International Journal of Earth Sciences Knowledge and Applications
journal homepage: http://www.ijeska.com/index.php/ijeska

Research Article e-ISSN: 2687-5993

Sedimentary Petrology and Paleogeography of the Eocene-Sandstone Facies of Ilaro Formation, Dahomey Basin, South-Western Nigeria

Christopher Uyabeme Enuenwosu[1]*, Moses Uyota Ohwo[1], Ayamezimi Oziofu Ehinlaiye[1]

[1]*Department of Geology, Faculty of Physical Sciences, University of Benin, Benin City, Edo State, Nigeria*

INFORMATION

Article history
Received 23 August 2024
Revised 03 October 2024
Accepted 07 October 2024

Keywords
Provenance
Pebble morphometric analysis
Petrology
Lithofacies
Paleocurrent

Contact
*Christopher Uyabeme Enuenwosu
uyabeme.enuenwosu@physci.uniben.edu

ABSTRACT

This study examines the depositional processes and paleo-environment of sediments and pebbles from three sampled locations of the Tertiary Ilaro Formation in the Nigerian section of the Dahomey Basin. Petrographic analysis revealed that the sandstones are primarily arenites and sub-feldspathic arenites, based on the proportions of quartz, feldspar, and lithic fragments. The textural immaturity of the sandstones suggests that the sediments were transported from a nearby source and deposited along a passive continental margin. Grain size analysis indicated that the mean, standard deviation (sorting), skewness, and kurtosis values for sediment samples from the three locations ranged from 0.3 to 1.7, 0.7 to 2.0, and 0.4 to 1.5, respectively, indicating medium- to coarse-grained sandstones; 0.3 to 1.5, 0.5 to 0.8, and 0.8 to 1.2, indicating poorly sorted to very poorly sorted sandstones; 0.6 to 0.46, -0.08 to 0.19, and 0.07 to 0.25, indicating fine skewed with a few coarsely skewed; and 0.8 to 3.28, 0.81 to 1.5, and 0.93 to 1.23, indicating platykurtic, leptokurtic to mesokurtic, respectively. Grain size analysis indicates medium- to coarse-grained sandstones, with poor sorting indicating rapid deposition by strong, fluctuating currents. Bivariate plots help distinguish fluvial depositional environments from others. The C-M pattern of these sediments indicates transportation by bottom suspension. Pebble morphometric analysis and environment indicator plots suggest a fluvial paleoenvironment of deposition. A Mineralogical Maturity Index (MMI) of 14.30 and a Zircon-Tourmaline-Rutile (ZTR) index of 68.01% indicate mineralogically mature deposits and chemically immature to sub-mature sandstones. The combined results of granulometric statistics, morphometric indices, petrography, bivariate plots, and the absence of fossils or trace fossils suggest that these sediments were transported by rolling and bottom suspension over a short distance and deposited by a moderate- to high-energy fluvial system close to the source.

1. Introduction

Granulometric, morphometric, and petrographic analyses are extensively employed in sedimentology as effective methods for identifying sedimentary processes and depositional environments. The distribution of particle sizes is a crucial physical characteristic of sediment (Wang et al., 2021) and serves as an important tool for classifying sedimentary environments (Blott and Pye, 2001). The composition of sediments results from the source material, weathering, and transportation, linking sandstone framework compositions to their provenance (Dickinson et al., 1983). Grain size influences the entrainment, transport, and deposition of sediments, offering insights into their transport history, energy conditions, depositional environments, provenance, and mode of transportation (Blott and Pye, 2001; Boggs, 2009; Rahman et al., 2022).

Additionally, grain properties and textures impact porosity, permeability, and other rock properties (Boggs, 2009; Folk, 1966). Morphometric analysis can be used to determine provenance, weathering and transport history, energy conditions, and depositional environments (Barudžija et al., 2020; Boggs, 2006; Wadell, 1934). Sedimentary particles can exhibit a wide range of morphometric properties and shapes depending on their history (Boggs, 2006). Information can be derived from the clasts' size and shapes, their overall distribution and size fraction percentages, the sediment's textural maturity, the surface texture, and the general morphology of the particles (Krumbein and Sloss, 1963; Syvitski, 2007). Numerous researchers have utilized framework composition to enhance provenance models and deduce the tectonic origins of sandstones (Crook, 1974; Dickinson et al., 1983; Suttner et al., 1981; Weltje and Von Eynatten, 2004).

Provenance analysis of siliciclastic sedimentary rocks has been employed to uncover the composition and geological evolution of sediment sources and to characterize the tectonic setting of depositional basins (Zaid, 2013). Textural characteristics of sediments are influenced by sedimentary processes such as weathering, erosion, and transportation (Ilevbare and Omodolor, 2020). Parameters like mean grain size, sorting, skewness, and kurtosis provide insights into the size, shape, and sorting of grains.

Previous studies have used grain size statistics to interpret sandstone environments; for example, Keller (1945) and Mason and Folk (1958) examined beaches versus dunes, Friedman (1961) studied fluvial versus beach versus dune environments, and Rogers and Strong (1959) compared beaches and fluvial settings. Different grain size distributions correspond to variations in transport and depositional processes, reflecting the distinct sedimentary environments (Ma et al., 2020). Sedimentologists focus on three main aspects of grain size (Boggs, 2006): (a) measurement methods, (b) techniques for presenting data graphically or statistically for easy evaluation, and (c) the genetic relevance of the data.

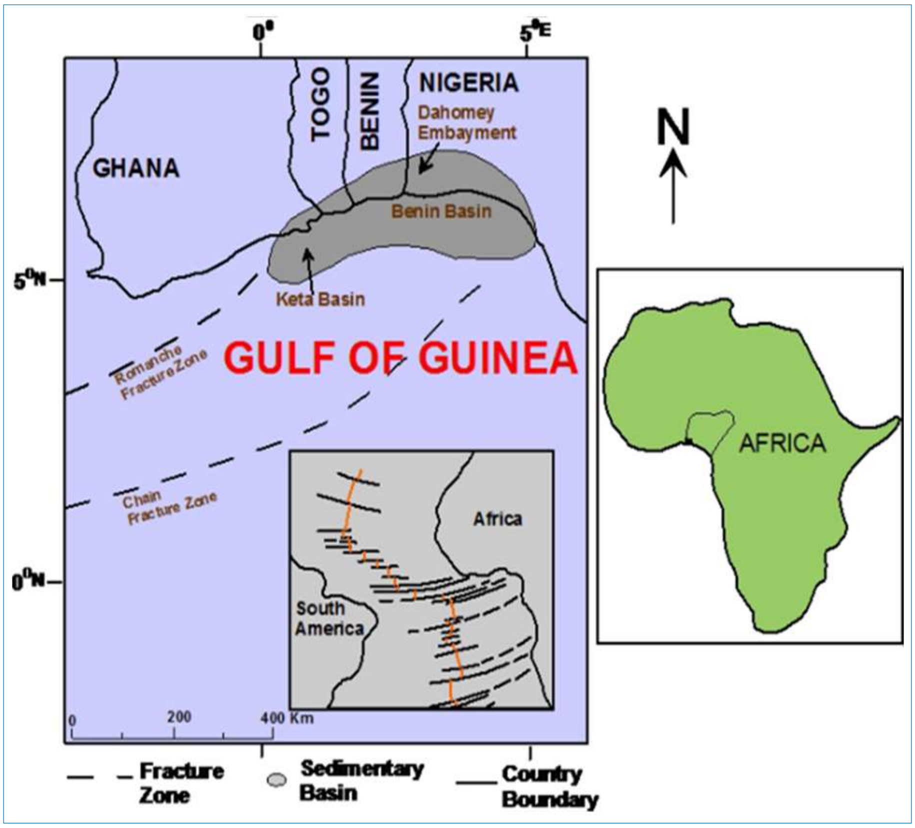

Fig. 1. Dahomey Basin is shown on a regional Gulf of Guinea map in respect to other basins (Adapted from Brownfield et al., 2006)

Grain size data can be represented graphically or mathematically/statistically. The graphical method involves plotting grain size data, while the mathematical approach uses statistical variables such as mean, sorting/standard deviation, kurtosis, and skewness. In pebble morphometric studies, form indices have proven useful for indicating depositional environments (Pettijohn, 1975; Barudzija et al., 2020). Three main parameters control the morphometric characteristics of clastic sediments: shape, roundness, and sphericity (Boggs, 2006). Clast shape is influenced by factors such as the original grain shapes from the source area, orientation and fracture spacing in bedrock, sediment transport intensity and nature, and post-depositional processes that might alter the clasts original shape (Boggs, 2006). For example, sphericity reflects depositional conditions, while roundness indicates the degree of abrasive history (Pettijohn, 1975). Pebble morphometry has been instrumental in distinguishing between modern beach and river sediments, aiding in reconstructing ancient sedimentary environments (Blatt, 1959; Cailleux, 1945; Dobkins and Folk, 1970). Despite their utility in studying siliciclastic sedimentary rocks, grain-size parameters have limitations. One major limitation is the alterations or modifications that a framework component undergoes due to diagenesis (Ahmad et al., 2021; Ghaznavi et al., 2019). Nonetheless, grain size parameters have been effectively used in previous research to understand sediment transportation mechanisms, provenance, and depositional environments. The Tertiary section of the Nigerian sector of the Dahomey Basin presents a significant challenge due to the lack of comprehensive sedimentological data; to address this challenge, this study's main goals are to characterize the sandstone and understand the paleo-depositional environment of the Tertiary sediments from the Nigerian sector of the Dahomey Basin. This approach is essential for advancing geological knowledge and driving sustainable development in the region.

2. Regional Geology and Tectonic Settings

The Dahomey Basin (Fig. 1) in Nigeria borders the Niger Delta Basin's northwest axis and stretches westward across Western Nigeria to the Volta Delta Complex in Ghana (Whiteman, 1982). It is separated from the Northern Niger Delta Basin in the southeast by the Okitipupa Ridge, a submarine basement high and an extension of the Ilesha Spur. A fault defines the Benin hinge line, which is located near the ridge's southeasterly tip. (Adegoke and Omatsola, 1981; Ejedawe and Coker, 1984). Sedimentary formations from the Cretaceous to the Tertiary make up the Basin and are exposed in an arcuate strip that runs nearly parallel to the former coastline (Omatsola and Adegoke, 1981).

According to prior research, the basin has remained largely steady throughout the Cretaceous period, with the main factors affecting sedimentation being subsidence, uplift, and alterations in sea level. Tertiary basin formation appears to be somewhat complicated, due to differing structural characteristics and depositional patterns, the Cretaceous and Tertiary ages can be distinguished by this feature. Overlying the basement rocks across the basin is the Abeokuta Group, which comprises several folded conglomerates consisting of sandstones and sands with kaolinitic clay intercalation.

The other subgroups of the Abeokuta Group are the Early Cretaceous Ise Formation, the Cenomanian to Maastrichtian Araromi Formation, which is roughly equivalent in age to the "Npkoro Shale" in the Anambra Basin, and the Afowo or Agwu Formations, which is made up of Cenomanian shales and Turonian sandstone. Above the Abeokuta Group are the Paleocene-Lower Eocene Ewekoro Formation and the Eocene Akinbo Formation.

