SEDIMENTOLOGY AND PETROGRAPHIC ATTRIBUTES OF OUTCROPPING SEDIMENTS OF COASTAL PLAIN SANDS FROM ABUDU AND ITS ENVIRONS, SOUTHERN NIGERIA

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Relying on field and laboratory evidences, outcropping sediments at Abudu and its environs were studied for their sedimentological and petrographic attributes. Based on field and sedimentological evidences, two lithofacies, sandstone and claystone were identified in the study area. The claystone facies include two (2) sub-lithofacies of silty clay and sandy clay; while the sand facies include medium to coarse-grained friable sands and, fine to medium-grained sands. Particle size analysis shows sorting values ranging from 0.94 to 2.10 indicating moderately to poorly sorted; skewness values of -0.13 to 0.2 indicating near symmetrical to positively skewed and kurtosis values in the range of 0.77 to 1.34 suggestive of platykurtosis to leptokurtosis. The petrographic analysis reveals the major framework minerals to include quartz (76.9 to 97.5%), rock fragment (0 to 12.9%) and feldspar (0 to 15.4%) and mineral maturity index (MMI) range from 3.8 to 39.0. Poor to moderate porosity was inferred for the sediments. Using field evidences and scatter plots of Skewness versus sorting and mean versus sorting, a fluvial depositional setting was interpreted for the sediments. The sediments range from sub-mature to super-mature; subarkosic to quartz arenites and sediments have undergone intense chemical weathering and/or erosion as evident in the predominance of quartz over feldspar. A craton interior source with contributions from recycled orogen is suggested for the sediments of the study area.

Key words: Sedimentology, petrography, provenance, paleodepositional environment, fluvial environment.

INTRODUCTION

Outcrop studies provide analogs which are widely used in quantitative prediction of reservoirs as well as describing architecture and facies distribution of sedimentary deposits at a subseismic scale (Tetyukhina et al., 2014). Such studies also represent a more direct approach for the study and understanding of the Earth – its materials, resources, processes, field relationships, history and/or evolution (Rahaman, 2009).

Petrographic analyses aid the understanding and interpretation of the mineralogical (petrographic) details of rocks – their composition, abundance, and morphology among others. Coupled with field studies, petrographic studies are commonly used in reconstructing the geological history of rocks, particularly the maturity, provenance, tectonic setting, diagenesis and paleoclimate of the sediments (Ogungbesan and Akaegbobi, 2011). Although the Niger Delta remains one of the most widely studied basins in Nigeria, studies on the petrography of the basin are scarce. The most notable petrographic studies of the Benin Formation known to us are those of Onyeagocha (1978) and Avbovbo (1978).

The need to combine sedimentological and petrographic analyses is borne out of the fact that relying on textural analysis alone may result in gross interpretational errors, especially if diagenetic or disaggregation processes have significantly altered textural properties of such sediments (Wilson and Pittman, 1979). This paper reports the results of field mapping and laboratory analyses aimed at determining the paleodepositional environment and provenance of outcropping sediments from Abudu and its environs in southern Nigeria.

Location of the study area

This study was carried out in parts of Delta and Edo states, south-southern Nigeria, extending from Latitude 6°15′ to 6°27′N and Longitude 6°2′ to 6°22′ (Figure 1). Climatically, the area of the study is tropical continental, with wet and dry alternating seasons. The area is characterized by high humidity and annual rainfall, usually exceeding 2000mm. The vegetation is tropical rainforest (Olobaniyi et al., 2007). A mean evapotranspiration of 1117mm has been reported for the study area (Akpoborie et al., 2011). The area is generally lowland (plain) devoid of mountainous relief and crystalline rocks. Notable rivers in the study area include Rivers Orhionmwon, Ohordua, Atarhi and Mbiri, most of these rivers being seasonal with the exception of the River Orhionmwon the most notable exception.

Previous studies and current status of the Niger Delta

Parkison (1907) and Reyment (1965) were among the earliest studies on the Niger Delta. Reyment (1965), Short and Stauble (1967), Knox and Omatsola (1989), Whiteman (1982) and Doust and Omatsola (1990) have all studied and reported on the Benin Formation (Coastal Plain Sands) as part of the broader Niger Delta Basin with regards to its origin, stratigraphy, structure, sedimentation and age.

Recent studies have also included understanding the geology of the offshore Niger Delta (Chinotu, David Matteo, 2012). Briggs (2007) has studied and reported on the structural geology of the offshore Niger Delta just as Reijers (2011), provides a framework for the sedimentological and stratigraphic understanding of the Niger Delta.

