Integrated Geophysical Mapping of Turonian-Maastrichtian Bitumen Saturated Sand in Selected Part of Central Portion of Eastern Dahomey Basin.

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ABSTRACT

Bitumen, also known as oil sand, across Nigeria is hosted in the Eastern Dahomey Basin spanning over several kilometers. Integration of five (5) traverses of 2D electrical resistivity tomography (ERT), four (4) vertical electrical sounding (VES) and two (2) borehole lithological logs have led to delineation of five geoelectric layers – namely topsoil, lateritic soil, clay, shale/ marly limestone, bituminous sand and sandstone geoelectric units. The bituminous sand is characterized with high resistivity value as contrast to previous values obtained in other regions of the basin, ranging from 4177 Ωm to 70,000 kΩm with thickness ranges from 15 m to 28m. 2D ERT shown that the bituminous sands occur within a relatively shallow depth with a resistivity value ranging from 3225 Ωm to about 80,000 Ωm and a thickness range of 5 to about 30m. The survey shown that bitumen occurrences are overlain by relatively thin overburden (0-25m), and underlain by mudstone facies and limestone facies. Similarly, relatively deeper bituminous sands have higher resistivity range and are laterally continuous than the shallow occurrences. This suggests the sands comprising the shallow and deeper occurrences are probably deposited under different geologic setting.

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1.0 INTRODUCTION

Bituminous sand is a combination of water, sand, clay, and a highly viscous black and tar-like petroleum product that accumulates at the earth's surface in the form of asphalt springs or in other forms as a result of oil reservoir hydrostatic pressures (Payam Salimi *et al.*, 2014). It is also known as oil sand, tar sand, or asphalt. Nigeria is believed to have vast quantities of oil sands inside a several kilometers of long band that spans across the states of Lagos, Ogun, Ondo, and Edo in southwestern Nigeria with estimated reserve of about 42 billion barrels (Ayeni, 2009). Enu (1985) estimated oil sand porosity to vary from 16% and 35% and characterized the composition and occurrence of Nigerian oil sand, noting that it is composed of sand (84%), bitumen (17%), clay (2%), and water (4%). Exploration for bitumen in the Nigeria section of the Dahomey basin is still at minimal due to lesser funding and also already developed oil and gas sector in the country. However, with the growing interest in diversification of the country economy from only oil and gas, the bitumen sector has seen an increase in exploration activities in recent times.

With the advancement of science and technology coupled with the use of more advanced equipment and basic necessities of geophysics, mineral prospecting has become easier. Various geophysical approaches have been used to study bituminous minerals such as gravity, electromagnetic and geoelectrical techniques due to geological condition.

The geoelectrical resistivity method is one of the most extensively used geophysical techniques for near-surface research, with applications in hydrogeological, environmental, engineering, and agricultural studies. For deep geological formations, its penetration depth extends from tenths of meters to kilometers. The ERT method has an advantage over other traditional and regular approaches in that it studies variations in electrical apparent resistivity in space either laterally (constant spacing traversing (CST)) or vertically (vertical electrical sounding, VES). Bituminous sands are usually characterized by high resistivity values of ranges usually greater than 3000 Ωm except when associated with salt water or any other conductive fluid, where it exhibits low resistivity values. (Opatola et.al. 2022, Haliburton, 2001; Akinmosin et al., 2012).

Bitumen extraction is notoriously messy, posing environmental risks, particularly to groundwater and agricultural operations. The study location in Odogbolu Local Government Area, is a rapidly developing town, due to existence of multiple industrial operations, and the country's huge agricultural input. In this work, 2D ERT, VES, and borehole lithological logs were used to map out the bituminous sands in specific regions of Odogbolu Local Government Area in order to identify potential locations prone to future contamination from bitumen mining.

2.0 GEOLOGICAL FRAMEWORK

The regional geology comprises sedimentary rocks that cover approximately three quarters of the total surface area stretching from northwest to southwest and the basement complex rock, which underlay the remaining one-quarter of the surface area of the region (figure 1). The sedimentary rock units consist of the Abeokuta Formation lying directly above the basement complex. This is in turn overlain by the Ewekoro, Oshosun, and Ilaro Formations, which are themselves overlain by the coastal plain sands (Jones and Hockey, 1964). The study area falls within the sedimentary rock of the Abeokuta Formation.

