SEDIMENTOLOGICAL AND SCANNING ELECTRON MISCROSCOPIC DESCRIPTIONS OF AFOWO OIL SAND DEPOSITS, SOUTH WESTERN NIGERIA

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Abstract

Sedimentological and scanning electron microscopic analyses of some shallow reservoir tar sand samples in parts of Southwestern Nigeria were carried out with the aim of characterizing the reservoir properties in relation to bitumen saturation and recovery efficiency. The production of impregnated tar from the sands requires the reservoir to be of good quality. A total of thirty samples were collected at different localities within the tar sand belt (ten out of these samples were selected for various reservoir quality analyses based on their textural homogeneity). The result of particle size distribution study showed that bulk of the sands is medium – coarse grained and moderately sorted. The grain morphologies are of low to high sphericity with shapes generally sub-angular to sub-rounded, implying that the sands have undergone a fairly long transportation history with depositional energy having a moderate to high velocity. The quartz content was made up of about 96% of the total mineralogical components; the sediments of the Afowo Formation can be described to be mineralogically and texturally stable. The result of the scanning electron microscopy (SEM) analysis revealed that the oil sands contained minerals which had been precipitated and occurred as pore filling cement; these minerals include sheet kaolinite, block kaolinite, vermiform kaolinite, pyrite crystals and quartz. The SEM images also showed micro-pores ranging from 0.057µm to 0.446µm and fractures. The study showed that the clay minerals contained in the Afowo reservoir rocks were mainly kaolinite. Kaoline unlike some other clays (e.g Montimorillonite) does not swell with water, hence it is not expected to have any negative effects on the reservoir quality, especially during enhanced oil recovery operations.

From overall results of the reservoir quality assessment, Oso J4 and Gbegude sands should be expected to make better reservoirs with good oil recovery efficiency due to their low content of fines and better sorting characteristics when compared to sediments of other areas.

Key words: Tar sand, Kaolinite, Texture, Mineralogy, Reservoir, Micro-pores, Quartz.

1 INTRODUCTION

Much of the world's oil (more than two trillion barrels) is in the form of tar sands, although it is not all recoverable. However, tar sands are found in many places worldwide. Tar sands (bituminous sand) were discovered in Nigeria at the beginning of the 20th century around 1900 [3], however, intense investigations were only commenced in the mid-70's and have been conducted until now. The pioneering efforts of the investigations were initiated by the Geological Consultancy Unit of the University of Ife (now Obafemi Awolowo University). In Nigeria, the oil sands belt stretches from east of Ijebu-Ode (Ogun State) to the Siluko and Akotogbo areas in Okitipupa (Ondo State) to Edo State and parts of Lagos State, stretching across the Cretaceous belt of 120 km with consistently high oil saturation [6], Figure 1. The Nigeria's reserve is estimated to be about 30-40 billion barrels with potential recovery of 3,654 x 10^6 billion barrels [1].

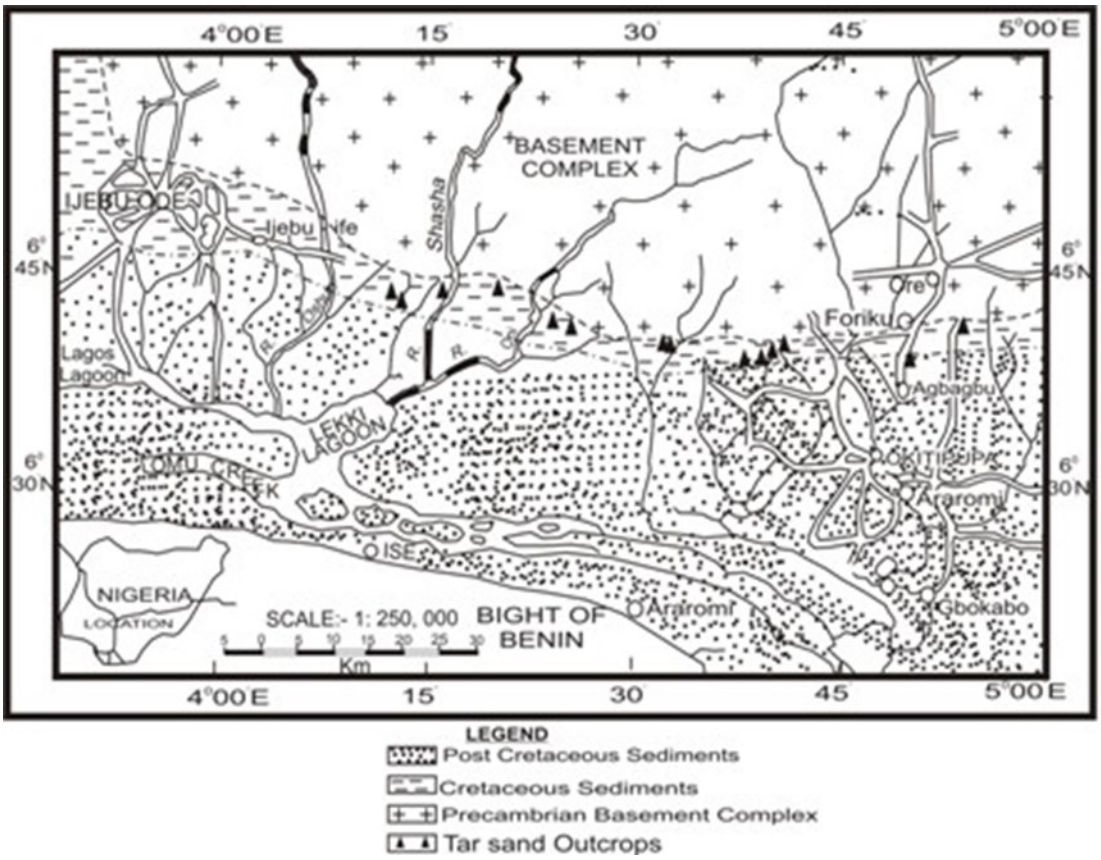

Figure 1: Geological map of south-western Nigeria showing the tar sand outcrop belt (Adapted from Enu, 1985).

