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Petrological Characterisitics and Paleodepositional Environment of the Sandstones of the Ameki Group (Eocene) In Bende and Isimkpu Areas, Southeastern Nigeria

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Abstract: *Petrological characteristics of sandstones outcropping in Bende and Isimkpu areas was carried out using sieve analysis and pebble morphometric studies in determination of the paleodepositional environment for Sandstone facies of the Ameki Group. Lithostratigraphic studies show that the area is underlain by sandstones, calcareous sandstone, shales, mudstones and clays. This has been organized into: Unit A: Idima junction shale; B: Bende sandstone; C: Onuinyang calcareous siltstone and D: Isimkpu sandstone, from oldest to youngest. Representative sandstone samples were collected from outcrops widely distributed in the area. Results show that the sandstones are fine to coarse grained and the pebbles are rounded to sub-rounded and dominantly bladed to elongate. Computed percentages indicate the sandstones are dominantly well sorted, negatively skewed and extremely leptokurtic. Mean values for the flatness index, elongation and oblate-prolate index (OPI) are 0.47, 0.70 and 2.37 respectively. The synthesis and integration of these values indicated fluviatile with subordinate littoral/shallow marine setting for sandstones of Ameki Formation in the study area.*
Keywords: *Paleodepositional environment, sandstones, Ameki Formation, pebble morphometry.*

I. Introduction

The Bende- Ameki Formation as first named by Wilson and Bain (1928) outcrops in a broad belt running southeast through Onitsha, Awka and Orlu Divisions (Simpson, 1954). The Ameki Formation (Reyment, 1965) consists of Nanka Sand, Nsugbe and Ameki Sands (Nwajide, 1979) as lateral equivalents. The Ameki Formation was classified by Simpson (1955) into two lithological groups viz: the lower part which consists of fine to coarse grain sandstones and intercalations of calcareous shales and thin shelly limestone and upper part which comprise coarse, cross-bedded sandstone with bands of fine, grey-green sandstone and sandy fossiliferous clays. The age of the formation has been considered to be either early Eocene (Reyment, 1965) or early middle Eocene (Berggren, 1960; Adegoke, 1969). The depositional environment of the Ameki Formation has been interpreted based on the faunal content. White (1926) interpreted an estuarine environment because of the presence of the fish species of known estuarine affinity. Adegoke who preferred open marine depositional system suggested that the fish may probably have been washed into the Ameki sea from inland waters. Nwajide (1979) and Arua (1986) suggested environment that ranged from nearshore to intertidal and subtidal zones.

The sandstones of the study area belong to the Ameki Formation (Eocene) (Reyment, 1965) which underlies the Imo shale (Paleocene) which conformably overlies the Nsukka Formation. The Ameki Formation consists predominantly of alternating shales, clayey sandstone and fine – grained fossiliferous sandstone with thin limestone bands. The age has been considered to be early – middle Eocene (Bergren, 1960; Reyment, 1965; Adegoke, 1969; Arua, 1986). The depositional environment has been interpreted variously as estuarine (White, 1922); open marine (Adegoke, 1969); nearshore to interidal/subtidal zones of the shelf environment (Nwajide, 1979; Arua, 1986) and marine (Fayose and Ola, 1990). The position of Ameki Formation relative to other formations in southeastern Nigeria is shown in Figure 1.

Textural analysis is an important tool for discriminating and interpreting paleodepositional environment. The purpose of this study is to reconstruct the paleodepositional environment of the Ameki Group by studying the grain size distribution of the sandstone lithofacies and also analyze the shapes and forms of vein quartz pebbles in the sandstone lithofacies with diameters between 5.00 mm – 2.25 mm, and to use the results to evaluate the paleodepositional environment of the Ameki Group.