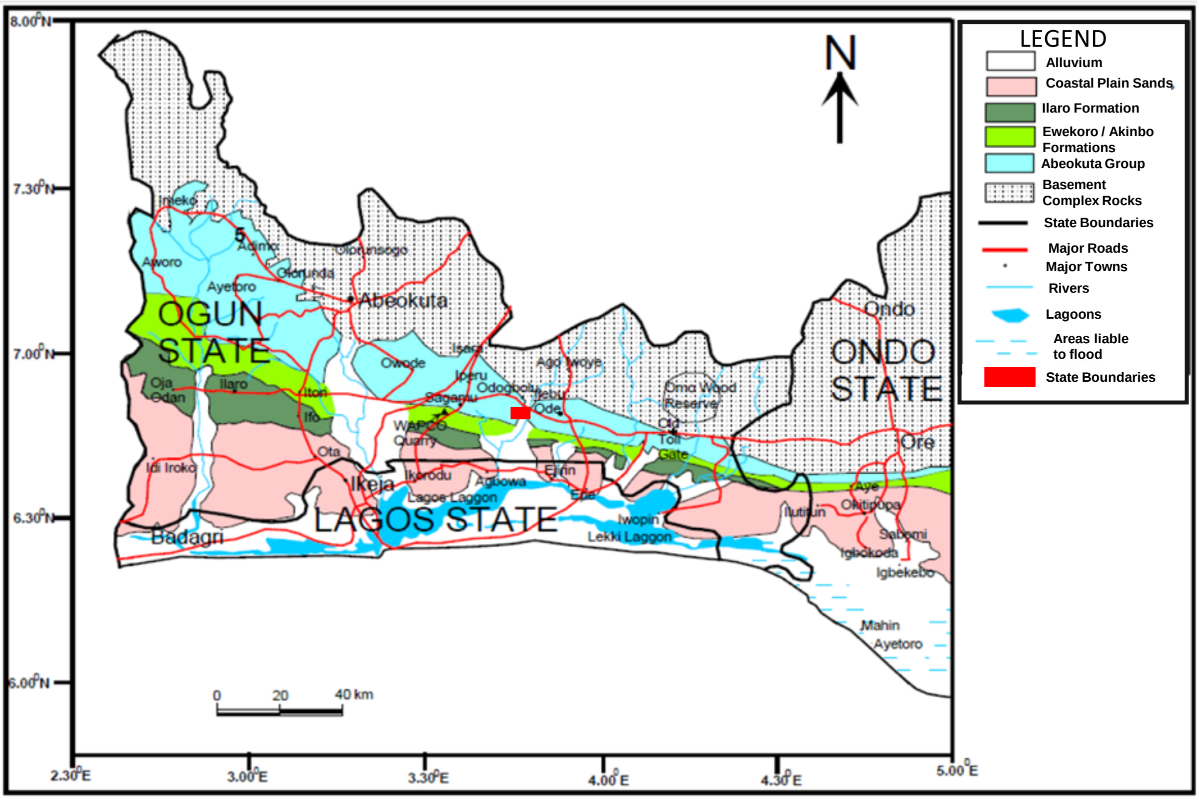

Figure 1: Map of Eastern Part of Dahomey Basin showing Study Area (Okoro and Onuoha, 2020).

3.0 MATERIALS AND METHODS

To describe the strata, two borehole lithological logs were gathered. Integration of geoelectrical resistivity approaches, including Vertical Electrical Sounding (VES) and 2D electrical resistivity tomography (ERT), using Ohmega resistivity meter equipment, four electrodes, four wire-reels, a tape rule, a hammer, and a GARMIN 76S portable GPS device for georeferencing. The basemap was digitized and georeferenced using ArcGIS 10.3.1. (figure 2).

