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Petrology and Environment of Deposition of Ihugh – Mede Sandstones, Lower Benue Trough, Southeastern Nigeria

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Abstract Sandstones in Ihugh-Mede area, Lower Benue Trough, had been grouped into three based on locality/granulometry; Mede-1fossiferous feldspathic sandstones (FSS); Mede-2 arkosic sandstone (AKS), and Ihugh greywackes (GWK). They unconformably overlie Obudu basement, their main progenitors eastward. The FSS and AKS are characteristically pinkish white, the GWK is dark grey. They are all medium-coarse grained, moderately to well sorted, texturally mature as aquifer materials and petroleum reservoir sands, except the GWK. The grey wackes is massive, has > 25% matrix, chlorite as main cement, grades from fine-medium-coarse, shows numerous sink holes, and wood fragments, indicating deposition from continental turbidities. The AKS and FSS consist of 75-92% framework elements, 2-10% matrix and 10-14% cement respectively, characteristically laminated and trough cross-bedded, indicating deposition from fluvial continental environment. All the sandstones are enriched in quartz: GWK-60vol.%; AKS-82vol.%; FSS-94vol.%, with polycrystalline quartz *i.e.* monocrystalline quartz. Feldspar constitutes 10–15vol.% in the AKS and FSS, muscovite ~2vol.% in the AKS and FSS. All the sandstones are depleted in hematite, tourmaline, and chlorite, except the greywackes, which is relatively enriched in chlorite, corroborating its sub-mature character. Various discrimination diagrams classify the AKS and FSS as unimodal, well sorted, mature beach arenites, deposited under minor regressive-transgressive phases.

Keywords Benue Trough, Environment of deposition, petrology, progenitors, sandstones

1. Introduction

Sandstone, an arenaceous sedimentary rock is one of the most important rock suites, which constitute aquifers that hosts global water resources, petroleum reservoir sands and provides important aggregates for engineering and building construction and other industrial and development programs. This very important natural resource occurs in the western part of Lower Benue Trough in Southeastern Nigeria. They occur in subordinate amounts to the basement gneisses, granites and schists. The area is geographically located between latitudes 6°50' – 7°00'N and longitudes 9° 00' - 9° 10'E (Figs 1 & 2). Geological exploration and mapping of the Benue Trough had been extensive but inadequate [1-2]. However, more systematic, detailed and extensive work still need to be done to properly elucidate and classify the enormous petrological, lithological and environment of deposition of the Benue Trough, southeastern Nigeria. The present work aims at contributing in unraveling these enormous geologic complexities.

2. Geological Setting

Ihugh-Mede area is a part of the southern Benue Trough bordering the Obudu-Bamenda Basement outcrop in the west (Fig.2). The Trough is a vast NE – SW; > 800km trending hoist-graben structure developed during the early Cretaceous System. It resulted from the failed arm of the triple point RRR aulacogen. It has been variously

intruded and metamorphosed in places [3-4] more recently Agumanu [2] and Petters [5] etc, studied the sedimentary rocks of the Lower Benue Trough. They all agree that the oldest sedimentary deposit in the area is the Albian Asu River Group (ARG), comprising the Awi and Awe formations, and the Odukpani Formation in the Calabar Flank. This is followed by the Eze-Aku Shales, unconformably overlain by the Awgu Formation, Nkporo shale, Mamu Formation (Lower Coal Measures); Ajali Formation (False bedded sandstones), and the Nsukka Formation (Upper Coal Measures), the youngest out-cropping Campanian - Maastricthian sedimentary deposits in the area (Table 1).

All the formations consist of sandstones, shales, limestones, clays, with the Mamu and Nsukka formations which bear coal horizon for which they were so named. Studies had shown that the provenance sources of these sediments are the Obudu Plateau and Oban Massifs of southeastern Nigeria. Fig. 2 is the sample location map of the area, while Fig. 3 is the geological map of the study area. Table 1 summarizes the litho-stratigraphy of the area.