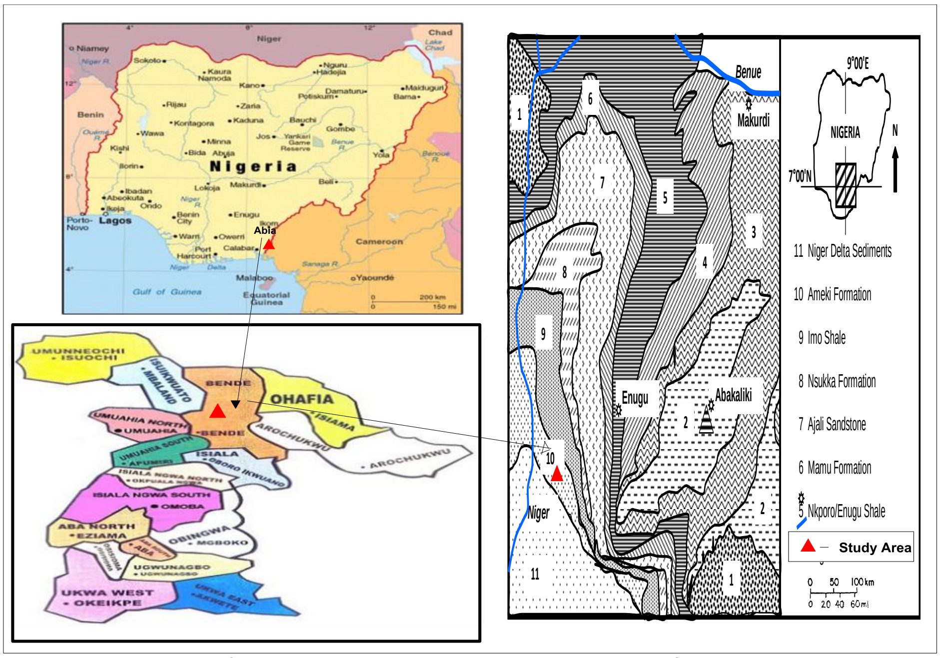

Figure 1: Geological map of southeastern Nigeria showing position of Ameki Group relative to other formations.

II. Method Of Study

Sieve analysis was carried out on twelve (12) representation sandstone samples of the Ameki Formation and pebble morphometric studies were conducted on thirteen (13) pebble batches, totaling a hundred and thirty pebbles collected from different sample locations of the Isimkpu Sandstone. The sandstones were disaggregrated without disturbing their original properties such as grain size, grain shape and roundness of grains. The fifity (50) grams of each sample was sieved for fifteen minutes using a set of Jurgens's and Endocott's laboratory sieve at ½ phi interval on a Fritsch sieve Ro tap shaker. The material retained was carefully weighed and recorded using a chemical balance. The cumulative weigh and other parameters were deduced. The arithmetic log probability graph was used in the plot of log / normal cumulative frequency curves of the grain size distribution. The percentile values were deduced graphically while other statistical parameters like mean, median, standard deviation (dispersion or sorting), skewness and kurtosis were calculated using folk and ward (1957) formulae. The unbroken pebbles were collected, washed and numbered for pebble morphometry. Their long (L), short (S) and intermediate (I) length were measured using vernier calipers. The roundness of each pebble was taken as the proportion of the convex parts of the pebble along its maximum projection perimeter and it was measured using the pebble image set of Krumbein (1974) and Sames (1966).

III. Results And Discussion

3.1 Lithostratigraphy/ Field Relationship

Walker (1984) defined facies as a body of rock showing lateral variations in the aspects of defined lithological characteristics. On the basis of this, and to achieve simplicity, objectivity, repeatability and comprehensiveness, four broad lithostratigraphic units have been recongnized and mapped. These have been designated as: Unit A: Idima junction shale; B: Bende sandstone: C: Onuinyang calcareous siltstone and D: Isimkpu sandstone, from oldest to youngest (see fig 2).

