LITHOFACIES TYPES AND INFLUENCE ON BITUMEN SATURATION IN X-HORIZON OF THE NIGERIAN TAR SAND DEPOSITS.

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ABSTRACT

Bitumen saturation, particle size distribution and mineralogical analyses were carried out on some tar sand deposits in parts of southwestern Nigeria with a view to determining their sedimentological properties and the degree of bitumen saturation of the respective lithofacies. Fifty one fresh samples collected at 1 m intervals from 13 different locations were prepared for further studies by soaking in toluene, to extract the bitumen from the reservoir sands and subsequently subjected to granulometric analysis. The sands were air-dried and dry-sieved to establish the grain size classes for the different locations. The dry samples were further analyzed petrographically to deduce the textural characteristics and transportation history. Moreover, heavy mineral analysis was carried out to determine the sediments' maturity and their provenance. From the textural study, five different lithofacies were established namely: very fine sand, fine sand, medium sand, coarse sand and very coarse sand. Results showed that the samples from some locations were well sorted, while others ranged from poorly sorted to well sorted with average standard deviation range of 0.32 – 1.28Φ. The average graphic mean of 1.24Φ and average standard deviation value of 0.91Φ revealed that majority of the sands were medium grained. Most of the sediments were leptokurtic while others were mesokurtic to platykurtic. The skewness of all the samples varied from very fine skewed to very coarse skewed. The grain shape ranged from angular to well rounded. The heavy mineral analysis result showed that the sediments were mostly mineralogically immature except for those from Idiobilayo, Loda and Trianga. The average percentage bitumen impregnation for Imeri (coarse sand) was 15.5%; Okerisa (medium sand) was 25%; while that of Tirianga (fine sand) was 30.60%. The results generally showed that fine-grained facies had higher tar saturation than the medium and coarser grained sizes, which suggested that bitumen saturation in the study area was influenced by particle size.

Keywords: Bitumen, Tar Sand, Provenance, Maturity, Sorting, Lithofacies.

INTRODUCTION

Nigeria has seven prominent sedimentary basins namely Sokoto Basin, Middle Niger Basin, Chad Basin, Benue Trough, Anambra Basin, Dahomey Basin and Niger Delta (Fig. 1). Of these basins, the abundance of hydrocarbon has been discovered as crude oil in the Niger Delta basin and as bitumen in the eastern part of the Dahomey Basin. At present, exploration and exploitation activities of the hydrocarbon found in the Niger Delta province have already attained an advanced stage. The same however, cannot be said of the natural bitumen occurrences which are found in sandstone reservoirs (tar sands) in Ogun, Ondo and Edo States of southern Nigeria. Two major bitumen horizons (X and Y) occur within depths of 100 m along latitude $6^0$36'N of the Nigerian tar sand belt. This work is aimed at determining the sedimentological properties of the X-Horizon (upper bituminous sediments), with depth range of 9-22 m from the surface (MMSD, 2010).

Description of the Study Area

The study areas lies between Latitude 6^o 30' and 6^o 54'N and Longitude 3^o 58' and 5^oE (Fig. 2.). The Benin (Dahomey) Basin is part of the system of the West African peri-cratonic (margin sag) basin (Klemme, 1975; Kingston *et al*., 1983) developed during the commencement of rifting, associated with the opening of the Gulf of Guinea in the Late Jurassic to the Early Cretaceous (Burke *et al*, 1971; Whiteman, 1982). The crustal separation, typically preceded by crustal thinning, was accompanied by an extended period of thermally induced basin subsidence through the Middle – Upper Cretaceous to Tertiary times as the South American and the African Plates entered a drift phase to accommodate the emerging Atlantic Ocean (Storey, 1995; Mpanda, 1997).

The Ghana Ridge, presumably an offset extension of the Romanche Fracture Zone, confines the basin in the west while the Benin Hinge Line, a Basement escarpment which separates the

Okitipupa Structure from the Niger Delta Basin, confines it in the east. The Benin Hinge Line supposedly defines the continental extension of the Chain Fracture Zone. The onshore part of the basin covers a broad arc-shaped profile of about 600 km^2 in extent. The onshore section of the basin attains a maximum width, along its N-S axis, around 130 km in the proximity of the border between Nigeria and Republic of Benin. The basin narrows to about 50 km on the eastern side where the basement assumes a convex upwards outline with concomitant thinning of sediments. Along the northeastern fringe of the basin where it rims the Okitipupa high is the occurrence of tar (oil) sands and bitumen seepages (Ekweozor and Nwachukwu, 1989). The lithostratigraphic units of the Cretaceous to Tertiary sedimentary succession of the eastern margin of Dahomey Basin according to Idowu *et al.* (1993) are summarized in Table 1.

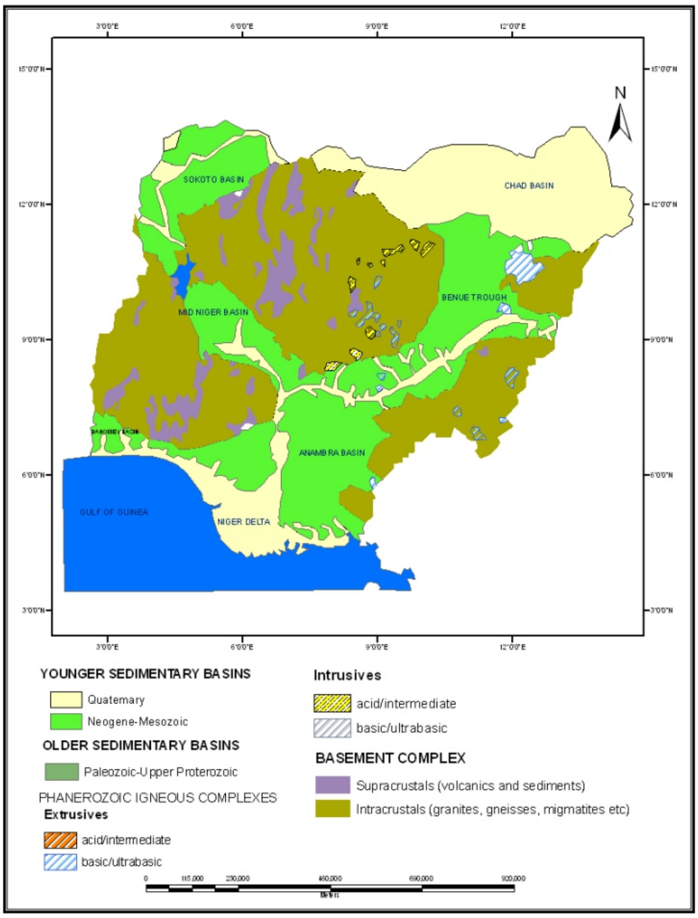

Fig. 1: Geological map of Nigeria, showing distribution of Basement Complex Rocks and Sedimentary Basins (Oyawoye, 1972).