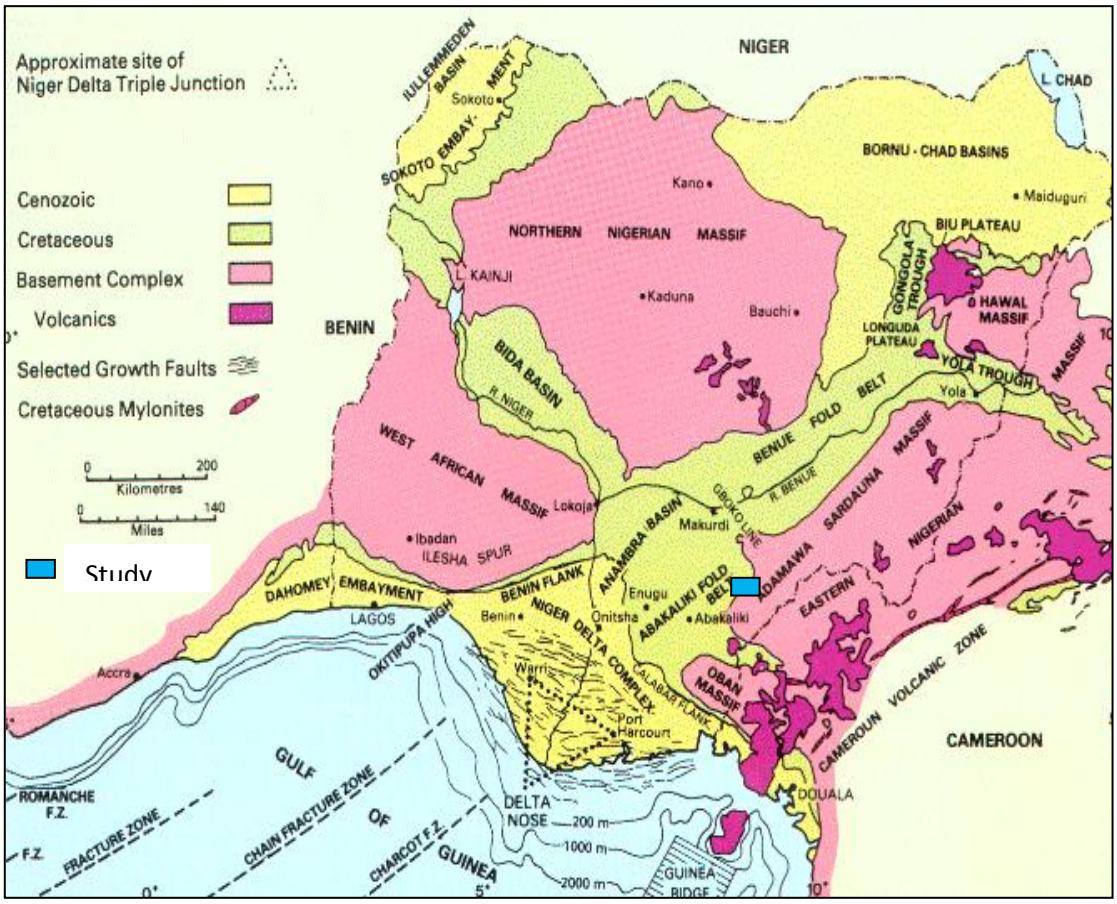

Figure 1: Genarelised Geological Map of Nigeria showing location of study area extending from Benue Trough to Obudu Plateau, in Southeastern Nigeria [6-7]

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3. Methodology

The study involved a systematic field investigation, geological mapping and sampling, petrography and laboratory analysis.

