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Provenance and Depositional Environment of Sediments of the Awi Formation, Calabar Flank, Southeastern Nigeria

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Abstract:

The Awi Formation is a significant ancient deposit of fluvial origin and provides a comprehensive record of the geomorphologic and sediment history that occurred during their deposition. Five (5) sediment samples and four hundred (400) pebbles were collected from the Awi Formation for heavy mineral and pebble morphometric analysis respectively in order to determine their provenance and depositional environment. A total of six hundred and seven (607) non-opaque heavy mineral grains were counted and their properties were studied. The dominant heavy mineral grains in the study area based on the analyzed sample include: tourmaline (34.7%), zircon (21.9%) and rutile (21.3%). The Zircon Tourmaline Rutile (ZTR) index of the study area was calculated and ranged from 45% to 85%. This implies that the sediments of the Awi Formation ranged from mineralogically mature – mineralogically immature sediments. Most of the heavy mineral grains (tourmaline and zircon) are sub-rounded while others (staurolite, garnet, kyanite and apatite) are angular. This implies that sediments of the Awi Formation have multiple sources. The heavy mineral grains studied are tourmaline (34.7%), zircon (21.9%), rutile (21.3%), staurolite (9.8%), garnet (7.3%), kyanite (2.9%) and apatite

(2.1%). These heavy mineral assemblages indicate that the igneous and metamorphic rocks of the Nigerian basement complex (particularly the Oban Massif) are the source of these sediments. The flatness ratio (FR) for the pebbles has a range of 0.28-1.44 while the mean elongation ratio (ER) evaluated for the pebbles of Awi Formation falls within 0.39 - 0.83. The forms of the pebbles in the studied area are Compact (C), compact bladed (CB), Bladed (B) and compact elongate (CE) which indicate a fluvial setting with little beach influence. The average roundness value of the pebbles from the study area is 57.6 % with a range of 38.2% - 73.3%. This further confirms the beach influence on the environment. Most of the sphericity values for the pebbles in the study area are greater than 0.66 and therefore indicative of a fluviatile origin with minor beach influence. The bivariate plot of sphericity versus oblate-prolate index indicates that the pebbles were dominantly from a river environment with little beach influence. Bivariate plot of elongation versus roundness indicates littoral influence on the pebbles while bivariate plot of maximum projection sphericity versus oblate-prolate index is suggestive of a dominant river environment with minor beach influence. The deductions from the bivariate plots of pebbles of the Awi Formation are a pointer to the fact that the Awi Formation was deposited by fluvial processes with little littoral influence.

Key words: Awi Formation, Calabar Flank, Depositional environment, Fluvial, Heavy mineral, Littoral, Pebble morphometry, Provenance.

1.0 INTRODUCTION

The geology of the Calabar Flank is characterized by stratigraphic successions of mostly Cretaceous age. The basal arkosic sandstones and conglomerates with limestones in the middle and a capping alternating calcerous sandstones, limestones and shale was assigned to a sequence called the Odukpani Formation (Reyment, 1965). Fayose (1978) subdivided the Odukpani Formation into two distinct formations based on their tectonism and lithologic identity. Adeleye and Fayose (1978) went on and proposed the name "Awi Formation" for the basal arkosic sandstones and conglomerates of the Odukpani Formation of Reyment (1965) and delineated the type section but retained the Odukpani Formation for the rest of the succession. Adeleye and Fayose (1978) gave a detailed description of the Awi Formation as fluvio-deltaic, partly fossilferous, folded and cyclothemic comprising of cross bedded sandstones, siltstone, mudstones, claystone, conglomerates and shales. A recent study by Ekhalialu *et al*. (2016) based on outcrop sections described the Awi Formation as a vertically stacked sedimentary sequence that displays a fining upwards repetitive cyclic pattern of sedimentation with clasts of varying roundness and size. The Awi Formation is about 50m thick (Nyong, 1995) and consists dominantly of conglomerate and sandstone lithologic units with minor mudstone, shales and some carbonaceous materials in a cyclic fining upward unit (Nyong, 1995; Umeji, 2006; Ekhalialu et al., 2016). The Awi Formation sits uncomfortably on the Oban Massif basement complex. Nton (1999) and Ekhalialu *et al*. (2016) encountered the sharp contact between the Awi Formation and the gneiss of the Oban Massif.

