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RESEARCH ARTICLE

PROVENANCE STUDIES OF SANDSTONE IN IMOBI AND ITS ENVIRONS SOUTH WESTERN NIGERIA

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ABSTRACT

The integration of mineralogical and geochemical data of a sedimentary rock can reveal the nature of source regions, the tectonic settings of the sedimentary basins and the paleoclimatic conditions. The aim of this research is to determine the dominant minerals in sandstone sample from part of the Eastern Dahomey Basin in order to infer the origin and its environmental effect. Eight (8) rock samples collected from the study area were subjected to geochemical analysis in order to determine their chemical composition using X ray fluorescence; thin sectioning of the sample were also done for petrographic description of the mineral compositions. Quartz, Iron Oxide and Microcline are the dominant minerals identified from the petrographic studies. Result of the geochemical analysis revealed sixteen (16) elements and oxides which include 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, Cr_2O_3 while Quartz, Iron Oxide, Microcline with some Accessory minerals were dominantly observed under the microscope. The presence of element and oxides such as Br, V_2O_5, ZrO_2, CuO, Rb_2O, As_2O_3 and MnO (especially Br of 12%-27%) suggests the depositional environment to be shallow marine or near marine environment, however abundance of SiO_2 and Fe_2O_3, especially Fe_2O_3 suggests the incorporation of the sediments into the environment from a metamorphic source. The CIW′ and CIA' value of the Sandstone samples vary from 69 to 95 (mean ~86, *s*=9; median ~88), and 58 to 87 (mean ~80, *s*=12; median ~83) respectively, both implying a high degree of weathering and alteration of the alkali minerals. The parent rock is a metamorphic rock which was recycled and deposited in shallow to near marine environment with Iron Oxide acting as the dominant cementing material.

INTRODUCTION

The knowledge of geochemical distribution of elements in the earth particularly in the crust and of processes that leads to the observed distributions makes it possible to locate and use effectively essential minerals and to predict their dispersal pattern when they re-enter the natural environment. The distribution of sediments is controlled by the interaction between sediment supplies, hydrodynamic processes and human intervention. The provenance of sedimentary rocks which include the nature of source regions, the tectonic setting of sedimentary basins and paleoclimatic conditions can be revealed when Geological, Petrographic and geochemical data are well integrated. (Dickson and Suczek, 1979; Dickson et al., 1983; Dickson 1985) suggests that the different tectonic settings of sedimentary rocks especially sandstone contain their own rock type which when eroded, produce sandstones with specific compositional ranges. Although some geochemical ratios can be altered during weathering through oxidation (Taylor and McLennan 1985) or diagenesis (Nesbit and Young 1989; Milodowski and Zalasiewicz, 1991), as long as the bulk chemical composition is not totally altered, geochemical analysis is a valuable tool in the study of sandstones (McLennan *et al.,* 1993). This research work is done in order to determine the geochemical distribution of elements in sediments of the study area; predict the dispersal pattern of the elements; and determine the mineral composition of the rocks in order to infer their origin.

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The study area is situated within latitudes N 6^0 34'- N06^0 43'and longitude 004^0 08'-004^0 20' in the South western part of Nigeria; it is accessible by major and minor roads. The climatic condition of the area is tropical and is expressed as an alternation between wet and dry seasons. These two regimes of tropical climate show a fairly wide seasonal and diurnal variation in temperature which range between 35^0C during dry season and 25^0C during wet season. There are two peak periods of rainfall from June – July with a slight break in August referred to as "August Break" (Onakomaya, 1992). The period of wet and dry season have a remarkable effect on the vegetation of the area. Trees and plant growth is controlled by systematic seasonal changes. During wet season, plants exhibit fresh looking green leaves and radiant flowers with all types of plant showing luxurious growth. These disappear during dry season as many trees shed their leaves. The area have moderate to low relief that is fairly lowland to low. The drainage of the study area is somewhat integrated, having a network of streams that is sub-dendritic in nature.