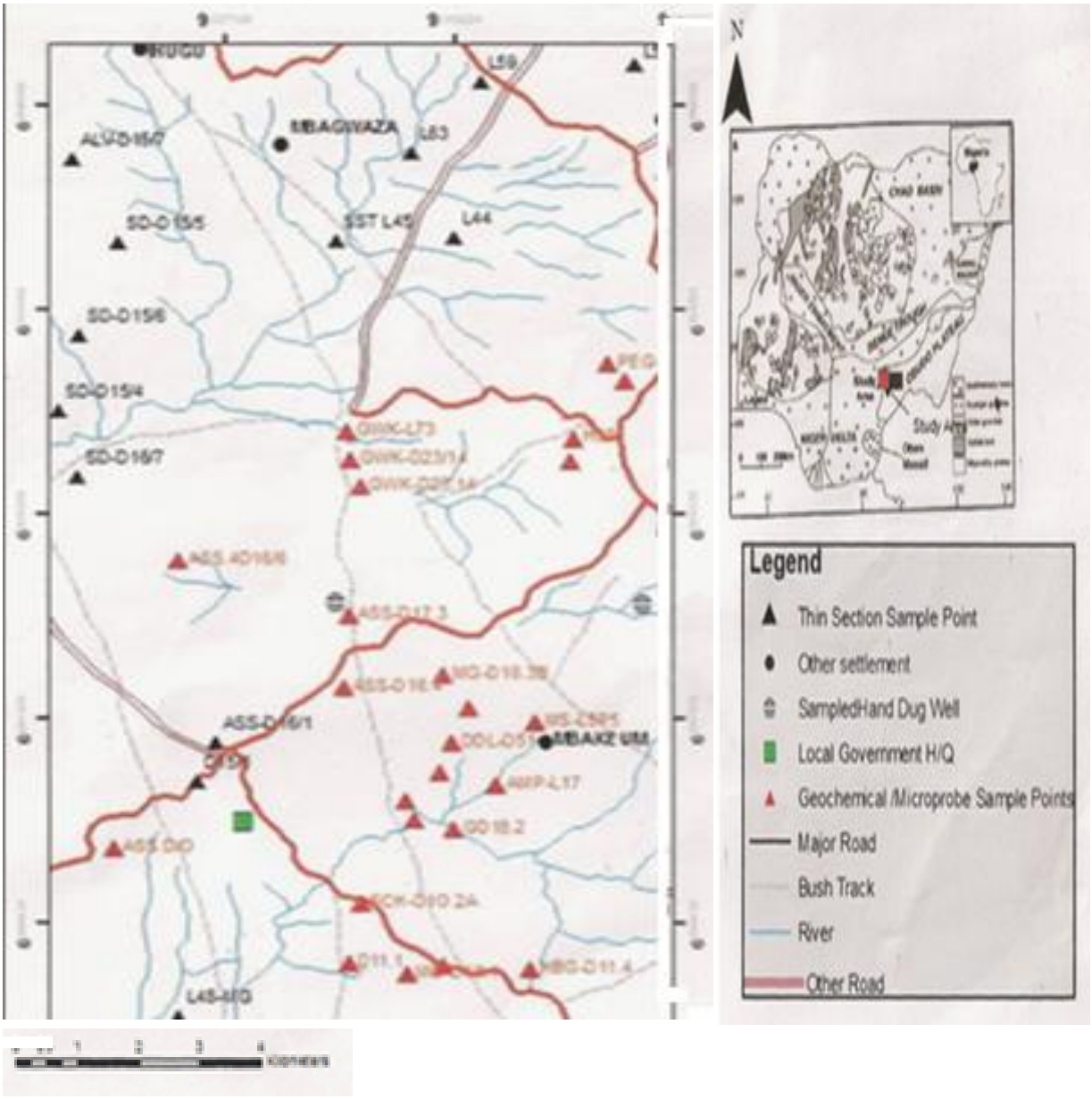

Figure 2: Sample location map of the Study Area [4] Ihugh – Mede Area Lower Benue Trough.

3.1 Sieve Analysis

Sieve analysis, a mechanical technique used for the soil /rock samples particles study. It enabled the granulometric study for classifying the sandstones into grain size classes. It was based on the Uden-Wentworth modified Grade Scale, and the US Standard Sieve meshes after the American Standard for Testing and Materials (ASTM). A comparison of the result was made with the British Standard of Testing and Materials (BSTM). These methods have the great advantage of being performed on any type of non-organic or organic granular materials including sands, crushed rocks, clays and soil.

3.2 Mineralogy

Microscopic observation shows that the mineral composition of the sandstones consist of quartz, feldspars, lithic fragments and heavy minerals (tourmaline, apatite and rutile), the matrix, cement and pores helped in elucidating the provenance of the sediments. The mineralogy of the matrix and cement were essentially similar consisting dominantly of silica, calcite and siderite.