This work is based on detailed studies of ten surface tar samples taken from the study area. Several works have highlighted relevant aspects of the geochemical and sedimentological characteristics of the deposit. Oil Sands seepages discovered in the villages of Imeri through Goodluck, Ogun State, Figure 2, served as an indication that they are from a reservoir in the subsurface. It is therefore important to determine the reservoir characteristics such as grain size parameters in order to assist with future production procedures.

2 STRATIGRAPHY OF THE DAHOMEY BASIN

The study area lies within a longitude of 004° 00' E to 004° 24' E and a latitude of 06° 36' N to 06° 48' N, and is located in Ogun State, South Western Nigeria which falls under the eastern flank of the Dahomey Basin. The stratigraphy of the eastern margin of Dahomey Basin's Cretaceous to Tertiary sedimentary sequence can be divided into the following: the Abeokuta Group, the Imo Group, the Ilaro Formation, coastal plain sands and recent alluvium. The oldest sediments in the basin belong to the Abeokuta Group [9] which in turn consists of the Ise Formation, Afowo Formation and Araromi Formation. The Araromi Formation which is the youngest unit of the Abeokuta Group is overlain by the Imo Group which consists of the Ewekoro and Akinbo Formations. The Ewekoro Formation is the oldest of the tertiary sediments. Overlying the Ewekoro Formation is the Akinbo Formation which is overlain conformably by the Oshoshun Formation and succeeded by the Ilaro Formation. The coastal plain sands are the youngest formation in the basin, Figure 3.

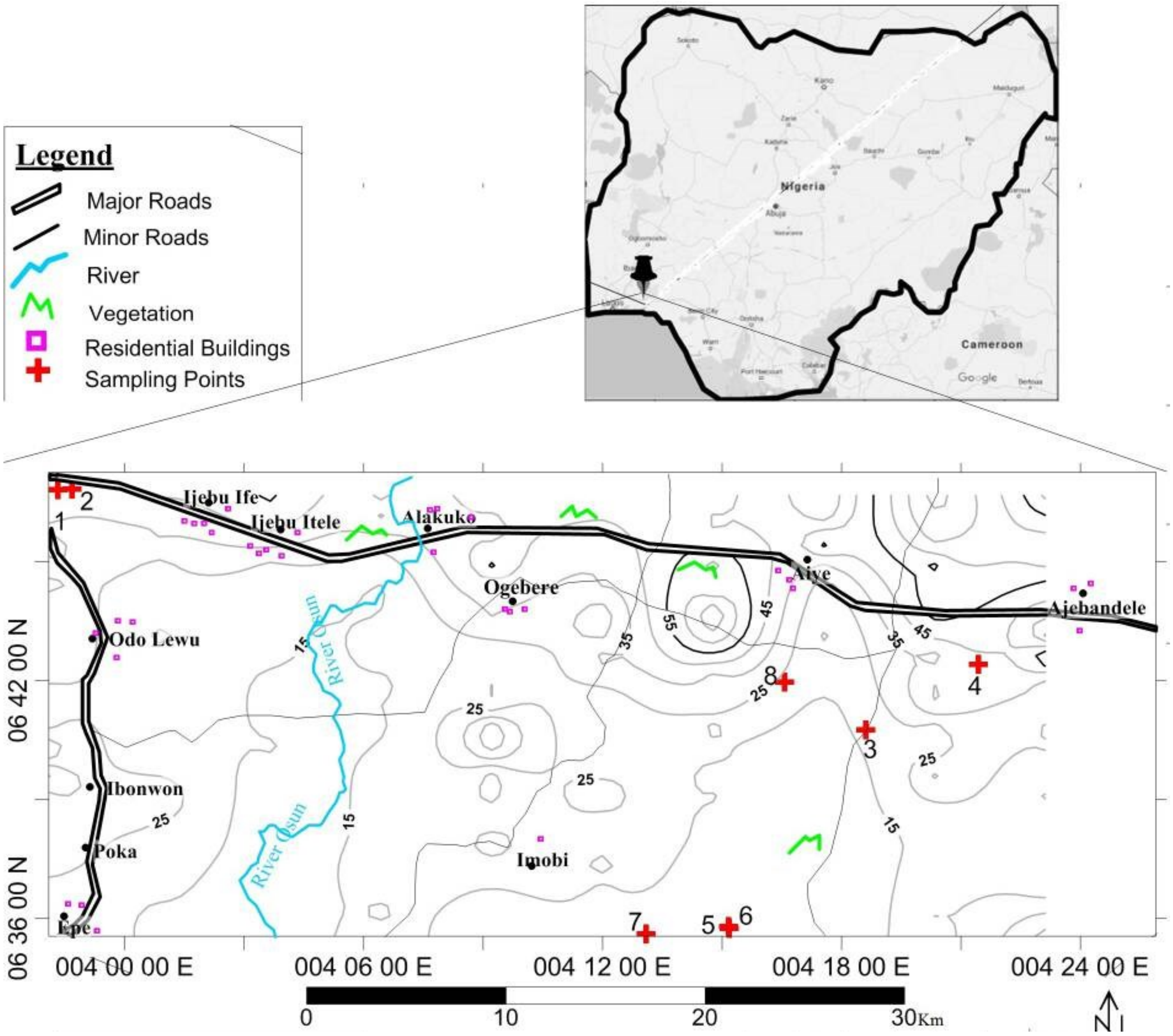

Figure 2: Map of the study area.

