***Original Research Article***

**GRAIN SIZE DISTRIBUTION OF SEDIMENTS AND ITS ENVIRONMENTAL IMPLICATIONS ON UBULU OKITI, OGWASHI-ASABA FORMATION**

**ABSTRACT**

Grain-size Distribution of sediments and dynamics of transportation was carried out to reveal the depositional environment condition and energy, as well as the mode of transportation along the study area. In total 10 ditch cutting samples were collected in the study area and sent to the laboratory for granulometric analysis. The study showed the great sensitivity of the interrelationships of various grain size statistical parameters (mean size, sorting, skewness, and kurtosis) to the slight variations in the compositional formula of the sediment mixture. Textural and statistical parameters were then calculated from the results of the particle size distribution. The result shows that the grain size ranges from -3φ – -2φ (granules) to 2φ – 3φ (very fine sand). The average mean of the population is 0.79φ, with a modal class in the 1φ – 2φ size grade. The average sorting value is 1.34σ which indicates a poorly sorted population. The fluctuation between moderately well-sorted to well-sorted sediments and from coarse skewed to fine skewed under leptokurtic to platykurtic nature was distinguished at different localities and relevant environmental implications. Different discrimination tools as bivariate cross plot of grain size parameters, Linear Discrimination Functions (LDF), skewness and kurtosis relationship as a non-dimensional expression of sediment/energy simulation, Energy Process diagram, and mode of transportation (C-M diagram), indicates the marine signature followed the riverine input as a function of the sediments locality. Depositional processes were mainly hydraulically controlled through active energy processes of the marine environment. The fluvial nature of sediment demonstrated the graded suspension and saltation modes as the prime factors for transportation, influenced by marine and turbidity environment actions, within a shallow agitated marine environment.

Key words: Grain-size Distribution, Depositional processes, turbidity, marine environment, depositional environment.

**1.0: INTRODUTION**

Grain-size analysis is ubiquitously employed by sedimentologists, geomorphologists, geographers and civil engineers working with outcrop and core datasets in clastic sedimentary systems. In detailed studies, where a description using a hand-lens is insufficient, further methods are required to build a more quantitative description of grain-size and sorting. Older methods for grain-size analysis are based on sedimentation rates for fine-grained (clay to silt) fractions and sieving for coarse-grained (silt and larger) fractions (Buller and McManus, 1972; Gee and Bauder, 1986). Rivers are bodies of water that flow downhill or downstream due to the influence of gravity. They are agents of erosion of weathered materials from highlands, and also, agents of transportation and deposition of sediments. They are usually the link between the land where weathering occurs and seas, lakes, and ocean bodies where deposition of a thick succession of sediments takes place. Also, some of the sediments they carry are deposited on land areas like flood plains and alluvial plains where extensive and thick fluvial sedimentation takes place. The heavily discharge of the Niger Delta fluvial deposition to the Atlantic ocean through its main branches, gradually developed the delta (Late Pliocene), since 6000-8000 years B.P. (Stanley, 1990; Said, 1993; Stanley and Warne, 1993). However, marine and other environmental processes transported some of the discharged sediments in cross-shore and alongshore directions on the continental shelf (Stanley, 1990). Grain-size analysis is generally used to define and reconstruct the depositional environments of clastic sediments (Passega, 1957, 1964; Passega and Byramjee, 1969). Longshore and cross-shore grain-size distribution reflect the operated waves and currents that result in sorting process of beach sand ( Frihy and Komar, 1993; Frihy et al., 1995). This study attempts to investigate the characteristics of grain size the grains size distribution of the sediments and infer depositional energy, its relevant environmental implication to reveal depositional environment bas on energy and hydrodynamic conditions and mode of transportation of the study area sediments.

