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Facies and Granulometric Analysis as Proxies for the Paleodepositional Environment of the Imo Formation, Southeastern Nigeria

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Abstract
Facies and granulometric analysis were carried out so as to decipher the paleodepositional environment of the Imo Formation in the study area. Results suggest the presence of eleven lithofacies, which are grouped into six lithofacies association, namely; swaly cross-bedded sandstone, laminated shale, sandstone / shale intercalations, bioturbated sandstone, fossiliferous shale and planar crossbedded sandstone facies associations. Results of pebble morphometric indices suggest a high energy (beach) environment for the sandstones of the Imo Formation. Pebble form indices for the formation have coefficient of flatness (F.R. %) =37.342 ± 8.916 (beach), elongation ratio (E.R.) = 0.743 ± 0.138 (torrents, brooks and rivulets), maximum projection sphericity index (M.P.S.I.) = 0.565 ± 0.090 (beach) and oblate - prolate index (OP index) = -2.313 ± 5.72 (beach). Scatter plots of coefficient of flatness versus sphericity and sphericity versus oblate-prolate index suggests that pebbles were formed in a shallow marine high energy (beach) environment. Bivariate plots of sand textural parameters such as graphic skewness versus graphic standard deviation and second moment skewness versus second moment standard deviation also confirm the high energy (beach) origin of sandstones. These results thus suggest a generalized spectrum of marine environments ranging from upper offshore through lower to upper shoreface to the foreshore for the Imo Formation
Keywords: Imo Formation, Lithofacies, Sphericity, Oblate – Prolate Index, Coefficient of Flatness

1. Introduction

The Imo Formation was first referred to as Imo River Shales by Tattam (1944) in an unpublished report of Shell-BP. Subsequent workers such as Groove (1951), Simpson (1954), and Reyment and Barber (1956) referred to the formation as Clay-Shales. Reyment (1965) described the formation as the Imo Shales with the type locality on outcrops along the Imo River near the Umuahia – Okigwe road in southeastern Nigeria. The Imo Formation is made up of three constituent sandstone members, Igbabu Sandstone, Ebenebe Sandstone and Umuna Sandstone (Reyment, 1965). The Imo Shale is generally regarded to have been deposited under marine conditions. Murat (1972) suggested that the Imo Formation is composed of shallow marine and deeper marine clastic facies. Arua (1980) on the basis of some fossil assemblages interpreted the depositional environments of the Imo Formation as marine and indicating deposition under tropical and littoral conditions. The depositional environment of the sandstone facies of the Imo Formation was previously interpreted as a delta front sand bar on the basis of lithology and ichnofossils (Anyanwu and Arua, 1990). Nwajide and Reijers (1996) suggested the depositional environments of the Imo Formation as reflecting shallow marine shelf conditions in which foreshore and shoreface sands are occasionally preserved. The Imo Formation has been regarded as an outcrop equivalent of the Akata Formation; the main hydrocarbon source rocks of the Niger Delta basin. It thus becomes important to study the paleodepositional environment of Imo Formation as exposed up dip in the northern fringes of the delta. The present study thus evaluates the paleodepositional environment of the Igbabu Sandstone facies of the Imo Formation using an integrated study of lithofacies analysis, ichnology, paleontology, pebble morphometric indices and sand textural analysis. The study area lies within the area bounded by latitudes $5^{o}25'$ N and $5^{o}37'$ N and longitudes $7^{o}37'$ E and $7^{o}48'$ E (Fig 1), including localities such as Ameke Abam, Idima Abam, Ndiwo and Ikporom and thus covers a surface area of about 404 km^2.

2. Geological Setting

The Paleocene Imo Formation is considered as the basal unit of the Tertiary Niger Delta Basin outcrops (Frankl and Cordry, 1966, Short and Stauble, 1967). Its subsurface equivalent is the prodelta Akata Shale

(Table 1). The Niger Delta originated as a result of the sea level rise during the Paleocene, which terminated the filling of the Anambra Basin. The Imo Formation was deposited during the transgression, while the Cainozoic Niger Delta developed as a result of the succeeding regression. In the study area the Imo Formation is underlain by the Nsukka Formation and overlain by the Ameki Formation (Table 2). Anyanwu and Arua (1990) described the Imo Formation as consisting of thick clayey shale, fine textured, dark grey to bluish grey with occasional admixture of clay ironstone and thin sandstone bands. Wilson (1925) opined that the formation becomes sandier upwards where it may consist of alternation of bands of sandstone and shale. A geological map of south-eastern Nigeria, showing the location of the study area is given in Fig. 2.

3. Methodology

A composite lithologic section of the Imo Formation logged systematically along Ikporom – Ndiwo road is shown in Fig. 3. The lithofacies and lithofacies associations was interpreted using textures, sedimentary structures, nature of bedding and bedding contacts and fossil contents. Paleocurrent measurements using cross-beds were also obtained. Pebbles were carefully and randomly selected from pebbly units for pebble morphometric analysis. The three axis of the pebbles; long (L), intermediate (I), and short (S) axes were measured using the venier calliper as described by Sneed and Folk (1958), Dobkins and Folk (1970) and Stratten (1974). The morphometric indices; Flatness ratio (FR), Elongation ratio (ER) and Oblate – Prolate index were evaluated using the formula of Lutig (1962) and Dobkins and Folk (1970) respectively. Maximum Projection Sphericity index (MPSI) and roundness index were obtained following Sneed and Folk (1958) and Krumbeins (1941) image chart respectively. Nwajide and Hoque (1982) and Odumodu and Ephraim (2007a & 2007b) utilized this method and obtained reliable results. Grain size analyses was done on representative sandstones and the various textural parameters were calculated using both graphic and moment measures as described by Folk and Ward (1957), Folk (1974), Friedman (1967 & 1979) and Moiola and Weiser (1968).

4. Results and Interpretation

4.1 Facies Analysis and Interpretation

The sedimentary facies of the Imo Formation were defined based on lithology, primary sedimentary structures and ichnology using Collinson (1969) and Walker (1992) model. Eleven recurring sedimentary facies (Table 3) were recognised, and subsequently are grouped to get five facies associations. Facies associations can be defined as groups of facies which are genetically related to one another and having some environmental significance (Collinson, 1969). Biogenic, sedimentary structures and fossils from the Imo Formation are shown in Fig. 4 and 5. The five facies associations in the Imo Formations are thus;

4.1.1 Swaly cross- bedded sandstone – Middle shoreface

The swaly cross-stratified sandstone facies association occurs in the basal part of the section studied along Ikporom – Ndiwo road (Loc. 1)(Fig. 3). It consists of bioturbated sandstone (F4B), swaly cross – stratified sandstone (F6B), and planar cross bedded sandstone (F5B). The bioturbated sandstone is fine grained and also planar crossbedded. The trace fossils present include *Ophiomorpha nodosa* and *Rosselia socialis*. Swaly cross-stratification is the most prominent sedimentary structure in the swaly cross-stratified sandstone. Other sedimentary structures include planar cross-beds and *Ophiomorpha nodosa* burrows. The planar cross-bedded sandstone consists of poorly sorted, medium grained sandstone with several sets of planar crossbeds.. The planar cross-beds have dip values that vary between 20° and 25° in a direction of 315°.

