GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL, 9, NO.2, 2011 241-251

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CARBONATE MICROFACIES AND MAJOR ELEMENT CONTENT OF THE PALEOCENE – EOCENE SECTIONS EXPOSED AT THE SAGAMU QUARRY, EASTERN DAHOMEY BASIN, NIGERIA.

I.M. AKAEGBOBI, G.O. OGUNGBESAN AND J.E. OGALA

(Received 26 September 2006; Revision Accepted 15 December 2006)

ABSTRACT

The Paleocene-Eocene limestone and shale units exposed at the Sagamu quarry, southwestern Nigeria, were investigated for the carbonate microfacies and major geochemical elements to deduce the depositional environment and the diagenetic history of the limestone. From field observations the limestone is generally massive to wavy laminated, yellowish brown to light grey and fossiliferous. The shales are light to dark grey, fissile, clayey and concretionary.

Based on the microfacies studies, the limestone include: sandy bioclastic packstone, biomicritic mudstone, biomicritic wackestone, biosparitic grainstone, biomicrtic packstone and oolitic packstone-grainstone. Gastropods, peleycpods, foraminifera, ostracodes and algae constitute the major bioclasts while pellets and lithoclasts are the major non-bioclastic components of the lithofacies.

Geochemically, the limestone is rich in CaO (46.82%), SiO_2 (5.72%) and MgO (1.97%). The values indicate non-dolomitic limestone. The CaO and MgO contents are however lower at the base than at the top of the limestone and probably reflects the sandy nature of this part. Ternary plot shows that the limestone is richly calcitic. The shales are rich in SiO_2 (44.43%), Al_3O_2 (15.90%) and Fe_2O_3 (7.68%). The high values of CaO (6.35%) and MgO (2.62%) make them calcareous shales.

The lithologic, paleontologic and petrographic data indicate deposition of the units in a shallow marine shelf-lagoon environment, formed during the Maastrichtian sea flooding into Dahomey Basin. The porosity and permeability of the limestones are generally low while fracturing and dissolution improved the permeability, the effect of late diagenesis reduced it significantly.

KEYWORDS: Dahomey Basin, Limestone, Microfacies

INTRODUCTION

The Dahomey Basin is an extensive sedimentary domain on the continental margin of the Gulf of Guinea. It extends from southeastern Ghana through Togo and Benin Republics to the western flank of the Niger Delta (Jones and Hockey, 1964; Ogbe, 1972; Omatsola and Adegoke, 1981, Billman, 1992) (Fig.1). It forms part of a system of the West African pericratonic (Margin sag) basins which developed during the commencement of the rifting associated with the opening of the Gulf of Guinea. Although, several hypotheses have been advanced on the origin of the basin, the rift hypothesis which relates the origin to the separation of South America plate from Africa plate is widely accepted (Burke *et al*., 1971; Omatsola and Adegoke, 1981; Storey, 1995). The basin consists of Cretaceous–Tertiary sedimentary formations outcropping in an arcuate belt roughly parallel to the ancient coastline and thickens from shore margin to the offshore (Whiteman, 1982).

Several geological studies have been done on the eastern Dahomey Basin, viz: stratigraphy and paleontology (Reyment 1966; Fayose, 1970; Ogbe, 1972; Fayose and Asseez, 1972; Omatsola and Adegoke, 1981; Okosun, 1998; Nwachukwu *et al*., 1992; Bankole *et al*., 2006), sedimentology (Nton, 2001; Nton and Elueze, 2005), hydrocarbon source potential (Nwachukwu and Adedayo, 1987; Ekweozor and Nwachukwu, 1989, Idowu *et al*., 1993; Elueze and Nton, 2004; Nton *et al*., 2006; Adekeye et al., 2006).

The limestone and shale units belong to the Ewekoro and the Akinbo formations respectively, and are exposed at the three faces of the Sagamu quarry. They were investigated to identify their microfacies and infer their corresponding environments. The geochemical analysis of the limestone and shale units was also undertaken. Reyment (1965) assigned Late Paleocene age to the Ewekoro Formation and further described the unit as a lateral equivalent of the Imo Formation. Adegoke *et al.* (1971) subdivided the formation into three microfacies units, namely the basal Sandy Biomicrosparite, Shelly Biomicrite and the top Algal Biosparite. Ogbe (1972) added a fourth microfacie unit of the topmost red Phosphatic Biomicrite and also proposed the Akinbo Formation for the overlying shale unit. Fayose and Assez (1972) argued that the limestone unit and the overlying massive shale units are members of the Imo Formation, and assigned Lower Eocene age to the Formation. Bankole *et al.* (2006) assigned Late Paleocene – Early Eocene to the exposed shale unit in Sagamu quarry based on palynomorphs but erroneously change the nomenclature of the shale unit from Akinbo Formation to Oshosun Formation.

