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PETROGRAPHY AND GEOCHEMICAL APPRAISAL OF AFOWO SANDSTONE FACIES, DAHOMEY BASIN, SOUTHWESTERN NIGERIA

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ABSTRACT
Sandstones are sedimentary rocks formed by the cementation of sediment by material cements and they show a great deal of variation in mineral composition, degree of sorting and roundness.
A petrographic and geochemical study of sandstones in the Afowo Formation of Dahomey basin southwestern Nigeria was carried out to infer the various elemental compositions, mineralogical composition, degree of sorting and degree of roundness of the sandstones in order to classify them.
Seven (7) samples were collected and subjected to standard laboratory preparation and analytical method which include geochemical x-ray fluorescence for (trace and major elements analysis), and thin section petrography. The result of the geochemical analysis revealed the presence of some major elements (SiO_2,Al_2O_3,Fe_2O_3,CaO,Br,and TiO_2) and trace elements (V_2O_5,SO_3,P_2O_5,CuO,MnO,Rb_2O, and AS_2O_3) respectively. The mineral compositions obtained from the petrographical analysis are Quartz, Aluminum oxides, and high percentage of Iron oxides acting as the cementing material. The high percentage of Fe_2O_3 indicates that the sandstone is ferruginous while high concentration of Bromine (Br) suggest a shallow marine environment of deposition of the sandstone.
Key words: Petrography, Sand stone, Aluminum, Bromine, Marine, Quartz,

1. INTRODUCTION

Sedimentary rocks are formed from the erosion, transportation, sorting, deposition and lithification of sediments derived from physical, biological and chemical weathering of pre-existing igneous, metamorphic and sedimentary rocks. Sediments are the collective name for loose, solid particles that originate from the weathering and erosion of pre-existing rocks and the chemical precipitation from solution including secretion by organisms in water. Sandstones are sedimentary rocks with sand grains of 1/16 to 2mm in diameter and they possess quality reservoir characteristics and mineralogy.
Sedimentary studies are vital in prospecting for economic mineral reserves, because an overwhelming percentage of the world's economic mineral deposits, in monetary value, come from sedimentary rocks. This study of sediments is now being pursued intensely especially as new deposits become harder to locate. Dickson and Suczek (1979) suggest that the different tectonic settings of sedimentary rocks especially sandstone contain their own rock type which when eroded, produce sandstones with specific compositional ranges. Therefore, deciphering the composition and properties of sedimentary rocks are cogent in interpreting stratigraphy, tectonic activity of the source area, character of the environment of deposition, and the cause of changes in thickness or lithology as well as to correlate beds precisely by mineral work. This research work envisages the determination of the mineralogical composition and geochemical distribution of elements in the sandstone facies in order to classify the sandstone.

The study area falls within the eastern part of Dahomey basin and it is situated between latitude N06^{0}42' and 060'45' and longitude E04^{0}18' and 04021' in the southwestern part of Nigeria (Fig. 1). The area is accessible by major and minor untarred road networks and the climatic condition is tropical as expressed in alternation of wet and dry seasons. These two regimes of tropical climate show a fairly wide seasonal and diurnal variation in temperature ranging between 35^{0}C during dry season and 25^{0}C during wet season (Ikhane *et al*., 2011).
The period of wet with two rainfall peak from June-July and dry season have a remarkable effect on the vegetation of the area as trees and plant growth is controlled by this systematic seasonal changes. Therefore, during wet season plants exhibit fresh luxurious growth with green leaves and radiant flowers this disappears during the dry season as many trees shed their

leaves. The area is characterized by moderate to low relief and the drainage is sub-dendritic as a result of numerous network of stream.