Interpretation

The swaly cross-stratification (scs) is interpreted to have been deposited in the middle shoreface using the MacEarchern and Pemberton (1992) model. Walter and Plint (1992) suggested that SCS represents prograding storm-dominated shorefaces, in which storm processes have overprinted all records of fair-weather sedimentation.

4.12 Laminated siltstone / shale – Offshore Transition

This facies association consists of parallel laminated dark-grey siltstone-shale heterolith (F2A), overlain by 2.5 m thick parallel laminated dark gray shale (F1A). The shale contains microforms of gastropods and bivalve shell fragments.

Interpretation

This lithofacies association is interpreted as an offshore transitional facies deposited between the offshore and the lower shoreface by storm generated oscillatory waves, below the fair-weather wave base but above the storm wave base (Dott and Bourgeois, 1982; Leckie and Walker, 1982; Duke, 1985; MacEarchern and Pemberton, 1992). The parallel laminated shale and the presence of marine fossils indicate deposition in a quiet water offshore environment. The thinly laminated siltstone-shale-sandstone heterolith suggests deposition in a storm influenced, fluctuating high and low energy conditions between the offshore and lower shoreface.

4.1.3 Interbedded sandstone and shale – Upper shoreface

This facies association consists of five units; bioturbated sandstone (F3B), wave ripple laminated sandstone (F1B), crossbedded sandstone (F7B), laminated shale (F1A) and pebbly sandstone (F9B). The bioturbated sandstone consists of well sorted fine grained sandstones, containing *Ophiomorpha* and *Chondrites* ispp. The wave rippled sandstone are also coarse grained and intensely bioturbated. The crossbedded sandstone is fine grained, moderately bioturbated and planar to trough crossbedded. The laminated shale consists of parallel laminated dark gray shale which is overlain by poorly sorted, yellowish, pebbly sandstone.

Interpretation

This facies association is interpreted as a wave and storm influenced upper shoreface following Walter and Plint (1992] Model. The bioturbated, planar crossbedded fine grained sandstone, the wave ripple laminated coarse grained sandstone, the trough crossbedded fine grained sandstone and the coarse grained pebbly sandstone are interpreted as wave and storm influenced upper shoreface deposits.

4.1.4 Bioturbated Sandstone – Upper shoreface

This facies association consists of bioturbated sandstone (F1B), wave ripple laminated sandstone (F8B), and crossbedded sandstone (F2B). The bioturbated sandstone consists of bioturbated, planar cross-bedded coarse grained sandstone. The wave ripple laminated sandstone is medium grained. The cross-bedded sandstone consists of fine to medium grained sandstones. The biogenic sedimentary structures in this facies association include *Ophiomorpha* and *Chondrites* ispp.

Interpretation

This lithofacies and associated physical sedimentary structures suggest deposition in a wave and storm influenced shallow marine environment. The planar crossbedded sandstone and the wave ripple laminations suggest that they are wave and storm influenced deposits. The presence of *Ophiomorpha* and *Chondrites* ispp supports a high energy environment within the Upper shoreface dominated by waves and current action (Reinson, 1984).

4.1.5 Fossiliferous shale – Upper Offshore

The fossiliferous shale facies association consists of bioturbated sandstone (F2B), shale heterolith (F3B), laminated shale (F1A), shelly beds (F11B) and fossiliferous massive sandstone (F10B). The bioturbated sandstone and sandstone / shale heterolith contains *Thalassinoides*, *Planolites* and *Ophiomorpha* ispp. The laminated shale consists of parallel laminated dark grey shales. The shelly beds contain the bivalves *Ostrea kauffmani* and *Ostrea assezi* (Fig. 5). The fossiliferous fine grained sandstone contains moulds and cast of belemnites and bivalves.

Interpretation

Using the Model of Banns et al (2004), the laminated shale lithology in this facies association is interpreted as being suggestive of standing water depositional environment beyond the reach of most currents or waves. The fossiliferous shelly bed and mudstone with abundant moulds of bivalves are suggestive of storm beds. This lithofacies reflect deposition in an Upper Offshore, open marine environment.

4.1.6. Planar cross-bedded sandstone – Upper shoreface - foreshore

This facies association consists of wave rippled laminated sandstone and clay heterolith (F3A) which is overlain by bioturbated planar cross-bedded fine grained sandstone (F3B). Biogenic sedimentary structures include *Ophiomorpha* and *Chondrites* ispp. This facies is characterized by sub-parallel to low angle seaward dipping planar laminated moderately sorted, medium grained sandstone.

Interpretation

Following McEarchern and Pemberton (1992) Model, this facies is interpreted as a wave dominated upper shoreface to foreshore deposit.

4.2 Pebble Morphometry and Implications for Paleoenvironment

Quartz pebbles for morphometric studies were obtained from the sandstone facies of the Imo Formation at Ikporom, Ameke-Abam and at Ugwu-Omerenamma (Fig. 1). 250 pebbles were measured and the results of the pebble morphometric indices as well as roundness data are presented in Tables 5, 6 and 7. The mean of the form indices; flatness ratio (F.R), Elongation Ratio (E.R), Maximum Projection Sphericity index (M.P.S.I) and oblate-prolate (O.P) index and roundness of the pebbles of the Imo Formation are respectively 0.328, 0.727, 0.547, -2.618 and 0.705. The mean FR for the Imo Formation (0.328 ± 0.089) indicate a beach environment (Lutig, 1962). The mean ER for the Imo Formation pebbles (0.727 ± 0.158) is indicative of torrent type flowing water or brooks and rivulets (Lutig, 1962). The total mean MPSI and OP index for the Imo Formation (0.547 ± 0.09) and (- 2.62 ± 5.72) are indicative of a beach environment (Dobkins and Folk, 1970).Several authors including Dobkins and Folk (1970), Stratten (1974) and Els (1988) have shown that the appropriate lower index limits for pebbles shaped in fluvial environments are; sphericity = 0.65 / 0.66, coefficient of flatness = 45% and oblate-prolate index = - 1.5. The mean of all the form indices for the pebbles from the Imo Formation are presented in Table 5. These indices has values that lies below the lower limits for fluvial pebbles and are thus suggestive of a beach depositional environment. Scatter plots of coefficient of flatness versus sphericity, and sphericity versus oblate-prolate index were also used to evaluate the form indices following the methods of Stratten (1974) and Dobkins and Folk (1970) respectively. Bivariate plots of coefficient of flatness versus sphericity indicate a beach environment. All the means too, plot in the beach field (Fig. 6). The mean sphericity of pebbles (0.547 ± 0.090) is lower than the mean (0.65 calculated by Stratten (1974) for quartzite river pebbles in Southern Africa. The average coefficient of flatness obtained for pebbles in this study is 32.8 ± 8.92, which is below the minimum value of 45 % suggested by Stratten (1974) as required for river pebbles. Bivariate plots of sphericity versus oblate-prolate index also suggest a beach environment for the pebbles. Here, also the means of the pebble form indices plot in the beach field (Fig. 7). The study of form indices of pebbles therefore suggests a beach depositional setting for the sandstone facies of the Imo Formation.The roundness values for the five pebble sets varies from 0.605 ± 0.171 – 0.784 ± 0.103 with a mean of 0.705 ± 0.093 (Table 7), which is suggestive of a long distance transport from source.

