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Sedimentology and Geochemical Characteristics of Upper Cretaceous Sediments of Imo Formation Around Arimogija Okeluse, Southwestern Nigeria

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ABSTRACT

Sediments of the Paleocene Imo Formation exposed at the southwestern flank of Anambra Basin at Sobe, Arimogija and Okeluse area, southwestern Nigeria. The sediments consisting limestones, sandstones and minor claystones and shales and intercalated ironstones were studied based on sedimentological and petrological charateristics for paleoenvironmental deduction. Field observation indicated that all the beds constituting this exposure are laminated and exhibit a coarsening upward succession.

The statistical result from the grain size analysis of the siliclastic sediments shows the sandstones are coarse to medium sands (0.20 to 1.50ϕ), very well to moderatelywell sorted (0.26 to 1.12 ϕ) with skewness value ranges from nearly symmetrical though very positively skewed to positively skewed (-0.07 to 0.91) characterized by platykurtic to extremely leptokurtic (0.76 to 6.83) particle size distributions. Petrographic study of these sandstone reveal that its constituents is averagely of angular to sub-angular quartz (85%), feldspar (1.4 %), rock fragment and (9.5 %) and $\leq$3% cementing iron-oxide (goethite and haematite) phases, texturally immature and sub-arkosic.

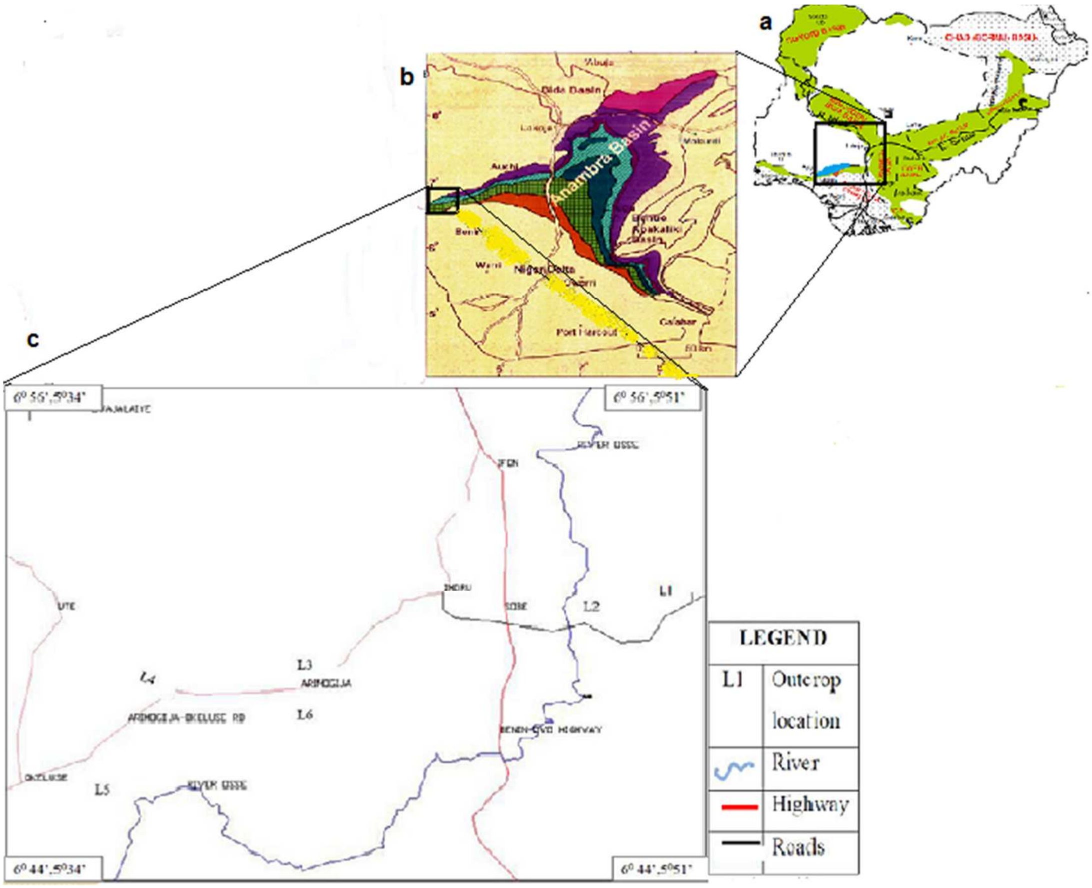
The limestone comprises of bioclastic wackestone, bioclastic wackestone-packstone, dolomitised bioclastic-wackestone and mudstones microfacies with the bioclasts being broken shells of pelecypods, brachiopods and algae much of which have been partly recrystallised to sparry calcites. Geochemical and mineralogical constituents also show that the limestones are shallow marine deposits that have variably suffered early to mid diagenesis including dolomitisation. The prevailing basin condition was highly fluctuating with diverse fluvial channel and relatively-protected shallow marine depo-environments.

Keywords: Paleocene, Imo Formation, microfacies, paleoenvironment, depositional environment

INTRODUCTION

The Anambra basin is located in the southwestern end of the Benue Trough and contains up to 9 km thick of siliciclastic sedimentary strata (Whiteman, 1982) and covers an area of about 40,000 km^2 which extends northward to the lower Benue River and also forms a boundary with the Tertiary Niger Delta to the south and Dahomey basin to the west. It is extended north westward to form the Benin flank which has been described as gently plunging complimentary syncline of the Anambra basin terminating along the NE-SW trending flexure or fault zone of the Okitipupa Hinge (Murat, 1972; Whiteman, 1982).

The study area (Arimogija-Okeluse environs) is situated south of Owo Town in Ondo state, southwestern Nigeria and lies between Longitude 5°34' to 5°46'E and latitude 6°45' to 6°50'N (Fig. 1). The investigated sections are found around Sobe, Sabongida-Ora, Okati, Imoru, Arimogija and Okeluse community which are accessible by a network of a foot-paths, tarred, untarred roads and the Owo-Benin highway through Sobe, Imoru and Ijagba towns linking them. The area falls within the tropical rain forest belt of Nigeria with tall trees and dense grass undergrowth with the rainy season while the dry season usually begins in November and ends in March. The area is generally gently dipping to



lat-lying and rivers flow from North to South with most of them seasonal and well drained by river Iyuto generally flowing southeasterly with a tributary of the Osse discharges directly into the Bight of Benin.

Though, the Imo Formation in other parts has been variously well studied for aspects of its deposition, stratigraphy, tectonics, paleontology and petroleum potential as well as sedimentology by various authors including Agagu *et al.* (1985), Obi *et al.* (2001) and Rahman *et al.* (2012). However, the occurrence of this Formation in the Benin flank has not been well documented, except for the economic potential evaluation by the consultancy unit of Obafemi Awolowo University, Ile-Ife in 1978. Therefore, the main objective of this study is to determine the paleoenvironment and depositional condition of the sediments in the area based on the lithological and petrological characteristics.

Fig. 1: Map showing (a) Nigeria, (b) Anambra basin and (c) study area

GEOLOGY OF THE AREA AND REVIEW OF PREVIOUS WORK

The origin/evolution and stratigraphy of the Anambra basin have been extensively discussed and documented by several workers based on different hypotheses such as Offodile (1976), Olade (1976), Petters and Reijers (1987). Reports of various authors indicated that the basins evolved consequent to the late Jurassic to Cretaceous basement fragmentation, block faulting, subsidence, rifting and drifting apart of the South American and African plates.