**2.0: Location and Geology of Study Area**

The study area (Figure 1) is located within longitude 060 371 E and 060 451 E and latitude 060 051 N and 060 171 N. It is is located within the northern flank of the Niger Delta Basin. The area is accessible by good road network, footpaths and the River Niger. The area is well drained by two rivers, River Atakpo and River Anwai and the drainage pattern is basically dentritic. Because the soil is porous, the surface water is recharged by run off and is infiltrated. Subsurface water is also available from the underlying formations: The Pleistocene to Recent Alluvium, the Eocene Ogwashi – Asaba Formation and the Oligocene – Miocene Ameki formation. The Alluvium is presently

The River Niger and the Asaba Plateau with its undulating slopes dominate the Asaba landscape. These slopes descend gently eastwards towards the River Niger such that Asaba city itself is located on the valley and west bank of the river. Okpanam and Ibusa are located on the scarp of the Asaba plateau. The plateau itself disappears completely just south of Asaba. Several streams that originate as springs at higher elevation dissect the plateau slopes but only one, the relatively broad Amilimocha River joins the River Niger at Asaba town. Mean annual temperatures range from about 220C to 340C, while rainfall is between 1,501mm and 1850mm; mean evapotranspiration is 1117mm [11].

**3.0: Materials and Methods**

The project work undertook both field work and laboratory study approach. The samples obtained from the field were subjected to laboratory analysis and interpretation.

**3.1: Sample Collection**

The study area is located along the Western part of Niger Delta and samples were collected at ten different locations along the course of the Western areas of the Ashaba Ikiti in Delta State. The collected samples are distributed along 19 points, spaced by 1 to 3 km, perpendicular to the shoreline and extend into the land from the beach line to 40-50 m south of the shoreline, including one sample from the river bed. The samples are distributed along 3 main profiles parallel to the shoreline; the first profile A starts at the shoreline; the second B is taken from the semi -wet area at less than 20 m from the shoreline, and the third profile C is collected from the dry area at 40- 50 m or less. Each representative beach sample (1-2 kg) was collected from the upper 15 cm of the sand beach face using a plastic scoop and kept in plastic bags. The position of each station along the study area was determined using a GPS and illustrated in Fig1. Fresh samples were collected from the riverbed with the help of divers, and sediment colour and grain sizes were noted. They were packaged in bags and labeled and then transported to the laboratory for analysis. Ten samples representing the ten locations were presented for grain size analysis in the laboratory. They were oven-dried to remove moisture content and poured into a set of BSS standard sieves with known aperture sizes and mechanically vibrated for at least fifteen minutes to enable the grains to separate into their different sizes. The result was used to calculate the statistical parameters of the grain population of the sediment according to (Folk 1991). The parameters are the median, mean, mode, sorting (standard deviation), skewness, and kurtosis of the grain population.

1) Median Diameter (Md) This is the average size of the sample at a percentile of 50% where half of the grains are coarser, and half are finer than the median.

2) Mean (GM): The average size of the distribution. This is the best measure of average grain size, which is derived from the spread of percentile values of a grain size distribution. It is calculated from:

M=ϕ (6+ϕ50+ϕ 84)

3

3) Mode (Mo) The modal class is that with the highest representation on a size-frequency plot. It is the commonest grain size.

4) Sorting Co-efficient (So) / Standard Deviation (GSD) (σ): This is a measure of the spread of the size distribution on either side of the average diameter.

GSD = ϕ84- ϕ16+ ϕ95- ϕ5

4 6.6

5) Skewness (GSK) This is the tendency for a grain size distribution to deviate from normality and lean to one side. It is a positively or negatively sign dimensionless number. It has neither metric nor phi values and lies between the range -1 to +1:

GSD = ϕ84- ϕ16-2(ϕ50)+ ϕ95- ϕ5-2(ϕ50)

2 (ϕ84- ϕ16) 2 (ϕ84- ϕ16)

6) Kurtosis (K) It is a measure of the peakedness of the grain distribution. It is related to the dispersion and normality of the distribution.

K= ϕ95- ϕ5

2.44 (ϕ75- ϕ25)