The study area (figure 1) is located along Okoyong Usang Abasi -Njagachang road and Calabar – Ikom road (Km 12) and constitute parts of the Awi Formation.

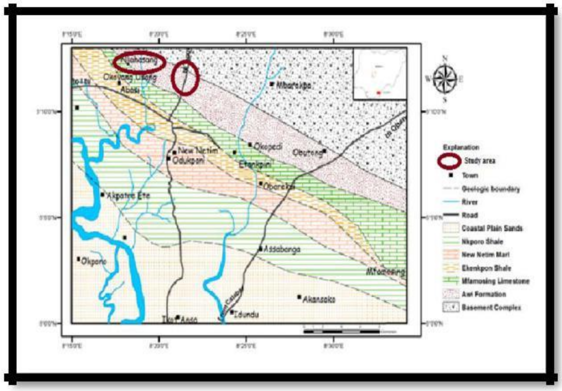

Figure 1. Geology map of the Calabar Flank showing the study area (modified from Nyong, 1995)

2. GEOLOGIC SETTING AND STRATIGRAPHY OF THE CALABAR FLANK

Earliest studies on the geology of the Calabar Flank was done by Reyment (1965) and Dessauvagie (1965) who attempted to establish the biostratigraphic information of the basin, although Reyment (1965) treated it as part to be part of the Benue Trough. Murat (1972) explained that the Calabar Flank underwent a somewhat different phase of tectonism and stratigraphic development in comparison to adjacent Anambra basin and lower Benue Trough sedimentary basin and therefore classified it as a distinct basin. The study of Nyong and Ramanathan (1985) defined the location of the Calabar Flank as the easternmost part of the Gulf of Guinea which forms part of Nigerian continental margin between the Cameroon volcanic trend to the east, the Ikpe platform to the west, the Oban Massif and Calabar hinge line to the North and South respectively (figure 2).The Calabar Flank is a diminutive Nigerian sedimentary basin; a fringe which forms on the edge of the Gulf of Guinea. The major difference between the Calabar Flank and the southern Benue Trough resulted from the initial rifting of southern Nigeria margin which led to the formation of two principal sets of faults, the NE-SW and the NW-SE trending sets of faults which characterize the Benue Trough and the Calabar Flank respectively (Murat,1972). Murat (1972) defined the tectonic components of the Calabar Flank to include the Ikang Trough and the Ituk High which were a mobile depression and stable mobile submarine ridge respectively. Nyong and Ramanathan (1985) have shown that the Calabar Flank is underlain by horsts and graben structures (figure 3). Sedimentation started in the Calabar Flank with the deposition of fluvio-deltaic clastics (the Awi Sandstone) of probably Aptain age on the Precambrian crystalline basement complex, the Oban Massif. This was followed by the first marine transgression in the Mid Albian which accounted for the deposition of the Mfamosing Limestone, particularly on the horst and relatively stable platform areas and their flanks (Nyong and Ramanathan, 1985).

The Mfamosing Limestone is overlain by a thick sequence of black to grey shale unit, the Ekenkpon Formation (Petters and Reijers, 1987). The formation is characterized by minor intercalation of marls; calcerous mudstone and oysters beds. This shale unit was deposited during the Late Cenomanian-Turonian times (Petters and Reijers, 1987). The results of Ukpong and Ekhalialu (2015) based on foraminifera and palynomorphs further confirms the Cenomanian – Turonian age of the Ekenkpon Shale. The Ekenkpon Shale is overlain by a thick marl unit, the New Netim Marl (Petters *et al.,* 1995). This unit is nodular and shaly at the base and is interbedded with thin layers of shale in the upper section (Petters *et al.,* 1995). Foraminifera suggest early Coniacian age for this marl unit (Nyong and Ramanathan 1985). The New Netim Marl is unconformably overlain by carbonaceous dark grey shale, the Nkporo Formation (Reyment, 1965). This shale unit was deposited during the Late Campanian-Maastrictian times and it caps the Cretaceous sequence in the Calabar

Flank (Petters *et al.,* 1995). The Nkporo Shale sequence is overlain by a pebbly sandstone unit of the Tertiary Benin Formation.