4.3 Sieve Analysis and Interpretation

The results of textural analysis of the sandstones computed from the grain size data using both graphic mean, inclusive graphic skewness, inclusive graphic standard deviation (sorting) and moment mean grain size, moment standard deviation and moment skewness were computed so as to use the bivariate plots of Friedman (1967, 1979) and Moiola and Weiser (1968) to infer the depositional environment of the Imo Formation. The mean size of the sandstones range from 0.23 to 1.72 ϕ with an average of 1.19 ϕ suggesting that they are medium to coarse grained. Standard deviation (sorting) and skewness values range from 0.41 to 1.77 (an average of 0.66 ϕ) and – 0.23 to 0.18 (an average of – 0.07 ϕ), respectively, indicating that the sandstones are mainly moderately sorted and negatively to symmetrically skewed. Most of the skewness values computed lie within the range of – 0.20 to 0.02 suggested by King (1971) as indicating a beach origin. The results also agree with Friedman (1979) suggestion that river sands are generally poorly sorted and negatively skewed, indicating deposition in high energy conditions. Bivariate plots of graphic skewness versus graphic standard deviation (sorting) (Fig. 8a), 3rd moment skewness versus 2nd moment standard deviation (Fig. 8b) suggest a beach origin for the sandstones. Bivariate plots of mean cubed deviation versus cubed standard deviation (Fig. 8c) suggest a transitional environment for the sandstones.

5. Conclusions

The mean sphericities and coefficients of flatness results obtained for the five sets of pebbles from the sandstone facies of the Imo Shale have generally shown that the pebbles were shaped in a beach environment. This finding complements an already convincing set of criteria indicating a foreshore and shoreface depositional environment for the sandstone. Plots of coefficient of flatness against sphericity as well as plots of sphericity against oblate-prolate index indicate that the pebbles were formed in a beach environment. Mean roundness indices calculated for pebbles from the sandstone facies of the Imo Shale is suggestive of a very long distance of transport. The results of the sand textural study support a high energy (beach) marine environment for the origin of the sandstones. The paleocurrent analysis is suggestive of a coastal provenance for the sandstone while the lithofacies analysis indicates a spectrum of marine environments ranging from upper offshore, lower to upper shoreface to the foreshore.

References

Anyanwu, N.P.C. and Arua, I. 1990. Ichnofossils from the Imo Formation and their paleoenvironmentalsignificance. *Nigerian Journal of Mining and Geology*. V. 26 (1), p. 1 – 4.

Arua, I. 1980. Paleocene macrofossils from the Imo Shale in Anambra State, Nigeria. *Jour. Min. Geol*., 17 (1), pp. 81 – 84.

Avbovbo, A.A. 1978. Tertiary Lithostratigraphy of the Niger Delta. *American Association of Petroleum Geologists Bulletin*, 62, pp. 295 – 300.

Bann, K.L., Fielding, C.R., McEarchern, T.A. and Tye, S.C. (2004), Differentiation of estuarine and offshore marine deposits using integrated ichnology and sedimentology: Permian pebbly Beach Formation, Sydney basin, Australia. In Mcllroy (ed.),The Application of ichnology to Paleoenvironmental and Stratigraphic analysis. Geological Society, London, Special Publications, 228, pp. 179 – 212.

Collinson, J.D., 1969. The sedimentology of the Grindslow Shales and the Kinderscout Grit: a deltaic complex in the Namurian of northern England. *Journal of Sedimentary Petrology*, v. 39, p. 194 – 221.

Dobkins, J.E. and Folk, R.L. 1970. Shape development on Tahiti-Nui: *Journal of Sedimentary Petrology*. V. 40, pp. 1167 – 1203.

Dott, R.H., Jr., and Bourgeois, Joanne, 1982, Hummocky stratification: Significance of its variable bedding sequences: *Geological Society of America Bulletin*, v. 93, pp. 663 – 680.

Duke, E.L., 1985, Hummocky cross stratification, tropical hurricanes, and intense winter storms.Sedimentology, v. 32. pp. 167 – 194.

Els, B.G. 1988. Pebble Morphology of an ancient conglomerate: The Middelvlei Gold Placer, Witwatersrand, South Africa. *Journal of Sedimentary Petrology*. V. 58 (5), pp. 894 – 901.

Folk, R.L. 1974. Petrology of sedimentary rocks. Hemphil Publishing Company, Austin Texas, 182 p.

Folk, R. L and Ward. W. C (1957). A study in the significance of grain size parameter. *Journal of Petrology*.v. 37, pp. 327-354.

Frankl, E.J., and Cordry, E.A., 1967. The Niger Delta oil province – Recent developments onshore and offshore. In 7th World Petroleum Congress Proceedings, Mexico City, Vol. 1B, pp. 195 – 209.

Friedman, G. M. 1967. Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. *Journal of Sedimentary Petrology*, 37, pp. 327 – 354.

Friedman, G.M. 1979. Differences in size distributions of populations of particles among sands of various origins. *Sedimentology*, 26, pp. 3 – 32.

Grove, A.T. (1951). Land use and soil Conservation in parts of Onitsha and Owerri provinces. Geological survey of Nigeria Bull, No 21.

King, C.A.M. 1971. Techniques in Geomorphology. Edward Arnold Publishers Limited, London. pp. 273 – 302.

Krumbein, W.C., 1941. Measurements and geological significance of shape and roundness of sedimentary particles. *Journal of Sedimentary Petrology*, v. 11, pp. 64 –72.

Leckie, D.A., and Walker, R.G., 1982. Storm and tide-dominated shorelines in Cretaceous Moosebar-Lower Gates interval-outcrop equivalents of Deep Basin Gas Trap in Western Canada. *American Association of Petroleum Geologists Bulletin*, v. 66, pp. 138 – 157.

