Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.5, No.17, 2015
www.iiste.org

Lithofacies Analysis and Depositional Environments of the Eocene Nanka Sand as Exposed at Alor and Environs, Southeastern Nigeria: Evidence from Field Study and Granulometric Analysis

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Abstract
The genetic relationship between depositional processes and rock properties provide a potentially powerful tool for interpreting ancient depositional environments. Field study and granulometric analysis have been used to detect the lithofacies and depositional environment of the Eocene Nanka Sand. The field data shows Nanka Sand as medium to coarse grain sand that is loose and unconsolidated, with cross bedded white to yellow sand having intercalation of silty sand and clay with bands of fine grained sandstone and sandy clay on top. The granulometric study shows Nanka Sand to be coarse to medium grain and negatively skewed. Sorting is moderately well sorted to poorly sorted, and kurtosis is leptokurtic. The frequency histogram showed both unimodal and bimodal characters. Bivariate results together with linear discrimination functions of the sand samples reveal both shallow agitated marine and fluvial deposits. The paleocurrent shows bimodal - bipolar current directions, while the observed sedimentary structures include reactivation surfaces, clay drapes, flaser and wavy beddings, burrows of *Skolithos* and *Ophiomorpha*, with herringbone and planar cross beds, indicative of tidally influenced environment. Three distinct lithofacies observed were heterolithic, cross bedded sand facies, channel sand facies, and clay stone facies, and these has allowed the depositional environment of the Eocene Nanka Sand to be interpreted as a tide dominated estuaries characterized by tidally influenced fluvial to mixed energy environment.
Keywords: Granulometric, Lithofacies, Heteroliths, Tides, Paleocurrent, Ichnofacies.

1. Introduction

To put together the geologic history of a region, geologists analyze the depositional environment of its sedimentary rock, thus, revealing the geography of the past – where the mountains, basins, river channels, and bays of the oceans were. Depositional environments of ancient sediments are recognized using a combination of sedimentary facies, facies association, sedimentary structures and fossils, particularly trace fossil assemblages, as they indicate the environment in which they lived. Consequently, knowledge about sedimentary processes that cause the production, transportation and deposition of these sediments is the most important in environmental reconstruction.

In this study, we have employed granulometric and lithofacies analysis, as well as sedimentary structures from field evidence in the study of Nanka sand exposed at Alor, Oraukwu, Abatete and surrounding communities to determine the depositional environments, bearing in mind that the genetic relationship between depositional processes and rock properties provide a potentially powerful tool for interpreting ancient depositional environments.

2. Geological Setting

The study area is located within Anambra central (figure 1a) and is bounded by latitude 6^0 3' 0"N to 6^0 9'0"N and longitude 6^0 54' 0"E to 7^0 0' 0"E. The geologic evolution of the study area has been traced to the evolution of the south eastern sedimentary basins. The formation of the basin was controlled by the regional tectonic events in three dimensional cycles (Kogbe, 1976). Sedimentation began in southeastern Nigeria during the Cretaceous (Albian), which was mainly pyroclastics. The Asu River Group sediments of about 300m thick were deposited in a shallow marine transgressive environment (Reyment, 1965 and Kogbe, 1975).

In the Calabar Flank, sedimentation started during the upper Albian with the basal grits of the continental Awi Formation (Adeleye and Falose, 1978). They are overlain by a sequence of fossilferous siltstone, shale, and limestones belonging to Odunkpani Formation (Cenomenian – Turonian). During the Turonian, thick marine sediments were deposited by a transgressive sea which covered greater part of southeastern Nigeria (Reyment, 1965). These sediments are assigned to Ezeaku Formation and known to underlie both Anambra Basin and Afikpo Syncline. In the Anambra Basin, the Ezeaku Formation was overlain by the marine Awgu Shale (Coniacian). The Coniacian sediments are however missing in both Afikpo Syncline and Calabar Flank. The Anambra platform lying to the west and southwest off Abakaliki Folded Belt, subsided to form the Anambra Basin (Rayment, 1965).

The Campano-Maastrichtian sequence includes the shallow marine Nkporo Shale and its lateral equivalent; the Enugu Shale, the Coal bearing Mamu Formation and Nsukka Formation, and the conspicuously cross bedded Ajalli Sandstone. The sudden retreat of the trangressive marine sedimentation during the tertiary led to the deposition of the thick blue-grey fossilferous Imo Shale (Paleocene) and the heterolithic Ameki Formation and its lateral equivalent Nanka Sand (Eocene), which is the formation of interest. The Nanka Sand and its lateral equivalents form the surface equivalent of the subsurface Niger Delta sediments.

3. Methodology

The sedimentological methods employed in this work include grain size, lithofacies and paleocurrent analysis. Detailed field mapping of the exposed outcrop at Alor and surrounding communities was carried out and the lithology, sedimentary structures, fossils and paleocurrent patterns were properly studied. Textural features of the sand grains were analyzed, and the log section of the outcrops produced.

Six samples were collected from Alor, Oraukwu, Alor/Nnobi boundary and were sieved according to the technique of Friedman (1979). The nest of sieve was arranged with the coarsest at the top and the finest pan at the bottom. The disaggregated and weighed samples of the sand were each poured into the uppermost part of the sieve and shaken for 15 minutes.