3.1.1 UNIT A: THE IDIMA JUNCTION SHALE

This lithologic unit consists of dominantly of sands and shales interbeds intercalated with brownish mudstones, calcareous snadstone, ferruginized sandstone and argillaceous clays. This unit is not exposed along Bende-Amaeka Abam road. The shales are dark in colour. The dark colour may be due to high content of organic or carbonaceous matter. The shale unit comprises of a thinly laminated part and sandy part, shows mottling. The sandy shale form a greater part of the shale units and consists of intercalations of calcareous sandstone, brownish mud stone and clays. The beds strikes NW-SE and dips about 7^{o}-8^{o}SW.

3.1.2 UNIT B: THE BENDE SANDSTONE

Well exposed outcrops of this unit were observed along Bende - Igbere road, Ndiekeugoh, Bende, along Bende - Amaeke Abam road, Ndiokoriekwu, Nkporo;Ubibia and Amaba. The unit consists dominantly of very fined-grained sandstone, which is whitish to yellowish in colour, except along Bende – Igbere road where they are fine to medium grained and ferruginized with ophiomorpha burrows. Some parts of the sandstone are highly calcitic especially along Bende road. The calcitic sandstones are very fossiliferous showing macrofossil of pelecypods, gastropods and echinoids. The beds dip generally at about 7^o -9^oSW and strikes in the NW-SE direction.

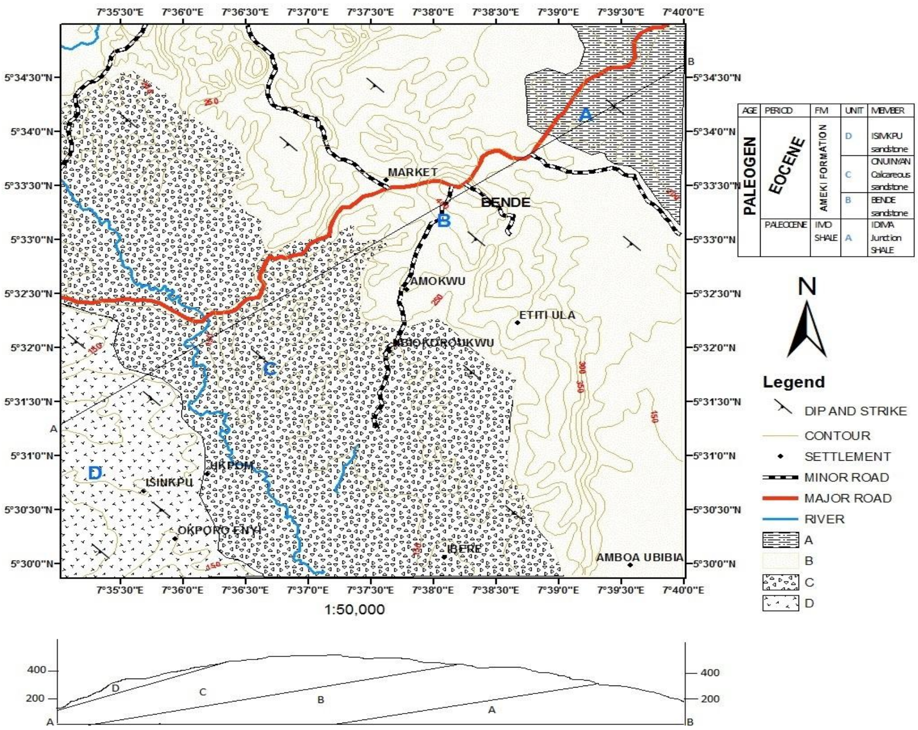

Fig. 2.0: Geologic map of Bende and Environs.

3.1.3 Unit C: Onuinyang Calcareous Siltstone

Well exposed outcrops of this unit were observed at River Inyang, and along Bende road, Onuinyang. This unit conformably overlay unit B. It is composed of fine grained calcareous siltstones, carbonaceous mudstones, grayish mottled clays and thin limestone. The unit is highly fossiliferous (over 50% fossil content).
The Calcareous siltstones are whitish in colour and very fine grained. It is interbedded with sandstones which are also very fine grained and yellowish in colour, with thin grayish mudstone which has impressions and fossils of bivalves as in the calcareous siltstones. The Calcareous siltstones is very calcitic and has calcium carbonate ($CaCo_3$) cement. The mudstone shows plant's remains and carbonaceous cement. The lime stone unit is thin (about 15ch-17cm). It is composed of well-crystallized calcite grains and shows impressions of bivalve fossils, the limestone is highly carbonaceous. The unit dip generally between 6^0-12^0SW and strikes a t NW- SE direction.