GEOLOGIC SETTING

The study area falls within the Eastern Dahomey basin of Nigeria, a basin that lies within latitudes $6^0 00^1$N – $8^0 30^1$N and longitudes $0^0 15^1$E – $6^0 00^1$E extending from eastern part of Ghana to the Okitipupa/Benin Hinge (Agagu, 1985). Various workers (Russ, 1924), Jones sand Hockey, 1964), Omatsola and Adegoke, 1981) and (Agagu, 1985), had worked on the stratigraphic of the Eastern Dahomey basin from surface as well as sub-surface data. In most part of the stratigraphy is dominated by monotony of sand and shale alteration with minor proportions of limestones and clays, (Agagu, 1985). The stratigraphy of the Eastern margin of the cretaceous to tertiary sedimentary basin, which unconformably overlies the basement complex includes the following lithostratigraphic limits.

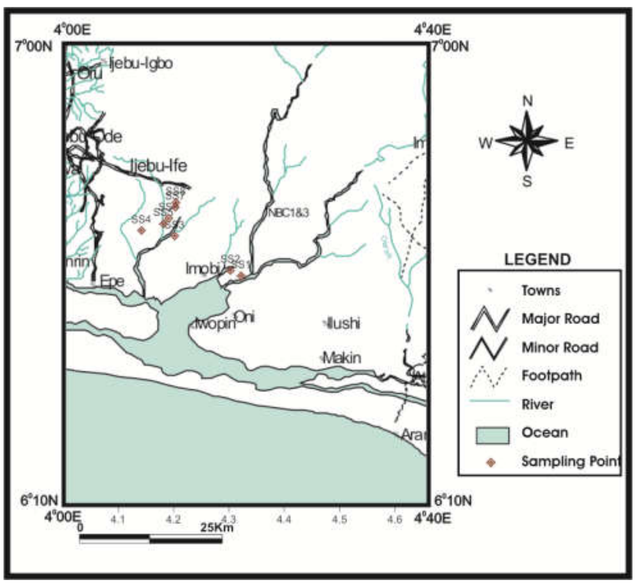

Fig 1: Location Map Showing all the Sampling Points

The Abeokuta Group

The basement complex rock throughout the entire Dahomey basin is overlain unconformably by the Abeokuta group which is the oldest unit (Hockey and Jones, 1964). It consists of conglomerates, sand stones, sandy siltstones, clays, shales and thin limestone beds. This unit has been from the Neocomian to Paleocene and it is the thickest single sedimentary unit in the basin. This unit contains heavy oil and it is the prime target for petroleum exploration. (Omatsola and Adegoke, 1980) subdivided the group into 3 district formation, based on the lithologic homogeneity and similarity of origin, the following are the subdivisions.

Ise Formation: This is the oldest formation in the group and it unconformably overlay the basement complex. It consists of conglomerate at the base, gritty to medium grained loose sand, capped by kaolinite clay (Omatsola and Adegoke, 1981), (Agagu, 1985). The maximum thickness of the members is about 1965m and 600m penetrated by the Ise-2 well, while similar section were exposed near Ode-Remo on the Lagos-Ibadan expressway. The grains are sub-angular to sub-rounded, poorly sorted, and positively skewed. From the grain size distribution, clastic sediments are leptokurtic, and nearly symmetrical. Clays from the major matrix and poor cementation makes the rock very friable. The age was given as Necomian and the unit has not been found to be bituminous both at surface and subsurface section.

Afowo Formation: Afowo formation indicates the commencement of deposition in a transitional environmental after the entire basal and continental Ise formation. The sediments are composed of interbedded sands, shales and clays, which ranges from medium to fine grained in size (Omatsola and Adegoke 1982) (Agagu, 1985) outcrops of this formation are commonly encountered within the bituminous sands belt and are easily recognizable because of the presence of sticky and viscous heavy oil seeping out of the sand portion of the Afowo formation. The age is Maastrichain.