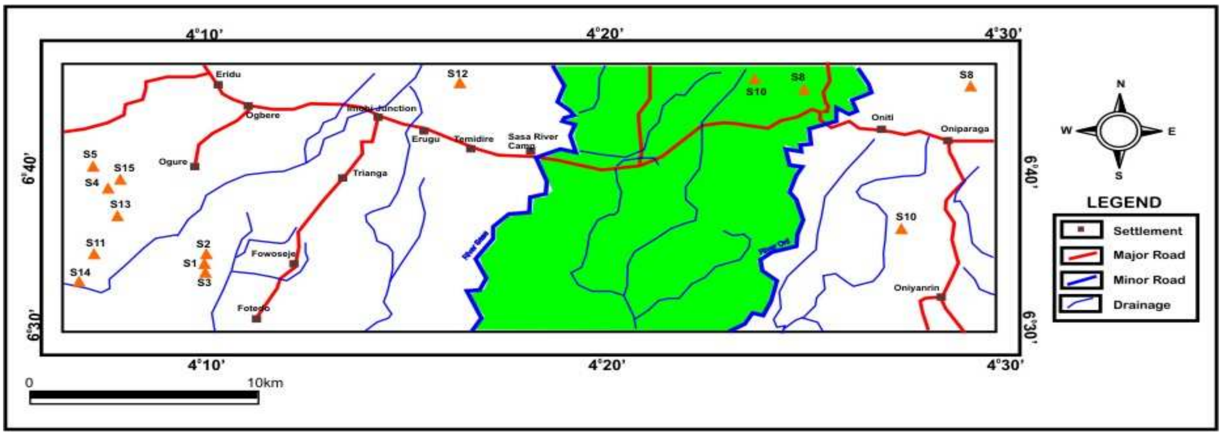

Figure 1: Index map of the study area

2. GEOLOGIC SETTING

The study area falls within the Nigeria sector of the Dahomey basin. The basin is a marginal pull-apart basin initiated during the Early Cretaceous separation of South American and Africa plates thereby constituting part of a system of West Africa pre-cratonic basins developed during the commencement of rifting, associated with the opening of the Gulf of Guinea in the Late Jurassic to Early Cretaceous (Adegoke, 1980). It extends from Southeastern Ghana through Togo and Benin Republic on the west side to the Okitipupa ridge on the east side in the southern part of Nigeria. The basin consists of Cretaceous-Tertiary sequence, which outcrops in an arcuate belt roughly parallel to the ancient coastline. The Tertiary sediments thin out to the east and are partially cut off from the sediments of Niger Delta basin against the Okitipupa basement ridge.

The stratigraphy and stratigraphic architecture have been well established by various workers (Jones and Hockey 1964; Omatsola and Adegoke 1981; Agagu 1985; Enu 1990, Nton, 2001, Nton *et al.,* 2006). However, Agagu (1985) placed together the stratigraphy of eastern Dahomey basin from surface as well as subsurface data, deciphering that in most part of the basin, the stratigraphy is dominated by monotony of sand and shale alternations with minor proportion of limestone and clay. The stratigraphy of the Cretaceous to Tertiary sedimentary pile which unconformably overlies the basement complex includes the following lithostratigraphic units and is summarized in (Table 1a). Abeokuta group is the oldest group of sediment in the basin, lying non-conformably on the basement (Jones and Hockey, 1964). Omatsola and Adegoke (1981) on the lithostratigraphy of Dahomey basin recognized (3) formations belonging to the Abeokuta group based on lithologic homogeneity and similarity of origin. This group is the thickest sedimentary unit within the basin. The formations from oldest to youngest are Ise, Afowo and Araromi formation. Ise formation unconformably overlies the basement complex of Southwestern Nigeria, consisting of conglomerates and grits at the base which is in turn overlain by coarse to medium grained sands with interbeded kaolinite. The conglomerates are imbricated and at some locations where ironstones occur (Nton and Elueze, 2005). An age range of Neocomian-Albian is assigned to this formation based on paleontological assemblages.

Afowo formation overlies the Ise formation, and composed of coarse to medium grained sandstone with variable but thick interbedded shale, siltstone and claystone. The sandy facies are tar-bearing while shales are organic-rich (Enu, 1990). Using palynological assemblage, a Turonian age is assigned to the lower part of this formation, while the upper part ranges into Maastrichtian.

The youngest Cretaceous formation in the group is Araromi formation, which conformably overlies the Afowo formation. It is composed of fine-medium grained sandstone at the base, overlain by shales, silt-stone with interbedded limestones, marl and lignite. Omatsola and Adegoke (1981) assigned a Maastrichtian to Paleocene age to this formation based on faunal content

Table 1a: The stratigraphic units of Eastern Dahomey Basin.