The data obtained were used in plotting the cumulative probability curves in order to determine the grain size parameters of the sand. The parameters include; mean (Mz), median, mode, Skewness (Sk), Kurtosis (KG), and graphic standard deviation ( ).

The linear discrimination functions (Y1, Y2, Y3) of Sahu (1964) and the bivariate plots of skewness against standard deviation (Friedman, 1961), mean diameter against standard deviation (Moiola and Weiser, 1968), and Y2 against Y1 adopted from Onuigbo *et al*. (2012) and Alsharhan & EL- Sammak (2004) were used for environmental discrimination.

The paleocurrent analysis was done by plotting 60 cross bed foresets on a rose diagram and determining the paleocurrent direction and provenance.

4. Results and Interpretation

The paleoenvironments interpretation of the Eocene Nanka Sand was attempted based on the facies association, sedimentary structures, petrography and texture, paleocurrent analysis of the cross bed forsets and using the concept of process – response model of Folk and Ward (1957), Sahu (1964), Friedman (1961), and Moiola and Weiser (1968).

The sedimentological analysis of the sediments permitted the recognition of distinct facies and facies associations in the study area. The different facies identified are;

- ♦ Heterolithic, cross bedded Sand facies
- ♦ Channel sand facies
- ♦ Claystone facies

4.1 Heterolithic; cross bedded sand facies

This consists of fine to medium grain sand that is unconsolidated and loose. The unit is yellowish white in colour and display colour variations. It shows heteroliths of sand and mud, having flaser and wavy bedding. Sedimentary structures observed in this unit include herringbone and planar cross beds, reactivation surfaces and mud drapes (figure 2a, 2b). Biogenic structures found in this unit include cylindrical burrows of *Ophiomorpha*, bioturbations and sub vertical burrows of *Skolithos* (figure 2c, 2d).

4.1.1 Interpretation

The characteristics of this facies which include herringbone cross stratification, clay drapes, flaser and wavy bedding, rippled sand and wavy mud laminations, as well as reactivation surfaces allows it to be interpreted as a tidal facies (intertidal). The rippled sands are deposited during maximum tidal flows, whereas mud drapes form during ensuing slack water periods (Plink-Bjorklund, 2005).

The presence of trace fossils such as cylindrical burrows of *Ophiomorpha* and sub vertical burrows of *Skolithos* Ichnofacies maybe additional evidence. Ojo (2012) and Amireh & Abed (1994) reported clay drapes and worm burrows as signatures of tidally influenced environments.

The paleocurrent pattern is bimodal showing tidal current reversals. Klein and Amajor (1984) suggested that current direction reversals are associated with tidal processes.

Flaser and wavy beddings with marine trace fossils typically indicated deposition from reversing tidal current (Reineck and Wunderlich, 1968; Reineck & Singh, 1980) and represents an inter tidal succession of decreasing current energy (Dalrymple, 1992). Thus, tidal flat (inter tidal zone) has been suggested as the depositional environment of this facies.

4.2 Channel sand facies

This facies comprises of medium to coarse grain pebbly sand. It shows a fining upward sequence with sub angular to sub rounded pebbles occurring at the base. Where this unit outcrops at the boundary between Alor and

Abatete, a highly ferruginised sandstone about 8mm thick showing an exhumed surface is seen separating what is envisaged as two channel systems (figure 3a). The second channel, attributed to be a sub facies comprises of a layer of gravely sand at the base and grades upward into fine to medium sand. Pebbles observed in this unit trends at 240^0 and are mainly unidirectional. Also common with this unit are horizontal strata showing normal and coarse – tail grading (figure 3b), and soft sediment deformation structure (slump structure). This is significantly observable at Alor and Alor/Nnobi boundary.

4.2.1 Interpretation

This facies comprising of medium to coarse grain pebbly sand is interpreted as channel deposit within an estuary, which was deposited during high energy current, however, the fining upward sequence is an indication of decrease in the energy level of transport and fluvial impact. The sub angular and sub rounded pebbles are indications that the sediments are sub matured texturally. The sub facies showing horizontal strata with normal and coarse tail grading may represent decrease in the transport energy of the river as time passes, whereas the soft sediment deformation structure (slump structures) indicates high deposition rates in this environment, allowing sediments to pack loosely.

The unidirectional current pattern observed from the pebbles, and absence of marine biogenic features allows fluvial action to be strongly supported (Ojo & Akande, 2003; Rust & Jones, 1987). The coarse grain size of the channel fills, the low abundance of overbank deposits and relatively low paleocurrent variability suggest that the channel has relatively low sinuosity (Bridge *et al*., 2000).

4.3 Claystone facies

The dirty white claystone facies with reddish stain were observed at Alor/Abatete boundary, but were well represented at the boundary between Alor/Nnobi. It is about 0.5m thick from the observed outcrop. They are horizontally layered (figure 4a) appearing in beds with reddish surfaces which may be as a result of iron water percolating through it. They contain intense burrows of trace fossils (figure 4b) and show shrinkage crack features.

4.3.1 Interpretation

The dirty white claystone with red stains has been interpreted as tidal mud flats characterized by low to high energy moving water in an inter tidal zone. The presence of intense bioturbation created by infaunal organisms supports this interpretation because mudflats are characterized by higher organic loads. The mode of transport with duration of periods of submergence favours deposition of muds in the high tidal flats, interbedded mixed lithologies of mud and sand in the mid flat zone, and sand in the low tidal flat zone (Beali, 1968), thus, allowing this facies to be interpreted as tidal mud flat deposited in an inter tidal (high tidal) zone.

