Fjrs.futa.edu.ng
FUTA Journal of Research in Sciences
ISSN: 2315 – 8239 (Print); E-ISSN: 2489 - 0413

FUTA Journal of Research in Sciences, Vol. 13 (2), October, 2017: 371-383

CHEMOSTRATIGRAPHY OF THE LIMESTONE IN EWEKORO FORMATION AT ITS HYPO-STRATOTYPE IN SAGAMU, NIGERIA

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ABSTRACT

The limestone part of the Ewekoro Formation as exposed at a mining site in Sagamu was subjected to lithostratigraphic and geochemical studies. The study aims at a more detailed lithologic description including major elements determination of the limestone deposit at bed levels to better understand the richness of the rocks in terms of calcium content and its sedimentology. Detailed lithostratigraphy of the outcrop was carried out in the field; samples taken were studied using atomic absorption spectrometer (AAS) and gravity method. The samples were scanned using scanning electron microscope. The exposure consists of five beds of two groups of limestone: packstone (Beds, 2, 4 and 5) and wackstone (Beds 1 and 3). Three layers of motorable hardground separated the beds (one between bed 1 and 2, the second between bed 2 and 3 and the third between the limestone and the overlying shale). The richest bed in terms of CaO_2 is Bed 3, which also have the lowest $SiO_{2,}$ reflecting the bed that was deposited in the deepest environment. Directly on top of the limestone is the Akinbo shale which consists of two shale facies – black and grey. Generally the limestones were deposited under varying environment of deposition and have been subjected to some varying environmental condition.

Keywords: Ewekoro Formation, limestone, beds, hardground, Calcium Oxide

INTRODUCTION

The Ewekoro Formation is one of the stratigraphic units in the Nigerian part of the Dahomey Basin (Fig.1). It conformably overlies the Afowo Formation (old name – Abeokuta Formation). The formation is not encountered offshore and in coastal boreholes (Reyment, 1965; Fayose, 1970; Billman, 1976, 1992). Where not encountered, it is replaced by the predominantly shaley Imo Formation which uncomformably overlies the Afowo Formation (Fayose, *op. cit.).* Borehole studies have revealed that Ewekoro Formation is lens – shaped, thinning out and eventually disappear in all directions. It has a maximum thickness of 34 m at Ibeshe (Fayose and Assez, 1972). The Ewekoro Formation has its type locality at the Ewekoro limestone quarry. There, it consists of 10 to 12.5 m of thinly bedded glauconitic and sandy limestone at the base, which then becomes massive grey and fossiliferous in the middle and fine grained, marly and algal in the upper part (Dessauvagie, 1975: Adegoke, 1977). The top highly scoured layer consists of red, dense, glauconitic, phosphatic and fossiliferous limestone. The Ewekoro Formation is highly fossiliferous. Adegoke (1977) identified more than 220 mollusks and echinoderm species and subspecies from the formation. It also contains abundant foraminifera, ostracodes and algae.