Onyeagocha (1978) studied the petrography and depositional environment of the Benin Formation. He reported the occurrence of quartz (99%) and heavy minerals (in coarser grains) which are mainly monocrystalline within the formation. Avbovbo (1978) and Knaap (1971) have also reported the occurrence of feldspar in sediments within the Coastal Plain Sands.

According to Amajor (1991), the sands of the Benin Formation range from very fine to coarse grained; sub-angular to sub-rounded, poorly sorted to well sorted and are mostly lithic arenites. Similarly, Ogala et al. (2010) asserted that the Benin Formation is characterized by sandstones ranging from fine to coarse-grained, poorly sorted, mostly mesokurtic and positively skewed. According to them, the pebbles of the formation have flatness ratio of 0.544, elongation ratio of 0.794, maximum projection sphericity index (MPSI) of 0.713 and oblate - prolate index of -0.955. Ogala et al. (2010), assigned a transitional to fluvial paleodepositional environment for the Benin Formation based on granulometric (sedimentological) and morphometric attributes of sediments from the formation.

The current stratigraphic division of the basin into three (3) units: Akata Formation, Agbada Formation and Benin Formation (Coastal Plain Sands) was given by Short and Stauble (1967). Although this stratigraphic classification of the Niger Delta remains the generally accepted stratigraphy of the basin, a review of the stratigraphy has been advocated (Omatsola and Cordrey, 1976; Doust and Omatsola, 1990; Rejers, 2011).

Doust and Omatsola (1990) faulted the stratigraphic division of the Niger Delta arguing that the extant classification (Short and Stauble, 1976) is based on ‘vague’ characteristics, the most important being the sand-shale ratio. Also, Reijers (2011) has proposed the elevation of the three (3) formations into groups, while according to the author, the Afam Clay and other identified members within the basin fall within the status of formations. Similarly, Omatsola and Corderey (1976) had earlier assigned the Afam Clay Member the status of a formation.

Remarkably, as Nwajide (2013) clearly pointed out, such reviews, elevations and/or alteration of the existing stratigraphy of the basin would remain in the domain of “proposals” and can only be accepted if adopted by the Niger Delta Stratigraphic Commission. Until this is done, the stratigraphic classification of the Niger Delta by Short and Stauble (1967) would remain the acceptable stratigraphy for the basin.

METHODOLOGY

This study was carried out in two phases, a field mapping phase and a laboratory analyses phase. The field mapping involved the geological survey-type as described by Rahaman (2009) while the laboratory analyses involved sieve analyses and preparation of slides for thin section analysis. The slides were then observed under plane polarized light (PPL) and crossed polarized light (XPL) for their petrographic attributes.

RESULTS AND DISCUSSIONS

Based on field observations and sedimentological analysis, two (2) lithofacies, sands (sandstone) and claystone were identified in the study area. The sands faciesconsist two (2) sublitho-facies: fine to medium grained sands and medium to coarse grained, friable sands whereas the claystonefacies consist of sandy clay and silty clay. The Abudu and Asaboro sediments were friable sands while the sediments from Mbiri, Ewohimi and Idumuje-Ugboko were mainly clayey sands; the Ozanogogo sediments were silty clay whereas the Ekpon sediments are sandy clay.

The particle size analysis using Folk and Ward (1957) statistical parameters shows that the sand facies are mainly poorly sorted and range from nearly symmetrical to positively-skewed Table 1. This moderate to poor sorting and positive-skewness in sediments are interpreted to be characteristic of fluvial depositional environment (Acra et al., 2013; Dickinson, 1988; Bassey and Eminue, 2012). The poor sorting and positive skewness must have resulted from occasional fluctuations between high and low transportation energies characteristic of river systems. The fluvial depositional environment is further supported by the bivariate plots of Mean versus Sorting and Skewness versus Sorting as shown in figures 2A and 2B. Also, the Ozanogogo clays are thought to have been deposited in a point bar. This inference is based on the characteristic fining-upward sequence observed