The log sections of the outcrops were correlated with the estuaries lithofacies after Horne *et al*, (1978) adopted from Kendall (2005) lecture on clastic hierarchies and eustasy, and is shown in figure 5.

4.4 Granulometric results and interpretation

The statistical parameters of grain size distribution have been a major parameter in delineating the influence of depositional processes. The textural analysis shows that Nanka Sand in the study area is coarse to medium grain, nearly symmetrical to negatively skewed, moderately well sorted to poorly sorted sand and average kurtosis is leptokurtic (Tables 1).

The coarse and medium grain nature of the Nanka Sand indicates that the sediments were deposited in a mixed energy environment; however, the presence of little or no fines indicates that higher energy current dominates the deposition of the sediments. This is in conformity with the negative skewness (coarse skewed) exhibited by the samples which is correlated to high energy and winnowing action (removal of fines). Sign of skewness is related to the environmental energy (Duane, 1964). The poor sorting exhibited by most of the sands may be attributed to fluctuation in energy of deposition.

The samples plotted as mesokurtic indicating that the sorting agent was uniform for the entire grain distribution, platykurtic indicating tails better sorted than the central point, and leptokurtic indicating that the central part is better sorted than the tail. However, the average values for the samples show that kurtosis is leptokurtic (excessively peaked) indicating that the centre is better sorted than ends.

4.5 Environmental discrimination

The linear discrimination functions of Sahu (1964) adopted from Onuigbo *et al*, (2012) for finding the relation between variances exhibited by parameters were used to discriminate the environment.

(a) For the discrimination between Aeolian processes and littoral (intertidal) environments, the discriminate function used is given below:

$$Y1 = -3.5688\ MZ + 3.7016\ \delta 1^2 - 2.0766\ SK1 + 3.1135\ KG$$

Where MZ is the grain size mean, δ1 is inclusive graphic standard deviation (sorting), SK1 is skewness and KG is the graphic kurtosis.

When Y1 is less than -2.7411, Aeolian deposition is indicated whereas if it is greater than -2.7411, a beach environment is suggested.

(b) For the discrimination between beach (back- shore) and shallow agitated marine (subtidal) environment, the discriminate function used include;

$$Y2 = 15.6534\, MZ + 65.7091\, \delta I^2 + 18.1071\, SK1 + 18.5043\, KG$$

If the value of Y2 is less than 65.3650 beach deposition is suggested whereas if it is greater than 65.3650 a shallow agitated marine environment is likely.

(c) For the discrimination between shallow marine and the fluvial environments, the discriminate function below was used.

$$Y3 = 0.2852\, MZ - 8.7604\, \delta I^2 - 4.8932\, SK1 + 0.0482\, KG$$

If Y3 is less than -7.419 the sample is identified as a fluvial (deltaic) deposit, and if greater than -7.419 the sample is identified as a shallow marine deposit.

From the values of Y1, Y2, and Y3 for the analyzed samples as shown in table 2;

All analyzed sand samples showed Y1 values that are greater than -2.7411, and thus indicates beach environment.

All analyzed sand samples showed Y2 values that are greater than 65.3650 and thus, indicates shallow agitated marine environment.

83.3% of the sand samples showed Y3 values that are less than -7.419 and thus, is identified as fluvial.

4.6 Bivariate plot

The bivariate scatter plot of the discriminate function (Y1 vs Y2), skewness against standard deviation of (Freidman, 1961) and mean deviation against standard deviation of (Moiola and Weiser, 1968) improved the success rate and refinement of the discrimination method in relation to depositional environment. The plot shows the samples to be of shallow agitated marine/beach environment (figure 6), however, 66.6% of the sand samples fell within fluvial when plotted using the scatter plot of Miola and Weiser, (1968), indicating that some of the sediments may have been brought in by fluvial process.

4.7 Paleo-current reconstruction

The rose diagram (figure7) plotted from 60 cross bed forests indicate bimodal- bipolar paleocurrent pattern. The bi- directional paleo - flow is in the North eastern and Westerly directions indicting that provenance is from south western and easterly directions respectively. The bi-modal paleocurrent pattern indicates tidal current. Klein (1970) and Amajor (1984) suggested that current direction reversals are associated with tidal processes.

5. Discussions and conclusion

The paleo environment of the Eocene Nanka Sand has been interpreted as tide dominated estuaries characterized by tidally influenced fluvial to mixed energy environment. The interpretation is based on the characteristics of the sedimentary facies, the linear discrimination functions and using the estuary model (Figure 8) of Dalrymple *et al*. (1992), modified by Plink-Bjorklund, (2005).

The results of the linear discrimination function, as well as the interpretations of the associated facies has displayed that the paleoenvironment is a transition zone (estuary), having both the influence of river and marine. However, the marine influence was observed to be purely tide dominated.

According to Zimmerle and Zimmerle (1995), ancient tidal processes are recognized on sedimentary rocks by the presence of paleocurrent patterns indicating bi-directional flow, the abundance of reactivation surfaces and clay drapes, and presence of sedimentary features indicating repeated, small scale alternations in sediment transport.