I.M. Akaegbobi, Department of Geology, University of Ibadan Ibadan
G.O. Ogungbesan, Department of Earth Sciences, Olabisi Onabanjo University, Ago-Iwoye
J.E. Ogala, Department of Geology, Delta State University, Abraka

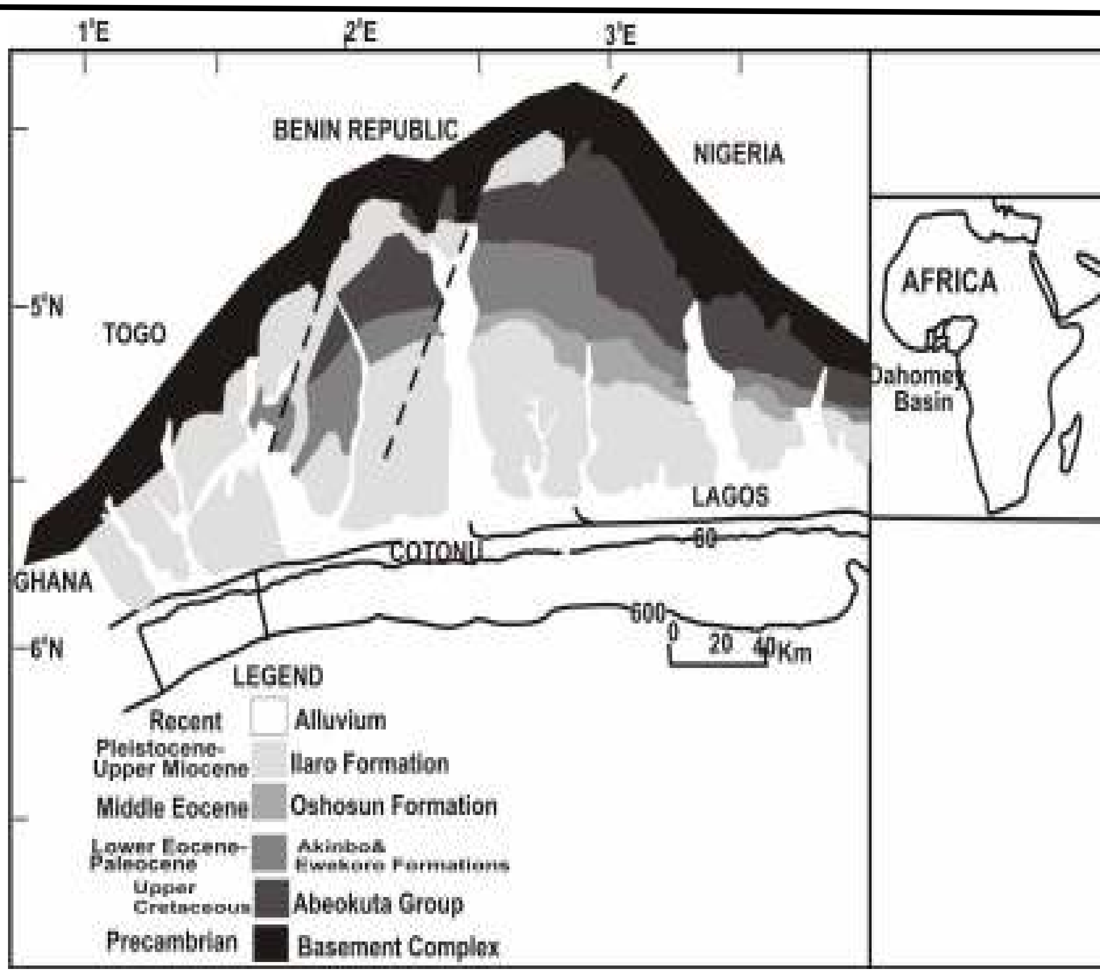

Fig. 1: Generalized geological map of Dahomey Basin. Insert is a map of Africa showing the location of Dahomey Basin. (Modified after Billman, 1992

GEOLOGY AND STRATIGRAPHY

Several studies have been carried out on the geology, stratigraphy and sedimentology of the lithic fills of the eastern Dahomey Basin. The lithostratigraphic formations of the eastern Dahomey Basin from the oldest to youngest (Fig. 2) include: Abeokuta Group (Cretaceous), Ewekoro Formation (Paleocene), Akinbo Formation (Late Paleocene-Early Eocene), Oshosun Formation (Eocene), Ilaro Formation (Eocene).The Abeokuta Group is subdivided into three lithostratigraphic units of formational rank. These are Ise, Afowo and Araromi formations. The Ise Formation (Neocomian - Albian) is the oldest lithic unit and is unconformably disposed on the Basement Complex. It is made up of conglomerate and grit at the base and overlain by coarse-grained loose sand interbedded with kaolinitic clays (Omatsola and Adegoke, 1981).

The Ise Formation is overlain by the Afowo Formation which is composed of medium-grained sandstones interbedded with shales, siltstones and claystones. The lower part of the formation contains well-sorted, subrounded clean loose tar-bearing sands (Omatsola and Adegoke, 1981). The shale components increase progressively from base to the top. The formation has been dated Turonian-Maastrichtian by Billman (1992). Araromi Formation is the youngest Cretaceous deposit in the eastern Dahomey Basin (Omatsola and Adegoke, 1981). It is composed of fine – medium grained sandstone at the base, overlain by siltstone and shale interbedded with limestone, marl and lignite (Maastrichtian- Paleocene).