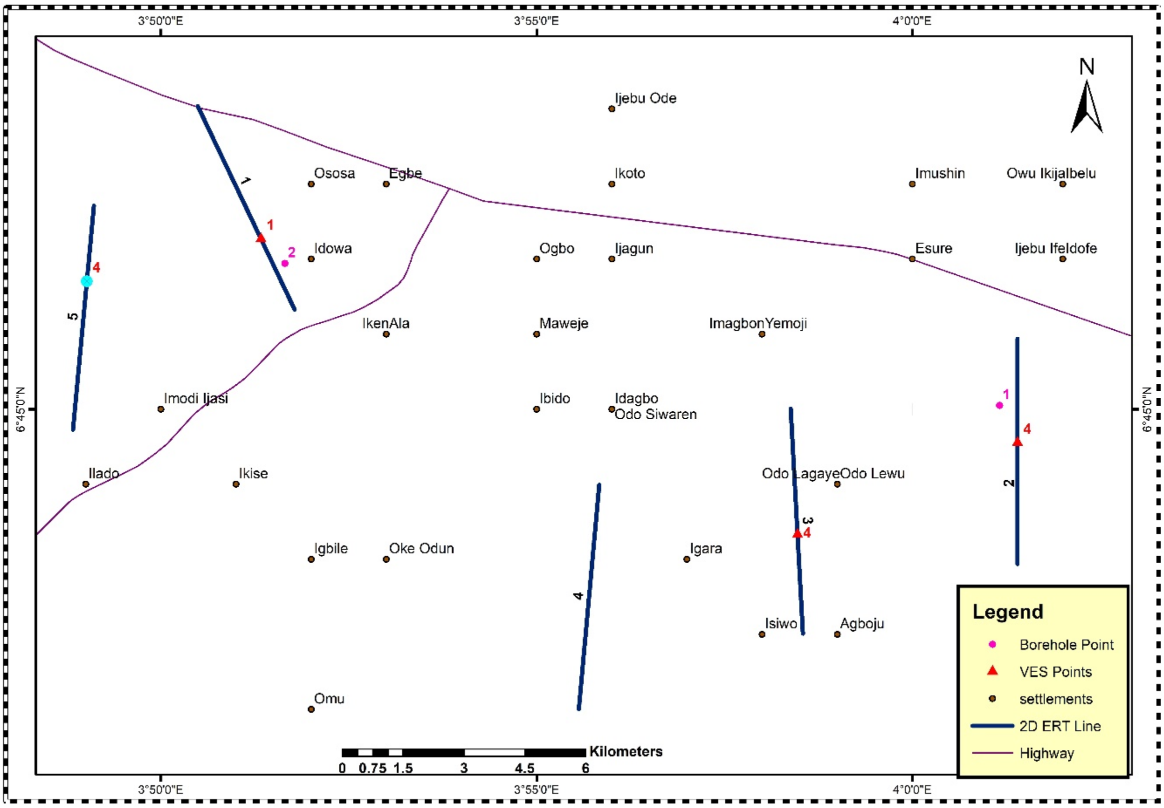

Figure 2: Basemap of the study area.

3.1 Borehole Interpretation

Two borehole lithological logs (BH-1 and BH-2) (Figure 3) encountered bituminous sands in order to provide stratigraphic/ lithological correlation of layers.