3.1.4 Unit D The Isimkpu Sandstone

The Isimkpu Sandstone conformably overlies the Onuinyang calcareous siltstone of unit C. This is the youngest lithofacie member of the area. This unit is well exposed at Isimkpu village. The unit is composed of ferruginized pebbly sandstone. Infact, the sandstone outcrops over the entire area of Isimkpu Aro and it is prominent at Ugwu Ajarata covering a distance of over 200 meters.

This pebbly sandstone forms the tops of the study area, suggesting that the entire sequence is upward coarsening. The top of this sandstone is very coarse grained. The colour of the sandstone is reddish due to the dissemination of hematite which may constitute the cement (pettijohn, 2000). The sandstone is moderately to well sorted with sub-angular to well rounded pebbles (conglomerates).

3.2 Petrology

3.2.1 Sieve Analysis:

All environments and processes may not affect the distribution of grains uniformly; hence it may become more useful to combine two or more parameters to differentiate the various environments. These parameters include:

Mean (X)

The mean is the overall grain size in a frequency distribution as influenced by sources of supply, depositional processes and environment (folk, 1974; Friedman, 1967), The mean indicates the average kinetic energy of the depositing agent. From the analysis, the mean size of the samples analyzed ranged from 1.22Φ 0-1.27Φ .about 30% of the sandstones are coarse grained, 60% are fine grained while 10% are medium grained.

Median

The median indicates the corresponding Φ50 mark of the cumulative curve. It disadvantage is that it is not affected by extremes of the curve, therefore, does not reflect the overall size of the samples. About 30% of the sandstones are coarse grained, 60% are fine grained while 10% are medium grained. The median indicates the corresponding Φ50 mark of the cumulative curve. It' disadvantage is that it is not affected by extremes of the curve, therefore, does not reflect the overall size of sediments and it is no a good indicator of environments (Folk, 1974). However, the median grainsize for the samples ranged from 1.22 Φ – 1.28 Φ.

Standard Deviation

Standard deviation describes the degree of spread of or uniformity of the grain particles. It is the degree of scatter about the mean (Folk and Ward, 1957). From the analysis, the standard deviation vary from 0.14 Φ – 44 Φ indicating very well sorted to well sorted; this is an indication of moderate energy of deposition. Such deposition is prominent in marine environment (Folk and Ward, 1957; Pettijohn, 2002). About 40% are very well sorted while 60% are well sorted.

Skewness (Sk Value)

This measures the asymmetry of the grainsize frequency distribution i.e. whether a curve has an asymmetrical tail to the on the left or right (Folk and Ward, 1957). The skewness of the samples ranged from 0.096Φ – 0.18Φ indicating negative skew to positive skew. About 60% are negatively low skewed, 20%, nearly symmetrical while 20% are positively skewed. This indicates a relatively low energy shallow marine environment of deposition (Friedman and Sanders, 1978).

Kurtosis (Kg Value)

Kurtosis measures the peakness of a grain size frequency distribution curve. This is not a very sensitive parameter for environmental analysis. However, the kurtosis value of the samples ranged from 1.09 Φ – 5.00 Φ indicating mesokurtic to extremely leptokurtic. About 60% are extremely leptokurtic, 20%, leptokurtic and 20% mesokurtic. Folk and Ward suggested that fluctuation is restricted within the central part of the average velocity for a greater time than normal.