**4.0: PRESENTATION AND DISCUSSION OF RESULTS**

The calculated statistical parameters of the studied sediments of Ashaba Ikiti river bed are presented in Table.1 and 2, and Fig. 3–8. The grain size represented in the sediments collected ranges from -2 φ – -1 φ (granules) to 3 φ – 4 φ (very fine sand). The average mean of the population is 0.89 φ, which is the coarse sand fraction. From the analysis, the modal class is 1 φ to 2 φ (medium sand size) in most of the samples, with exception of AI 4 which is polymodal with the modal class in the -1 to -0 φ class. 40% of the Sediments are unimodal with more than 80% of the grains in the modal class, while, others display bimodal to polymodal distributions. The sorting of samples ranges from well-sorted through moderately sorted to poorly sorted. The average sorting value is 1.26 σ which implies poorly sorted. 30% are symmetrical in their skewness, 10% are positively skewed, and 60% are negatively skewed to very negatively skewed. 60% of the sediments range from leptokurtic to extremely leptokurtic, 10% are very platykurtic, 10% are platykurtic and 20% are mesokurtic. The cumulative curves of the sediment show transport were majorly by traction and saltation as the sizes all fall within the granules and fine grain sands. It is also observed that the sediments from location AI 1 to AI 6 have little or no fine sands but infiltration of fine sands occurs from AI 7 to AI 10, which could be interpreted as saying the grains become finer downstream.

|  |  |  |
| --- | --- | --- |
| DEPTH | SAMPLE | DESCRIPTION |
| 4 |  | Reddish brown top surface sand(Alluvium) @ 9M |
| 8 |  |
| 12 |  |
| 16 |  | Brownish fine to medium grained sandstone with dark brown intercalations. |
| 20 |  |
| 24 |  |
| 28 |  |
| 32 |  | Whitish gray fine-medium grain sandstone with hard surfaces at 52m |
| 36 |  |
| 40 |  |
| 44 |  |
| 48 |  |
| 52 |  |
| 56 |  | Whitish gray wet clay mixed fine grain sandstone and a thick lignite bottom. |
| 60 |  |
| 64 |  |
| 68 |  |
| 72 |  |
| 76 |  |

**Figure.1: Lithologic Description of the sampled area.**

**TEXTURAL ATTRIBUTES OF SEDIMENT**

The fluvial sediments from the tropical rivers in Kelantan show a wide range of textural facies including fine, medium, coarse sands and gravels. Interestingly, there is no consistent pattern of downstream locations were enriched with the fine sand. Overall, most of the sediments has relatively high sorting values and categorised as very poorly sorted, with couples of samples fall under the category of poorly sorted. Kurtosis analysis show that all samples (except SK1) are better sorted at the tail than the central portions, hence the very platykurtic curves. The nature of measured kurtosis values indicates that the sands are of matured and is believed due to aggregation of sediment particle size by compaction and variation in the sorting values (Ramanathan 2010)

**Table.1: SUMMARY OF PARTICLE SIZE DISTRIBUTION RESULT**

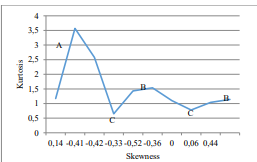
|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S/N** | **DEPTH**  **M** | **SIEVE DIAMETERS (mm)** | | | | | | | | | |
| **2** | **1.4** | **0.7** | **0.5** | **0.355** | **0.25** | **0.18** | **0.125** | **0.09** | **0.063** |
| 1. **1** | 3-9 | 100 | 100 | 95.1 | 88.0 | 77.2 | 62.1 | 45.8 | 37.3 | 35.1 | 34.5 |
| 1. **2** | 9-12 | 100 | 99.8 | 55.3 | 41.8 | 32.0 | 27.2 | 20.7 | 17.3 | 16.4 | 16.1 |
| 1. **3** | 24-27 | 99.7 | 86.3 | 47.2 | 32.3 | 21.6 | 19.9 | 10.0 | 6.8 | 4.9 | 3.2 |
| 1. **4** | 36-39 | 99.4 | 92.5 | 61.9 | 38.9 | 23.4 | 14.5 | 6.7 | 3.8 | 2.5 | 1.3 |
| 1. **5** | 39-42 | 95.3 | 79.3 | 45.0 | 30.9 | 18.7 | 10.0 | 6.2 | 3.7 | 2.5 | 1.2 |
| 1. **6** | 42-45 | 97.8 | 88.5 | 56.8 | 37.6 | 17.1 | 11.5 | 4.5 | 2.7 | 1.9 | 0.7 |
| 1. **7** | 45-48 | 93.3 | 86.7 | 55.7 | 39.4 | 18.8 | 12.6 | 5.2 | 3.3 | 2.3 | 1.2 |
| 1. **8** | 48-51 | 93.9 | 83.4 | 50.0 | 33.3 | 21.9 | 19.7 | 12.1 | 8.0 | 6.1 | 4.2 |
| 1. **9** | 51-54 | 98.5 | 92.8 | 60.5 | 38.1 | 21.2 | 10.0 | 5.6 | 3.2 | 1.9 | 0.2 |
| 1. **10** | 54-57 | 98.6 | 92.6 | 62.8 | 41.3 | 19.1 | 8.6 | 4.6 | 2.9 | 2.1 | 1.3 |

