Journal of Multidisciplinary Engineering Science Studies (JMESS)
ISSN: 2458-925X
Vol. 3 Issue 4, April - 2017

Heavy Minerals And Mineralogical Composition Of Subsurface Coastal Plain Clastic Deposits Of Eastern Dahomey Basin, Southwestern Nigeria.

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***Abstract*—Investigation into subsurface coastal plain clastic deposits of eastern Dahomey Basin around Lagos area using heavy minerals and mineralogical composition was to infer the provenance, transportation history and depositional environment of these deposits. Drill - samples were collected at every three [3] meters from five [5] different boreholes with their depths ranging from 162meters to 225meters. Studies of heavy minerals and mineralogical composition were conducted to characterize the deposits. The mineralogical analysis revealed an average of 95.80% quartz, 2.64% feldspar and 1.56% rock fragments. This is an indication that clastic deposits (sandstone and siltstone facies) of this study are of quartz arenite variety. Their heavy mineral study revealed the presence of opaque and non-opaque minerals which typify deposits from acidic igneous rocks, medium to high grade metamorphic rocks and reworked older sedimentary rocks of the southwestern Nigeria basement complex.**

Keywords—Coastal Plain, clastic deposits, Dahomey Basin, Provenance, Heavy Minerals, and Mineralogical Composition.

INTRODUCTION

A proper understanding of modern sedimentary environment is based mainly on three parameters which are their physical, chemical and biological characteristics. These could be related to a number of features in the study area including its geology, geomorphology, climate and fossils. Facies analysis which is the study of vertical and lateral sequences of a litho unit is aimed at establishing the depositional environment and reconstructing the paleogeographic model of such a unit [Walker [1997]. This is done by making use of imprints found on the sediments, including primary sedimentary structures, texture and mineralogy; among others.

The study area is within the Dahomey Basin. The basin stretches for about 285 kilometers from Cotonou in Benin Republic to the western flank of the Niger Delta [Tiamiyu, 1989]. This study is to identify the provenance, transportational history and depositional environment of clastic sediments in the area. Its scope covers collection of samples from these boreholes for various laboratory analyses, including characterisation of heavy minerals and mineralogical composition as well as their interpretations.

The lithologic description of sediments of the study area was based on drill samples taken at every 3.0 meters from the five selected boreholes.

LOCATION AND ACCESSIBILITY

The study area spans from the western end of Agbara Town to Ajah in the southwestern part of Lagos [Fig 1]. The boreholes investigated are located at Agbara , Victoria Island, Ikoyi, Ikeja and Ajah . These settlements fall between longitudes 3º 4' and 3º 35' East and latitudes 6º 22'and 6º 41' North, within the southwestern Nigerian margin. These localities are accessible both by major and feeder roads as well as footpaths

Series of research work have been conducted on Dahomey Basin, among the studies carried out in this part of the basin include exploration for petroleum by various oil companies between 1954 and 1961, which led to drilling of such wells as Bodashe-1, Illepaw-1, Afowo - 1, and Ojo-19 well [Fayose, 1970]. Published reports on ecology, sedimentation and foraminifera of Lagos lagoon and Gulf of Guinea include those of Yoloye [1969]; Fayose [1970]; Adegoke et al [1971, 1974, 1980]; Adegoke[1975]; Tiamiyu[1989]; Nwachukwu et al[1992] and Akinmosin et al [2005].

Bassey [1996] assessed grain size and heavy minerals composition of beach sands in Badagry and Victoria Island of Lagos State. He traced the origin of the heavy mineral assemblage [comprising staurolite, kyanite, zircon, sillumanite, garnet, hornblende and magnetite] in the sediments to highly metamorphosed and acidic igneous rocks of the adjoining Nigerian basement complex , though some were transported by long shore currents from Ghana-Togo coast to the Lagos shore. He further stated that the Nigerian coastal region is vested with numerous sediment-laden rivers which flow more or less southward through extensive hinterland into adjourning Atlantic Ocean. The sediments so supplied are dispersed by tides generated by long shore drift that flow directly onto the coast.