Table 1: Summary Of Geological Significance Of The Parameters

PARAMETERS	EXHIBITED CHARACTERISTICS	ENVIRONMENTAL INDICATION
MEAN	Ranges from 1.22 Φ – 1.27 Φ with 30% coarse grain, 10% medium grain and 60% fine grain.	This indicates a shallow marine environment with gentle change in depositional kinetic energy (Pettijohn 2002).
MEDIAN	Ranges from 1.22 Φ – 1.28 Φ	Not a good indicator of environment (Folk, 1974).
STANDARD DEVIATION (DISPERSION)	Ranges from 0.14 Φ – 0.44 Φ with 40% very well sorted and 60% well sorted.	Indicates a shallow marine environment of deposition (Folk and Ward, 1957; Friedman and Sanders).
SKEWNESS (*SK VALUE*)	Ranges from 0.096 Φ – 0.18 Φ with 60% negatively skewed, 20% nearly symmetrical and 20% positively skewed.	Indicates shoreface to shallow marine environment (Friedman and Sanders, 1978).
KURTOSIS (KG VALUE)	Ranges from 1.09 Φ – 5.00 Φ with 60% extremely leptokurtic, 20% leptokurtic and 20% mesokurtic.	Not very sensitive in environment analysis. Excessively peaked (Folk and Ward, 1957).

3.2.2 Pebble Morphometry

Flatness Ratio

Flatness ratio is a measure of the ratio of the Short axis (S) to the Long axis (L) i.e. S/L. the average flatness ratio for the pebbles of the sandstone of the study area is 0.47 indicating a marine environment. Lutig (1962) developed a format for different flatness ratio for pebbles from different environments.

Elongation Ratio

This is a measure of the ratio of the Intermediate axis (I) to the Long axis (L) i.e. I/L. the measured elongation ratio of the pebbles ranges from 0.62 – 0.98 with a mean value of 0.70.

Maximum Projection Sphericity

Maximum projection sphericity is a measure of the equidimensionality of a pebble showing the approach of a sphere. Sneed and Folk (1958) method was used. It measures the maximum projection as cube root of the ratio between the square of the short axis (S) and the product of the long axis (L) and intermediate axis (I). Mathematically, $(S^2 / LI)^{1/3}$. This method is best because it reflects the behavior of the particles during transportation in a fluid medium (Sneed and Folk, 1958). The maximum projection sphericity values of the sandstones ranged between 0.61 – o.72 with a mean value of 0.67.

Form

This is a measure of the relationship between the three mutually perpendicular dimensions of pebble. The sphericity – from diagram of Sneed and Folk (1958) was used to determine the form name for each pebble. About 46% constitutes Bladed, 38% elongated while 15% were Compact elongate. The average form is Bladed.

Oblate-Prolate Index (Opi)

The OP index is a measure of how close the intermediate axis (I) of the pebble is to long axis (L) or the short axis (S). The ŌP index values of the Isimkpu pebbly sandstones ranges from 0.53 – 4.70 with a mean value of 2.37. There is only one negative value, this indicates how close the Intermediate axis (I) are to the Short axis (S).

Roundness

Roundness may be expressed as a ratio of the average radius of curvature of the several corners or edges to the radius of curvature of the maximum inscribed sphere (Pettijohn, 1975). Lutig also defined roundness as the percentage of convex parts along the exterior circumference of a particle or pebble. According to Pettijohn (1975), roundness is a poor indicator of environment because pebbles may be rounded after only a short distance of transport. The pebble of this sandstone unit ranges from 42% to 64% with mean value of 56%.

IV. Interpretation And Environmental Synthesis

Sames (1966) observed that the size and shape eventually acquired by pebbles are functions of both inherited and environmental factors. Blatt (1959) has shown that the original sphericity of a vein pebble is probably strongly influenced by relatively large scale stress phenomena such as joiting, faulting and ezfoliations; thus, the final sphericity depends on the mode and rigour of transport. However, the initial or inherited shape or form of the pebbles has a persistant effect on the final sphericity (Nwagidea nd Hoque, 1985; Swan, 1974 ;).

