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Geophysical and Sedimentological Characterization of a Tar Sand Rich Area in South-western Nigeria.

Gabriel O. Adeyemi[1], Adewale A. Akinmosin[2], Adedipe O. Aladesanmi[3*], Ganiyu O. Badmus[4]

1. Department of Geology, University of Ibadan
2. Department of Geoscience, University of Lagos
3. Department of Geoscience, Afe Babalola University, Ado Ekiti (ABUAD).
4. Department of Physics, Afe Babalola University, Ado Ekiti (ABUAD).

*E-mail of Corresponding Author: jideadedipe@yahoo.com.

Abstract

Although huge deposits of tar sands have been discovered in parts of south-western Nigeria, detailed geological studies of many locations are yet to be executed. Such studies would not only help in quantitative evaluation but also help in generating baseline data that would help in evolving exploitation technique that will be environmentally friendly. Vertical electrical Soundings of southwest Okitipupa were extensively carried out while core samples were studied in order to generate subsurface model of the study area. Detailed sedimentological studies of core samples were also executed. Correlations of geoelectric sections with borehole litho-logs revealed three layers from top to bottom of lateritic soil/clay, shale and sand/bituminous sand. The depth to tar sand horizon ranged from 0.5 to 50.0 m. Groundwater level of about 13 to 15m measured in dug wells occur above tar sand horizon. The most abundant mineral in the tar sand is quartz with subordinate amounts of microcline, muscovite and biotite. The medium grained and moderately sorted nature of the tar sands coupled with low amount of fine particles, indicate that the oil sand reservoir is of good quality. Open cast mining can be employed but precaution must be taken to prevent blowout that may be induced by the overlying water bearing horizon. The fairly thick impervious clayey overburden will prevent pollution of groundwater by waste likely to be associated with tar sand exploitation.

Key words: Tar sand, electrical sounding, correlation, horizon, particles, groundwater.

1. Introduction

The heavy (API gravity‹21°) oil in tar sand is commonly called bitumen. In the raw state it is a sticky, viscous, black substance and easily soluble in organic solvents (e.g chloroform) (meyer,1997).Tar sand is formed by the up-dip migration of crude oil into porous sands near the surface of the earth ,where it is altered (biodegraded and water washed). Tar sand is composed of sand, heavy oil and clay that are rich in minerals and water, In Nigeria, total reserves of heavy oil are estimated to exceed 30 billion barrels (bbls) with future potential recovery of 3654 x 10^6 bbls (Adegoke et al,1991), the tar sands are currently exploited mainly for road construction works but its prospects as potential alternative energy source remain high. Because of the Federal Governments desire to diversify the nation’s economic resources base, the Committee for the implementation of the bitumen project was set up and operated between 1989 and 1993.Recently (August, 2000), the Federal Government has set up another Bitumen Committee to oversee the economic exploitation of Nigeria’s bitumen reserves. The terms of reference of this Committee are not readily available but may have been aimed at serving the overall economic interest of Nigeria and the producer states in particular. This project work present the results, of the geophysical investigation and sedimentological characterization of the tar sand in Okitipupa Southwestern part, to determine the nature and occurrence of tar sand deposit in this area. This deposit consists of a mixture of about 84-88wt% sand and mineral-rich clay with 8-12wt% bitumen and 4wt% water. Okitipupa oil sands have similarity of the grain/water relationship with Canadian oil sands which is referred to as water wet (Coker,1988), makes it characteristically easy to derive comparative studies on processing of our deposit ,and draws the difference from those oil wet deposits of Califonia, New Mexico and Utah.