Tucker (1982) also noted that paleocurrent pattern in shallow marine shelf can be bimodal through tidal current reversals, and can be unimodal if one tidal current dominates. The heterolithic, cross bedded sand facies and the claystone facies interpreted as tidal flats (inter-tidal), exhibits these features described above. The presence of trace fossils (*Ophiomorpha* and *Skolithos* Ichnofacies) showing escape structures, and presence of ripple sands draped by mud laminations and causing flaser and wavy beddings are additional evidence.

The Channel sand facies which is interpreted as channel deposit within an estuary forms part of the estuary dominated by the influence of river current. The unidirectional movement of paleocurrent observed from the pebbles has been envisaged to be the seaward movement of the channel current. The decrease in grain size towards this direction reflecting a decrease in the river current as it migrates seaward supports this view. River current decreases in strength and relative importance in seaward direction through both estuaries and deltas, because of the decreasing physical and hydraulic gradient as the river approaches the sea (Dalrymple *et al*., 2006).

The suggested depositional environment for the Eocene Nanka Sand which is a tide dominated estuaries characterized by tidally influenced fluvial to mixed energy (inter-tidal) environment supported Nwajide

& Hoque (1979), and Onuigbo *et al* (2011) views that Nanka Sand was deposited in an inter- tidal, relatively low to high energy environment.

References

Adeigbe, C.O and Salufu, A.E (2009), Geology and depositional environment of Campano- Maastritchtian sediments in the Anambra Basin, Southeastern Nigeria: Evidence from field relationship and sedimentological study. Earth science research journal, vol 3, pp. 13-25.

Alsharhan, A.S. and EL- Sammak, A.A., (2004), Grain- size analysis and characterization of sedimentary environments of the United Arab Emirates coastal area. Journal of coastal Research 20 (2), 464- 477.

Amireh, B. S., Schneider, W., & Abed, A. M. (1994). Evolving fluvial – transitional-marine deposition through the Cambrian sequence of Jordan. Sedimentary Geology, 89, pp65-90.

Dalrymple, R.W. (2006), Morphologic and facies trends through the fluvial–marine transition in tide-dominated depositional systems: A schematic framework for environmental and sequence-stratigraphic interpretation: Earth-Science Reviews 81 (2007) 135–174.

Dalrymple, R.W. (1992), Tidal depositional systems. In: Facies Models: Response to Sea Level Changes (Eds R.G. Walker and N.P. James), pp. 195–218. Geology Association Canada.

Friedman, G.M., (1961), Distinction between dune, beach and river sands from their textural characteristics. Journal of Sedimentary Petrology, 31, pp514- 529.

Moiola, R.J. and Weiser, D., (1968), Textural parameters: an evaluation". Journal of Sedimentary Petrology, 38, pp45- 53.

Nwajide, C.S., (2005), Anambra Basin of Nigeria: synoptic basin analysis as a basis for evaluating its hydrocarbon prospectivity. In: Okogbue, C.O. (Ed.), Hydrocarbon Basin. In: Reijers, T.J.A. (Ed.), Selected chapters on Geology, SPDC,pp 133- 147.

Nwajide, C.S., and Hoque, M., (1979), Trace fossils from the Nanka Formation, Southeastern Nigeria. Geologie en Mijnbouw. 58, pp.85- 88.

Nwajide, C.S., (1980), Eocene tidal sedimentation in the Anambra Basin, Southern Nigeria. Sedimentary Geology. 25, 189- 207.

Ojo.O.J. (2012), Sedimentary Facies Relationships and Depositional Environments of the Maastrichtian Enagi Formation, Northern Bida Basin, Nigeria: Journal of Geography and Geology 4 (1), pp136-147.

Onuigbo et al. (2012), Tide-generated Sedimentary Structures, Lithofacies and Particle Size Distribution: Proxies to the depositional setting of the Ajali Sandstone in the Anambra Basin, Southeastern Nigeria: Journal of natural science research 2 (6), pp100-112.

Onuigbo et al. (2011), Lithofacies analysis and textural characteristic of Eocene Nanka sand, southeastern Nigeria: Natural and Applied Sciences Journal 11 (1).

Plink-Bjorklund, P. and Steel, R. (2005), Stacked fluvial and tide-dominated estuarine deposits in high frequency (fourth-order) sequences of the Eocene Central Basin, Spitsbergen: International Association of Sedimentologists, 52, pp391-428.

Reineck, H.E., and Singh, E.B., (1980), Depositional sedimentary environments, 2nd ed. Springer Verlag, New York.

Sahu, R., (1964), Textual Parameters: An Evaluation of Fluvial and Shallow Marine Deposits. J Sed. Pet., Vol. 34, pp. 513-520.

Tucker, M.E., (1982), Sedimentary petrology: An introduction (vol.3). Blackwell Scientific Publications, London. pp. 40- 42.

Zimmerle, W., and Zimmerle, H., (1995). Petroleum Sedimentology. In 1995(edn) 413. London: Kluwer academic publishers.

