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Textural and bitumen saturation analyses of tar sand deposits in Southwestern Nigeria

Analiza teksture in nasičenosti z bitumnom v nahajališčih naftnega peska v jugozahodni Nigeriji

A. Akinmosin[1,*], A. O. Adelaja[2]
[1]University of Lagos, Geosciences Department, Nigeria
[2]Olabisi Onabanjo University, Department of Earth Sciences, Ago-Iwoye, Nigeria
*Corresponding author. E-mail: waleakinmosin2001@yahoo.com

Abstract
The sedimentological properties of tar sand deposits in Idiobilayo and Ajegunle areas of Southwestern Nigeria were studied with the aim of determining the subsurface occurrence and reservoir properties of tar sand horizons. Altogether, twenty seven tar sand samples were for textural and bitumen saturation analyses.
Results of the textural analysis showed that the subsurface tar samples are mainly very coarse grained, angular to sub-angular and poorly sorted, which shows that the sediments have not been transported far from the source. The surface samples are medium-grained sands, sub-angular to sub-rounded, and are moderately sorted implying that the sands have undergone a fairly long transportation history.
The textural and morphological characteristics of the surface sands show that they have been transported and deposited by currents of moderate energy, probably streams.
Results of bitumen saturation analysis revealed that the average percentage weight of bitumen in the deeper horizons is 25 %, while that of the shallow horizon is 22 %.
The medium-grained and moderately sorted characteristics of analysed tar sands together with low fine particles.

Key words: Bitumen, saturation, textural, reservoir, surface and subsurface.

Izvleček
Namen preučevanja sedimentoloških značilnosti nahajališč naftnega peska na področjih Idiobilayo in Ajegunle v jugozahodni Nigeriji je bil opredeliti podzemno razširjenost in rezervoarne lastnosti horizontov tega peska. V raziskavo teksture in nasičenosti z bitumnom je bilo zajetih 27 vzorcev naftnega peska.
Rezultati teksturne analize kažejo, da so globlje ležeči peski večinoma zelo debelozrnati, zrna so oglata do zmerno oglata in slabo sortirana, kar nakazuje kratek transport sedimenta od izvirnega področja. Vzorci s površine pripadajo srednjezrnatim peskom s fragmenti, ki so zmerno oglati do zmerno zaobljeni in zmerno sortirani, kar priča o dokaj dolgem transportu.
Teksturne in morfološke značilnosti površinskih peskov nakazujejo transport in sedimentacijo iz vodnih tokov srednje energije, najbrž rek.
Rezultati analize nasičenosti z bitumnom kažejo v globljih nivojih povprečno 25 % in v plitvejših 22 % bitumna.

Ključne besede: bitumen, nasičenost, tekstura, rezervoar, površina in globina

Introduction

Asphalt impregnated sandstones, otherwise referred to as oil sand (tar sand) and active oil seepages occur in southwestern Nigeria within the Eastern Dahomey (Benin) basin, a marginal pull apart (Klemme, 1975) or marginal sag (Kingston et al., 1983) basin. The oil sand outcrops in an E-W belt, approximately 120 km long and 4–6 km wide, extending from Edo/Ondo-Ogun States (Enu, 1985).

Occurrence of the seepage and tar sand deposit over the Okitipupa ridge in the Dahomey basin provided the initial impetus for oil exploration in Nigeria. From the turn of the century to date, no less than fifteen groups comprising public and private ventures have shown varying degrees of interest. Arising from these, a total of one hundred and fifteen (115) boreholes have been drilled across the basin and have confirmed the presence of oil sands and heavy oil. An intense investigation by Ako et al., (1980) was conducted over an area of 17 km^2, just north of Agbabu village and this particular study has provided a vast amount of information on the oil sand deposits.

