves, in which half of the current electrode separation, AB/2, is plotted on the abscissa (x-axis), while the corresponding apparent resistivity is plotted on the ordinate (y-axis) (Figs. 1-7). The scales of both axes are logarithmic.

The curves are interpreted qualitatively in terms of the vertical distribution of the calculated formation resistivities using the traditional methods of auxiliary point techniques and curve-matching procedure employing albums of theoretical curves. Quantitative interpretation of the curves involved partial curve matching using two-layer Schlumberger master curves and the auxiliary K, Q, A and H curves.

The geoelectric layers obtained from the curves generated from the field data are 3-8 layers. The curve types obtained from the field data are 3 - layer H (VES 1 and VES 7), 4-layer HA (VES 2 and VES 5), 5 - layer HAA (VES 3), 5 - layer KHA (VES 6) and 8-layer KHAKHK (VES 4).

The results showed high electrical resistivity values. Moreover, the display of relatively lower resistivities of locations outside the impacted areas compared to resistivity values within the impacted areas shows that these areas are impacted [6].

It is important to note that vertical electrical sounding, VES also referred to as "depth sounding" is undertaken on the assumption that the earth is made up of layers of approximately constant resistivity separated from others of differing resistivity by a plane surface.

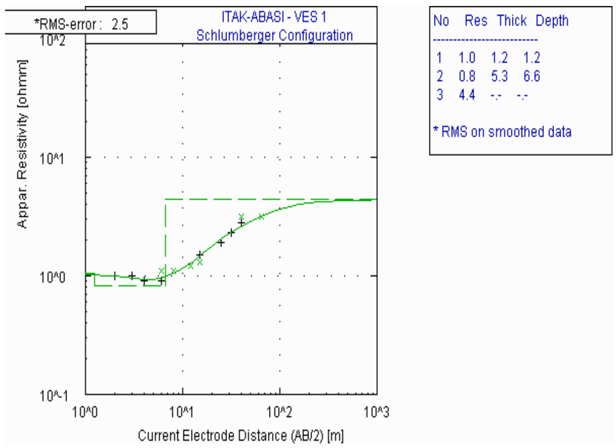


Fig. 1 Geoelectric Sounding Curve Obtained from VES 1

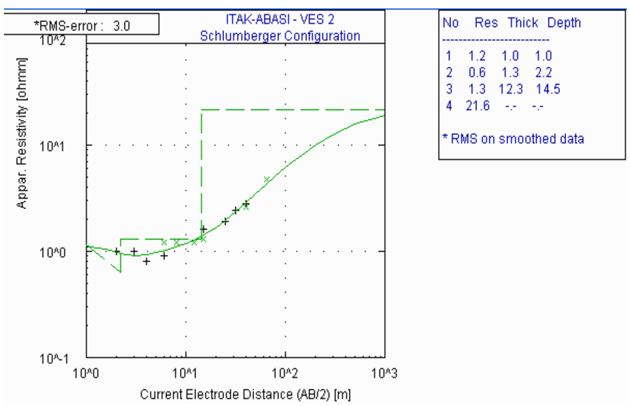


Fig. 2 Geoelectric Sounding Curves Obtained from VES 1 and VES 2

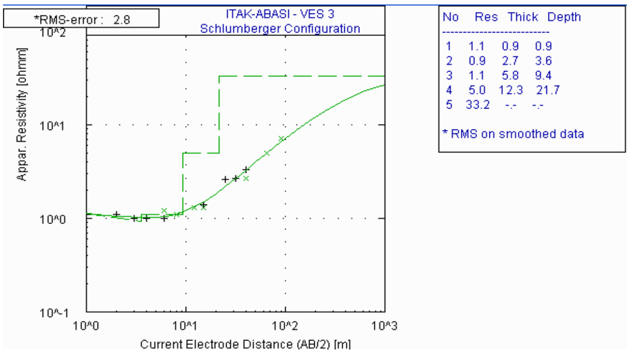


Fig. 3 Geoelectric Sounding Curve Obtained from VES 7

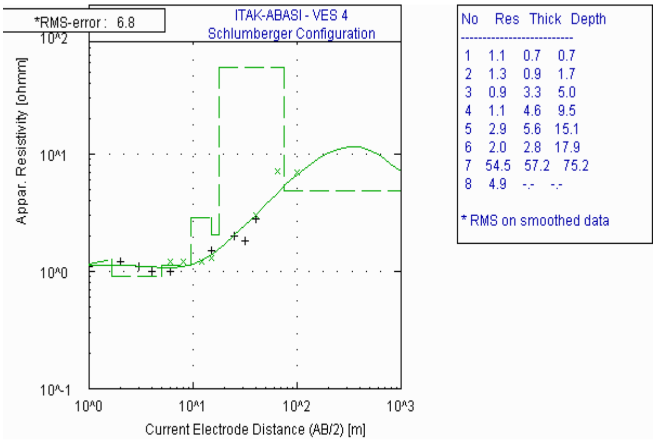


Fig. 4 Geoelectric Sounding Curves Obtained from VES 4

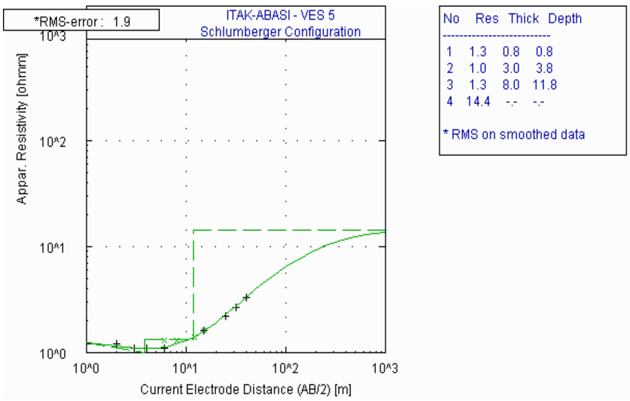


Fig. 5 Geoelectric Sounding Curve Obtained from VES 5

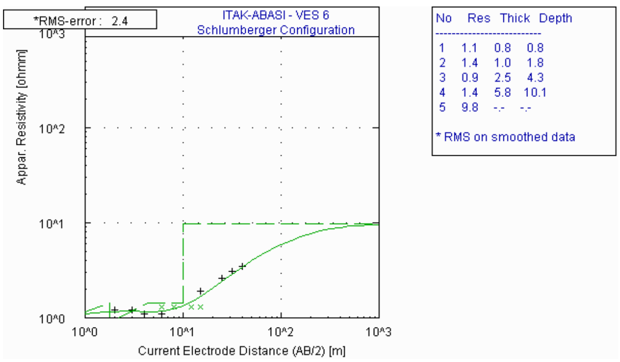


Fig. 6 Geoelectric Sounding Curves Obtained from VES 6

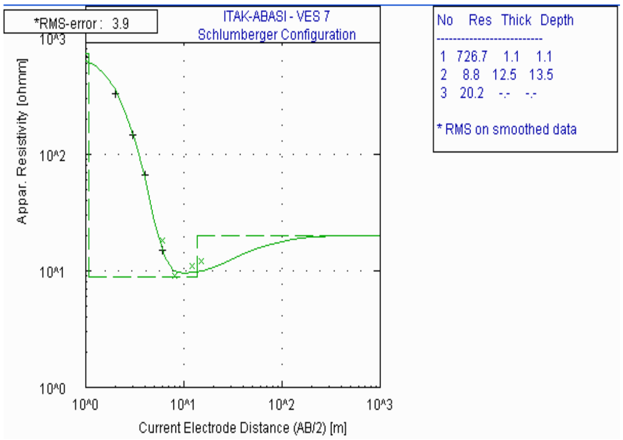


Fig. 7 Geoelectric Sounding Curve Obtained from VES 7

1. Geoelectric Parameters and Geoelectric/Stratigraphic Sections

A Geoelectric section has been generated for the VES data interpretation results in Itak-Abasi. Summary of the interpretation results in terms of geo-electric/geologic layering as classified from Figs. 1 to 7 and depicted in Fig. 8 is presented in Table III.