Fig. 2: Map of Study Area

Table 1: Age and Stratigraphic Relationship of the Formations of the Dahomey Basin

Jones and Hockey (1964)			Omatsola and Adegoke (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						

MATERIALS AND METHOD OF STUDY.

Most of the outcrops are located around streams and channels and were studied based on the facies changes and bed thicknesses. At each location, assessment of the areal extent of the outcrop(s) was carried out, after which fresh samples were collected at 1m interval. The lithologic logs of the exposed surfaces were drawn to depict the sedimentological characteristics of the outcrops. For textural analysis, after cleaning and drying, 100 g of the samples were dry-seived using vibrating sieving machine for 15 minutes with sieves of the following mesh sizes: 2 µm, 1.4 µm, 1 µm, 0.5 µm, 0.25 µm, 0.18 µm, 0.125 µm, 0.09 µm, 0.075 µm, 0.063 µm and pan, corresponding to -1Φ, -0.5Φ, 0Φ, 1Φ, 2Φ, 2.5Φ, 3Φ, 3.5Φ, 3.75Φ, 4Φ and 5Φ on the logarithmic scale values respectively. The individual cumulative weight with their percentages was determined. These data were used to plot histograms and cumulative frequency curves for individual samples on arithmetic and semi-log graphs. The parameters were computed by using moment statements mean, mode, standard deviation, kurtosis, and skewness (using formulae by Folk and Ward, 1957).

For bitumen saturation analysis, ten grams of each sample was put into a measuring cylinder with toluene for about 24 hours. The samples were afterwards washed and decanted, and the procedure was repeated until the samples were clean of bitumen. The washed samples were air dried and re-weighed. The new weights were noted, recorded and subtracted from the initial weights. The difference in weight were converted to percentages and recorded. 75 µm grain size fraction of 10 grams weighted sediments, obtained from each sample by sieving was subjected to heavy mineral separation using bromoform (s.g. 2.85). The separation subsequently was according to the principle of gravity setting (funnel separation). The heavy mineral grains were subsequently mounted on a micro-slide glass with Canada balsam. The relative mineral abundance was determined under petrological microscope by modal technique.

RESULTS AND DISCUSSION

Lithological Description of Study Locations

Field Observation of the study area showed that bitumen seepages occur mainly on farm lands, road cuts and near streams. It could be established from the field assessment that tar bearing sandstones were all underlain by dark grey shale almost in all the locations. Texturally from visual examinations, the grains of the sandstone vary from fine to very coarse with varying degrees of bitumen impregnation. The thickness of the sandstone body also ranges from 1 m to 4 m (Figs. 3-10)

Grain Size Analysis Results

The summary of results of the grain size statistical parameters namely sorting, skewness and kurtosis for the 51 samples analyzed and their respective bitumen saturation percentages are shown in Table 2. The table shows that the least mean value of -0.227 (very coarse sand) was obtained for sample OJ4 3, while the highest value of 3.312 (very fine sand) was obtained for TIR 2. The least standard deviation (sorting) of 0.32 (very well sorted sand) was obtained for LOD 3, while the highest standard deviation value of 1.298 (poorly sorted sand) was calculated for Idiopopo. Computed values for skewness show that the least value of -0.73 (very coarse skewed) was obtained for ORI 2 and the highest value of 0.418 (very fine skewed) was obtained for OJ4 3. Computations for kurtosis shows that the least value of 0.68 (platykurtic) was obtained for ORI 1 while the highest value of 1.631 (very leptokurtic) was obtained for OJ4 3.

Bitumen Saturation Results

Column 2 of Table 2 shows the bitumen saturation results for the 51 analyzed samples. It shows that the least saturation value (14%) was obtained at Imeri (IME2), while the highest value (33%) was obtained at Trianga (TIR2). Figure 11 is a histogram (for easy comparison) showing the bitumen saturation values for all the analyzed samples, while Figure 12 is a histogram showing the average bitumen saturation for the respective locations.

Lithofacies Grouping and Corresponding Bitumen Saturation values

The analyzed samples were classified into different lithofacies based on mean grain sizes according to Udden (1914) and Wenthworth (1922) grain size scale. The identified lithofacies are very coarse (VC), coarse (C), medium (M), fine (F) and very fine (VF) sand. Table 3 summarizes the lithofacie type(s) per location and also the average percentage bitumen saturation values for the various locations. The dominant lithofacie type per location is asterisked (*). Figure 13 is a histogram showing the average percentage bitumen saturation per facie type per location. The least average saturation (15.50%) by facie is the coarse sand at Orita J4, while the highest average saturation (33%) by facie type is the very fine sand at Tirianga. Figure 14 shows the average percentage bitumen saturation map per location.