**Table.2: GRAN SIZE ANALYSIS PARAMETERS**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **S/n** | **Depth (m)** | **% Gravel** | **% Sand** | **% Fines** | **Cu** | **Cc** | **K (cm/sec)** |
| 1. 1 | 3-9 | 0 | 65.5 | 34.5 | - | - | - |
| 1. 2 | 9-12 | 0 | 83-9 | 16.1 | - | - | - |
| 1. 3 | 24-27 | 0.3 | 96.5 | 3.2 | 5.0 | 1.42 | 4.86X10 -4 |
| 1. 4 | 36-39 | 0.6 | 98.1 | 1.3 | 3.5 | 1.06 | 6.615 X 10 -4 |
| 1. 5 | 39-42 | 4.7 | 94.1 | 1.2 | 5.0 | 1.13 | 8.64 X 10 -4 |
| 1. 6 | 42-45 | 2.2 | 97.1 | 0.7 | 5.0 | 0.70 | 8.64 X10 -4 |
| 1. 7 | 45-48 | 6.7 | 92.1 | 1.2 | 4.0 | 0.85 | 7.935 X10 -4 |
| 1. 8 | 48-51 | 6.1 | 89.7 | 4.2 | 7.0 | 0.13 | 3.375 X10 -4 |
| 1. 9 | 51-54 | 1.5 | 98.3 | 0.2 | 3.0 | 0.94 | 9.375 X10 -4 |
| 1. 10 | 54-57 | 1.4 | 97.3 | 1.3 | 3.0 | 0.83 | 1.0935 X10 -3 |

**ENVIRONMENTAL AND FACIES INTERPRETATION**

The systematic variations in the grain size distribution parameters proposed by (Folk 1991), when plotted against each other can be used to observe changes and variations in depositional environment, transport history, and energy of transporting and depositional current amongst others. Fig.2 are the bivariate plots of skewness versus kurtosis which can be used to interpret the depositional energy and facies distribution. From Fig.2, it is observed that the Odi River sediments are deposited within changing spectrum of energy. The sediments are deposited in high and low energy regimes. About 60% of the sediments are leptokurtic to extremely leptokurtic which indicates exceptionally good sorting, it is represented by the first section of the graph with high kurtosis at peak A in Fig.2. High kurtosis can be achieved by high energy, which has the ability to winnow sediments according to their sizes to enable good sorting. The moderate and low energies are associated with the mesokuric and platykurtic sediments with moderate and poor sortings respectively indicated on the graph by B and C. Fig. 2shows that 80% of the sediments are symmetrical to very negatively skewed indicating the coarseness of the sediments, which are approximately granules to coarse sands facies. This does not satisfy (Folk 1966). who opined fluvial sediments are mainly saltation load infiltrated by some suspension loads and they are positively skewed and leptokurtic.



Ashaba Ikiti sediment

Fig.2. Plot of kurtosis versus skewness showing variation in the energy of the depositional environment

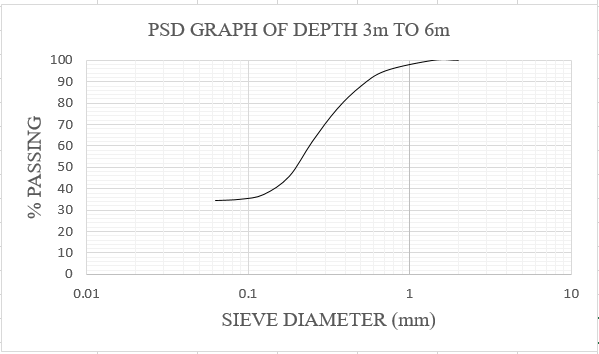
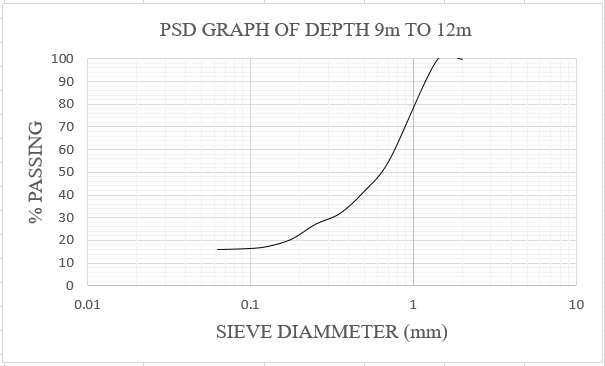
 