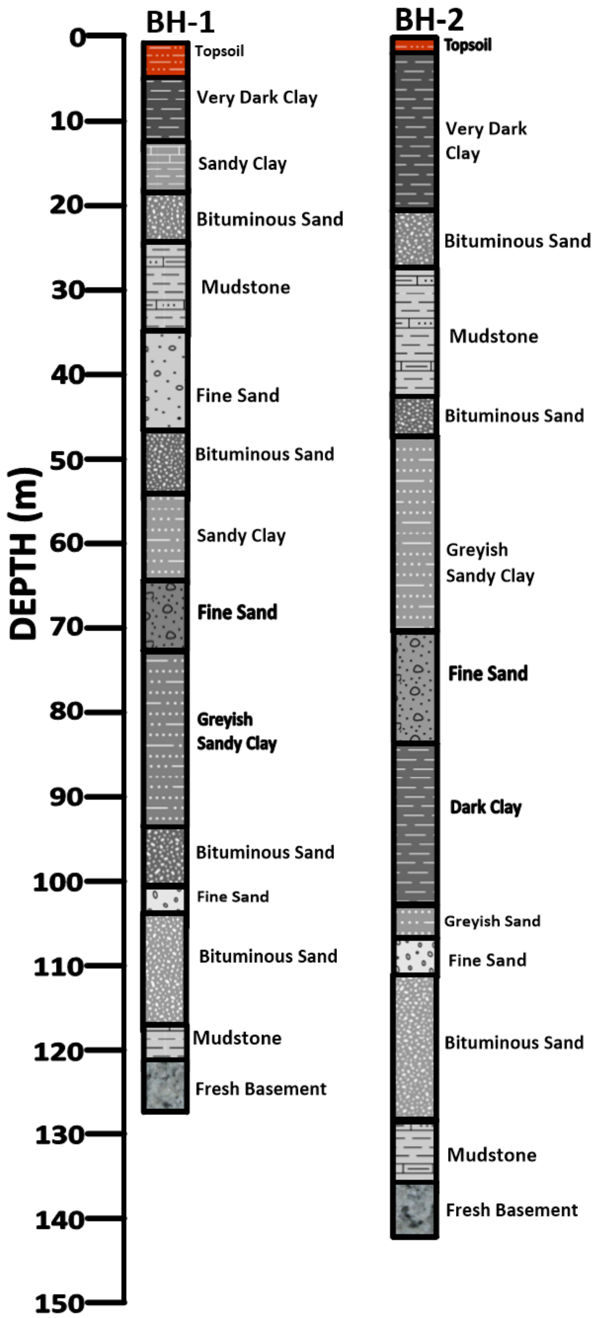

Figure 3: Borehole lithological Log of the Study Area.

3.2 Vertical Electrical Sounding

In this research work, the Schlumberger array was adopted for the vertical electrical sounding technique using the Ohmega resistivity meter. Four (4) VES stations were occupied in the study area (Figure 2) with AB/2 of minimum of 1 m to a maximum of 800 m. The data were interpreted with the aid of partial curve matching and iterated using WINRESIST software, the results generated were used to generate the geoelectric sections with the use of Surfer version 16.

3.3 2D Electrical Resistivity Tomography (ERT)

Five (5) traverses were occupied for the ERT study by placing a pole-dipole array on a 500 m traverse length using the Ohmega Resistivity Meter. The setup entails a less time-consuming field operation. The pole-dipole array in question employs four (4) electrodes (two (2) each for current and potential electrodes), with one of the current electrodes set suitably far away from the profile line (Loke, 2000). To increase data quality, multiple combinations of electrode spacing "*a*" and dipole factor "*n*" values were used, with a ranging from 5 m to 30 m and n ranging from 1 to 10. Using the AGI Earthimager 2D program, the collected data were utilized to build resistivity models for the subsurface. The goal of the inversion method was to lower the root mean square (RMS) value by minimizing the difference between the measured and estimated apparent resistivity.

4.0 Results and Discussion

4.1 Vertical Electrical Sounding (VES)

The geoelectric section (figure 4) of the four (4) VES at the study area delineated four to five geoelectric layers – namely topsoil, lateritic soil, clay, shale/ marly limestone, bituminous sand and sandstone, showing the vertical variations of the underlain materials with respective to their resistivity values. The topsoil's resistivity values and thickness ranges from 446 Ωm to 1633 Ωm and 1.1 m to 3 m respectively. The resistivity values and thickness of the lateritic soil is between the range of 118 Ωm to 694 Ωm and 11.5 m to 15.3 m respectively. The resistivity values and thickness of clay ranges between 23 Ωm to 57 Ωm and 12.5 m to 93 m while shale/ marly limestone is between 14 Ωm to 27 Ωm and 47 m to 77 m respectively. The bituminous sand has resistivity values and thickness of range 4177 Ωm to 7850 Ωm and 52 m to 55 m respectively. The sandstone has resistivity value of range 287 Ωm to 654 Ωm with thickness of 54 m.