The physico-chemical characteristics of the tar sands from outcrops and drillholes in the Agbabu/Ore areas in Ondo state have been extensively reported. The salient aspects of the comprehensive information published within the last two decades covering sedimentological properties, oil saturation, bitumen ultimate analysis, stock-tank properties, calorific values, etc have been published by Adegoke et al. (1980), Oshinowo et al. (1982), Oluwole et al. (1985), Ekweozor & Nwachukwu (1989); Akinmosin et al. (2005 and 2006).

Studies carried out on the series of outcrop sections, cores and drilled cuttings obtained from the various exploration campaigns at the northwestern flank of the belt have shown presence of two horizon-bearing sediments designed as horizons “X” and “Y” (Figure 1). “The X-horizon”, being the shallower of the two, constitutes a prominent outcropping unit in most areas, though significantly eroded in the north western part of the basin. The thickness varies from 9 m to about 22 m, with an average of 15 m.

The Y-horizon is a prominent outcropping sequence in the northwestern part of the basin

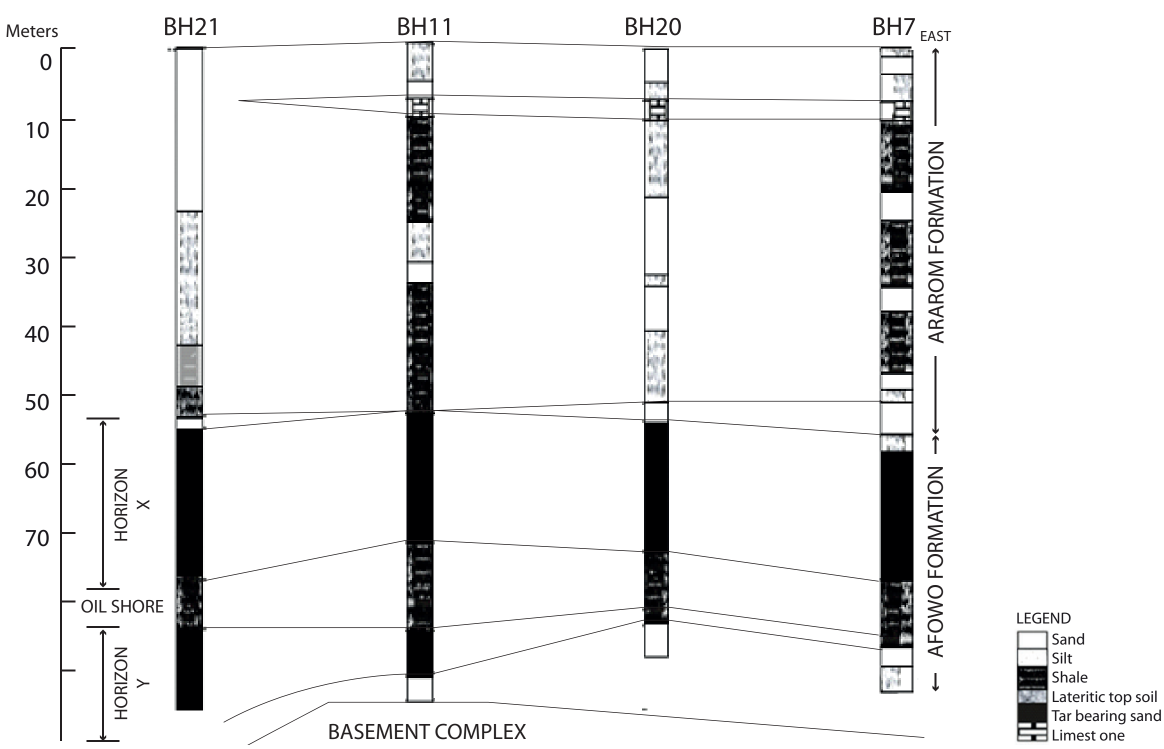

Figure 1: *Schematic geological east-west cross-section based on drillholes showing the stratigraphic position of horizon containing tar sands horizons in some boreholes (modified from Ekweozor and Nwachukwu, 1989).*

where “X horizon” has been largely eroded. Thickness of Y-horizon varies from 3 m in the east to 22.6 m in the west with an average of about 12 m.