The Araromi Formation: Sediments of the Araromi formation represent the youngest topmost sedimentary sequence in the group. The formation is composed of shales, fine-grained sand, thin interbeds of limestone clay and lignite bands (Omatsola and Adegoke 1985), (Agagu, 1985). It is an equivalent of a unit known as Araromi shale. The shale are grey to black in colour, are marine and rich in organic matter. The age range is from Maastrichain to Paleocene. The Abeokuta group, begin the thickest single sedimentary basin and consisting of interbeds of organic rich shale with porous and permeable sand stone together with its depth of burial makes it a prime target for petroleum exploration Dahomey basin, (Agagu, 1985).

Imo Group: It conformably overlies the Abeokuta group and comprises of shales limestone and marls. The group contains two lithostratigraphic units, which are:

Ewekoro Formation: Directly overlies the Abeokuta group as it has been observed from the section at Ewekoro and Sagamu quarries as well as the core sections at Ibeshe. It is made of grayish – white and occasionally greenish limestones which are sandy towards the base and having a thickness that varies between 15 – 30 meters. This formation is dated Paleocene in age.

Akinbo Formation: This is mostly found in the western part of the Imo group directly overlying the Ewekoro formation. It constitutes the upper part of the Imo group. It is essentially greenish, highly fossiliferous and thickly laminated. It was accorded a formation status by Kogbe (1976) with the type section at Ewekoro quarry. The base of this formation is defined by the presence of a glauconitic rock band. It comprises thick section of grey fossiliferous shales of about 100 meters. Overlying this unit is a unit of marine phosphate bearing shale with interbedded sandy units extending from the Volta Delta area in Ghana to the Okitipupa ridge. The Dahomey basin thickens towards the republic of Benin and down dip towards the Atlantic. It is floored by the crystalline basement complex rocks which are block faulted into a series of horst and graben, (Agagu, 1985). Although, very little post depositional tectonism within the basin has been observed.

Ilaro Formation: This is also known as Oshosun formation. It is conformably overlying the Imo group in this basin, it's a

Table 1: Stratigraphic Profile of the Eastern part of Dahomey Basin

ERA	JONES&HOCKEY (1964)		ADEGOKE&OMATSOLA (1981)	
	Age	Formation	Age	Formation
Quaternary	Recent	Alluvium		
Tertiary	Pleistocene-Oligocene	Coastal Plain Sands	Pleistocene-Oligocene	Coastal Plain Sands
	Eocene	Ilaro	Eocene	Ilaro Oshosun
	Paleocene	Ewekoro	Paleocene	
Late cretaceous	Late Silurian	Abeokuta	Maastrichtian	Araromi Afowo Ise

Table 2: Showing the modal count percentages

Mineral(Modal %)	SSt1	SSt2	SSt3	SSt4	SSt5	SSt6	SSt7	SSt8
Quartz	40	40	35	60	50	35	35	50
Iron Oxide	55	50	60	35	45	35	60	40
Accessory Minerals	5	5	5	5	5	5	5	5
Microline	-	5	-	-	-	5	-	5

Table 3: The average chemical composition of sand stone after Leith and Mead.

OXIDES	$Si0_2$	$Ti0_2$	Al_20_3	Fe_20_3	Fe0	MgO	CaO
(%)	78.3	0.25	4.77	1.07	0.3	1.16	5.5
OXIDES	Na_2O	K_2O	H_2O	P_2O_5	CO_2	SO_2	Ba_2O
(%)	0.45	1.31	1.63	0.68	5.03	0.07	0.05

Table 4: The elements and oxides in the samples (Values in percentages(%))