Jones and Hockey (1964)			Omatsola and Adegoke(1981)		Agagu (1985)	
	Age	Formation	Age	Formation	Age	Formation
Quaternary	Recent	Alluvium			Recent	Alluvium
Tertiary	Pleistocene - Oligocene Eocene Paleocene	Coastal plain sand Ilaro Ewekoro	Pleistocene-Oligocene Eocene Paleocene	Coastal Plain sand Ilaro Oshosun Akinbo Ewekoro	Pleistocene-Oligocene Eocene Paleocene	Coastal Plain sands Ilaro Oshosun Akinbo Ewekoro
Cretaceous	Late Senonian	Abeokuta	Maastrichtian - Neocomian	Araromi Afowo Ise	Maastrichtian - Neocomian	Araromi Afowo Ise
Precambian Crystalline Basement Rocks						

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The Imo Group overlies the Abeokuta group and chronologically consists of two lithostratigraphic units which ranges from oldest to youngest are Ewekoro and Akinbo formation. Ewekoro formation overlies the Araromi formation in the basin and is described by (Adegoke, 1977) to be a shalley limestone unit. This formation is an extensive limestone body, which is traceable over a distance of about 320km from Ghana in the west, towards the eastern margin of the basin in Nigeria (Jones and Hockey, 1964). It is highly fossiliferous and Paleocene in age. Akinbo formation which is made up of shale and clay sequence overlies the Ewekoro formation (Ogbe, 1972). The claystones are concretionary and are predominantly kaolinite. The base of the formation is defined by the presence of glauconitic bands with lenses of limestone (Ogbe, 1972). Also based on faunal contents the formation is Paleocene-Eocene in age.

Oshosun formation overlies the Akinbo formation and consists of greenish-grey or beige clay and shale with interbeds of sandstones. The shale is thickly laminated and glauconitic. This formation is phosphate-bearing (Jones and Hockey, 1964). An Eocene age is assigned to this formation based on fossil content.

Conformably overlying the Oshosun formation is the Ilaro formation and consists of massive, yellowish, poorly consolidated cross-bedded sandstone. The formation shows rapid lateral facies changes. The youngest stratigraphic sequence in the eastern Dahomey basin is the Benin formation. It is also known as the coastal plain sands (Jones and Hockey, 1964) and consists of poorly sorted sands with lenses of clays. The sands are in parts cross bedded and show transitional to continental characteristics. The age is Oligocene to Recent.

3. METHODS

A thorough and careful traversing by foot was carried out and the location of different rock types outcropping in the area was noted. This was achieved with the aid of a global positioning system (G.P.S). Also useful information on locations of outcrops and easy accessibility to the location was made possible by the villagers.

However the field operation involves visual observation of rocks at locations, determination of the location of outcrops where observations were made. All these information were plotted on the topographical map and recorded on the field note book. Description of outcrops made include texture, visible minerals, colour of fresh surface, degree and pattern of weathering as well as structural features. Fresh samples were taken for further study and properly labeled to avoid mix-up before keeping them in the sample bags. Fifteen (15) samples labeled S1-S15 were collected all together and seven (7) of these samples were sent for Petrographic studies and geochemical analysis respectively.

For the petrographic analysis, the samples were cut into smaller sizes of about 2mm in thickness using the rock cutting machine. A lapping blade was then placed on the table with a mixture of little water and carborundum. The glass slide was then lapped on the surface until it became smooth. The slab was later displayed on the carborundum to make it smooth and air free. The glass slide and the slab were together heated on a hot plate to dryness before they were fixed together using Araldite. They were exposed to another grinding machine to give a thickness of 1mm and further lapped again to achieve a thickness of 0.3mm. The slides were observed under the petrologic microscope in order to ascertain the various mineral compositions and to estimate their modal percentages whilst also taking the photomicrograph of the slides.

For the XRF analysis, the initial samples were reduced by splitting them into smaller size of about 30g before they were pulverized into a fine powder to create an XRF sample. The samples were then analyzed with ARL 9900 XP total cement analyzer, which is used to analyze cement and its raw materials includes9, clay, gray shale, iron ore, alluvial sand and gypsum. The XRF analysis entails weighing of 5.0g of the pulverized sample into the drying dish or crucible and drying to a constant weight (± 0.01g) in the oven before cooling in the desiccators. This is then followed by preparation of fused bead (Drying of the crucible and the platinum mould in an oven at 110^0C-120^0C for about thirty minutes). 6.000 ±0.0001g of lithium tetraborate is weighed into another crucible and 1.000 ±0.0001g of sample is added followed by the addition of 0.0200g of lithium bromide using a clean small spatula or glass rod to mix properly before labeling and transferring of the fused bead into the X-ray analyzer's sample holder ready for analysis.