The Araromi Formation is supercedes by the Ewekoro Formation (Paleocene) which is composed predominately of limestone. The limestone is traceable for a distance of about 320 km from Ghana towards the eastern margin of the Dahomey Basin. The Akinbo Formation (Paleocene-Eocene) overlies the Ewekoro Formation and consists of shaley/clayey units (Ogbe, 1972; Nton *et al*., 2005). Its base is defined by a glauconitic band exposed at the Ewekoro quarry. The shale is grayish, fissile, clayey and concretionary. The formation extends into the Republics of Benin and Togo (Slanky, 1962).

Younger and successive units from the bottom-up are Oshosun, Ilaro and Benin formations. The Oshosun Formation is phosphate-bearing, with greenish grey or beige clay, and shaley with interbeds of sandstones (Okosun, 1998). The Ilaro and Benin formations are comprised mainly of cross-bedded, poorly sorted sandstones with transitional to continental characteristics.

Two formations - the Ewekoro and the Akinbo formations are well exposed at the Sagamu quarry. The lithologic sections consist of limestone overlain by shale. The limestone unit is generally light grey-yellowish brown in colour (Fig.3), coarse-to medium-grained, poorly sorted and fossiliferous with abundant preserved gastropods, brachiopods, pelecypods shells, echinoid fragments, skeletal debris with increasing sandy components towards the base of the sections (Fig. 4). The thickness of the limestone unit is about18.5m. The shale overlying the limestone is generally light to dark grey, fissile and occasionally with lensoidal carbonatic concretions (Fig. 5). The thickness of the shale is about 8m.

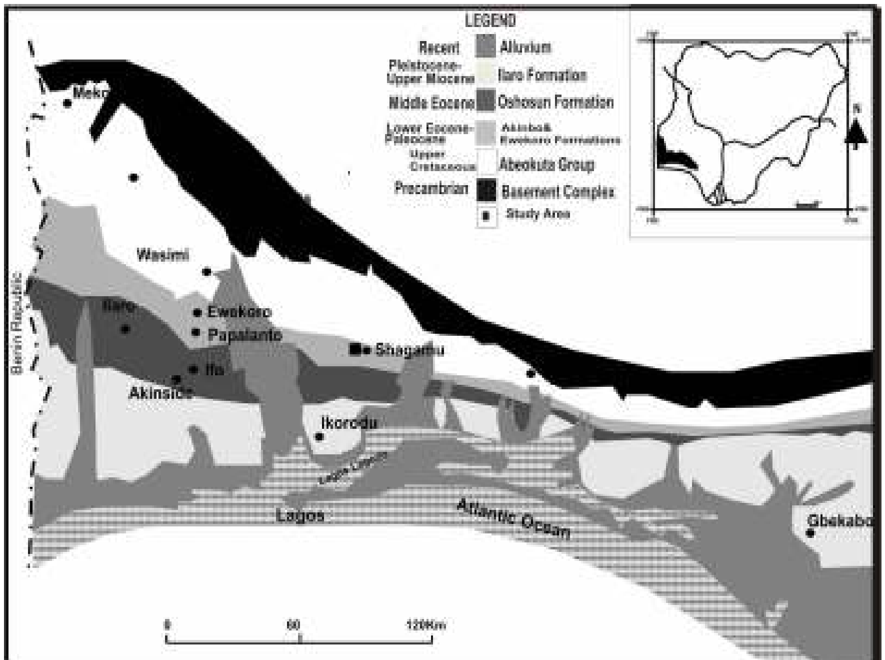

Fig. 2: Geological map of eastern Dahomey Basin. Insert is a map of Nigeria showing the location of Dahomey Basin. (Modified after Bankole *et. al.*, 2006)

