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Textural Analysis, Erodibility Index Analysis and Hydro Network Pattern Delineation of Eocene Strata, South-Eastern Nigeria

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Abstract- Detailed field based studies were carried out on Eocene Strata of Nanka Sandstone, unit of Niger Delta. Textural analyses were carried out on twenty-one samples of the rock collected from various units across the study area. Gradistat v.8.0 was used to analyze the data obtained for sieve analysis. TRI-PLOT v. 1-4-2 was used to analyze the data obtained for pebble morphometry. The sieve analysis data were also subjected to the Erodibility Index Analysis (EIA) to estimate Erodibility Tendency (ET). By manual delineation, and the use of ArcGIS, the Hydro Network Pattern (HNP) was carried out. A reflection of a predominant shallow marine depositional environment controlled by tidal influence with its corresponding stratigraphy was observed. Very severe Erodibility Tendency (ET) was predicted based on very high values of Soil Loss (R) through the calculated erodibility indices, direct heavy raindrop impact on the sediments and the Hydro Network Pattern (HNP) which favor intense erosion of the study area. The criticality of this intense accelerated erosion is being factored by the friability and very high sand to clay ratio of Nanka Formation.

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I. Introduction

Eocene Nanka Formation was early published under Anambra Basin, southern Nigeria by Nwajide (1980). The Eocene Nanka Formation is under Ameki Group, which is a lateral equivalent of the Agbada Formation in the subsurface Niger Delta (Short and Stauble, 1967) (Figure 1). This particular group consists of Nsugbe Formation (formerly called Nsugbe Sandstone), Nanka Formation (formerly referred to as Nanka Sandstone), and Ibeku Formation (formerly known as Ameki Formation) (Nwajide, 1980; Ekwenye, 2014). Above Ibeku Formation lies Nanka Sandstone, follows by Ogwashi-Asaba Formation, then Benin Formation which is topmost unit.

Quite a lot have been done on the palaeocurrent, palaeoecological and paleo environmental manifestations of outcropping units of Niger Delta (Nwajide, 1980; Arua and Rao, 1986; Arua, 1990; Obi, Mode, Ekwe, Nnebedum, Ede, Egbu, 2013; Chukwuemeka, Odumodu, Mode, 2014; Ekwenye, Nichols, Okogbue, Mode, 2016). Other works focus on the erosion of the area (Obiadi, Nwosu, Ajaegwu, Anakwuba, Onuigbo, Akpunonu, Ezim, 2011; Nwabineli, Otti, 2012; Osadebe, Abam, Obiora, Sani, 2014)

This study aims at making use of combination of textural analysis, Erodibility Index Analysis (EIA) and Hydro Network Pattern (HNP) to estimate erosion susceptibility of Nanka Formation as regards to its environment of deposition.

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II. Methods

a) Field Methodology

The study covers an area of about 85.5625km2, with the boundary: latitudes 6°00´N and 6°05´N and longitudes 7°00´E and 7°05´E (Figure 2). Systematic logging of the exposures, and rock identification and sampling were done in towns – Aku, Ezinifete, Aguluezechukwu, Igbo Ukwu, Neni, Nnoha, Okpu-Agulu, Amaezike, Nwanchi, Aguluzigbo, Nanka, Isuofia, Umuchi Omeke, Ekwulobia (Figure 3). Most outcrops were in gullies. Global Positioning System (GPS) helped in spot locations and elevation. Outcrops were studied with lithological characteristics recorded and samples taken. Silva compass was used to measure the attitude of beds and other structures. Most exposures were mainly sandstones, intercalated by mudstones. The gully sites have general dimensions of approximately 550m, 300m and 50m as length, width and depth respectively. Because of such dimension and variable exposure of lithologies, the gully sites were studied station by station which enabled to undertake proper mapping.