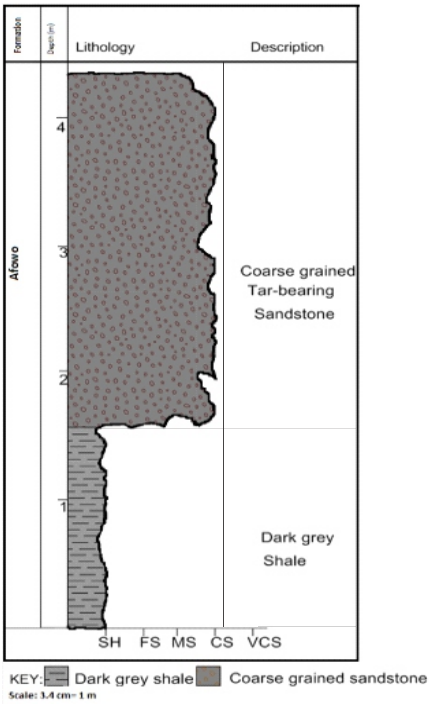

Fig. 3: Lithologic log for Gbegude

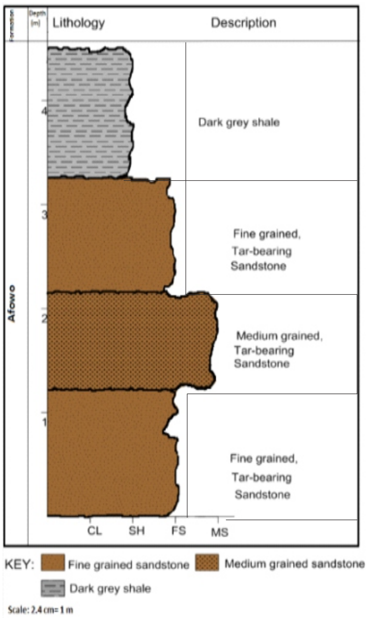

Fig. 4: Lithologic log for Idiobilayo

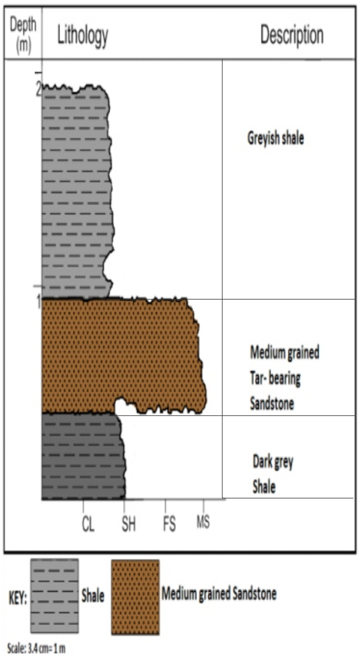

Fig. 5: Lithologic log for Idiopopo

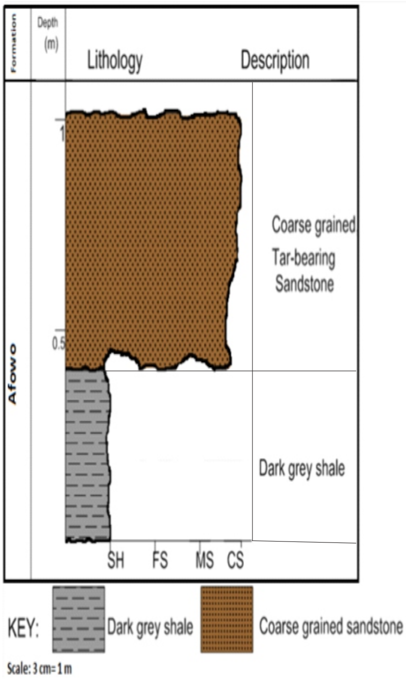

Fig. 6: Lithologic log for Imeri

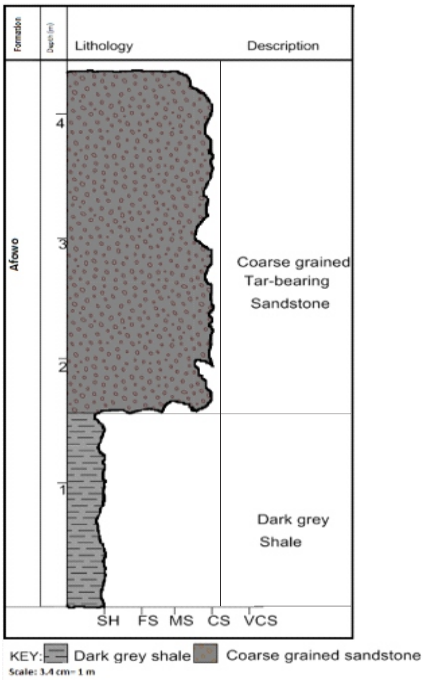

Fig. 7: Lithologic log for Loda

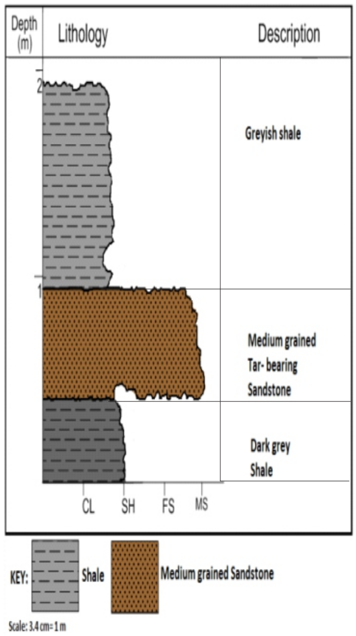

Fig. 9: Lithologic log for Orita J4

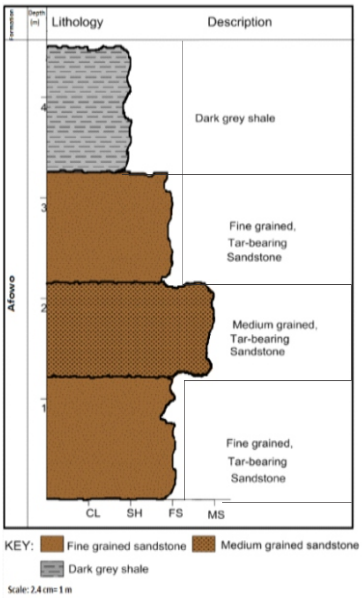

Fig. 8: Lithologic log for Looto

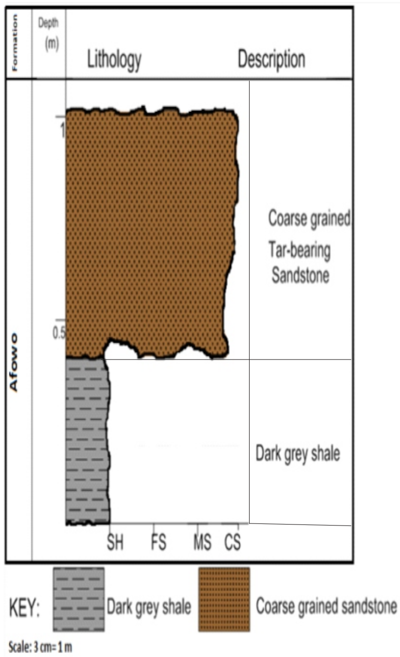

Fig. 10: Lithologic log for Tirianga

Table 2: Summary of Percentage Bitumen Impregnation and Grain Size Analysis

Sample No.	Bitumen Impreg-nation (%)	Grain Size (mean)		Sorting/Standard Deviation		Skewness		Kurtosis	
		Result	Interpre-tation	Result	Interpre-tation	Result	Interpre-tation	Result	Interpre-tation
GBD 1	18	0.443	Coarse sand	1.061	Poorly sorted	0.258	Fine skewed	1.138	Leptokurtic
GBD 2	20	0.244	Coarse sand	0.968	Moderately sorted	0.120	Fine skewed	0.971	Mesokurtic
GBD 3	20	0.347	Coarse sand	1.018	Pooly sorted	0.176	Fine skewed	1.164	Leptokurtic
GBD 4	19	0.508	Coarse sand	1.000	Moderately sorted	0.139	Fine skewed	1.093	Mesokurtic
IDB 1	31	2.013	Fine sand	1.047	Poorly sorted	0.049	Symmetrical	0.953	Mesokurtic
IDB 2	28	2.090	Fine sand	1.148	Poorly sorted	0.023	Symmetrical	1.047	Mesokurtic
IDB 3	29	1.928	Medium sand	1.155	Poorly sorted	-0.179	Coarse skewed	1.168	Leptokurtic
IDB 4	27	2.125	Fine sand	1.107	Poorly sorted	-0.049	Symmetrical	1.320	Leptokurtic
IDB 5	25	2.309	Fine sand	1.216	Poorly sorted	-0.023	Symmetrical	1.347	Leptokurtic
IDP 1	19	1.224	Medium sand	1.235	Poorly sorted	0.019	Symmetrical	0.795	Platykurtic
IDP 2	16	0.411	Coarse sand	0.976	Moderately sorted	0.278	Fine skewed	1.127	Leptokurtic
IDP 3	20	0.431	Coarse sand	1.006	Poorly sorted	0.204	Fine skewed	1.158	Leptokurtic
IDP 4	22	0.620	Coarse sand	1.187	Poorly sorted	0.252	Fine skewed	1.001	Mesokurtic
IDP 5	19	1.058	Medium sand	1.298	Poorly sorted	0.017	Symmetrical	0.831	Platykurtic
IME 1	15	0.412	Coarse sand	0.765	Moderately sorted	0.089	Symmetrical	1.081	Mesokurtic
IME 2	14	0.636	Coarse sand	0.833	Moderately sorted	0.081	Symmetrical	0.994	Mesokurtic
IME 3	17	0.492	Coarse sand	0.950	Moderately sorted	0.177	Fine skewed	1.254	Leptokurtic
IME 4	16	0.800	Coarse sand	1.022	Poorly sorted	0.180	Fine skewed	0.999	Mesokurtic
IMO 1	18	1.581	Medium sand	0.745	Moderately sorted	-0.297	Coarse skewed	0.941	Mesokurtic

IMO 2	23	1.770	Medium sand	1.132	Poorly sorted	-0.484	Very coarse skewed	0.997	Mesokurtic
IMO 3	18	2.262	Fine sand	0.867	Moderately sorted	-0.477	Very coarse skewed	1.561	Very leptokurtic