Figure.3 Figure.4

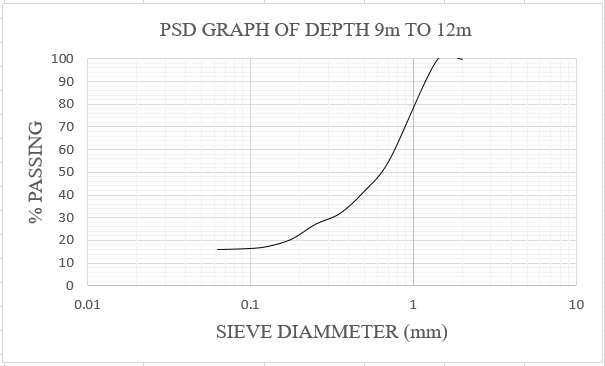
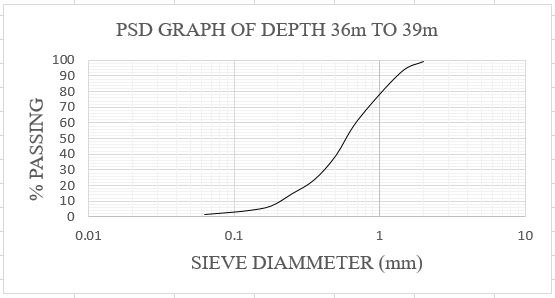
 

Figure.5 Figure.6

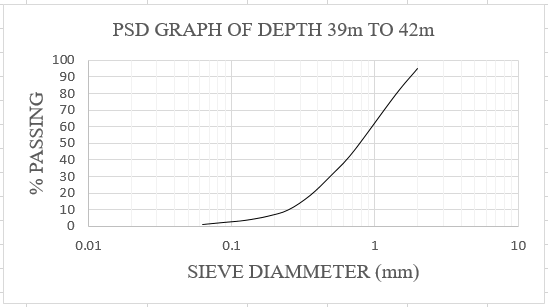
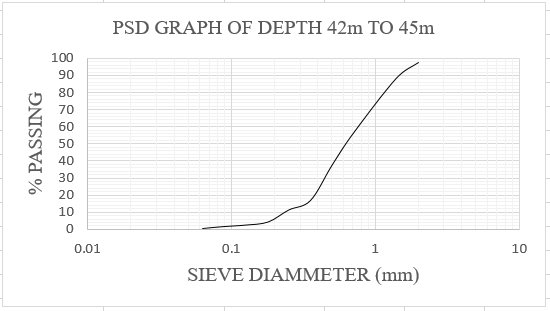
 

Figure.7 Figure.8

Fig 3-8: PSD graph showing the variation of particle size distribution

The relationship between mean (φ) and sorting (σ) shows the variation of the mean grain size with changes in the environment. The average mean of the sediments is 0.98 φ and it falls within the coarse sand size while, the average sorting is 1.26 σ indicating poorly sorted, which is typical of river sediments. Environment, where there is a high variation in transport energy associated with increase in mean grain size and a decrease in sorting (σ), is typical of fluvial and fluvioglacial channels. In such a case, low energy transport alternate with high energy and deposit coarse materials when energy is declining leading to poorly sorted materials, while at low energy, sorting takes place (Harasimiuk, 1991, Ludwikowska-Kędzi, 2000). Evaluation of the sediments from Ashaba Ikiti River bed indicates a spectrum of high and low energies which are associated with grain size ranging from granules to fine sands. The plot shows that 90% of the sediments are moderately sorted to poorly sorted.