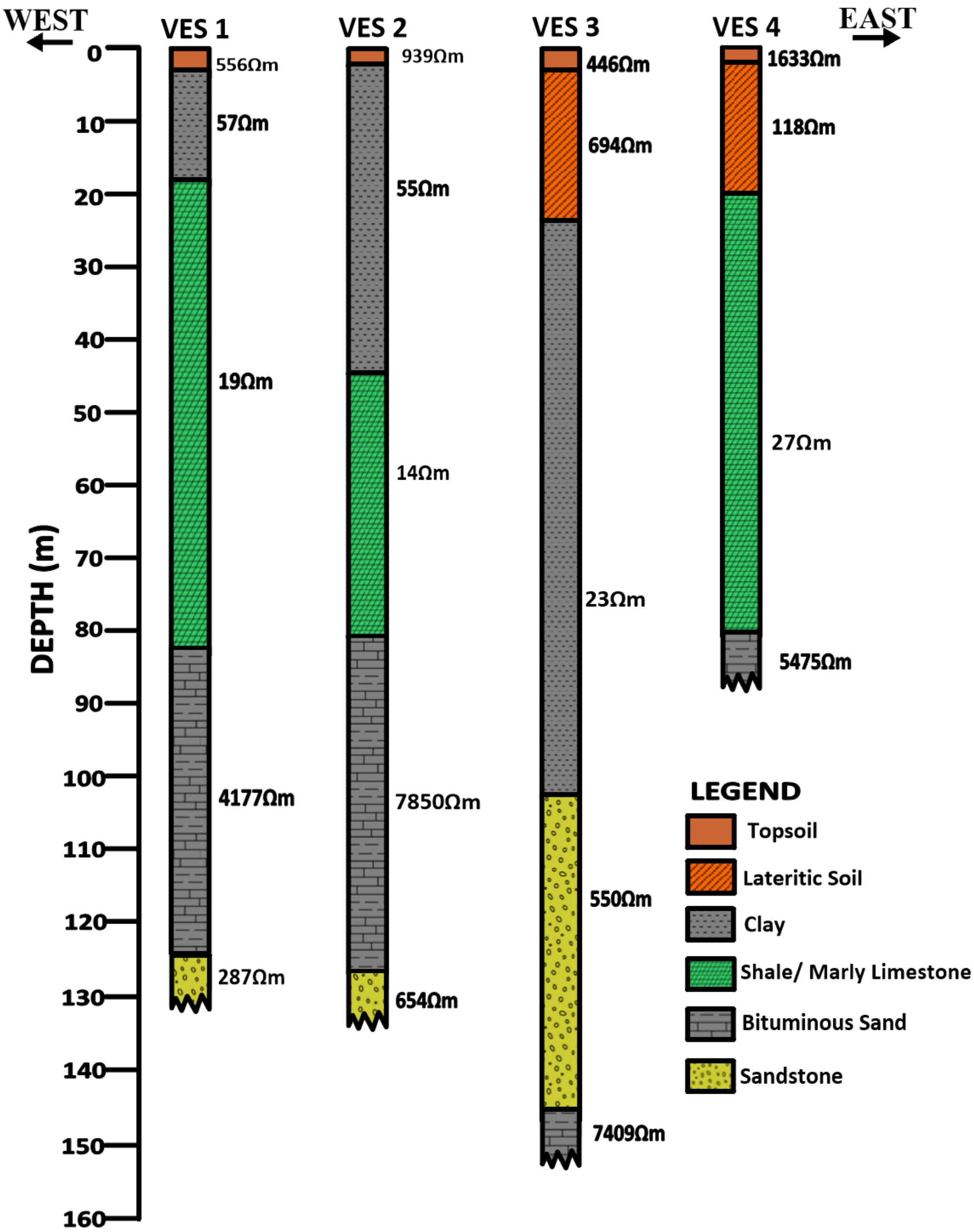

Figure 4: Correlation of geoelectric sections beneath VES 1 – 4 in the West to East direction