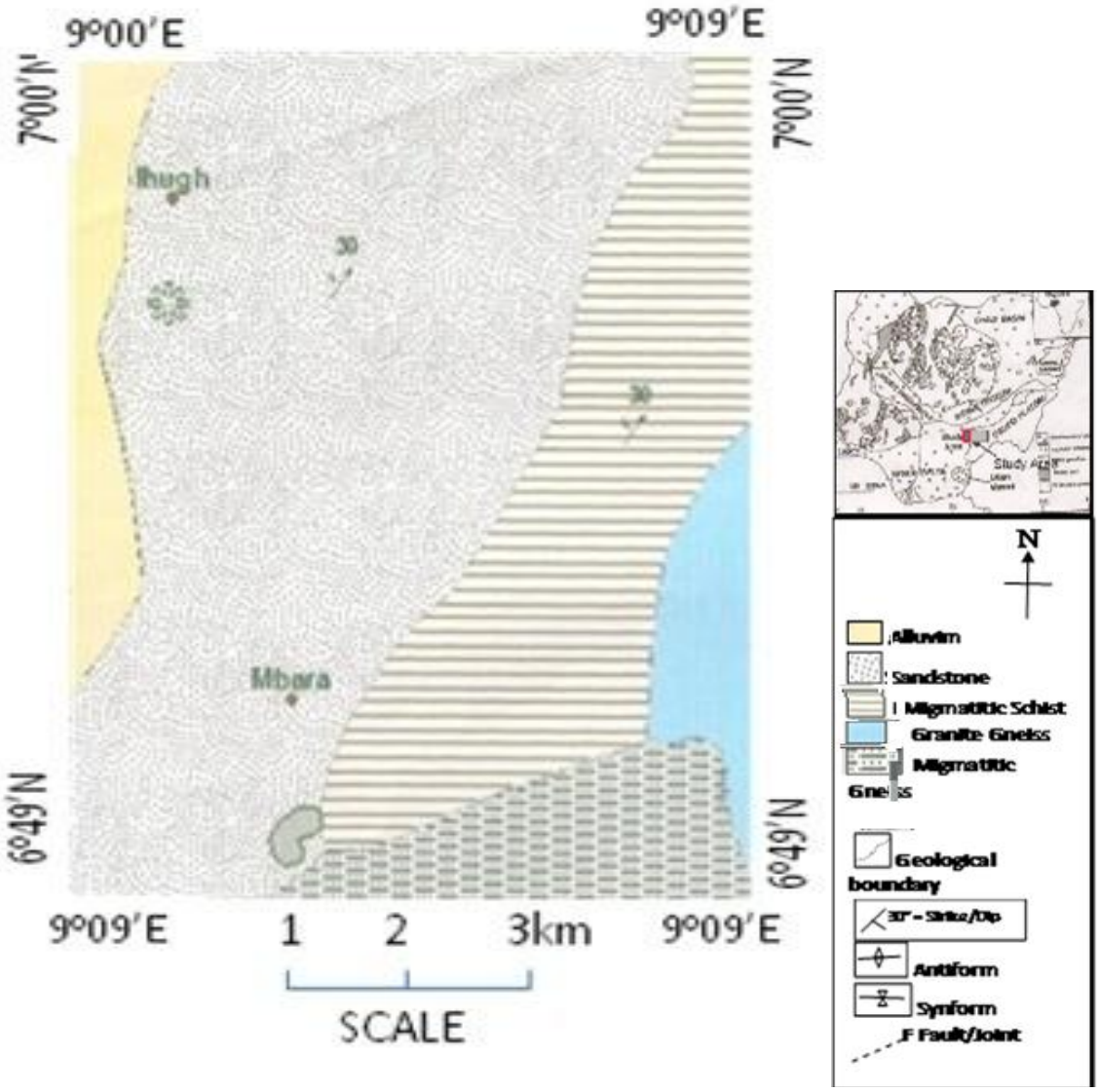

Figure 3: Geological Map of the Study Area. Inset: Map of Nigeria showing location of the Study Area in the Lower Benue Trough

Table 1: Lithostratigraphy of the Study area (Ihugh-Mede Area Lower Benue Trough)

PERIOD	AGE	FORMATION	LITHOLOGY	ENVIRONMENT
CRETACEOUS	Campanian-Maastricthian	Mamu	Sandstone, Shale, Coal seam, clay	Regressive; Fluvial-Deltaic
	Cenomanian	Eze-Aku Shale	Shale, Sandstone, Coal seam, clay	Transgressive Marine
	Albian	ASU River Group (ARG)	Sandstone, Shale, Limestone, clay	Regressive

The Modal composition of the sandstones is summarized in Table 2. The table shows that all the sandstones are enriched in quartz (90%, 74% and 60% in the FSS, AKS and GWK respectively), and feldspar (2%, 10% 23% in the FSS, AKS and GWK respectively), Muscovite (2%, 4% and 5%, in the FSS, AKS and GWK respectively) with minor amount of apatite, zircon, tourmaline, chlorite and glauconite (Table 2), which summarizes the modal composition of the sandstones.

The quartz consist mostly of both mono-crystalline and poly- crystalline grains (Table 2), which when examined in detail under the petrological microscope are seen to display a number of distinctive features such as undulose extinction, which is typical of rocks of volcanic and / or hyperbyssals derivation. The abundance of polycrystalline quartz over monocrystalline quartz grains (Table 2) are strong indicator of derivation from gneisses, schists, quartzites, granites and recrystallized chert of the Basement Complex rocks . The grains are coarse to very coarse in texture, indicating derivation from plutonic igneous rocks under slow cooling condition. They often show scored-base, with undulose extinction, often with irregularly sutured boundaries, which is indicative of grains of metamorphic derivation [2].

Plagioclase and orthoclase are the main varieties of feldspar minerals occurring in sandstones of Ihugh-Mede area (Table 2). The mineralogy of the feldspar provides the best indication of source rock composition, particularly where very suitable varieties are present. A high proportion of plagioclase implies proximity to source and dominance of calcic over plagioclase indicates volcanic origin. A low proportion of plagioclase reflects source rock composition, selective destruction during weathering, or both. Recycling of feldspars is of minor importance except where erosion and deposition have taken place under dry conditions

Muscovite is the dominant mica mineral occurring in the Ihugh-Mede sandstone samples, while chlorite and biotite are relatively depleted (Table 2), possibly because of their unstable nature under weathering processes. Hence they are usually abundant only close to their protoliths sources or where weathering is dominantly mechanical. The lithic grains constitute lesser proportion of the analyzed sandstone samples of Ihugh-Mede Lower Benue Trough. The Igneous lithic grains normally consist of finely crystalline volcanic rock types. The basic varieties consist largely of plagioclase feldspar or basaltic glass, which are restricted to immature sandstone; acidic varieties with greater quartz content are more widely distributed.

3.3 Heavy Minerals

Most of the sandstones analyzed contain some proportion of accessory minerals of terrigenous origin, with specific gravity greater than 2.8 [8], Table 2), denser than quartz and feldspar. They include garnet, zircon, rutile, tourmaline, staurolite and magnetite. These heavy minerals are very useful for the interpretation of the provenience of the source rock materials. Zircon -SG 4.3 is an accessory mineral indicative of acid igneous rock origin or deposition under detrital environment. Tourmaline -SG 3.1 is an accessory cyclo-silicate mineral indicative of pneumatolytic acid rock origin from schist and gneiss, rutile -TiO_2 is an important heavy mineral -SG 4.2, indicative of igneous pegmatite or impure metamorphosed limestone sources (Kyanite and sillimanite, -Al_2SiO_5, are alumina-silicate minerals, indicative of derivation from moderate to high temperature thermal metamorphic rocks.

3.3 Granulometry

The granulometric study (Table 3) was based on the method after Folk and Ward [9], The table shows that the mean grain size ranged from -1 to 0.0 indicating coarse to very coarse sand in the Feldspathic and Arkosic sandstomes. And from 1.0 to 3.0 indicating very fine to coarse sand in the graywackes. Thus corroborating their derivation from turbite current. The sorting (Phi) was <0.35 indicating that the FSS and AKS were very well sorted, while that of the GWK ranged from 2.0 – 0.5 showing poorly sorted to well sorted sand (Table 3). The skewness ranged from +0.30 to 1.0 in the FSS and AKS indicating positive to very positively slewed sand (Table 3). The kurtosis ranged from <0.6 to 0.90 indicating that the FSS and AKS were platykurtic to very platykurtic in character. That of the GWK ranged from 0.90 to 3.0 showing they were mesokutic to very leptokurtic (Table 3).