Anambra basin developed during the second phase of the Nigerian sedimentary basins stratigraphic history referred to as Anambra-Benin phase (Campanian-mid Eocene) which is believed to have resulted from the Santonian folding and uplift of the Abakaliki region and dislocation of the depocenter into the Anambra Platform and Afikpo region according to Reyment (1965). The resulting sediment successions consist of the Nkporo/Enugu, Mamu, Ajali, Nsukka, Imo and Ameki formations (Table 1). The Nkporo Formation comprises of interbedded sandstones and shale with coal seams in the lower half of the formation but restricted to the central part of the basin. The lateral equivalents of Nkporo Formation which is overlain by Mamu Formation in all part of the basin are carbonaceous Enugu shale and Owelli sandstone. The Mamu Formation exhibit very distinct lateral sandstone and coal facies change across the basin (Akande and Mucke, 1993). It is overlain by the middle Maastrichtian Ajali sandstone and upper Maastrichtian Nsukka Formation. The sequence is capped by the Tertiary Nsukka Formation and Imo shale. The Imo Formation consists of dark grey clays, shale and black shale with bands of calcareous sandstone, marl and limestone with the presence of Ostracods and foraminiferas' biostratigraphy (Reyment, 1965) and microfauna recovered from the basal limestone unit indicate a Paleocene age for the formation (Adegoke *et al.*, 1980).

Table 1: Stratigraphic Succession of Anambra Basin.

AGE		ANAMBRA BASIN	CYCLE OF SEDIMENTATION
TERTIA RY	EOCENE	AMEKI/NANKA FORMATION	3RD CYCLE OF SEDIMENTATION
	PALEOCENE	IMO FORMATION	
UPPER CRETACEOUS	MAASTRICHTIAN	NSUKKA FORMATION	
		AJALI FORMATION	
		MAMU SHALE	
	CAMPANIAN	ENUGU/NKPORO FORMATION	
	SANTONIAN-CONIACIAN	AWGU FORMATION	2ND CYCLE OF SEDIMENTATION
	TURONIAN	EZE-AKU GROUP. (KEANA, MAKURDI, AGALA AND AMASERI FORMATIONS)	
	CENOMANIAN	ODUKPANI FORMATION	
LOWER CRETACEOUS	ALBIAN	ASU RIVER GROUP	1ST CYCLE OF SEDIMENTATION
	APTIAN		
PRECAMBRIAN		BASEMENT COMPLEX	

METHODOLOGY

The basic methodological approach for this study are geological field work and laboratory analysis. The geological field work was undertaken in October 2010. This involves the examination of roads, pits and river banks outcrops in term of grain size, textural composition and sedimentary structures following the logging, diagrammatic representation, collection of the representative rock samples, measurement and description of the rock types at each location as each stratigraphic section was examined and described from the top to the bottom and documented accordingly. Fresh samples of each lithology were collected, sealed in sample bag and labeled properly for further investigations.

A total of thirty-six (36) rock samples were collected; sixteen (16) sandstones, thirteen (13) limestone and seven (7) clay/shale samples. Granulometric analysis of the sandstone samples, thin section preparation and study of these sandstones and limestone samples with the staining were carried out (according to Friedman, 1959) at the Geological workshop, Department of Geology and Mineral sciences, University of Ilorin. Some of these representative samples were also prepared and sent to ACTA Laboratory, Canada and Nigeria Raw Material Research and Development Council (RMRDC), Kaduna for inorganic geochemical analysis using Induced coupled plasma mass spectrometry (ICP-MS) and mineralogical analysis using X-Ray Diffraction (XRD) respectively.

RESULTS AND DISCUSSION

Facies Characteristics

The study area is underlain by the following lithologies: sandstones, claystones/shale/ironstone and limestones.

Facies A (Sandstone)

The exposure containing this facies are found at Arimogija Township ($6^0 49^' 20.25^{''}$N; $5^0 42^' 04.07^{''}$E), Km 3.5 Sobe-Sabongida Ora road ($6^0 50^' 51.33^{''}$N; $5^0 48^' 36.40^{''}$E), Km 19 Sobe-Arimogija-Okeluse road ($6^0 48^' 57.52^{''}$N; $5^0 38^' 31.64^{''}$E) and about 100m east of the River Iyuto bridge on Sobe-Arimagija-Okeluse road. The sandstone is parallel laminated, friable and are easily susceptible to erosion, fine to medium grained, moderately-sorted and occasionally highly compacted/cemented. They are generally brownish and greyish-whitish in colour, parallel laminated, friable and are easily susceptible to erosion. The main characteristic sedimentary structures are flaser bedding, planar cross beds with intervening mud-drapes. There are also presence of reactivation surface and iron stains. The crevices of the undulating bedding planes were later filled by clayey sediment with some of it washed away by erosion leaving the crevices open or gapped. This structure may be an indication of deposition in shallow marine environment according to Pettijohn (1975).

The colour of this sandstone are ferruginized and greyish white. The former types are characterized by; thickly laminated, medium to fine-grained sandstone (Bed AR3S1 and AR3S2), thinly laminated, bioturbated and mottled, medium-grained sandstone and medium to coarse-grained sandstone (Bed AR3S3), a friable coarse-grained ferruginised sandstone (Bed AR4S7), thickly conglomeratic sandstone (Bed AR5S3) with pebbles and cobbles with average size 5-10 cm. The thickly laminated ferruginised sandstone also show scattered clay concretions (grayish-white) which shows indication of bioturbation (Bed AR4S5). The greyish-white are friable and medium grained (Bed AR4S3).

Facies B (Claystone/Shale/Ironstones)

This facies forms the base of the outcrop and is commonly seen at Km. 3.5, 7.5 and 19, Sobe Sabongida Ora road ($6^0 50^' 51.33^{''}$N, $5^0 48^' 36.40^{''}$E; $6^0 50^' 28.24^{''}$N, $5^0 50^' 06.50^{''}$E and $6^0 48^' 57.52^{''}$N, $5^0 38^' 31.64^{''}$E respectively). The sections are made of repetitive or cyclic deposition of thickly and thinly bedded claystone and shale at an almost equal proportion with different characteristics. The thinly laminated claystone (Bed SB2S3), thick and massively-bedded claystones and sandy-claystone are grey and impermeable while the massive pebbly-claystone (Bed SB2S2) and thickly bedded concretional clayey-ironstone are ferruginized. The shales are dark in colour and fissile in some places and massive in others.

Facies C (Limestone)

Dunham (1962) and Wilson (1975) classifications were adopted for the description and naming based on lithological characteristics and field occurrence. The carbonate microfacies identified occurring in outcrops in the southwestern part of Arimogija and Okeluse are stream channel sections ($6^0$46ʾ40.02ʺN; 537’02.30ʺE and $6^0$48ʾ55.08ʺN; $5^0$41ʾ48.21ʺE). The limestone microfacies of Okeluse sections comprises biomicritic limestone and massive mudstone (greyish, thick, mottled, plastic and poorly fissile) while the Arimogija sections comprises of dolomitic limestone with pods or pockets of un-recrystallized mud. The limestone are greyish with dominantly of broken pelecypodal shells with indication of re-crystallization of aragonitic shells.