4. RESULT AND DISCUSSION

The lithology of sandstones, in terms of the grains to matrix ratio which is the main detrital constituents and cement can commonly be identified in the field, but detailed description and classification required Petrographic and geochemical analysis which is the main thrust of this work.

4.1 Mineralogical Classification

Keller (1945) created a qualitative, apprehensive and geologically meaningful mineralogical classification of sandstones where he stressed sandstones mineralogy as a powerful indicator of tectonics and drew qualitative lines between five sandstone types, expressing composition by triangular diagrams based on poles of Quartz; Feldspars; Micas including clays, rock fragments and matrix.

Quartz are indicative of prolong chemical/ physical attack or else of derivation from an older sedimentary source terrain, the end member rock type being the orthoquartzites. All feldspars and all plutonic and volcanic rock fragments are indicative of igneous sources, the end member rock type being arkose. Metamorphic fragments, Micas, and metaquartzites fragments are indicative of metamorphic source, the end member rock type being the greywacke.

The following parameters were used according to (Pettijohn *et al.,* 1973).

i when quartz is greater than 90%, it is termed Quartz arenites.

ii. When feldspars constituent is greater than 15%, it is termed arkoses.

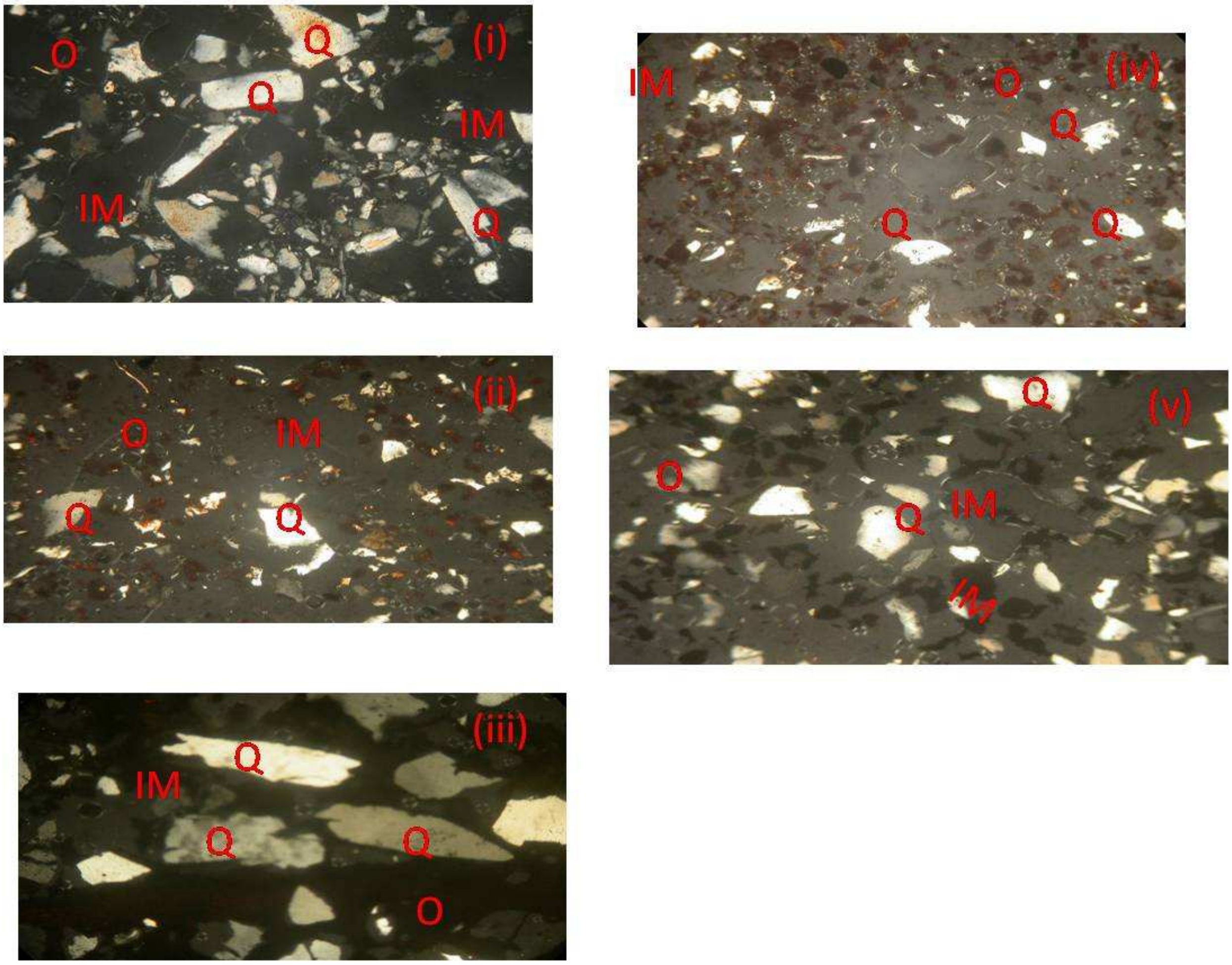
iii. When the fine- grained matrix is greater than 15%, it is termed Greywacke.