4.2 2D Electrical Resistivity Tomography (2D ERT)

Traverse One

Figure 5 depicts the interpreted 2D inverted resistivity section. The subsurface resistivity spans from 1 Ωm to 100 Ωkm over this stretch, and a depth of approximately 166 m was studied. Based on the vertical and lateral fluctuation of resistivity measurements, three geo-electric strata have been defined throughout this traverse. The first geoelectric layer comprises the Topsoil, Clay, Lateritic soil, and Sand. This area is defined by varied electrical resistivity ranges of 1 to 5623 Ωm and a depth range of 30 to 45 m. The second and third geo-electric layers have electrical resistivity ranges of 316 Ωm and 100 kΩm, respectively, with areas having electrical resistivity ranges of 316 to 5623 Ωm expressing Sand and Limestone layers. Meanwhile, at a lateral distance of 100 to 270 m, anomalies with a significantly high electrical resistivity range of 5623 Ωm to 100 kΩm are discovered, indicating the presence of a bituminous layer. This bituminous layer's depth spans from 74 to 90 m.

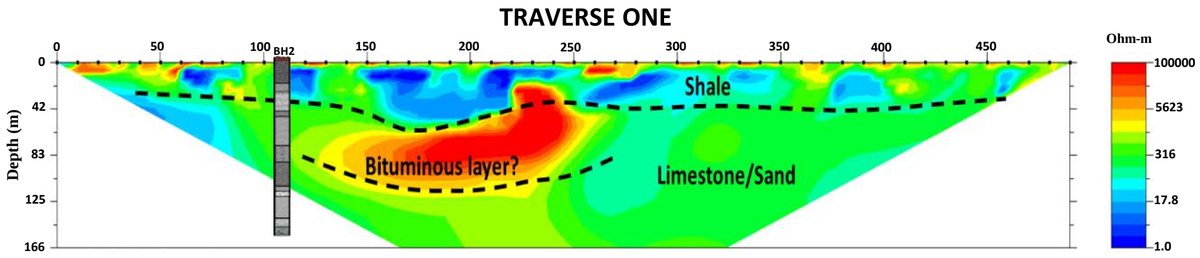

Figure 5: Interpreted Inverted 2D Electrical Resistivity Section along Traverse One.

Traverse Two

The interpreted 2D inverted resistivity section is presented in Figure 6. The subsurface resistivity along this section ranges from 4 Ωm to 36 kΩm and a depth of about 148 m was investigated. Three to four geo-electric layers have been delineated along this traverse based on the vertical and lateral variation of resistivity values. The first geoelectric layer comprises the topsoil, Sand, and Lateritic soil which is characterized by an electrical resistivity range of 403 to 36,686 Ωm and delineated to a depth range of about 18 to 35 m. The second geo-electric layer is represented by a relatively low electrical resistivity range of 4 to 42 Ωm indicative of Shale and delineated to a depth range of 65 to 74m. The third geo-electric layer is with electrical resistivity range of 403 to 36686 Ωm expressive of Limestone/Sandstone layers and delineated to an average depth of 166 m. High resistivity anomalies (3843 to 10521 Ωm) that can be associated with a bituminous layer are observed within the lateral distance of 150 to 300m and depth range of 90 to 110m.

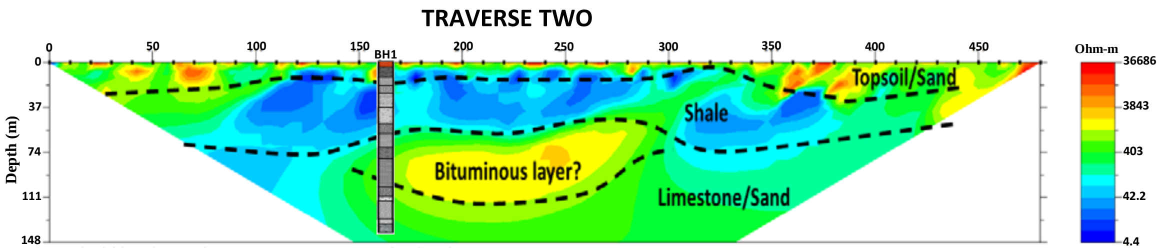

Figure 6: Interpreted inverted 2D Electrical Resistivity section along Traverse Two.