Sample	$Si0_2$	Al_20_3	Fe_20_3	CaO*	V_2O_5	ZrO_2	SO_3	K_2O	Br	P_2O_5	CuO	
Sst1	37.94	1.7	44.05	0.78				0.44	14.09	0.64		
Sst2	36.13	2.36	46.93	0.68			0.29	0.44	12.53	0.5		
Sst3	38.49	2.7	41.84	0.44		0.09	0.34	0.19	14.9	0.18		
Sst4	51.41	3.02	22.27	0.81	0.06	0.48			20.1			
Sst5	37.24	9.64	31.14	0.64	0.25	0.15	0.13	0.79	18.06	0.27		
Sst6	21.78	8.73	48.6	0.38	0.73	0.19	0.13		17.37			
Sst7	16.1	8.04	53.01	0.85	0.46	0.11	0.23	0.57	18.55	0.41		
Sst8	43.06	9.4	17.09	0.48	0.21	0.2		0.88	26.36	0.64	0.01	
Sample	TiO_2	MnO	Rb_2O	As_2O_3	Cr_2O_3	$log(Fe_20_3/K_20)$	$log(Si0_2/Al_20_3)$	CIW	CIA	$SiO_2/20$	$TiO_2+ Fe_2O_3$	Al_2O_3/SiO_2
Sst1	0.25		0.01	0.07	0.05	2	1	69	58	1.897	44.3	0.04
Sst2	0.15		0.01			2	1	78	68	1.8065	47.08	0.07
Sst3	0.8			0.04		2	1	86	81	1.9245	42.64	0.07
Sst4	1.57	0.05	0.01	0.1	0.07	0	1	79	79	2.5705	23.84	0.06
Sst5	1.52	0.03		0.05	0.1	2	1	94	87	1.862	32.66	0.26
Sst6	1.9	0.04	0.02	0.01	0.11	0	0	96	96	1.089	50.5	0.40
Sst7	1.44	0.02	0.01	0.09	0.11	2	0	90	85	0.805	54.45	0.50
Sst8	1.45	0.02	0.01	0.15	0.05	1	1	95	87	2.153	18.54	0.22
							Mean	85.8	80.2			
							Median	88.2	83.0			
							Std. Dev	9.9	12.0			

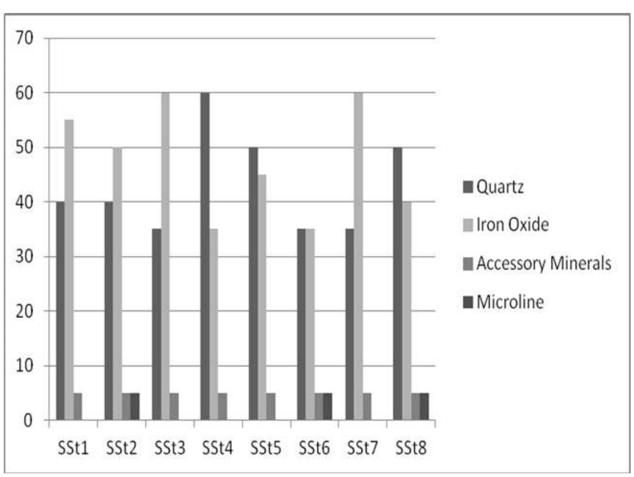

Fig 2: Modal Percentage (%) of Minerals studies on the Thin Section

lateral equivalent of Ameki formation in Eastern Nigeria, (Adegoke, 1969) and the formation was named by Jones and Hockey, 1964). It consists of coarse to fine grained sands, clays and shale with occasional thin sands of phosphate beds being observed at Ifo (in Ogun State). The formation includes both marine and continental sedimentation form South and North and from the lower beds (Oshosun) to the higher ones (Jones and Hockey, 1964). The Ilaro formation is best developed towards the Federal Republic of Benin border with Nigeria where a thickness of about 400 meters has been attained, (Agagu, 1985). Textural analysis of these sands indicates beaches or shore line and near shore environments with sub-rounded to rounded grains and the formation is Eocene in age. Fossils are very rare but benthonic foraminifera are formed.