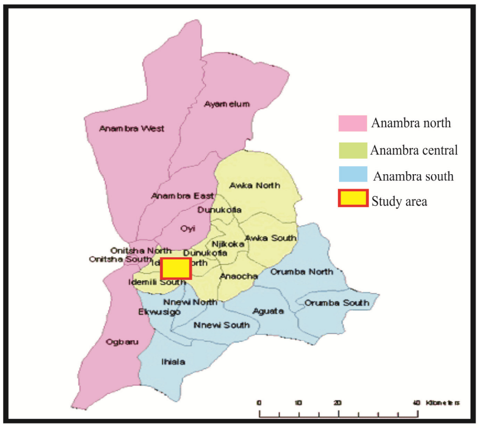


Figure 1a: Map of Anambra state showing the study area.

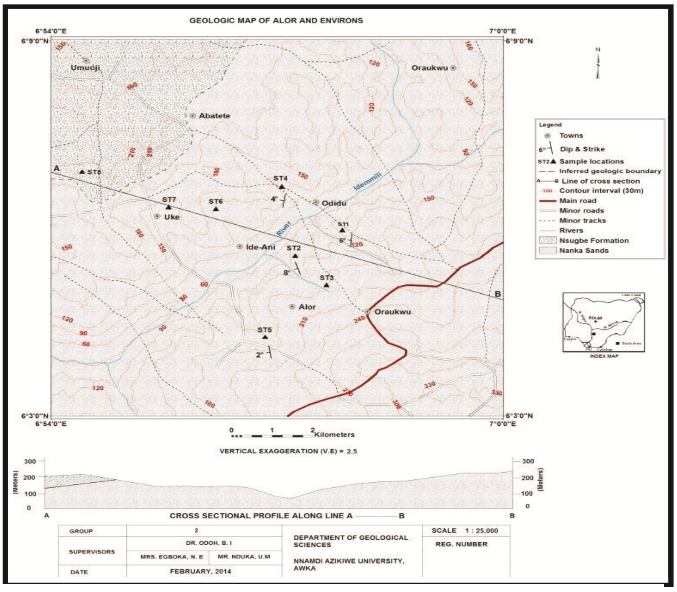


Figure 1b: Geologic map of the study area with cross section taken across A-B

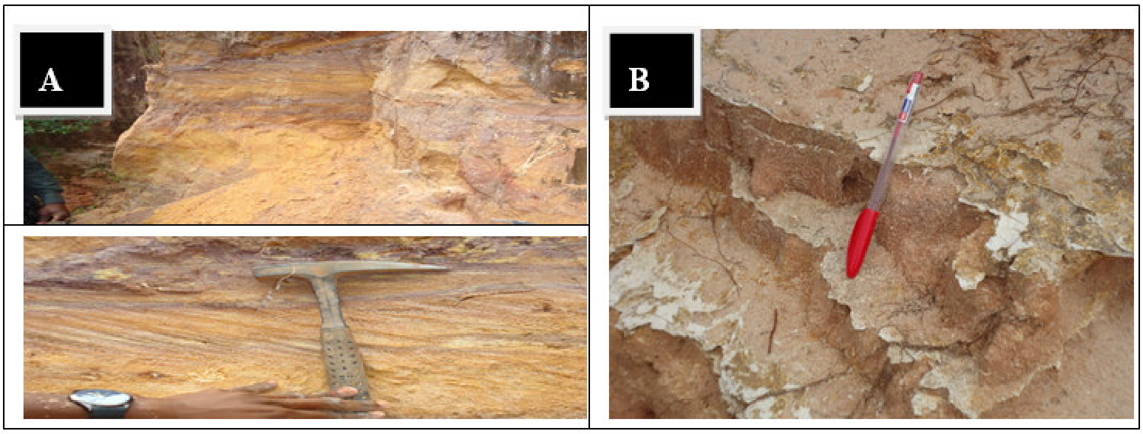


Figure (2a) shows herringbone and planar cross beds, reactivation surfaces and colour variation; (2b) shows flaser and wavy bedding with mud laminations.

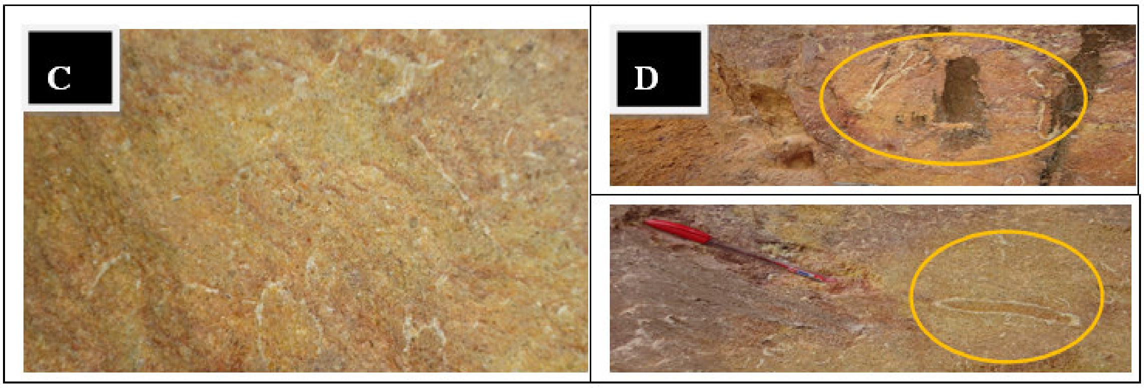


Figure (2c) Moderate bioturbation found within Nanka Sand exposed in Alor; (2d) shows sub vertical burrows of Skolithos and cylindrical burrows of Ophiomorpha.