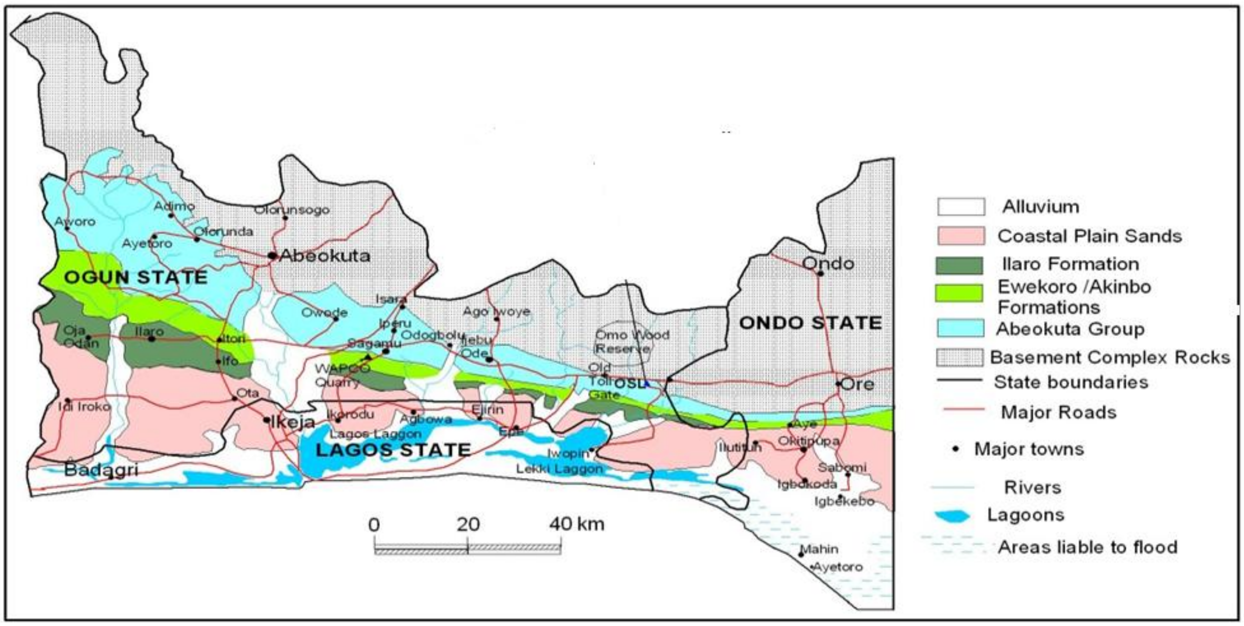

Figure. 1. Geological Map of southwestern Nigeria Showing the location of the Study Outcrop in Black dot

The age of Ewekoro Formation is controversial with prevailing two schools of thought. Reyment (1965), Adegoke (1969), and Adegoke et al. (1970) proposed a Paleocene age on the basis of the occurrence in the strata of macrofossil and microfossil assemblages. The foraminiferal assemblage consists of by *Globorotalia pseudobulloides, G. velascoensis, G. acita, Globigerina triloculinoides and G. linaperta*. Reyment (1965) also listed a typical Paleocene ostracode fauna retrieved from the formation. However, Fayose and Assez (1972) disagreed with the Paleocene age. They pointed out that the presence of *Globorotalia subbotinae Morozova* (a Lower Eocene index fossil) and other diagnostic Lower Eocene fossils *(including Bolivina ottaensis and pseudohastigerian wilcoxensis)* in the strata is significant and should not be overlooked. They therefore placed the Paleocene – Eocene boundary in southwestern Nigeria within some calcareous shale – limestone interbedded sequence below the massive shelly limestone unit. Evidences in favour of a Paleocene age for the Ewekoro Formation appear to be quite convincing and very well documented. It is possible, however, that part of the sequence exposed at Ewekoro and also occurring in boreholes in southwestern Nigeria (especially the shales overlying the limestone i.e. Akinbo Formation) could be lowermost Eocene in age (Odebode et al., 1996)

The Ewekoro Formation is exposed in several limestone's quarries in southwestern Nigeria (Ewekoro, Shagamu and Onigbedu); Benin and Togo Republic where it is being used for cement production. Investigation of the limestone as a source of raw materials for cement production started in 1956 by Associated Portland Cement Manufacturers, Limited. According to Adegoke et al (1980) the formation is about 11 m thick, and consists of yellow and pale grey shelly limestone at its type locality in Ewekoro.

This study aims at a more detailed lithologic description of the beds of the formation at a better exposed section in Sagamu. The major element geochemical analysis of the limestone at beds level is carried out to understand the richness of the rocks in terms of calcium content and clastic influx that may serve as pollutant to the limestone, and the degree of alteration of the limestone. This determination was carried out to ascertain if the studied rocks were subjected to alteration or not and their usefulness for industrial purposes.

GEOLOGICAL SETTING

The Dahomey Basin is a one-sided source asymmetry basin that occupies the intermediate crustal zone between thick continental crust and thin oceanic crust. Evolution of the basin was in response to the opening up of the Central and South Atlantic in the Middle Jurassic and that of the Cretaceous times. According to Omatsola and Adegoke (1981), deposition was initiated in the fault controlled structural depression on the crystalline basement complex during early Cretaceous. The subsidence led to the deposition of a very thick (over 1400m) sequence of continental grits and pebbly sands over the entire basin, which covers parts of Southwestern Nigeria, the Benin Republic, Togo and Ghana (Lehner and Ruiter, 1977). During the Santonian there was another episode of major tectonic activity in the basin that was probably associated with the closure and folding of the Benue Basin. The basement rocks (granite gneiss and associated pegmatite) as well as the uncomformably overlying sediment in the basin were tilted and block –faulted giving rise to series of horst and graben (Bodashe Horst, Ilepaw Horst, Afowo Graben, Ojo Platforms, Orimedu Graben and Ise graben (Omatsola and Adegoke, 1981) that are still active till date (Ola and Olabode, 2018). Sediment accumulation in the basin varies in thickness on the on-shore coaster section from 100m to 1,400 m along strike and well over 2,000 m in the offshore part of the basin.

Stratigraphy

The stratigraphy of the Cretaceous and Tertiary formations in the Nigerian sector of the basin is controversial. This is primarily because different stratigraphic names have been given to the same formation in different localities in the basin (Billman, 1992; Coker 2002). This situation can be partly blamed on the lack of good borehole coverage and adequate outcrops for detailed stratigraphic studies. Earlier studies on the basin stratigraphy by Jones and Hockey (1964) recognized both Cretaceous and Tertiary sediments. Other subsequent workers recognized three chronostratigraphic units: (i) pre-Lower Cretaceous folded sequence, (ii) Cretaceous sequence, and (iii) Tertiary sequence (Omatsola and Adegoke, 1981; Billman 1992). Figure 2 summarizes the generalised stratigraphic column showing age, lithology, and sequence of the formations and tectonic stage of basin development in the Nigerian sector of the Benin Basin (Ola and Olabode, 2017).