Coastal Plain Sands (Benin Sand Formation): The coastal plain sand or the Benin sand formation as well as the Recent Alluvium are the youngest sedimentary units in the basin. The coastal plain sand overlies the Ilaro formation though evidence for this is lacking (Jones and Hockey, 1964). It consists of sandy clay, rare thin lignite and is distinguishable from the Ilaro formation on the field. They are unfossiliferous and weathered to the surface to form a brown sandy earth grits. Their thickness is as much as 400m towards the coast (Agagu 1985) and they range in age from Oligocene to Pleistocene.

Recent Alluvium: This is the youngest unit in Eastern Dahomey Basin. They have been thought to overlie the Ilaro formation but convincing evidence for this is lacking (Jones and Hockey, 1964). The exposure at the road cuttings between Ofada and Mokoloki on the Ogun River reveal coarse clayey sorted sands with clay lenses and occasional pebble beds they are lithologically indistinguishable from typical coastal plain sand strata.

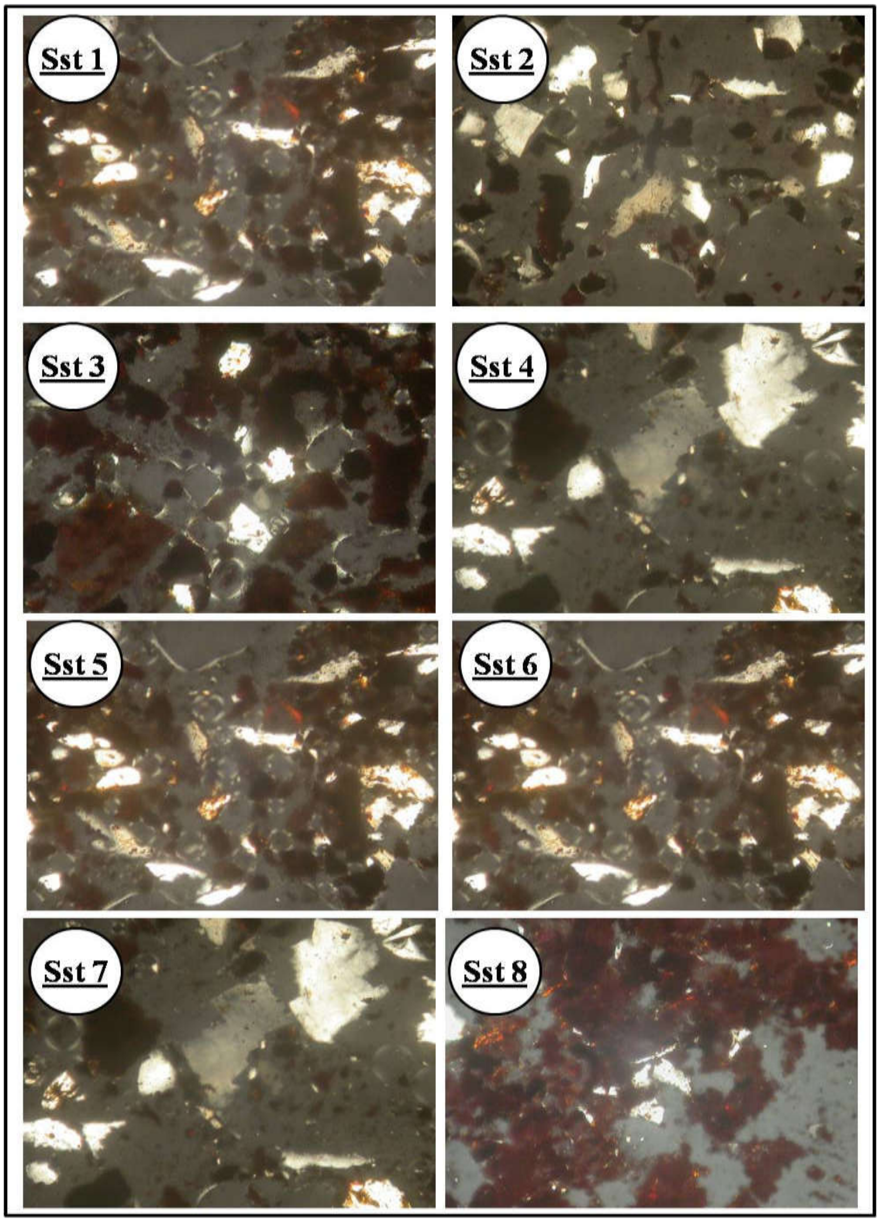

Fig 3: Photomicrograph of the Sandstone samples (Sst1- Sst8)