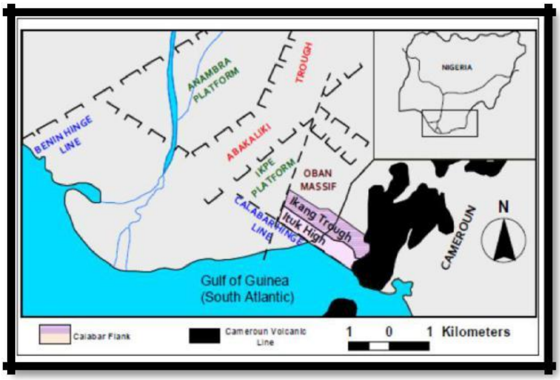

Figure 2: Structural elements of the Calabar Flank and adjacent areas (after Nyong and Ramanathan, 1985)

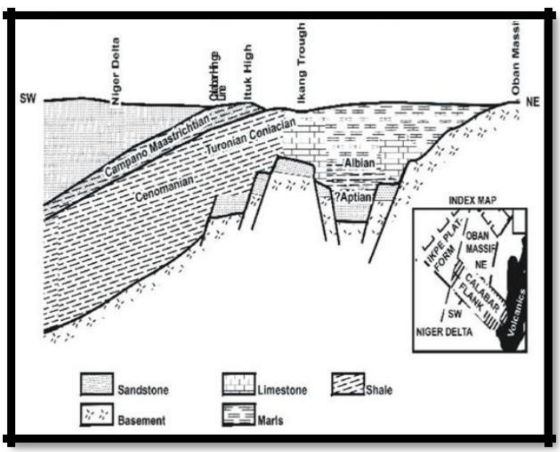

Figure 3. Structural elements of the Calabar Flank (Nyong and Ramanathan, 1985)

3. METHODOLOGY

The pebble samples used for this study were collected at the basal unit of the Awi Formation. The sample locations are found along Okoyong Usang Abasi -Njagachang road and Calabar – Ikom road (Km 12). Nton (1999), Okon (2015) and Ekhalialu *et al.* (2016) carried out a detailed description of the lithologic units of the Awi Formation. The pebble morphometric method of Sneed and Folk (1958) adopted by Dobkins and Folk (1970), Sames (1966), Luttig (1962), Nwajide and Hoque (1982) were used in this study. Precautions were taken during the collection of the pebbles as suggested by Sames (1966). A total of four hundred (400) unbroken quartz pebbles were collected from the basal conglomerate of the Awi Formation. The pebbles were grouped into forty (40) batches and measurements of the three mutually perpendicular diameters (long axis, L; intermediate axis, I; and short axis, S) of each pebble using the vernier caliper were done. The results from the three mutually perpendicular diameters were tabulated and the following formulae were used:

- Coefficient of Flatness, S/L (Stratten, 1974; Els,1988).
- Elongation Ratio, I/L (Sames, 1966;Luttig,1962).
- Maximum Projection Sphericity $(S_2/LI)_{1/3}$ (Sneed and Folk, 1958)
- Form, (L – I / L – S) (Sneed and Folk, 1958).
- Triangular Sphericity Form Diagram of Sneed and Folk (1958) will be used to determine the shapes.
- The roundness of each pebble was estimated using Sames (1966) Pebble Image Set.