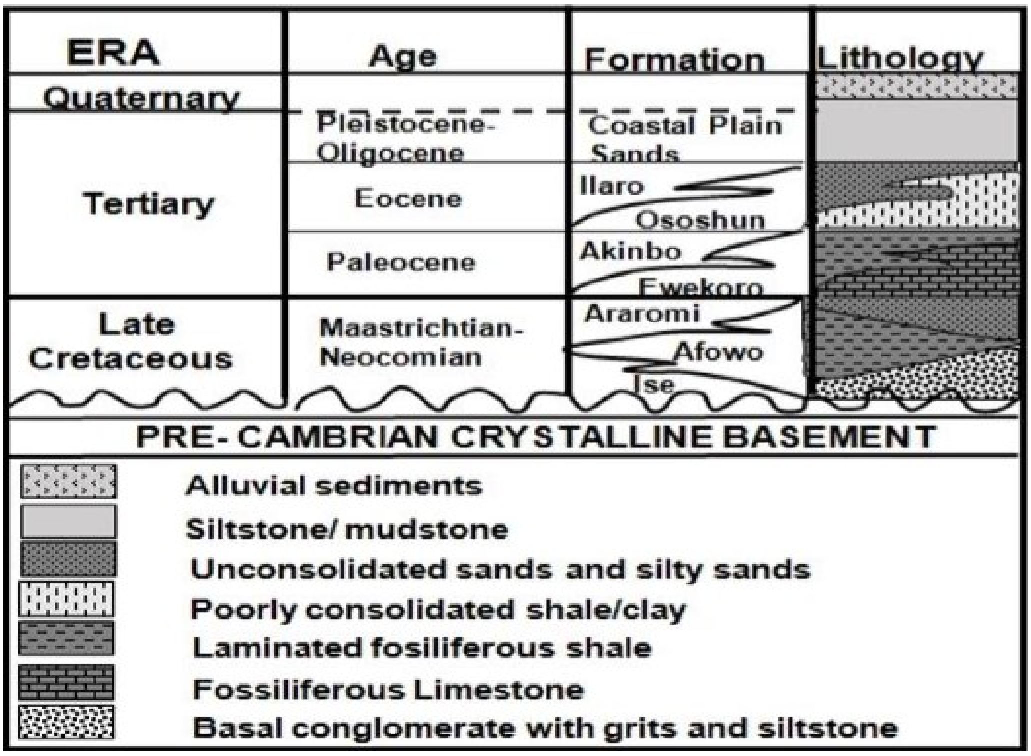

Figure 3: Stratigraphy and lithological features of the Dahomey Basin (Omatsola and Adegoke, 1981).

3 METHODOLOGY

The field work, which involved outcrop examination and the collection of samples, was carried out on the Afowo Formation of the Dahomey Basin, in the villages of Imeri, Orisunbare, Oso, Gbegude and Goodluck, Ogun State, South Western Nigeria. The establishment of coordinates of the locations was carried out with the aid of a global positioning system (Garmin e-trex^{Tm} GPS unit).

An oral interview was conducted in order to gather information from the villagers and farmers around the study area. The outcrops were located and their coordinates marked on the topographical map. Sampling tar sands was conducted with the use of a geologic hammer, cutlass and chisel to chip out samples into sample bags. A total of thirty samples were collected from five different localities (due to textural homogeneity of the collected samples, ten were selected for further analyses). Lithologic logs of exposed surfaces were drawn in the field notes with the aid of a pencil to depict the sedimentological characteristics of the outcrops. The various outcrops were also captured in photographs with a camera.

For the purpose of this work, each sample was first properly examined and air dried. Thereafter, about 400 g of each sample was weighed using a top loading balance (Scout-Pro) and soaked in an organic solvent for about 24 hours to free the sediments, after which it was washed, dried and reweighed. The new weights were noted, recorded and subtracted from the initial weights. The difference in weight was converted to percentage and recorded (Table 3).

- The liberated sediments were subsequently subject to the following analyses:
- Granulometric analysis
- Petrographic analysis (mineralogical composition and provenance study)

Ten air dried samples each weighing 50 g were run through a set of mechanical sieves of the following mesh sizes: 2mm, 1.4mm, 1mm, 0.5mm, 0.355mm, 0.25mm, 0.18mm, 0.125mm, 0.090mm, 0.075mm, 0.063mm and Pan respectively arranged in order of the coarsest sieve on top and the finest below. This analysis was conducted with a mechanical shaker agitating for ten (10) minutes for each sample. The amount retained on each sieve was then weighed using a sensitive weighing balance. The bottom of the sieve was then cleaned thoroughly to dislodge the grains partially stacked in the mesh holes to avoid contamination of subsequent samples.

GreenSmith [7] and Oronsaye [10] have discussed some constraints of this method, which include errors introduced as result of sieve apertures not being of constant size and/or grains adhering to the sieves. Inadequacy or over sieving and non-standardization of the quantity of samples being sieved are other sources of error inherent in the sieving method. However, the adoption of 50 g of sample and fixed sieving period of about ten minutes for all samples analysed are considered effective checks on some of these constraints.

The individual and cumulative weights with their percentages were determined. The data were used to plot histograms and cumulative frequency curves for each individual sample on arithmetic and semi-log graphs. The parameters were computed by using moment statements like mean, mode, standard deviation, kurtosis and skewness (using formulae by Folk & Ward, 1957).

The slides were viewed under plane polarized and crossed nicols. Minerals present in each of the samples were identified by comparing them with standard mineralogical charts, and their percentage composition was estimated. In addition to such minerals like quartz, feldspars and micas, sands may also contain other detrital minerals which can be referred to as accessory or heavy minerals. This method was adopted because of quartz abundance in the sediments, and its characteristics of high mechanical and chemical stability under any surface condition when subjected to a prolonged period of sedimentation without losing its form.