b) Textural Analysis

i. *Sieve (granulometric or grain size) analysis*

Twenty-one sand samples were collected, at regular intervals, from sandstone units of the outcrops and labelled systematically from top to bottom. The samples were sun-dried at room temperature (25°C). The sediment samples were further disaggregated in the laboratory using a mortar and a rubber padded pestle (Pettijohn, 1957). Fifty gram of each samples were measured using a beam balance and sieved for 20 minutes with a Ro-tap sieve shaker using sieve mesh seizes of half-phi interval. The retained fractions were reweighed with a beam balance to an accuracy of 0.1g and recorded (Appendix 1). The data obtained were analysed with the aid of Gradistat v.8.0 software tool. Cumulative frequency curves of the data were plotted on an arithmetic log probability paper (Visher, 1969). Critical percentile phi values (φ5, φ16, φ25, φ50, φ75, φ75, φ84 and φ95) were extracted from the cumulative percentile curve and used to compute the univariate statistical parameters (Folk and Ward, 1957) namely: Mean Size (*x*), Sorting (σ), Skewness (*Sk*) and Kurtosis (*K*). Multivariate analysis of these parameters give prediction of the environment of study.

ii. *Pebble Analysis*

A total of six hundred pebbles were collected from three different locations (two hundred pebbles for each location) namely: *Nanka Outcrop 001, Nanka Outcrop 004 and Nanka Outcrop 005*. During sampling, deformed pebbles with distinct fresh breaks, flatness or clear primary elongation as well as those that show lithological in homogeneity were removed to ensure that readings obtained from caliper measurements were a true reflection of their dimension (Sames, 1966). The pebbles were divided into ten sub-populations of ten pebbles each out of the hundred pebbles for each location obtained after discrimination and measured on different days to eliminate operator bias (Sneed and Folk, 1958). The veneer caliper was used to measure the Long (L), the Intermediate (I) and the Short (S) axis (Dobkins and Folk, 1970). The following indices were determined for each pebble:

- Maximum Projection Sphericity (MPS)

  MPS= (S^2/LI) 1/3 (Sneed and Folk 1958)

- *Oblate - Prolate Index (OPI)*

  OPI= {[L-I/L-S]-0.5}/{S/L} (Dobkin and Folk 1970)

- Flatness Index (FI)

  FI= (S/L) % (Lutting, 1962)

The data obtained were computed with the aid of TRI-PLOT v1-4-2 software tool.

c) *Erodibility index analysis*

i. *Soil erodibility determination*

Eight rock samples from eight locations were taken from various depths for soil structural classification.

ii. *Indirect method analysis*

The sieve computation with Gradistat v.8.0 (see above section), instead of the laboratory test with hydrometer (*direct method*), was looked into to get information on the percentage of sand, silt and clay in the sediment samples taken from those localities. From such *indirect method*, erodibility index (K) was known using equation: K = ((SAN + SIL)/CLA) * (1/100) (Bouyoucos, 1935) SIL, SAN, and CLA are percent silt, sand, and clay respectively.

iii. *Erosion Prediction*

The rainfall factor or erosivity (R) was calculated from:

R = 0.5 H (Roose, 1977)

The mean annual rainfall (H) is circa 1875mm/year (73.875inches/year) for study area. Amount of soil loss in each of these sites was predicted using RUSLE (Revised Universal Soil Loss Equation):

A = 2.242 R K

R is rainfall factor, A is soil loss converted to tons/ha/yr by multiplying by 2.242 and K is erodibility factor (Hudson, 1995).

d) *Hydro network delineation*

Manual delineation of watersheds with done using the study area topographic map. Contour lines in topo map were used to locate drainage divides. Representation of flow directions (arrows) were drawn perpendicular to each contour, in the direction of the steepest descent. Manual delineation of drainage divides is hard and time consuming task; and errors from this process are not uncommon. Therefore, through ArcGIS Hydro Data Model with associated ArcInfo functionality by using a DEM data of the study area from Earth Explorer, watershed and catchment boundaries were pinpointed accurately and automatically.