4. Results

Table 4 is the average results of the mechanical sieve analysis of the Ihugh-Mede sandstones. The Table shows that all the sandstones are depletes in pebbles < 1.5 % in the arkosic sandstone at Mede 1, about 2.5 % in Mede 1 sandstone, 5.8 % in the feldspathic sandstone at Mede 2, and maximum of % in the greywackes at Ihugh (Table 3). All the sandstones consist dominantly of sand grade particles > 90 %, with the arkosic sandstone (ASS) at Mede 1 showing ~ 12.0 % coarse sand, 22% medium sand, 55 % fine sand and 5 % silts (Table 3). The feldspathic sandstone (ASS) at Mede 2 consists of 23 % coarse sand, 27 % medium sand, 48 % fine sand and < 2 % silt. The greywackes at Ihugh consists of > 42 % coarse sand, 28 % medium sand, ~ 28 % fine to very fine sand and < 3 % silts. While the Ogoja sample is composed of 25 % coarse sand, 13 % medium sand and 58 % fine – very fine sand.

Table 2: Average modal composition (vol. %) of sandstones of Ihugh -Mede area Lower Benue Trough Nigeria

MINERAL	**FELDSPATHIC SANDSTONE (FSS) n X 6**	**ARKOSIC SANDSTONE (ASS) n X 6**	**GREYWACKES (GWK) n X 6**
	DETRITAL/FRAMEWORK GRAINS		
Quartz	90% comprising: PC-Qtz, 23%, MC-Qtz 32%, microphanerite (Gnt), VRF 10%, and SRF/chert constitute the rest	74% comprising: PC-Qtz, 20%, MC-Qtz 25%, microphanerite (Gnt), VRF 10%, and SRF/chert constitute the rest	60% comprising: PC-Qtz, 10%, MC-Qtz 25%, microphanerite (Gnt), VRF 10%, MRF 20% and SRF/chert constitute the rest
Feldspar	2% comprising: mainly Orth & Vol. Rf. And Plag. mainly, microphanerite with minor amounts of VRF, MRF, & SRF	10 comprising: mainly Orth & VRF. plagioclase mainly microphanerite, with minor amount of, MRF, & SRF	23% comprising: mainly Orth & Rf., plagioclase mainly microphanerite, with minor amount of VRF, MRF, & SRF
Muscovite	2	4	5
Glauconite	1	3	4
Chlorite	1	3	5
Tourmaline	1	2	2
Zircon	2	2	-
Apatite	1	2	1
Total	100	100	
	MATRIX COMPONENTS		
Silica	√	√	-
Calcite	†	†	-
Siderite	-	-	†
Hematite	-	-	√
	CEMENT COMPOSITION		
Silica	√	√	-
Calcite	†	†	-
Hematite	-	-	†

KEY: √ = Very dominant, † = High, - = Minor/negligible.
PC-Qtz = Polycrystalline quartz,
MC-Qtz = Monocrystalline quartz,
VRF = Volcanic rock fragments,
MRF = Metamorphic rock fragments,
SRF = Sedimentary rock fragments.

Table 3: Interpretation of granulometric analysis results [9] and [10] grain size statistical parameters

Grain Size (Ø)	Interpretation	Sorting (Phi Range)	Verbal Description of Sorting	Skewness	Verbal Description	Kurtosis	Verbal Description
-1 – 0.0	Very coarse sand	< 0.35	Very well sorted	+0.30 to 1.00	Very positively skewed	< 0.67	Very Platykurtic
0.0 – 1.0	Coarse sand	0.35 – 0.50	Well sorted	+0.10 to +0.30	Positively skewed	0.67– 0.90	Platykurtic
1.0 – 2.0	Medium sand	0.50 – 0.71	Moderately well sorted	-0.10 to +0.10	Near symmetrical	0.90– 1.11	Mesokurtic
2.0 – 3.0	Fine sand	0.71 – 1.00	Moderately sorted	-0.30 to -0.10	Negatively skewed	1.1 – 1.50	Leptokurtic
3.0 – 4.0	Very fine sand	1.00 – 2.00	Poorly sorted	-1.00 to -0.30	Very negatively coarse skewed	1.5 – 3.00	Very leptokurtic
4.0 – 5.0	Coarse silt	2.00 – 4.00	Very poorly sorted			> 3.00	Extremely leptokurtic
➢ 5	Fine silt	➢ 4.00	Extremely poorly sorted				

Table 4: Average Results of the mechanical sieve analysis of Ihugh-Mede Sandstones, Northwest Obudu Plateau Southeastern Nigeria