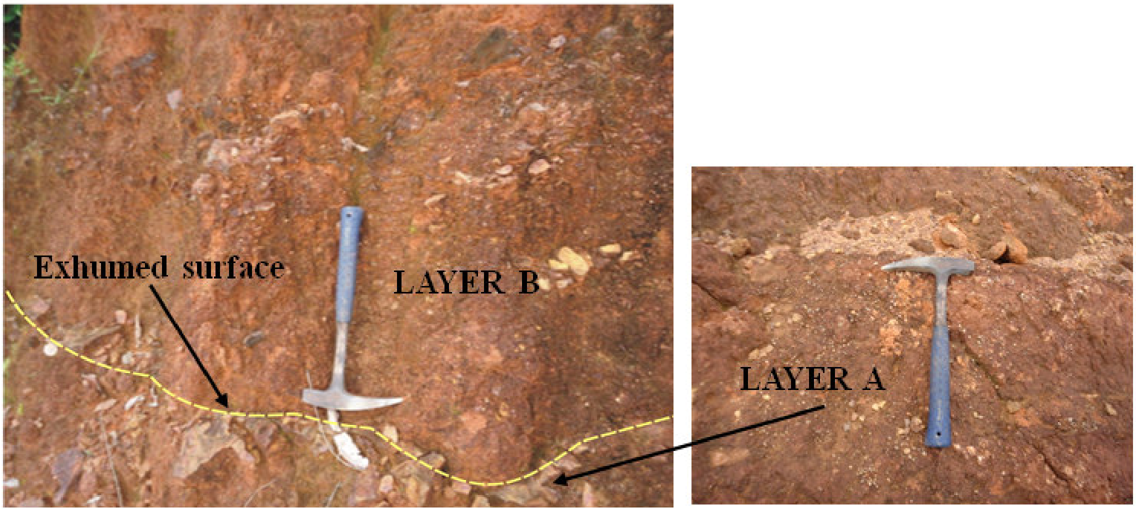


Figure 3a: Channel sand exposed at the boundary between Alor/Abatete (observe the ferruginised sandstone between the two layers (channels), and the gravely packed base of layer B)

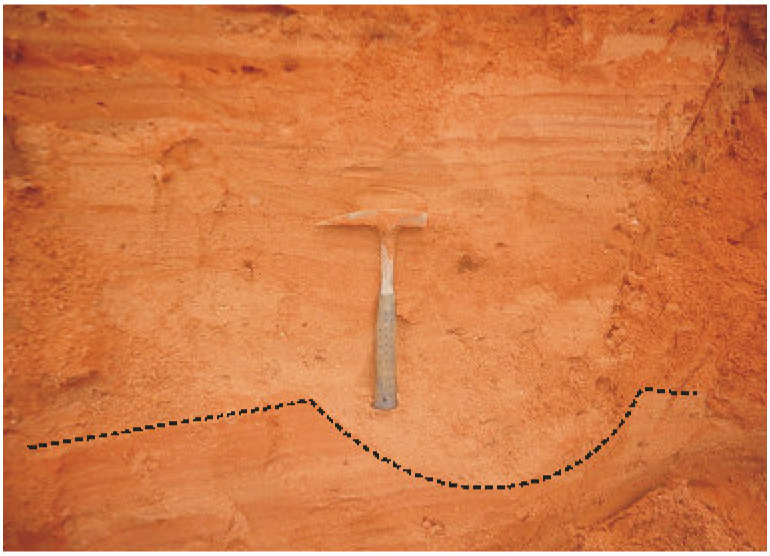


Figure 3b: Soft sediment deformation structure (slump structure), with horizontal beddings and laminations above the hammer head showing normal and coarse tail grading.

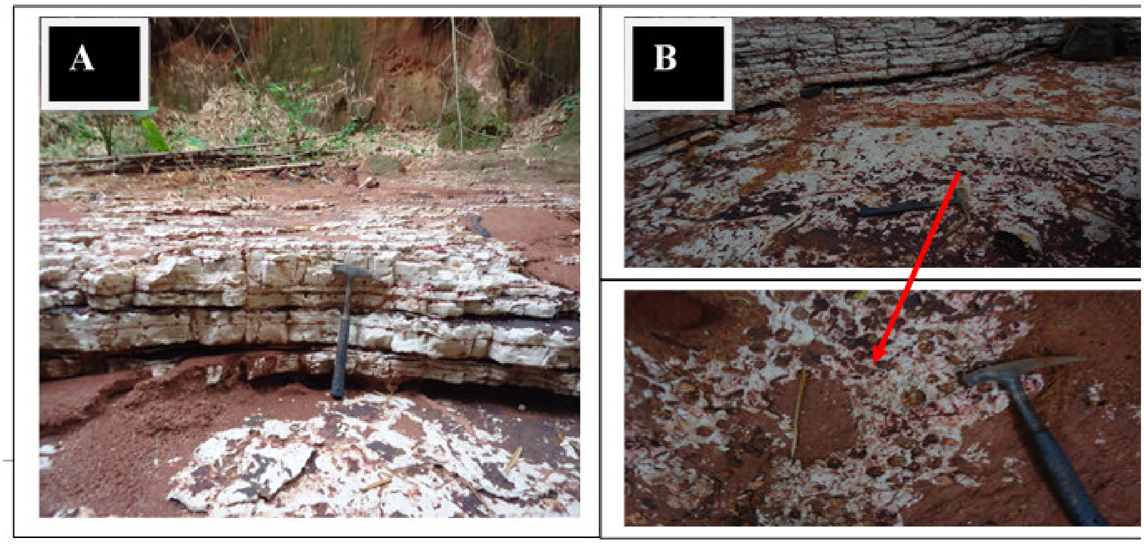


Figure (4a) shows horizontally layered beds; (4b) shows intense bioturbations caused by infaunal organisms.