Lutig, G. 1962. The shape of pebbles in the continental, fluviatile and marine facies. *Int. Assoc. Sci. Hydrol. Publ*. V. 59, pp. 253 –258.

MacEachern, J.A. & Pemberton, S.G., 1992. Ichnological aspects of Cretaceous shoreface successions and shoreface variability in the Western Interior Seaway of North America. In Pemberton, S.G. (ed.) Applications of Ichnology to Petroleum exploration: A Core Workshop. Society of Economic Paleontologists and Mineralogists, Core Workshops, Tulsa, Oklahoma, 17, pp. 57 – 84.

Moiola, R.J. and Weiser, D., 1968. Textural parameters; An Evaluation. *Journal of Sedimentary Petrology*, 33, pp. 45 – 53.

Murat, R.C., 1972. Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in southern Nigeria. In Dessauvagie, T.F.J. and Whiteman A.J. (ed.) African Geology, Ibadan, Nigeria, University of Ibadan.

Nwajide, C.S. and Hoque, M., 1982. Pebble Morphometry as an aid in environmental diagnosis: an example from the Middle Benue Trough, *Nigerian Journal of Mining and Geology*, 19 (1), pp. 114 – 120.

Nwajide C.S., and Reijers, T.J.A., 1996. Anambra basin Excursion Guide. In Reijers, T.J.A. (ed). Selected Chapters on Geology, pp. 149 – 197.

Odumodu, C.F.R. and Ephraim, B.E., 2008a. Paleoenvironmental analysis of the Nsukka Formation, using pebble morphometry. *Natural and Applied Sciences Journal*. V. 8 (1), pp. 73 – 84.

Odumodu, C.F.R. and Ephraim, B.E., 2008b. Pebble Morphometry as an indicator of the depositional environment of the Ajali Sandstone. *Natural and Applied Sciences Journal*. v. 8 (2), pp. 132 – 143.

Reinson, G.E., 1984. Barrier – Island and associated strand – plain systems. In Walker, R.G., (ed.) Facies models. Geological Association of Canada. Geoscience Canada Reprint Series, 1, pp. 119 – 140.

Reyment, R.A., 1965. Aspects of the Geology of Nigeria, Ibadan University Press, Nigeria, 145 p.

Reyment, R.A. and Barber, W.M., 1956. Nigeria and Cameroons in "Lexique Stratigraphique International", v. 4, Afrique, pp. 25 – 26.

Sames, C.W. 1966. Morphometric data of some recent pebble associations and their application to ancient deposits. *Journal of sedimentary Petrology*, v. 36, pp. 126 –142.

Short, K.C. and Stauble, E.A. 1967. Outline Geology of the Niger Delta. *American Association of the Petroleum*

Geologists Bulletin. 51, pp. 761 – 781.

Simpson, A. 1954. The Nigerian coalfield: The geology of parts of Owerri and Benue provinces. Bulletin of the Geological Survey of Nigeria, No. 24, 85 p.

Sneed, E.D. and Folk, R.E. 1958. Pebbles in the lower Colorado River, Texas: a study of particle morphogenesis. Journal of Geology, v. 66, pp. 114 – 150.

Stratten, T. 1974. Notes on the application of shape parameters to differenciate between beach and river deposits in southern Africa. *Trans. Geological Society of South Africa*, v. 77, pp. 59 – 64.

Tattam, C.M., 1944. A Review of Nigerian stratigraphy. Report of the Geological Survey of Nigeria, No. 13, 61 p.

Tucker, M.E. 1981. Sedimentary Petrology; An Introduction. John Wiley and Sons Inc., New York, p 25.

Walker, R.G., 1992. Facies, facies models and modern stratigraphic concepts. In Walker, R.G. (ed.), Facies models, Geological Association of Canada, Geoscience Reprint series, 1, pp. 1 – 14.

Walter, R.G. and Plint, A.G., 1992. Wave and storm-dominated shallow marine systems. In Walter, R.G. and James, N.P. (eds.), Facies models: Response to sea level change. *Geological Association of Canada*, pp. 219 – 238.

Wilson, R.C. 1925. The Geology of the Eastern railway. *Geol. Surv. Nigeria. Bull.*, 1, pp. 1 – 95.