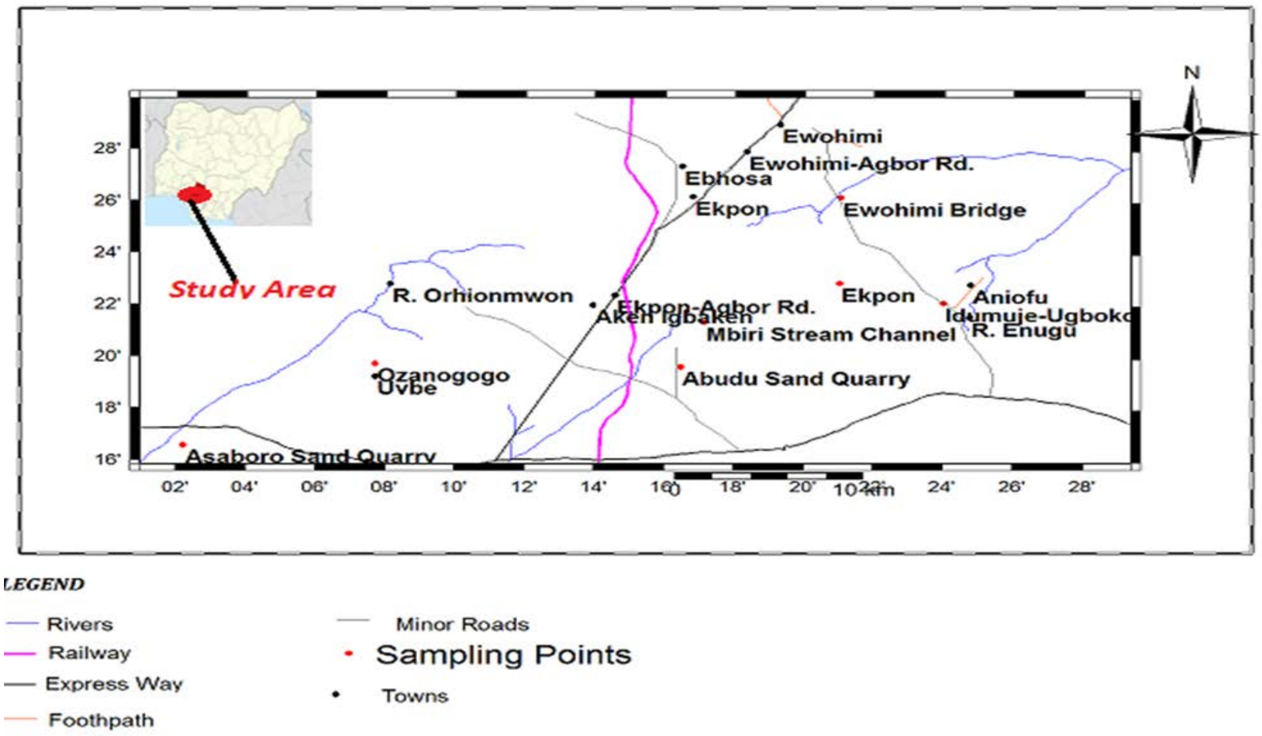

Figure 1. Location map of the study area.

at Ozanogogo.

The petrographic analysis of the Abudu sediments shows the framework mineral to include quartz, rock fragments and feldspar (Table 2), quartz being the dominant; mineral – ranging from 76.9 to 97.5% (table 3). Monocrystalline and polycrystalline quartz were identified in the sediments with undulose extinction. The quartz are subangular to subrounded (Plates 1 to 8) without elongated

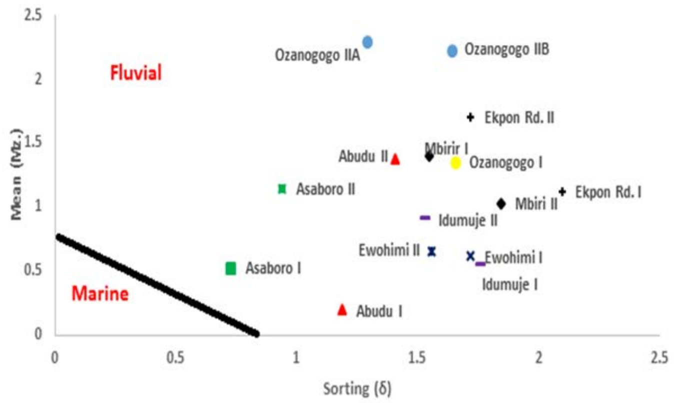

Figure 2a. Bivariate plot of mean Vs. sortng (boundary modified after Moiola and Weiser (1968)).

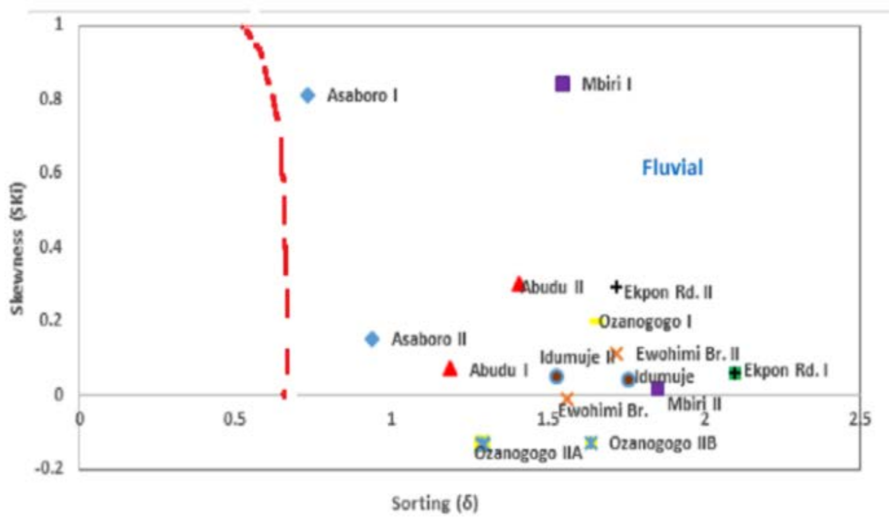

Figure 2B. Bivariate Plot of Skewness Vs. Sorting (boundary modified after Friedman (1967)).