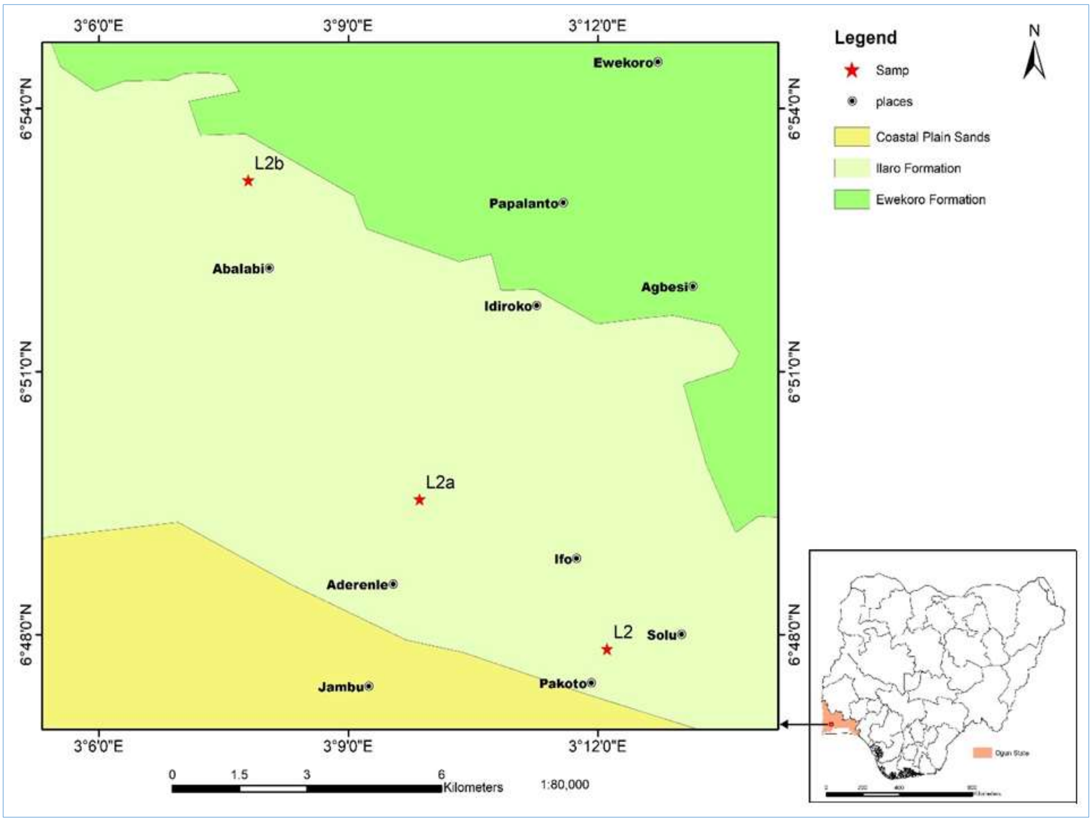

Fig. 2. Geological map of the studied location

The Ewekoro Formation consists of coquinoidal limestone, whereas the Akinbo Formation consists of shallow marine shale and clayey succession. The Imo Formation is comparable to the Akata Formation in the Niger Delta and the Ewekoro Formation in the Eastern Dahomey Basin. The marine and sandy shales of the Eocene Oshosun Formation, which sits on top of the Imo Formation, are usually dominated by phosphatic minerals. At the Ilaro type locality, the Ilaro Formation, which overlies the Oshosun Formation, consists of massive, fine- to coarse-grained, crossbedded sandstones and clays, with occasional phosphate beds. The most recent geological segment within the Dahomey Basin, extending from the western to the eastern regions, is the Miocene to Recent Benin Formation. This formation consists mainly of sand sequences found in marine shelf environments. They are also used as filling materials in construction works and as a major constituent in fertilizer production. Sediments rich in clay minerals occur as weathered regolith above basement rocks, especially where the rocks are rich in silicate minerals; or as materials carried into depositional basins during erosional phase. The Benin Formation (Fig. 1) is one of the sedimentary basins in Nigeria characterized by the deposition of sediments. Although there have been a number of studies in the Benin Formation, the clay deposits of the Benin Formation have not been fully explored by researchers.

2.1. Location and geology of the Study Area

The research area and its surroundings are located in Papalanto, Ajegunle and Ifon situated within the Ilaro Formation. Major and minor roads, as well as other nearby routes, make the studied location accessible. The map depicting the study's location, the sampling points, and the geological map were generated by collecting GPS coordinates during field investigations (Fig. 2). The region, which spans portions of Ondo and Ogun states of southwest Nigeria, is located within Nigeria's humid tropical rainforest zone. It has high and lowlands and is undulating. The thinnest part of the basin is from Abeokuta to Ifon about 15 km and towards the east (Ore) after Ijebu-Ode is the deepest basin ward part of the Basin. Erosional activities have resulted in the present-day topography of the area. Geological outcrop sections are distributed, showing a good representation of the area.

3. Methodology

The methods employed in this paper are granulometric, petrographic, heavy mineral separation, paleocurrent, and pebble morphometric analyses. The analyses were carried out in laboratories at the Department of Geology, University of Benin, Nigeria.

3.1. Granulometric analysis

Granulometric analysis was aimed at determining the size of the particles and their distribution within the rocks in the study area. The samples were first air-dried. Twenty-five (25) samples were selected for the grain size analysis by sieving. The samples were sieved through a nest of eight standard sieves that have progressively smaller openings at 1 phi intervals in a Ro-top mechanical sieving machine for 10 minutes.

The portion remaining within each sieve is weighed using a precise weighing scale. The obtained weights were then converted into weight percent, cumulative weight percent, and passing percentage. Using probability paper, the cumulative weight percent was plotted versus the mesh size in phi units. Percentile values of Φ5, Φ16, Φ25, Φ50, Φ75, Φ84 and Φ95 are derived from the Probability plots were created using Folks (1974) principles to calculate textural metrics such as mean grain size, sorting or standard deviation, skewness, and kurtosis.

3.3. Heavy mineral analysis

The method used for the heavy mineral separation was the gravity settling method as prescribed by Milner (1962) and the heavy minerals were identified using a reflecting microscope. The Zircon, Tourmaline, Rutile (ZTR) Index was calculated using the percentage of the combined zircon, tourmaline and rutile grains for each sample (Hubert, 1962).

Table 1. Sedimentology parameters of sandstone sediments at Ajegunle outcrop, Ilaro Formation

No	Median	Mean Description	Std. Deviation Sorting Type	Sk Skewness Type	KG Kurtosis Type
1	1.60	0.98- Coarse Sand	1.21- Poorly Sorted	-0.97- Strong Coarse Skewed	1.07- Mesokurtic
2	1.70	1.07-Medium Sand	1.04- Poorly Sorted	-0.40- Strong Coarse Skewed	1.45- Leptokurtic
3	1.50	1.59- Medium Sand	1.11- Poorly Sorted	-0.27- Coarse Skewed	1.27- Very Platykurtic
4	1.70	1.14- Medium Sand	1.28- Poorly Sorted	1.00- Strong Fine Skewed	0.80- Very Leptokurtic
5	1.20	1.02- Medium Sand	1.06- Poorly Sorted	0.19- Fine Skewed	1.41- Leptokurtic
6	1.30	1.10- Medium Sand	1.12- Poorly Sorted	0.26- Fine Skewed	1.52- Leptokurtic
7	1.50	1.09- Medium Sand	1.38- Poorly Sorted	-0.70- Strong Coarse Skewed	0.76- Leptokurtic
8	1.70	1.65- Medium Sand	-0.11- Poorly Sorted	-0.77- Coarse Skewed	1.30- Platykurtic
9	0.80	1.11- Medium Sand	1.21- Poorly Sorted	0.71-Strong Fine Skewed	0.77-Platykurtic
10	1.90	1.30- Medium Sand	1.04- Poorly Sorted	0.05- Strong Coarse Skewed	0.10- Mesokurtic
11	1.00	1.50- Medium Sand	1.25- Poorly Sorted	0.07- Near Symmetrical	0.93- Mesokurtic
12	1.50	1.23- Medium Sand	1.19- Poorly Sorted	-0.11- Coarse Skewed	0.99- Mesokurtic

Table 2. Sedimentology parameters of sandstone sediments at Papalanto outcrop, Ilaro Formation

No	Median	Mean Description	Std. Deviation Sorting Type	Sk Skewness Type	KG Kurtosis Type
1	1.70	1.63- Medium Sand	1.25- Poorly Sorted	-0.18-Strongly Coarse Skewed	0.65- Very Platykurtic
2	1.70	1.60- Medium Sand	1.08- Poorly Sorted	-0.40-Strongly Coarse Skewed	1.17-Leptykurtic
3	1.70	1.50- Medium Sand	1.30- Poorly Sorted	-1.00- Strong Coarse Skewed	1.56- Leptokurtic
4	1.80	1.70- Medium Sand	1.30- Poorly Sorted	-0.87- Strong Coarse Skewed	1.60- Platykurtic
5	0.80	0.70- Coarse Sand	1.21- Poorly Sorted	-0.97- Strong Coarse Skewed	1.07- Mesokurtic
6	0.20	0.30- Coarse Sand	1.30- Poorly Sorted	0.88-Strong Fine Skewed	1.61-Platykurtic
7	1.10	1.79- Medium Sand	1.23- Poorly Sorted	-0.20- Coarse Skewed	1.56- Platykurtic
8	0.50	0.73- Coarse Sand	1.10-Poorly Sorted	-0.25- Coarse Skewed	1.19- Very Platykurtic
9	0.80	0.87- Coarse Sand	1.00- Poorly Sorted	-0.97-Strongly Coarse Skewed	1.09-Mesokurtic
10	1.00	1.07- Medium Sand	1.21- Poorly Sorted	-0.27- Coarse Skewed	1.58- Platykurtic
11	0.90	0.90- Coarse Sand	1.31- Poorly Sorted	0.57- Strong Fine Skewed	1.53- Leptokurtic
12	1.00	1.17- Medium Sand	1.70- Poorly Sorted	-0.70- Strong Fine Skewed	0.77- Platykurtic

Table 3. Sedimentology parameters of sandstone sediments at Ifon outcrop, Ilaro Formation

No	Median	Mean Description	Std. Deviation Sorting Type	Sk Skewness Type	KG Kurtosis Type
1	1.30	1.3- Medium Sand	1.02- Poorly Sorted	-0.03- Near Symmetrical	1.07- Mesokurtic
2	1.50	1.40- Medium Sand	0.95- Moderately Sorted	-0.13- Coarse Skewed	1.23-Leptokurtic
3	1.60	1.53- Medium Sand	1.05- Moderately well sorted	-0.11- Coarse Skewed	1.22-Leptokurtic
4	1.30	1.30- Medium Sand	1.10- Poorly Sorted	-0.11- Coarse Skewed	0.98-Mesokurtic
5	1.20	1.27- Medium Sand	0.98- Moderately Sorted	0.08- Near Symmetrical	1.01-Mesokurtic
6	1.40	1.37- Medium Sand	1.18- Poorly Sorted	-0.07- Near Symmetrical	1.03-Mesokurtic
7	0.30	0.40- Coarse Sand	0.87- Moderately Sorted	0.25- Fine Skewed	0.96-Mesokurtic
8	1.30	1.30- Medium Sand	1.04- Poorly Sorted	0.05-Strongly Coarse Skewed	0.10-Mesokurtic
9	1.40	1.50- Medium Sand	1.25-Poorly Sorted	0.07- Near Symmetrical	0.93-Mesokurtic
10	1.30	1.23-Medium Sand	1.19-Poorly Sorted	-0.11- Coarse Skewed	0.99-Mesokurtic