The plot of skewness versus sorting in Fig. 2 separates the sediments into two facies: the coarse moderately well sorted to poorly sorted sands on the left negative side and the fine sands on the right with poor sorting. Both facies are channel bed sediments but the finer sands occur where stream energy is less. The point where skewness is zero is the boundary between the two facies, it is the zone that has the best-sorted grains (Ludwikowska-Kędzia, 2000). The bivariate plot of the median and skewness in Fig. 2, plot the sediments in the river deposits domain according to (Stewart, 1958).

**Discrimination of Environmental Boundaries**

A plot of skewness vs standard deviation is the most effective in differentiating between river and beach sands (Friedman, 1967), while (Moiola and Weiser, 1968) pointed out, that the plot of mean size vs standard deviation is used for discriminating beach and river sands. Fig. 2 of mean size and standard deviation reveal that the beach environment is the samples environment deposition according to (Friedman, 1967) boundary. The Fluvial influence is evident from the abundance of fine grain size, while beach environment is evident from the better sorting character, driven by the energy wave motion on beaches. Accordingly, beach environment near a river mouth is predominant as a deltaic outcome. (Moiola and Weiser, 1968) documented that the coastal dune environment is predominate over the river and beach environments attributed to both the better sorting and the fine grain size of the sand sediments.

**Energy and Hydrodynamic Conditions**

Based on the cross correlation between Y1, and Y2 values, the sediments are distributed in the aeolian process based on Y1 values where the energy fluctuations are least and the sediments are best sorted and within shallow agitated water based on Y2 values. Shallow marine water is proposed upon Y3 values as the

**CONCLUSION**

The grain size distribution of sediments along the three profiles revealed the dominance of unimodal fine sand sediments with a value of 2.5 Φ, represent the distribution of the pure sand, mainly Nile sand sources, indicating a consistent depositional process along the study area. The predominance of fine sand population mode mixed with varying subordinate populations tends to be fine towards the backshore, where a small tail of silt is observed. The slightly coarser trend towards shoreline could be attributed to enrichment in shell fragments along the shoreline and removal of fine particles by the winnowing action of waves and currents in an absence of riverine supply. Generally, the eastern area of Rosetta mouth tends to be more fine than the western area, due to littoral drift of current influence that carry the discharged sediments towards east of the Rosetta mouth. The shoreline sediments along profile A are dominated by moderately well-sorted, mostly negative skewness values and leptokurtic nature of sediments, suggesting a high energy environment, through the continuous reworking action of beach ridges and screening process of waves and currents. The backshore dry area along profile C is characterized mainly by moderately well sorted, positive skewness values and mesokurtic nature corresponding to riverine/aeolian input within an unidirectional transport, controlled by relatively low energy condition compared to the shoreline, and resulted in accumulation of finer sediments that originally built up sand promontories on the delta faces. The semi-wet areas along profile B that represent intermediate area between shoreline and backshore area, has a common trend along the study area of most well sorted nature, most positive skewness values and most mesokurtic nature attributed to the equal intermixing of the subordinate population with the predominant sediment mode and explained as a function of energy conditions sediments from marine and riverine/aeolian processing‟s.

The predominance of well-sorted fine sand with near symmetrical character of skewness and leptokurtic nature of kurtosis distribution of river bed sample corresponds to the unidirectional river supply and transport (channel), besides the local impact of the depositional environment and relatively high energy condition that linked to the active Rosetta mouth environment and the fishing cages activity. The study shows the great sensitivity of grain size parameters to the small changes in the compositional formula of the sediment mixture. Both the graded suspension and suspension with rolling mode (saltation) are the prime factors for transportation, where the sediments deposited and reworked by turbidity and marine actions, within a shallow agitated marine environment.

**References**

Allen JRL. (1965). Late quaternary Niger Delta and adjacent areas: sedimentary environments and lithofacies. American Association of Petroleum Geologists Bulletin, 49(5)49–600.

Blott, S. J. and Pye, K. (2001). GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth surface processes and Landforms, 26(11): 1237-1248. Doi:10.1002/esp.261

Boggs Jr., S. (2009). Petrology of sedimentary rocks. Cambridge university press, 600pp. Doi:10.1017/cbo9780511626487

Davies J.C. (1972). Statistics and Data Analysis in Geology. Wiley and Sons, New York, 1986, pp. 190–198. Reinneck HE and Singh IB. Genesis of laminated sand and graded rhythmites in storm – sand layers of shelf mud. Sedimentology, 18:123–128.