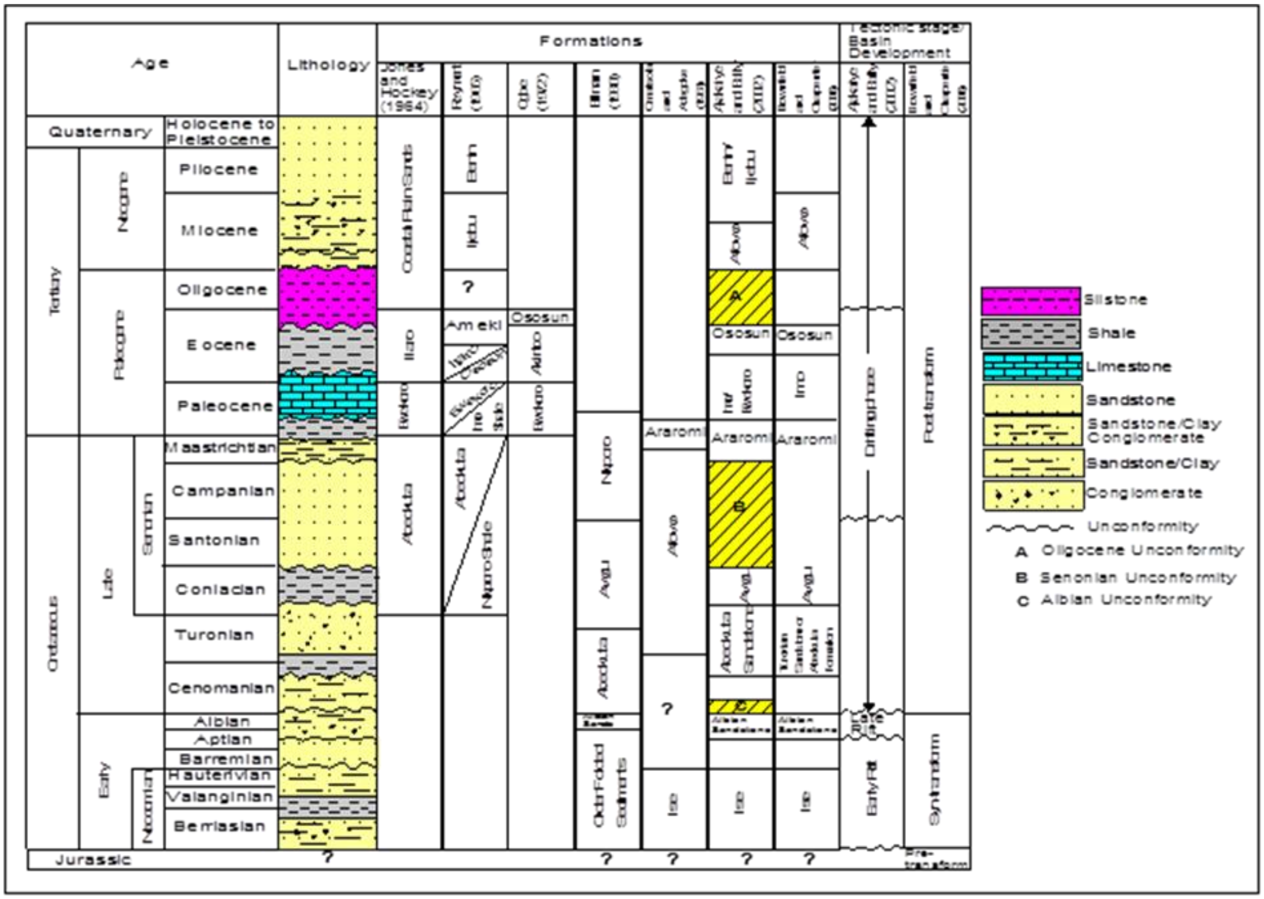

Fig. 2. Generalised stratigraphic column showing age, lithology, and sequence of the formations and tectonic stage of basin development in the Nigerian sector of the Benin Basin (Ola and Olabode, 2017)

Cretaceous Successions

The Cretaceous stratigraphy as compiled from outcrop and borehole records consists of Abeokuta Group sub-divided into three informal formational units, namely, Ise, Afowo, and Araromi (Omatsola and Adegoke, 1981).