	L33 Mede 1 Sandstones			L32A Mede 2 Sandstones			L32B Ihugh Sandstones			L1 Ogoja Sandstones		
Sieve size (mm)	Mass retained (g)	Mass passing (g)	% mass passing	Mass retained (g)	Mass passing (mm)	% mass passing	Mass retained (g)	Mass passing (g)	% mass passing	Mass retained (g)	Mass passing (g)	% mass passing
2.00	0.95	61.90	98.50	4.35	70.15	94.20	5.45	61.85	92.00	1.85	62.10	97.30
1.180	2.55	59.35	94.40	5.90	64.25	86.20	11.85	50.00	74.30	5.50	56.6	88.50
0.850	2.55	56.80	90.30	6.55	57.70	77.40	12.30	37.70	56.00	9.85	46.75	73.10
0.600	5.80	54.25	86.30	9.60	48.10	64.60	11.00	26.70	39.70	14.90	31.85	49.80
0.425	9.15	45.10	71.80	12.05	36.05	48.40	5.70	21.00	31.20	8.10	23.75	37.10
0.300	15.80	29.30	46.60	15.05	21.00	28.20	6.30	14.70	21.80	11.20	12.55	19.60
0.150	18.70	10.60	16.90	13.85	7.15	9.60	9.10	5.60	8.30	8.25	4.30	6.70
0.075	5.9	4.70	7.50	4.15	3.00	4.00	4.30	1.30	1.90	2.85	1.45	2.30
Pan	1.1	3.60	5.70	1.9	1.10	1.50	1.00	0.30	0.4	1.00	0.45	0.70

4.2 Discrimination Diagrams

The graphic signature of the plots of the mean grain diameter against percentage finer on the US Standard sieve sizes shows similar distribution for all the analyzed sandstone samples (Figs. 4 A-D). The signatures of the histogram plots (Figs. 5 A-D) depict sediments characterized by two major depositional regimes; River-Beach and combined river/beach depositional regimes. The signature shows Mede 1 and Mede 2 sandstones (Figs. 5 A & C) to be unimodal indicating beach sand/shallow marine environment. Figs. 5 B & D plots show bimodal signature indicating deposition from two main sources: beach/shallow marine environment/continental fluvial river deposits environment. [11, 12, 14].