Fig. 3: Photography of the exposed fossiliferous Limestone at Sagamu quarry

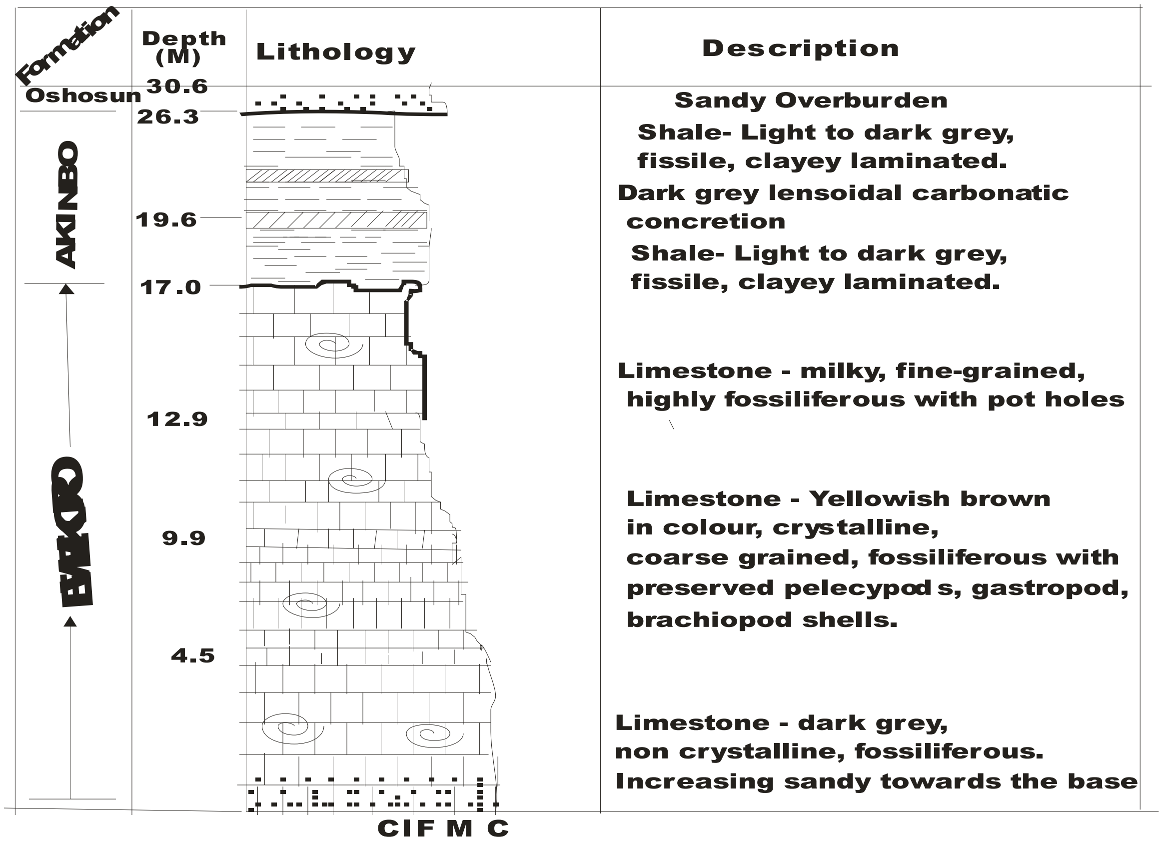

Fig. 4: Lithostratigraphy of the Sagamu quarry

Fig. 5: Photography of the exposed fissile, concretionary Akinbo shale at Sagamu quarry

MATERIAL AND METHODS

Exposed lithologic sections at the three faces of the Sagamu quarry were described. Thirty eight fresh samples of limestone and shale were collected for the petrographic analysis and major elements determination.

Twenty-five limestone samples were prepared for thin section. Each sample was smoothened and mounted on a glass slide using Canada balsam and then polished with carborundum. The slides were studied under a flat stage petrographic microscope and point counted, with an average 900 counts per thin section. The limestone was classified using both Folk (1959) and Dunham (1962) methods.

Eight limestone and nine shale samples were pulverized and sieved for analysis. 0.2gm of each was taken in an airtight plastic container. The samples were digested using the fusion technique where lithium metaborate fusion was employed. The resulting bead is rapidly digested in a weak nitric acid solution. The major elements were determined using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) with a detection limit of 0.01% and precision of +/-0.1% at Activation Laboratory, Canada.

RESULTS

Major Elements Geochemistry

The results of the analysis for the major oxides of the selected samples are presented in Table 1. CaO (42.1 – 54.64%) constitutes the major oxide and in the limestone, others are $Fe_2O_3^t$ (0.48 – 4.41%), MgO (0.57 – 4.87%), Al_2O_3 (0.27 – 2.98%) and SiO_2 (0.64 – 15.04%). The values indicate that the limestone is calcitic and non-dolomitic. The CaO and MgO values are lower in samples from the base than from the top of the formation, probably reflecting the sandy nature of this part of the formation (Oladeji, 1992). The significant amount of SiO_2 (0.64 – 15.04 %) and Al_2O_3 (0.27 – 2.98%) confirm the presence of non-carbonate detritus especially at the base.

The result also show the predominance of SiO_2 (26.36 – 48.93%), Al_2O_3 (9.75 – 17.41%), $Fe_2O_3^t$ (5.59 – 13.47%) and CaO (4.1 – 25.09%) in the shale samples. The shales are richer in CaO (6.35%) and MgO (2.61%) than in Na_2O (0.10%) and K_2O (9.95%) suggesting the shales are calcareous. The average loss on ignition (LOI) of 40.13% and 20.41% in the limestones and shales samples respectively is high, showing great potential of both the limestone and shale for carbonaceous compound. Ternary plot of SiO_2 – CaO – MgO for the limestone and shale reveals that the limestone is high in CaO (80%) while SiO_2 and MgO are less than 20%, and the shale is high in SiO_2 (80%) while CaO and MgO are less than 20% (Fig.6). The moderate increase in K_2O with depth is attributed to diagenetic implication of increase in illite with depth of burial (Robert, 1988).