TABLE III
GEOELECTRIC/STRATIGRAPHIC CHARACTERISTICS OF ITAK ABASI

| Layers | Layer Characteristics | | |
|---|---|---|---|
| | **Soil Texture** | **Layer Resistively** | **Layer Thickness** |
| **1st** | Topsoil; Beach Sand | 1.0–727Ω-m | 0.7 – 1.2 m |
| **2nd** | Sand Substratum (saline water based oil impacted + sea water incursion) | 0.6–1.4Ω-m | 1.3 – 5.3 m |
| **3rd** | Sand (Medium level of oil impaction) | 1.1–1.4Ω-m | 4.6 – 8.0 m |
| **4th** | Clay/sandy clay? (Low level of impaction) | 1.3–14.4Ω-m | 8.4–12.3 m |
| **5th** | Sand Column (Fresh water column?) | 20.2–54.5Ω-m | 14.5–21.7 m |

2. Groundwater Quality

The resistivity values of rocks are strongly influenced by the degree of fluid saturation and the chemistry (or salinity) i.e. quality of saturating fluid**;** the higher the concentration of dissolved solute (e.g. chloride) the lower the resistivity. At Itak-Abasi, the upper horizons presented very low resistivity characteristics. Thus, the level of saline water-based oil impact is apparently higher than at deeper level. The resistivity values of the impacted upper horizons vary between 0.6**Ω**-m and 1.4**Ω**-m. The level of impact within the third horizon is of medium ranking based on the assumption that the horizon is saturated by sea water only. An impermeable layer in form of clay with restricted infiltration of sea water and saline water based crude oil presumably exists at the fourth layer, thus enabling fresh water saturated fifth layer. Thus, shallow fresh water aquifer exists beneath the Itak-Abasi area.

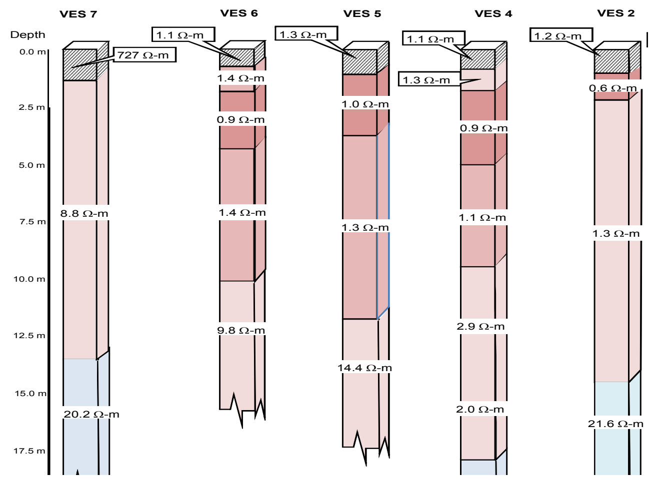


Fig. 8 1-D Geoelectric Sections of VES 7, VES 6, VES 5, VES 4 and VES 2 (Itak-Abasi)

Low level of impact within Itak-Abasi community is suggested at VES 7 near existing hand-dug well. The claim of occasional infiltration of crude oil by members of the community corroborates the geoelectric characteristic presented by the results of the study. As at the time of our study, the community depended solely on the well for their domestic water needs. The groundwater quality within the immediate surroundings of the oil impacted areas of Itak-Abasi has been degraded as evidenced in the low resistivity characteristics and amplitude attenuation characteristics presented by the electrical resistivity and ground penetrating radar results respectively.

*B. GPR of Oil Polluted Soils*

GPR profiles of the study locations clearly shows the distribution, thickness and lateral extent of hydrocarbon contamination as represented on the radargram reflector tones. This corroborates previous significant oil input into the studied location. Contaminations were of varying degrees, ranging from slight to high, indicating levels of substantial attenuation of crude oil contamination over time as shown by the 3-D Cartesian images of oil contaminant plume depicted by red, light brown and magenta for high, low and very low oil impacted areas.