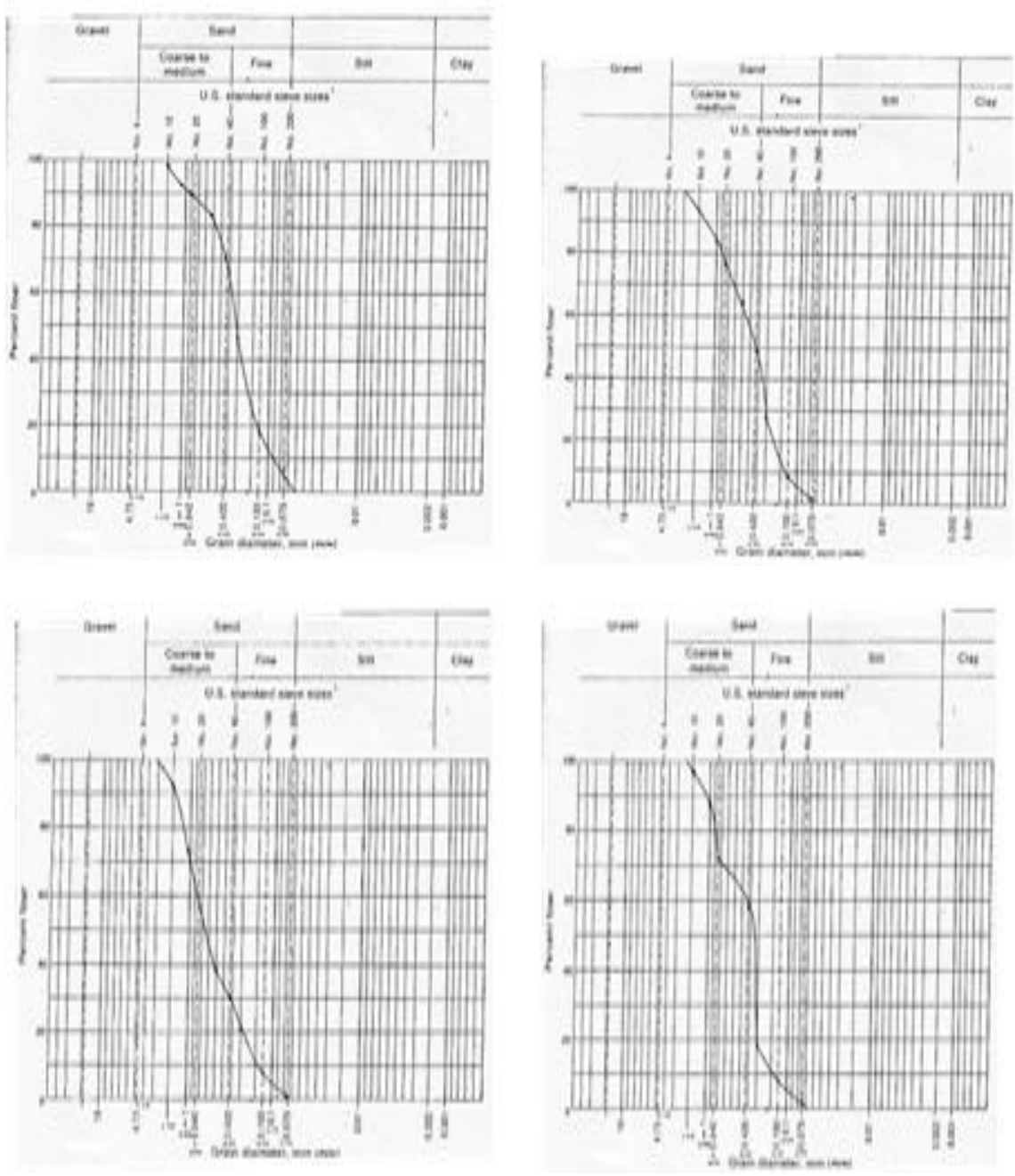

Figure 4: Graphic plots of mean grain size versus percent (%) passing; for textural classification of the Ihugh- Mede Sandstones, Southeastern Nigeria

On the plot of standard Deviation (phi) versus mean grain diameter (Figs. 6 A – D), for the determination of the environment of deposition of the Ihugh- Mede sandstones (Sahu, 1964; Friedman, 1966) > 60 % of the greywackes plot in field of river sand, 20 % beach sand and 20n%combined beach and river sand (Fig. 6). About 60 % of the Mede 1 sandstones plot in the field of river sand environment while 40% plot in the field of beach sand deposit environment of beach sand deposit (Fig. 6).

On this discrimination diagram: the greywackes consists of > 60% river Sand, ~ 20% Beach Sand and 20% combined beach and River Sand. The Mede 1 Sandstone consists of 60% River Sand and 40% Beach Sand. The Mede 2 Sandstone consists of 50% Beach Sand, 25% River Sand and 25% combined beach and River Sand.

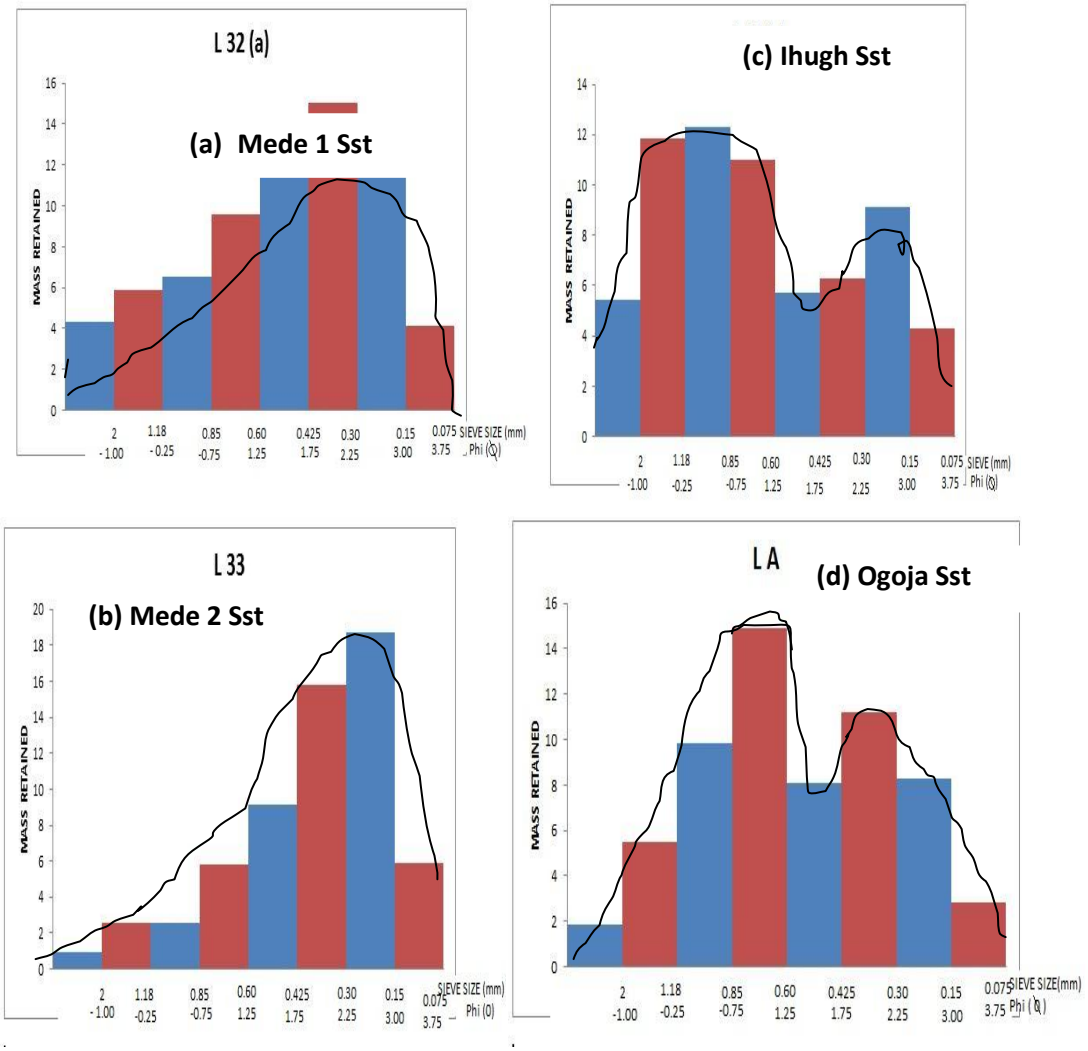

Figure 5: Histogram: Plots of grain size diameter (mm / Phi scales) against mass retained %, for the modal classification of the Ihugh-Mede Sandstones, Southeastern Nigeria. (a). Mede 1 Sandstone. (b). Mede 2 Sandstone. (c). Ihugh Sandstone(Greywackes). (d). Ogoja Sandstone.