For better understanding of the properties of the Nigerian tar sands, the present work focused on the north eastern flank of the belt to evaluate the textural properties of both surface and subsurface deposits. There are four core holes used for this study, this are coded as A4, A14, A15 and A16.

Geology of the dahomey basin

The study area lies within longitude 004°33’ E to 004°35’ E and latitude 06°37’ N to 06°39’ N, Figure 2.

The Benin (Dahomey) Basin is a 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 and 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 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 – 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. 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.

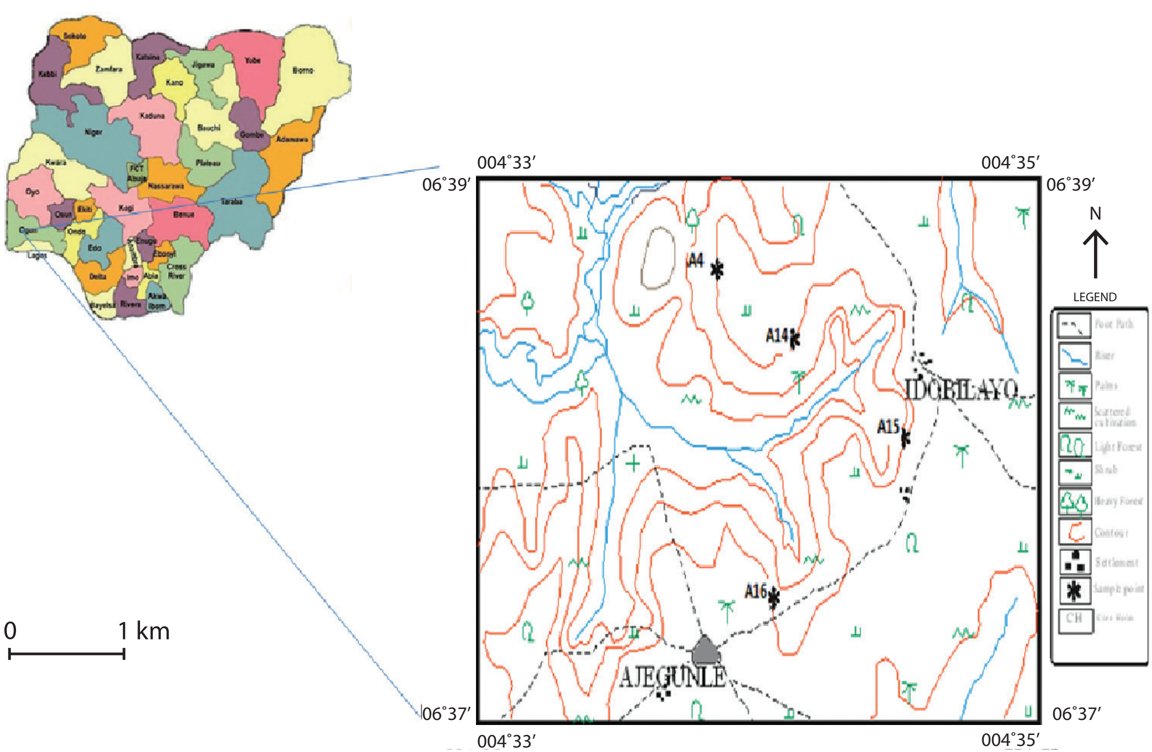

Figure 2: *Topographical map of the study area showing sampling points.*

Table 1: *Overview of Cretaceous and Tertiary Formations of the Eastern Dahomey Basin (After Idowu et al., 1993)*

Age		Formation			Lithology
		Ako et al., 1980	**Omatsola & Adegoke, 1981**		
Tertiary	Eocene	Ilaro Formation	Ilaro Formation		Sandstone
	Paleocene	Oshosun Formation	Oshosun Formation		Shale
		Ewekoro Formation	Ewekoro Formation		Limestone
Cretaceous	Maastrichtian		Abeokuta Group	Araromi Formation	Shale
	Turonian			Afowo Formation	Sandstone/shale
	Berremian			Ise Formation	Sandstone