MATERIALS AND METHODS

A careful and thorough transversing by foot was carried out and location of different rock types found in the study area was duly noted. This was done with the aid of a global positioning system (G.P.S), efforts of the villagers cannot be ignored as useful information on locations of outcrops and easy accessibility to the locations was made possible by them. The field operation entails visual observation of rocks at locations, determination of the location of outcrops where observations were made. Plotting of these data on the map and recording of the observations on the field note book. Description of outcrops made include texture, visible minerals, and colour and structures; fresh samples were taken for further study and labelled to avoid mix-up and were kept in the sample bags. Each sample was described in the field note with respect to their GPS co-ordinates in order to have a precise representation on the reconstructed map. Eight samples labelled Sst_1 …..Sst_8, were used, each sample was divided into different fractions. One fraction was used for petrographic studies and the other for geochemical analysis. For petrographic analysis, the samples were cut into smaller sizes

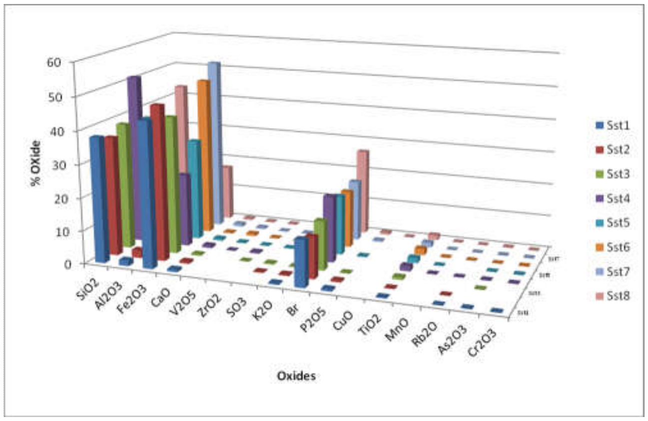

Fig 4: Bar Chart Showing all the Chemical Compositions of the Samples

compositions of the various rock samples and their modal percentage was estimated whilst the photomicrograph of the slides were taken. For the XRF analysis, the initial samples were reduced by splitting them into smaller size of about 30g. They were pulverized into a fine powder to obtain a fine powder to create an XRF sample. The sample were analysed with ARL 9900 XP total cement analyzer, which is used to analyse cement and it raw materials, clay, gray shale, iron ore, alluvial sand, gypsum and cement. The XRF analysis includes drying (Weighing of 5.0g of the sample into the drying dish/ceramic crucible, drying to constant weight (± 0.01g) in the oven or on the hot plate and cooling in the desiccators); preparation of fused bead (Drying of the crucible and the platinum mould in an oven at 110^{o}C-120^{o}C for about 30 minutes, Weighing of 6.000 ±0.0001g of lithium tetraborate into the crucible., Weighing of 1.000 ±0.0001g of sample and