Doust, H., and Omatsola, E., (1990.) Niger delta, in: Edwards, J.D., and Santogrossi, P.A., (eds.), Divergent/passive Margin Basins, American Association of Petroleum Geology Memoir 48, p.239-248.

Evamy, B.D., Haremboure, J., Kamerling, P., Knaap, W.A., Molloy, F.A., and Rowlands, P.H., (1978), Hydrocarbon habitat of Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin, vol. 62, p.277-298.

Fanos, A. M.; Khafagy, A. A. and Dean, R. G. (1995). Protective works on the Nile Delta coast. Journal of Coastal Research, 11(2): 516-528.

Folk R.L, and Ward W. (1957). Brazos River Bar: a study of the significance of grain size parameters. Journal Sedimentary Petrology, 27:3–26.

Folk, R. L. (1966). A review of grain-size parameters. Sedimentology, 6(2): 73-93. Doi:10.1111/j.1365-3091.1966.tb01572.x

Friedman, G. M. (1967). Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. Journal of Sedimentary Research, 37(2): 327-354. Doi:10.1306/74d716cc-2b21-11d78648000102c1865d

Frihy, O. E. (2007). The Nile Delta: processes of heavy mineral sorting and depositional patterns. Developments in Sedimentology, 58: 49-74. Doi:10.1016/S0070- 4571(07)58002-7

Frihy, O. E. (2017). Evaluation of future land-use planning initiatives to shoreline stability of Egypt‟s northern Nile delta. Arabian Journal of Geosciences, 10(5): 109. Doi:10.1007/s12517-017-2893-4.

Frihy, O. E. and Dewidar, K. M. (2003). Patterns of erosion/sedimentation, heavy mineral concentration and grain size to interpret boundaries of littoral sub-cells of the Nile Delta, Egypt. Marine Geology, 199(1-2): 27-43.

Frihy, O. E. and Komar, P. D. (1993). Long-term shoreline changes and the concentration of heavy minerals in beach sands of the Nile Delta, Egypt. Marine Geology, 115(3-4): 253-261. Doi:10.1016/0025-3227(93)90054-Y

Ghoneim, E.; Mashaly, J.; Gamble, D.; Halls, J., and AbuBakr, M. (2015). Nile Delta exhibited a spatial reversal in the rates of shoreline retreat on the Rosetta promontory comparing pre-and post-beach protection. Geomorphology, 228: 1-14. Doi:10.1016/j.geomorph.2014.08.021

Goldsmith, V. and Golik, A. (1980). Sediment transport model of the southeastern Mediterranean coast. Marine Geology, 37(1-2): 147-175. Doi:10.1016/0025- 3227(80)90015-8

Haack, R.C., Sundaraman, P., and Dahr, J., (1997), Niger Delta Petroleum System in Extended Abstracts. American Association of Petroleum Geologists Hedberg Research Symposium Petroleum Systems of the South Atlantic Margin, November 16-19, 1997, Rio de Janerio Brazil, p. 213-231.

Hamouda, A.; El-Gharabawy, S.; Awad, M.; Shata, M. and Badawi, A. (2014). Characteristic properties of seabed fluvial-marine sediments in front of Damietta promontory, Nile Delta, Egypt. The Egyptian Journal of Aquatic Research, 40(4): 373-383. Doi:10.1016/j.ejar.2014.11.006

Hereher, M. E. (2010). Vulnerability of the Nile Delta to sea level rise: an assessment using remote sensing. Geomatics, Natural Hazards and Risk, 1(4): 315-321. Doi:10.1080/19475705.2010.516912

Harasimiuk M.Vistulian (1991). Glacial cycle of the fluvial processes development in the valley of Middle Wieprz River (SE Poland). Annales UMCH,;46:81–109.

Hooper, R.J., Fitzsimmons, R.J., Grant, N., and Vendeville., B.C.,( 2002). The Role of deformation in controlling depositional patterns in the South Central Niger, West Africa. Journal of Structural Geology, Vol. 24, p. 847-859.

Hospers, J., (1965), Gravity field and structure of the Niger Delta, Nigeria, West Africa. Geological Society of American Bulletin, vol. 76, p. 407422.