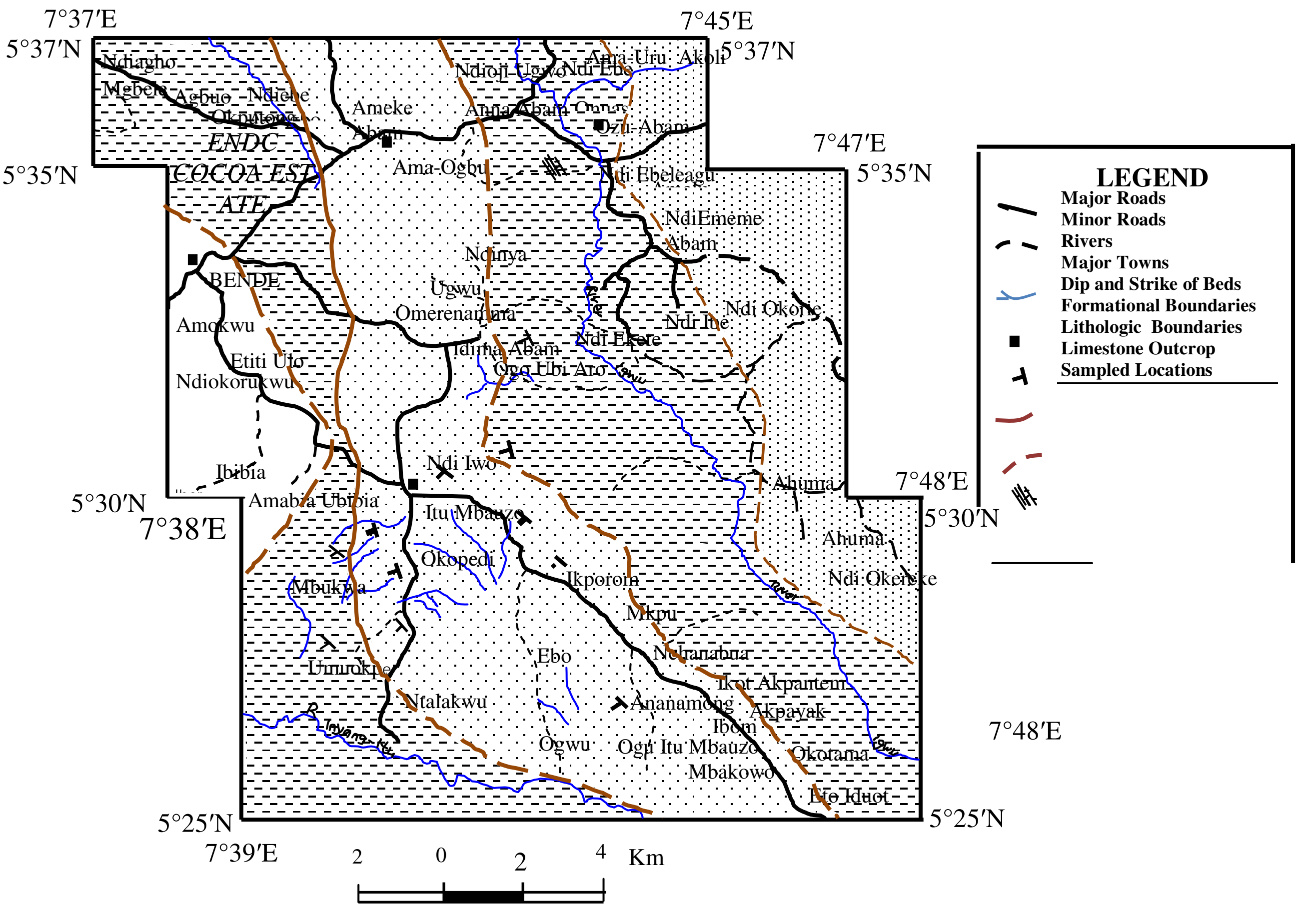

Fig. 1: Geological map of the study area

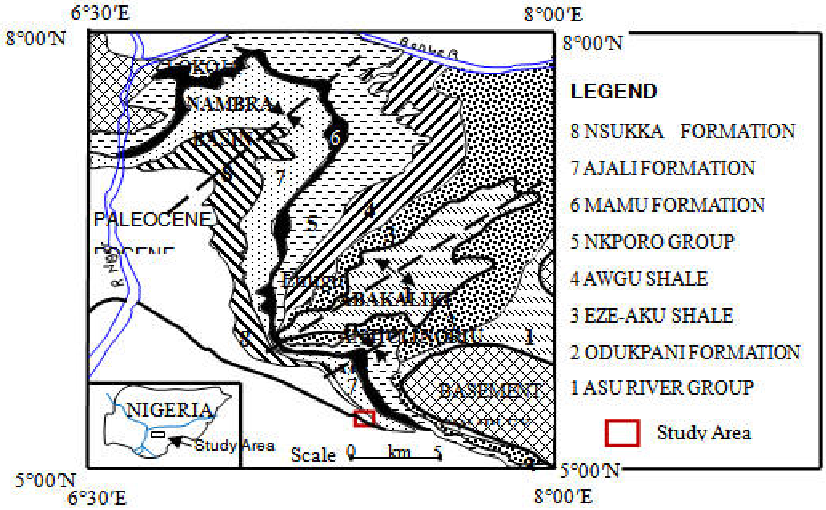

Fig. 2: Geologic map of southeastern Nigeria showing the study area

Table 1: Correlation of subsurface formations in the Niger Delta with outcrops (Short and Stauble, 1967; Avbovbo, 1978).

Age	Surface	Subsurface Niger Delta
Miocene - Recent	Benin Formation	Benin Formation
U. Eocene	Ogwashi-Asaba Formation	Upper Agbada Formation
Middle – Lower Eocene	Nanka Fm / Ameki Fm	Agbada Formation
Paleocene	Imo Formation	Akata Formation

Table 2: Stratigraphic succession in South-eastern Nigeria (Reyment, 1965)

AGE		SOUTHERN BENUE TROUGH, ANAMBRA BASIN & AFIKPO SYNCLINE
TERTIARY	Paleocene	Ameki / Nanka Formation
	Eocene	Imo Formation
		Nsukka Formation
UPPER CRETACEOUS	Maastrichtian	Ajali Formation
		Mamu Formation
		Enugu / Nkporo Formation
	Campanian	
	Santonian Coniacian	Awgu Formation
	Turonian	Ezeaku Shale Group
	Cenomanian	Odukpani Formation
LOWER CRETACEOUS	Albian	Asu River Group
	Aptian	Ogoja Sandstone
PRE CAMBRIAN		Basement Complex

Table 3: Summary of facies used in this study to characterize the strata of the Imo Formation

Description	Occurence and contact	Sedimentology / Accessories	Ichnology / Fossils	Interpretation
F1A Laminated Shale	• Sharply overlies F2A ,F2B, F10B & F9B.	• Horizontally laminated shale	• Absence of bioturbation	Upper Offshore
F2A Siltstone – shale heterolith	• Gradational contact with F1A above	• Horizontally parallel laminated shale	• Absent or rare bioturbation	Offshore transition
F3A Wave ripple laminated heterolith	• Sharp contact with F1A at base & F3B above	• Wave ripple laminated	• Absence of or no bioturbation	Upper shoreface - Foreshore
F1B Bioturbated coarse grained sandstones	• Contains sharp contact with F8B above	• Planar cross bedded	• *Ophiomorpha* & *Chondrites* burrows are very abundant	Upper Shoreface
F4A Sandstone – shale heterolith	• Has a sharp contact with F2B at base & top.	• Horizontally parallel laminated	• Contains *Planolites*, *Thalassinoides* & *Ophimorpha* burrows	Upper Offshore
F2B Bioturbated fine grainedsandstone	• Contains sharp contact with F85 and F9A above	Typically contains high angle planar crossbedded	• Contains Ophiomorpha and Chondrites burrows	Upper shoreface
F3B Crossbedded sandstone	• Contains sharp contact with F8B below & F2B above	• Contains low angle crossbeds	• Ophiomorpha and chondrites burrows are abundant	Upper Shoreface
F4B Bioturbated sandstone	• Contains sharp contact with F4A below & F1A above	• mottled	• moderately bioturbated	Upper offshore
F5B Planar crossbedded sandstone	• Has sharp basal & top contacts	• Typically planar crossbedded	• Ophiomorpha burrows present	Middle shoreface
F6B Swaly cross-stratified sandstone	• Gradational contact below	• Contains swaly cross-stratification • Planar crossbedded	• Ophiomorpha and Rosselia socialis	Lower Shoreface
F7B Coarse grained pebbly sandstone	• Has a sharp contact with F1A at base	• Massive	• Absent	Upper shoreface
F8B Wave rippled laminated medium grained sandstone	• Has a sharp contact with F1B below & F2B above	• Wave ripple laminated	• Absent or rare	Upper shoreface
F9B Trough crossbedded fine grained sandstone	• Has a sharp contact with F1A above & F1B below	• Trough crossbedded	• Absent or rare	Upper shoreface
F10B Fossiliferous mudstone	• Has a sharp contact	• Massive	• Planolites	Upper offshore
F11B Shelly bed	• Has a sharp contact	• Massive	• Absent	Upper offshore