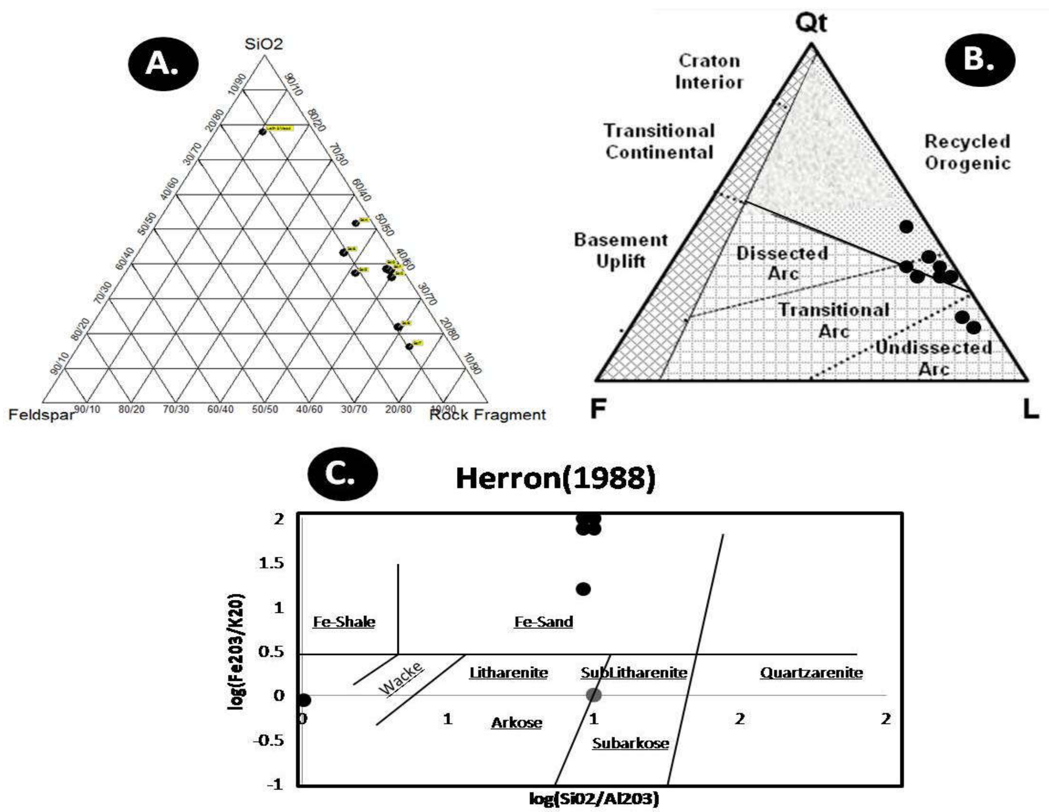

Fig 5: (A.) QFR triangular classification plot (Folk, 1974) of different sandstone samples from the Imobi, Eastern Dahomey Basin. (B.) Detrital Constituents Provenance Indicator Triangular Diagram of Dickinson (1985). (C) The log (SiO_2/Al_2O_3) *vs.* log (Fe_2O_3/K_2O) diagram of Herron (1988).

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 then displayed on the carborundum to make it smooth and free from air contact, further more the slides were heated, this was done by putting both the glass slide and the slab on a hot plate so as to heat for dryness. This was followed by fixed of the glass slide and the slab and this was done by the use of Araldite. They were then taken to another grinding machine to give a thickness of 1mm. the slides were lapped again to give a thickness of 0.3mm. The slides were observed under the petrologic microscope in order to ascertain the various mineral

putting on the lithium tetraborate in the crucible followed by 0.0200g of lithium bromide using a clean small spatula, Mixing properly with a clean spatula/glass rod, labelling and transferring of the fused bead into the X – ray analyser's sample holder ready for analysis.

RESULTS AND DISCUSSION

The minerals identified during the petrographic studies are listed in Table 2, with relative abundances which is plotted in fig 2. The snapshot of the different sample slides is shown in fig. 3.; there is preponderance of Quartz with minimum estimated percentage of 35% and maximum values of 60%.

The quartz generally are sub-angular to sub rounded, which implies little abrasion and transport from their origin. Other minerals presence include Iron Oxide and Microline, the iron oxide is suggestive of predominant continental conditions, where the Iron is acted a cementing material between the Quartz grains, other minerals and the matrix. Microline are typically metamorphic Potassium feldspar which implies that the sediments are sourced from an initial metamorphic rock.