IWO 1	30	1.139	Medium sand	0.898	Moderately sorted	-0.139	Coarse skewed	0.995	Mesokurtic
IWO 2	25	1.316	Medium sand	0.979	Moderately sorted	-0.190	Coarse skewed	0.763	Platykurtic
LOD 1	27	2.983	Fine sand	0.325	Very well sorted	-0.036	Symmetrical	0.737	Leptokurtic
LOD 2	28	2.956	Fine sand	0.443	Well sorted	-0.203	Coarse skewed	1.276	Leptokurtic
LOD 3	30	2.960	Fine sand	0.320	Very well sorted	0.075	Symmetrical	0.745	Leptokurtic
LOD 4	30	2.956	Fine sand	0.330	Well sorted	0.037	Symmetrical	0.741	Leptokurtic
LTO 1	18	1.324	Medium sand	1.058	Poorly sorted	0.186	Fine skewed	0.767	Platykurtic
LTO 2	21	1.072	Medium sand	1.089	Poorly sorted	0.320	Very fine skewed	0.950	Mesokurtic
OKE 1	29	1.254	Medium sand	0.853	Moderately sorted	-0.092	Symmetrical	0.942	Mesokurtic
OKE 2	25	1.288	Medium sand	1.011	Poorly sorted	-0.054	Symmetrical	0.987	Mesokurtic
OJ4 1	24	0.404	Coarse sand	0.976	Moderately sorted	0.349	Very fine skewed	1.119	Leptokurtic
OJ4 2	21	0.115	Coarse sand	1.184	Poorly sorted	0.316	Very fine skewed	1.083	Mesokurtic
OJ4 3	22	-0.227	Very coarse sand	0.898	Moderately sorted	0.418	Very fine skewed	1.631	Very Leptokurtic
OJ4 4	20	0.034	Coarse sand	0.837	Moderately sorted	0.313	Very fine skewed	1.244	Leptokurtic
OJ4 5	19	0.467	Coarse sand	1.057	Poorly sorted	0.395	Very fine skewed	1.130	Leptokurtic
OJ4 6	16	0.210	Coarse sand	0.907	Moderately sorted	0.359	Very fine skewed	1.184	Leptokurtic
OJ4 7	20	0.409	Coarse sand	0.614	Moderately well sorted	0.117	Fine skewed	1.265	Leptokurtic
OJ4 8	19	0.214	Coarse sand	0.761	Moderately sorted	0.201	Fine skewed	1.240	Leptokurtic
OJ4 9	19	0.205	Coarse sand	0.833	Moderately sorted	0.241	Fine skewed	1.292	Leptokurtic

OJ4 10	24	0.185	Coarse sand	0.818	Moderately sorted	0.297	Fine skewed	1.234	Leptokurtic
ORI 1	21	1.550	Medium sand	0.824	Moderately sorted	-0.482	Very coarse skewed	0.680	Platykurtic
ORI 2	23	1.714	Medium sand	0.807	Moderately sorted	-0.730	Very coarse skewed	0.782	Platykurtic
ORI 3	20	1.672	Medium sand	0.699	Moderately well sorted	-0.116	Coarse skewed	1.013	Mesokurtic
ORI 4	18	1.377	Medium sand	0.857	Moderately well sorted	-0.162	Coarse skewed	0.820	Platykurtic
ORI 5	26	1.085	Medium sand	0.779	Moderately sorted	-0.334	Very coarse skewed	0.891	Platykurtic
ORI RD 1	21	1.666	Medium sand	1.286	Poorly sorted	-0.378	Very coarse skewed	1.020	Mesokurtic
ORI RD 2	19	1.644	Medium sand	1.275	Poorly sorted	-0.395	Very coarse skewed	1.044	Mesokurtic
TIR 1	29	1.411	Medium sand	0.841	Moderately sorted	-0.181	Coarse skewed	0.972	Mesokurtic
TIR 2	33	3.312	Very fine sand	0.393	Well sorted	-0.123	Coarse skewed	1.064	Mesokurtic
TIR 3	30	2.980	Fine sand	0.673	Moderately well sorted	-0.461	Very coarse skewed	1.433	Leptokurtic