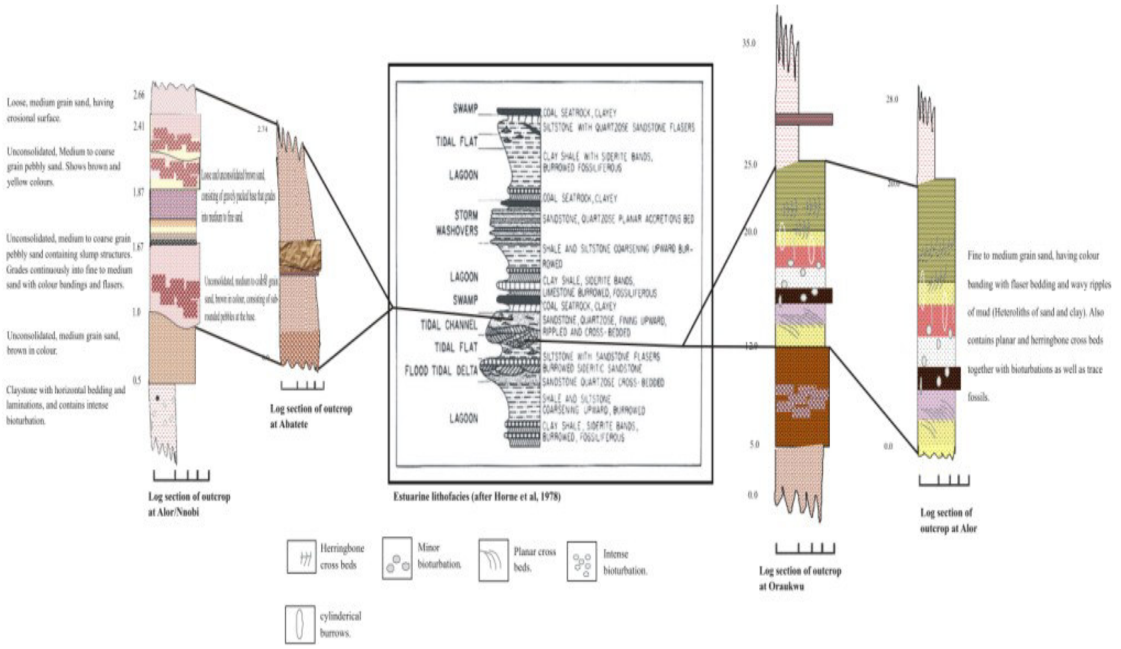


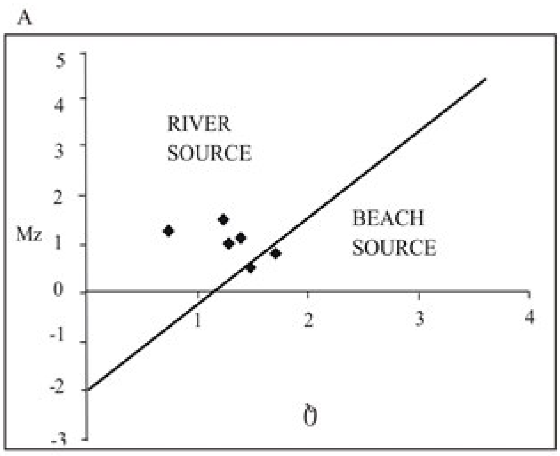
Figure 5: Log sections of the outcrops correlated with the estuaries lithofacies model of Horne *et al*, 1978.

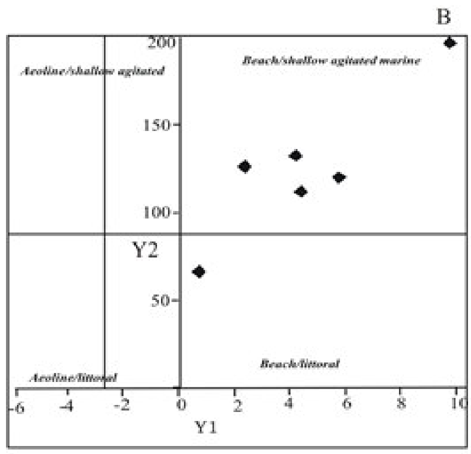
Table 1: Computed grain size parameters derived from probability curves

Sample No	Sorting	values	Skewness (Sk)	Values	Kurtosis (KG)	Values	Mean (Mz)	Values
SP1	Poorly sorted	1.22	Nearly symmetrical	-0.07	Mesokurtic	1.06	Medium sand	1.08
SP2	Poorly sorted	1.13	Negatively skewed	-0.17	Leptokurtic	1.27	Medium sand	1.52
SP3	Poorly sorted	1.15	Negatively skewed	-0.23	Leptokurtic	1.18	Medium sand	1.00
SP4	Poorly sorted	1.62	Negatively skewed	-0.18	Platykurtic	0.80	Coarse sand	0.71
SP5	Poorly sorted	1.23	Negatively skewed	-0.17	Leptokurtic	1.16	Coarse sand	0.55
SP6	Moderately well sorted	0.71	Negatively skewed	-0.12	Leptokurtic	1.27	Medium sand	1.33