GEOLOGY OF DAHOMEY BASIN

The Dahomey Basin is one of the sedimentary basins on the continental margin of the Gulf of Guinea, extending from southeastern Ghana in the west to the western flank of the Niger Delta [Jones and Hockey, 1964; Omatsola and Adegoke, 1981; Fig. 2]. The basin is bounded in the west by faults and other tectonic structures associated with the landward extension of the Romance fracture zone. Its eastern limit is similarly marked by the Hinge line that forms a major fault

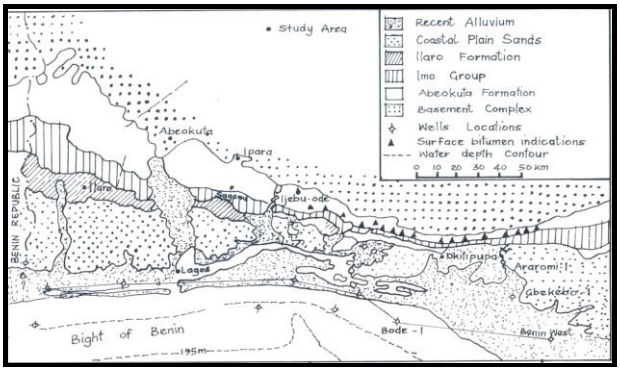


Figure 1: Geological Map Of The Eastern Dahomey Basin [After Agagu, 1985]

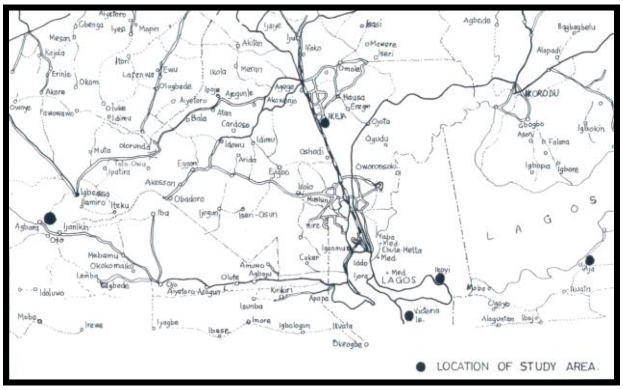


Figure 2: S Figure 2: Sketch Map Of Study Area[Adapted From Lagos Sheet 68, 1st Edition Fed. Surveys Nigeria, 1966]

structure marking the western limit of Niger Delta [Omatsola & Adegoke, 1981]. Also, it is bounded in the north by the Precambrian basement rocks, and by the Bright of Benin in the south.

Tectonically, the Dahomey Basin was formed consequent to the opening of the South Atlantic during the Mesozoic (Omatsola and Adegoke, 1981). It is associated with a major tectonic episode that occurred during early Cretaceous and may be related to the closure of the Benue Trough.

STRATIGRAPHY OF DAHOMEY BASIN

Stratigraphic studies of this basin were conducted by various researchers, among whom are Jones and Hockey, [1964]; Reyment, [1965]; Adegoke,[1980];and Omatsola and Adegoke,[1981]. The general sequence of the lithounits from bottom to top consists of the cretaceous Abeokuta Group and Paleogene sediments belonging to the Imo Group, Oshoshun Formation and Ilaro Formation which are capped by the coastal plain sands of Oligocene to Recent age.

The Abeokuta Group comprises the basal Ise Formation which consists essentially of continental sands, grits and siltstone overlying the basement complex unconformably and is assigned Neocomian to Albian age. It is overlain by the Afowo Formation which consists of coarse to medium grained sandstones with variable interbeds of shales, siltstones and clay, thus indicating sediments of transitional to marginal marine environment and is assigned Turonian to Maestrichtian age. The Araromi Formation which conformably overlies the Afowo Formation comprises essentially of sands, overlain by dark grey shales with limestone and marl interbeds and occasional lignite bands. The formation is assigned Maestrichtian to Paleocene age. Overlying the Abeokuta Group is the Imo Group comprising the Ewekoro Formation which consists of a thick fossiliferous limestone that displays 3 – 4 microfacies and is dated Paleocene age (Ogbe,1972; Adegoke,1977). The Akinbo Formation overlies Ewekoro Formation conformably and comprises shale, glauconitic rock, gritty to pure grey sands with occasional clay lenses and is assigned Paleocene – Eocene age.

The Oshoshun Formation which overlies the Imo Group consists of mostly pale greenish grey laminated phosphatic marls, light grey to white-purple claystone with sandstone interbeds and Agagu (1985) assigned it an Eocene age. This is conformably overlain by a regressive sandstone unit called Ilaro Formation which shows rapid lateral facies change and is dated Eocene – Oligocene. The coastal plain sands are the youngest sediments that cap the stratigraphic sequence in the eastern Dahomey basin and is dated Oligocene to Recent.

MATERIAL AND METHOD

Studies were conducted on clastic sediments retrived from five different boreholes and samples were collected at 3.0 meters interval. A total of 30 samples were selected from a sum of 324 samples for this study. Precaution was taken during sample collection not to contaminate them. Heavy minerals which are defined as those minerals with specific gravity greater than 2.85 were separated from lighter minerals, such as quartz, feldspar or calcite using bromoform liquid which has a specific gravity of 2.85.