Materials and Methods

Description of tar horizons from the drillcores

- Core hole A4: two 9 m and 6 m tar horizons were identified from core logging analysis at the depths of 75.10–84.10 m and 87.10–93.10 m. They are thick respectively. Samples within the tar horizons were taken every 1.5 m. Ten samples were collected altogether.
- Core hole A14: a 6 m thick tar horizon was identified at a depth of 27 m to 33 m. Four samples at interval of 1.5 m were collected.
- Core hole A15: similar to the drillcore A4, two tar horizons were identified at the depths of 18–21 m and 27–30 m, each of them being 3 m thick. Four samples at 1.5 m interval were collected.
- Core hole A16: 3 m thick tar horizon was identified at a depth of 9–12 m. Two samples were collected 1.5 m apart from each other.

Twenty-seven samples of Tar sand (twenty drillcore samples and seven shallow samples) were collected and used for this study around Ajegunle and Idiopopo areas of Southwestern Nigeria (Figure 2).

Preparation of samples for textural and bitumen saturation analyses

For textural analysis, after cleaning and drying, 100 g were dry-seived using vibrating sieving machine for 15 min with sieves of the following mesh sizes 2.00 mm, 0.180 mm, 0.125 mm, 0.075 mm which are equivalent to (1.00, 1–25, 2.50, 3.00 and 3.75) mm phi values respectively. The individual and cumulative weights, with their percentages were determined. These data were used to plot histogram and cumulative frequency curve for individual sample 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 & Ward, 1957).

For bitumen saturation analysis, ten grams of each sample were put into a measuring cylinder with toluene for about 180 min. 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 percentage and recorded.

Figures 3, 4, 5, 6 are showing lithologies of the respective drill holes.

Results and Discussion

Bitumen saturation

The analysis carried out on both the subsurface and surface samples revealed that the weight percentage of bitumen in the subsurface samples ranged between 12 % and 47 % with an average bitumen saturation of 27.14 % while that of The weight percentage of bitumen in surface samples lower, with a range between 16 % and 29 % and an average saturation of 22 % (Table 2). This is a little low compared to the Athasbasca oil – sands in Canada (41 %)