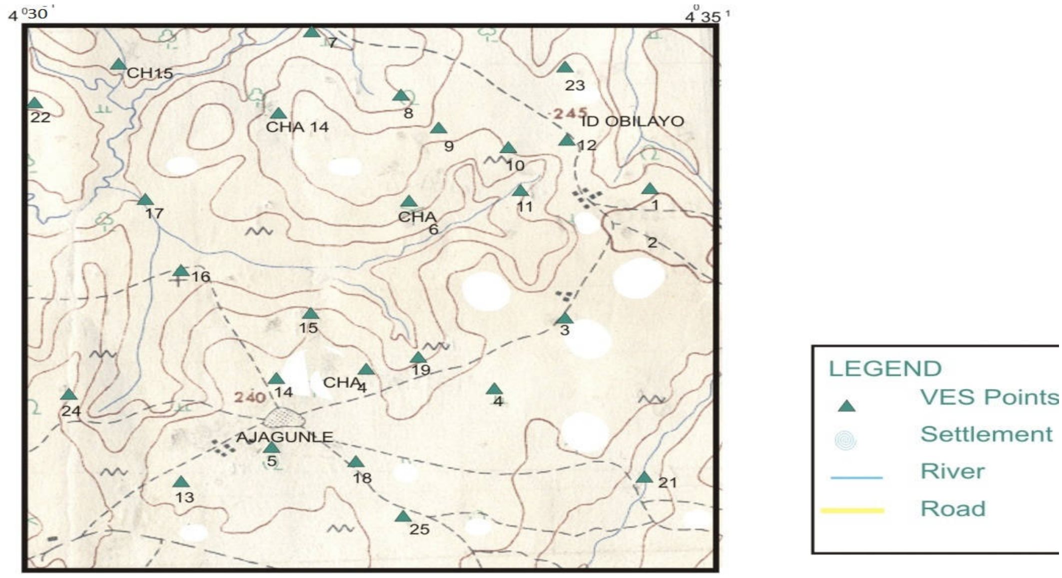

Fig1.Location map of the study Area showing tar sand outcrop points

1.1 Geology and Stratigraphy

The tar sand belt falls within the Nigerian sector of the eastern Dahomey basin. The stratigraphy of the basin was studied by Billman (1976) but was reviewed by Omatsola & Adegoke (1981)on the basis of new subsurface data. The Dahomey basin is a coastal sedimentary basin filled with over 2500m of cretaceous and younger sediments unconformably overlying the block faulted Basement Complex rocks. The basin's sedimentary fill was subdivided into three intervals by Durham Picket (1966) namely (a) Sand and sandstones at the base (b) alternating sands and shale and (c) upper shales which correspond to the three formations of Ise, Afowo and and Araromi respectively (Omatsola &Adegoke,1981).

Ise Formation: This formation is the oldest, and overlies the weathered basement complex. It is comprised of conglomeratic sands showing upward fining variation into finer grained sands. Kaolinitic clays are quite obvious as interbeds and at the sediment/basement contact ,Quartz is the major constituent of the sands although some other minerals (mica, heavy minerals) have been reported in the stratigraphic record as most of it had been eroded following the Santonian tectonics that affected the basement complex, rocks. A Niccomian age is assigned to Ise formation.

Afowo Formation: Afowo sediments indicate the commencement of deposition in a transitional environment after the entirely basal and continental Ise formation. The sediments are composed of interbedded sands, shales and clays. The sands are tar-bearing whilst the shales are organic –rich .Outcrops of this formation are commonly encountered within the tar sand belt and are easily recognizable because of the presence of sticky and viscous tar seeping out of the sandy portions of the Afowo Formation. The age is Maastrichitian.

Araromi Formation: Sediments of the Araromi formation represent the youngest and topmost sedimentary sequence in the subbasin. They are comprised of shales, fine grained sands, thin interbeds of limestone, clay and lignitic bands. It is attributed an age range of Maastrichitian to Paleocene (Billman 1976,Omatsola and Adegoke,1981).

Table 1: The Stratigraphic Units of Eastern Dahomey Basin

Jones and Hockey (1964)			**Adegoke and Omatsola(1981)**		**Agagu (1985)**	
	Age	**Formation**	**Age**	**Formation**	**Age**	**Formation**
Quaternary	Recent	Alluvium			Recent	Alluvium
Tertiary	Pleistocene-Oligocene	Coastal plain sands	Pleistocene to Oligocene	Coastal Plain sands	Pleistocene to Oligocene	Coastal plain sands
	Eocene	Ilaro	Eocene	Ilaro Oshoshun	Eocene	Ilaro Oshoshun
	Paleocene	Ewekoro	Paleocene	Akinbo Ewekoro	Paleocene	Akinbo Ewekoro
Late Cretaceous	Late Santonian	Abeokuta	Maastrichtian – Neocomian	Araromi Afowo Ise	Maastrichtian -Turonian– Neocomian	Araromi
						Afowo
						Ise
Precambrian Crystalline Basement Rock						

2. Methods

2.1 Geological Investigation and Core Description

Geological mapping of the study area was carried out, during which strikes and dips of foliations were measured and recorded, lithology and geological contacts were determined, and drainages were noted. The coordinates of important features were also taken and recorded. The identification and description of primary sedimentary features such as lithology, grain size, sedimentary structures and post depositional diagenetic effect were considered for the core description.

2.2 Sedimentological Studies

The tar sand samples were collected at four major wells (core samples) in the Idobilayo and Ajegunle areas of Ondo State. Samples were also collected in the mapped area for petrographic studies. A total of fourteen (14) tar sand samples were collected for comparing the properties and characteristics of the two major tar sand horizons (X and Y). The laboratory analyses carried out are: Bitumen Saturation, Textural Analysis, Morphological study, Heavy Mineral Analysis.

2.3 Geophysical Survey

The VES electrical resistivity method investigates subsurface conditions by using Schlumberger configuration because the method is sensitive to locating Formation layers, fracture faults and joints in basement complex environment. The maximum current electrode spacing (AB/2) range between 55m-140m depending on space constraint encountered on the field. A total of 25 VES points were established at locations of mapping. The field were interpreted quantitatively by partial curve matching and computer iteration methods (Resist by Vander Velper B.P.A of Netherlands). This provided the thickness and resistivity values for the different subsurface layers.