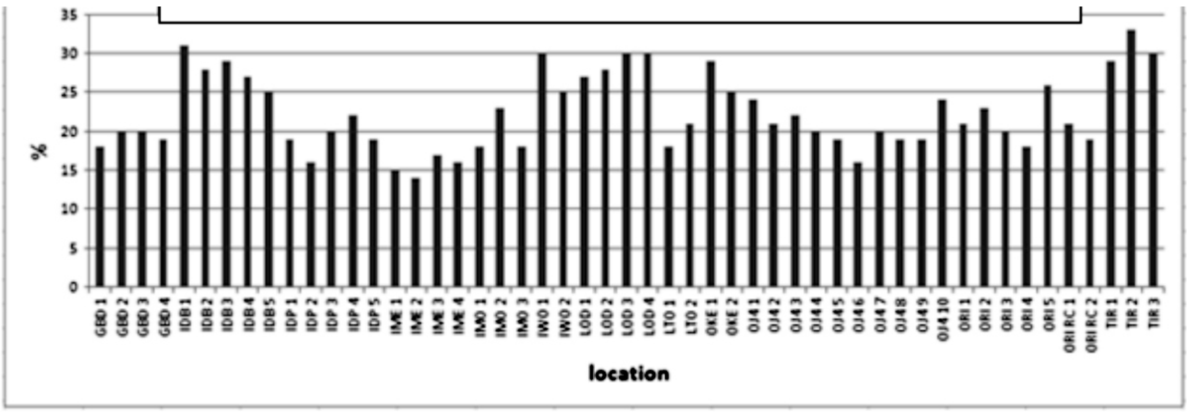

Fig. 11: Percentage Bitumen Saturation of Tar Sand Samples

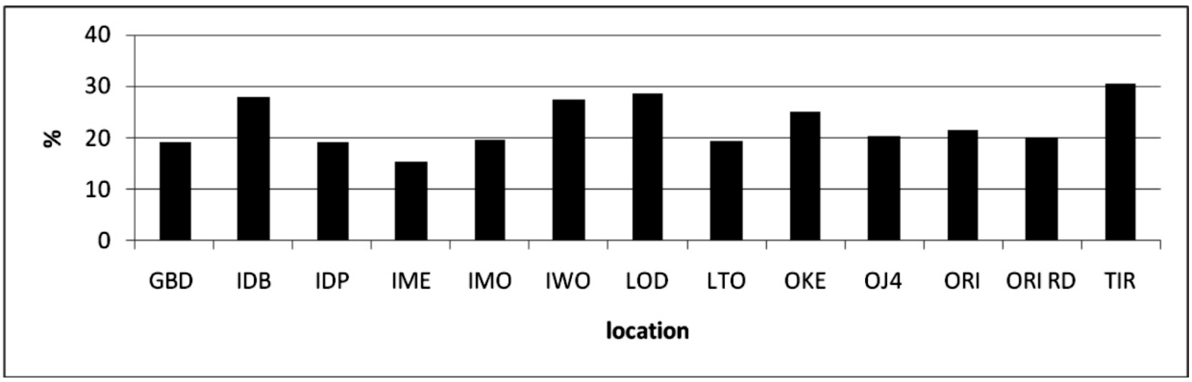

Fig. 12: Average Percentage Bitumen Saturation of Sampled Locations

Table 3: Summary of Lithofacies Types Per Location, Their Average Percentage Bitumen Saturation and Average Percentage Bitumen Saturation Per Location

Location	Facie Type	Individual Facie % Bitumen Saturation	Avg. Locations % Bitumen Saturation
Gbegude	C	C - 19.25	19.25
Idiobilayo	F* - M	F - 27.75, M - 29	28.00
Idiopopo	M	M - 19.20	19.20
Imeri	C	C - 15.50	15.50
Imobi	F – M*	F – 18, M – 20.5	19.67
Iwopin	M	M – 27.50	27.50
Loda	F	F – 28.75	28.75
Looto	M	M – 19.50	19.50
Okerisa	M	M – 25.00	25.00
Orisumbare Village	M	M – 21.60	21.60
Orisumbare Road	M	M – 20.00	20.00
Orita J4	C * - VC	C - 20.22, VC - 22.00	20.40
Tirianga	VF – F - M	VF - 33; F - 30; M - 29	30.60

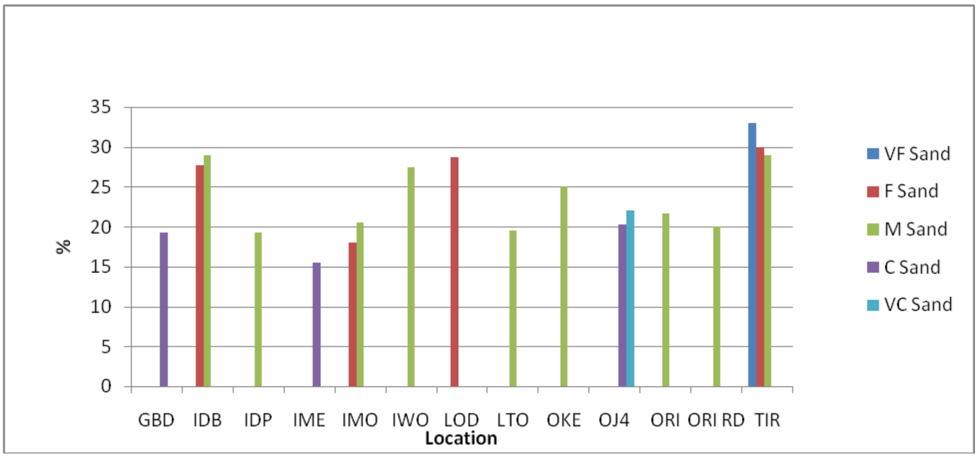

Fig. 13: Lithofacies Types and Their Percentage Bitumen Saturations Per Location.