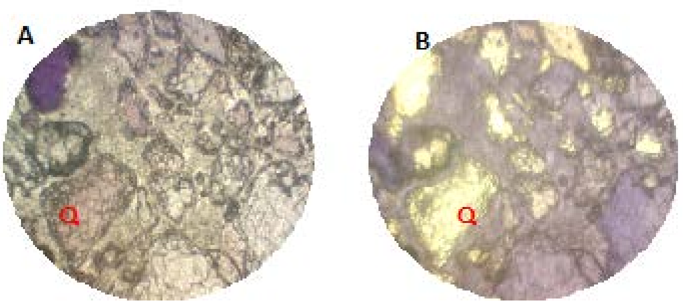

Plate 1. Photomicrograph of Abudu (A = PPL; B XPL; Q = Quartz); magnification: x 100.

and/or flattened morphology and range from submature to supermature (table 4). Quartz overgrowths with inclusions and fractures were also observed in the sediments
(Plates 2, 5 and 7).

The percentage modal composition of feldspar in the sediments range from 1.3 to 15.4% (Table 3).The feldspar being mainly orthoclase. The orthoclase feldspar are untwined

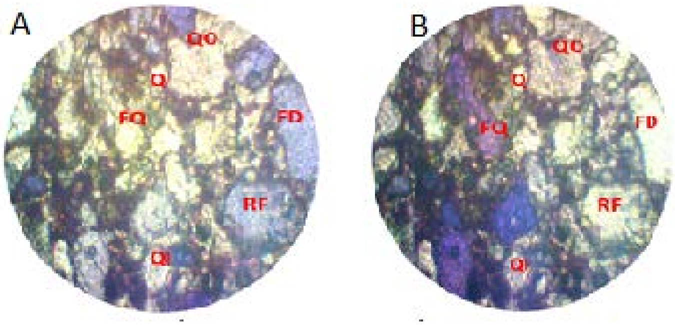

Plate 2. Photomicrograph of Asaboro (A = PPL, B = XPL; QO = Quartz Overgrowth, FQ = Fractured Quartz, QI = Quartz Inclusion, FD = Feldspar, RF = Rock Fragment); magnification: x 100.

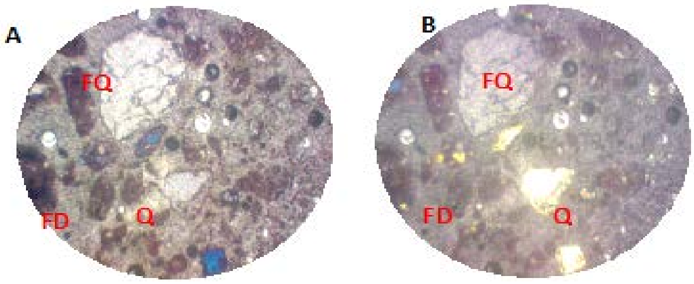

Plate 3. Photomicrograph of Ozaanogogo I (A = PPL, B = XPL; Q = Quartz, FQ = Fractured Quartz, FD = Feldspar); magnification: x 100

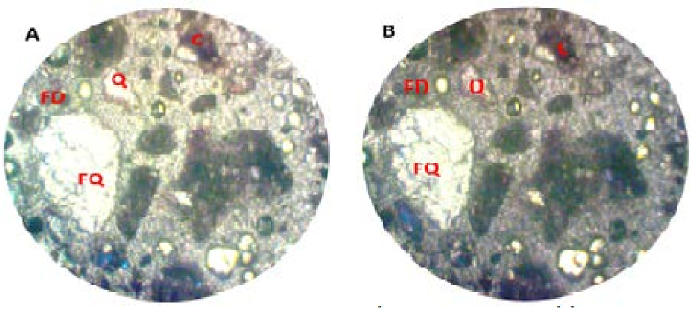

Plate 4. Photomicrograph of Ozaanogogo II (A = PPL, B = XPL; Q = Quartz, FQ = Fractured Quartz, FD = Feldspar, C = Calcite); magnification: x 100.