3. Result and Discussion

3.1 Textural Analysis:

Table 2a: Textural Analysis Parameters Represent Subsurface Samples

Sieve Number	Phi	Mass of Empty Sieve (g)	Mass of Sieve+Soil Retained (g)	Soil Retained (g)	Cumulative Soil Retained	% Soil Retained	% Cumulative Soil Retained
0.850	0.25	493.5	539.6	46.1	46.1	46.47	46.67
0.600	0.75	488.8	503.7	14.9	61.0	15.01	61.68
0.25	1.25	460.3	472.2	11.9	72.9	11.99	73.67
0.300	1.75	454.2	467.4	13.2	86.1	13.31	86.98
0.212	2.25	409.2	417.7	8.5	94.6	8.55	95.53
0.150	2.75	419.3	422.6	3.3	97.9	3.32	98.85
0.075	3.75	404.1	404.9	0.8	98.7	0.81	99.66
Pan	-	503.5	504.0	0.5	99.2	0.50	100
Total				99.2			

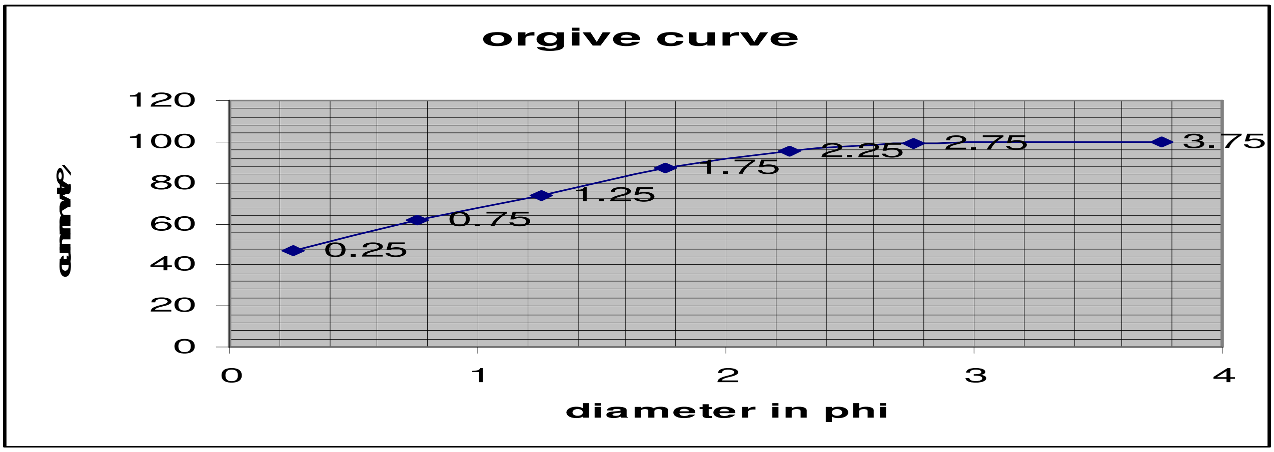

Fig2a: Cumulative Frequency Representing Subsurface Samples

Mode	0.25
Median	0.40
Graphic Mean	0.73 (coarse grain)
Inclusive Graphic standard deviation	1.02 (Poorly sorted)
Inclusive Graphic Skewness	1.48 (Strongly fine skewed)

Table 2b: textural analysis parameters represent surface samples

Sieve Number	Phi	Mass of Empty Sieve (g)	Mass of Sieve+Soil Retained (g)	Soil Retained (g)	Cumulative Soil Retained	% Soil Retained	% Cumulative Soil Retained
0.850	0.25	493.5	519.1	25.6	25.6	25.88	25.88
0.600	0.75	488.8	500	11.2	36.8	11.32	37.20
0.425	1.25	460.3	471.7	11.4	48.2	11.53	48.73
0.300	1.75	454.2	467.8	13.6	61.8	13.75	62.48
0.212	2.25	409.2	420.1	10.9	72.7	11.02	73.50
0.150	2.75	419.3	429.4	10.1	82.8	10.21	83.71
0.075	3.75	404.1	414.1	10.0	92.8	10.12	93.83
Pan	-	503.5	509.6	6.1	98.9	6.17	100
Total				98.9			