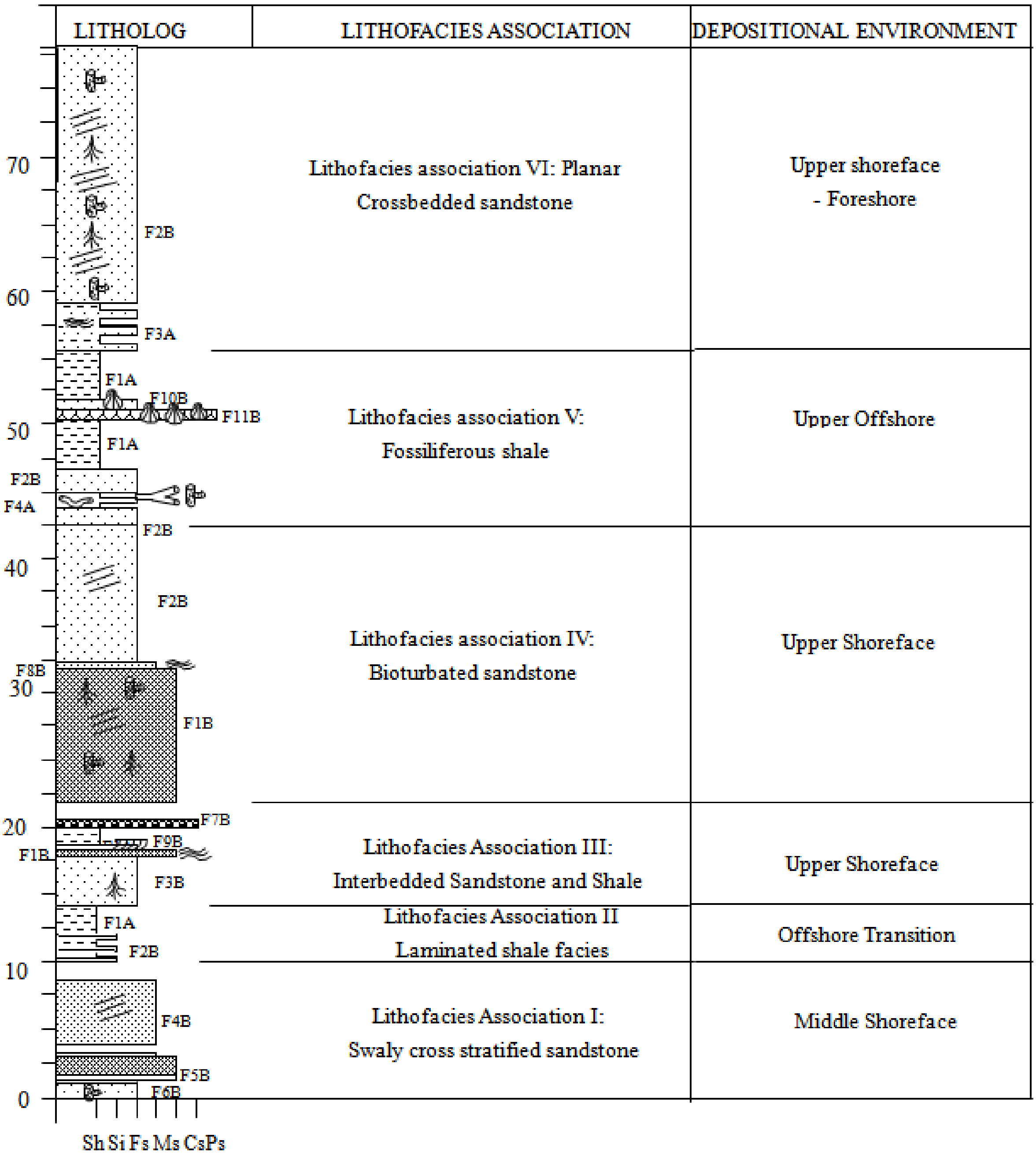

Fig. 3: Composite Litholog of the Imo Formation along Ikporom – Ndiwo Road

Fig. 4(a) Biogenic and sedimentary structures from the Imo Formation.(a) & (b) *Roselia socialis* (c) *Ophiomorpha nodosa* (d) Planar crossbeds (e) *Thalassinoides suevicus* (f & j) Planar crossbeds (h & i) *Chondrites g. Unidentifiable isp.*

Fig 5: Fossils from the Imo Formation (a) *Ostrea Kauffmani* and (b) *Ostrea assezi*

Table 4: Grain size scales for pebbles (modified from Tucker, 1981)

mm	*Phi*	*Class Term*
48 - 64	> - 5.5	
32 – 48	> - 5.0	
24 – 32	> - 4.5	
16 – 24	> - 4.0	*Pebble*
12 – 16	> - 3.5	
8 – 12	> - 3.0	
6 – 8	> - 2.5	*Granule*
4 - 6	> - 2.0	

Samples	n	L	I	S	I/L	L-I/L-S	Coefficient of flatness (S/L)	Sphericty	Oblate Prolate Index	Roundness
L1	50	1.888	1.342	0.602	0.721 ± 0.132	0.419 ± 0.204	32.522 ± 10.057	0.525 ±0.105	-2.947 ± 6.402	0.683 ±0.087
L2	50	1.586	1.136	0.478	0.731 ± 0.124	0.384 ± 0.167	30.87± 9.038	0.504 ±0.085	-3.735 ±5.453	0.700 ±0.084
L3	50	1.624	1.157	0.503	0.727 ± 0.181	0.401 ± 0.262	31.428 ± 7.654	0.516 ± 0.086	-3.396 ± 8.942	0.669 ±0.099
L4	50	1.411	1.033	0.479	0.739 ± 0.116	0.397±0.165	34.546± 8.916	0.542 ± 0.083	-1.094 ± 2.083	0.690 ±0.097
L5	50	2.130	1.480	0.722	0.715 ± 0.114	0.432 ± 0.148	34.646 ±9.829	0.547 ± 0.093	- 1.920 ± 5.064	0.784 ± 0.103
MEAN	250	1.728	1.230	0.557	0.727 ± 0.138	0.407 ± 0.200	32.802 ± 8.916	0.547 ± 0.090	-2.618 ± 5.72	0.705 ±0.092