A total of five (5) thin section slides (Table 1b) were prepared and they were viewed under the Petro logical microscope (Fig. 2) it was observed that the ferruginous sandstones were of fine –grained matrix of iron –oxide cement.

Based on this study, it was found that the quartz percentage is greater than (0% with very little proportion of feldspars which is less than 2%). Upon this, the ferruginous sandstones can be said to belong to the class of Quartz arenites. (Folk, 1974) and Pettijohn, (1972)

(Table 1b): Estimated modal analysis in (%) for the Afowo Sandstones in transmitted light.

Minerals	Modal Analysis (%) for slide1	Modal Analysis (%) for slide 2	Modal Analysis (%) for slide 3	Modal Analysis (%) for slide 4	Modal Analysis (%) for slide 5
Quartz	70	30	30	20	60
Fe II oxides(Fe_2O_3)	20	50	50	70	30
Others	10	20	20	10	10
Total	100	100	100	100	100



Bar Scale = 20mm *Magnification: X40* *Resolution: (150 dpi)*

Figure 2: Photomicrographs of Afowo Sandstone in transmitted light showing Quartz (Q), Iron Oxide minerals (IM) and Other Opaque minerals (O).

4.2 GEOCHEMICAL CLASSIFICATION

Result of the geochemical analysis carried out on the analyzed samples is represented in Table 2 below. Results from the XRF analysis revealed a total number of eighteen (18) elements and oxides which are SiO_2, Al_2O_3, Fe_2O_3, CaO, V_2O_5, ZrO_2, SO_3, K_2O, Br, P_2O_5, CuO, TiO_2, MnO, Rb_2O, As_2O_3, Cr2O3, WO_3 and ZnO. The compositions of the samples were compared with lead and Mead's (1915) standard for chemical composition of average sandstone (Table 3). It was discovered that most of the chemical oxides were present, although in different and varying quantities from one sample to another. Some oxides like FeO, MgO, Na_2O, H_2O, SO_2, BaO were absent in the samples, however some other elements and oxides were present, some in recognizable quantity, like Bromine which ranges between 9.85-39.30%, others includes V_2O_5, ZrO_2, Br, CuO, Rb_2O, AsO_3 Cr_2O_3, MnO (Table 2)

The chemical analysis reveals that the major elements and oxides of SiO_2, Fe_2O_3, Al_2O_3 occurred in minor quantities and the rest occurred in trace quantities.

Petrographic studies of the thin section slides shows that quartz and iron oxide were the main mineral constituents present in the sandstone of Afowo study area while Zircon, Rutile and other opaque minerals make up the accessory constituents . However it can be shown from the geochemical analysis of the Afowo sandstones that the abundance of Bromine (Br), suggests that the environment of deposition is that of a shallow marine or near marine environment, with the siliciclastic sediments being deposited in the environment. Fe_2O_3 is being incorporated into the environment via oxidation processes.