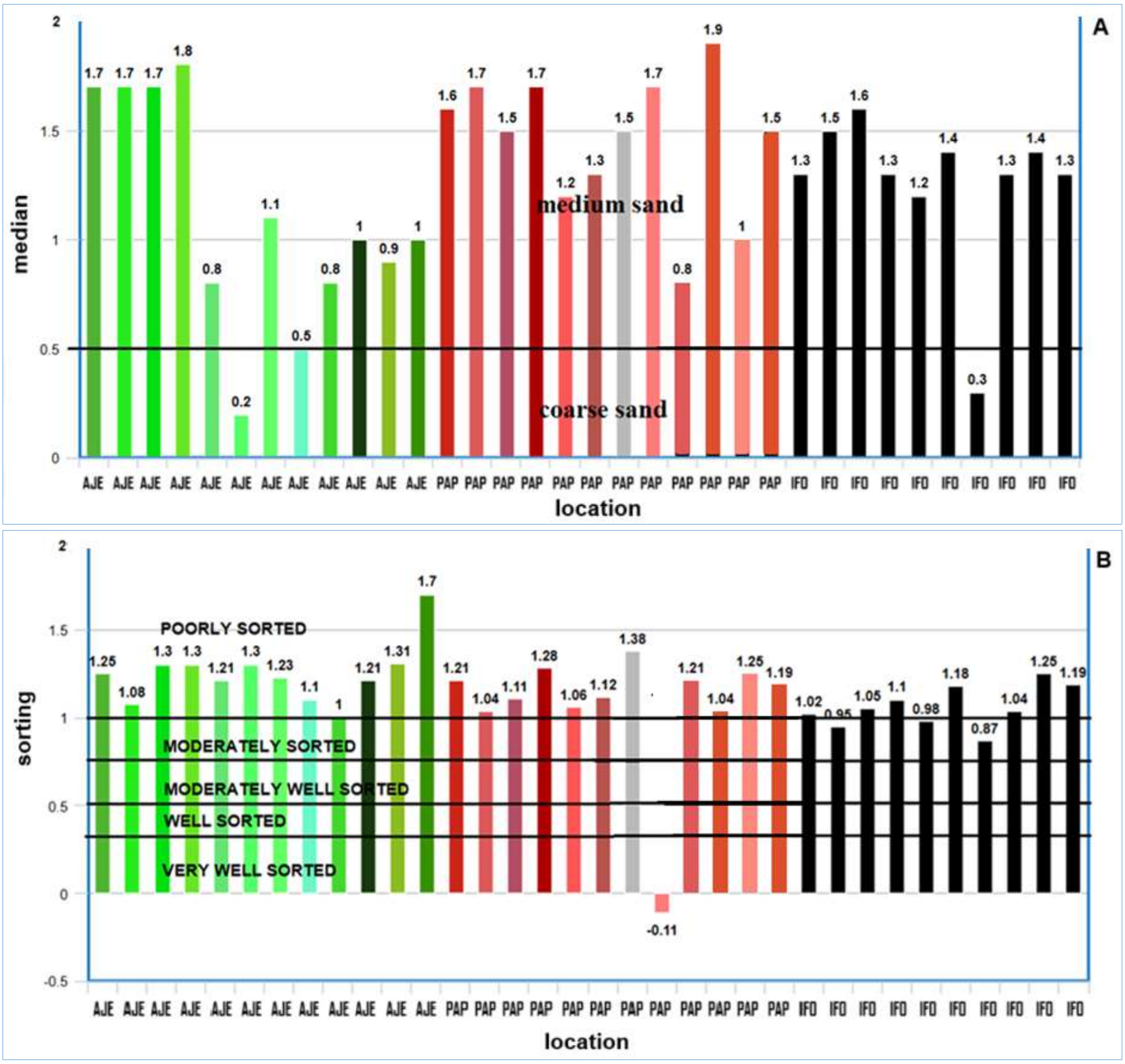

Fig. 3 (A and B): Calibrated median and sorting statistical variables of sands in Ajegunle, Papalanto, and Ifon outcrops, Ilaro Formation, (Modified after Phani, 2014)

3.4. Petrographic analysis

A total of twenty-five (25) sandstone samples were selected for petrographic analysis. The procedures described by Ekwenye et al. (2015) were followed for the petrographic analysis. Twenty-five thin sections were prepared and studied using petrographic microscopes for mineral identification under plane-polarized light (PPL) and cross-polarized light (XPL). Sandstone classification was done using the ternary diagram for mineral-based apexes of quartz (Q), feldspar (F) and rock (RF) after Folk (1974) and Pettijohn (1975).

3.5. Paleocurrent analysis

The azimuth and dip of cross-bedded sandstones were measured in the field using a compass clinometer. The values obtained were then plotted on a rose diagram to determine the provenance and the direction of the ancient current flow.

4. Results

4.1. Sedimentology Parameters of Ilaro Sandstones (Ajegunle, Papalanto, and Ifon Outcrops)

Table 1 presents the sedimentological results of sandstones from the Ajegunle outcrop in Ilaro Formation indicating medium normal with poorly sorted grains; the majority of these grains are coarsely skewed (66.67%), followed by finely skewed (25%) and nearly symmetrical (8.3%) grains. 25% of the sediments are mesokurtic, 41.7 % are leptokurtic, and 25% are platykurtic. Most of the sediments are leptokurtic (Table 1). Table 2 presents the sedimentological result of sandstone from the Papalanto outcrop in Ilaro and it depicts poorly sorted coarse to medium sands, with 25% of the grains being finely skewed and 75% of the grains being coarsely skewed. 16.7% of the sandstone is mesokurtic, 58.3% of it is platykurtic, and 25% of it is leptokurtic (Table 2). Ifon outcrops depicted sands with a sorting grade of poor to moderate. 40% very coarse skewed and 60% coarse skewed data. 80% of the sands are mesokurtic, and 20% are leptokurtic. (Table 3).

Table 4. Grain size, with minimum, maximum, and average values for Ajegunle, Papalanto, and Ifon sandstone outcrops, Ilaro Formation

Location		Mean	Sorting	Skewness	Kurtosis
Ajegunle	Max.	1.7	1.5	0.6	3.28
	Min.	0.30	0.3	0.46	0.8
	Avg.	1.0	0.9	0.26	2.04
Papalanto	Max.	2.0	0.8	0.19	1.5
	Min.	0.7	0.5	-0.08	0.81
	Avg.	1.35	0.65	0.05	1.16
Ifon	Max.	1.5	1.2	0.25	1.23
	Min.	0.40	0.8	0.07	0.93
	Avg.	0.95	1.0	0.09	1.08

The graphic mean, a central tendency indicator (Gz) can be determined using the formula in *Appendix*. The measured values for the sandstones in Ajegunle, Papalanto, and Ifon, respectively, ranged from 0.3 to 1.7, 0.7 to 2.0, and 0.4 to 1.5 (Table 4). The vales have a predominance of medium to coarse sand-size sediments in general (Fig. 3A).

The particle size distribution sorting or homogeneity is depicted by the graphic standard deviations. The values vary from 0.3 to 1.5, 0.5 to 0.8 and 0.8 to 1.2 (Table 4) for the sandstone in Ajegunle, Papalanto, and Ifon, respectively. Find the formula for its computation in *Appendix*. The sample as a whole is largely poorly sorted. (Fig. 3B).

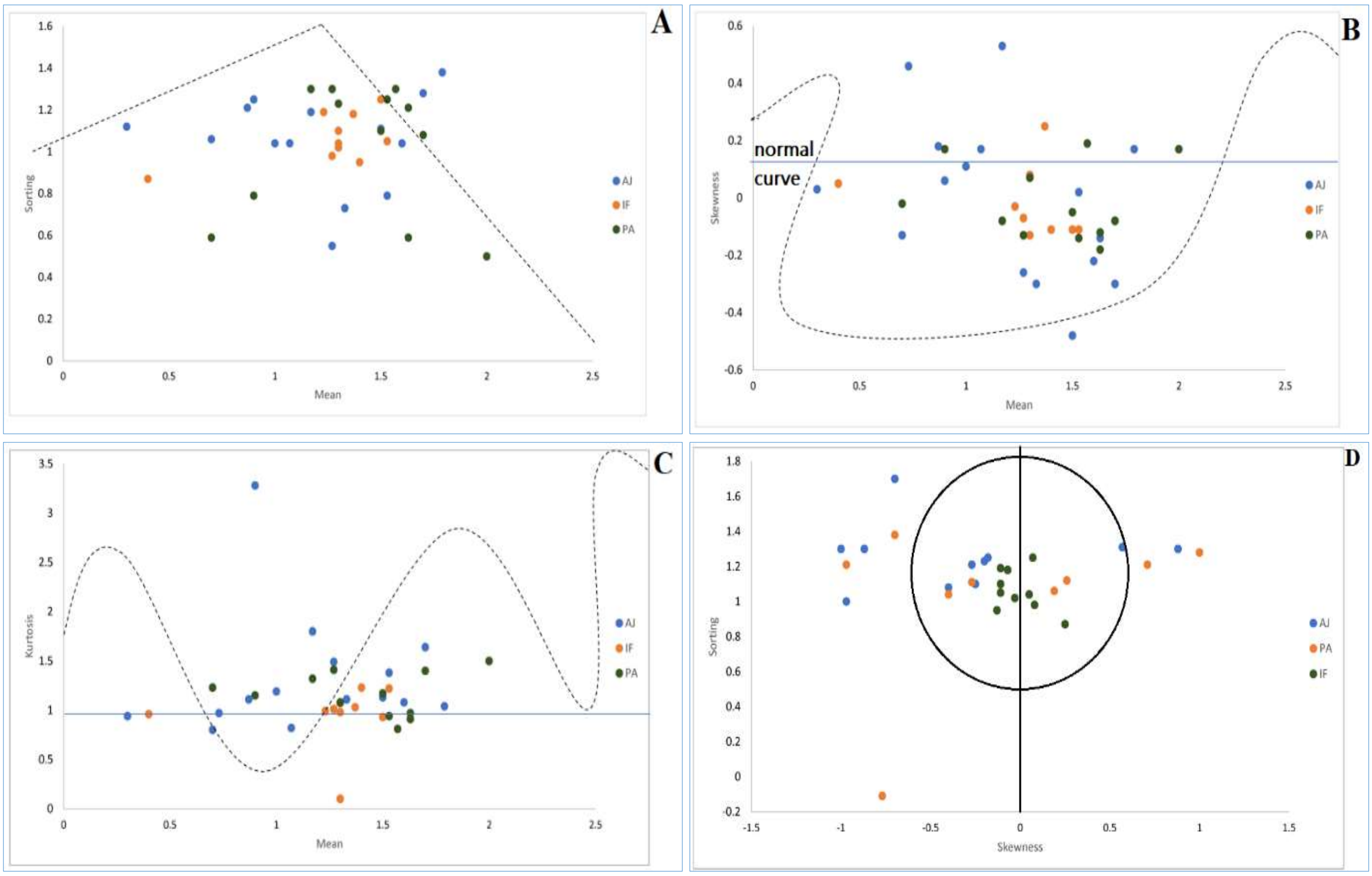

Fig. 4. A) Comparison of Sorting against Mean, B) Skewness versus Mean, C) Kurtosis versus Mean and D) Sorting versus Skewness bivariate diagrams illustrating the positioning of the current data within the adapted modal plot, as per Phani (2014)

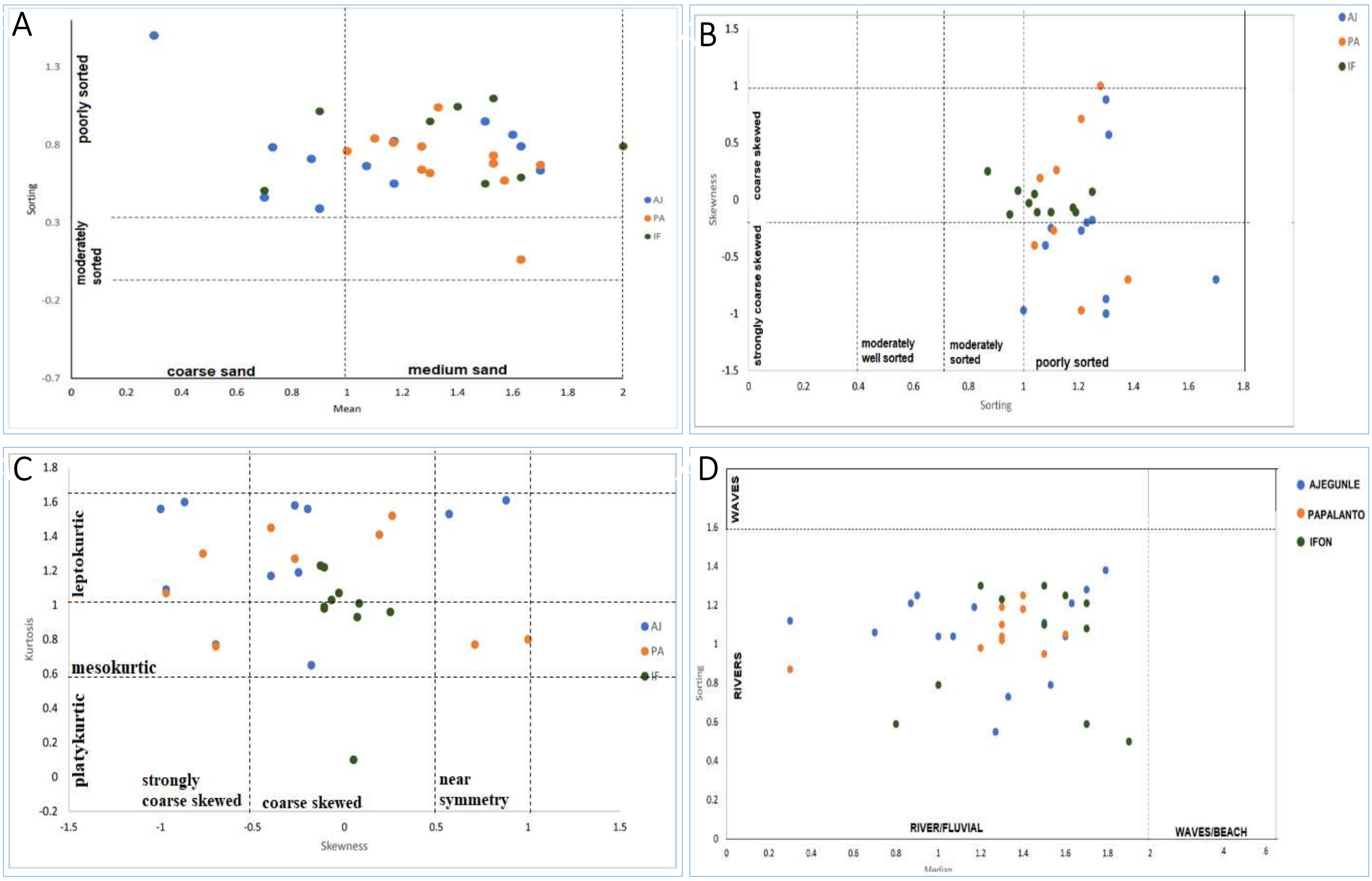

Fig. 5. A) Bivariant plot of Sorting against Mean, B) Bivariant connection of Skewness and Sorting, C) Bivariant relationship between Kurtosis and Skewness and D) Bivariant plot of Inclusive Standard Deviation (Sorting) vs. Median (modified after Friedman, 1961 and Miola and Weiser, 1968)