Table 1: Results of the Major Elemental Analysis for the Limestones and shales (Oxides in Wt %)

Sample No	Lithology	SiO_2	Al_2O_3	$Fe_2O_3^{(t)}$	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	Total
R1	Limestone	11.88	2.56	2.56	0.016	1.36	42.31	0.04	0.25	0.331	0.44	35.80	97.50
R2	Limestone	15.04	2.98	4.41	0.020	1.03	39.87	0.07	0.33	0.374	0.44	34.80	99.37
R3	Limestone	4.57	1.97	7.82	0.031	4.87	40.74	0.02	0.15	0.075	0.17	39.80	100.20
R4	Limestone	0.64	0.20	0.72	0.059	0.27	54.33	0.06	0.03	0.007	0.19	43.19	99.69
R5	Limestone	4.59	1.68	1.74	0.024	3.80	45.43	0.06	0.08	0.102	0.22	41.42	99.15
R6	Limestone	5.27	1.89	1.56	0.021	2.34	46.89	0.06	0.10	0.119	0.26	40.66	99.17
R7	Limestone	2.90	1.27	1.01	0.020	1.48	50.34	0.05	0.10	0.052	0.09	41.92	99.24
R8	Limestone	0.78	0.27	0.48	0.022	0.57	54.64	0.05	0.03	0.007	0.13	43.41	100.40
R9	Shale	46.80	17.41	7.57	0.039	2.44	4.73	0.04	0.96	0.938	0.26	19.53	100.10
R10	Carbonaticc oncretion	26.36	9.75	5.59	0.125	1.52	25.09	0.07	0.56	0.531	0.14	29.26	99.00
R11	Shale	47.93	16.86	6.67	0.146	3.13	2.70	0.08	0.99	0.905	0.23	18.98	98.62
R12	Shale	48.93	16.41	5.88	0.055	2.69	3.54	0.08	0.97	0.981	0.23	18.92	98.68
R13	Shale	46.96	16.67	8.24	0.125	3.08	3.51	0.05	1.03	0.890	0.24	18.87	99.67
R14	Shale	46.34	17.91	6.29	0.020	2.45	4.75	0.06	1.03	0.939	0.25	20.34	100.40
R15	Shale	47.18	16.19	8.42	0.110	2.97	4.10	0.44	1.08	0.915	0.26	18.95	100.60
R16	Shale	46.33	16.06	7.03	0.090	2.96	4.33	0.06	1.01	0.888	0.22	19.88	98.86
R17	Shale	43.67	15.86	13.47	0.053	2.32	4.44	0.06	0.91	0.873	0.27	18.93	100.90

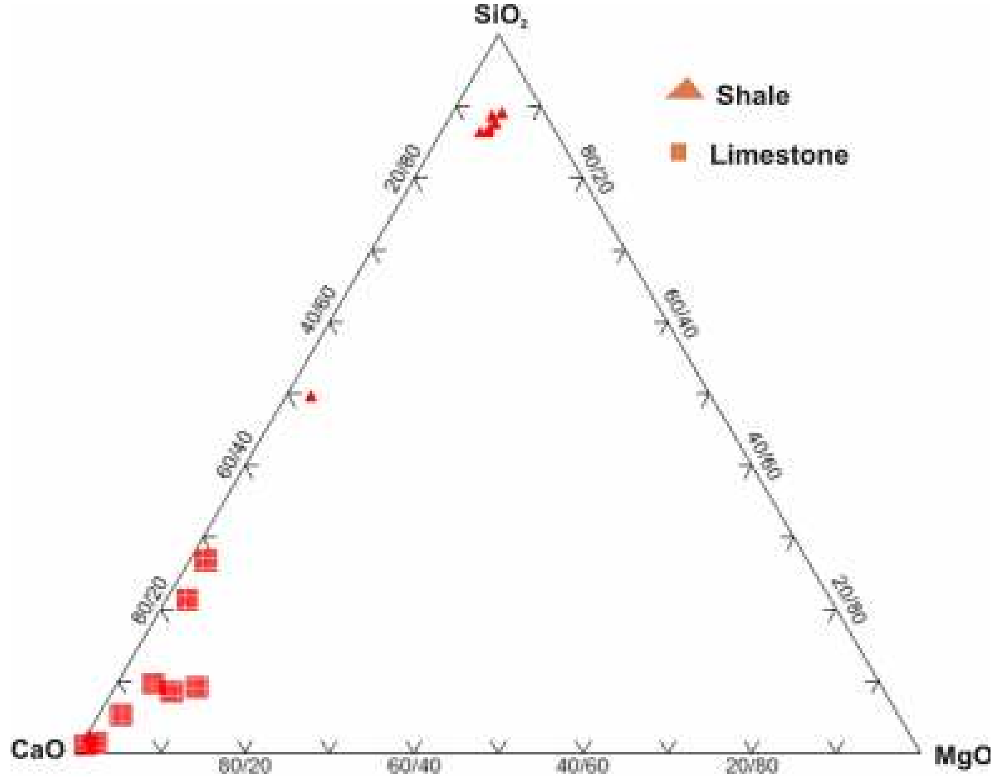

Fig. 6: Ternary plot of CaO-SiO_2- MgO content in the Limestone and Shale samples.