The results of the GPR survey are presented as radargrams i.e. radar profiles (Figs. 9-12). The left vertical axis on the radargram shows the two way travel time in nanoseconds. Adopting the velocity value of 0.33m/ns for freshwater and 0.6m/ns for freshwater saturated sand, the equivalent depth in meters is shown on the right vertical axis of the radargram. The radargram represents parallel 'slices' through the ground to a high confidence depth of 4.2m (processed data) and 6.0m (raw data) below the ground surface.

The GPR signals typical of hydrocarbon plume is seen directly on the radargrams as change in contrast between dielectric permittivity of sand and water compared to lack of contrast between sand and oil.

The GPR sections present horizontally stratified near-surface high amplitude events indicating sand units. The raw field sections present barely visible amplitude patterns at depths in excess of 40 nanoseconds (2.5m). This is presumably due to attenuation of the electromagnetic waves by the conductive horizons through which the waves were propagated. The high conductivity occasioning the attenuation is due to severity of saline water based crude impact and the ubiquitous sea water in the environment. Applications of high level of gain in the processed sections reveal the existence of high amplitude horizons (suggestive of sand) to 12m depth on Profile 2.

The longitudinal and transverse GPR profiles clearly shows the lateral distribution of the hydrocarbon contamination represented on the radargrams by the light grey and whitish reflector tones deeper than 6m at the survey area.

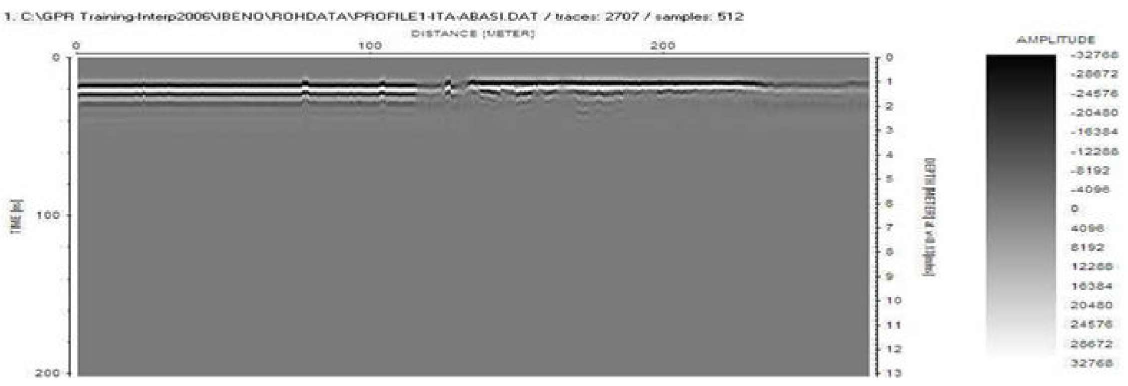


Fig. 9 Profile 1 Raw Field GPR Data (Itak-Abasi)

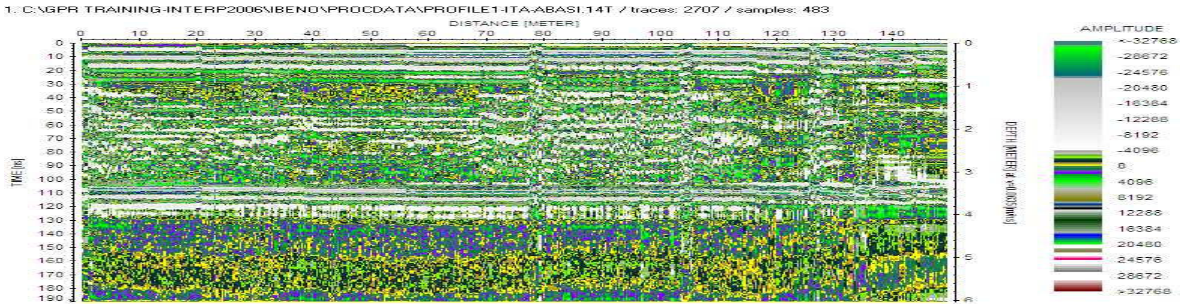


Fig. 10 (a) Profile 1 Processed Field GPR Data (0-148m)