Tertiary Successions

The oldest Tertiary sequence in the Dahomey Basin is the Ewekoro Formation, the focus of this study. The Ewekoro Formation (where encountered) is uncomformably overlain by the predominantly shaley formation, which Ogbe (1972) named Akinbo Formation. Where the Ewekoro Formation is missing, the Akinbo Formation lays uncomformably on the Afowo Formation (Bilman, 1992).

The shales of the Akinbo Formation grade into the overlying mudstones and claystones of the Oshosun Formation. The presence of glauconites, phosphates and abundant planktic foraminifera in the Oshosun Formation indicates deposition in a fairly deep marine environment, probably in the bathyal zone. Overlying the Oshosun Formation, is the Ilaro Formation, described by Jones and Hockey (1964) in shallow boreholes drilled at the Akinside and Ifo areas. The Ilaro Formation consists of coarse, angular and poorly sorted sand with considerable amount of clay layers and few occurrence of shale. Capping all the formations is the often referred to as Coastal Plain Sands (Jones and Hockey, 1964). It consists of yellow and white, sometimes cross-bedded sand, pebbly beds and clays with some sandy clay lenses. Its thickness is unknown except in the Niger Delta where it measures about 2000 m (Merki, 1972).

METHODOLOGY

Data collection.

For administrative purposes, the exposed limestone deposits in Sagamu quarry is divided into three phases (Lagos, main and Sagamu) by the operating company (Plate 1). Each of the phases are also divided into three benches (lower, middle and upper). Stratigraphically, five distinct beds (Plate 2) could be identified at each of the phases, which guided our sampling procedures. Representative samples were taken in each bed and within each of the phases. In all fifteen samples were selected for study

Digestion and Analytical Determination of Major Elements in the samples

Five grams of the representative sample was weighed into crucible and digested with 10 mL nitric acid. The mixture was warmed and filtered into 100 mL standard flask. The residue was further washed with distilled water and added to the solution and make up to the mark for analysis of the metals. The residue was dried at 105^0C, cooled and transferred into a weighed Teflon beaker and then re-weighed. Then 10 mL hydrofluoric acid was added, heated until dryness and then weighed to determine the silica content.

The major elemental determination was carried out to determine the following elements from where there oxides were calculated: Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+}, Na^{+}, K^{+} and Al^{3+} using Flame Atomic Absorption Spectrometery (FAAS); while classical gravimetric method was used to determine the amount of Si in the samples

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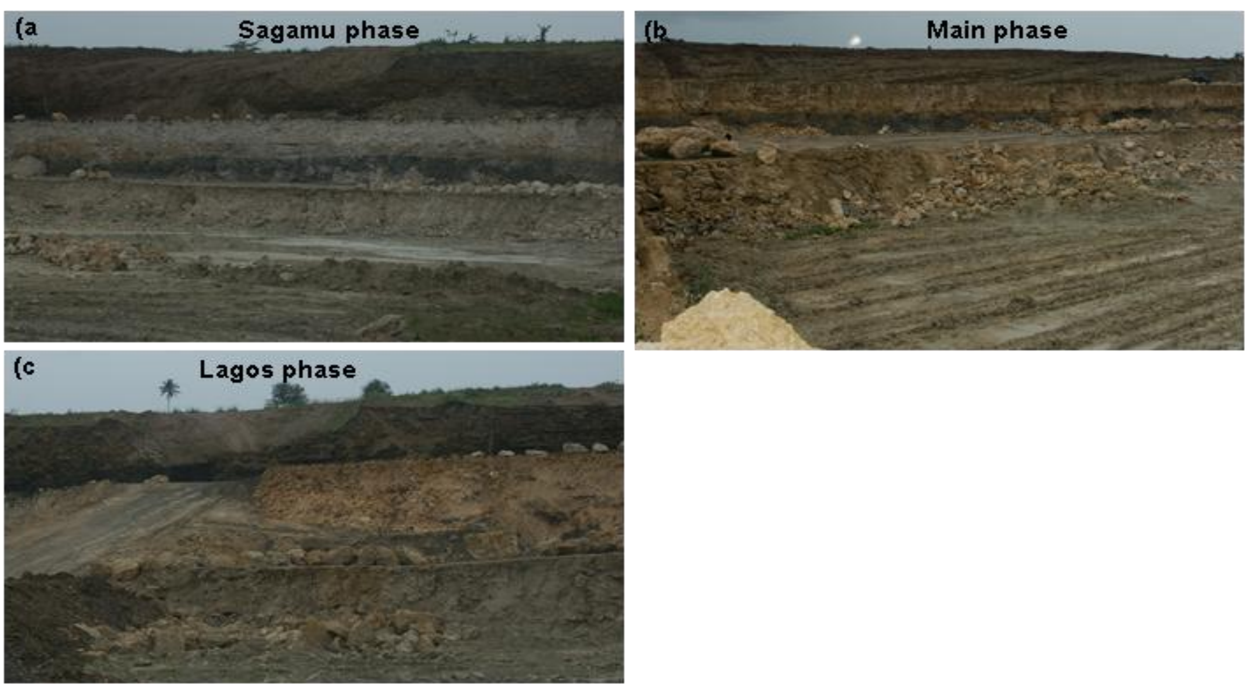


Plate 1. Photography of each of the phases of the limestone deposit. The division is based on the operating company's administrative purposes. Not taken to scale for reasons of distance

Plate 2 Photographs of the exposed limestone and shale beds at the Sagamu quarry of a cement producing company. Note the five limestone beds in A. B is the close up view showing the papery characteristics (flaggy) of the shale Not taken to scale for reasons of distance.