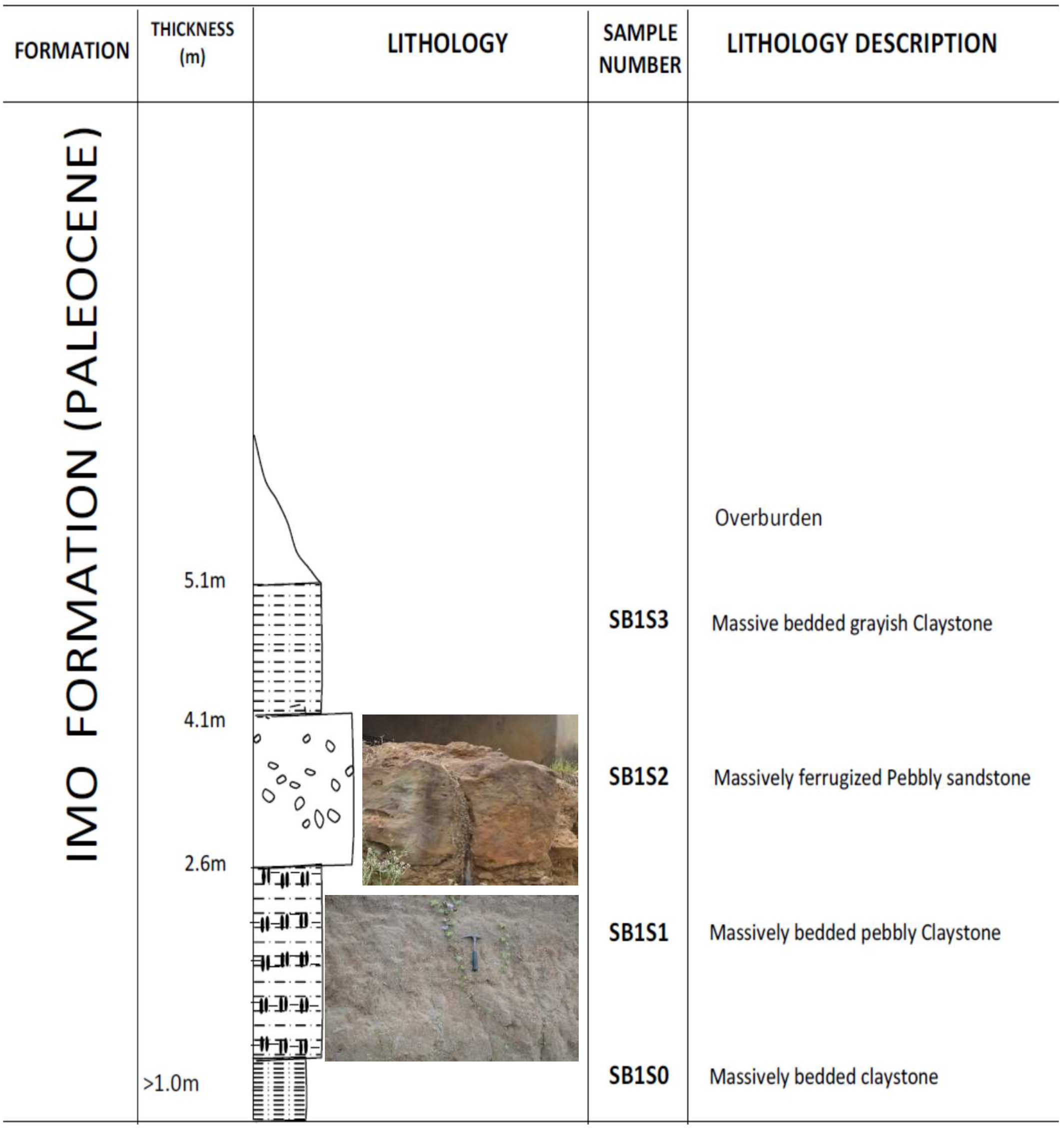


Fig. 2a: Lithology of Imo Formation and photograph of Ferruginized Pebbly Sandstone of the Imo Formation at Sobe area.

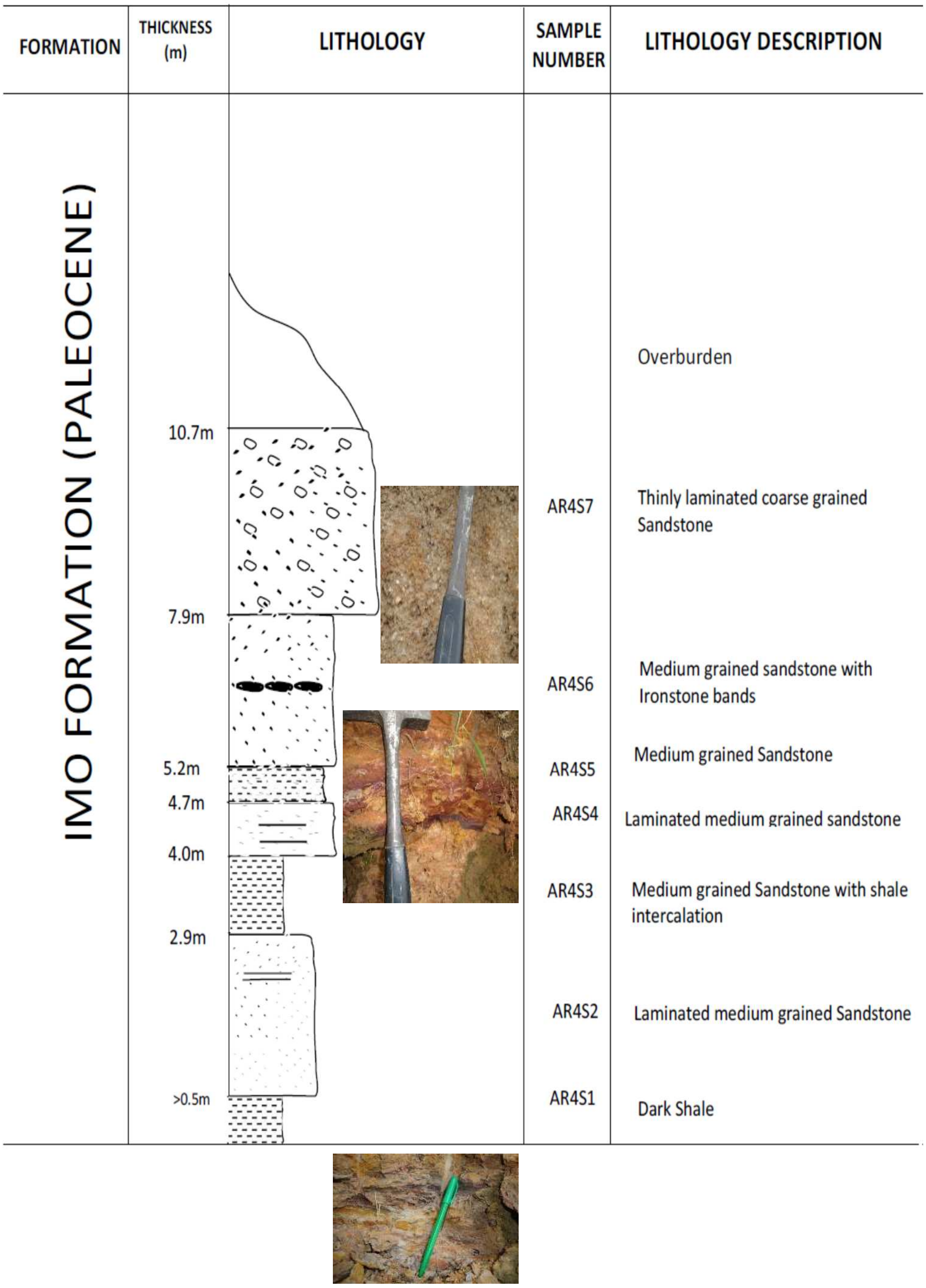


Fig. 2b: Lithologies of Imo Formation and photograph of sandstone with bands of ironstone at Km 19, Arimogija-Okeluse road.