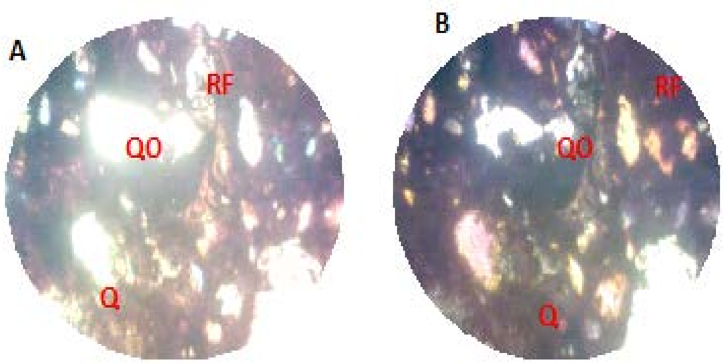

Plate 5. Photomicrograph of Mbiri (A = PPL, B = XPL; Q = Quartz, QO = Quartz Overgrowth, RF = Rock Fragment); magnification: x 100.

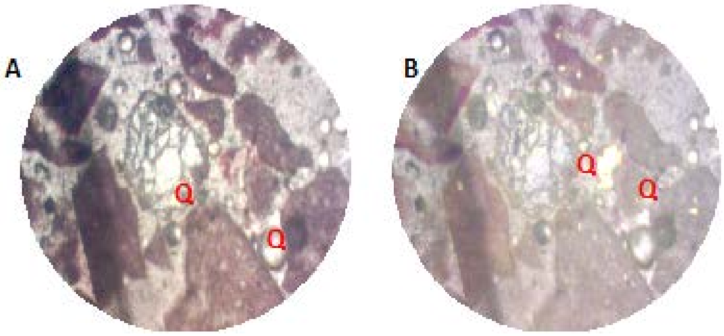

Plate 6. Photomicrograph of Mbiri (A = PPL, B = XPL; Q = Quartz); magnification: x 100.

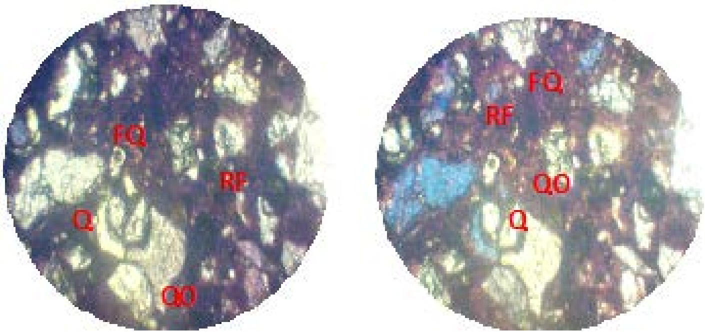

Plate 7. Plate 5: Photomicrograph of Ewohimi (A = PPL, B = XPL; Q = Quartz, QO = Quartz Overgrowth, RF = Rock Fragment, FQ = Fractured Quartz); magnification: x 100.

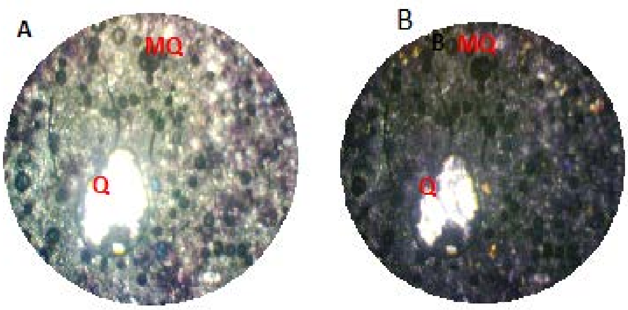

Plate 8. Photomicrograph of Idumuje-Ugboko Road (A = PPL, B XPL; Q = Quartz, MQ = Micro Quartz); magnification: x

and only distinguished from the quartz using the differences in their refractive index – quartz has a high refractive index, usually higher than that of the Canada balsam unlike orthoclase with low RF. Also, because orthoclase is more susceptible to weathering, it appears more cloudy and/or brownish in PPL relative to quartz (Adams et al., 1984; Akpofure and Etu-Efeotor, 2013). The relatively low percentage of feldspar suggests intense weathering and long distance transportation from provenance. The percentage of rock fragment range from 0 to 12.9% (Table 3), both quartz-poor and quartz-rich lithic fragments. This multiplicity of rock fragment-types suggests multiple sediment sources.

Ternary plots of quartz, feldspar and rock fragments (QFR) clearly show that the sediments range from sub-arkose to quartz arenites (Figures 3 and 4). The dominance of quartz with relatively very low percentage of feldspar and the calculated mineralogical maturity index (MMI) was interpreted to imply that the sediments are allogenic and must have undergone transportation across some distance

Table 1. Grain size analysis.