Though this analysis shows that these pebbles have been heavily modified with respect to sphericity, Lutig (1962) suggested that 55 – 65% roundness ranges is a feature of fluviatile pebbles while 70 95% ranges characterizes marine pebbles. Sames (1966) suggested a range of 45 – 90% for littoral pebbles. The roundness values of the sandstones are 54%. This may be suggestive of a littoral or fluvial setting. However, roundness is a poor indicator of depositional environment (Pettijohn, 1979, 2002). The mean elongation ratio of the pebbles is 0.70. Lutig (1962) classified pebbles with elongation ratio value of 0.65 – 0.75 as torrent type, which may have accumulated in flowing water or in brook and rivulets. The mean flatness ratio for the pebbles is 0.47. lutig (1962) and Sames (1966) assigned the flatness ratio between 0.40 – 0.50 for marine deposited pebbles. This confirms that the pebbles were deposited in a marine environment.

A plot of roundness versus elongation ratio following Sames (1966) shows that 100% of the pebbles plot in the littoral field (see fig. 3.0). The plot therefore indicates that the pebbles were deposited in a littoral environment. The significance of the sphericity values may be better appreciated by comparing them with those obtained by Dobkins and Folk (1970) in the sphericity plot. The 0.66 sphericity line, best separates beaches and rivers pebbles. The lower values are typical of beaches while the higher values suggest fluvial deposits (see fig 2.0). This suggests a dominantly littoral environment of deposition (Sames, 1966; Dobkins and Folk, 1970). The oblate – prolate (ŌP) index for the pebbles ranges from -0.53 to 4.70 with an average of 2.37. however, following Dobkins and Folk (1970), a plot of maximum projection sphericity versus ŌP index indicates a littoral environment of deposition.

Table 2: Summary Of Environmental Diagnosis Of Pebble Morphometry

MORPHOMETRIC PARAMETERS	CHARACTERISTICS EXHIBITED BY THE PEBBLES	ENVIRONMENTAL INDICATORS	REFERENCES
ROUNDNESS	Mean value 56% Ranges 42 – 65%	Not a very good environmental indicator (Pettijohn, 1975, 2002)	Low value of mean. Subangular to angular confirms that the source is near the site of deposition (Pettijohn, 1975).
FLATNESS RATIO (S/L)	Mean values 0.47 Range 0.42 – 0.52	Within the littoral range 0.4-0.5. indicates littoral environment	Range of 0.25 – 0.35 for fluvial and 0.4 – 0.5 for marine. (Lutig, 1962; Sames, 1966).
ELONGATION RATIO (I/L)	Mean values 0.70 Ranges 0.62 – 0.98	Indicates a strong littoral environment of deposition	Rang of 0.065 – 0.75 are indicative of torrent types, following water or brook and rivulet (Lutig, 1962; Dobkins and Folk, 1970).
PEBBLE FORM	Bladed 46%, Elongated 38%, Compact elongate 15%	Indicating littoral environment	Sneed and Folk (1955); Dobkins and Folk, (1970)
OBLATE – PROLATE Ōp Index	Mean value 2.37 Range -0.53 – 4.7	Littoral with 100% confirmation	Dobkins and Folk (1970)
Plot of Ōp Index Versus Sphericity.	Scattered and high plots observed in beach region.	Suggests fluvial environment	Dobkins and Folk (1970)
Plot of mean roundness versus mean elongation ratio.	Plot falls within the littoral region.	Strongly suggests environment.	Lutig, 1962; Sames, 1966

The sandstones of the second sedimentary cycle are less feldsparthic and high in quartz than the sandstones of the first sedimentary cycle which are highly felespartic (Hoque, 1976). This suggests that the sandstones may have been deposited during the second sedimentary cycle (Campanian - Eocene) and were derived from the granitic basement northeast and east of the study area.