Traverse Three

The interpreted 2D inverted resistivity section is presented in Figure 7. The subsurface resistivity along this section ranges from 2 Ωm to 100 kΩm and a depth of about 166 m was investigated. Three geo-electric layers have been delineated along this traverse. The first geoelectric layer comprises the topsoil, Sand, and Lateritic soil which is characterized by an electrical resistivity range of 466 to 100k Ωm and delineated to a depth range of about 18 to 35 m. The second geo-electric layer is represented by a low electrical resistivity range of 2 Ωm to 31 Ωm indicative of Shale/Marly limestone and delineated to a depth range of 120 to 145 m. The third geo-electric layer is with electrical resistivity range of 31 to 120 Ωm which can be associated with Limestone/Sandstone layers and delineated to an average depth of 166 m.

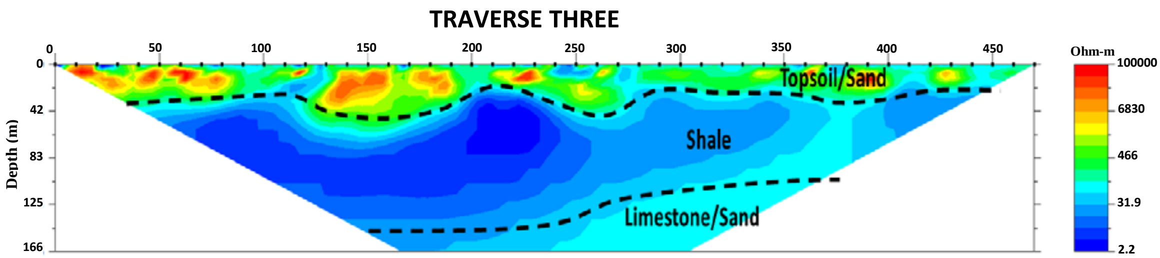

Figure 7: Interpreted inverted 2D Electrical Resistivity section along Traverse Three

Traverse Four

The interpreted 2D inverted resistivity section is presented in Figure 8. The subsurface resistivity along this section ranges from 8 Ωm to 23,152 Ωm and a depth of about 166 m was investigated. Three geo-electric layers have been delineated along this traverse. The first geoelectric layer comprises the topsoil, Sand, and Lateritic soil which is characterized by an electrical resistivity range of 449 to 23152 Ωm and delineated to a depth range of about 21 to 35 m. The second geo-electric layer is represented by a low electrical resistivity range of 8

Ωm to 63 Ωm indicative of Shale/Marly limestone and delineated to a depth range of 125 to 132 m. The third geo-electric layer is with electrical resistivity range of 168 to 449 Ωm which can be associated with Limestone/Sandstone layers and delineated to an average depth of 166 m.

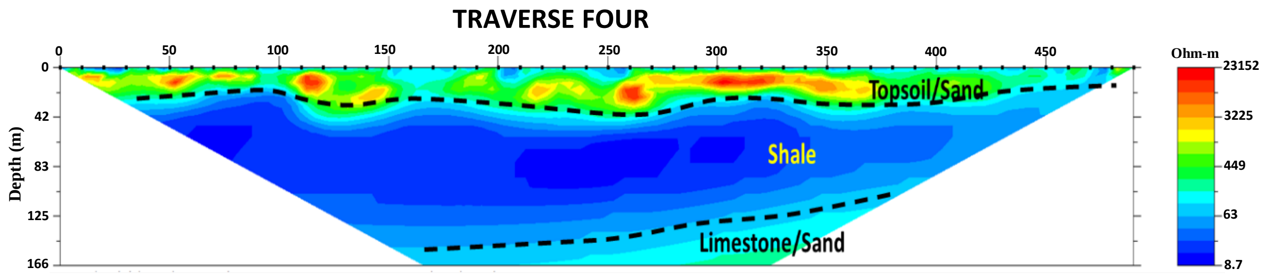

Figure 8: Interpreted inverted 2D Electrical Resistivity section along Traverse Four.