The provenance study should reveal the transportation history of any sedimentary particle. The angular and rounded minerals seen in the same specimen indicate multiple source areas (recycled or reworked sediments). The petrographic approach employed for the provenance study consists in the quartz varieties determination. Based on the Krynine genetic classification of quartz types [8], the origin of a particular quartz variety can be determined. His classification was based on the following:

- Extinction (straight, wavy or undulose extinction)
- Inclusion (minerals or vacuoles)
- Grain shape and contact or boundary relationship
- Number of quartz crystals in a sand grain (single or composite grain)

Ten slides of the prepared samples were examined under a petrographic research microscope for the quartz varieties determination based on the Krynine criteria of classification. Inclusions in quartz crystals may be in a form of minerals, e.g. feldspar, biotite etc., or in a form of vacuoles which are mostly trapped in air during the classification. A space may be left in a form of re-entrant angle formed as a result of leaching away of labile or unstable mineral included on the surface of the quartz. The grain shape may be equant, subequant to irregular, stretched or elongated depending on the prevalent factor during crystallization. The composition of monocrystalline quartz in sand grain is often associated with igneous origin while polycrystalline quartz may have either igneous or metamorphic origin.

Ten samples were analysed under a scanning electron microscope. The samples were pulverised to obtain an enough representative sample of minimum height, to be mounted on a SEM sample stub. The samples were attached to the stub with a sticky carbon tape. All samples were then coated with an Iridium layer, to improve and ensure conductivity using a Quorum Q150T ES coater for 90 seconds. The samples were introduced to the Zeiss Auriga SEM and analysed at specific parameters as saved per image. The optimum working range was approx. 10–12.m and an EHT voltage 5Kv. The inLense detector was used depending on the level of reflectance observed per sample.

4 RESULTS AND DISCUSSION

Field observations 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. The thickness of the sandstone body also ranges from 1 m to 3 m (Figures 4-6).