Table 3: Average Values Of Parameters For Pebble Morphometric Analysis

S/N	**L(cm)**	**I(cm)**	**S(cm)**	**S/L**	**I/L**	**L-I/L-S**	**$(S^2/LI)^{1/3}$**	**ŌP INDEX**	**FORM NAME**	**ROUNDNESS %**
1	1.58	0.92	0.67	0.43	0.69	0.68	0.67	4.70	B	58
2	1.66	1.02	0.69	0.42	0.62	0.66	0.66	3.85	E	64
3	1.48	1.14	0.77	0.54	0.77	0.43	0.61	-0.53	B	42.5
4	1.49	1.02	0.69	0.47	0.69	0.59	0.68	1.95	B	60
5	1.28	0.91	0.66	0.47	0.98	0.47	0.64	0.98	B	48.5
6	1.56	0.94	0.67	0.44	0.61	0.68	0.68	4.30	E	60.0
7	1.52	1.03	0.75	0.52	0.70	0.60	0.71	2.34	CE	65
8	1.74	1.21	0.80	0.47	0.71	0.52	0.67	1.13	B	49
9	1.44	1.01	0.75	0.52	0.71	0.60	0.72	1.91	CE	61
10	1.80	1.12	0.78	0.45	0.63	0.63	0.67	3.66	E	52.5
11	1.54	1.06	0.68	0.44	0.69	0.53	0.65	1.11	B	55.5
12	1.60	1.05	0.74	0.47	0.66	0.60	0.69	2.58	E	52
13	1.35	0.91	0.65	0.49	0.67	0.62	0.70	2.83	E	54
MEAN VALUE	1.54	1.02	0.71	0.47	0.70	0.58	0.67	2.37	B	58

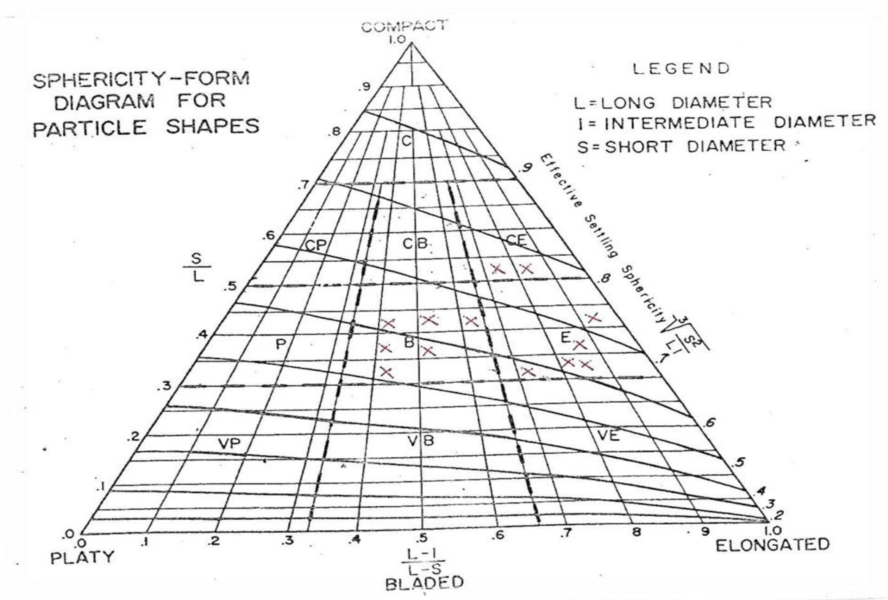

Fig 3: Sphericity – form diagram for the particle shapes

V. Conclusions

Grainsize analysis has been applied widely as a tool in the assessment of depositional environment. This study has been classified into two, viz: sieve analysis for grains between 0.62mm – 2mm, and pebble morphometric analysis for grains between 2mm – 64mm. each of these are studied with certain diagnostic parameters which are used to infer and recognize paleo – depositional processes and environment. With this method, the Folk and Ward (1957) and Dobkins and Folk (1970) mathematical formular was used to study the depositonal environment of the Bende and Isimkpu Sandstones respectively. The Bende Sandstone consists of medium to coarse grained ferruginized pebbly sandstone. Both correlatable with the Imo Shale of Paleocene age. This study indicates a paleoenviroment of deposition for these sandstones to vary from fluviatile to shallow marine/ littoral (shoreface) environment.

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