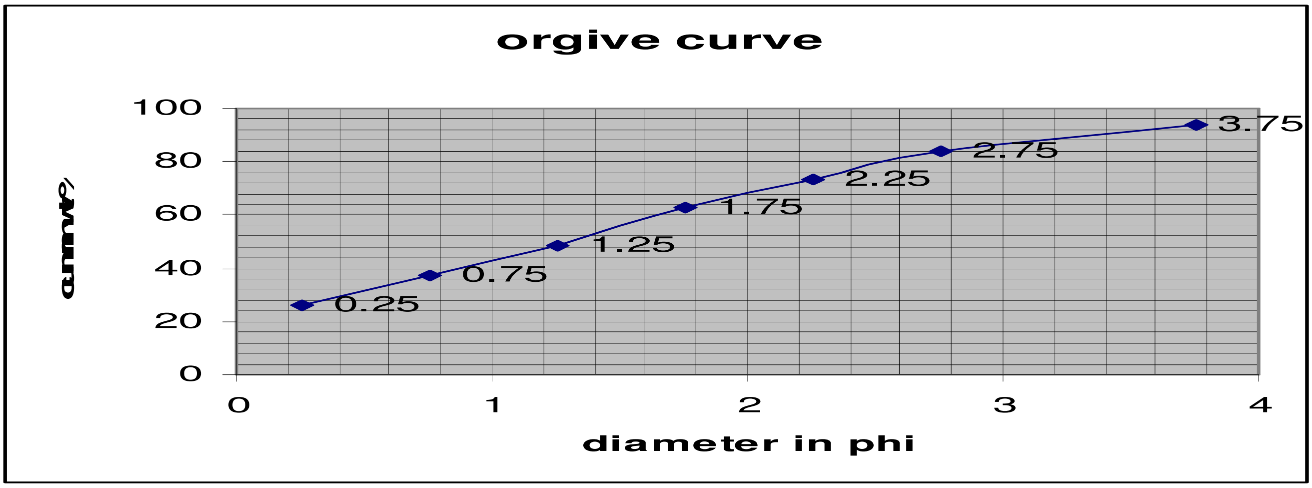

Fig2b: Cumulative Frequency Representing Subsurface Samples

Mode	0.25
Median	1.25
Graphic Mean	1.66 (medium grain)
Inclusive Graphic standard deviation	0.85 (Moderately sorted)
Inclusive Graphic Skewness	0.46 (Strongly fine skewed)

Grain Size:

The grain size of the tar bearing sands vary from coarse to medium grained. The average mean grain sizes of the subsurface samples to surface samples range between -0.199phi to 1.13phi corresponding to a very coarse grained sand to medium grained sand. This can be characterised with upward fining. Other statistical parameters determined for the sands include standard deviation (S.D.),Kurtosis (K) and Skewness (SK). SD values (2.186-0.65phi) show that the sands are essentially very poorly sorted to moderately well sorted. Skewness (-0.084-0.05) and Kurtosis positively skewed and mesokurtic respectively. A very poorly sorted value for the tar sands indicates that they have a great amount of variability among the diameters of their particles. This indicates that the sediments are not matured and can probably be said to be residual because they have not been transported (if at all) not far away from its source. A moderately well sorted value for tar sands shows that there is a fair amount of variability among the diameters of their particles. This means that the sediments are matured to a reasonable extent and the particles have been transported quite far away from its source. Results obtained from the granulometric analyses indicate that all the sediments are unimodal which shows that they are from the same parent source and the same process of deposition. This can also be inferred from the shape of the cumulative curves (see appendix). From these curves, it can be inferred that the sediments were deposited by stream considering the shape of the curve and the bivarate plot of skewness versus sorting after(Friedman 1967).From the cumulative frequency curve also, the mode of sediments transportation can either be by saltation or suspension but mainly by saltation (Visher 1969).

Packing:

The structural framework of a tar sand sediment grain shows that the pore space between the grains is occupied by oil. The oil is not in direct contact with the grains because a thin water fill surrounds the quartz grains hence it is described as being water wet. The oil occupy to 90% of the pore space, in the sediments acting in most cases as the connecting material between the grains.

Roundness:

The grain shape and roundness of the tar sand grains show a wide variation. It ranges from subangular to subrounded. It was however observed that the fine grains are more angular than the coarser grains. This shows that some sands have undergone a long duration of transportation while some, a short one.

Mineral Composition:

Quartz is the dominant mineral of the tar sands and it constitutes over 80% of the entire assemblage of mineral grains. Feldspar, mica and clay minerals occur in minor amounts. The beds at the base of the tar bearing sands are not impregnated rather they contain a higher amount of feldspar (arkosic) and clays than the overlying tar rich sands. Clay mineral studies on the tar sand sequence (Enu et al,1981) have shown that the clays are essentially Kaolinite, with illite, smectite and mixed layers in small amounts. The clay content in the tar impregnated sand is lower (2-7)% than that present in the lower sands devoid of tar (7-20)%.

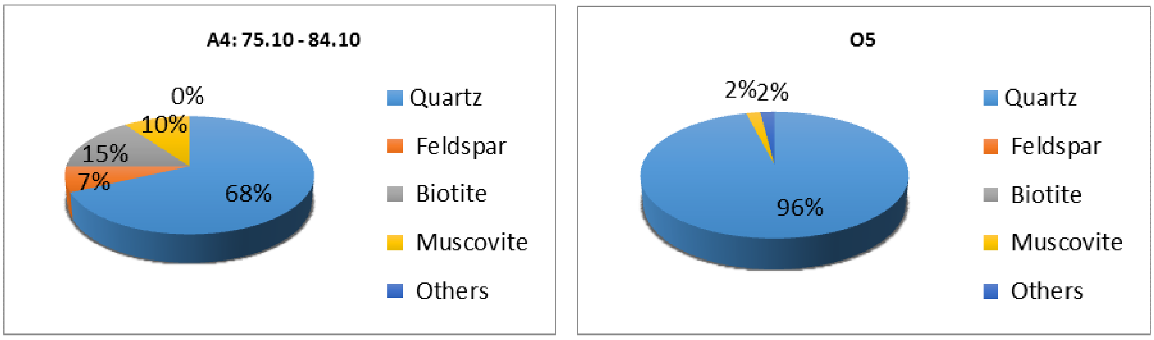

Fig 3: Piechart Representing the Mineral Composition% of Subsurface Samples and Surface Samples