Heavy mineral slides were prepared and examined under a transmitted light on a flat stage petrographic microscope to identify the non-opaque minerals while the opaque minerals were examined under reflected light. The mineral types were identified based on their optical properties and using point counting technique to calculate the ZTR index, the maturity index of the sediments was assessed [Hubert, 1962]. This was calculated using the percentage of the sum of Zircon, Tourmaline and Rutile grains from the non opaque minerals over the total sum of non opaque minerals;

$$\text{i.e. ZTR Index} = \frac{\text{Zircon + Tourmaline + Rutile}}{\text{Total of non opaque minerals}} \times \frac{100}{1} \%$$

Mineralogical Composition

A selective staining technique was utilized to separate quartz, feldspar and rock fragments. The lighter mineral fraction of 2mg were collected and placed in a lead and bath in warm concentrated hydrochloric acid [HCl] for a minute. After thorough washing, the sample was immersed in one percentage aqueous solution of malachite green for five minutes and was then rinsed and dried. The sample was again mounted on a slide with Canada balsam, and studied under a petrographic microscope. Quartz remains unchanged in colour while feldspars stain yellowish and rock fragment stain brown. The relative proportion of different detritus minerals were determined by point counting and results recorded in percentage.

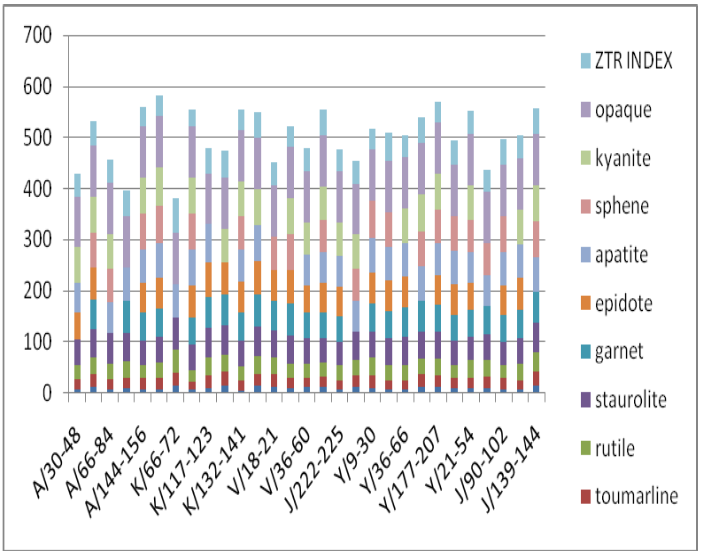
	A/6-18	A/30-48	A/54-60	A/66-84	A/88-144	A/144-156	K/33-51	K/66-72	K/90-96	K/117-123	K/126-129	K/132-141	K/186-193	V/18-21	J/144-180	V/36-60	V/96-105	J/222-225	V/135-210	Y/9-30	Y/102-114	Y/36-66	Y/66-78	Y/177-207	Y/150-177	Y/21-54	J/54-60	J/90-102	J/60-90	J/139-144
zircon	15	7	13	8	11	8	7.5	14	7	10	15	6	15	13	11	12	12	8	13	10	7	7.5	13	13	9	11	10	8	8	14
tourmaline	27	20	24	19	19	21	23	27	16	25	27	19	23	25	18	19	20	18	23	25	19	18	24	23	20	20	23	23	18	28
rutile	34	27	34	30	33	27	30	45	23	36	34	28	36	31	29	27	27	28	30	35	30	30	31	32	27	34	31	25	31	39
staurolite	54	51	55	60	56	48	50	61	49	56	56	51	56	53	55	49	49	46	55	50	51	55	53	52	47	46	51	45	51	56
garnet	61	0	58	0	61	54	55	0	54	62	61	55	62	58	63	51	51	51	0	55	54	58	60	54	51	51	56	53	56	61
epidote	71	54	63	0	0	59	60	0	63	67	63	60	67	62	66	54	56	56	0	60	61	61	0	58	60	54	0	58	62	0
apatite	74	56	0	62	67	65	68	67	68	74	0	62	69	0	0	58	61	62	60	68	65	63	67	62	64	60	59	65	64	67
sphene	0	0	66	65	0	69	73	0	70	0	0	66	0	65	68	0	63	0	63	73	68	0	69	66	69	63	64	70	0	70
kyanite	76	70	71	68	0	71	75	0	72	0	66	68	72	0	71	63	66	64	66	0	0	70	73	69	0	68	0	0	69	72
opaque	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

RESULT AND DISCUSSION

Heavy Mineral Analysis

Heavy minerals found in the samples analyzed were differentiated into opaques and non opaques, with the non opaque constituting a large percentage [Table 2]. The opaque minerals identified are ilmenite, hematite, magnetite and limonite; all constitute about 33.5% of the total heavy minerals. The ultra stable non opaques found are zircon, tourmaline, rutile [ZTR] group while the stable to moderately stable ones are staurolite, mica, garnet, epidote, and apatite. Others are sphene and kyanite [Hubert, 1962].