Table 6 : Pebble Form Indices for the Imo Formation pebbles

	n	Coefficient of flatness ×	s	Sphericity ×	s	Oblate -Prolate Index ×	s
(A) Combined form Data for pebbles larger than – 2.0 phi							
Locality							
1.	50	32.52	10.06	0.525	0.105	- 2.947	6.602
2.	50	30.87	9.04	0.504	0.085	- 3.735	5.453
3.	50	31.43	7.65	0.516	0.086	- 3.396	8.942
4.	50	34.55	8.92	0.542	0.083	- 1.095	2.083
5.	50	34.65	9.83	0.547	0.093	- 1.918	5.064
(B) Form Data for Location 1							
Phi Class							
> - 3.0	17	32.26	8.44	0.539	0.080	0.432	4.307
> - 3.5	24	34.96	11.49	0.549	0.117	- 2.228	5.631
> - 4.0	9	26.52		0.433	0.056	- 11.246	4.413
(C) Form Data for Location 2							
> - 3.0	31	31.29	7.71	0.520	0.069	- 1.140	4.344
> - 3.5	19	30.19	11.07	0.477	0.103	- 7.969	4.356
(D) Form Data for Location 3							
> - 3.0	36	32.48	7.577	0.540	0.077	- 0.085	5.264
> - 3.5	11	28.43	7.593	0.466	0.078	- 7.282	6.386
> - 4.0	3	29.85	8.323	0.413	0.072	- 28.871	4.043
(E) Form Data for Location 4							
> - 2.5	2	26.39	0.72	0.510	0.016	2.803	0.742
> - 3.0	41	35.42	7.93	0.552	0.070	- 1.019	1.912
> - 3.5	7	31.80	13.91	0.489	0.138	- 2.651	1.740
(F) Form Data for Location 5							
> - 3.0	7	34.05	10.47	0.536	0.083	- 1.751	0.781
> - 3.5	26	34.24	11.39	0.539	0.108	- 2.606	5.540
> - 4.0	16	35.55	7.37	0.565	0.071	- 0.691	3.617
> - 4.5	1	34.87	-	0.537	-	- 4.822	-

Table 7 : Roundness indices for the pebbles from the Imo Formation

A) Combined roundness indices for pebbles of different sizes for the five locations studied

Roundness Location	n	×	s
1	50	0.683	0.087
2	50	0.700	0.084
3	50	0.669	0.099
4	50	0.690	0.097
5	50	0.605	0.171

B) Roundness indices for different fractions at the five locations studied

	1			2			3			4			5		
	n		s	n	×	s	n	×	s	n	×	s	n	×	s
> - 2.5										2	0.695	0.262			
> - 3.0	17	0.695	0.060	31	0.698	0.076	36	0.679	0.090	41	0.690	0.089	12	0.688	0.183
> - 3.5	24	0.678	0.109	19	0.704	0.099	11	0.633	0.108	7	0.689	0.113	26	0.612	0.162
> - 4.0	9	0.675	0.067				3	0.683	0.165				12	0.506	0.140

C) Combined roundness indices of all pebbles for the different size fractions

Roundness	n	×	s
>- 2.5	2	0.393	0.160
>- 3.0	137	0.405	0.120
>- 3.5	87	0.396	0.182
>- 4.0	24	0.491	0.113

× is ths mean roundness; s is the standard deviation of the observations

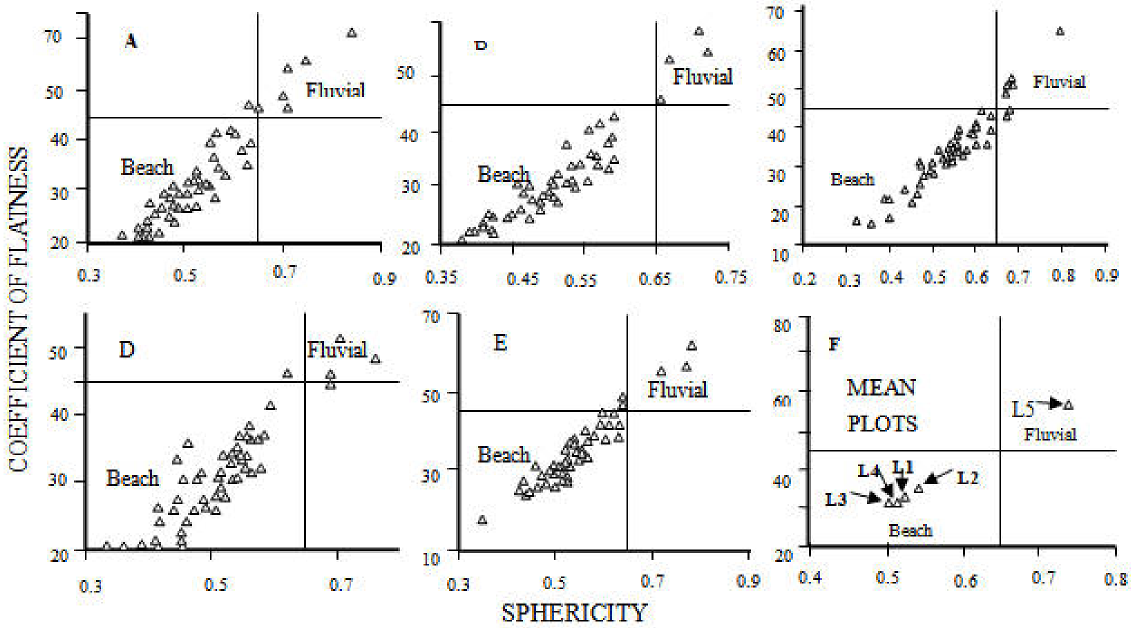

Fig. 6: Plots of Coefficient of Flatness against Sphericity for pebbles from the Sandst
facies of the Imo Formation

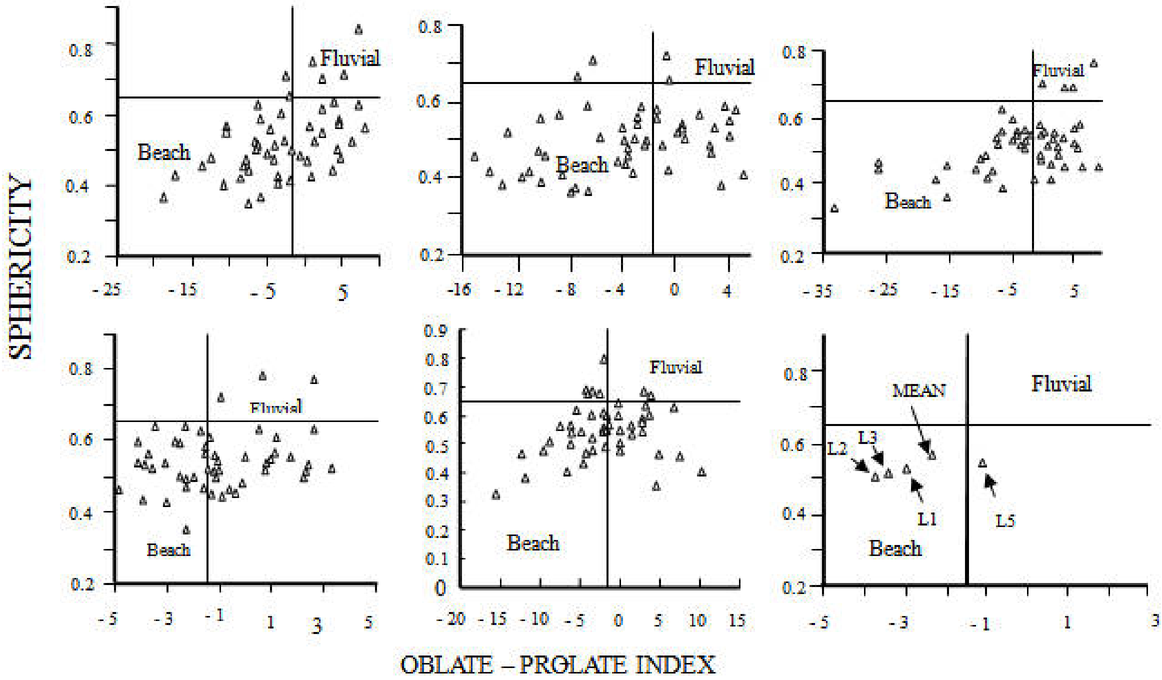

Fig. 7: Plots of Sphericity against Oblate – Prolate index for pebbles from the sandstone unit.