Heavy Minerals:

The heavy mineral suite contain the following non-opaques: staurolite,tourmaline,zircon,rutile,sillimanite,garnet and andalusite .Some of those heavy minerals could turn out to be economically viable as large tonnages of sands (Enu and Adegoke,1984;Coker,1990). the presence of Zircon, Rutile and Tourmaline, Apatite, indicates an Acid Igneous Rock source. Straurolite, Garnet, Andalusite, Epidote, indicate a dynamo thermal metamorphic source. It can be inferred that the source rock is a Migmatite. This is because Migmatite is a high grade metamorphic rock which compose of an intimate mixture of granitic igneous rock.

Porosity:

The intergranular voids are occupied by oil, water and air. The porosity of the tar sands vary from one sample to another because of the variability of the pore spaces in the sediments. Porosity values obtained from a number of methods employed (leaching technique, direct analysis etc.). Show that porosity of the tar sands is in the range of 16 to 35% (Oyegoke, 1984). Most samples have porosity values between 24 and 35% (Enu,1985).

Bitumen saturation

The analysis carried out on both the subsurface and subsurface samples revealed that the percentage weight of the bitumen occupied by the tar sands in the subsurface sample ranged between 12% and 47% with an average bitumen saturation of 27.14wt% while that of the surface sample ranged between 1.6% and 29% with an average bitumen saturation of 22wt% . This is a little low compared to the Athasbasca oil – sands deposits in Canada which is 41% and the Eastern Venezuela deposit which is relatively 48% (Tissot and Weite, 1984). Though it might be a bit low, it is saturated enough for exploitation.

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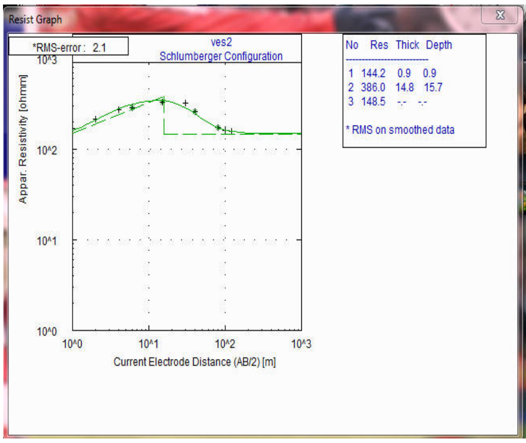
3.2 Resistivity Survey Results:



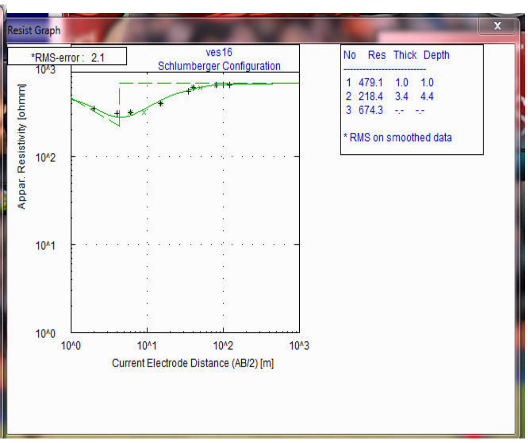


Fig 4a: Typical K Ves curve-type in the area. **Fig 4b: Typical H Ves curve-type in the area**

The computed apparent resistivity values and response curves after computer iteration for the VES stations were used to present the 3 interpreted electrofacies units that were generally identified within the study area. Knowledge of the conductivity or resistance of these litho-types and the interpretation from the geophysical investigation gave an informal electrofacies classification.

Table 3: Electro-facies Classification

Geoelectric-facies class	Resistivity Values	Possible Lithofacies
Type A	0-250Ωm	Sandyclay/laterite/coal/Bituminous sand
Type B	250-1500Ωm	Clayey sand/laterite and clean sand
Type C	1500-αΩm	Hardpan/cong and weathered basement

The type A (0-250Ωm) geoelectric facies has a characteristic of high conductivity indicating the presence of low resistivity material discernable by visual inspection of the VES curve. Judging from the sequence of stratification in the borehole correlated, the bituminous sand falls within this package. It is thus,not identifiable as a separate recognizable electro-facies. This package constitutes the middle electro-facies.

The type B (250-1500Ωm) geoelectric facies correlates with the laterite, clean sand and the clayey sand portion, which have a fairly high resistivity value and are usually above the shale or clay portion. This is what constitutes the top electro-facies.

The type C (1500-αΩm) geoelectric facies correlates with the lowermost lithofacies sequences overlying crystalline basement rocks; comprising: conglomeratic sands, feldsphatic/arkosic sands, hardpan and or weathered-crystalline rock.