The ratio between sorting the tail and the center region of the curve is measured by the graphic kurtosis (KG), which is the distribution's peak. If the tail is more carefully sorted than the center, it is said to be platykurtic; conversely, the leptokurtic situation exists when the central portions are better sorted. Both have mesokurtic conditions if they are equally sorted.

The values for the sandstone in Ajegunle, Papalanto, and Ifon are 0.8 to 3.28, 0.81 to 1.5, and 0.93 to 1.23, respectively (Table 4). Due to the significant share of medium-grained material, the sandstone in Ajegunle is platykurtic, the sandstone in Papalanto is leptokurtic, and the sandstone in Ifon is mesokurtic. The graphical skewness measures the organized dispersion of the majority of medium to coarse sediments (Sk). The negative numbers contribute coarsely skewed materials, whereas the positive values indicate more materials that are finely skewed. The range of the values is (0.6 to 0.46), (-0.08 to 0.19), and (0.07 to 0.25) (Table 4) for the sandstone found in the locations of Ajegunle, Papalanto, and Ifon, respectively.

From Table 4, it can be seen that the sandstone at Ajegunle is medium-grained sand, with a graphic mean of 1.0 and poorly sorted grains from an average inclusive graphic mean of 0.9. The (0.263 and 2.041) values for skewness and kurtosis point to sands that are finely skewed and leptokurtic. The sandstone in Papalanto is medium-grained and has an average graphic mean of 1.35phi. The average values for inclusive graphic mean, skewness, and kurtosis are 0.65, 0.05, and 1.155, respectively. These values result in sands that are poorly sorted, almost symmetrical, and platykurtic.

According to average values of 0.95 and 1.0 for the graphic mean and inclusive graphic mean (Table 4), medium to coarse sands with poor sorting characterize the sandstone in the Ifon outcrop. Moreover, typical values of 0.09 and 1.082 for the skewness and kurtosis suggest that the grain exhibits mesokurtic characteristics.

The inverted V-shaped trend's left limb's collection of points in a limited scope of mean values is depicted by the mean and standard deviation plot (Fig. 4A).

According to Folk and Ward's (1957) sinusoidal curve, the medium to coarse sand from the examined samples falls into a negatively to positively skewed area, demonstrating that it is of medium-grained, poorly sorted character and comes from a fluvial environment. The sample data mean vs. skewness curve indicates two size classes of the sediments are mixed proportionally (Fig. 4B). The same conclusion is shown by the Mean vs. Kurtosis plot (Fig. 4C). All samples are coarse to nearly symmetric, according to the Graph of Skewness and Standard Deviation, most of the data points fall inside the circle in (Fig. 4D). The graphs depicting the relationship between standard deviation and kurtosis, as well as skewness and kurtosis, reveal that the sediment characteristics are mainly confined to a limited kurtosis range, primarily from mesokurtic to leptokurtic which agrees with statistical analysis. These graphs validate the conclusion reached based on the prior bivariant plot.

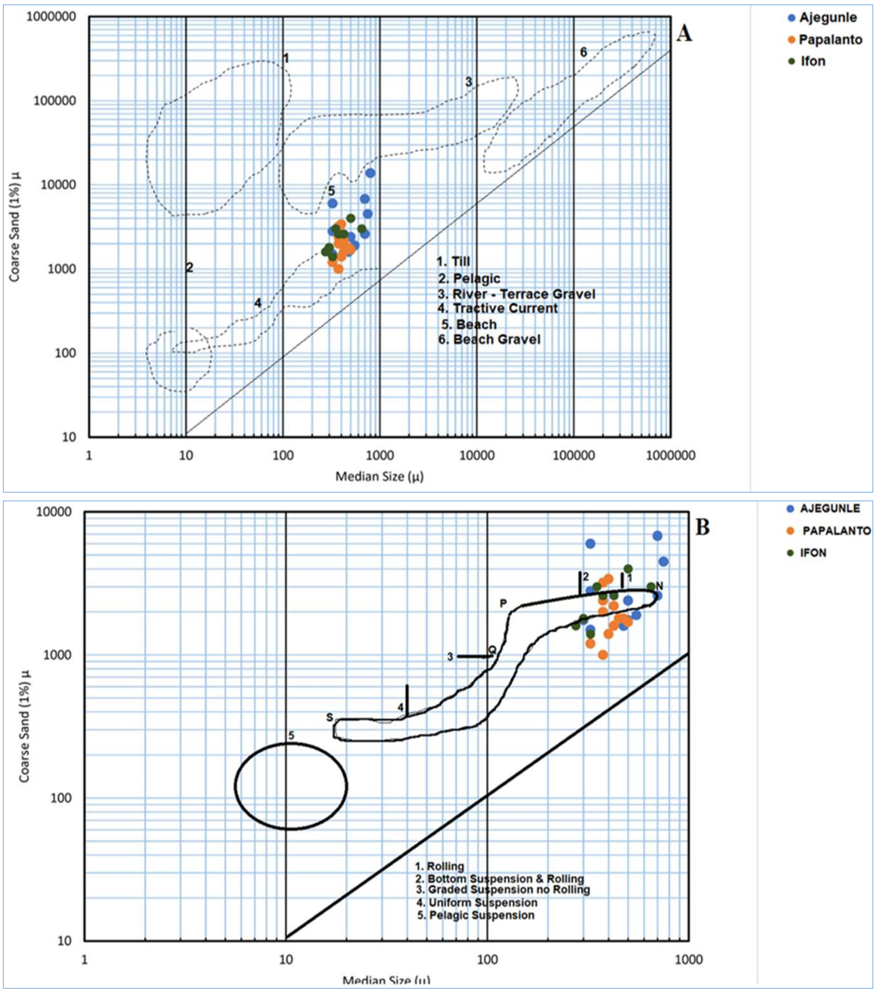

Fig. 6. (A) Diagram from a CM plot by Passega (1957; 1964) and (B) Tractive current deposit of sediments in Ilaro Formation

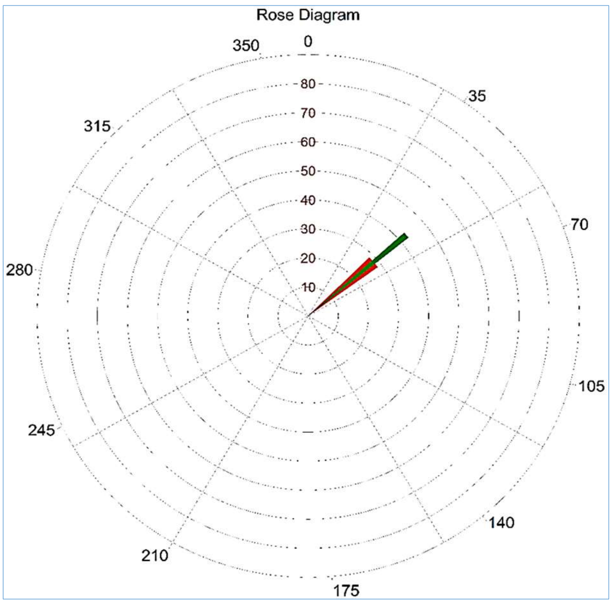

Fig. 7. Rose diagram depicting dominant paleocurrent flow directions in the cross bedded sandstone facies in the Ilaro Formation (Ajegunle, Papalanto and Ifon outcrops)

Table 5. Heavy minerals and ZTR index

Sample	Zircon	Rutile	Tourmaline	Staurolite	Garnet	Kyanite	Opaque	ZTR Index
AJ1	6	6	7	5	3	4	24	61.29
AJ2	7	5	7	4	2	4	23	65.52
AJ3	8	6	8	6	5	2	28	62.86
AJ4	8	5	6	4	3	2	29	67.86
AJ5	9	8	4	5	3	4	28	63.64
AJ6	6	7	8	6	5	3	30	60
AJ7	7	6	6	4	3	3	25	65.52
AJ8	8	6	5	4	2	4	27	65.52
AJ9	8	6	9	5	3	3	28	67.65
AJ10	7	7	9	6	2	2	29	69.7
PA1	7	5	6	3	4	3	26	64.29
PA2	5	6	5	4	4	5	29	55.17
PA3	6	7	5	3	5	2	28	64.29
PA4	7	7	5	5	4	4	26	59.38
PA5	9	8	10	4	3	3	29	72.97
PA6	8	6	7	5	4	2	30	65.63
PA7	9	5	8	4	2	2	27	73.33
PA8	10	6	8	3	4	2	29	72.73
PA9	8	8	9	6	4	2	26	67.57
PA10	6	5	7	4	3	3	26	64.29
IF1	8	6	4	3	2	3	27	69.23
IF2	7	7	8	4	3	4	28	66.67
IF3	8	7	6	5	4	3	26	63.64

Fig. 8. Photomicrograph of Heavy Mineral analysis of Sandstone located at Ajegunle, Papalanto and Ifon outcrops (30x). Legend: Z is for Zircon, R is for Rutile, T is for Tourmaline, G is for Garnet, S is for Staurolite, and O is for Opaque. The ZRT index is calculated by adding Z, R, and T, and then dividing this sum by the total opaqueness. The result is then multiplied by 100

4.2. Bivariant Relationship of Some Grain Parameters

Sedimentologists have attempted to discern between various depositional settings by utilizing the bivariant plot (Fig. 5). This approach is grounded in the idea that the reliability of statistical parameters reflects variations in the mechanisms governing the flow of fluids during sediment transport and deposition, as suggested by Sutherland and Lee (1994). Fig. 5A demonstrates that medium-sized, poorly sorted clusters are clustered. The outcome of the bivariant plots shows that the transit and depositional medium have intermediate to high energy, it is indicative of a fluvial environment. The Ilaro sediments' sorting and skewness relationships are depicted in Fig. 5B. The sandstone data points are concentrated in the coarse to severely coarse skewed range, indicating environments where erosion and deposition effects are almost balanced (Akofure and Akane, 2019).

According to Friedman (1961), dune sand can be found in fluvial, Barrier Island, or coastal lake environments and is typically positively skewed. Evaluating how normal the size distribution is, the Kurtosis against Skewness plot (Fig. 5C) is a very effective tool for understanding the formation of sediment (Folk, 1966). The graphic demonstrates that the Mesokurtic to Leptokurtic range includes the Ilaro deposits. As per Friedman's 1962 findings, most sands fall within the leptokurtic range and exhibit either positive or negative skewness.

Friedman (1962) suggests that Kurtosis values that are exceptionally high or exceptionally low may indicate that certain sediments underwent sorting processes in high-energy environments. Leptokurtic to very leptokurtic and platykurtic to very platykurtic sediments, then, arise from environments with extremely low and high energy levels (Dora et al., 2011). The mesokurtic to leptokurtic pattern evident in Fig. 5C indicates that the Ilaro sediments were laid down in an environment characterized by moderate high energy. This observation confirms that there were fluctuations in energy levels during the sediment deposition process.