Carbonate Petrography and Microfacies

Table 2 shows the modal composition, the texture and the limestone types. Our classification of the limestone into microfacies is after Folk (1959) and Dunham (1962). Six carbonate microfacies were identified namely: Sandy Bioclastic Packstone, Biomicritic mudstone, Biomicritic Wackstone, Biosparitic Grainstone, Biomicritic Packstone and Oolitic Packstone-grainstone. The petrography of the above is discussed in the following paragraphs.

Sandy Bioclastic Packstone: This occurs towards the base of the section at the quarry. The rock is grain supported with substantial amount of mud (Fig. 7). The principal bioclasts are pelecypods, gastropods, ostracodes and algae, with the bioclast embedded in micrite. The interparticle space is filled with microspar and drusy cement.

Biomicritic Mudstone: This microfacie is rare and of true micrite (Fig. 8). Micritization process has preserved occasional relics of pelecypod fragments and other unidentified broken bioclasts. The micrite is crystallized to drusy cement.

Biomicritic Wackstone: The biomicritic wackstone shows a mud-supported texture with the carbonate grains including broken gastropods, pelecypod shells, ostracodes and foraminifera (Fig. 9). Interparticules spaces are filled with drusy and microspar cement and pervasive internal micritization occurs in some of the grains. Few peloids of small size are present with abundant lime mud in the micrite.

Biosparitic Grainstone: This microfacie shows a grain-supported texture. Worn and fragmented bioclasts of gastropods occur. Dissolution features are cemented by sparry calcite (Fig. 10) and the associated fragments still preserved the ooids.

Biomicritic Packstone: The rock is grain-supported but contains substantial amount of mud. High percentage of bioclasts and few lithoclasts recognized with pelecypods, gastropds, ostracodes, algae and foraminifera representing the principal bioclasts in the rock. These bioclasts are embedded in micrite and the interparticles spaces are filled with drusy cement (Fig. 11).

Oolitic Packstone-grainstone: normally packed oolites with mostly well formed multiple coated, spherical grains observed (Fig. 12). The nuclei are made up of foraminifera and molluscan grains. The grains are commonly lined with fine drusy calcite cement which provides a good preservation of the rinds of some peloids. The internal micrite is commonly replaced by drusy cement.

Table 2: Estimated Modal Analysis of the Limestone

Sample No	Depth	Components (%)							Depositional Texture recognized	Classification
		Micrite	Sparite	Fossil	Peloid	Quartz	Ooid	Intraclast		
LS/01	0.9	40	10	14	-	20	13	-	Grain supported, not organically bound, contains mud	Sandy bioclastic packstone
LS/02	3.2	40	35	10	-	5	10	-	Not organically bound, mud supported and over 100% grains present	Biomicritic wackstone
LS/03	8.0	60	10	20	-	-	10	-	Not organically bound, contains mud and is mud supported	Biomicritic packstone
LS/04	10.1	50	20	20	-	-	8	-	Not organically bound, mud supported and over 100% grains present	Biomicritic wackstone
LS/05	12.3	50	15	15	8	-	10	-	Not organically bound, contains mud and is mud supported	Biomicritic packstone
LS/06	0.9	40	10	25	8	15	-	-	Not organically bound, contains mud and is mud supported	Sandy bioclastic packstone
LS/07	3.0	70	5	14	1	5	3	-	Not organically bound, mud supported and less than 100% grains present	Biomicritic mudstone
LS/08	5.8	50	10	-	8	-	20	10	Not organically bound, contains mud and is mud supported	Biomicritic packstone
LS/09	8.9	60	15	10	5	-	-	8	Not organically bound, contains mud, mud supported with more than 10% grains	Biomicritic wackstone
LS/10	0.9	35	15	10	-	20	5	10	Not organically bound, contains mud and is mud supported	Sandy bioclastic packstone
LS/11	2.5	15	44	15	10	14	-	-	Original component not bound together during depositions, lacks mud but is grain supported	Biosparitic grainstone
LS/12	5.1	60	10	20	-	7	7	3	Not organically bound, contains mud and is mud supported	Biomicritic packstone
LS/13	7.7	50	15	20	8	-	-	5	Not organically bound, contains mud and is mud supported	Biomicritic packstone
LS/14	9.8	60	15	20	5	-	-	5	Not organically bound, contains mud, mud supported with more than 10% grains	Biomicritic wackstone
LS/15	12.2	45	14	20	5	-	20	-	Not organically bound, contains mud in some areas but is grain supported	Oolitic packstone-grainstone
LS/16	1.5	10	50	20	-	10	10	--	Not organically bound, lacks mud but is mud supported	Biosparitic grainstone
LS/17	0.4	40	20	10	8	20	-	-	Not organically bound, contains mud and is mud supported	Sandy bioclastic packstone
LS/18	3.0	60	10	20	-	10	-	-	Not organically bound, contains mud and is mud supported	Biomicritic packstone
LS/19	5.1	60	15	15	2	8	-	-	Not organically bound, contains mud and is mud supported	Biomicritic packstone
LS/20	0.5	40	20	15	-	20	5	-	Not organically bound, contains mud and is mud supported	Sandy bioclastic packstone
LS/21	2.3	8	45	20	5	5	-	-	Not organically bound, lacks mud but is mud supported	Biosparitic grainstone
LS/22	6.0	10	40	20	-	16	14	-	Not organically bound, lacks mud but is mud supported	Biosparitic grainstone
LS/23	9.1	45	15	15	5	-	20	-	Not organically bound, contains mud in some areas but is grain supported	Oolitic packstone-grainstone
LS/24	11.5	40	20	20	5	-	10	3	Not organically bound, contains mud and is mud supported	Biomicritic packstone
LS/25	17.2	15	15	-	5	10	-	-	Not organically bound, contains mud and is mud supported	Biomicritic packstone