Geoelectric section along Traverse E-F(North-South Trend)

The Traverse runs North-South of the mapped area is one of the cross-sections studied. It covers VES stations 7, 12 and 1. The top soil is moderately thick, ranging from 1m in VES station 7 to 1.8m in VES station 12. This indicates high thickness overburden in the centre of the area. The resistivity value range from 285Ωm in VES station 12 to 520 Ωm in station 7.This suggesting lateritic top soil. Underneath this layer we have low resistivity layer which is suspected to be bitumen saturated sands particularly in Ves 1 run across the stations. The thickness of the layers varies from 1.6m in station 12 to17.7m in station 7. There is a trend of increase in thickness in Northward direction which indicates direction of deposition. This depth also falls within the first bitumen bearing X-horizon of Adegoke, (1982), Ako et al (1983).

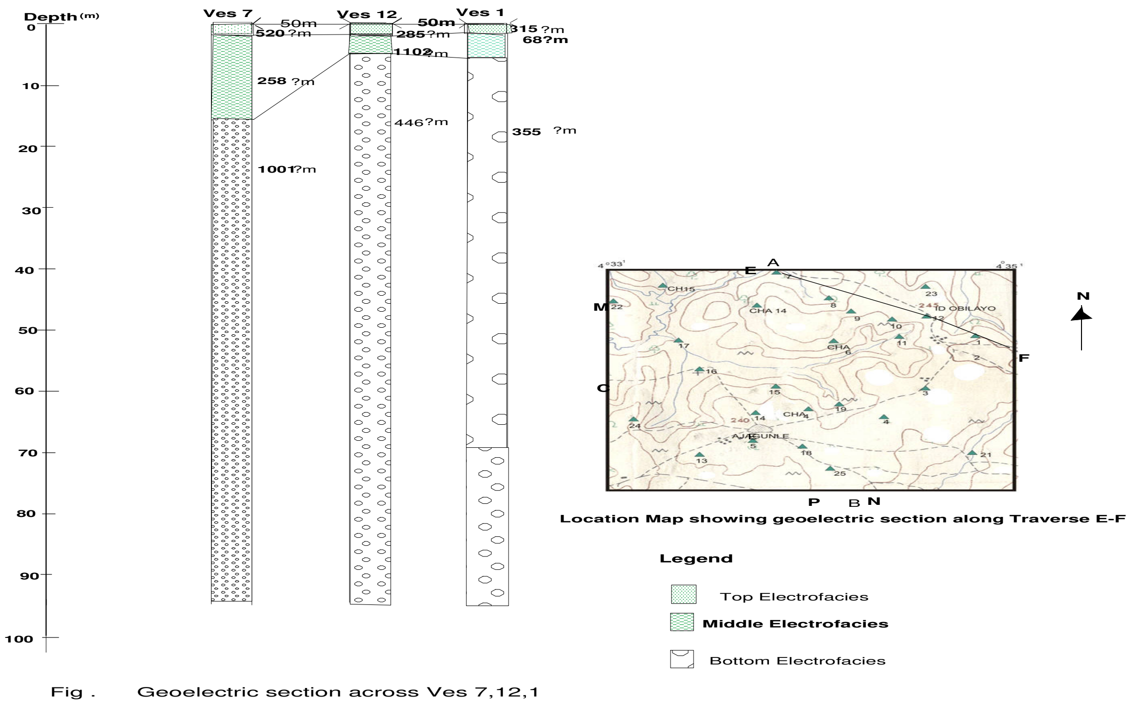


Fig 5: Geoelectric Section across ves 7, 12, 1

Columnar Section

The columnar section of these VES points (1,2,3,16 and 22) are carefully study for detail description . The top soil is mostly laterite with thickness varying between 0.4m and 2m this indicate a thin layer as a result of washing away of top soil in the study area .the clayey sand represent a high resistive layer next to the top soil, the thickness range from 2.7m to 4.8m.VES 1 did not show any value for clayey sand , the point shows the bitumen directly after top soil. In the columnar section , bitumen are commonly encountered in layer 5 to 6 of the section above of which we have saturated sand and sand of higher resistivity values. Thickness range is between 4.2m to71.8m.The depth to the top of the bitumen saturated sand is between 1m to 27m.The column revealed the trend of increase of bitumen saturated sand in the westward direction towards south and the overburden thickness. It depict horizon that is suspected to be interbedded sands, shales and clays (Enu 1990) suggested, the tar-sand are tar bearing whilst the shale are organic-rich.