Table 2: Linear discrimination functions (Y1, Y2, and Y3) results for the analyzed samples

Sample No	Y1	Y2	Y3
SP1	4.80273	133.1860	-12.3497
SP2	2.95387	128.6612	-9.93043
SP3	4.49660	119.6464	-10.0265
SP4	10.7166	217.8564	-24.4812
SP5	6.90274	126.3687	-12.1998
SP6	0.81016	75.36540	-3.39608





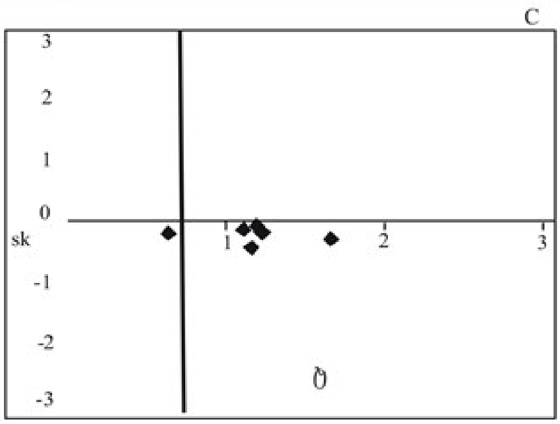


Figure 6: Bivariate plot of the sand samples adopted from the template of Alsharhan and El-sammak (2004).

(a) Mean against standard deviation
(b) Y2 against Y1
(c) Skewness against standard deviation

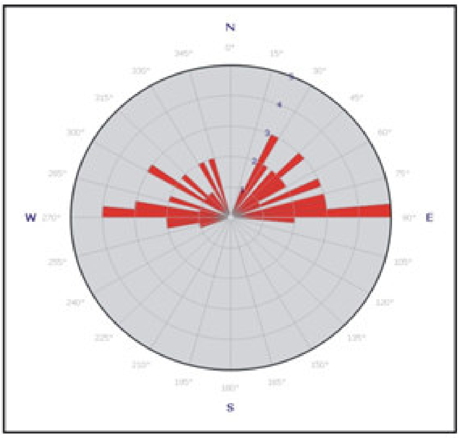


Figure 7: Rose diagram plot showing current directions

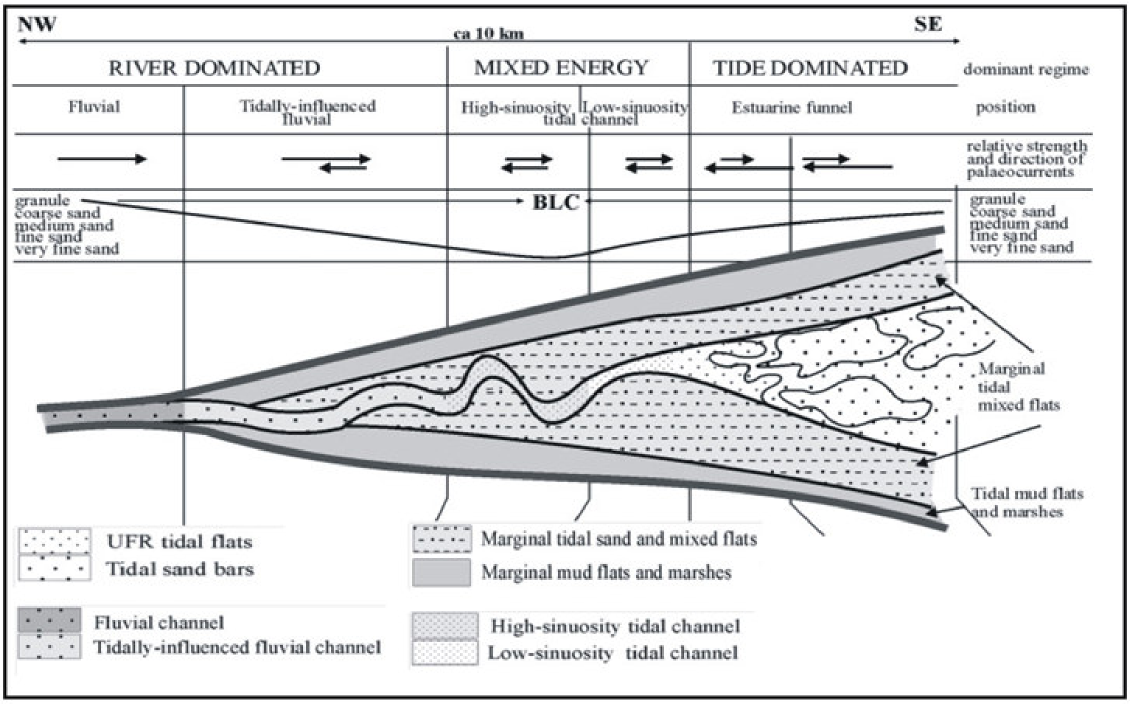


Figure 7: Estuary model of Dalrymple, (after Plink-Bjorklund, 2005).