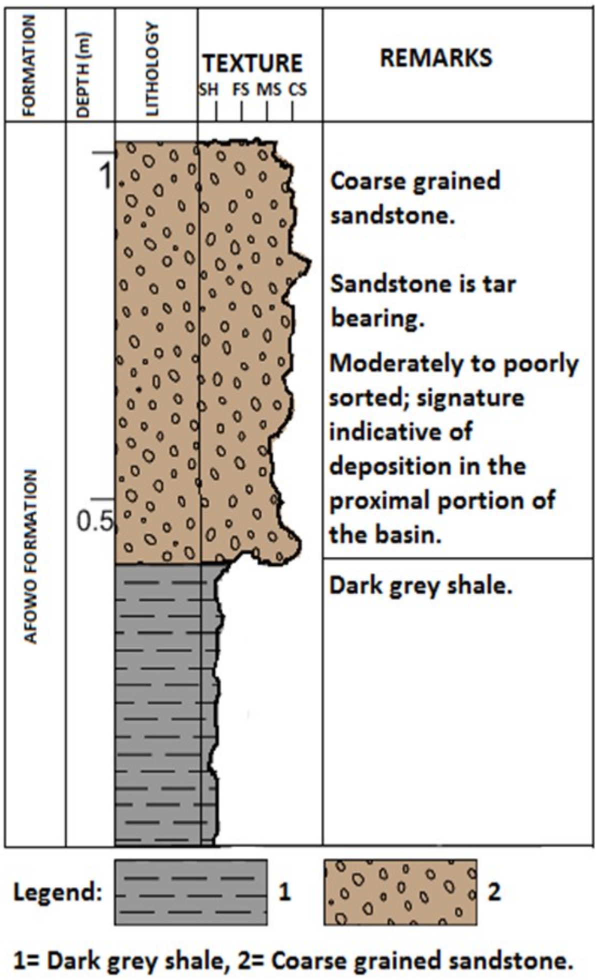

Figure 4: Lithologic log for Imeri

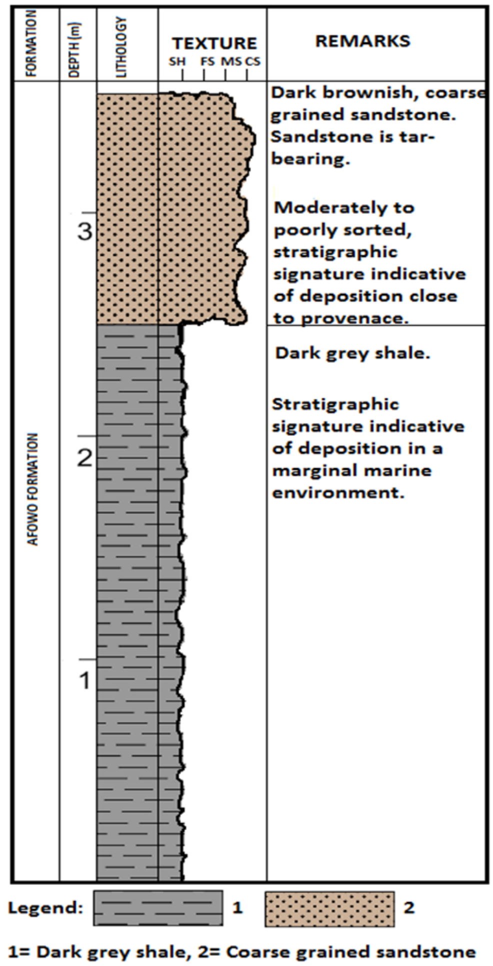

Figure 5: Lithologic log forOrita J4

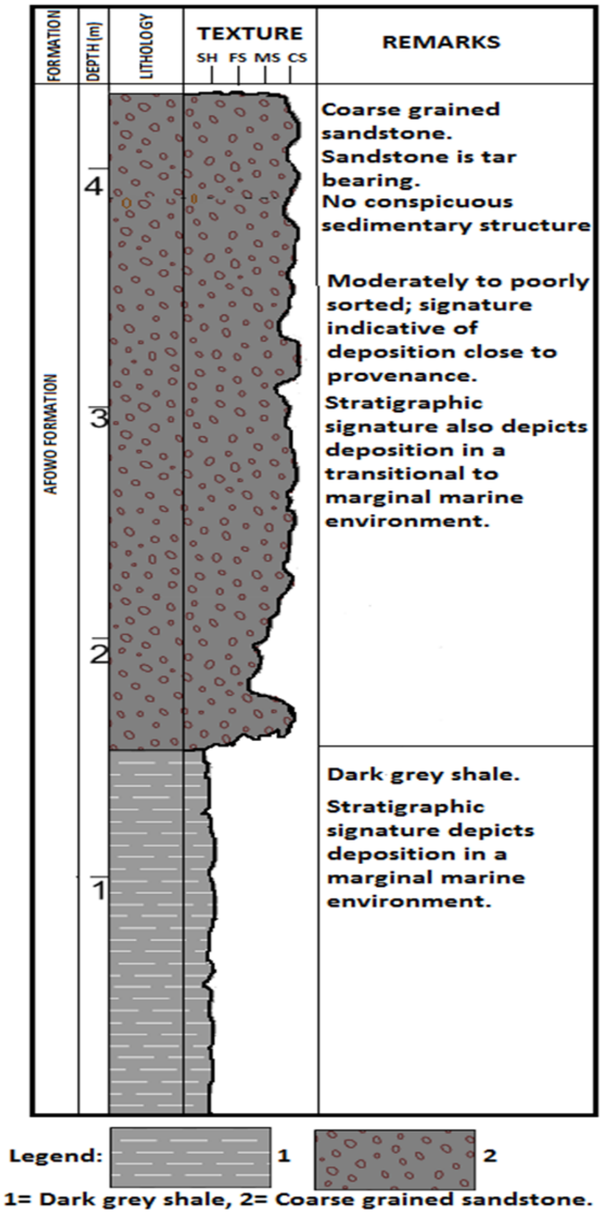

Figure 6: Lithologic log for Gbegude

From the analyses, the tar impregnated sediments can be seen to be predominantly unimodal. The sands of the study area are mainly medium to coarse grained (Plates 1 and 2). This result corresponds to the granulometric analysis of Akinmosin and Imo, 2016, in their paper titled "Lithofacies types and influence on bitumen saturation in X horizon of the Nigerian tar sand deposits". Low content of fines allow for high bitumen content; withdrawal efficiency is strongly reduced if clusters of fines occur in a coarser mix [11], [12]. The reservoir is expected to be better off in the sediments of Oso J4 and Gbegude which are better sorted with higher porosity than the sediments in other areas.

The sieving analysis was interpreted with the aid of Microsoft excel spread sheet 2010 as well as gradistat software which plotted all granulometrics diagrams as well calculating the statistical part of granulometrics such as mean, median, mode, sorting, skewness etc. A summary of the granulometric analysis results is shown in Table 1, while the histogram and cumulative frequency plots on some of the results obtained from the granulometric analysis are shown in Figures 7 and 8 respectively.

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Table 1: Summary of grain size analysis.

Sample No.	Grain size (Mean) (MZ)		Sorting (Standard Deviation) (σ1)		Skewness (Sk1)		Kurtosis (KG)	
	Result	Interpretation	Result	Interpretation	Result	Interpretation	Result	Interpretation
I1	1.238	Medium sand	0.888	Moderately sorted	-0.389	Very coarse skewed	0.961	Mesokurtic
I2	1.198	Medium sand	0.842	Moderately sorted	-0.339	Very coarse skewed	1.096	Mesokurtic
I3	1.246	Medium sand	0.853	Moderately sorted	-0.308	Very coarse skewed	1.630	Very leptokurtic
J1	-0.045	Very Coarse sand	0.622	Moderately well sorted	0.138	Fine skewed	0.873	Platykurtic
O1	1.364	Medium sand	1.051	Poorly sorted	-0.097	Symmetrical	0.960	Mesokurtic
O2	0.533	Coarse sand	0.825	Moderately sorted	-0.030	Symmetrical	1.302	Leptokurtic
GB1	0.109	Coarse sand	0.690	Moderately well sorted	0.030	Symmetrical	0.751	Platykurtic
G1	0.575	Coarse sand	1.016	Poorly sorted	0.069	Symmetrical	0.784	Platykurtic
G2	0.930	Coarse sand	0.951	Moderately sorted	-0.110	Coarse skewed	1.016	Mesokurtic
G3	1.279	Medium sand	1.166	Poorly sorted	-0.154	Coarse skewed	0.943	Mesokurtic

The medium – coarse grains range in shape from sub-angular to sub-rounded. Compaction is moderate with little or no cementing material. Cementation and authigenic mineral growth are lacking probably due to early bitumen impregnation. The grain morphology viewed under the petrological microscope shows low – high sphericity. Quartz is present on average of 96% having low relief, with undulose extinction and fractures. It appears colourless under plane polarised nicols. Mica was identified to constitute about 4% of the sand content, Plate 3. Feldspar was not identified under the microscope and this can be indicative of mechanical maturity of the sediments. The results of the mineralogical analysis are shown in Table 2.

Table 2: Summary of percentage composition of minerals.

Sample	Quartz	Mica	Accessory
I1	99	-	1
I2	99	-	1
I3	98	1	1
J1	98	1	1
O1	99	-	1
O2	99	-	1
GB1	99	-	1
G1	96	3	1
G2	97	2	1
G3	99	-	1