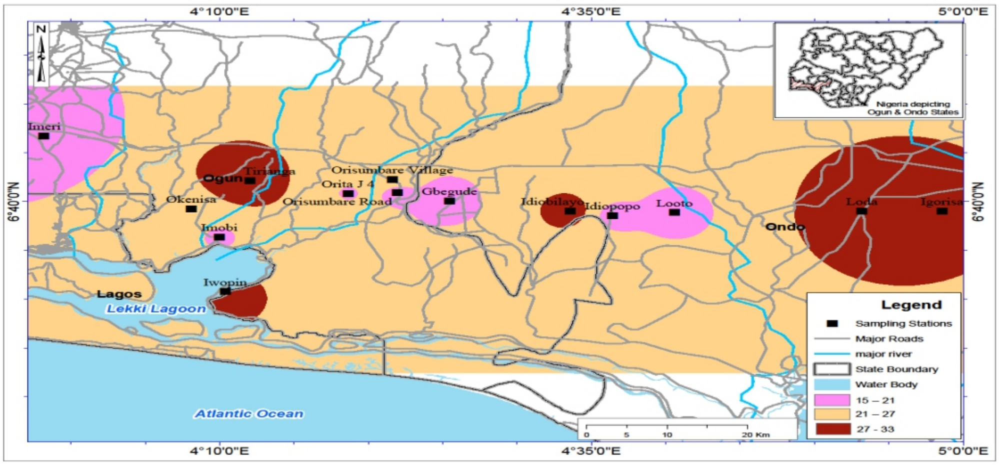

Fig. 14: Average Percentage Bitumen Saturation Map of the Studied Locations.

Figure 15 is a map showing the tar sands lithofacie types in the study locations and the average percentage bitumen impregnation of the locations.

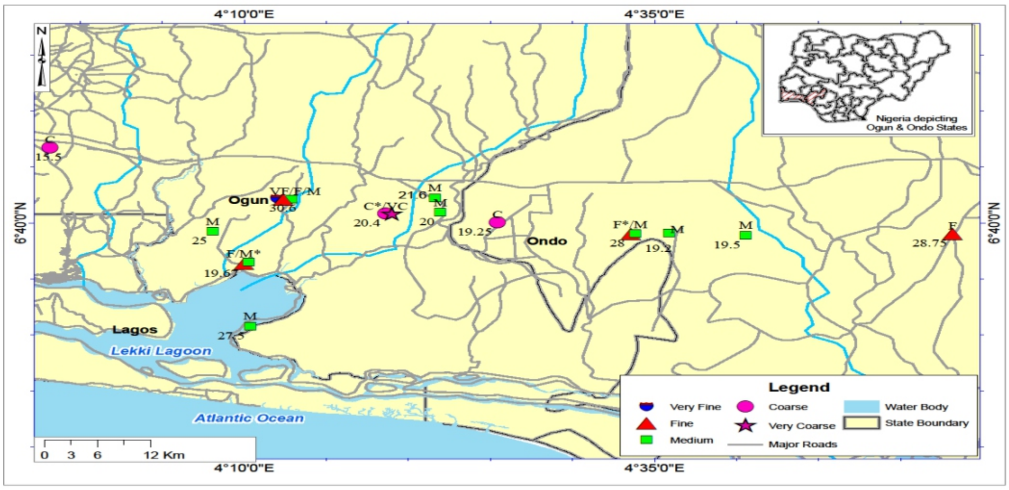

Fig. 15: Lithofacies Types in the Study Area/Average Percentage Bitumen Saturation Per Location – the symbols stand for: VF – very fine; F – fine; M – medium; C – coarse and VC – very coarse (the asterisked symbols are the dominant lithofacies type for locations with more than one lithofacies type).

Figure 16 gives the general summary of the lithofacies bitumen saturation trend in the study area. The figure was obtained from the average saturations of the different lithofacie types.

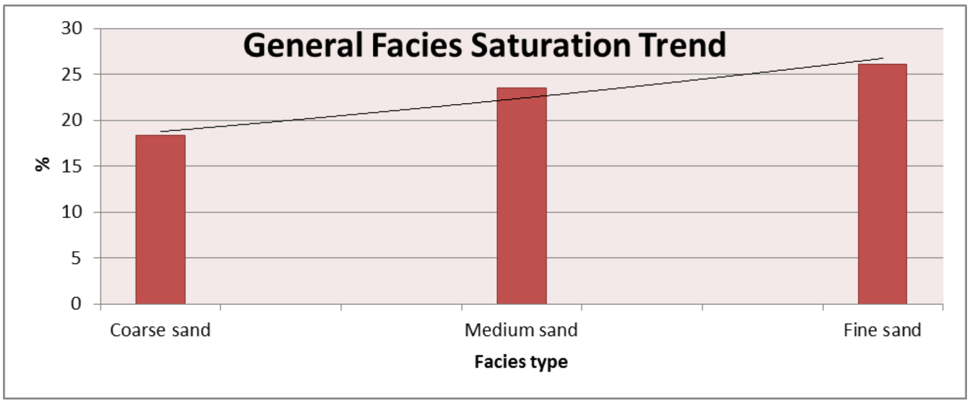

Fig. 16: Summary of Facies Saturation Trend in the Study Area.

Heavy Mineral Analysis Results

The heavy minerals were used principally for provenance deduction of the tar bearing sediments. Results showed that the sediments are composed of the following heavy mineral suites: staurolite, epidote, tourmaline, garnet, zircon, augite, rutile and the opaque minerals. Table 4 shows the heavy mineral results for individual mineral types at the different locations and their ZTR index. The results show that Loda and Tirianga have ZTR index values of 75% and 76%, while the rest locations have values that are less than 75%, (Fig. 17). Figure 18 is a histogram showing the distribution and amounts of these heavy minerals at the different locations, while Figure 19 is a pie chart summarizing the ZTR index values for all the locations.