The Awi Formation was sampled at two (2) locations (A and B). Location A is situated along Okoyong Usang Abasi - Njagachang road while Location B is situated along Calabar – Ikom road (Km 12). Sample one (1), two (2) and three (3) were collected from location A (Okoyong Usang Abasi -Njagachang road) while sample four (4) and five (5) were collected from location B (Km 12, Calabar – Ikom road). Sample collection was carried out by digging two (2) feet deep trenches on different stratigraphic intervals in locations A and B.

The five (5) selected samples for the analysis were disaggregated separately and all plant remains were removed. 50g of sediment was taken from each of the five (5) samples. This was subjected to washing with clean water, until the water runs clear. The heavy mineral separation was carried out using the very fine sand fraction (0.125-0.063 mm) which is known to contain the bulk of the heavy minerals. The samples were washed to remove soluble salts and treated by boiling with diluted HCl (10%) to remove carbonates and then dried. The heavy minerals were separated from each dried sample using bromoform based on the standard laboratory techniques of Lewis and McConchie (1994). The heavy mineral grains were mounted in Canada balsam for detailed microscopic examination. The description and identification of the heavy mineral grains were based on the work of Mange and Maurer (1992). The counting of the heavy mineral grains was done by several horizontal runs at about equal distances apart to ensure that the entire slide was covered.

4. RESULT AND DISCUSSION

4.1 Heavy mineral analysis

The high density accessory mineral (heavy mineral / heavies) found in siliciclastic sediments are very important in determining the provenance and reconstruction of the source areas of sediments. The result of the heavy mineral analysis from sediments of the Awi Formation is presented in Table 2. The results show dominance of some ultrastable grains (zircon, tourmaline and rutile) and less stable grains (kyanite, garnet) with few less stable grains (staurolite, apatite). Okon (2015) and Nton (1999) also reported similar heavy mineral assemblages from the Awi Formation. The non-opaque minerals were counted using point counting techniques. Figure 4 shows the distribution of these minerals. Transparent heavies constituted 100% of the recovered heavy minerals. The percentage of individual transparent mineral varied from one sample to another from different areas. Most of the heavy mineral grains are rounded (tourmaline and zircon) while others are angular (staurolite, garnet, kyanite and apatite). This implies that the sediments of the Awi Formation have multiple sources (Folk, 1980). The heavy mineral grains (according to their abundance) are tourmaline (34.7%), zircon (21.9%), rutile (21.3%), staurolite (9.8%), garnet (7.3%), kyanite (2.9%) and apatite (2.1%). These heavy mineral assemblages indicate that sediments of the Awi Formation were sourced from igneous and metamorphic rocks of the Nigerian basement complex (particularly the Oban Massif). This conforms to the study of Boggs (2007), Pettijohn (1975) and Okon (2015). The Zircon Tourmaline Rutile (ZTR) index of the study area was calculated and it ranged from 45% to 85% among the samples analyzed. This implies that the sediments of Awi Formation range from mineralogical mature – mineralogical immature sediments (Hoque and Ezepue, 1977). Folk (1980) noted that the presence of zircon, rutile and tourmaline may indicate prolonged abrasion and/or chemical attack on the sediments. It could also indicate that the minerals were being reworked from older sediments. Most of the heavy minerals retain their original crystal habit indicating a short distance of transportation while others are distorted indicating long distance of travel from source (Folk, 1980). The results of the analyzed samples show variation in the percentage of the heavy mineral grains counts. This variation may be attributed to local transport processes and selective deposition which probably led to the accumulation of mostly dense mineral species in the sediment. The variation in heavy mineral percentage could also be due to destruction of less dense transparent mineral species by erosion and transportation processes while the loss of heavy minerals (zircon, apatite, garnet, kyanite, staurolite) may be attributed to interstratal dissolution under the influence of low temperature acidic groundwater (Friis, 1976; Morton, 1984; Morton, 1986).