III. Results

a) *Field Methodology*

Eight localities were visited i.e. Nanka Outcrop 001 to 008. The sand units are generally poorly sorted, medium to coarse grain and friable (unconsolidated). The friability of the sand unit across the study area is due to the very high sand to clay ratio (Figure 4 – 7). Meanwhile, at the top of some units are lateritic reddish materials which would suggest areal exposure and at the base of some units are quartz pebbles which would also suggest a high energy condition, showing generally WSW to ENE pebble imbrication. Most sand units have mud clasts/ drapes while some are intercalated by mud laminar and beds. Decrease in suture force of the slope of the gully wall was also observed due to the tendency of slide.

b) *Textural Analysis*

i. *Sieve (granulometric or grain size) analysis*

Distribution plots of grain sizes for the twenty-one samples show grain size distribution of rock samples analysed. The gravel sand mud and sand silt clay diagrams were also plotted to identify the sample type, textural group and sediment name (Figure 10 & 11). The cumulative frequency (log-probability) plots are presented in Figure 12. Two-segment and three-segment curves are present with the three-segment curves being the most predominant. There are four two-segment curves depicting the combination of traction and saltation, and suspension subpopulations and seventeen three segment curves depicting separated traction, saltation and suspension subpopulations. Table 1 summarizes the result of computed grain size parameters and their verbal terminology of all the twenty-one samples and the environment of deposition of each sample. The samples are generally medium to very coarse grained in size, unimodal, bimodal and trimodal. The samples are also generally poorly to moderately sorted. Skewness values show the samples are generally very positively (very fine) skewed, positively (fine) skewed, symmetrical skewed, negatively (coarse) skewed and very negatively (very coarse) skewed. The values are also predominantly mesokurtic, platykurtic, leptokurtic and very leptokurtic. The statistical parameters are also used to discriminate the environment following discriminant function analysis (Sahu, 1964). Two of discriminant functions were found relevant in the present study.

- $Y_{aeolian:beach}\ (Y_1) = -3.5688\ M_Z + 3.7016\ \delta^2 - 2.0766\ S_K + 3.1135\ K_G.$
- $\mathbf{Y_{beach:\ shallow\ marine}\ (Y_2) = 15.6534\ M_Z + 65.7091\ \delta^2 + 18.1071\ S_K + 18.5043\ K_G}$
- $\mathbf{Y_{shallow\ marine:\ fluvial\ (deltaic)}\ (Y_3) = 0.2852\ M_Z - 8.7604\ \delta^2 - 4.8932\ S_K + 0.0482\ K_G.}$

The following classifications were used in order to distinguish the different depositional environments:

- $Y_{beach:shallow\ marine} < 65.3650$---***beach environment***
- $Y_{beach:shallow\ marine} > 65.3650$---***shallow marine environment***
- $Y_{shallow\ marine:fluvial} < -7.4190$---***fluvial environment***
- $Y_{shallow\ marine:fluvial} > -7.4190$---***shallow marine environment***

Data obtained from the discriminant functions (Table 2) shows the twenty-one samples have *shallow marine* and *fluvial boundaries*. However *shallow marine* is the most dominant environment.

ii. *Pebble Analysis*

- *For Nanka Outcrop 001*

The total Oblate Prolate Index (OPI) for the pebbles was given as 24.99873538, while the mean OPI obtained was 0.249987354. The total Flatness Index (FI) was 2817.243993%, while the mean FI was 28.17243993%. Also, the value for the total Maximum Projection Sphericity (MPS) was 38.03225011 while the mean value of MPS was 0.380322501. Details of measurements are shown in Appendix 2 while the results of the computations are shown in Table 3.

- *For Nanka Outcrop 004*

The total Oblate Prolate Index (OPI) for the pebbles was given as -59.19296583 while the mean OPI was obtained as -0.591929658. The total Flatness Index (FI) was 3215.950318%, while the mean value of FI was obtained as 32.15950318%. Also, the value for the total Maximum Projection Sphericity (MPS) was obtained as 40.47722031 while the mean value of MPS was 0.404772203. The results of the computations are shown in Table 3.

- *For Nanka Outcrop 005*

The total Oblate Prolate Index (OPI) for the pebbles was given as 9.018641699 while the mean OPI was obtained as 0.090186417. The total Flatness Index (FI) was 2978.09253%, while the mean value of FI was obtained as 29.7809253%. Also, the value for the total Maximum Projection Sphericity (MPS) was obtained as 38.35189856 while the mean value of MPS was 0.383518986. The results of the computations are shown in Table 3.