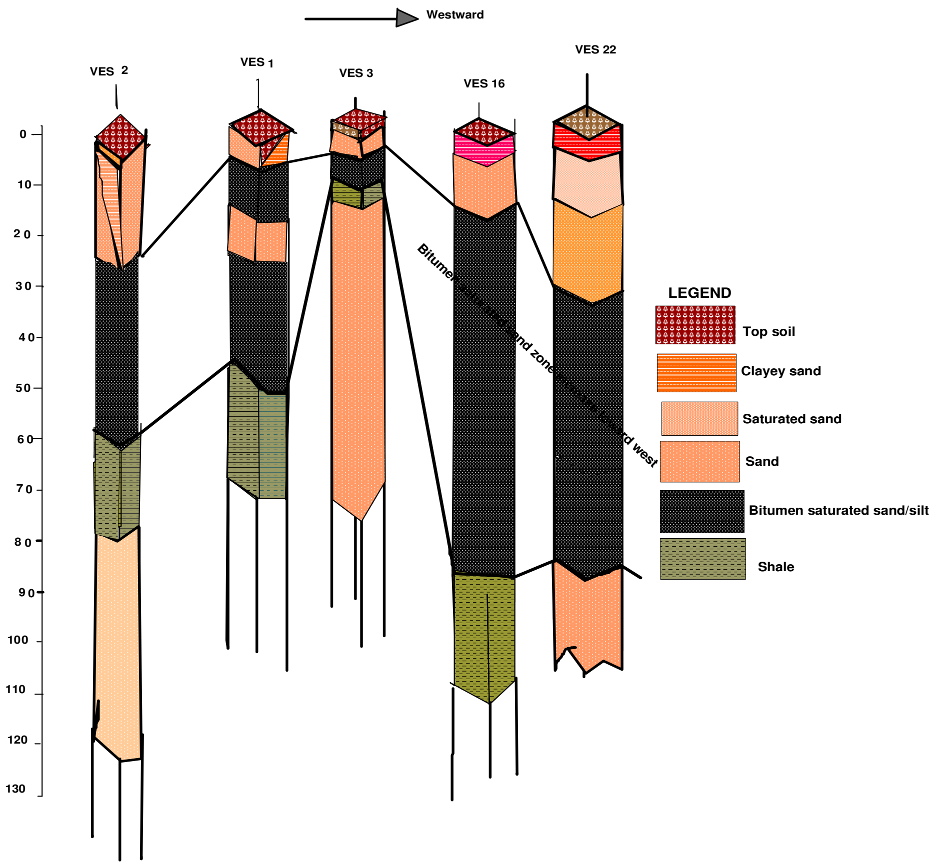


Fig 6: Columnar section of the various VES in the mapped area.

Correlation of Geoelectrical and Borehole data along the same Traverse.

In the NE-SW traverse in the mapped area the correlation of geoelectrical section along these transverse was taken across the borehole point on it.

In the NE-SW direction we have VES point 22, and16 correlate with BH4, in the E-W direction we have VES point 1 correlate with BH15, BH14 and BH16 correlate along the same traverse. It is evident that although it was not possible to distinguish the fine lithotypes shown in the geological section from resistivity data, the correlation between resistivity and borehole lithologic data is good (Ako,1990) the correlation show a consistent increase in the thickness of the overburden southwards and the increase of bitumen saturated zone westwards. The geometrical data also revealed the uneven nature of the basement topography, as the configuration of the layer are not even, thus demonstrating the effect of block faulting (Ako et al 1983), along the NE – SW traverse the depth range of bitumen is clearly related to the bitumen range in BH4. Along E-W the lithological stratigraphy of the borehole is closely related to the lithology probe in the VES 1, this is shown in figure 4.13 below.