Table 1. Distribution of heavy mineral grains in the sediment of the Awi Formation

S/N	Minerals	S1 (%)	S2 (%)	S3 (%)	S4 (%)	S5 (%)
1	Zircon	-	37	35	-	33
2	Tourmaline	35	29	22	48	32
3	Rutile	10	18	18	37	19
4	Staurolite	33	-	-	11	2
5	Kyanite	10	-	4	-	-
6	Garnet	7	12	11	5	-
7	Apatite	-	4	-	-	6
8	Others	5	-	10	9	8
9	Total	100	100	100	100	100
10	ZTR index (%)	45	84	75	85	84

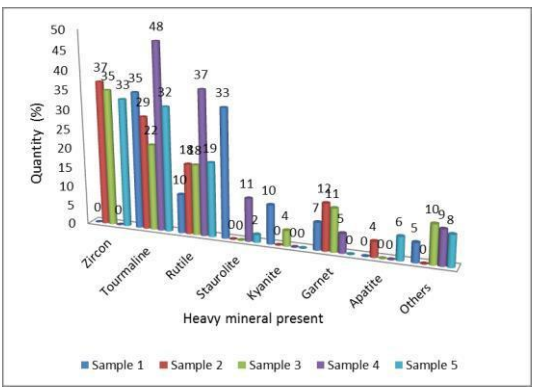

Figure 4. Percentage distribution of non-opaque heavy minerals in the Awi Formation

4.2 Pebble morphometric analysis

One of the methods of determining and understanding the paleo-environment of deposition and depositional processes is the use of pebble morphometric analysis. Pebble shape measurements (long, short, intermediate) are valuable tools for understanding the depositional processes and assessing the conditions that lead to the deposition of sediments. Studies on the demonstration and reliability of pebble morphometric analysis as a paleoenvironmental indicator is well documented in literature. The pebble morphometric analysis results of the study are presented in Table 2. From the results (table 2), the flatness ratio (FR) for the pebbles has a range of 0.28-1.44. The mean elongation ratio (ER) evaluated for the pebbles of Awi Formation falls within 0.39 - 0.83. Dobkins and Folk (1970) identified different forms of Sneed and Folk (1958) that are diagnostic of certain environments. The presence of compact (C), compact bladed (CB), compact elongate (CE) and elongate (E) pebbles are indicative of fluvial depositional environments, while platy (P), bladed (B), very bladed (VB) and very platy (VP) are more common in beach environments. The pebble forms common in the study area are Compact (C), compact bladed (CB) Bladed (B) and compact elongate (CE) (Table 2 and figure 5) which indicate a fluvial setting for the pebbles with little beach influence.

As noted by Sneed and Folk (1958), pebble roundness increased downstream from river to beaches. Roundness of less than 35% typifies fluvial environment while roundness of greater than 45% characterizes littoral environments (Sames, 1966). The average roundness value of the pebbles from the Awi Formation is 57.6 % with a range of 38.20% - 73.3% indicating a beach environment. The sphericity (M.P.S.I) values for most of pebbles are above the 0.66 sphericity line that separates beach and river pebbles. Lower sphericity values are typical of beach pebbles while higher sphericity values indicate fluvial setting (Dobkins and Folk, 1970). Most of the sphericity values for the pebbles in the study area are greater than the 0.66 line and therefore indicative of a likely fluviatile origin with minor beach influence. The bivariate plot of sphericity versus oblate-prolate index indicates that the pebbles were dominantly from a river environment with little beach influence (figure 6). Bivariate plot of elongation versus roundness indicates littoral influence on the pebbles (figure 7)**.** Bivariate plot of maximum projection sphericity versus oblate-prolate index (figure 8) is suggestive of a dominant river influence with minor beach influence. The sediments of the Awi Formation can be described to be dominantly deposited by fluvial processes with little littoral influence. Pebble morphometry results from the present study agree with the findings of Ekhalialu *et al*. (2016), Itam and Inyang (2015), Okon (2015) and Nton (1999).

Table 2. Results of the pebble morphometric measurements from the Awi Formation.