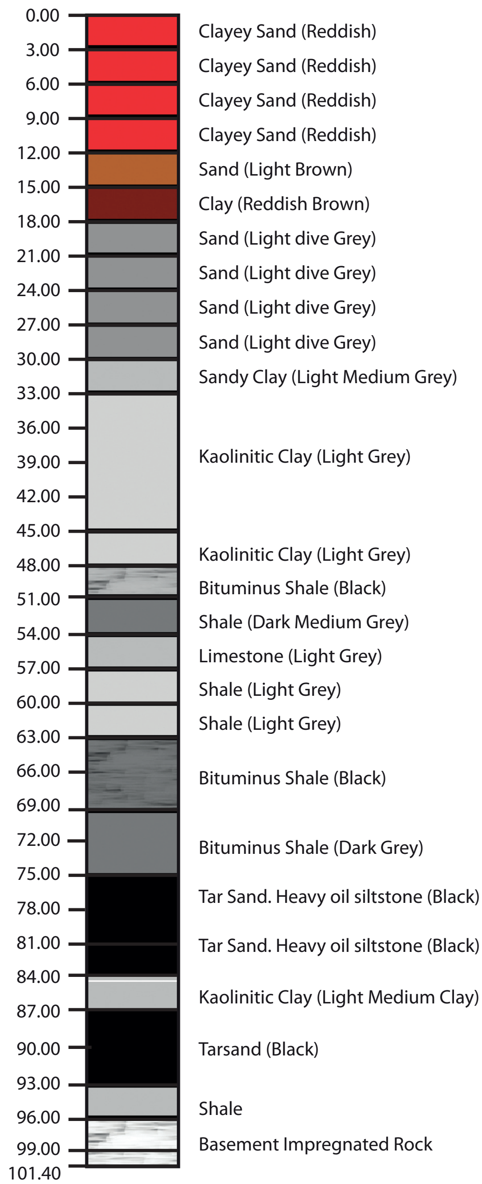

Figure 3: *Lithological units of the drill hole A4.*

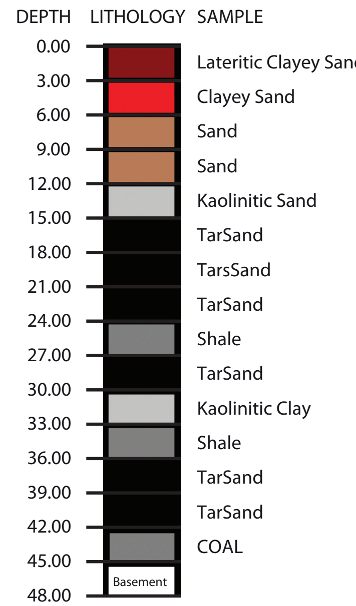

Figure 4: *Lithological units of the drill hole A14.*

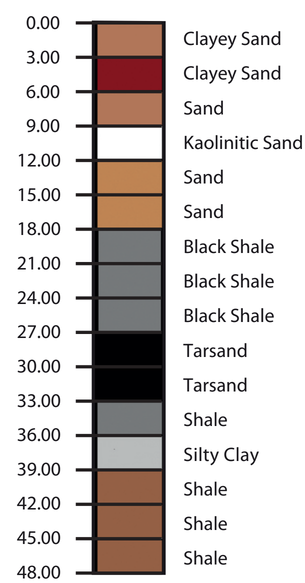

Figure 5: *Lithological units of the drill hole A15.*

and the Eastern Venezuela deposit (48 %; Tissot and Weite, 1984). According to Coker, (1988), tar sands with bitumen saturation above mass fraction 10 % (or above volume fraction 19.2 %) is classified as bitumen-rich sands. Based on analyses of both, surface and sub-surface deposits of the Nigerian tar sands can be categorized as rich in bitumen.

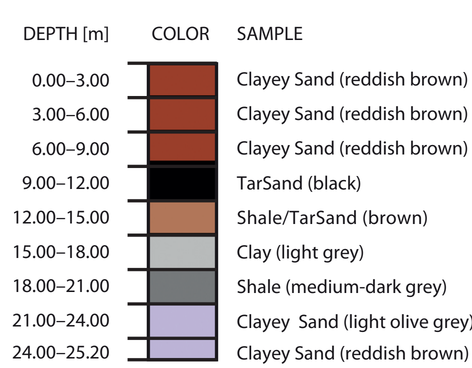

Figure 6: *Lithological units of the drill hole A16.*

Textural analysis

Mean results for textural analysis carried out on the twenty (20) subsurface samples and seven (7) surface samples are shown in Tables 3 and 4.

Average bitumen saturation for subsurface samples is (24.83 %) with a ranges between 12 % and 41 %, while average bitumen saturation for surface samples is (22 %) with a ranges between 16 % and 29 %.

Table 2: *Bitumen saturation*

Subsurface Sample Code/ Depth (m):	**Number of samples**	**Mass fraction of tar (w/%)**
A4: 75.10–84 10	6	12
A4: 87.10–93.10	4	31
A14: 27–33	4	41
A15: 18–21	2	26
A15: 27–30	2	25
A16: 9–12	2	14

Surface Sample	**Number of samples**	**Mass fraction of tar (w/%)**
A1	1	22
B2	1	21
E1	1	29
F4	1	16
M1	1	20
O5	1	21
P3	1	25

Table 3: *Summary of textural analysis result for both surface and subsurface tar sand samples*