S/N	Sample location	Median (MdØ)	Mean (Mz.)	**Sorting (δ)**	Skewness (SK_i)	Kurtosis	Description
1.	Abudu A	0.04	0.19	1.19	0.07	0.87	Fine sand, poorly sorted; nearly symmetrical; platykurtic
2.	Abudu B	1.18	1.37	1.41	0.30	0.89	Coarse sand, poorly sorted; positive-skewed; platykurtic
3	Asaboro A	0.16	0.52	0.73	0.81	1.04	Medium sand, moderately sorted; very positive-skewed; mesokurtic
4.	Asaboro B	1.08	1.14	0.94	0.15	1.34	Medium sand, moderately sorted; positive-skewed; leptokurtic
5.	Ozanogogo A	1.09	1.35	1.66	0.20	1.29	Clay, poorly sorted; positively skewed; leptokurtic
6.	Ozanogogo B1	2.42	2.30	1.29	-0.13	0.88	Clay, poorly sorted; nearly symmetrical; platykurtic
7.	Ozanogogo B2	2.37	2.23	1.64	-0.13	0.64	Silty clay, poorly sorted; nearly symmetrical; very platykurtic
8.	Mbiri A	1.14	1.39	1.55	0.84	1.21	Medium sand, poorly sorted; very positive skewed; leptokurtic
9.	Mbiri B	1.08	1.02	1.85	0.02	0.92	Medium sand, poorly sorted; nearly symmetrical; mesokurtic
10.	Idumuje-Gboko Rd. A	0.63	0.54	1.76	0.04	0.77	Medium sand, poorly sorted; nearly symmetrical; platykurtic
11.	Idumuje-Gboko Rd. B	0.91	0.90	1.53	0.05	0.98	Medium sand, poorly sorted; nearly symmetrical; mesokurtic
12.	Ekpon Railway Cut A	1.19	1.12	2.1	0.06	0.85	Clay, very poorly sorted; nearly symmetrical; platykurtic
13.	Ekpon Railway Cut B	1.23	1.70	1.72	0.29	1.17	Sandy clay, poorly sorted; positive-skewed; leptokurtic
14.	Ewohimi Bridge A	0.73	0.61	1.72	0.11	0.81	Coarse sand, poorly sorted; nearly symmetrical; platykurtic
15.	Ewohimi Bridge B	0.73	0.65	1.56	-0.01	0.92	Medium sand, poorly sorted; very negative-skewed; mesokurtic

Table 2. Percentage (%) mineralogical composition of the sediments.

S/N	**Location (%)**	**Quartz (%)**	**Rock Fragment (%)**	**Feldspar (%)**	**Cement (%)**	**Mica (%)**	**Matrix (%)**
1.	Abudu	78	2	5	15	0	0
2.	Asaboro Quarry	75	1	12	10	0	2
3.	Mbiri	65	0	20	12	0	3
4.	Ewohimi Bridge	40	12	21	20	1	6
5.	Ekpon Road	50	5	10	30	0	5
6.	Idumuje -Ugboko Road	30	4	25	40	0	1
7.	Ozanogogo A	30	6	6	55	0	3
8.	Ozanogogo B	45	8	12	35	0	0

Table 3. Calculated Percentage (%) Modal Mineralogical Composition for the Sediments.

Location	Quartz (%)	Feldspar (%)	Rock fragment (%)
Abudu	97.5	2.5	0
Asaboro Quarry	96.2	1.3	2.6
Mbiri	95.6	0.0	4.4
Ewohimi Bridge	80.6	6.5	12.9
Ekpon Road	83.3	8.3	8.3
Ewohimi/Idumuje-Gboko Road	85.7	11.4	2.9
Ozanogogo I	76.9	15.4	7.7
Ozanogogo II	84.9	15.1	0

Table 4. Mineralogical maturity index (MMI) of the sediments after Nwajide and Hoque (1985).

Location	MMI	Description
Abudu	39.0	Super-mature
Asaboro Quarry	24.7	Supper-mature
Mbiri	21.7	Supper-mature
Ewohimi Bridge	4.2	Sub-mature
Ekpon Road	5.0	Sub-mature
Idumuje-Gboko Road	6.0	Sub-mature
Ozanogogo I	3.8	Sub-mature
Ozanogogo II	5.6	Sub-mature
Average MMI =	13.8	Mature