The petrographic features of these opaque minerals are black colour, without extinction and plaeochroism. Some of the non opaque minerals are colourless (zircon, apatite and garnet) while others display colours ranging from brown to green and yellow to green[tourmaline, epidote], rich red to brown [rutile]. Their relief and birefringence generally vary from low through moderate to high. Some non opaque minerals are plaechroic [tourmaline, epidote] while others, such as zircon, rutile, apatite and garnet, are not. The ZTR index calculated [Table 3] falls within the range of 38 to 67% ,with an average of 48%. According to Hubert [1962], zircon, tourmaline and rutile are ultimately concentrated in siltstone and sandstone by prolonged abrasion that tookplace during their transportation [plate 1-5].



The younger sediments generally contain a greater number of different heavy mineral species than older rocks. Pettijohn [1975] reported further that heavy minerals of many Paleozoic sediments consist entirely of the most stable species such as zircon, tourmaline, rutile and garnet. He attributed this to intrastratal [diagenetic] solution since older rocks are more susceptible than younger rocks that occur in this study area.

From heavy mineral assemblage, the origin of the coastal plain clastic deposits of the study area could be deciphered. The heavy presence of staurolite couple with kyanite and garnet in the samples studied isindicative of medium to high grade metamorphic rocks [Hubert, 1962]. The presence of zircon, garnet and tourmaline in the sediment indicates that parts of the sediments were derived from acidic igneous rocks, as well as from pre-existing sedimentary rocks. These rocks include, among others,
amphibolites and gneisses of the southwestern Nigerian

Basement Complex. Adeleye and Fayose [1978] reported that these heavy minerals [tourmaline, zircon, rutile, staurolite and kyanite] constitute an important heavy mineral suite in Nigerian sedimentary rocks and that their origin is presumed to be Precambrian crystalline rocks of the Basement Complex. Allen [1965] revealed that long shore current is powerful enough to transport some of the heavy minerals from far away Ghana-Togo coast to Lagos shore. It may therefore be suggested that these heavy minerals in the sediments could be sourced from the adjoining coastal region[Bassey, 1996]. Figures 10 and 11 show the graphical representation of heavy mineral assemblage and ternary plot of the percentage composition of ZTR index.

Mineralogical Composition

Results of mineralogical composition revealed the sandstone and siltstone facies to be quartz arenite consisting an average of 95.80% quartz, 2.64% feldspars and 1.56% rock fragments [Table 4 and 5]. The ternary plots of framework grains of the sandstone facies and the relationship of framework grains of sandstone and tectonic setting are shown in figures 12 and 13 respectively. The sandstone and siltstone facies are therefore classified as quartz arenite [Folk, 1974]. They consist mainly of quartz as the framework constituent; feldspar and rock fragments occur only as subordinates though the former are also seen as silt sized particles. Larger percentage of the quartz occurred as monocrystalline, and are generally sub angular to rounded and equant to spherical in shape. The extinction displayed by monocrystalline quartz is strongly undulose, while it varies in polycrystalline quartz from slightly to strongly undulose and semi composite.

Blatt, et al., [1972] reported that polycrystalline quartz includes grains with strongly sutured intercrystal
boundaries which typify metamorphic rocks. Most of the polycrystalline quartz grains contain about five crystals per grain, which scarcely show definite preferred orientation. Such polycrystalline quartz grains have been traced to plutonic source by Bassey and Ajonnia[2002].

Tucker [1988] discussed that under hot climatic conditions, feldspar weathers to clay minerals, though very rapid erosion and short transport history that characterize high relief source area, favours feldspar preservation. Hence the presence of both fresh and weathered sub rounded to rounded feldspar grains in the sandstone is indicative of their derivation and deposition in a humid hot climate in which feldspar survival was only guaranteed by such rapid erosion in relation to weathering and short transportation of the sediment in a high relief terrain [Bassey and Ajonnia, 2002]. The rock fragments are mainly of metamorphic origin, dominated by gneisses and quartzite, though some acid igneous plutonic rocks are observed. The matrix is made up of very tiny irregularly shaped pieces of micaceous minerals, clay, feldspar and quartz which infiltrate the inter-granular void and binded the framework grains. The sub rounded state of the feldspar grains in these sediments could be due to their physiochemical nature which is indicative of their derivation from a humid climatic environment.