To distinguish the variations in river, wave, and slack water processes between beach and dune sands, the comparison of standard deviation and median size has been employed. (Friedman, 1961; Miola and Weiser, 1968). To define these limits, they sorted by median. The graphic that matches and resembles Friedman's (1961) original was plotted with the samples of Ilaro sandstone. The figure shows sediments from rivers (Fig. 5D).

4.3. Analysis of CM Pattern of Ilaro Sandstone

The Ilaro Sandstone's plotted data demonstrates that it was by bottom suspension transportation (Fig. 6A) in a setting with a tractable current (Fig. 6B). This outcome is consistent with Rajganapathi et al., (2012).

4.4. Paleocurrent Analysis

Paleocurrent analysis makes use of main sedimentary features known as directional structures that can be used to quickly determine which direction the depositing current was flowing at a certain point in geologic time. Cross beddings, sole marks, and grain fabric were included in the list of these essential characteristics provided by Potter and Pettijohn (1977) and Pettijohn (1975).

Table 6. Study of Sandstone's compositional and textural maturity

Sample	Quartz (Grain Type)	Angular boundary	Number of count	Ratio of polycrystalline to Monocrystalline	Textural maturity	Compositional maturity
AJE 1	Polycrystaline Monocrystaline	Angular to sub-angular Sub-rounded to Rounded	55 42	55:42	Mature	Mature (= 90%Qtz)
AJE 2	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	57 49	57:49	Mature	Mature (= 90%Qtz)
AJE 3	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	49 61	61: 50	Mature	Mature (= 91%Qtz)
AJE 4	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	52 46	52: 46	Mature	Mature (=89%Qtz)
AJE 5	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	59 50	59: 50	Mature	Mature (= 91%Qtz)
AJE 6	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	60 45	60: 45	Mature	Mature (= 92%Qtz)
PAP 1	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	61 52	61: 52	Mature	Mature (= 90%Qtz)
PAP 2	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	58 41	58: 41	Mature	Mature (= 91%Qtz)
PAP 3	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	60 51	60: 51	Mature	Mature (= 90%Qtz)
IFON 1	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	59 43	59: 43	Immature	Mature (= 90%Qtz)
IFON 2	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	60 47	60: 47	Mature	Mature (= 90%Qtz)
IFON 3	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	63 45	63: 45	Immature	Mature (=91%Qtz)
IFON 4	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	53 44	53: 44	Immature	Mature (= 91%Qtz)
IFON 5	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	61 49	61: 49	Mature	Mature (= 90%Qtz)
IFON 6	Polycrystaline Monocrystaline	From angular to sub-angular Sub-rounded to Rounded	54 46	54: 46	Immature	Mature (= 90%Qtz)

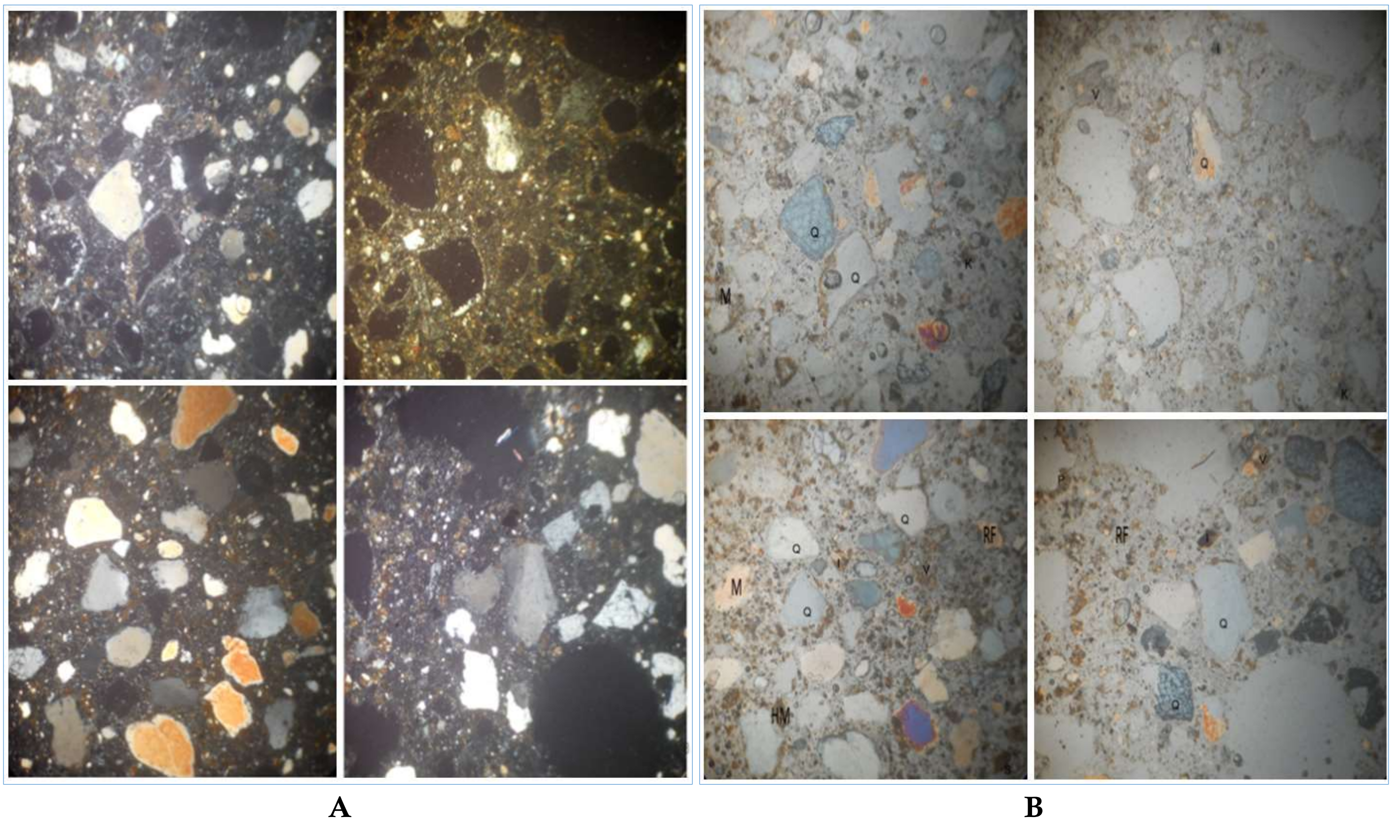

Fig. 9. A) Photomicrographs of sandstones thin section under Cross Polarized Light (XPL) and B) Photomicrographs of sandstones thin section under Plane Polarized Light (PPL) at Ajegunle, Papalanto and Ifon outcrops, Ilaro Formation. RF (Rock Fragments), Q (Quartz) and (Heavy Minerals)

Table 7. Mineralogical maturity and modal composition of sandstone facies

Sample	Quartz (Qtz)	Feldspar (FSP)	Rock (Lithic) Fragment (RF)	FSP + RF	MMI	Mineralogical Maturity Index (MMI)
AJE	90	2	4	6	90/6	15
AJE	90	3	4	7	90/7	13
AJE	91	2	3	5	91/5	18.2
AJE	89	3	4	7	89/7	12.71
AJE	91	2	4	6	91/6	15.16
AJE	92	2	4	6	92/6	15.33
PAP	90	3	5	8	90/8	11.25
PAP	91	2	4	6	91/6	15.16
PAP	89	3	3	6	90/6	15
IFON	91	2	4	6	90/6	15
IFON	90	3	4	7	90/7	15
IFON	91	2	4	6	91/6	12.85
IFON	89	3	4	7	91/7	13
IFON	90	2	4	6	90/6	15
IFON	90	3	4	7	90/7	12.85
Average	90.2	2.4	3.9	6.4		14.30

Table 8. Comparison of the percentage of mineral maturity of Ilaro Sandstone with Nwajide and Hoque (1985)

Nwajide and Hoque (1985)	Range percentage (%)	The present research
Quartz	95–90	90.20
F + RF	5–10	6.40
MMI	19–9.0	14.30
Maturity	Mature	Mature

Cross beddings reflect the lee-sides of migratory ripples and dunes that have been preserved, and they also have paleocurrent value, which represents the direction of paleoflow. The paleocurrent that predominated during deposition has been identified by measuring the dip azimuths of foresets from the investigated outcrops. The research demonstrates that cross beddings frequently exhibit the NE trend (Fig. 7).

4.5. Heavy Mineral Analysis of Ilaro Sandstone Facies

The Zircon- Tourmaline-Rutile (ZTR) index was computed (Table 5) from the assemblages of heavy minerals in the sandstone, and the results were used to estimate the chemical maturity of the sandstone (Table 5). This process was made easier by the petrographic analyses of the sandstone (Fig. 8).

4.6. Analysis of Maturity of Ilaro Sandstone Facies

The analysis indicated, except samples from Ifon outcrops, which are texturally immature but compositionally mature,

Table 6 demonstrates that the sandstone from the research locations is both texturally and compositionally mature. The photomicrographs, (Figs. 8 and 9) of the sandstone of the studied locations from the petrographic examination were found to be composed of Quartz (Q), Muscovite (M), Heavy minerals (HM) and Rock fragment (RF).

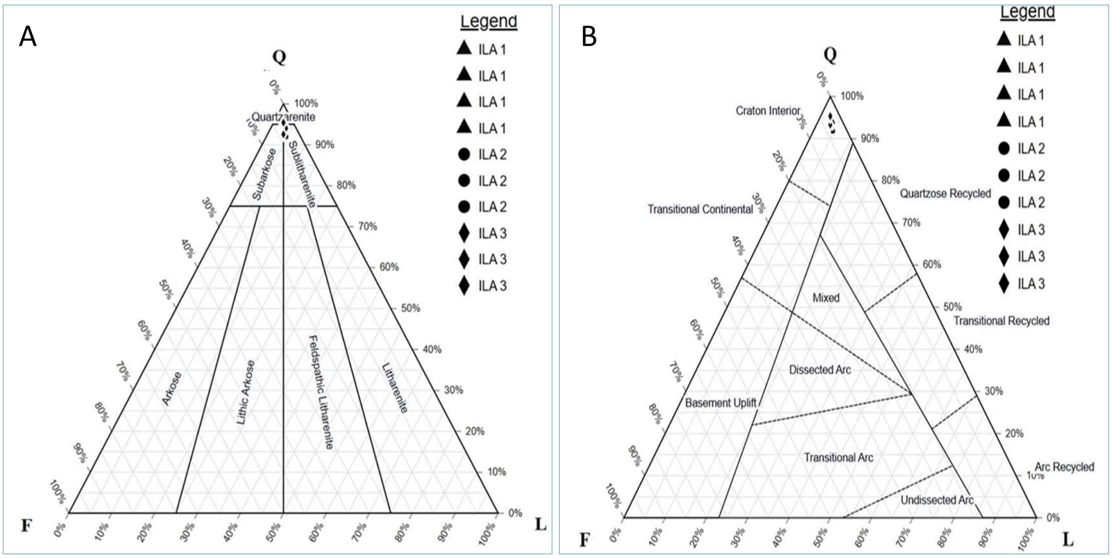

Fig. 10. A) QFL Classification Scheme illustrating the study areas' plot of Sandstone types (Folk, 1974) and B) QFL Ternary plot of Tectonic setting (after Dickinson, 1983)