S/N	L	I	S	S/L	I/L	L-I/L-S	MPSI	OPI	SPHERICITY	ROUNDNESS	FORM NAME
1.	3.03	1.47	2.25	0.74	0.49	2.00	1.04	11.1	0.71	65.0	C
2.	2.83	1.38	2.18	0.77	0.49	2.23	1.07	13.3	0.72	60.0	C
3.	3.10	1.20	1.70	0.55	0.39	1.36	0.93	4.73	0.59	62.0	CB
4.	2.37	1.01	1.70	0.71	0.43	2.03	1.08	10.86	0.64	73.3	C
5.	2.55	1.52	2.01	0.79	0.60	1.91	1.01	4.03	0.84	67.0	C
6.	2.80	1.38	1.95	0.70	0.49	1.67	0.99	8.19	0.69	54.5	C
7.	2.56	1.34	1.90	1.44	0.52	1.85	1.05	19.44	0.69	52.5	C
8.	3.73	2.63	1.65	0.44	0.71	0.53	0.65	0.68	0.68	53.5	B
9.	3.0	1.32	2.14	0.71	0.44	2.00	1.05	10.65	0.68	51.0	C
10.	3.28	1.51	2.23	0.68	0.46	1.7	1.00	8.16	0.68	48.5	CE
11.	3.19	1.50	2.48	0.78	0.47	2.38	1.09	24.10	0.71	49.5	C
12.	3.57	2.67	1.66	0.46	0.71	0.47	0.66	24	0.70	62.9	B
13.	2.85	1.38	2.17	0.76	0.48	2.16	1.20	21.84	0.71	58.0	C
14.	3.52	2.57	1.51	0.43	0.73	0.47	0.63	28	0.68	64.1	B
15.	3.03	1.47	2.25	0.74	0.49	2.00	1.04	0.69	0.71	65	C
16.	2.96	2.28	1.58	0.53	0.77	0.49	0.72	-0.18	0.74	55	CB
17.	2.78	2.25	1.3	0.47	0.81	0.36	0.67	-2.97	0.72	52	B
18.	3.39	2.61	1.94	0.57	0.77	0.54	0.75	0.70	0.76	70.2	CB
19.	3.26	2.08	1.84	0.56	0.64	0.83	0.79	5.89	0.71	65	CE
20.	2.80	2.0	1.54	0.55	0.71	0.63	0.75	1.81	0.73	60.5	CE
21.	2.83	2.37	1.74	0.61	0.83	0.42	0.77	-1.3	0.80	55.80	CB
22.	3.10	1.98	0.8	0.28	0.64	0.49	0.47	-0.36	0.55	50.00	VB
23.	2.68	2.12	1.42	0.53	0.79	0.44	0.71	-1.13	0.74	69.00	CB
24.	3.04	2.42	1.72	0.57	0.8	0.47	0.74	-0.53	0.77	49.00	CB
25.	2.80	1.80	1.10	0.39	0.64	0.59	0.62	2.30	0.63	53.20	B
26.	3.04	2.45	1.55	0.51	0.81	0.40	0.68	-1.96	0.74	54.90	CB
27.	2.78	1.98	1.24	0.45	0.71	0.56	0.65	1.33	0.68	55.60	B
28.	2.60	2.00	0.9	0.35	0.77	0.35	0.54	-4.28	0.26	62.00	B
29.	3.25	2.44	1.7	0.52	0.75	0.52	0.71	0.38	0.73	55.5	CB
30.	3.1	2.23	1.50	0.48	0.73	0.54	0.33	0.83	0.70	56.00	VB
31.	2.52	1.89	1.20	0.48	0.75	0.56	0.67	1.25	0.70	70.80	B
32.	2.63	1.98	1.4	0.53	0.75	0.53	0.75	0.57	0.74	38.80	CB
33.	2.90	2.11	1.32	0.46	0.73	0.50	0.68	0	0.69	60.00	CB
34.	2.78	2.1	1.32	0.47	0.76	0.47	0.67	-0.63	0.71	68.00	B
35.	2.81	2.25	1.57	0.56	0.80	0.45	0.73	-0.89	0.77	38.20	CB
36.	2.70	1.60	1.34	0.50	0.80	0.80	0.42	6	0.66	58.00	E
37.	2.98	2.13	1.33	0.45	0.71	0.52	0.65	0.44	0.68	61.00	B
38.	2.61	2.1	1.4	0.54	0.80	0.42	0.71	-1.48	0.65	46.22	CB
39.	2.45	2.12	1.62	0.66	0.87	0.40	0.80	-1.52	0.82	53.00	CB
40.	2.50	1.90	1.22	0.49	0.76	0.47	0.31	-0.61	0.71	58.22	VB