RESULT INTERPRETATION

Lithostratigraphy and Mode of Occurrence of the Limestone and its Overlying Shale.

The limestone as exposed at the Sagamu quarry varies laterally and vertically both in thickness and textural features. Five distinct beds (Plate 2) could be identified at the Sagamu quarry. Each of the beds varies in thickness from 2.3 m to 4.5 m. Beds1 and 2, 2 and 3 and 5 and the overlying shale are separated by hardground. The hardground is a highly cemented layer of sandstone. They are parallel to bedding planes and probably represent diagenetic precipitation resulting from basin development pauses. The overlying shale deposit is the Akinbo Formation.

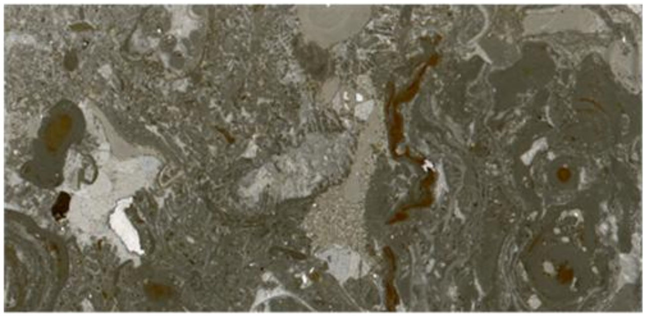
Limestone

Geological Description of the Beds

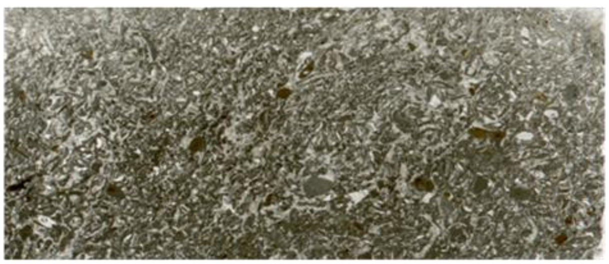
This is the first unit that is delineated in the lower bench and it is exposed in all the three phases. It varies in colour from dark grey to greyish white and occasional light brown to milky white. It is siliceous, micritc and contains abundant fossils. Fossils present include; pelecypod, cephalopod and gastropod. This bed is well cemented but with few vugs arranged in pockets within it. The vugs are not connected and likely formed as a result of total decay of fossils occupying the space. Towards the upper part of the bed, there is an increase in the quantity of skeletal fragments and reduction in silica content. The grains are not well rounded, medium sized and exhibit variable sizes. There is a development of springs at the base of this bed. The thickness of the bed is generally less than 3 m. A scanned slide of the section of the limestone bed reveals the occurrence of shell fragments, micritic matrix and non-carbonate grains (quartz) (Plate 3). The matrix is of higher percentage as shown on the scanned slides.

The second bed exhibits gradational contact with the underlying one. The distinguishing feature is the gradual change in colour from the bed below. The colour varies from light grey to white with light brown patches. It contains abundant fossils. Fossils delineated are cephalopod and gastropod. The bed is less indurated than the one below. The thickness of the bed varies from 1.5 to 2.5 m. A scanned slide of the thin section prepared from the limestone reveals the occurrence of shell fragments and micrite matrix (quartz) (Plate 3). The grains are of large size with smaller matrix when compared with the lower bed.

Bed 1 – Sagamu Quarry.

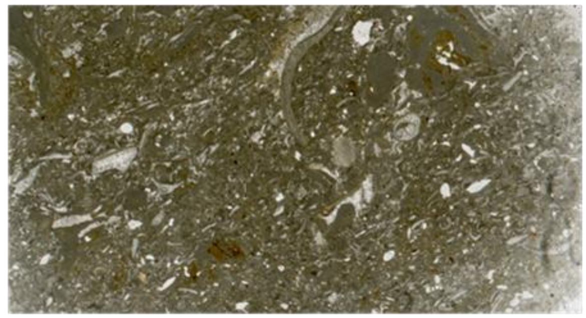


Bed 2 – Sagamu Quarry



Bed 3 – Sagamu Quarry.