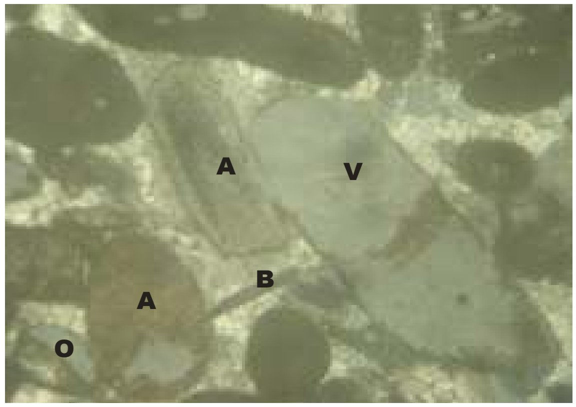

Fig 7: Photomicrograph showing sandy bioclastic packstone with preserved bioclasts; A: algae, O: Ostracode, B: Bivalve, V: Void. (XPL, X40)

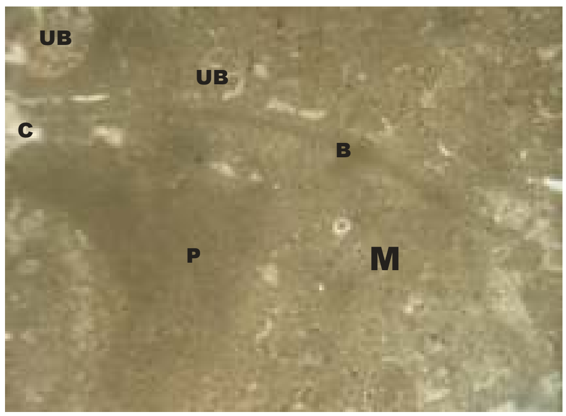

Fig. 8: Photomicrograph showing Biomicritic Mudstone. P: Pelecypod, B: Bivalve, UB: unidentifiable bioclast, M: micrite (PPL, X 40).

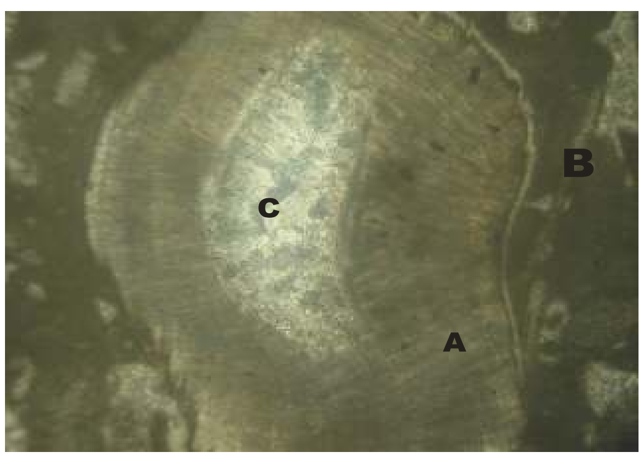

Fig. 9: Photomicrograph showing biomicritic wackestone with mud-supported texture. A: Algae mat, B: Bivalve, C: Cement. (XPL, X 40)

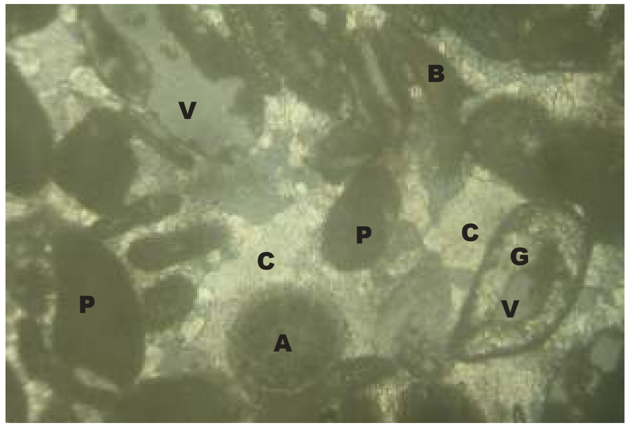

Fig. 10: Photomicrograph showing biosparitic grainstone with worn and fragmented bioclasts. A: Algae mat, P: Peloid, G: Gastropod, B: Bivalve (fragmented), C: Cement; V: Void. (XPL, X 40)

Fig. 11: Photomicrograph showing biomicritic packstone with bioclasts embedded in grain supported mud. o: ostracode, F: Foraminifera, B: Bivalve, C: Cement (XPL. X 40)