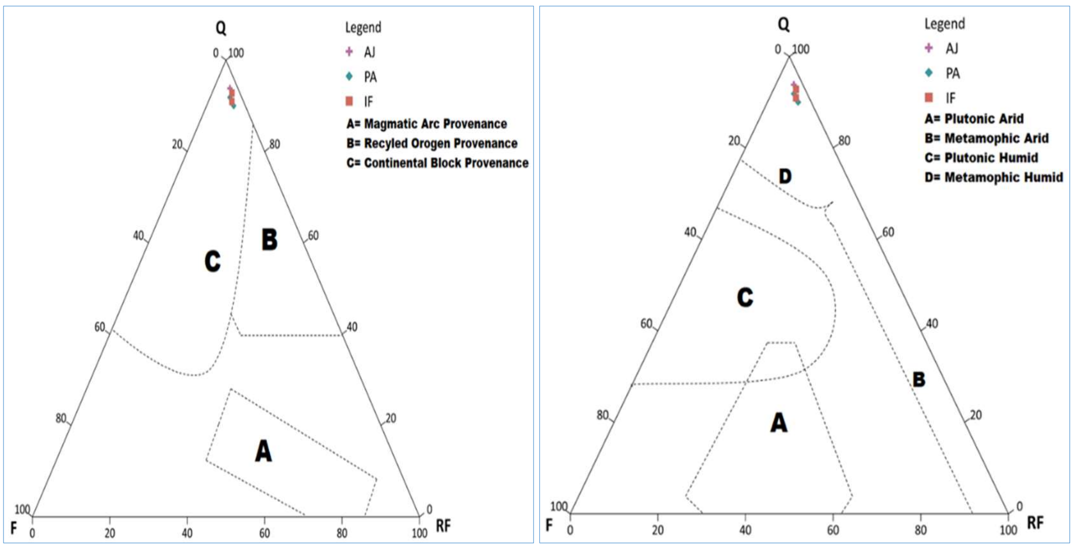

Fig. 11. A) Ternary plots of Provenance Setting for Ilaro Sandstone (modified after Dickinson, 1988) and B) Ternary plots for Paleoclimate for Ilaro Sandstone (modified after Sutherland, 1994)

Table 9. Average values of pebble morphometric data

Location	Long (cm)	Inter (cm)	Short (cm)	sh/lo	in/lo	Op. index	Form	Roundness	Lo-in/lo-sh	Maximum projection sphericity
AJE	1.21	0.84	0.37	0.30	0.69	-2.50	B	20	0.57	0.42
PAP	1.27	0.89	0.55	0.43	0.70	-0.77	B	20	0.46	0.70
IFON	1.31	0.78	0.55	0.42	0.59	0.86	CB	20	0.55	0.76
PAP	1.52	1.16	0.55	0.36	0.76	-4.88	P	20	0.29	0.61
IFON	1.36	1	0.66	0.48	0.73	-1.40	B	40	0.42	0.73
PAP	1.22	1	0.48	0.39	0.82	-5.11	P	20	0.26	0.63
AJE	1.63	1	0.65	0.40	0.61	-0.75	B	30	0.47	0.61
AJE	1.49	0.02	0.65	0.43	0.01	0.91	B	100	0.54	0.65
AJE	1.13	0.79	0.89	0.78	0.69	3.81	CE	40	0.74	0.82
PAP	1.69	1.00	0.76	0.45	0.59	1.60	CB	40	0.58	0.71
Average	1.38	0.84	0.6	0.44	0.62	2.26		35	0.49	0.66

Where; Long (L), Intermediate (I), and Short (S). Compact Elongate (CE) equals 10%; Platy (P) equals 20%; Bladed (B) equals 20%; and Compact Bladed (CB) equals 50%, respectively.

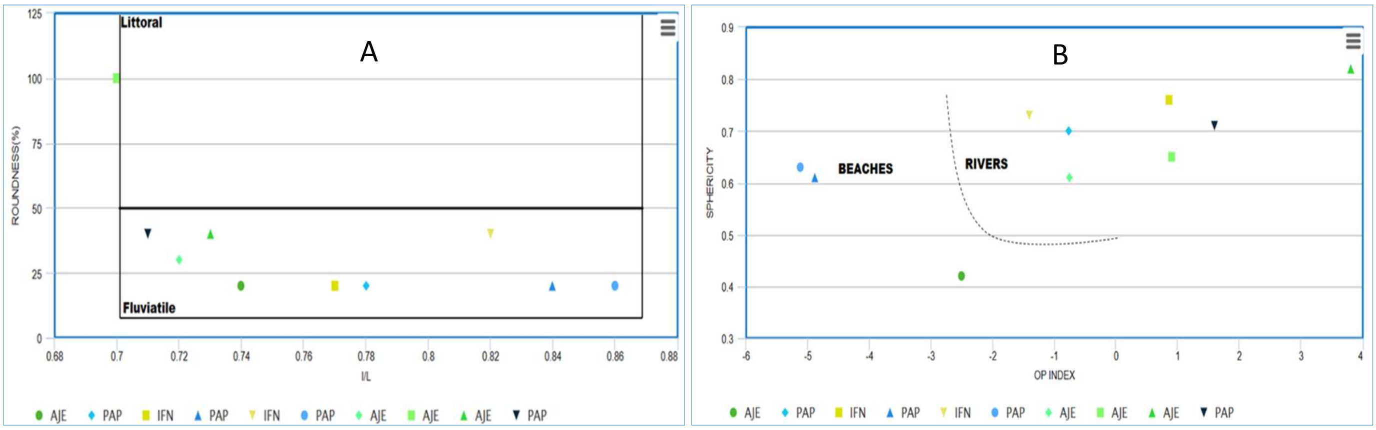

Fig. 12. A) Roundness versus Elongation Ratio (Sames, 1966) and B) Oblate versus Sphericity-Probate index (modified from Dubkins and Folk, 1970)

This mineral composition identification was used for the Modal composition of the sandstone (Table 6), from which the textural, compositional and mineral maturity index were determined (Tables 6 and 7). Ilaro Sandstone is hence mineralogically mature according to Nwajide and Hoque's (1985) classification system for mineral maturity (Table 8).

4.7. Ternary Diagrams of the Sandstone Facies in Ilaro Formation

The Sandstone is plotted in the quartz arenite zone, bordering the sub-arkose and sub-lithic arenite zones, according to the ternary plot from the thin section study. From Table 6, it can deduce that the sandstone samples located within the craton's inner region on the QFL ternary diagram (Figs. 10A and 10B) are mature. These sandstones likely originated from sources characterized by low-lying granitoid and gneissic formations, in accordance with Dickinson et al. (1983) findings, which may have involved recycled sands from adjacent platform or passive margin basins.

4.8. Depositional Paleoclimatic Conditions

Sediments in the area under study, plotted in the humid environment, according to the QFL (Fig. 10A), ternary plots (Fig. 10B) and a continental block provenance setting (Fig. 11) modified after Dickinson (1988) and Sutherland et al. (1994). The weathering processes are aided in the chemical maturity of the sediments by the humid climate's wet state. (Figs. 11A and 11B).

4.1.8. Morphometric Analysis and Its Environmental Indicator

Table 9 presents pebble morphometric data which can provide valuable information about pebble morphology to aid in the understanding of sediment transport and depositional processes. Pebbles in Ajegunle tend to be elongated while pebbles in Papalanto and Ifon show better roundness. The general trend reveals medium-sized pebbles (average of 1.38 cm), fairly elongated shapes (average lo-in/lo-sh ratio of 0.49 and moderate roundness (average of 62%).

Sames (1966) plot of roundness vs. elongation in the fluviatile environment has 99 percent of the data points, according to the results (Fig. 12A). This shows that a fluviatile paleoenvironment is where the sediments were deposited. According to the sphericity vs. oblate- shape indication, 97 percent of the data points once more fall within the category of a fluvial environment. (Fig. 12B). This further demonstrates that Ilaro Sandstone's environment of deposition was fluvial.

5. Conclusion

The Ilaro sandstones are older sediments from igneous-metamorphic source rocks, with mature sandstones originating from low-lying granitoid and gneissic sources. These sandstones may contain recycled sediments from associated platforms. The sediment in the study areas (Ajegunle, Papalanto, and Ifon) has standard deviation (sorting) average values of 0.7, 0.63, and 0.96 respectively. The sediments in the Ilaro formation are typically poorly sorted, suggesting they were deposited during periods of variable current velocity and turbulence. They fall within the range of 0.30 to 1.00 on the sorting scale, indicating a river or shallow marine environment. This is also supported by the bivariate plot (skewness against median), which plots in a fluvial environment, with 90% of plots in the fluviatile category. The indicator of sphericity vs. oblate probate (pebble morphometric analysis) shows that the pebbles of the sandstone under investigation in this research are in the river field (with a 70% plot of data points). The bivariant plot of skewness versus median, which charts in the river and fluviatile section for more than 90% of data plot points, further supports a fluvial environment. The outcomes are comparable when standard deviation (sorting) is represented graphically in relation to the median (which corresponds to a river or fluvial environment). The tractive current deposit diagram supports the predominating paleocurrent conditions from the sorting type. The Ilaro sediments were plotted on the CM diagram, showing they were in a beach and tractive current habitat. The mesokurtic to leptokurtic grains that make up the transport medium have an intermediate energy. Paleoenvironmental examinations using petrographic and sedimentological techniques found evidence of a fluviatile paleoenvironment that developed during humid paleoclimate. The sediments are 90.2 % quartz, 2.3% feldspar, and 3.9% lithic pieces, indicating a mature sandstone in terms of composition and mineralogy. The Zircon- Tourmaline-Rutile (ZTR) index was computed from the assemblages of heavy minerals in the sandstone, which was used to estimate the chemical maturity of the sandstone.

References

Adegoke, O.S., 1969. Eocene Stratigraphy of Southern Nigeria. Bulletining Bureau de Research Geologic ET Miners Memoir 69, 23-48.

Adegoke, O.S., 1977. Stratigraphy and Paleontology of the Ewekoro Formation (Paleocene) of South-Western Nigeria. Bulletins of American Paleontology 71 (296), 1- 275.

Adegoke, O.S., Ako, B.D., Enu, E.I., 1980. Geotechnical investigation of Ondo State bituminous sand Vol, 1 Geology and Research Estimate, Unpublished Geological Consultancy Department of Geology University of Ile-Ife, 257p.

Adegoke, O.S; Ogbe, F.A., Du Chene, R.E.J., 1970. Excursion to Ewekoro quarry (Paleocene- Eocene).

Adekeye, O.A., Holger, G., Samuel O.A., James A.A., Idris A.A., 2019. Biostratigraphic Analysis of the Cretaceous Abeokuta Group in the Eastern Dahomey Basin, Southwestern Nigeria, Journal of African Earth Sciences 152, 171-183.

Adekeye, O.A., Akande, S.O., Adeoye, J.A., 2019. The assessment of potential source rocks of Maastrichtian Araromi formation in Araromi and Gbekebo wells Dahomey Basin, southwestern Nigeria. Heliyon 5 (5), e01561. https://doi.org/10.1016/j.heliyon.2019.e01561.

Adeonipekun, P.A., Ehinola, O.A., Yussuph, I.A., Toluhi, A., Oyelami, A., 2012. Bio-Sequence Stratigraphy of Shagamu Quarry Outcrop, Benin Basin, Southwestern Nigeria. World Applied Sciences Journal 18 (1), 91-105.

Adegbenga, P., Adeonipekun, A.O, 2015. Palynology of Late Paleocene – Earliest Eocene Outcrop Sediments from Benin Basin, SW Nigeria: Implications for Paleoclimatology and PETM Record in the Tropics. Global Journal of Science Frontier Research: C Biological Science 15 (3), 15-26.

Afolayan, J.F. 2019. Reservoir Characteristics of Ilaro Formation in Dahomey Basin, Nigeria. Journal of Petroleum Exploration and Production Technology 9 (1), 727-738.

Ahmed, U., Ouenes, A., 2017. Reservoir Engineering Handbook (5th ed.).

Agagu, O.A., 1985. A geological scale guide to bituminous sediments in southwestern Nigeria. Unpublished/Rept. Dept of Geology, University of Ibadan pp. 2-16.

Agagu, O.K., Adighije, C.I.., 1983. Tectonic and Sedimentary framework of the Lower Benue Trough Southeastern. Journal of African Earth Sciences 1, 267-274.

Akande, S.O., Adekeye, O.A., Adeoye, J.A., Ojo, O.J., Adeoye, M.O., Dominic, W., Erdtmann, B.D., 2018. Burial and Thermal History of Cretaceous Sediments in the Dahomey, Anambra, and Gongola Rift Basins: Implications for Coal Facies Distribution and Petroleum Potential. Journal of Pure and Applied Sciences 3 (1), 308-325.

Akinsile, O., Adeyinka, S., Olusegun, O., Faseki, O., 2016. Palynology of the Cretaceous-Tertiary Sedimentary Succession of Sile Well, Offshore Dahomey Basin, Benin Republic. International Basic and Applied Research Journal (2) 8, 38-47.