Bed 4 – Sagamu Quarry.



Bed 5 – Sagamu Quarry.

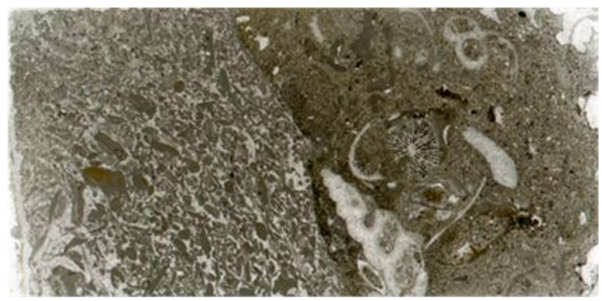


Plate 3. Scanned thin sections of the samples prepared from the limestone beds at Sagamu quarry. (not to scale)

Bed 3 is separated from bed 2 by a very sharp, highly indurated very thin layer that is less than 15 cm thick of cemented limestone (hardground). The most striking feature of this bed is the occurrence of very dark colour, which distinguishes the bed from others and allows it to be easily recognized in the quarry. The thickness of the bed is generally less than 3 m and contains abundant fossils, shell fragments and probably detrital materials. A scanned slide of the thin section prepared from the limestone reveals the occurrence of shell fragments and micrite matrix (quartz) (Plate 3). A sharp transition can also be observed in the quantity of grains in the thin section. More grains are present on one side of the thin section when compared to the other. Sorting in the limestone can be described as highly variable. Skeletal grains are not rounded, but fairly elongated and moderatly sized.

The contact between bed 4 and bed 3 is also very sharp and highly indurated. This layer is thin and is less than 12 cm in thickness. The colour of the bed is predominantly light brown, containing few milky white spots. The thickness of bed 4 is approximately 1.8 m and contains abundant fossils and shell fragments. Scanned thin section of the limestone reveals occurrence of abundant shell fragments and micrite matrix (quartz) (Plate 3). The sorting of the bed is fairly poor.

Bed 5 is the topmost limestone unit in Sagamu quarry. It is capped by hardground that separates it from marine shale above. The thickness of the hardground is generally less than 15 cm. The colour of the bed is predominantly white to milky white containing few light brown patches. The thickness of the bed is approximately 3.2 m. The bed contains abundant fossils and shell fragments. Scanned thin section of the limestone reveals the occurrence of abundant shell fragments and micrite matrix (Plate 3). Skeletal grains delineated include gastropods and others. The sorting of the bed is fairly highly variable containing a mixture of small and large skeletal grains.

Shale

In a similar manner to the limestone, the shale is exposed at Ewekoro, the type locality of the formation and the sagamu quarries. Two types of shale facies occur in this area unlike its lateral equivalent in the type locality of Ewekoro Formation that has glauconitic shale facies. The two shale facies are the black (carbonaceous) and grey shales. Ironically too, only the grey shale facies is exposed at Ewekoro quarry.

The black shale is slippery, smooth and flaggy. Most of the exposed sections are papery as a result of well-developed fissility. Crystals of quartz occur within the shale, growing from the run to fill some cavities. Also, regular horizontal bands of concretions are present. The thickness of this lithofacies is variable, essentially ranging from 3 m to 4.3 m overlying this carbonaceous shale is the brownish grey shale of approximately 5 m thick. Generally the shale is slightly variable in colour, slippery, smooth and papery. It contains quartz filling cavities and concretions also.

Geochemistry

Distribution of major elements in the three phases of the limestone gives an indication of the different chemical composition of the limestone deposits encountered in Sagamu quarry (Tables 1, 2 and 3). The ternary diagrams also confirm this (Fig. 3). Generally, the samples analyzed from all the three phases of the quarry exhibit high Ca^{2+} relative to the less mobile residual constituent of Al^{3+}(Tables 1, 2 and 3). Similarly where the CaO values are low the SiO_2 are high.

DISCUSSION

Limestone Classification.

Adegoke (1969) revealed that the limestone of the Ewekoro Formation is composed of three microfacies, which are sandy biomicrosparite, shelly biomicrite and algal biosparite. At sagamu exposure of the limestone, five beds of different facies were observed. The major element composition of each bed differ (Tables 1, 2 and 3). The relationship between the micrite (matrix) and skeletal grains in Bed1 constituting the basal unit shows that the bed contains abundant grains arranged in a matrix. The degree of grain roundness and size indicate poor sorting and possible short distance of transport. This type of limestone can be interpreted as product of low to intermediate energy environments, because of the occurrence of medium size grains in micrite matrix. The limestone is similar to sparse biomicrite and wackstone of Folk (1962) and Dunham (1962) respectively. Whereas, Bed 2 contains abundant grains arranged in a low quantity of matrix. The degree of grain roundness and size indicate moderate sorting. This type of limestone can be interpreted as product of intermediate to high energy environments, because of the occurrence of fairly large size grains in micrite matrix. The depositional texture of the limestone can be described as packed biomicrite and packstone (Folk, 1962; Dunham, 1962).