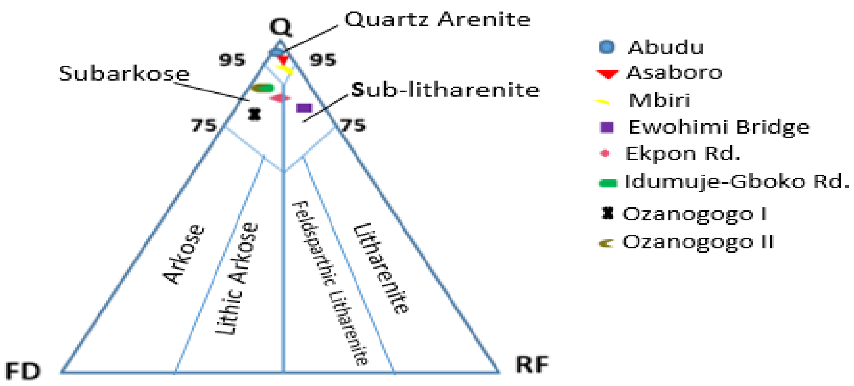

Figure 3. Ternary plot of framework minerals (modified Adams et al. (1984)).

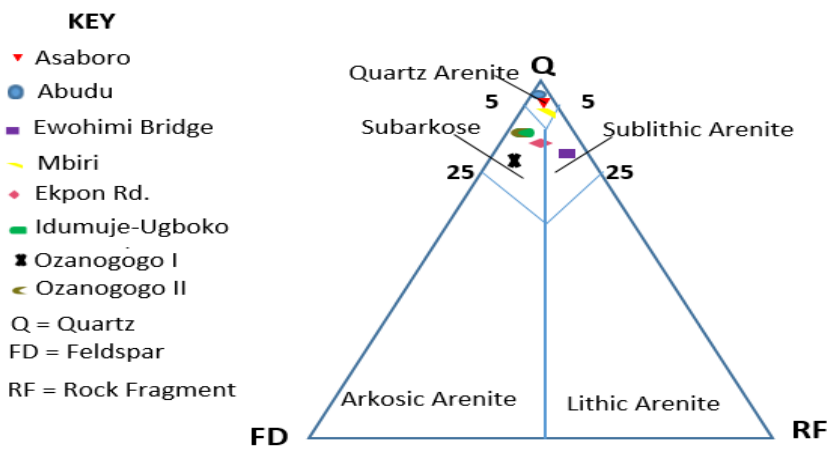

Figure 4. Framework classification of minerals (modified Dott (1964)).

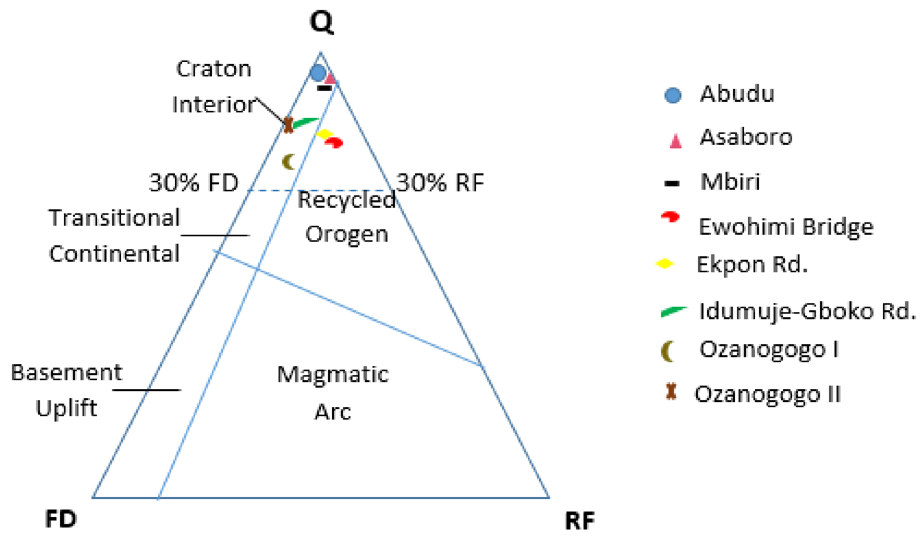

Figure 5. Ternary plot of framework model for sediments of the area of the study Strudy (modified after Dott, 1964 and Adams et al., 1984).