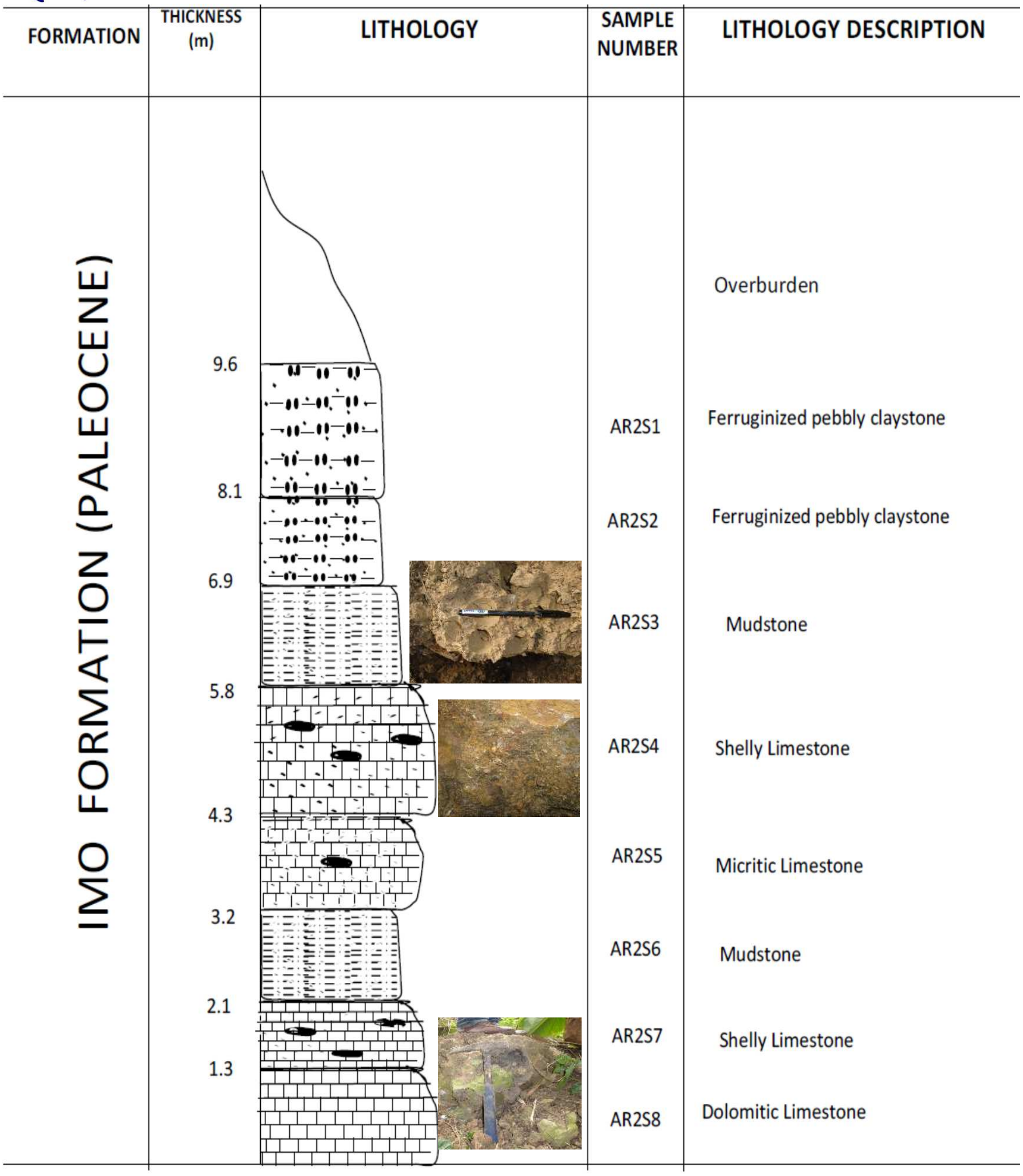


Fig. 2c: Lithology of Imo Formation exposed and a Photograph of limestone with broken shell of pelecypod at Arimogija erosional channel.

Grain Size Analysis, Transportational History and Paleoenvironment

The sieve analysis was carried out based on Folk and Wards (1957) model and the curve were plotted (Fig. 3). The mean values were used for classification of sandstones as it describes the average grain size of the sediments which is obtained with higher percentage of coarser material (0.20-0.99) and lower medium value (1.09-1.50), therefore, the higher mean value of coarser grained sandstones with lower mean values of medium grained sandstones characterized the siliclastics sediments of Imo Formation in the study area (see table 2). The coarse grained sandstones sediments observed were associated with high energy conditions in which smaller grains were washed away leaving the coarse grains which suggested upper course of a river regime while the medium grained sediments suggested to have been carried further down the river channel at a relatively lower energy of transportation that can be obtained in a lateral gradation or down grading condition.

The sorting measures the scatter around the mean because the better the scatter, the higher the standard deviation and the poorer the sorting. It is important also to know that the spread of sorting values is a reflection of distance of transportation, energy and environment of deposition of sediments. For this study, the calculated values indicated a sorting values range from 0.50 to 1.12 and defined moderately well sorted with only one sample (0.26) characterize poorly sorted (see table 2). This means that the sediments indicates relatively far away sediments transport from their source as a result of relatively lower energy of transportation at the distal part of the lower course of river channel or probably deposited within transitional environment at a relatively low sedimentation rate.

The skewness measures symmetry in the scatter of a distribution as well as the degree of lopsidedness of a curve. The calculated value of skewness of Imo Formation sediments as shown in table 2 has a disperse value ranges with a classification of positively skewed sediments and severely finely positively skewed sediments suit. The positively skewed nature of the sediments exhibits sediments input from various sources of tributaries whereas the very positively skewed nature implies a low velocity than normal. Therefore, higher value of very positively skewed relative low positively skewed indicative of higher energy of transportation whereby most of the sand grains present are dominant in the suspension segments, but moderate in saltation segments. Therefore, such sediment is suggested to have more hydraulic sorting impact in order to achieve moderately well sorted definition.

The statistical results in table 2 were also used for bivariate plots of Mean Size against Standard Deviation and Skewness against Sorting as shown in figure 4 indicates a fluvial dominated environment.