Bed 3 can be interpreted as product of varying depositional environments, probably from low to moderate energy. The depositional texture of the limestone can be described as a combination of packed biomicrite and sparse biomicrite (Folk, 1962). It falls in the wackstone classification of Dunham (1962). The occurrence of abundant grains when compared to the matrix allows the classification of the limestone in Bed 4 as packstone and packed biomicrite of Dunham (1962) and (Folk, 1962) respectively. The texture of the limestone contains a mixture of small and large skeletal grains and these could be interpreted as product of varying energy of depositional environments, probably from low to moderate energy. The limestone of bed 5 contains a mixture of small and large skeletal grains. With this the limestone formed under varying depositional environments, probably from low to moderate energy. The high proportion of grains compared with the lower proportion of micrite permits the classification of the limestone as packstone and packed biomicrite of Dunham (1962) and Folk (1962), respectively.

Chemostratigraphy.

Chemostratigraphy, or chemical stratigraphy, involves the characterization and correlation of strata using major- and trace-element geochemistry. Distribution of major elements in Tables and ternary diagrams gives an indication of the different chemical composition of the limestone deposits encountered in Sagamu quarry (Tables 1, 2 and 3 and Fig. 3).

Table 1 Concentration of oxides in percentages (%) Sagamu phase

Samples	CaO	MgO	NiO	Fe_2O_3	MnO	Na_2O	K_2O	Al_2O_3	SiO_2	LOI	Total
S5	63.48	0.483	0.0076	0.4722	0.038	0.144	0.087	0.99	3.01	33.09	99.99
S4	64.11	0.589	0.0080	0.2794	0.029	0.160	0.099	0.98	2.81	31.14	100.00
S3	71.98	0.695	0.0076	0.3832	0.123	0.152	0.90	0.57	2.69	23.00	99.61
S2	77.51	1.373	0.0098	0.8852	0.015	0.179	0.134	0.55	2.29	17.01	99.89
S1	50.52	0.963	0.0086	0.8528	0.014	0.191	0.132	0.73	2.13	43.15	98.73
Average	65.52	0.332	0.0050	0.5746	0.044	0.165	0.108	0.76	2.59	29.48	99.64

Table 2 Geochemical analysis results for Lagos phase

Samples	CaO	MgO	NiO	Fe_2O_3	MnO	Na_2O	K_2O	Al_2O_3	SiO_2	LOI	Total
L2	59.58	0.523	0.0081	0.5085	0.024	0.161	0.112	0.10	1.36	36.43	99.80
L3	60.09	0.578	0.0083	0.6635	0.025	0.162	0.114	0.89	1.37	36.08	99.91
L4	62.84	1.284	0.0075	0.6118	0.026	0.182	0.115	0.90	1.42	31.89	99.27
L5	57.82	0.872	0.0077	0.7465	0.017	0.190	0.116	1.21	3.12	34.99	99.08
L6	7.87	0.921	0.0052	2.8560	0.006	0.191	0.453	12.56	57.01	18.05	99.92
Average	49.64	0.836	0.0074	1.0773	0.0196	0.177	0.182	3.332	12.86	31.49	99.60

Table 3 Geochemical Analysis results for Main phase

Samples	CaO	MgO	NiO	Fe_2O_3	MnO	Na_2O	K_2O	Al_2O_3	SiO_2	LOI	Total
M5	29.23	0.358	0.0060	0.6922	0.022	0.176	0.145	3.02	25.15	41.05	99.95
M4	48.53	0.563	0.0080	0.7056	0.025	0.188	0.127	2.08	9.85	37.94	99.99
M3	56.81	0.587	0.0079	0.0571	0.424	0.175	0.152	0.99	2.27	36.95	99.43
M2	53.02	0.772	0.0081	0.6183	0.011	0.183	0.110	0.94	2.10	42.00	99.76
M1	0.99	0.366	0.0029	0.1320	0.002	0.186	0.220	16.22	63.07	17.70	99.89
Average	37.72	0.531	0.0066	0.3351	0.097	0.182	0.151	4.65	20.49	35.13	99.78

Generally, the samples analyzed from all the three phases of the quarry exhibit high Ca^{2+} relative to the less mobile residual constituent of Al^{3+}(Tables 1, 2 and 3). This implies that the limestone is characterized by low chemical index of alteration (CIA) (Nesbitt and Young (1982). However, exceptional cases could be observed in few samples from the Lagos and Main phases of the quarry with high Al^{3+} constituents with corresponding low Ca^{2+}. This is reflected in the ternary plot as values not aligned in the right hand side of the triangle (Fig. 3). It also implies that there are limestone beds within the quarry that have high values of CIA. These high values are interpreted as a consequence of surface weathering processes or indicating severe alteration.