Traverse Five

The interpreted 2D inverted resistivity section is presented in Figure 9. The subsurface resistivity along this section ranges from 2 Ωm to 100 kΩm and a depth of about 120 m was investigated. Three geo-electric layers have been delineated along this traverse. The first geoelectric layer comprises Topsoil, Clay, Lateritic soil, and Sand. This region is characterized by an electrical resistivity range of 34 to 487 Ωm and delineated to a depth range of about 15 to 25 m. The second geo-electric layer is with varying electrical resistivity ranges of 2 Ωm and 6977 Ωm of which regions with an electrical resistivity range of 2 to 34 Ωm are expressive of Clay, Shale, and Marly limestone. Meanwhile, at a lateral distance of 280 to 450m, a relatively high electrical resistivity range of 1843 Ωm to 6977 Ωm anomalies are observed which is indicative of a bituminous layer. The depth of this bituminous layer ranges between 85 to 100 m. The third geoelectric layer is with an electrical resistivity range of 10500 to 100,000 Ωm, suggestive of a Sandstone/Bituminous layer, and delineated to an average depth of 166m.

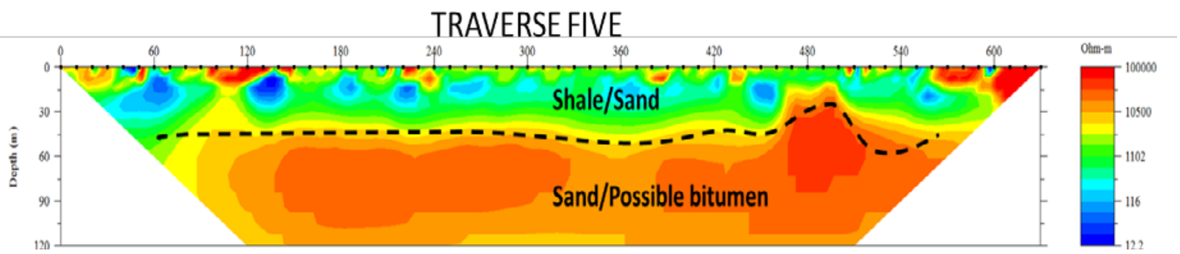

Figure 9: Interpreted inverted 2D Electrical Resistivity section along Traverse Five

4.3. Discussions

2D ERT of all the traverses (figures 5-9) indicates the bituminous sands occurs within a relatively shallow depth with a resistivity value ranging from 3225 Ωm to about 65,000 Ωm and a thickness range of 5 to about 30m. The survey shown that bitumen occurrences are overlain by relatively thin overburden (0-25m), and underlain by mudstone facies and limestone facies.

Similarly, the 2D ERT sections shown that the deeper bituminous sands have higher resistivity range and are laterally continuous than the shallow occurrences. This suggests the sands comprising the shallow and deeper occurrences are probably deposited under different geologic condition. This is similar to the scenario described by Opatola et.al., 2022 and Akinmosin et. al., 2012

The mudstones/clayey facie overlying the bituminous sand as observed on the 2D ERT serve as top seals and lateral seals that prevented migration of bitumen to the surface as bitumen seepages in the study area. Additionally, the mudstone/clayey units underlying the X and Y horizons appear to be the source rock from which bitumen generation and movement to the porous overlying sandy facies occurred, though the source of the bitumen within the basin is still generally disputable.

CONCLUSION

The integration of the geoelectrical resistivity method and borehole lithological logs to map the shallow bituminous sands deposits in the eastern part of Dahomey Basin has been established. The occurrence of the bituminous sands deposits in the study area are associated with high-resistivity contrast and this study have also been able to estimate the overburden thickness and thickness of the bituminous sands which are vital information for the reserve estimate and exploitation planning. In contrast to the commonly held belief that the bituminous layer is laterally continuous, the study found that the bituminous zones are not laterally continuous at the shallow depth, most likely due to stratigraphic control in the study region.

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