Allen, P.A., Allen, J.R., 2005. Basin Analysis: Principles and Appl ications. Blackwell Scientific Publications, Oxford, 549 p.

Amorosi, A., 1995. Glaucony and sequence stratigraphy: A conceptual framework of distribution in siliciclastic sequences: Journal of Sedimentary Research B65, 419-425.

Amorosi, A., 1997. Detecting compositional, spatial, and temporal attributes of glaucony: a tool for provenance research: Sedimentary Geology 109, 135-153.

Bally, A.W., Snelson, S., 1980. Realms of subsidence. Canadian Society of Petroleum Geologists Memoir 6, 9-94.

Baum, G.R., Vail, P.R., 1988. Sequence stratigraphic concepts applied to Paleogene outcrops, Gulf and Atlantic basins, in Wilgus, C.K; Hastings, B. S; Ross, C.A; Posamentier, H.W; Van Wagoner, J. and Kendall, C.G. eds., Sea-level Changes: An Integrated Approach: Society of Economic Palaeontologists and Mineralogists, Special Publication 42, 309-327.

Berggren, W.A., 1960. Paleocene Biostratigraphy and Planktonic Foraminifera of Nigeria (West Africa), Proc. 21st Inter. Geol. Cong. Copenhagen, 6, 41-55.

Billman, H.G., 1976. Offshore Stratigraphy and Palaeontology of the Dahomey (Benin) Embayment; West Africa Proccedings 7th Africa Micropal Coll. Ile-Ife.

Billman, H.G., 1992. Offshore Stratigraphy and Paleontology of the Dahomey Embayment, West Africa. Nigerian Association Petroleum Explorationists 7, 121-130.

Boggs, J.S., 2009. Frontmatter. In Petrology of Sedimentary Rocks (pp. I-Vi). Cambridge: Cambridge University Press.

Bouma, A., Ravenne, C., 2004. The Bouma Sequence (1962) and the resurgence of geological interest in the French Maritime Alps (1980s): The influence of the Grès d'Annot in developing ideas of turbidite systems. Geological Society 221, 27-38. https://doi.org/10.1144/GSL.SP.2004.221.01.03.

Brasier M.D., 1981. Microfossils from Recent and Fossil Shelf Seas. 380 pp., numerous figs. British Micropalaeontological Society Series. Chichester: Ellis Horwood.

Brownfield, M.E., Charpentier, R.R., 2006. Geology and Total petroleum systems of the Gulf of Guinea Province, West Africa. U.S. Geological Survey Bulletin 2207-C, 32 p.

Boboye, O.A., Omotosho, O.J., 2017. Petrological and Geochemical Evaluation of the Paleocene Eocene Lithofacies in Dahomey Embayment, Southwestern Nigeria. Open Journal of Geology 7, 690-719.

Burke, K., 1972. Longshore drift, Submarine Canyons and Submarine fans in the development of Niger Delta. AAPG Bulletin 56 (10), 1975-1983. https://doi.org/10.1306/819A41A2-16C5-11D7-8645000102C1865D.

Coker, S.J.L., 1982. Some aspect of the geology of the bituminous sand of part of the Benin basin Nigeria. Nigerian Mining and Geosciences Society 19 (3), 145-159.

Coker, S.J., Ejedawe, J.E., Oshiorienua, J.A., 1984. Hydrocarbon Source Potential of Cretaceous Rocks of Okitipupa Uplift, Nigeria. Nigerian Journal of Mining Geology 20, 163-169.

Coker, S.J.L., 1985. Sedimentology and Petroleum Geology of Okitipupa tar sand deposits unpublished.

Coker, S.J.L., 1987. Petroleum prospect of the Benin Basin, Nigeria. Journal of Mining and Geology 23, 27-43.

Coker, S.J.L., 1995. Outcrop Studies: A clue to subsurface analysis Nigeria. A clue of Pet. Explorationist. 13th Annual International Conference, Lagos.

Catuneanu, O., 2002. Sequence stratigraphy of clastic systems: concepts, merits, and pitfalls. Journal of African Earth Sciences 35 (1), 1-43.

Catuneanu, O., 2006. Principles of Sequence Stratigraphy. pp. 375. Amsterdam: Elsevier.

Dessauvagie, T.F.J., Whiteman A.J., 1970. Conference on African Geology, pp. 225-271. Ibadan: Ibadan University Press.

Dessauvagie, T.F.J., 1975. Explanatory note to the geological map of Nigeria, scale 1: 1,000,000. Journal of Mining and Geology 9 (1-2), 3-28.

Dickinson, W.R., 1983. Ternary sandstone composition and provenance. Geological Society London Special Publications 264 (1):79-99.

Dickinson, W.R., 1988. Provenance and Sediment Dispersal in Relation to Paleotectonics and Paleogeography of Sedimentary Basins. In: Kleinspehn, K.L., Paola, C. (eds) New Perspectives in Basin Analysis. Frontiers in Sedimentary Geology. Springer, New York, NY. https://doi.org/10.1007/978-1-4612-3788-4_1.

Dobkins, J.E., Folk, R.L., 1970. Shape Development on Tahiti – Nui. Journal of Sedimentary Petrology 40 (4), 1167-1203.

Dora, G.U., Kumar, V.S., Philip C.S., Johnson, G., Vinayaraj, P., Gowthama, R., 2011. Textural characteristics of foreshore sediments along Karnataka shoreline, west coast of India. International Journal of Sediment Research 26 (3), 364-377.

Downie, C., Hussain, M.A., Williams, G.L., 1971. Dinoflagellate cysts and acritarch associations in the Paleogene of southeast England. Geoscience Man, 3, 29-35.

Dunham, R.J., 1962. Classification of Carbonate Rocks According to Depositional Texture. In. Classification of Carbonate Rocks, pp 108-201.

Durand, B., Bernard, S., Potdevin, J.L., Dauphin, Y., 2004. Cap-rock facies variations in a regional-scale upper Jurassic carbonate reservoir/seal system (Paris Basin, France). Marine and Petroleum Geology 21 (7), 821-839.

Ehrlich, R., 2008. Reservoir characterization of the Jurassic Arab-D reservoir, Ghawar Field, Saudi Arabia: Implications for carbonate sequence stratigraphy. AAPG Bulletin 92 (3), 291-326.

Ekwenye, O.C., Nichols, G., Mode, A.W., 2015. Sedimentary petrology and provenance interpretation of the sandstone lithofacies of the Paleogene strata, south-eastern Nigeria. Journal of African Earth Sciences 109, 239-262. https://dx.doi.org/10.1016/j.jafrearsci.2015.05.0.

Evamy, B.D., Haremboure, J., Kamerling, P., Knaap, F.A., Molloy, F.A., Rowland, P.H., 1978. Hydrocarbon habitat of the Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin 62 (1), 1-39.

Fayose, E.A., 1970. Stratigraphic paleontology of Afowo-1 well, SW Nigeria. Journal of Mining and Geology 5 (1), 23-34.

Fayose, E.A., Asseez, L.O., 1972. Micropaleontological investigation of Ewekoro area, southwestern Nigeria. Micropaleontology 18, (3), 369-385.

Friedman, G.M., 1961. Distinction between dune, beach, and river sands from their textural characteristics. Journal of Sedimentary Research 31, 514-529.

Friedman, G.M., 1962. On sorting, sorting coefficient and the lognormality of the grain size distribution of sandstones. Journal of Geology 70, 734-753.

Friedman, G.M.,1967. Dynamic processes and statistical paramete rs compared for size frequency distribution of beach river sands. Journal of Sedimentary Research 37 (2), 327-354. https://doi.org/10.1306/74D716CC-2B21-11D7-8648000102C1865D.

Friedman, G.M., 1979. Difference in size distributions in population of particles among sands of various origins. Sedimentology 20, 3-32.

Folk, R.L., Ward, W.C., 1957. Brazos river bar: A studv in the significance of gram size parameters. Journal of Sedimentary Petrology 27, 3-26. https://doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D.

Folk, R.L., 1959. Practical Petrographic Classification of Limestone. Bulletin of American Association of Petroleum Geologist 43, 1-38.

Folk, R.L., 1962. Spectral Subdivision of Limestone Types in Classification of Carbonate Rocks (Ed. By W.E Ham), 1, pp 62-82.

Folk, R.L., 1966. A review of the grain size parameters. Sedimentology 6, 73-93.

Folk, R.L., 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Company, Austin Texas page 182.

Galloway, W.E., 1989. Genetic Stratigraphic Sequences in Basin Analysis II: Application to Petroleum Exploration. AAPG Memoir 48.

Garland, J., Ganey-Curry, P., 2006. Application of sequence stratigraphy to carbonate reservoirs: An overview. Geological Society, London, Special Publications 255 (1), 1-9.

Germeraad, J.H., Hopping, C.A., Muller, J., 1968. Palynology of Tertiary sediments from tropical areas. Review of Paleobotany and Palynology 6, 189-343. https://doi.org/10.1016/0034-6667(68)90051-1.

Haack, R.C., Sundararaman, P., Diedjomahor, J.O., Xiao, H., Gant, N.J., May, E.D., Kelsch, K., 2000. Niger Delta Petroleum Systems, Nigeria," Petroleum Systems of South Atlantic Margins: AAPG Memoir 73, 213-231.

Harms, J.B., Southard, D.R., Spearing, R.G.W., 1975. Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences 7, 10-15.

Hubert, J.T., 1962. Zircon-Tourmaline-Rutile Maturity Index and Interdependence of the Composition of Heavy Minerals Assemblages with the Gross Composition and Texture of Sandstones, Journal of Sedimentary Petrology 32, 440-450. https://doi.org/10.1306/74D70CE5-2B21-11D7-8648000102C1865D.

Madukwe, H., Ogungbesan, G., Aturamu, A., Ajisafe, Y., 2016. Provenance, Tectonic Setting, Source Area Weathering and Paleoenvironment of the Ilaro Formation, Dahomey Basin, Nigeria. Journal of Environment and Earth Science (6) 95-101.

Idowu, J.O., Ajiboye, S.A., Ilesanmi, M.A., Tanimola, A., 1993. Origin and significance of organic matter of Oshosun Formation Southweseastern Dahomey Basin. Nigeria Journal of Mining Geology 29, 9-16.

Ikegwuonu, O.N., 2015. Middle Palaeocene to Early Miocene Palynostratigraphy of Sediments in Bende – Umuahia Area, Niger Delta, Basin, Southern Nigeria. Unpublished M.Sc. Thesis, Department of Geology, University of Nigeria, Nsukka, 205 pp.

Ikhane, P.R., 2014. Geochemostratigraphic Characteristics of Siliciclastic Rocks in Parts of the Eastern Dahomey Basin, Southwestern Nigeria. Depart. of Geosciences Univ. of Lagos. Journal of Geography and Geology 6 (4), 88-108.

Jan du Chene, R.E., Perch-Nielsen, K., Petters, S.W., 1978. New Stratigraphic Data on the Paleogene Ewekoro and Akinbo Formations (Southwestern Nigeria) Revista Espanola De Micropaleontologia 10 (3), 379-393.

Jones, M.A., Hockey, R.O., 1964. The Geology of Part of South Western Nigeria. Nigeria Geological Survey Bulletin 31, 1-101.

Kingston, D.R., Dishroon, C.P., Williams, P.A., 1983. Global Basin Classification System. Bulletin of American Association of Petroleum Geology 67, 2175-2193.

Kogbe, C.A., 1976. Paleogeographic History of Nigeria from Albian Times. In Geology of Nigeria (C.A. Kogbe ed). Elizabethan Public. Co, Lagos.

Ladipo, K.O., Nwajide, C.S., Akande, S.O., 1992. Cretaceous and Paleogene sequences in the Abakaliki and Anambra basins, southeastern Nigeria: A field guide. Port Harcourt: International Symposium on Geology of Deltas.

Ladipo, K.O., 1988. Paleogeography, sedimentation and tectonics of the upper Cretaceous Anambra basin, south-eastern Nigeria. Journal of African Earth Sciences 7, 865-871.

Lucas, F.A., 2019. Recognition of Evamy et al, P-Zone in tertiary Sediment of F-Well, Niger Delta.

Lucas, F.A., Ishiekwene, E., 2010a. Dinoflagellate cysts biozonation model for late Cretaceous-Tertiary succession of Gbekebo-l well, Benin Flank, Anambra Basin Nigeria. World Journal of Applied Science and Technology 2 (3), 309-314.