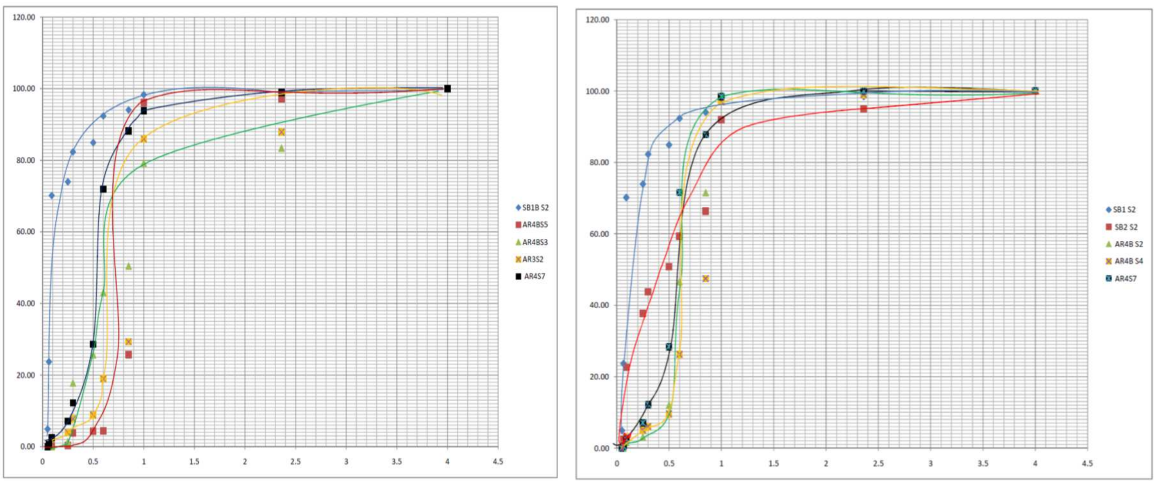
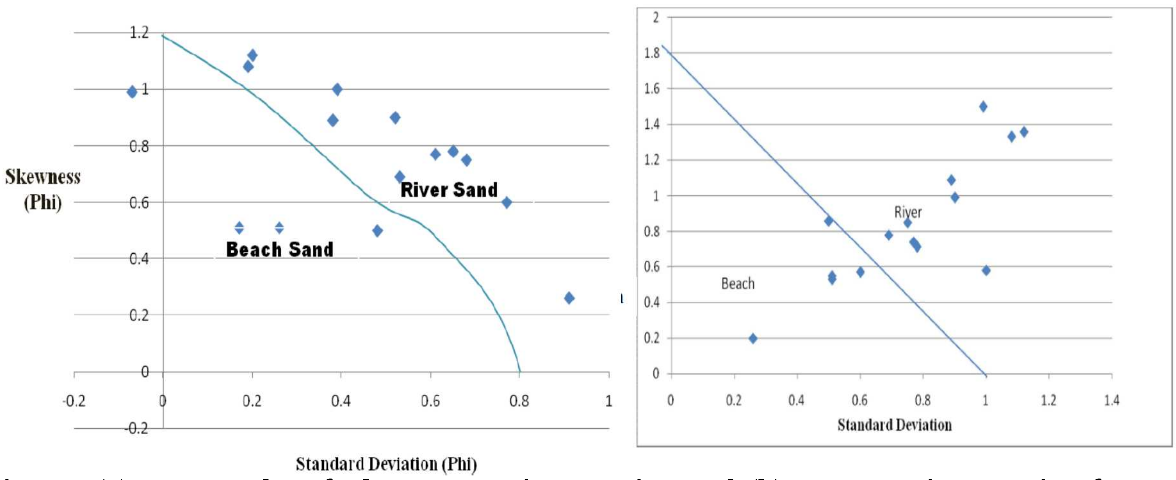


Fig. 3a & b: Grain Size curves for Sandstones of the Imo Formation at Arimogija-Okeluse,

Table 2: Calculated Values for Grain Size Parameters and Interpretation for the Imo Formation Sandstones.

Sample No	Mean	Sorting	Skewness	Kurtosis
SB1S2	0.20 (Coarse Sand)	0.26 (Very well sorted)	0.91 (Very Positively Skewed)	2.51 (Very leptokurtic)
SB2S2	0.71 (Coarse Sand)	0.78 (Moderately well sorted)	0.65 (Very Positively Skewed)	0.93 (Leptokurtic)
AR3S1	0.74 (Coarse Sand)	0.77 (Moderately well sorted)	0.61 (Very Positively Skewed)	2.48 (Very leptokurtic)
AR3S2	1.33 (Medium Sand)	1.08 (Moderately well sorted)	0.19 (Positively Skewed)	0.8 (Leptokurtic)
AR3BS2	1.36 (Medium Sand)	1.12 (Moderately well sorted)	0.20 (Positively Skewed)	0.92 (Leptokurtic)
AR4S2	0.58 (Coarse Sand)	1.00 (Moderately well sorted)	0.39 (Very Positively Skewed)	6.83 (Extremely Leptokurtic)
AR4BS2	0.85 (Coarse Sand)	0.75 (Moderately well sorted)	0.68 (Very Positively Skewed)	1.64 (Very leptokurtic)
AR4S3	0.57 (Coarse Sand)	0.60 (Moderately well sorted)	0.77 (Very Positively Skewed)	3.28 (Very leptokurtic)
AR4BS3	0.78 (Coarse Sand)	0.69 (Moderately well sorted)	0.53 (Very Positively Skewed)	1.74 (Very leptokurtic)
AR4S4	0.99 (Coarse Sand)	0.90 (Moderately well sorted)	0.52 (Very Positively Skewed)	3.03 (Very leptokurtic)
AR4BS4	1.09 (Medium Sand)	0.89 (Moderately well sorted)	0.38 (Very Positively Skewed)	0.82 (Leptokurtic)
AR4S5	0.86 (Coarse Sand)	0.50 (Moderately well sorted)	0.48 (Very Positively Skewed)	2.27 (Very leptokurtic)
AR4S6	1.50 (Medium Sand)	0.99 (Moderately well sorted)	-0.07 (Nearly Symmetrical)	0.76 (Leptokurtic)
AR4S7	0.53 (Coarse Sand)	0.51 (Moderately well sorted)	0.17 (Positively Skewed)	2.66 (Very leptokurtic)
AR4BS7	0.55 (Coarse Sand)	0.51 (Moderately well sorted)	0.26 (Positively Skewed)	3.12 (Very leptokurtic)

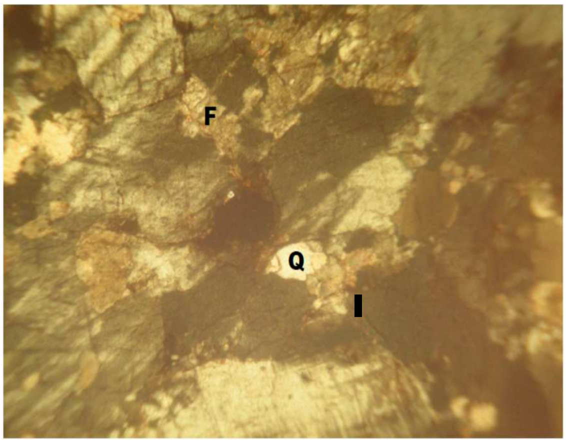


Figs. 4: (a) Scatter plot of Skewness against Sorting and (b) Mean against Sorting for Sandstones for Imo Formation at Arimogija-Okeluse (after Friedman, 1979).