Table 2:The modal composition of coastal plain sand from the study area

SAMPLE	QUARTZ	FELDSPAR	MICA	LITHIC FRAGMENT	FOSSIL FRAGMENT	TOTAL
AGB/6-18	94.82	2.86	-	2.32	-	100
AGB/30-48	96.48	2.80	-	1.56	-	100
AGB/48-54	96.70	1.37	-	2.43	0.05	100
AGB/54-60	97.50	2.20	-	2.30	-	100
AGB/72-84	97.87	1.52	-	0.61	-	100
AGB/144-156	96.80	2.03	0.01	1.16	-	100
KJA/24-30	98.51	1.05	-	0.44	-	100
KJA/39-51	97.50	1.92	-	0.58	-	100
KJA/51-57	98.56	-	-	1.44	-	100
KJA/66-72	99.85	0.15	-	-	-	100
KJA/84-144	99.72	-	0.02	0.28	-	100
KJA/117-123	96.42	2.64	0.02	1.92	-	100
KJA/126-129	98.59	0.03	-	1.36	0.01	100
KJA/132-141	99.22	0.92	-	0.13		100
KJA/153-159	97.84	0.52	-	0.56	1.00	100
VI/27-33	95.75	2.55	-	1.50	0.20	100
VI/60-63	94.80	2.05	-	1.50	1.10	100
VI/96-105	95.38	2.8	-	1.82	0.01	100
VI/180-198	96.10	3.64	0.01	0.21	0.25	100
VI/198-210	95.10	2.45	-	0.25	1.20	100
IKY/3-6	92.32	2.02	1.29	0.57	3.80	100
IKY/36-66	96.18	2.07	-	0.25	1.50	100
IKY/66-87	98.22	1.20	-	0.38	-	100
IKY/102-114	97.50	1.42	0.01-	0.38		100
IKY/144-150	96.13	2.38	-	0.86	-	100
IKY/150-198	97.57	1.80	-	0.63	0.01	100
IKY/207-222	97.83	1.74	-	0.43	-	100
AJ/0-15	96.09	2.63	0.50	0.77	0.01	100
AJ/21-30	93.10	2.70	-	0.75	1.02	100
AJ/90-102	95.75	2.50	-	1.70		100
AJ/144-168	95.56	2.25	-	0.94	0.25	100
AJ/222-225	97.98	1.50		0.52	-	100

- Provenance Evaluation
- Heavy minerals have long been used as indices of provenance. Bassey [1996] identified specific heavy mineral speciesfrom this area that revealed the composition of source rock to be acid igneous and medium to high metamorphic rocks. Blatt et. al, [1980] also described zircon as the most ubiquitous non opaque mineral in silica rich rock. In this study, the shape of zircon is elongate and, according to Folk [1974], it is indicative of a metamorphic source. Rutile is unstable in low grade metamorphic rock, but survives in high metamorphism [Force, 1980]. Tourmaline occurs in low grade metamorphic rocks and acid igneous rocks. Garnet is found in pegmatite and high grade metamorphic rock while staurolite survives both in contact and dynamothermal metamorphic rocks. Pettijohn [1975] had revealed that heavy minerals such as rutiles, zircon, tourmaline, apatite, garnet, illmenite and staurolite are ultrastable to stable in relation to this study. All these are indicative of sediments derived from plutonic igneous

and /or metamorphic terrain of the basement complex of southwestern Nigeria. Also, some of these sediments have been reworked and/or recycled from previous sediments deposited in this area.

Depositional Environment

The predominance of opaque minerals particularly hematite is an indication of aerated environment. This is reflected by the reddish brown colour observed in some of the sandstone and siltstone facies which confirms oxidizing condition. The plot of ternary diagram of the framework grains of these sediments suggests a continental block slightly mixed with recycled orogeny provenance due to the inter-mingling of the two fields [Dickson,1970].

CONCLUSION

The heavy mineral assemblage of the study area included zircon, tourmaline and rutile. This showed that the sediments attained high degree of maturity and stability. The predominance of opaque minerals particularly hematite is an indication of an aerated environment.

The very low percentage value of feldspar and rock fragment in the sediments under study indicate they were either derived and deposited under a humid and hot climate or they were transported for a long distance over an environment of relatively low relief. It has been ascertained that both conditions prevailed in the study area due to occurrence of many sediment-laden rivers from the hinterland which emptied into the basin couple with the prevalence of longshore drift that enhanced long distance transport of sediments.

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