Lucas, F.A., Ishiekwene, E., 2010b. Miospore (pollen and spore) biozonation model for late Cretaceous-Tertiary succession of Gbekebo-l well, Benin Flank, Anambra Basin Nigeria. World Journal of Applied Science and Technology 2 (2), 303-308.

Lucia, F.J., 1995. Rock-fabric/petrophysical classification of carbonate pore space for reservoir characterization. American Association of Petroleum Geologists (AAPG) Bulletin 79 (9), 1275-1300.

Magoon, L.B., Dow, W.G., 1994. The Petroleum System—From Source to Trap.

Saadu, M.B., Jimoh, A.Y., Adekeye, O.A., Issa, T.A., 2022. Biostratigraphy and Palaeoecological Studies of the Late Cretaceous-Tertiary Sediments in the Dahomey Basin, Nigeria. European Journal of Environment and Earth Sciences 3, 41-45

Mariam, B.S., 2022. Biostratigraphy and Palaeoecological Studies of the Late Cretaceous-Tertiary Sediments in the Dahomey Basin, Nigeria. European Journal of Environment and Earth Sciences 3 (4), 41-44.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous na nnoplankton zonation, in Proceedings of the Second Planktonic Conference Roma 1970, (ed. A. Farinacci), Edizioni Technoscienza, Rome 2, 739-785.

Merki, P., 1972. Structural Geology of the Cenozoic Niger Delta. African Geology, Dept. of Geology Univ., Ibadan, 635-646.

Machel, H.G., 2004. Concepts and models of dolomitization: A critical reappraisal. Geological Society, London, Special Publications 235 (1), 7-63.

Milton, N.J., Emery, D., 1998. Outcrop and Well Data. In: Emery, D. and Myers, K.J., Eds., Sequence Stratigraphy, Blackwell Science Ltd., 61-79.

Milner, H.B., 1962. Sedimentary Petrography, 2nd ed. Vol. 1, Methods in Sedimentary Petrography, Vol. 2, Principles and Application, New York, MacMillan Company, Vol. 1, 643 p. Vol. 2, 75 p.

Miall, A.D., 1985. Architectural-Element Analysis: A New Method of Facies Analysis Applied to Fluvial Deposits. Earth-Science Reviews 22, 261-308.

Miall, A.D., 1996. The Geology of Fluvial Deposits. Sedimentary Facies, Basin Analysis, and Petroleum Geology. XVI 582 pp.

Miall, A.D., 2013. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis, and Petroleum Geology. Springer

Milton, N.J., Emery, D., 1998. Outcrop and Well Data. In: Emery, D. and Myers, K.J., Eds., Sequence Stratigraphy, Blackwell Science Ltd., 61-79.

Moiola, R.J., Weiser, D., 1968. Textural Parameters: An Evaluati on: ERRATUM. SEPM J. Sediment. Res. 38

Mcrae, S.G., 1972. Glauconite: Earth Science Review 8, 397-440.

Murat, R.C., 1970. Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria.

Murat, RC. 1972. Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In Dessauvagie, T.F.G and Whiteman A.J. (eds): African Geology Dept. University.

Nichols, G., 2009. Sedimentology and Stratigraphy. Wiley-Blackwell.

Nwajide, C.S., 1980. Eocene Tidal Sedimentation in the Anambra Basin, Southern Nigeria. Sedimentary Geology 25, 189-207.

Nwajide, C.S., Reijers, T.J.A., 1996. Geology of Southern Anambra Basin. Sedimentary Geology and Sequence Stratigraphy in Nigeria. In selected Chapters on Geology, by Reijers, T.J.A.

Ocheli, A., Okoro, A.U., Ogbe, O.B., Aigbadon, G.O., 2018. Granulometric and pebble morphometric applications to Benin Flank sediments in western Anambra Basin, Nigeria: proxies for paleoenvironmental reconstruction. Environ Monit Assess 190, 286 (2018). https://doi.org/10.1007/s10661-018-6637-z.

Odin, G.S., Matter, A., 1981. De glauconiarum origine: Sedimentology 28, 611-641.

Odin, G.S., Fullagar, P.D., 1988. Geological significance of the Glaucony Facies. In: Odin, G.S. (Eds.). Green Marine Clay, Elsevier, Amsterdam, p. 295-332.

Ogbe, F.G.A., 1972. Stratigraphy of Strata Exposed in the Ewekoro Quarry, Saith Western Nigeria. In African Geology, pp.305-322.

Olabode, S., Mohammed, M., 2016. Depositional Facies and Sequence Stratigraphic Study in Parts of Benin (Dahomey) Basin SW Nigeria: Implications on the Re-Interpretation of Tertiary Sedimentary Successions. International Journal of Geosciences 7, 210-228.

Omatsola, M.E., Adegoke, O.S., 1981. Tectonic Evolution and Cretaceous Stratigraphy Basin. Journal of Mining and Geology 18, 130-137.

Onuoha, K.M., Ofoegbu, C.O., 1988. Subsidence and Thermal History of the Benin Embayment: Implications for Petroleum Exploration. Nigerian Association of Petroleum Explorationists Bulletin 3 (2), 131-142.

Ojeda, H.A.O., 1982. Structural Framework, Stratigraphy, and Evolution of Brazilian Marginal Basin, AAPG Bulletin 66 (6), 750-774.

Obonighie, P.O., 2016. Petrographic Studies and Paleoenvironmental Reconstruction of some Outcropping sediments in Parts of the Eastern Dahomey Basin, Southwestern Nigeria IOSR Journal of Applied Geology and Geophysics (4) 09-15.

Okada, H., Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low–latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). Marine Micropaleontology 5 (3), 321-325.

Okosun, E.A., 2015. Organic geochemistry of Akinbo shale: Implications for hydrocarbon source-rock potential in the Dahomey Basin, Nigeria. Arabian Journal of Geosciences 8 (11), 9739-9752.

Oyedele, K.F., Oyedele, D.J., 2017. Mineralogical and geochemical characterization of Ewekoro limestone for industrial and agricultural utilization. Journal of African Earth Sciences 129, 709-716.

Passega, R., 1957. Texture as Characteristic of Clastic Deposition. AAPG Bulletin 41 (9), 1952-1984. https://doi.org/10.1306/0BDA594E-16BD-11D7-8645000102C1865D.

Passega, R., 1964. Grain size representation by CM patterns as a geological tool. ournal of Sedimentary Research 34 (4), 830-847. https://doi.org/10.1306/74D711A4-2B21-11D7-8648000102C1865D.

Phani, P.R., 2014. Sedimentological Studies and Paleoenvironment of lower Gondwana Strata, North of Gkoc Mine, Kothaguedem Coalfields, Telangana, India. International Journal of Advancement in Earth and Environmental Science 2 (2), 31-38.

Petters, S.W., 1978. Mid-Cretaceous paleoenvironmental and biostratigraphy of the Benue Trough Nigeria. GSA Bulletin 89 (1), 151-154. https://doi.org/10.1130/0016-7606(1978)89<151:MPABOT>2.0.CO;2.

Petters, S.W., 1982. Central West African Cretaceous-Tertiary Benthic Foraminifera and Stratigraphy. Palaeontographica Abteilung 179, 1-104.

Petters, S.W., 1983. Gulf of Guinea planktonic foraminiferal biochronology and geological history of the South Atlantic. Journal of Foraminiferal Research 13 (1), 32-59. https://doi.org/10.2113/gsjfr.13.1.32.

Petters, S.W., Olsson, R.K., 1979. Planktic foraminifera from the Ewekoro type section (Paleocene) Nigeria Micropaleontology 25 (2), 206-213.

Pettijohn, F.J., 1975. Sedimentary Rocks (3rd edition). Harper and Row, New York.

Peters, K.E., Moldowan, J.M., 1993. The Biomarker Guide: Interpreting Molecular Fossils in Petroleum and Ancient Sediments. OSTI ID: 6066248, United States.

Potter, P.E., Pettijohn, F.J., 1977. Paleocurrent and Basin Analysis (3rd ed.) Berlin: Springer-Verlag, p. 425.

Posamentier, H.W., Vail, P.R., 1988. Eustatic controls on clastic deposition II – Sequence and systems tract models.in Wilgus, C.K; Hastings, B. S; Ross, C.A; Posamentier, H.W; Van Wagoner, J. and Kendall, C.G. Sea-level Changes: An Integrated Approach: Society of Economic Paleontologists and Mineralogists, Special Publication 42, 125-154.

Rajganapathi, V.C., Nedumuttath, J., Sundararajan, M., Bhat, K., Velusamy, S., 2012. Grain-size analysis and characterization of sedimentary environment along Tiruchendur coast, Tamilnadu, India. Arabian Journal of Geosciences 6 (12) 1-13. https://doi.org/10.1007/s12517-012-0709-0.

Reyment, R.A., 1963. Studies on Nigeria Upper Cretaceous and Lower Tertiary Ostracoda Part 2, Danian, Paleocene and Eocene Ostracoda. Stockholm Contributions to Geology 10, 1-286.

Rayment, R.A., 1965. Aspects of Geology of Nigeria. Ibadan University Press, 133.

Roberts, E.M., 2007. Facies Architecture and Depositional Environments of the Upper Cretaceous Kaiparowits Formation, Southern Utah. Sedimentary Geology 197, 207-233.

Sutherland, A.R., Lee, C., 1994. Discrimination between coastal subenvironments using textural characteristics. Sedimentology 41, 1133-1114. https://doi.org/10.1111/j.1365-3091.1994.tb01445.x.

Russ, W., 1924. The phosphate deposits of Abeokuta Province. Bull. Geol. Surv. Nig., 7. 43.

Sachs, J.Jr., Adegoke, O.S., 1975. Paleocene Nummulites from Nigeria. Journal of Foraminiferal Research 5, 71-75.

Salard-Cheboldaeff, M., 1990. Intertropical African palynostratigraphy from cretaceous to late quaternary times. Journal of African Earth Sciences 11, 1-24.

Sames, C.W., 1966. Morphometric data of some recent pebble ass ociations and their application to ancient deposits. Journal of Sedimentary Petrology 36, 126-142.

Selley, R.C., 2014. Elements of Petroleum Geology (3rd ed.).

Selley, R.C., 1998. Elements of Petroleum Geology. Academic Press.

Simpson, A., 1955. The Nigeria Coalfield: The Geology of Parts of Onitsha, Owerri and Benue Provinces. Geology 103, 385-397.

Stow, D., 2005. Sedimentary Rocks in the Field: A Colour Guide. 10.1201/b15204.

Taylor, K.J., Taylor, S.A., 1983. Introduction to Petroleum Geology (2nd ed.).

Tucker, M.E., 2003. Sedimentary rocks in the field, third ed., John Wiley and sons Limited, 234p.

Tucker, M.E., 2001. Sedimentary Rocks in the Field: A Colour Guide. Academic Press.

Vail. P.R., 1987. Seismic stratigraphy interpretation using sequence stratigraphy, part 1: seismic stratigraphy interpretation procedure. In: Bally, A.W., Ed., Atlas of Seismic Stratigraphy, AAPG Studies in Geology, Vol. 1, No. 27, 1-10.

Vail, P.R., Wornardt, W., 1991. An Integrated Approach to Exploration and Development in the 90s: Well Log-Seismic Sequence Stratratigraphic Analysis. Gulf Coast Association of Geological Societies Transactions 41, 630-650.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S., Hardenbol, J., 1988. An overview of the fundamentals of sequence stratigraphy and key definitions, in Wilgus, C.K; Hastings, B. S; Ross, C.A; Posamentier, H.W; Van Wagoner, J. and Kendall, C.G. Sea-level Changes: An Integrated Approach: Society of Economic Paleontologists and Mineralogists, Special Publication 42, 39-45.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M., Rahmanian, V.D., 1990. Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: Tulsa, Oklahoma, American Association of Petroleum Geologists Methods in Exploration Series 7.

Warren, J.K., 2016. Karst Geology and Hydrocarbon Reservoirs: Karst Features and Techniques for Predicting Reservoir Presence and Porosity. Elsevier.

Whiteman, A.J., 1982. Petroleum Geology, Resources and Potential. Graham and Trotman, London, Vols.1 and 2.

.