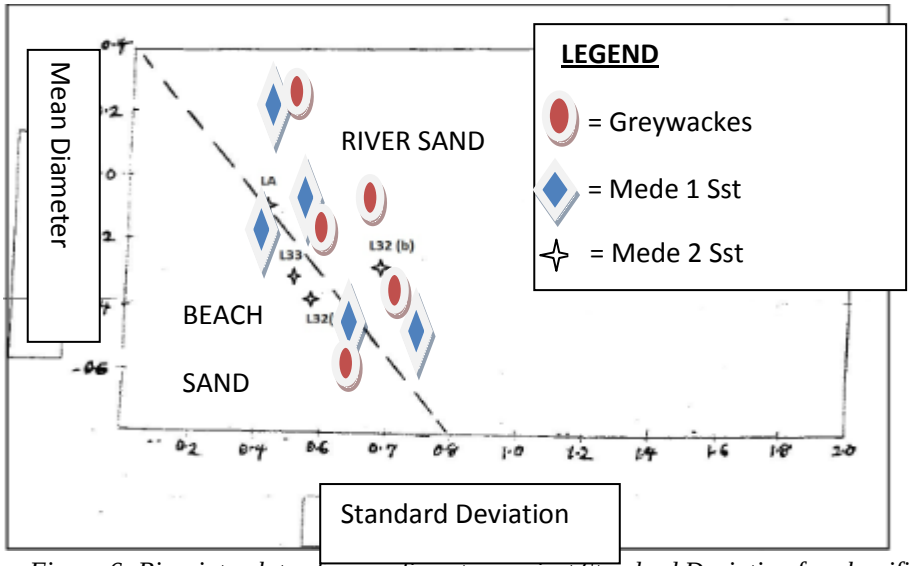

Figure 6: Bivariate plots of mean diameter against Standard Deviation for classification of environment of deposition of sandstones of Ihugh-Mede Area, Southeastern Nigeria [11-12].

5. Discussion

The study of rocks of Ihugh – Mede area, Lower Benue Trough, Southeastern Nigeria shows that sandstones (consisting mostly of arkoses, feldspathic sandstones and greywackes) constitute more than 70 % of the sedimentary rocks in the area. The sandstones, have been assigned Middle Cretaceous age based on their fossil content of *Ammonite, (costatum Vascoceras nigerience),* Wahiura Stream, The sandstones are composed of angular to sub-angular grains, making them gritty, and corroborating their short distance of transportation from the adjacent provenance sources, Obudu Plateau and Oban Massif, Southeastern Nigeria and Bamenda Massif of Western Cameroon [13], before deposition.

The sandstones are genetically related to the Asu River Group [6], Awi Formation of Petters (1982). The sandstones unconformably overly the western flank of the Obudu-Oban basement in a NE – SW trend, which indicates that their deposition were controlled by the underlying basement structures. Petrographic studies reveal that the sandstones are composed dominantly of quartz, feldspar, micas, lithic fragments and heavy minerals, and lesser amounts of chlorite and apatite which constitute both the matrix and cement.

Petrogenetic study of the samples using various chemical discrimination diagrams show that two out of the three analyzed samples were of delta or beach sand environments [11, 12] while the third is of fluvial continental environment [11, 12]. Correlation using both the histogram (Figs. 5) show that both the Mede 1 and Mede 2 sandstones are positively unimodal, and skewed to the finer grained fraction, corroborating their deposition under beach environment [11, 12], while the Ihugh and Ogoja sandstones are bi-modal, indicating deposition under mixed beach and fluvial continental environment (Fig. 6). Textural analyses using ASTM standard Sieves (Figs. 4 A-D) show that all the sandstones are well sorted and texturally mature, composed of 40 – 65 %, fine sand, 20 – 30 % medium sand and 10 – 30 % coarse sand, except the greywackes which grades from fines – coarse sand often pebbly and massive.

6. Conclusion

Uni-bimodal, well to very well sorted, beach to fluvial deltaic sandstone sediments, comprising mainly of arkoses, fossiliferous feldspathic sandstones and greywackes occur in the Ihugh – Mede area of Lower Benue Trough southeastern Nigeria. They strike NE - SW (0 – 20^{o}), dip ~ NW and unconformably overlie the westward projection of the Obudu Basement Complex of Southern Nigeria.

The sandstones are texturally fine – medium – coarse grained, mineralogically matured, porous and permeable, and capable of hosting surface and groundwater and petroleum resources, as well as providing engineering and building construction materials for industrialization and national developments. Currently the resources are being mined by local artisanal miners and individuals. However, National and multi-national co-operations/organizations may be necessary for effective development of these resources, which could provide income to the nation and job opportunities for the nation's teaming populations.

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