Table: 2 GEOCHEMICAL RESULTS OF THE ANALYZED SAMPLES

	Sample Location 1	Sample Location 2	Sample Location 3	Sample Location 4	Sample Location 5	Sample Location 6	Sample Location 7
SiO_2	56.09	53.75	56.27	30.25	27.02	62.52	2.16
Al_2O_3	6.20	2.81	3.69	4.49	8.36	2.52	1.17
Fe_2O_3	19.96	0.60	3.64	41.56	41.15	2.52	82.22
CaO	0.44	0.68	0.56	0.14	0.53	0.87	0.50
V_2O_5	0.03	-	-	0.39	0.24	0.10	1.24
ZrO_2	0.22	-	0.28	2.87	0.23	0.53	-
SO_3	0.09	-	-	-	0.30	-	1.35
K_2O	0.43	2.32	-	-	-	0.53	-
Br	14.69	39.30	34.23	13.79	20.14	26.75	9.85
P_2O_5	0.39	-	-	0.34	0.23	-	0.29
CuO		-	-	-	-	-	0.02
TiO_2	1.38	0.24	1.08	5.84	1.58	3.53	0.49
MnO	0.01	0.01	0.01	0.13	0.03	-	-
Rb_2O	0..1	0.03	-	0.01	0.01	0.01	0.01
As_2O_3	-	0.21	0.22	0.02	0.08	0.08	-
Cr_2O_3	-	-	0.04	0.08	0.07	-	0.70
WO_3	-	0.03	-	-	0.01	0.05	-
ZnO	-	0.02	-	0.09	-	-	-
SUM	99.97	100.00	100.00	100.00	99.98	100.00	100.00

Table 3: SHOWING THE AVERAGE CHEMICAL COMPOSITION OF SAND STONE AFTER LEITH AND MEAD'S (1915).

Oxides	Percentages (%)
SiO_2	78.30
TiO_2	0.25
Al_2O_3	4.77
Fe_2O_3	1.07
FeO	0.30
MgO	1.16
CaO	5.50

Na_2O	0.45
K_2O	1.31
H_2O	1.63
P_2O_5	0.68
CO_2	5.03
SO_2	0.07
Ba_2O	0.05

In terms of the classification of the Afowo sand stones, the concentrations of three major oxide groups has been used to classify sandstones; Silica and Alumna, Alkali oxides and iron oxides plus magnesia. The enrichment of SiO_2 over Al_2O_3 by mechanical and chemical process produces quartz arenites (Orthoquartzites) silica (quartz) enrichment is a measure of sandstone maturity, and is a reflection of the duration and intensity of weathering and destruction of other mineral during transportation. Abundant alkali (Na_2O and K_2O) characterize immature sandstone such as arkoses and greywacke. The ratio of Na_2O is determined by the sum of provenance and diagenesis.

The following are the parameter for the classification of sandstones based on chemical approach. They are used according to (Blatt *et al.,* 1972; Herron, 1988 and Pettijohn, 1972).

i. When log $SiO_2/ Al_2O_{3\,>}$ 1.5, such said stone is termed Arenites
ii. When log SiO_2 / Al_2O_3< and log (K_2O/ Na_2O) < 0, it is termed Greywacke
iii. When log (SiO_2/ Al_2O_3) < 1.5, log (K_2O/ Na_2O) >O and log (Fe_2O_3 + MnO + K_2O + Na_2O) >O, it is termed an Arkose.
iv. When log (SiO_2 / Al_2O_3) < 1.5 and either log (K_2O / Na_2O) > 0, it is termed to be lithic Arenites (including Sub-grey wacke and protoquartzites).

Sample 1

SiO_2 = 56.09
Al_2O_3 = 6.20
Log SiO_2 / Al_2O_3 = (56.09 / 6.20) 9.05
Log 9.05 = 0.96
K_2O = 0.43
Na_2O = 0.00
Log (A/B)
LogA-LogB
= 0.43 – 0
Log A- LogB = 0.43
Log 0.43 = -0.37
Fe2O3 = 19.96
MgO = 0.00
Log (Fe_2O_3 + MgO) / (K_2O + Na_2O)
Log (19.96 +0)/ (0.43+0)
Log 19.96/ 0.43 = 46.42
Log 46.42 = 1.67
$SiO_{2\,=}$ 53.75
$Al_2O_{3=}$ 2.81
K_2O= 2.32
Na_2O= 0
Fe_2O_3=0.60
Log SiO_2/ Al_2O_3 = 53.75/ 2.81 = 19.13
Log 19.13= 1.28
LogK2O/ Na_2O= 2.32/ 0
Log2.32= - 0.37
Log (Fe_2O_3+MgO)/ (K_2O+ Na_2O)