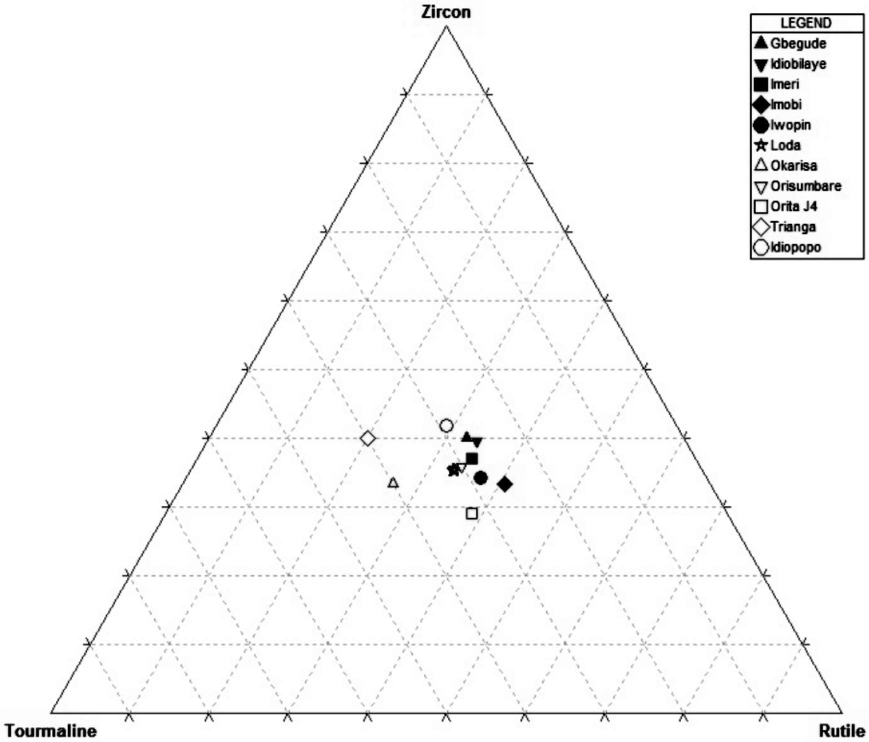

Fig. 17: ZTR Triangular Plots.

Table 4: Summary of Heavy Mineral Composition

Location	Zircon (Z)	Tourmaline (T)	Rutile (R)	Epidote (E)	Augite (A)	Garnet (G)	Staurolite (S)	Opaque (OP)	ZTRi
Gbegude	16	11	13	7	10	6	13	56	53
Idiobilayo	21	14	18	3	6	4	8	74	72
Idiopopo	13	9	9	6	3	5	9	61	57
Imeri	17	13	16	7	6	2	8	50	66
Imobi	9	7	11	4	3	3	7	44	61
Iwopin	12	10	13	6	5	8	11	40	54
Loda	17	15	16	4	5	1	8	51	75
Okerisa	15	18	12	8	6	7	10	49	60
Orisumbare	18	15	17	11	6	6	7	39	63
Orita J4	9	10	12	9	4	9	11	38	48
Trianga	14	14	7	2	2	1	6	70	76

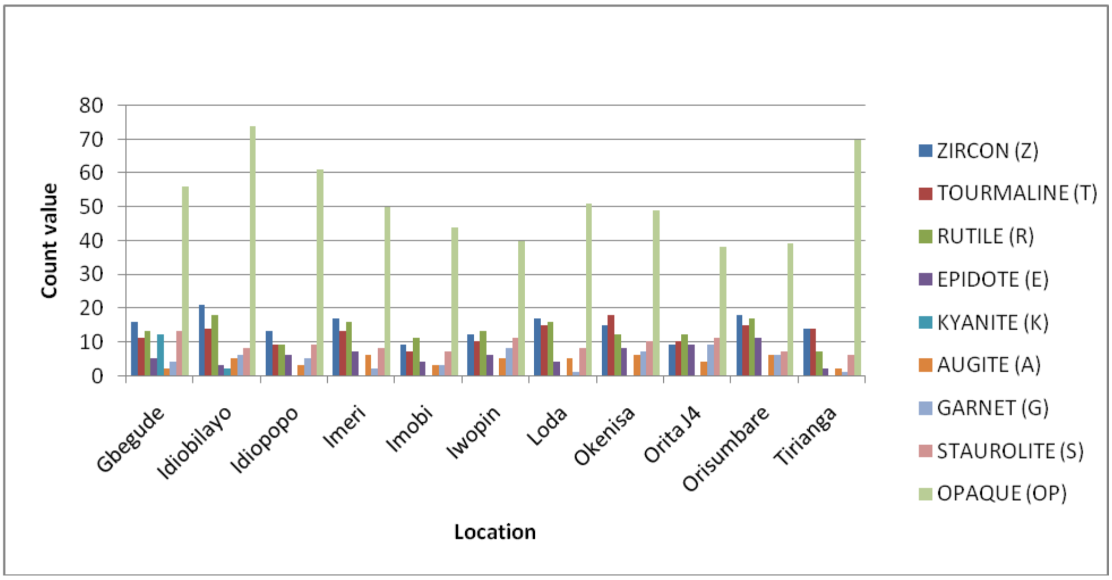

Fig 18: Histogram Showing Heavy Mineral Distribution in Study Locations

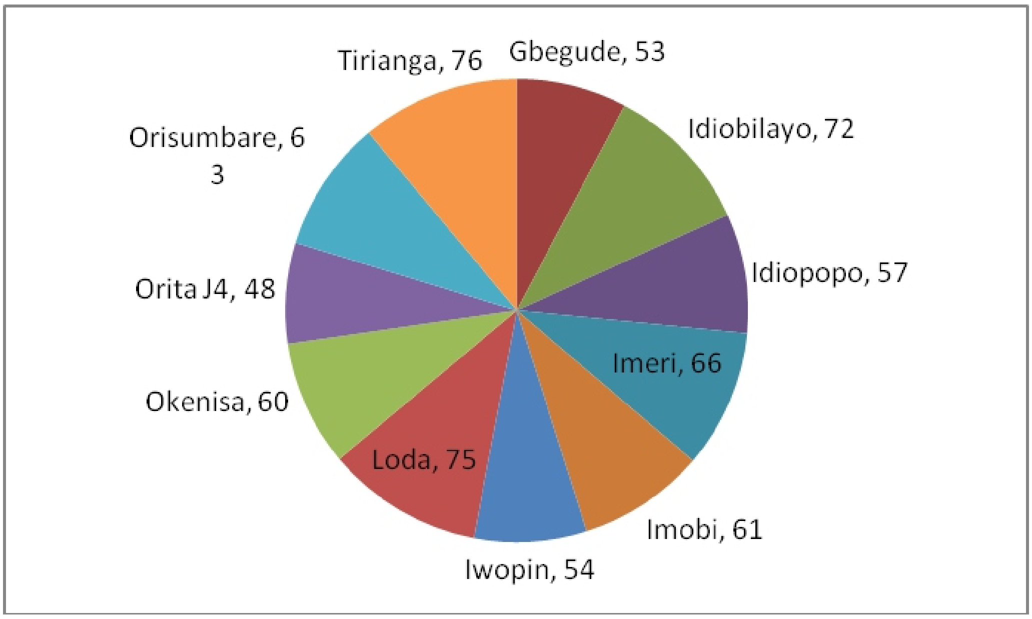

Fig: 19: Pie Chart Showing ZTR Index for the Study Locations

DISCUSSION

Textural Properties (Size, Shape and Sorting)