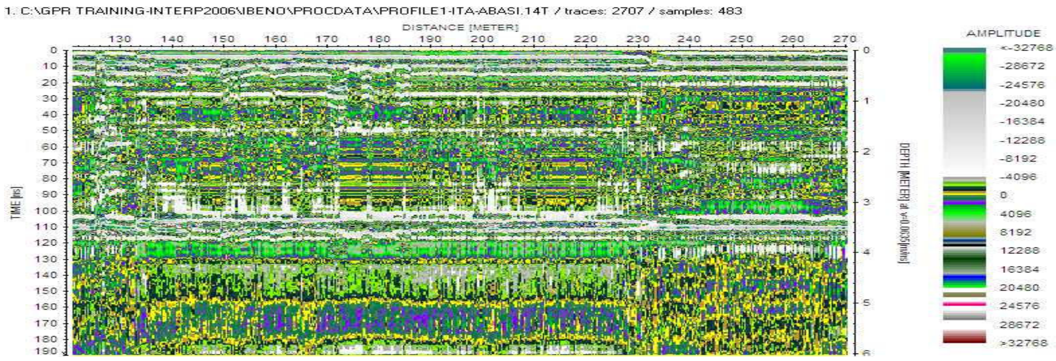


Fig. 10 (b) Profile 1 Processed Field GPR Data (110-270m)

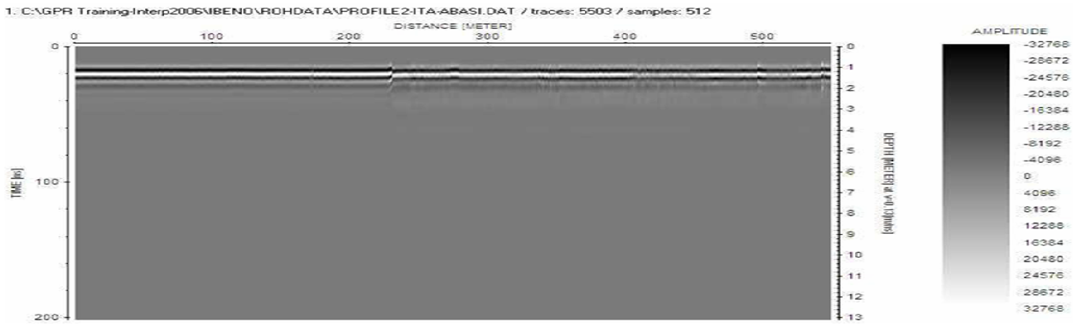


Fig. 11 Profile 2 Raw Field GPR Data (Itak-Abasi)

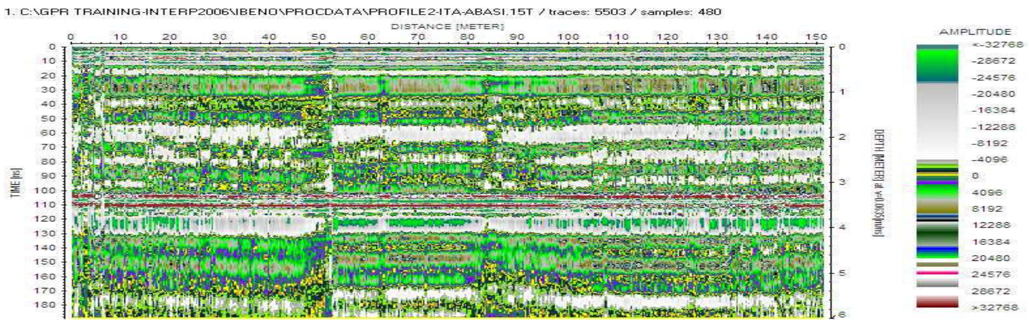


Fig. 12 (a) Profile 2 Processed Field GPR Data (1-150m)