Log (0.60+0) / (2.32 +0)
Log 0.60/2.32 = - 0.26
Log- 0.26 = - 0.59

Sample III

SiO_2 = 56.27
Al_2O_3= 3.69
K_2O = 0
Na_2O=0
Fe_2O_3=3.64
LogSiO_2/ Al_2O_3
Log 56.27 /3.69 =15.25
Log 15.25= 1.18
K_2O=Na_2O= 0
Log (Fe_2O_3+MgO)/ (K_2O+Na_2O)
Log 3.64/0 =3.64
Log3.64= -0.56

Sample IV

SiO_2 = 30.25
Al_2O_3 = 4.49
MgO= 0
K_2O = 0
Fe_2O_3 = 41.56
LogSiO_2/ Al_2O_3
Log 30.25/ 4.49 =6.74
Log 6.74 = - 0.83
LogK_2O/ Na_2O= 0
Log (Fe_2O_3 +MgO)/ (K_2O+Na_2O)
Log41.56 /0 = 41.56
Log 41.56= 1.6

Sample V

SiO_2= 27.02
Al_2O_3 = 8.36
K_2O= 0
Na_2O= 0
Fe_2O_3 = 41.15
LogSiO_2/ Al_2O_3
Log 27.02 / 8.36
Log3.2 =-0.5
Log K_2O/ Na_2O =0
Log (Fe_2O_3+MgO) / (K_2O+Na_2O)
Log 41.15/0 = log 41.15
=1.6

Sample VII
SiO_2= 2.16
Al_2O_3= 1.17
K_2O= 0
Na_2O= 0
Fe_2O_3= 82.22
LogSiO_2/ Al_2O_3
Log 2.16 / 1.17 = 1.85
Log1.85= -0.27
LogK_2O/ Na_2O= 0
Log (Fe_2O_3+MgO) / (K_2O+Na_2O)
Log82.22 = 1.91
From above calculations the Afowo sand stone fall into seven classes as observed in the Table.3 below.

Table 3: CLASSIFICATION OF THE SANDSTONES SAMPLES

Samples	Log SiO / Al_2O_3	Log K_2O/ Na_2O	LogFe_2O_3 + MgO/K_2O+Na_2O	Classification of Sandstones Type
1	0.96	**-** 0.37	1.30	Greywacke
2	1.28	**-** 0.37	-.59	Lithic arenites
3	1.18	0.00	-0.56	Lithic arenite
4	-0.83	0.00	1.60	Greywacke
5	-0.51	0.00	1.60	Greywacke
6	1.39	-0.28	0.00	Lithic arenite
7	-0.27	0.00	1.91	Greywacke

5. Conclusion

Based on the geochemical and the Petrographic analysis that was carried out on the Afowo sandstone samples, result of the above studies show that the sandstones has quartz and Iron III oxides grain greater than 90%, hence, mineralogically, it can be classified as a ferruginous sand stone. The grains of the quartz are angular in samples (i, ii,iii,iv&v) of Figure 2, indicating that they have not traveled far while the iron oxide acted as the cementing materials binding the grains together. In as much as the Bromine concentration of the sandstone is very high, there is the probability of contamination of the ground water in the area with Bromine.
However, the high concentrations of Bromine obtained from the geochemical analysis suggest a shallow marine environment of deposition for these sandstones. The Bromine may have been as a result of contaminations from sea water. By and large, relevant agencies should try to see that the ground water of the area should be treated for high Bromine concentration to make it suitable for drinking water and other industrial purposes. Moreover, values of less than 1.5 and greater than 1 were obtained for the of log SiO_2/ Al_2O_3 and Log (Fe_2O_3 + MgO/ (K_2O +Na_2O) respectively.
It can therefore be inferred from the geochemical point of view that the sandstone deposits can equally be classified as ferruginous arenitic sandstone.

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