PETROGRAPHIC STUDY

Sandstones

The sandstones are dominantly composed of quartz (80%), some opaque minerals (10%), feldspar, mica and rock fragments are about 10% (see Table 2). The quartz clast are colorless to pinkish and sub-angular to sub-rounded while the opaque minerals are also rounded to sub-rounded. The grain shapes indicate nearby sources at the distal parts of the basin. The quartz clasts are evidence of basement rocks derivation. Their ferruginization is indication of tropical type paleoclimate with high mobilization and deposition of iron oxide. The petrographic data in table 2 is thereby used for the ternary diagram plot (Fig. 6) and this classify the sandstone of Imo Formation exposed at Arimogija-Okeluse to be sub-arkosic and mineralogically immatured.



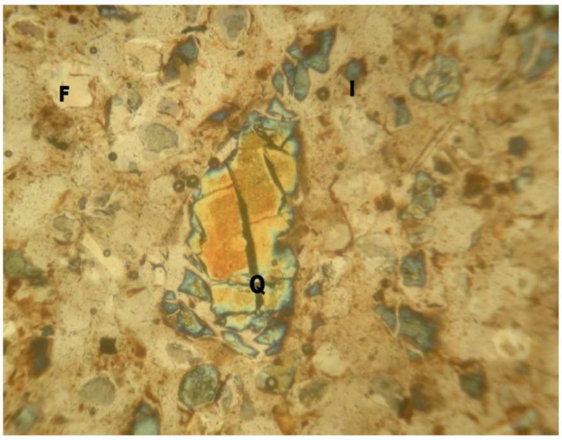


Fig. 5: Thin section photomicrogaph of Imo Formation sandstones at Arimogija-Okeluse; (a) AR4S4 and (b) AR3S2 (Note Q-quartz and F-feldspar and I-Iron oxide).

Table 3: Mineralogy of the sandstone of the Imo Formation at Arimogija-Okeluse

Sample No	Quartz		Feldspar	R.F	Matrix	Cement and Iron oxide
	Percentage	Shape				
AR4S$_4$	75%	Subangular to subrounded	6%	1%	13%	5%
AR4S$_2$	70%	Subangular to subrounded	10%	2%	8%	10%
AR$_3$S$_2$	85%	Subangular to subrounded	3%	2%	5%	5%
SB1S1	80%	Subangular to subrounded	4%	3%	4%	4%
SB2S3	82%	Subangular to subrounded	5%	4%	7%	2%

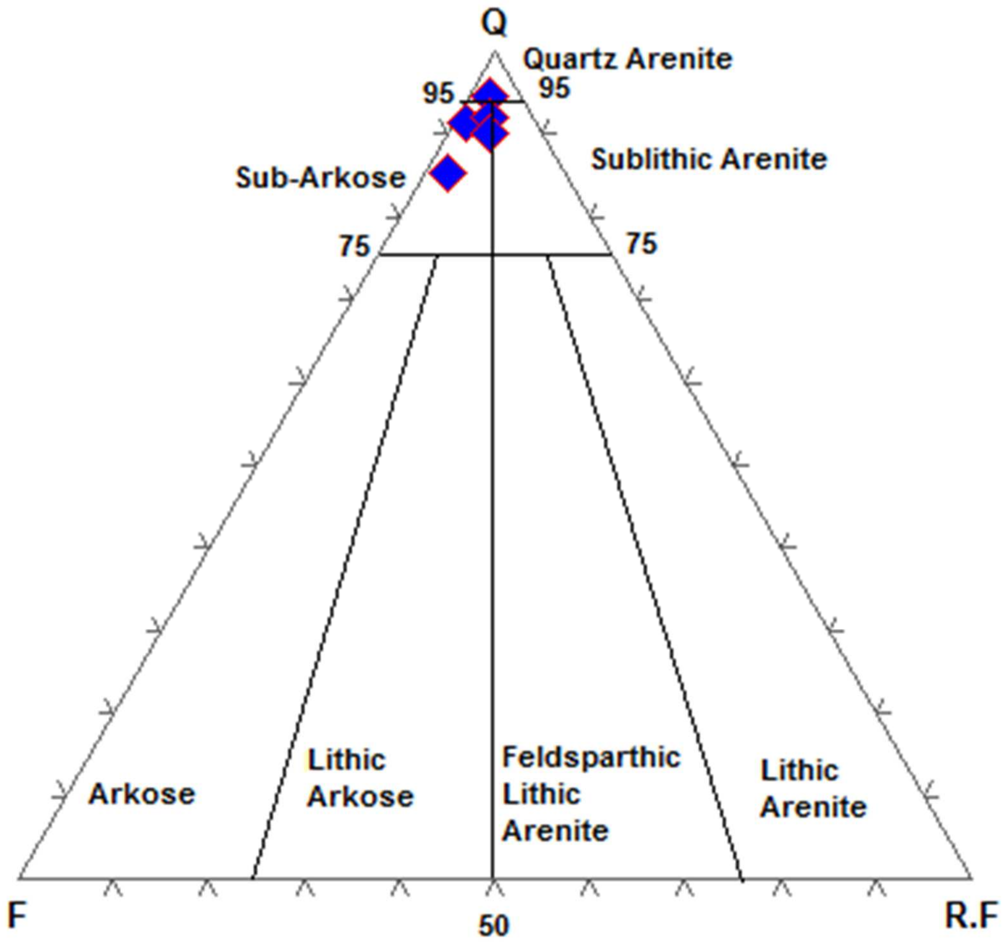


Fig. 6: Ternary plot indicating arkose to subarkose class for the Imo Formation sandstones (after Folks, 1974).

Carbonate Microfacies and Diagenesis

The carbonate microfacies identified occurring in the area of Arimogija-Okeluse, based on the depositional textures of Dunham (1962), Wilson (1975) and Flugel, (1982) are Mudstone**,** Bioclastic wackestone and Bioclastic wackestone-Packstone and Dolomitic bioclastic wackestone. The mudstone are micritic and occurs as massive beds and lacking fauna. It is essentially carbonate sediments that are indicative of low energy environment of deposition. They consist of less than 5% recrystalised fossil shell grains. Bioclastic wackestone consist of variable amounts of micrite-rimmed fragments from echinoderms, calcareous green algae, coralline algae, pelecypods and dispersed partly recrystallised lithoclast (Fig. 7a & b). This limestone would have accumulated in quiet, shallow subtidal environments, probably lagoons. Bioclastic wackestone-packstone is restricted to units at Arimogija, they are massively bedded and comprise dominantly of broken shells of pelecypods and other bioclasts and lithoclasts (Fig. 7c). The dolomitic bioclastic-wackestone is a highly indurated, fine-grained and dark greyish limestone deposits, its occurrences at Arimogija are slightly fossiliferous with scattered pods or pockets of un-recrystallized mud in places and it is restricted to the basal beds of the sections at Arimogija and Okeluse. (Fig. 7d).