The percentage of SiO_2 in the samples is not unconnected with clastic input of sediments from the continents. Although this is generally low in most of the samples, however there are samples from the Lagos and Main phases of the quarry with high percentages of SiO_2 (Table 1, 2 and 3). These samples correspond with samples characterized by high CIA. This indicate that during the formation of the limestone, there were occasions whereby clastic input was greater than carbonate production and consequently possible exposure to subaerial weathering. These combine processes may have resulted in high SiO_2 and CIA in similar samples.

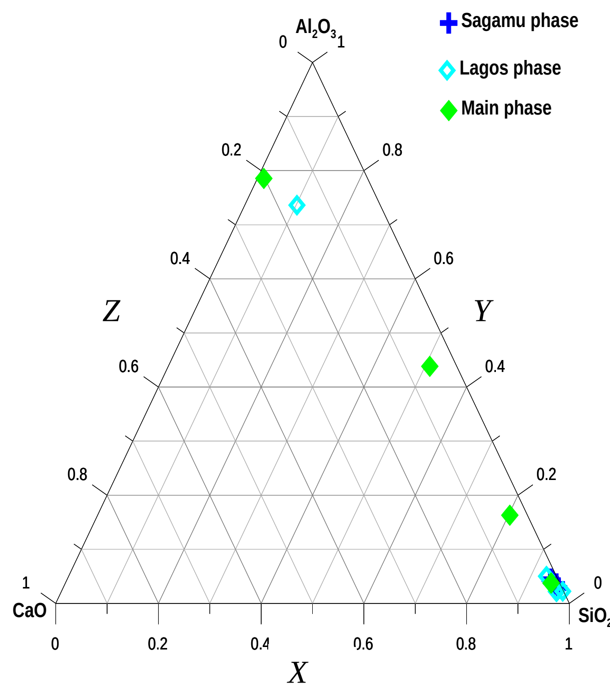


Figure 3. Ternary plot for the percentages of major oxides in the Sagamu quarry.

Basin Development

There is an observed increase in the values of CaO from the lowest beds to bed 3 (S3, L4 and M3) before a decrease to the uppermost bed in the three phases. This is a reflection of the development of the basin of deposition of the limestone from continental to marine environment and back to a shallower environment. In other word, the lowest beds had influence of influx of continental sediments. The black shale directly on top of bed 5 reflects the deepening of the basin after the deposition of the limestone. Black colourations in shales are due to a very high content of unoxidized organic matter (Prothero and Schwab, 1995). Usually they are deep water sediments with poorly oxygenated (anoxic or dysoxic) conditions as a result of isolation of the bottom waters from effects of wind driven vertical advection of oxygen rich surface waters (Katz and Pratt, 1993). Non-stratification with other facies suggests permanently deep and restricted basin without fluctuations in oxygen content. A gradual change in the environment probably resulted into oxygenated conditions and deposition of the grey shale. The quartz crystals present could be interpreted as diagenetic structures filling cavities created by fossils.

Hardground

Carbonate hardgrounds were most commonly formed during calcite sea intervals in Earth history, which were times of rapid precipitation of low-magnesium calcite and the dissolution of skeletal aragonite (Palmer and Wilson, 2004). Carbonate hardgrounds are surfaces of synsedimentarily cemented carbonate layers that have been exposed on the seafloor (Wilson and Palmer, 1992). Stratigraphers and sedimentologists often use hardgrounds as marker horizons and as indicators of sedimentary hiatuses and flooding events (Fürsich et al., 1981, 1992; Pope and Read, 1997). In this study, samples of the hardground were not subjected to geochemical studies. However, they serve as marker beds that probably formed during pauses in the development of the basin.

CONCLUSIONS

The limestone deposit of the Ewekoro Formation consists of five beds with varying major elemental compositions that suggests deposition under different environment of deposition. The beds are classified as wackstone (Bed 1), packstone (Bed 2), Wackstone (Bed 3), Packstone (Bed 4) and packstone (Bed 5). Bed 3 is the richest in terms of CaO_2 and lowest in SiO2 content, which makes it the best in cement production. The high percentage of CaO, low SiO_2 and Al_2O_3 in the Sagamu phase of the quarry makes the limestone at this section of the quarry an ideal one for cement production. However, the high CIA and high SiO_2 makes the limestone at Main and Lagos phases of the quarry an ideal hydrocarbon reservoir, if the same conditions occur in the subsurface.

ACKNOWLEDGEMENT

The chemical analysis was carried out under the supervision of Prof. Albert Adebayo. Dr. S. O. Olabode (while in the University of Glasgow) assisted in the Scanning of the samples. Both individuals are acknowledged with thanks.

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