Rock Geochemistry

The XRF analysis revealed a total number of sixteen (16) elements and oxides SiO_2, Al_2O_3, Fe_2O_3, CaO, V_2O_5, ZrO_2, K_2O,SO_2, Br, P_2O_5, CuO, TiO_2, MNO, Rb_2O, As_2O_3, and Cr_2O_3. The composition of the samples was compared with leith and Mead's standard chemical composition of an average sandstone, most of chemical oxides were present in the Imobi Sandstone samples although in different and varying quantities. FeO, MgO, Na_2O, H_2O, SO_2, BaO were not found in the samples, other elements and oxides in recognizable quantity include V_2O_5, ZrO_2, Br, CuO, Rb_2O, AsO_3 Cr_2O_3, MNO.

Parent Rock Lithology

When plotted on the Folk ternary diagram (fig 5.A), the sandstones samples lies within the region of litharenites, the SiO_2 represents the amount of quartz, while all alkali bearing minerals were considered as Feldspars, with the rock fragment or lithic being the other minerals present. The abundance of other oxides most especially the Fe_2O_3 contributed to the high value of the lithic recorded. Validating the results with the Herron (1988) (fig.5c) diagram supports the result of the folk plot, all of the most of the samples plotted on region of Fe-Sand, one in the region of Fe-Shale, and another on the boundary of litharenites, which implies the enrichment of Fe which contributed to the high percentage of lithic fragments. Overall, the samples have high concentration of SiO_2, Fe_2O_3, and Br; minor amount of Al_2O_3 and traces of the other elements and oxides. Quartz and Iron Oxide are the dominant minerals identified from the petrographic studies, the minor occurrences of Microcline (A feldspathic mineral that occurs usually in metamorphic rocks) in sample 2, 6 and 8, implies that the source rock is from metamorphic source. The presence of oxides like V_2O_5, ZrO_2, Br, CuO, Rb_2O, As_2O_3, Cr_2O_3 especially the abundance of Br suggests that the depositional environment is a shallow marine or near marine environment, with Fe_2O_3 being incorporated into the environment via oxidation.

Geochemistry and source area weathering

Weathering effects can be evaluated in terms of the molecular percentage of the oxide components, using the formulae of chemical index of weathering (CIW = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O]\times100$; Harnois, 1988) and chemical index of alteration (CIA= $[Al2O3/(Al_2O_3 + CaO^* + Na_2O + K_2O]\times100$); Nesbitt and Young, 1982) since alteration of rocks during weathering results in depletion of alkalis and alkaline earth elements and preferential enrichment of Al_2O_3 (Cingolani *et al.*, 2003). In this study, the value for Na_2O is null, as all the samples are depleted in Na^+, also the CaO contents are not thought to represent contributions from calcite or any calcareous material but purely to the abundance of plagioclase feldspar. The CIW′ value of the Sandstone samples vary from 69 to 95 (n=8, mean ~86, s=9; median ~88), which indicate intense weathering (recycling) for these sandstones. The CIA' value for the Imobi Sandstone range from 58 to 87 (n=8, mean ~80, s=12; median ~83), which implies high degree of alteration of the Alkali minerals (Feldspars) to clay.

Tectonic provenance

When plotted on the Dickson (1985) discrimant diagram, all the samples plotted on the boundary of Recycled orogens, peculiar with Dissected, Transitional and Undissected arc.

CONCLUSION

The presence of Microline suggest material from a metamorphic source, Br indicates deposition in a shallow marine to near marine environment while the CIA and CIW indices supports high degree of alteration of alkali mineral to clay, which is the indicated by the relatively high percentage of Alumina. Cementation of the siliclastic material occurred in a region close to the continent where the cementing material is Iron Oxide, tectonic discriminat plot suggests that the sediments are recycled which corroborates the results of the CIA and CIW.

The abundance of Iron Oxide suggests that the Sandstone is ferruginized sandstone, common in Tropical environment and which provides further evidence to why the sandstones plotted as Litharenites on the Folk diagram.

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