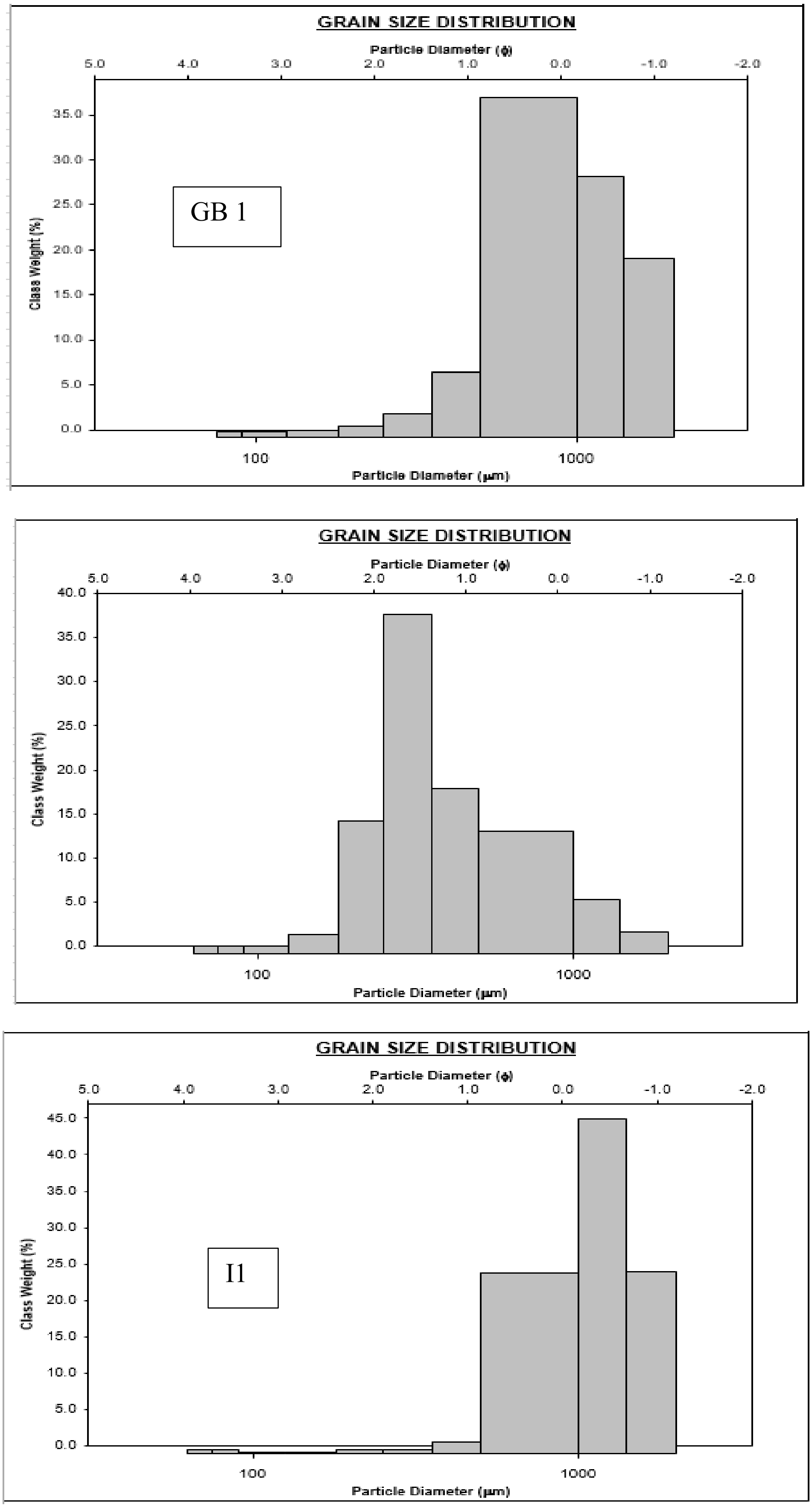

Figure 7: Histograms showing the grain size distribution of some of the sediments