Sample Description: **Subsurface Samples Code/ Depth (m):**	**Mean**	**Skewness**	**Kurtosis**	**Standard Deviation**
A4: 75.10–84.10	–0.7	–0.174	1.087	1.920 8
A4: 87.10–93.10	0.783	0.289	0.947	2.654 2
A14: 27–33	0.08	0.258	1.238	0.970 8
A15: 18–21	–0.737	–0.412	0.912	2.275 0
A15: 27–30	–0.26	–0.342	1.022	2.317 0
A16: 9–12	0.23	0.100	0.810	2.858 0
Average:	**–0.199**	**–0.0814**	**1.002**	**2.186**
Surface Samples:				
A1	0.76	–0.11	1.04	–0.78
B2	1.99	0.55	1.01	0.50
E1	1.43	–0.03	1.05	1.03
F4	1.48	–0.09	1.20	0.54
M1	0.55	0.01	1.15	0.71
O5	0.42	–0.07	2.26	1.1
P3	1.27	0.10	0.91	1.46
Average:	**1.13**	**0.05**	**1.23**	**0.65**

Table 4: *Interpretation of statistical parameters of both surface and subsurface tar sand samples*

Sample Description: **Subsurface Samples Code/ Depth (m):**	**Bitumen Saturation**	**Mean**	**Skewness**	**Kurtosis**	**Standard Deviation**
A4: 75.10–84.10	12 %	Very Coarse Grained sands	Coarse Skewed	Very Leptokurtic	Poorly sorted
A4: 87.10–93.10	31 %	Coarse grained sands	Fine Skewed	Mesokurtic	Very Poorly sorted
A14: 27–33	41 %	Coarse grained sands	Fine Skewed	Leptokurtic	Moderately sorted
A15: 18–21	26 %	Very Coarse Grained Sand	Strongly Skewed	Mesokurtic	Very poorly sorted
A15: 27–30	25 %	Very Coarse Grained Sand	Strongly Skewed	Mesokurtic	Very poorly sorted
A16: 9–12	14 %	Coarse Grained Sand	Fine Skewed	Platykurtic	Very poorly sorted
Average:	**24.83 %**	**Very Coarse Grained sands**	**Near Symmetrical**	**Mesokurtic**	**Very poorly sorted**
Surface Samples:					
A1	22	Medium Grained Sand	Near Symmetrical	Mesokurtic	Moderately sorted
B2	21	Fine Grained Sand	Near Symmetrical	Mesokurtic	Very well sorted
E1	29	Fine Grained Sand	Near Symmetrical	Mesokurtic	Moderately sorted
F4	16	Fine Grained Sand	Near Symmetrical	Leptokurtic	Moderately sorted
M1	20	Medium Grained Sand	Near Symmetrical	Leptokurtic	Moderately sorted
O5	21	Medium Grained Sand	Near Symmetrical	Very Leptokurtic	Poorly sorted
P3	25	Fine Grained Sand	Fine Skewed	Mesokurtic	Poorly sorted
Average:	**22**	**Medium Grained Sand**	**Near Symmetrical**	**Leptokurtic**	**Moderately well sorted**

Conclusions

The bitumen saturation and textural analyses show that subsurface samples contain coarse-grained sand and surface samples medium-grained sand. The textural and morphological characteristics of the subsurface sands indicate transportation and deposition by currents of moderate energy, probably streams. Histogram distribution plots and frequency distribution curves indicate a unimodal source for sediments of the surface samples. Medium grain-size of surface samples, their moderate sorting, and low content of fine grains suggest that Afowo oil sands reservoir will be of good quality. The percentage weight of bitumen in the subsurface sample ranges between 12 % and 41 %, with an average saturation of 25 % while that of the surface sample ranges between 16 % and 29 %, with an average saturation of 22 %. Bitumen saturation of analysed sands is lower in comparison to the Athasbasca oil–sands deposits in

Canada (mass fraction 41 %) and the Eastern Venezuela deposit (mass fraction 48 %; Tissot & Weite, 1984). Nevertheless, according to the classification of Coker (1988), this saturation however, the Nigerian tar sands can still be classified as tar-rich sands.

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