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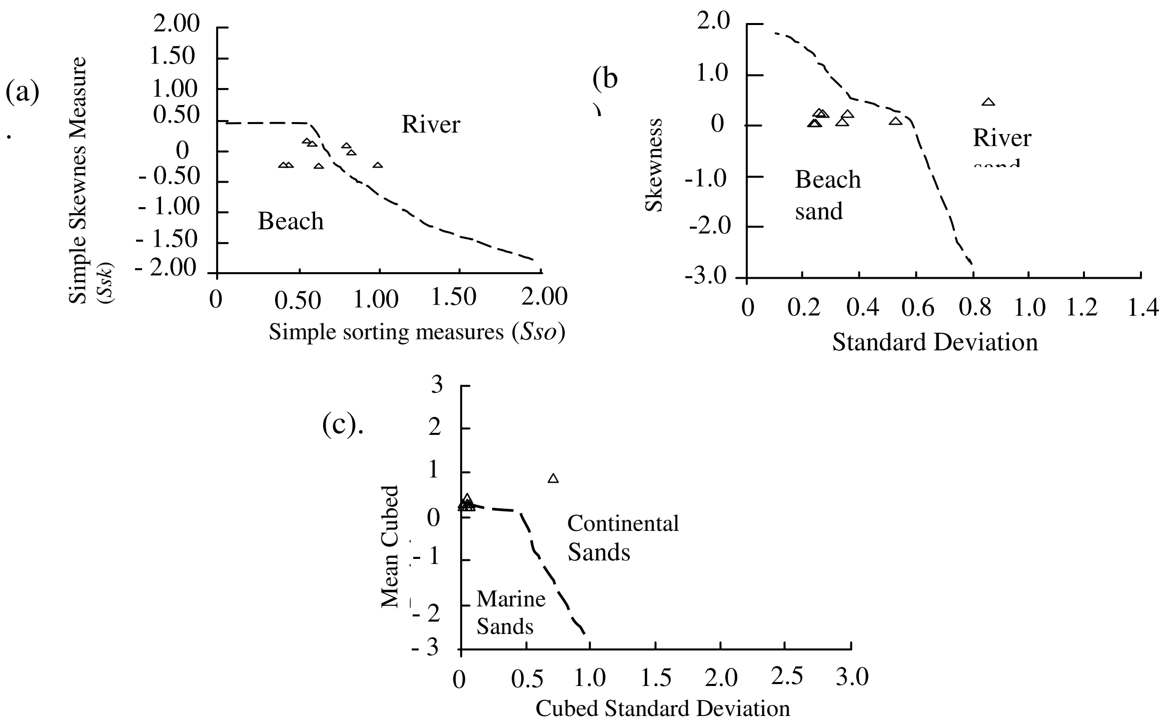

Fig. 8 (a) Plot of Simple Skewness measure (Sko) against Simple sorting measure for sandstones of the Imo Formation (b) Plot of 3rd Moment Skewness against 2nd moment Standard Deviation (sorting) for sandstones of the Imo Formation (After Friedman, 1979) (c) Plot of Mean Cubed Deviation against cubed standard deviation for sandstones of the Imo Formation

Table 4a : Sieve Analysis Result (Graphic method) for the Imo Formation

	Mean (Mz)	Standard Deviation (σ_o)	Skewness (S_k)	Kurtosis (K_G)	Interpretation / Remarks
L12S1U1	1.32	0.41	- 0.23	2.13	m,mws,fs,M
L12S3U3	1.87	0.55	0.18	1.01	m,mws,fs,M
L12S4U4	1.67	0.63	- 0.24	1.28	m,mws,cs,L
L12S5U5	0.23	0.83	- 0.01	0.55	c,ms,ns,VP
L13S1U1	1.27	0.59	0.13	1.15	m,mws,fs,L
L14S3U3	1.72	0.44	- 0.22	0.97	m,ws,cs,M
L14S4U4	0.43	0.99	- 0.23	0.46	c,ms,cs,VP
L14S5U5	0.98	0.80	0.10	1.64	c,ms,ns,VL
L08X1	0.88	0.74	0.10	1.08	c,ms,ns,M
L06X6	0.84	0.75	0.07	0.97	c,ms,ns,M
L07X7B	0.96	0.83	0.02	0.94	C,ms,ns,P
L07X7A	1.07	1.17	0.10	0.73	m,ps,ns,P

Legend
m = medium grained, c = coarse grained, ms = moderately sorted, ws = well sorted, mws = moderately well sorted, cs = coarse skewed, fs =fine skewed, ns = nearly symmetrical, M = mesoturtic, VP = very platykurtic, L = leptokurtic, P = platykurtic, VL = very leptokurtic.

Table 4b: Sieve Analysis Result (Method of moments) for the Imo Formation				
Sandstone Sample No	**1st Moment Mean Grain Size**	**2nd MomentStandard Deviation or Sorting**	**Skewness 3rd Moment**	**INTERPRETATION / REMARKS**
L12S1U1	0.47	0.23	0.07	c,vws,ns
L12S2U2	0.57	0.78	0.72	c,ms,vfs
L12S3U3	0.37	0.27	0.26	c,vws,fs
L12S4U4	0.46	0.36	0.24	c,ws,fs
L12S5U5	1.05	0.86	0.49	m,ms,vfs
L13S1U1	0.51	0.24	0.07	c,vws,ns
L14S3U3	0.39	0.27	0.24	c,vws,fs
L14S4U4	0.84	0.53	0.10	c,mws,ns
L14S5U5	0.60	0.34	0.08	c,vws,ns
L14S4U4	0.72	0.43	0.36	c,ws,fs
L17S1	0.39	0.19	0.17	c,vws,fs

Key
m = medium grained, c = coarse grained, ms = moderately sorted, ws = well sorted, mws = moderately well sorted, cs = coarse skewed, fs =fine skewed,vfs = very fine skewed