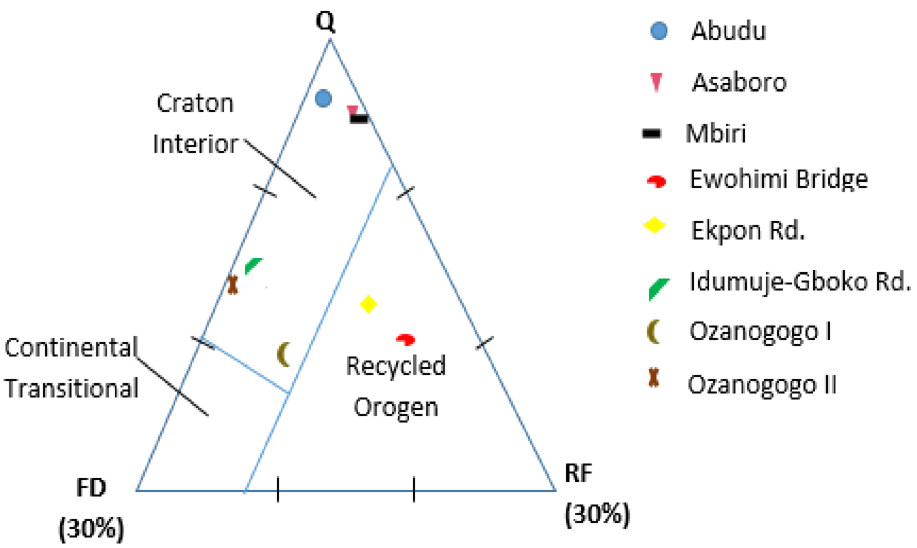

Figure 6. QFR Classification of provenance the outcropping sediments of the area of the study Study (modified after Osae et al., 2006).

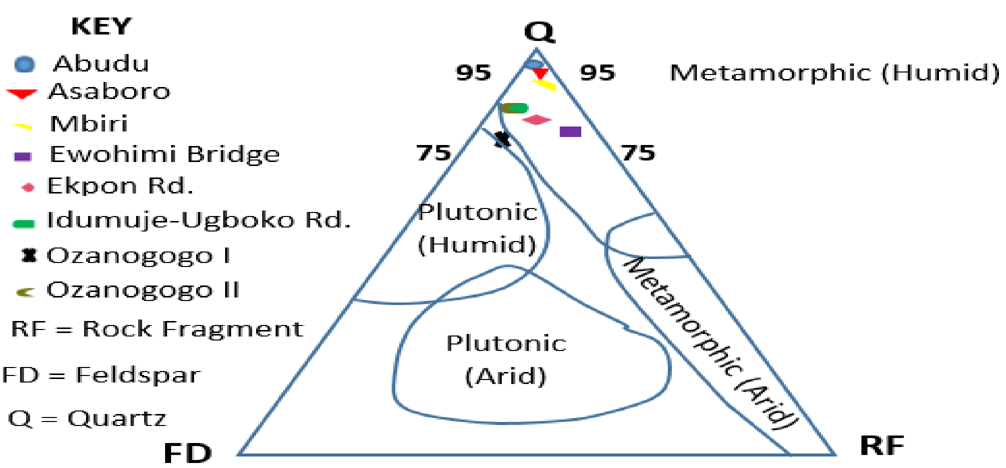

Figure 7. QFR Ternary plot as a function of paleoclimate (modified after Suttner et al. (1981)).

from their source before deposition occurred. This interpretation is also supported by the sub-rounded morphology of some of the quartz grains. The sub-roundness must have largely resulted from the abrasion of the grains in course of transportation. The sediments of the study area must have also undergone intense weathering and/or erosion. High quartz and low feldspar proportions in sediments and sub-rounded to rounded grain morphology have been reported to be indicators of high weathering, erosion and/or long distance transport of sediments (Osae et al., 2006).

Feldspar is chemically unstable and easily weathers under surficial conditions. The inference that the sediments are allogenic is further supported by the sub-rounded morphology of most of the quartz observed under thin section. Also, sedimentation in the study area occurred in a humid condition (Figure 8) which must have influenced the high chemical weathering of the sediments. The sediments were assigned craton interior to recycled orogen provenance based on ternary plot of the framework minerals modified from Dickinson et al. (1983).

Osae et al. (2006) and Noori and Rais (2014) pointed out that plot in this field (Figures 5, 6 and 7), indicates sediments derived from relatively low-lying granitic and gneissic sources supplemented by recycled sands from associated platform or passive margin basins. The sediments were therefore, interpreted to have originated from the Oban Massif and the Anambra Basin and/or the Lower Benue Trough.

CONCLUSIONS

The Coastal Plain Sands at Abudu and environs are medium- to coarse-grained, moderate to poorly sorted; sub-angular to sub-rounded. The sediments range from sub-arkose to quartz arenites and have undergone long distance transportation and/or intense chemical weathering. The sediments are sub-mature to super-mature and were deposited in fluvial paleodepositional environments. A craton interior tectonic setting with metamorphic humid climatic condition was interpreted for the sediments. The sediments of the study area derived from the granodiorites and gneissic rocks of the Oban Massif with perhaps, contributions from the adjoining Anambra Basin. The findings of this study are in agreement with those of some previous workers (Onyeagocha, 1978; Ogala et al., 2010; Nwajide, 2013.)

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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