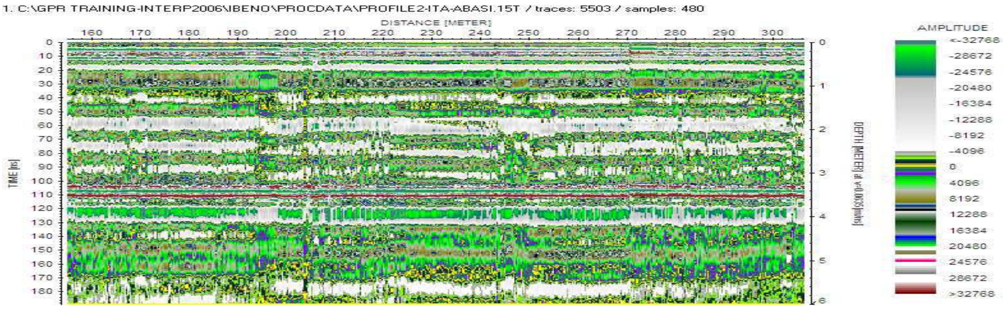


Fig. 12 (b) Profile 2 Processed Field GPR Data (150-310m)

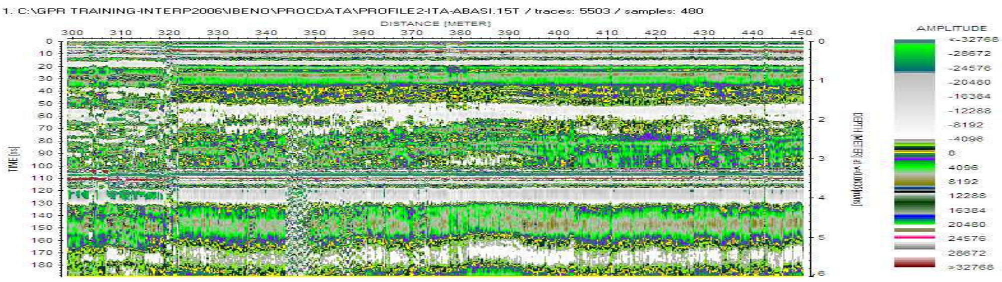


Fig. 12 (c) Profile 2 Processed Field GPR Data (300-450m)

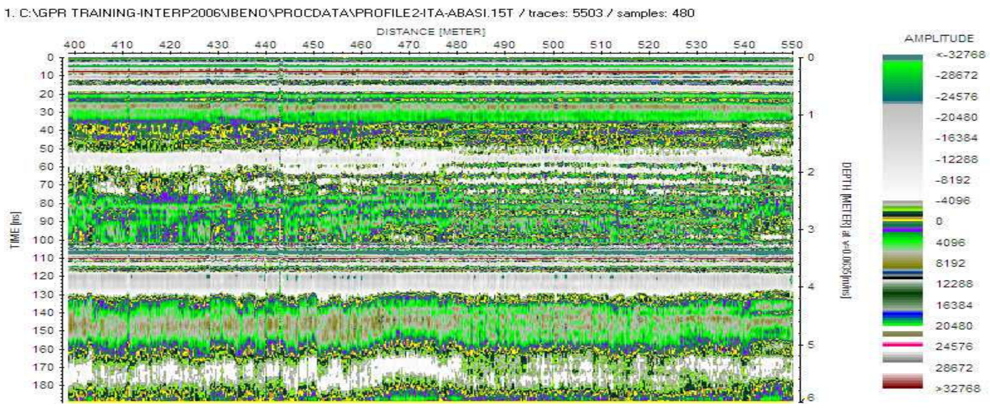


Fig. 12 (d) Profile 2 Processed Field GPR Data (400-550m**)**

## IV. Conclusion

From the results, it is obvious that there have been enormous oil input into the study area for decades [6]. The soils and water bodies in Ibeno LGA are therefore described as oil-polluted sites. According to a former chairman, Ibeno Clan Council of chiefs, late Chief E. W. Ndarake; the current paramount ruler of Ibeno LGA, HRM (Dr) Effiong Bassey Archianga and a former LG Council Chairperson, Hon. Mrs. Regina Ekpe, every inch of Ibeno land and water can be described as an oil-polluted site and needs to be cleaned up.

Under Nigerian oil industry regulations, oil spill sites should be rehabilitated [7]. This means that the soil and/or water at those sites should be treated to mitigate the impacts of pollution to as low as practicable (ALAP) and thus restore the sites, as far as possible, to their normal state. This will be impossible without the first step of delineation and inventorization of the oil polluted sites in Ibeno LGA.

## Acknowledgment

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