The carbonate deposits shows indication of having undergone different diagenetic processes including micritization, compaction, dissolution, neomorphism, and dolomitization. Early diagenetic micritization of the bioclast is observed in the bioclastic wackestone and bioclastic wackestone-packstone microfacies. The rinds of the bioclasts are commonly micritized. Compaction phase has also occur leading to the fragmentation of the limestones and sutured contacts between the skeletal grains in the bioclastic wackestone and bioclastic wackestone-packstone. These occur early in the diagenetic history due to overburden and probably due to prevalent mud-supported fabric in the Imo Formation limestones. Dolomitization also occur in the study area as dolomite replacing micritic mud and recrystalized skeletal grains. This might be due to the influx of marine sea water containing more magnesium ion which allow for the exchange for calcium ion bringing about dolomitization.

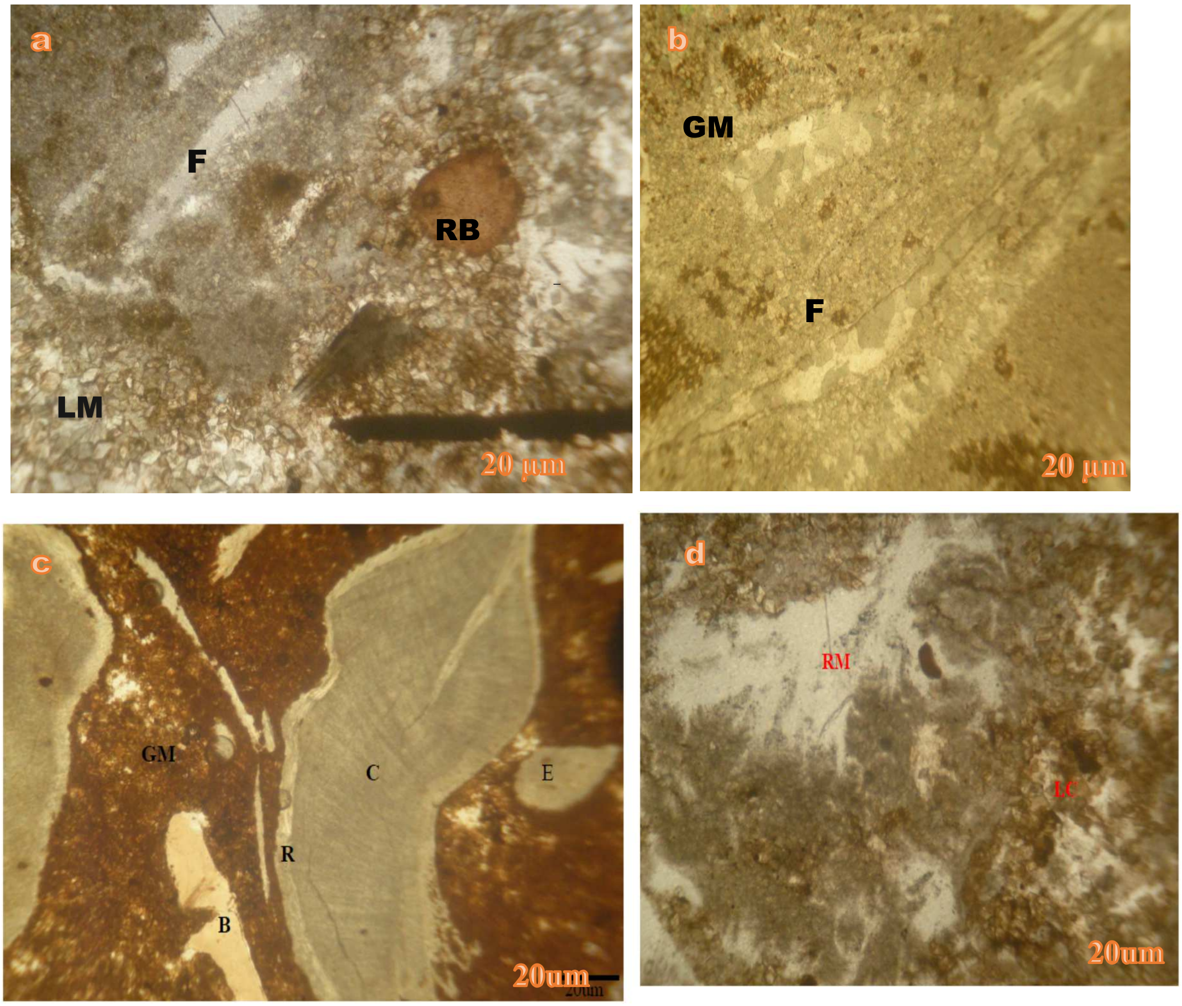


Fig. 7: Photomicrograph showing (a) and (b) Bioclastic Wackestone (AR2S5 & (AR2S8), (c) Bioclastic wackestone-packstone (AR2S6) and (c) dolomitised bioclastic wackestone (Note the coralline algae (C) with rim micritization (RM), echinoderm (E), recrystalized ground mass (GM) and dissolved bioclast (B), filamentous algae (F), rotten bioclast (RB), lime mud (L), lithoclastic ground mass (LM), dissolved lime ground mass (GM), filamentous algae (F) with internal recrystalization to blocks of sparry calcite and micritic ground mass (GM), (LC) large crystal that may have been dolomitised and the recrystallized mud (RM).

Geochemistry

Four samples of limestone were subjected for the elemental analysis for the major, trace and rare earth elements. The result in table 3 confirmed that the predominant mineral within the area is calcite (42.6 - 49.4%; mean=36.77). This is due to the fact that the limestone are primarily calcite (Pettijohn, 1984) and high degree of purity of the limestone which indicates deposition in waters receiving no significant amount of detritials as at the time of deposition, such waters would more likely be marine (Pettijohn, 1984). The very low magnesium content (0.73-1.24%; mean=1.58) suggests that they are essentially calcareous except the basal limestone at Arimogija (L2S8) that has 4.69% MgO and may be a function of the magnesium content of skeletal debris on the limestone (Aragonitic skeletal) and so, suggest limited dolomitization. The dolomitization would probably be due to influx of marine sea water that contain more magnesium ion which allow for the exchange of calcium ion bringing about dolomitization.

The composition of other constituents and their mean values in the limestone is shown in table 3; SiO_2 (2.48-4.96) Fe_2O_3 (2.29%-9.13%), Al_2O_3 (1.04% - 1.81%), K_2O (0.03% - 0.09%) and Cr_2O_3 (<0.01% - 0.07%). The percentages of silica and alumina are fairly low thus indicating low presence of non-carbonate detritus such as silt or sand, siliceous spicules or chert in the limestone. The 2.29-9.13% iron-oxide content would also be due to tropical type climatic conditions with high mobilization and deposition of iron-oxide. Iron could be incorporated into the calcite and dolomite while it could also occur as fine grained materials derived along with quartz and clays.