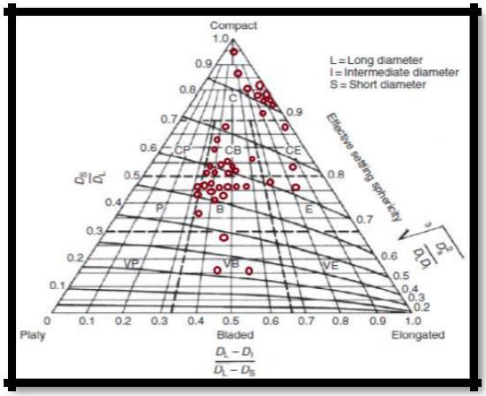

Figure 5: Sphericity – form diagram

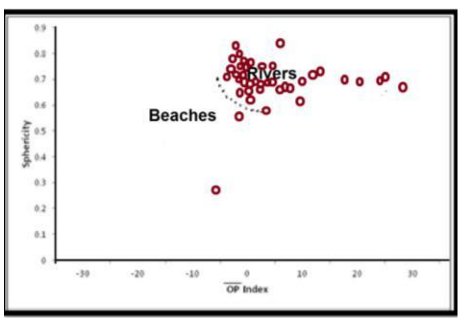

Figure 6: Bivariate plot of sphericity vs. oblate-prolate index

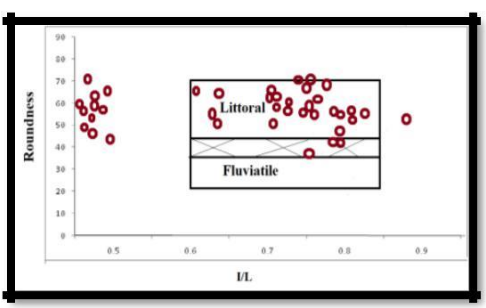

Figure 7: Bivariate plot of elongation vs. roundness

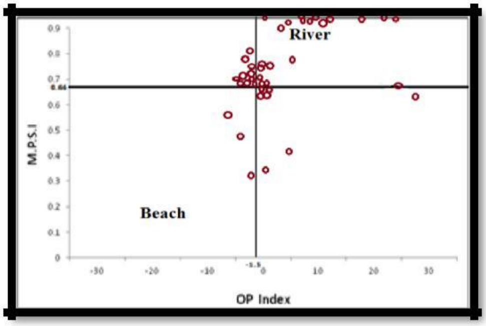

Figure 8: Bivariate plot of maximum projection sphericity vs. oblate-prolate index.

5.0 SUMMARY AND CONCLUSIONS

This present study demonstrates the use of heavy mineral analysis as a tool in provenance studies and the application of pebble morphometric analysis in the determination of depositional environments of sediments. The study area is characterized by fluvial sediments containing fine–coarse grained sands, in close association with conglomerates, sandstone, shales, and mudstones. The distribution patterns of non-opaque heavy mineral assemblages and heavy mineral indices of the Awi Formation were studied in detail. The non-opaque heavy mineral grains in the investigated fluvial sediments include tourmaline, zircon, rutile, staurolite, garnet, kyanite and apatite. The mineralogical assemblage of the sediments in the Awi Formation indicates their derivation from a multiple source and therefore points to the igneous and metamorphic rocks of the Nigerian Basement complex, particularly the Oban Massif. The pebble morphometric analysis of pebble samples from the Awi Formation indicate that the sediments were dominantly deposited by fluvial processes with little littoral influence.

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