The particle size distribution curves and cumulative frequency curves (Appendices 1&2) show that the origin of the bitumen reservoir sands are unimodal to bimodal and that the different sediment samples from the same location have almost same sedimentological characteristics, except for a few locations that have varying lithofacies types. Table 2 shows that the mean grain size for all the samples ranged from 0.227-3.312Φ (very coarse to very fine sand), with an average value of 1.2427Φ (medium grained sands). The standard deviation (sorting) ranged from 0.32-1.298Φ (very well sorted to poorly sorted), with an average value of 0.9090Φ. This indicates that bulk of the sediments are moderately sorted and have traveled a fairly long distance from their sources.

The grain morphology under petrological microscope indicate various grains diameters ranging from 0.10 mm (for fine grained sands from e.g. Loda and Tirianga), to about 0.22 mm (for medium grained sands from e.g. Imobi and Orisumbare), to 0.50 mm (for coarse grained sands from e.g. Imeri and Gbegude). The coarse grained sands (Gbegude, Imeri and Orita J4) have little or no fines and their shapes ranged from angular to sub-angular except for Imeri which is sub-rounded. It could therefore be said that they have not travelled very far from their sources, but their energies of deposition were high enough to have winnowed their fine contents. The shapes of the medium grained sand facies (Orisumbare, Imobi, Iwopin, Idiopopo, Okerisa), ranged from sub-angular to sub-rounded, with some of them having some quantum of finer particles. This denotes a fairly long distance of transportation with moderate depositional energy. Of the fine sands (Idiobilayo, Loda and Tirianga), the sediments from Loda and Tirianga are sub-rounded to rounded and have good sorting, while those from Idiobilayo are sub-angular to sub-rounded and poorly sorted. The fine sediments can be said to have traveled long distances and deposited by low energy currents.

Using the Friedman (1961a) sorting scheme for classifying sandstone environments, it could be said that the sediments could have been sourced from any of the following - rivers, lagoons or distal marine shelf since most of the sediments are moderately sorted.

Bitumen Saturation

From Figures 12, 13, 14 and Table 3, the bitumen saturation trend in the study areas show an increasing pattern from the northwest axis to eastern axis of the arc-shaped tar sand deposits study area. At Imeri (coarse grained sand) in the northwestern part, the average bitumen saturation is 15.50%. In the central portion of the study area, Orisumbare, Gbegude etc., (coarse and medium grained sands) the average bitumen saturation is 20.42%. While in the eastern axis where we have Idiobilayo and Loda (fine to very fine sand), the average bitumen saturation is 28.37%. Further after Loda in the eastern part of the study area, we find a very massive surface deposit of bitumen at Igorisa. The major exception to this trend is the highly saturated fine grained sediments at Tirianga in the northwestern part of the study area. This higher value of saturation in the finer sediments could be attributed to biodegradation and degradation by water washing of the bitumen in the impregnated sands (Ekweozor and Nwachukwu, 1989). Another factor that could have enhanced higher saturation in finer sands reservoirs is increased surface area, since the finer the particles, the larger the surface area in contact with the impregnated bitumen as opposed to the coarser sands (with reduced surface area).

A comparison of the result from this study with Coker (1982) bitumen saturation classification show that the average saturation of most of the tar sand deposits in the study area, belong to the rich sands category (19.2% and above). The only exception is Imeri which has a saturation of 15.50%. The results from this study also compared favourably with that of Akinmosin *et al.*, (2008) which obtained 22.1% as the average bitumen saturation.

Also the results of bitumen saturation for Idiobilayo, Loda and Tirianga (fine sands) show that Loda and Tirianga which are well sorted have higher values than Idiobilayo which is poorly sorted. It is therefore expected that sorting will have a positive influence on bitumen withdrawal efficiency.

Maturity and Provenance

The heavy mineral photomicrographs in Plates L-V (Appendix 2) show that zircon is predominant among the non-opaque minerals. Other relatively abundant non-opaque heavy minerals in most of the sediments are tourmaline and rutile. The zircons are mostly colourless and their shapes are euhedral to subhedral as they have only been fairly altered mechanically due to their high stability and lack of good cleavage. The tourmalines are brownish in colour (sometimes greenish) with their shapes being commonly euhedral. The red coloured variety of rutile was identified in the photomicrographs. Epidote, augite, garnet and staurolite are equally present in small proportions. The proportion of the opaque minerals present in all the samples is more than 30% in all the locations. Using the Hubert (1962) ZTR maturity index, the sands from Idiobilayo, Loda and Tirianga with calculated ZTR index of greater than 75% can be said to be mineralogically mature while those from other locations are immature to submature. These results confirmed the result of previous works of Akintola *et al.,* (2013) and Akinmosin *et al.*, (2008) in the same locations.

According to Feo-Codecido (1956) classification of heavy minerals and their possible source rocks, the heavy mineral suites as identified in this study indicates that the sediments from Idiobilayo, Loda and Tirianga are probably from reworked sediments, while the rest are from metamorphic rocks of nearby basement complex whose accumulations were controlled by geological processes of sedimentation (weathering, erosion, transportation and deposition).

CONCLUSION

The lithofacie type hosting bitumen in the X-Horizon of the study area is sandstone and the controlling factor for saturation is the particle size. The finer particles have higher saturations.

The sediments from most of the locations are mineralogically immature (ZTRi <70%) except for the ones from Idiobilayo, Loda and Tirianga (ZTRi>70%).

The sediments were derived from reworked sediments and regional metamorphic rocks of nearby basement complex whose accumulations were controlled by geological processes of sedimentation (weathering, erosion, transportation and deposition).

The grain size distributions in the study area follow the pattern of coarse grains in the northwest axis and finer particles in the southeastern axis of the arc shaped tar sand belt. There is a greater volume of medium grained sandstone facie across the study area than very fine, fine and coarse sand facies.

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