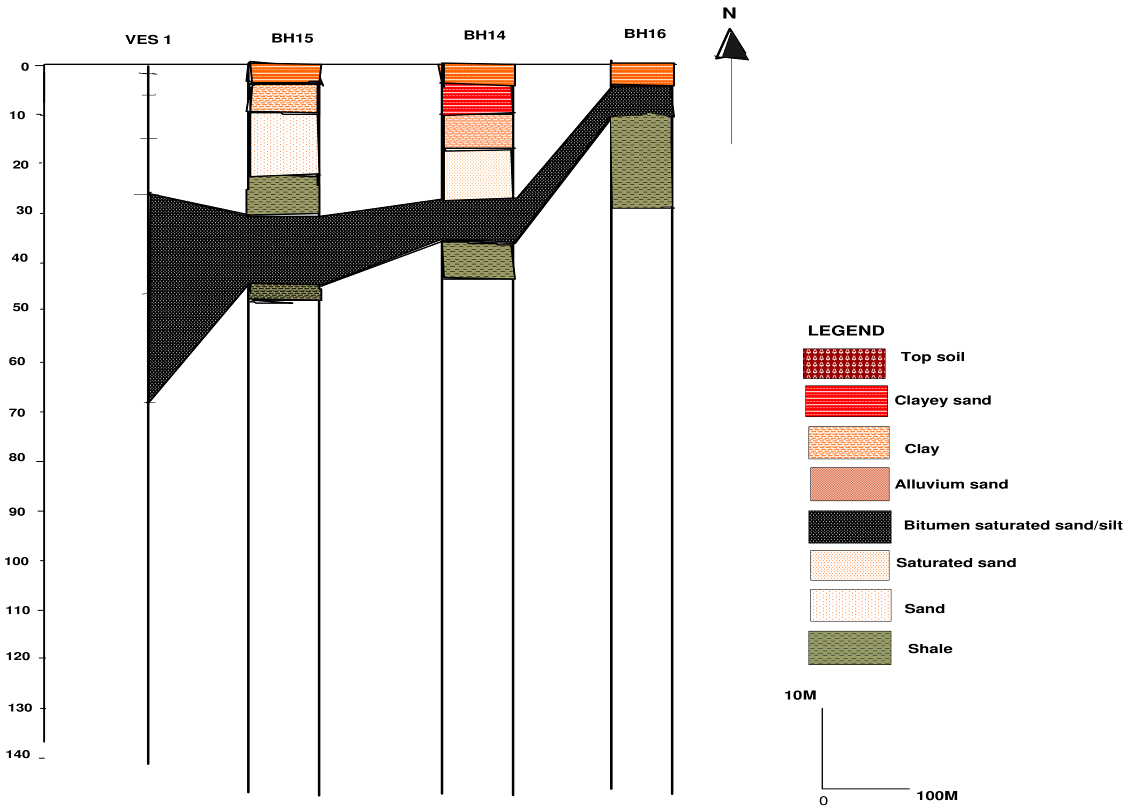


Fig.7 Geoelectrical section and borehole data along an E-W Traverse

Relationship between Tar and Water bearing Zones

The water bearing zone could not be identified directly from geophysical survey due to the effect of tar sands resistivity which in most cases coincide with resistivity (0-250ohm-m) of possible water bearing horizon. From the field mapping exercise and geophysical investigation carried out in the study area, it was observed that the tar sand deposits are overlain by overburden varying between 0 and 50m in thickness and most of the water bearing horizon from the dug wells (e.g Idobilayo and Ajegunle wells) were found to occur at the shallower depths than the tar sand horizons. This implies that the deposits can best be exploited by open cast mining method (Alberta Energy,2004).However, considering the relationship between tar sand horizons and water bearing zones, one of the dangers associated with this mining method from hydro geological point of view is flooding, either from shallow aquifer or precipitation. The confined aquifers are under pressure and removal of overburden, if care is not taken, can lead to 'blow out' causing sudden and uncontrollable over flooding, sinking of heavy duty machines and possibly foundation problems.

Plate 1: indicating the shallower water bearing zones over Tar sand horizons.

4. CONCLUSION

The occurrence and the characteristic nature of the Southwest tar-sands has been investigated using sedimentological and geophysical (Vertical electrical sounding) method. These have shown that abundant tar-sands occur in south-western part of Nigeria. From the interpretation of Textural Analysis, the values show that the tar sands are mainly very coarse grained sands for the subsurface samples which shows that the samples have not travelled away from the source. The surface samples shows Medium grained sands which shows that the sands have travelled a fairly long transportation history and textural maturity, the tar sands might Have been transported and deposited by currents of moderate energy, probably streams. The Histogram distributions and frequency distribution curves reflect a unimodal source for the sediments.

The medium grained and moderately sorted particles coupled with low fine particles content indicate that the Afowo oil sands reservoir is of good quality. From the heavy mineral analysis, it can be deducted that the subsurface samples are not mineralogically matured. The surface samples are mineralogically matured, the sands come from a source which is part of the Nigerian Basement Complex. A synthesis of the Geoelectric section, Columnar section and Borehole data correlation shows that the ridges are overlain by relatively thin overburden while the depressions are overlain by thick overburden. It also shown there is a consistent increase in the thickness of the overburden southwards and the increase of bitumen saturated zones westwards. With this, the amount of earth material to be excavated during bitumen exploitation can be assessed. This study would like to advice on the exploration techniques in the area and mode of operation such as open cast mining could be employed. But precaution must be taken to prevent blowout that may be induced by the overlying water bearing horizon.

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ABOUT THE AUTHOR

Adeyemi Gabriel Oladapo, is a professor of Geology in the University of Ibadan, Nigeria. His research activities are mainly in the field of Engineering Geology, part of his completed and progress research are on geotechnical evaluation of geomaterials, soil stabilisation, environmental engineering geology, evaluation of lateritic soils as high way subgrade materials. He holds his academic and professional qualifications from University of Ife now Obafemi Awolowo University.

Akinmosin Adewale A.is a Lecturer in Geoscience department, University of Lagos, Nigeria. His area of specialization are; Petroleum Geology, Sedimentology and Environmental Geology, part of his completed and progress research are on Geochemical composition and textural features of carbonate rocks, Provenance study of bituminous sands, Geochemical and mineralogical study of sandstones. He holds a Ph.D. degree in Environmental geology from University of Ibadan. Nigeria.

Aladesanmi Adedipe Olajide is a Lecturer in the Department of Geoscience Afe Babalola University Ado Ekiti (ABUAD). His research area is focus on sedimentary Environment. He holds an MSc. In Petroleum Geology/Sedimentology from the University of Ibadan and is presently doing his Ph.D at the University of Ibadan, Nigeria.

Badmus Olabode Ganiyu, is a lecturer in the department of Physics Afe Babalola University, Ado Ekiti (ABUAD). His research focus is based on Earthquake Seismology. He holds a MSc. degree in Physics (Solid Earth Physics) from the University of Ibadan, Nigeria.

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