Figure 13, 14 and 15 show their respective SHAPE (Sneed and Folk, 1958) triangular diagrams which display the dominance of plot points in P-B-E and VP-VB-VE regions suggesting *transitional E.O.D. and beach E.O.D* respectively*,* while few point are seen in CP-CB-CE region suggesting *fluvial E.O.D*.

c) *Erodibility index analysis*

From Table 4, soil loss rates predicted for the study area are generally very severe in a modified version (Chinatu, 2007). Annual soil loss erosion prediction ranges from 80.726 tons/ha/yr at *Nanka Outcrop 008* to 88.419 tons/ha/yr at *Nanka Outcrop 002*.

d) *Hydro network delineation*

The manually delineation of watersheds from a topographic map (Figure 16) shows the trajectory of flows, Atama watershed and Nanka subwatersheds. While, the ArcGIS Hydro Data Model with associated ArcInfo functionality by using DEM gave maps showing watershed, subwatersheds, flow trajectories and catchments (flow edge and edge catchments) which corresponded to the manually delineated one (Figures 17 & 18).

IV. Interpretation and Discussion

a) Textural Maturity

Data from granulometric analysis show that the clay portion never passes greater than 5% (values are mostly 0%); poor to moderate sorting was generally observed poor to moderate. Texturally, the sand is *submature to mature* (Folk, 1974). Poor to moderate sorting and major variations in skewness may indicate *fluctuating energy conditions or intermittent winnowing*. The log-probability (cumulative frequency) plots made an indication of either *a tidal flat or a shallow marine environment of deposition*.

b) Environment of Deposition

Nanka Formation depositional environment may be reconstructed by looking into its stratigraphic, lithological description, sieve analysis, pebble analysis and structural attributes. These description and analyses depict, in a general sense, *shallow marine depositional environment*. The presence of variegated and mudstone facies, and mud-draped sandstone are part of characteristics of *tidal channel, supratidal deposits and tidal flat (tide-dominated estuarine)*. Although, this may not be conclusive. It is important to look at Nanka Formation with regards to its environmental model approach (Figure 19). A correlation chart was also done to relate the basin signature to those of the litho-log.

c) Erosion Susceptibility

The determination of the erodibility indices of sediments showed that the particles in Nanka area are mainly unconsolidated and friable sandy sediments. These unconsolidated and friable sandy particles are known to have very low cohesive force and therefore are much more prone to removal and carriage by water as it is the medium peculiar in the area. However, high portion sand in sediment content favors high rate of infiltration and permeability of water into the rock which may increase tendency of landslide and erosion by increasing pore pressure, thereby decreasing the shear strength (resistance) of the units. The very high erodibility indices (K) and very high soil loss (R) values of the study area showed generally very severe tendency of erodibility.

The detachment and transportation of particles by water are aided by the direct raindrop impact on the sediments (Figure 20) and the hydro network pattern (due to the topographic setting) of the study area. All these factors the caused the accelerated erosion in the study area gave general geometry/ stage of active/ U-shaped at Nanka, Umuchiana and Agulu gully sites (Figure 21).

V. Conclusions

The detailed description of part of Eocene Nanka Formation and results from the textural analysis of twenty-one samples taken reflect a predominantly shallow marine depositional environment controlled by tidal influence with its corresponding stratigraphy. The results presented in this work provide clear knowledge of the geology of the area and region as a whole. Very severe erodibility tendency was predicted from the observation of very high values of soil loss (R) through the calculated erodibility indices, direct heavy raindrop impact on the sediments and hydro network pattern which favor intense erosion of the study area. Another factor that is critical to this intense accelerated erosion is friability and very high sand to clay ratio of the Nanka Formation. I would recommend, however, that detailed structural study of area is needed to identify the initiation of the gullies, extent of the tectonic events and their precise relationship with evolution of Benue Trough (southern) and Niger Delta.

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