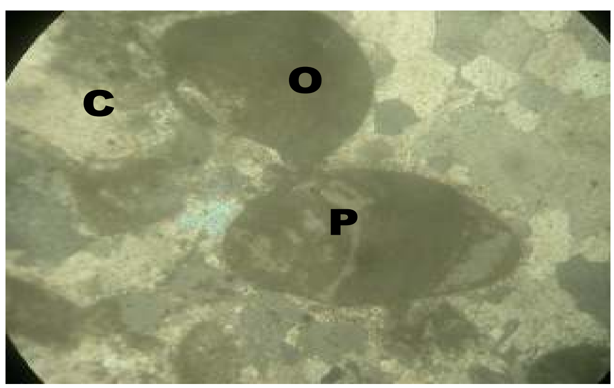

Fig. 12: Photomicrograph showing oolitic packstone-grainstone with coated spherical grains. P: Peloid fine drusy calcite cement, O: oolite (Broken) (XPL, X 40).

DISCUSSION

Depositional Environment

The interpretation of the depositional environment of the carbonate microfacies is based on the distinct lithologic, sedimentologic and paleontologic features observed. The sandy bioclastic packstone microfacie suggests deposits of barrier island complex with tidal channel connecting to back barrier lagoon usually surrounded by tidal flats. The beach and backshore dunes are supplied with sands particularly during storm surge. The bioclasts are those derived from carbonate secreting organism living in the shoreface area (Reinson, 1984).

The biomicritic mudstone mirofacies represent shoreward deposit of lagoonal mud. The prevalence of recrystallized micrite to drusy cement and worm burrows are common evidence of a shallow intertidal environment characterized by low energy (Wilson, 1975). The biomicritic wackstone and packstone consists of a few monotonous varieties of bioclasts. This probably indicates a harsh environment unsuitable for a wide variety of open marine biota. The presence of sandy lithoclast represents a textural inversion suggesting that particles from high energy environments have moved across the shoal down to low energy setting in the lagoon possibly in the middle shelf environment (Flugel, 1982). The abundance of lime mud in the groundmass combined with a shallow marine fauna also suggests that these facies were formed in a protected shallow marine inner shelf setting (Reijers and Petters, 1987).The biosparitic grainstone and the oolitic packstone-grainstone microfacies suggest a shoal and relatively high energy environment if deposition developed in a restricted inner shelf lagoonal environment probably proximal to the strandline (Wilson, 1975; Al-Juboury and McCann, 2008).

In general, the abundance of lime-mud supported carbonate rock and preserved gastropods and pelecypods shells with limited agglutinated benthic foraminifera and ostracodes and almost complete absence of planktonic foraminifera suggest a shallow marine, shelf lagoonal depositional environment (Reijers and Petters, 1987). This indicates that a barrier might have isolated the lagoon from the open sea except during surge. The restricted condition resulted in a hypersaline condition due to the reduced inflow of surface meteoritic water, which probably was the case during the carbonate deposition.

Diagenesis

Detailed analysis of the textural and structural features preserved in the carbonate samples reveal that the limestone samples were affected by several diagenetic process including cementation, micritization, compaction and dissolution. Five diagenetic stages were observed:

Stage 1: Diagenesis began at shallow depth soon after the deposition of the carbonates. The loose carbonate constituents were enveloped by micritic cement. Gastropods and pelecypods shells and foraminifera were preserved by micritic coating (Fig. 7).

Stage 2: This involved the partial and complete dissolution of the micritic coating and the internal micritization due to uplift. This led to the increased channel porosity in the biomsparitic grainstone with the interparticle and intraparticle porosities developed (Fig. 7, 10& 12).

Stage 3: Cementation in the active saturated fresh water phreatic zone occurs and the pores are filled with calcite (Fig. 11).

Stage 4: This stage involved compaction and cementation. The bioclastic and non bioclastic grains are moderately packed due to compaction (Fig. 10) followed by cementation of mouldic and interparticle porosity by calcite.

Stage 5: The recrystallization stage is the last stage of diagenesis observed in the carbonate diagenetic history. It involved recrystallization of micrite (Fig. 7 & 10), filling of vugs with sparrycalcite cement, growth of the calcite constituents. This final stage of diagenesis reduced the porosity and permeability significantly.

CONCLUSION

Selected surface samples of the Ewekoro and Akinbo formations exposed at Sagamu quarry were investigated for the carbonate microfacies and their corresponding depositional environments and diagenetic history.

The geochemical analysis of the limestone reveals the abundance of CaO (46.82%) and MgO (1.97%), suggestive of calcitic, non-dolomitic limestone. The excess of oxides of carbonate minerals over silicates minerals in the associated shales indicate that the shales are calcareous.

Based on carbonate petrography, the microfacies identified include: sandy bioclastic packstone, biomicritic wackstone, biosparitic grainstone, biomicritic packstone and oolitic packstone-grainstone. The abundance of lime-mud-supported carbonates, gastropods, pelecypods, ostracodes, limited benthic foraminifera indicate a shallow marine, shelf depositional environment formed during the Maastrichtian-Paleocene transgression into the eastern Dahomey Basin.

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