Trace elements have been applied with variable degrees of success to discriminate depositional environment. Based on the principle that primary differences inherent in the trace elements content of different environments are bound to reflect in the sediments formed, the trace element signatures can be useful in interpretation of depositional environment despite post diagenetic alterations (Brand, 1983). Trace elements analysis has been used in the differentiation of shallow water and deep water limestone. Many writers, including Flugel (1984), have also demonstrated that the Mn content and the varying amount in them such as Co, Ni, Zn, Mo, Pb can be useful in differentiating shallow water and deep water limestone. Flugel and Wedepohl, (1967) reported relatively low Sr values for shallow marine and relatively high Sr content for deeper water carbonates. This view is supported by low Sr value and relatively high Sr content for deeper water carbonates. Ba, Cr, Ni, U, Zn, and Zr variably occur in smaller quantity, this support that the carbonates are of shallow marine origin. These are elements with greater affinity for calcium and magnesium and would more probably be incorporated into the calcite and dolomite phases.

Table 4: Major Element Composition of studied Imo Formation

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	MnO
L1S1	3.53	1.71	2.29	47.8	0.73	0.02	0.04	<0.01	0.13
L2S2	29.2	11.75	42.6	0.15	0.08	<0.01	0.07	0.07	0.04
L2S4	4.96	1.81	9.13	42.6	1.15	0.04	0.09	<0.01	0.45
L2S5	2.48	1.24	2.52	49.4	1.24	0.02	0.04	<0.01	0.1
L2S8	2.94	1.04	2.47	43.9	4.69	0.02	0.03	<0.01	0.18
Mean	8.62	3.51	11.80	36.77	1.58	0.02	0.05	0.02	0.18

Table 5: Trace Elements Composition of studied Imo Formation

Elements	Ba	Co	Nb	Ni	Pb	Rb	Sr	Th	U	Zn	Zr
L1S1	24	2.4	2.2	7	<5	3.3	384	1.48	8.82	17	22
L2S2	77.7	23.5	10.4	36	52	9.3	21.8	23.8	12.25	107	273
L2S4	129	15.5	0.7	9	8	5.1	238	1.39	2.83	77	18
L2S5	15.6	2.1	1.4	10	<5	2.4	461	1.03	13.75	18	19
L2S8	16.4	2.1	1.4	5	<5	2.5	374	0.79	3.87	12	35
Mean	52.54	9.12	3.22	13.40	15.00	4.52	295.76	5.70	8.30	46.20	73.40

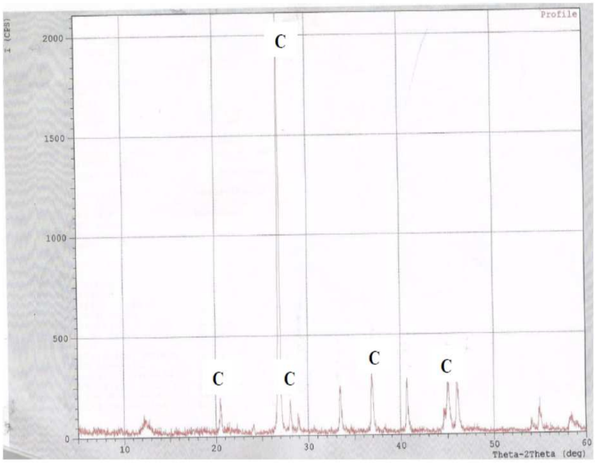
Mineralogy

X-ray diffractogram shows the sediments composed of calcite, aragonite, dolomite and pyrite. The shale is seen to be dominantly composed of kaolinite quartz and smectite. The abundance of calcite and dolomite relative to the absence of montmorillonite suggest a non-marine setting. The abundance of kaolinite mineral in the shale samples could be reflected of intense weathering and strong leaching of alumino-silicates rocks in a low latitude climate (Omosuyi *et al.*, 2002). During this period potassium is stripped from the clay-rich sediments to form kaolinite. The high percentage of kaolinite in the sample is an indication that the sediment were deposited under low energy condition.

The quartz present in the ferruginized sandstone confirms the earlier description as basically composed of arkose materials which are bounded together by iron-oxide. The ironstone pebbles is an indication of reworking of already deposited sediment through iron enrichment to form small pebbles of iron stones. Quartz also occurring abundantly, suggests it's secondary in origin having been accumulated from silica normally generated during chemical weathering. Presence of other non-clay minerals can be attributed to felsic origin. It is noted also that all carbonate sediments with their original mixed mineralogy are converted to low–Mg calcite during diagenesis. Grains cement originally composed of low–Mg calcite are perfectly preserved in limestone. Grains of aragonite are either replaced by calcite with some retention of original structure, or dissolved out completely to leave a mould, which later may be filled with calcite. Figs.13 show the XRD diffractogram for the analysed samples.

Depositional Environments

The limestones and dolomite at Arimogija-Okeluse have an environmental significance. The mudstone indicates deposition in a quiet water condition where micrite is abundant and winnowing of lime mud is minimal. The alternating clay-shale/siltstone and limestone units suggest relatively unstable carbonate shelf platform in which at intervals clastics were supplied from adjacent highlands at low sedimentation rate as suggested by Tucker and Wright (1990). This occurrences of pelecypods in the carbonate deposits are strong indication of shallow water environment, this has earlier been stated by Adegoke (1977).



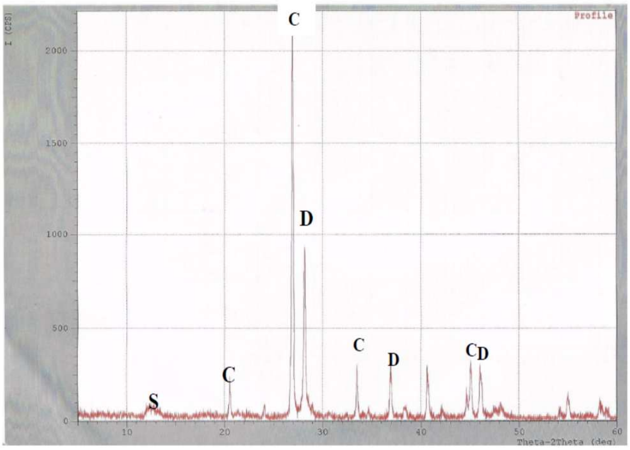


Figure 8: XRD chart of Limestone showing predominantly Calcite (C) peaks, (b-XRD chart of Dolomitic Limestone showing predominantly calcite (C) and Dolomite (D) peaks.

CONCLUSION

An evaluation of the field and sedimentological study of the Paleocene Imo Formation sediments at Arimogija-Okeluse shows that sediments in the area is characterized by sandstone, limestone and claystone/shale lithofacies. The sandstone facies signify finely upward grading and deductions from the grain size parameters indicates that the sandstone are moderately sorted, with a tail of excess coarse particles which suggests a proximal fluvial facies. These sandstones are sub-arkosic and texturally immature and signify a fluvial depositional environment.

The limestone microfacies; bioclastic-wackestone, bioclastic wackestone-packstone and dolomitic bioclastic-packstone are characterized with diagenetic imprints that have resulted from different stages of micritization, compaction, and neomorphism which characterizes products of clastic influenced inner to middle shelf carbonate environments. The dolomitic limestone consists essential of calcite, aragonite and anhydrites minerals. They also comprises of calcite, dolomite, smectite, anhydrites and other non-carbonate minerals. The minor shale contain clay minerals; Kaolinite, Smectite, Dickite e.t.c. while the ferruginized pebbly sandstone consists essentially of quartz, kaolinite and pyrite.

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