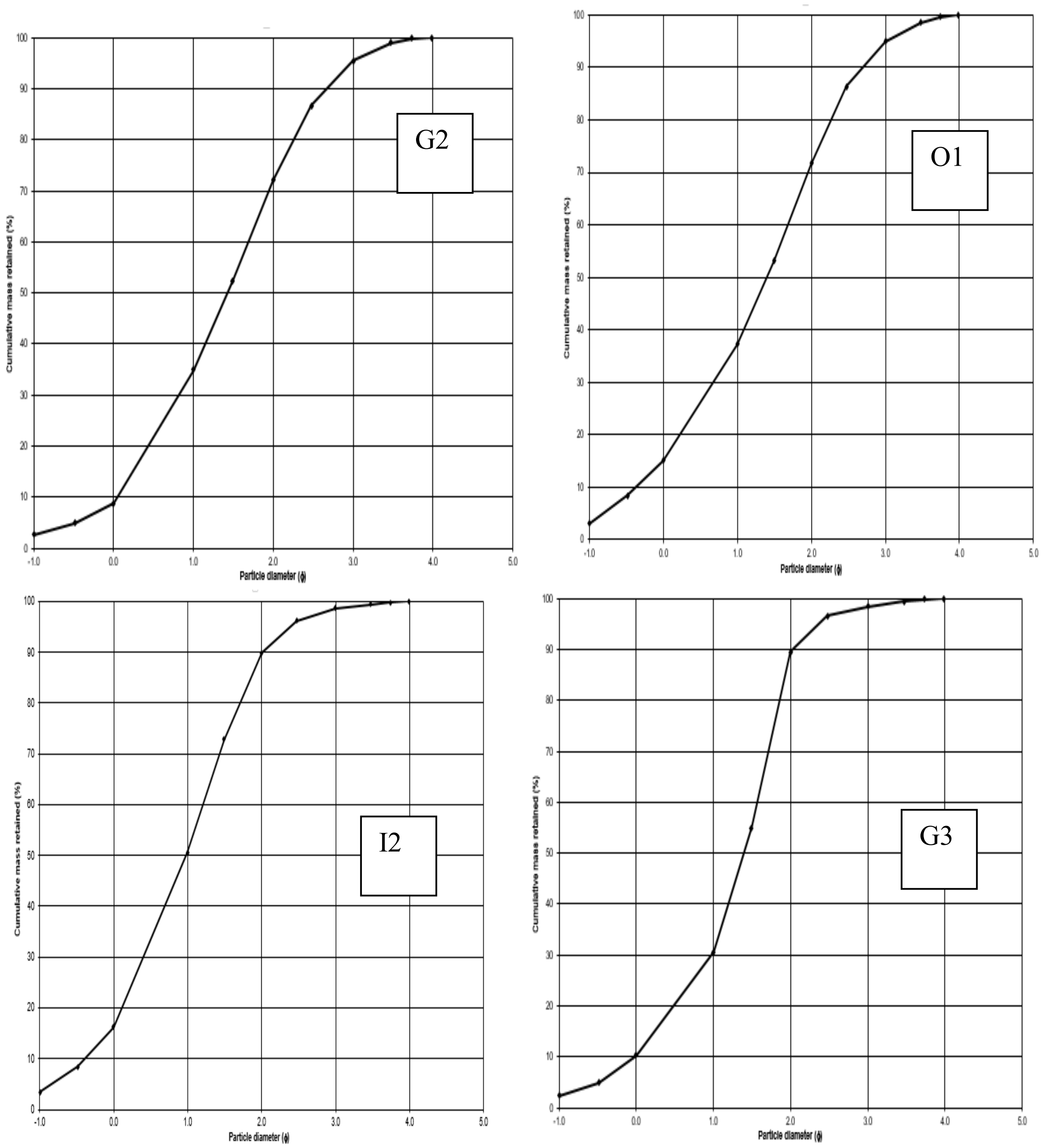

Figure 8: Cumulative frequency plots of some of the sediments sediments

Plate 1: Photomicrograph of a medium grained sandstone in plane polarised light.

Plate 2: Photomicrograph of a coarse grained sandstone in plane polarised light.

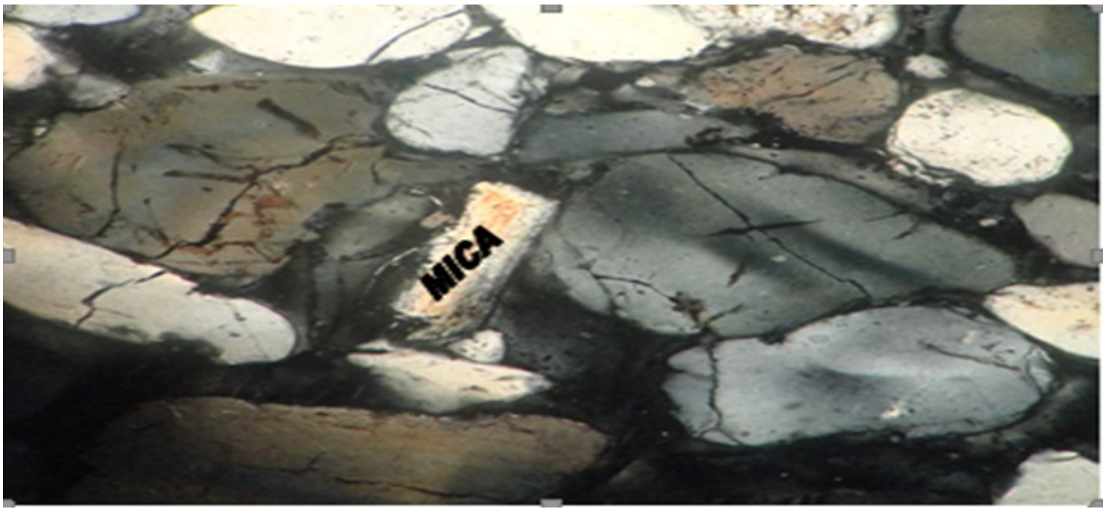

Plate 3: Photomicrograph showing mica in cross polarised light.

4.1 Provenance

Almost all samples examined under the petrographic microscope for their quartz varieties indicate the type referred to by Krynine [8] as common quartz. These quartz types were genetically classified as being plutonic igneous quartz. The quartz types show a very significant similarity with metamorphic quartz type in that their composite grain boundaries are often straight and in addition, grains have wide different optic orientation. Hence the sediments of the study area can be said to be of igneous origin since majority of the quartz crystals were seen to be monocrystalline under the petrographic microscope.

Table 2: Summary of percentage composition of minerals.

Sample	Quartz	Mica	Accessory
I1	99	-	1
I2	99	-	1
I3	98	1	1
J1	98	1	1
O1	99	-	1
O2	99	-	1
GB1	99	-	1
G1	96	3	1
G2	97	2	1
G3	99	-	1

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4.2 Bitumen saturation

Bitumen saturation refers to the weight % or volume % bitumen present per unit mass or volume of oil sands; the following categories of oil sand have been identified, [5]:

- Rich sands – Sb >10wt. % (>19.2 vol. %)
- Intermediate sands – Sb > 5 to < 10wt. % (9.9 to < 19.2 vol.)
- Lean sands – Sb > 2 to < 5 wt % (> 4 to < 9.9 vol. %)

The result of the bitumen analysis showed that the tar sand deposits belong to category one (i.e. rich sands) with an average bitumen saturation of 28.2 % (Table 3).

Comparing the result of this analysis to the work of [2], in their paper titled "Sedimentological and Reservoir Description of Afowo Oil Sands Deposit, South Western Nigeria"; while grain texture plays no significant role in bitumen saturation, same may not be said regarding its recovery, especially if the fine types are the ones that swell when in contact with water, e.g. Montmorillonite.

Considering Tables 1 and 3, for instance G3 has the highest bitumen saturation and is poorly sorted while J1 has the lowest bitumen saturation and is moderately well sorted. This means that J1 is likely to have a better oil recovery efficiency than G3 and is therefore a better reservoir.

From the overall results, considering the reservoir quality, Oso J4 and Gbegude sands should be expected to have better reservoirs with good oil recovery efficiency due to their low content of fine particles because they are better sorted than the sediments in other areas.

Table 3: Bitumen saturation results.

Sample number	Initial weight of tar samples (g)	Final weight of tar samples (g)	Weight of tar (g)	% of bitumen saturated	Facies
I1	417.6	314.4	103.2	24.7	Medium grained sandstone
I2	450.5	352.3	98.2	21.8	Medium grained sandstone
I3	402.7	309.9	92.8	23.0	Medium grained sandstone
J1	458.7	399.5	59.2	12.9	Very coarse grained sandstone
O1	460.6	277.2	183.4	39.8	Medium grained sandstone
O2	472.1	353.2	118.9	25.2	Coarse grained sandstone
GB1	517.4	384.1	133.3	25.8	Coarse grained sandstone
G1	451.8	299.7	152.1	33.7	Coarse grained sandstone
G2	415.1	283.5	131.6	31.7	Medium grained sandstone
G3	499.2	282.2	217	43.5	Medium grained sandstone

4.3 Scanning electron microscopy

Quantifying clay mineralogy provides sufficient information regarding the effect of clay minerals on reservoir characteristics. The microscopic distribution of small proportions of authigenic clay minerals may have a profound effect on a reservoir regardless of each clay mineral's specific proportions [13], [14].

The oil sand samples were identified having clay minerals which had become precipitated and occurred as pore filling cement; these included: sheet kaolinite, vermiform kaolinite, pyrite crystal and quartz (see Plate 4).

The SEM images were found to have micro-pores and fractures. The micro-pores range in size from 0.057µm to 0.446µm.

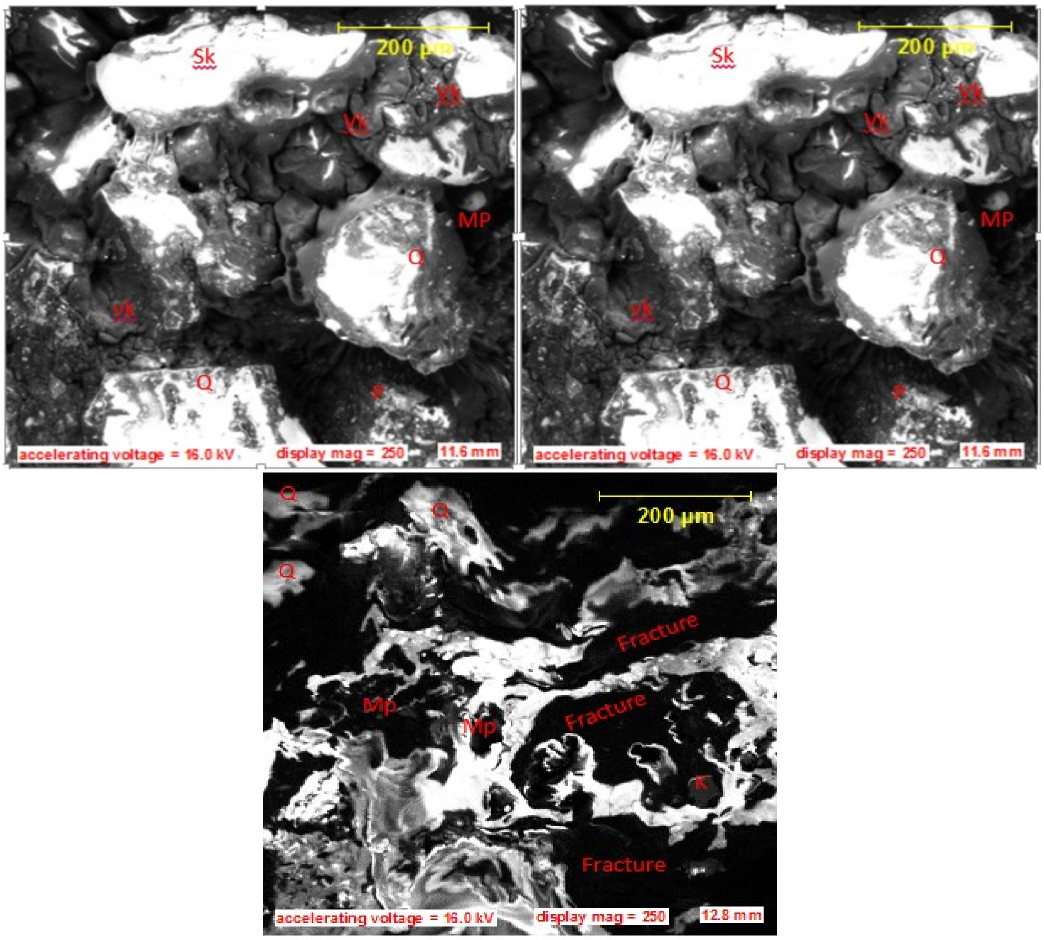

Plate 4: Scanning electron micrographs of sheet kaolinite, block kaolinite, pyrite, quartz, Vermiform kaolinite, fractures and micro-pores.

5 SUMMARY AND CONCLUSION

The particle size distribution of the deposits as seen in this study varies without a definite pattern. The sands are medium – coarse and mostly moderately sorted with no significant fines. Except for few locations with poor sorting, the bulk of the sediments are moderately sorted. This quality, coupled with insignificant fines content, will in no doubt enhance both saturation and withdrawal efficiency positively.

The medium – coarse grain-size of surface samples, their moderate sorting, and the low content of fine grains show that the Afowo oil sands reservoir would be of good quality; the average bitumen saturation of the surface samples is 28.2 %.

The quartz content on the average is greater than 96 % with little or no feldspar. The sands as observed from the analyses can be classified as being mechanically stable, mineralogically and texturally mature. The sub-angular to sub-rounded shapes of the grains coupled with little or no fines may be the indication of a fairly long period of sediments transportation with depositional energy having a moderate to high velocity.

The scanning electron microscopy description revealed that the oil sands contained minerals which had been precipitated and occurred as pore filling cement; these minerals include sheet kaolinite, block kaolinite, vermiform kaolinite, pyrite crystals and quartz. The SEM images also showed micro-pores of 0.057µm to 0.446µm and fractures. The study showed that the clay minerals contained in the Afowo Formation were mainly kaolinite which is not expected to have any negative effects on the reservoir quality, especially during enhanced oil recovery operations.

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