Inman DL.( 1949). Sorting of sediments in the light of fluid mechanics. Journal of Sedimentary Petrology,;19:51–70.

Inman, D. L. and Jenkins, S. A. (1984). The Nile littoral cell and man‟s impact on the coastal zone of the southeastern Mediterranean. Proceedings of 19th International Conference on Coastal Engineering, American Society of Civil Engineers, 1600- 1617pp. Doi:10.9753/icce.v19.109

Kulke, H., (1995), Nigeria, in: Kulke, H., (ed.). Regional Petroleum Geology of the world. Aprt II: Africa, Australiax and Antactica: Berlin, Gebruder Bogrntraeger, p.143-172.

Lehner, P., and de Ruiter, P.A.C., (1977), Structural history of Atlantic Margin of Africa. American Association of Petroleum Geologists Bulletin, vol. 61, p. 961-981.

Ludwikowska-Kędzia M. , (2000). Ewolucja środkowego odcinka doliny rzeki Belnianki w późnym glacjale i holocenie. (Evolution of the Middle Segment of the Belnianka River Valley in the Late Glacial and Holocene) Dialog press, Warsaw, 180 pp.

Marriner, N.; Flaux, C.; Morhange, C. and Kaniewski, D. (2012). Nile Delta‟s sinking past: Quantifiable links with Holocene compaction and climate-driven changes in sediment supply?. Geology, 40(12): 1083-1086. Doi:10.1130/G33209.1

Moiola, R. J. and Weiser, D. (1968). Textural parameters; an evaluation. Journal of Sedimentary Research, 38(1): 45-53. Doi:10.1306/74d71ad2-2b21-11d7- 8648000102c1865d.

Murat, R.C., (1972), Stratigraphy and Paleogeography of the Cretaceous axnd Lower Tertiary in Southern Nigeria. 1st conference of African Geology, Ibadan proceedings; Ibadan, Nigeria, Ibadan University Press, p. 251-266.

Passega, R. (1957). Texture as characteristic of clastic deposition. AAPG Bulletin, 41(9): 1952-1984. Doi:10.1306/0BDA594E-16BD-11D7-8645000102C1865D

Passega, R. (1964). Grain size representation by CM patterns as a geologic tool. Journal of Sedimentary Research, 34(4): 830-847. Doi:10.1306/74D711A4-2B21-11D7- 8648000102C1865D.

Passega, R. and Byramjee, R. (1969). Grain-size image of clastic deposits. Sedimentology, 13(3‐4): 233-252. Doi:10.1111/j.1365-3091.1969.tb00171.x

Petroconsultants, (1996a). Petroleum exploration and production database: Houston, Texas, Petroconsultants, Inc., [database available from Petroconsultants, Inc., P.O. Box 740619, Houston, TX 77274-0619].

Reijers, T.J.A., (1996). Reservoir geological core description using standardized lithofacies and the associations in the Tertiary Niger Delta. Nigerian Association of Petroleum Explorationist Bulletin, Vol. 10, p.27-39.

Said, R. (1993). The River Nile: geology, hydrology and utilization. New York, Pergamon Press, 320pp. Doi:10.1016/C2009-0-11234-5

Short, K.C. and A.J. Stauble, (1967). Outline of geology of Niger Delta. Am. Assoc. Petrol. Geol. Bull., 51: 761-779. DOI: 10.1306/5D25C0CF-16C1-11D7-8645000102C1865D

Sly, P. G. (1978). Sedimentary processes in lakes. In: "Lakes". Lerman, A. (Ed.) Springer, New York, NY, 65-89pp. Doi: 10.1007/978-1-4757-1152-3\_3

Stacher, P., (1995). Present understanding of the Niger Delta hydrocarbon habitat, in: Oti, M.N and G. Postman, (eds.). Geology of Deltas, p. 257-267

Stanley, D. J. (1990). Recent subsidence and northeast tilting of the Nile delta, Egypt. Marine Geology, 94(1-2): 147-154. Doi:10.1016/0025-3227(90)90108-V

Stanley, D. J. and Warne, A. G. (1993). Nile Delta: recent geological evolution and human impact. Science, 260(5108): 628-634. Doi:10.1126/science.260.5108.628

Stanley, J. D.; Goddio, F.; Jorstad, T. F. and Schnepp, G. (2004). Submergence of ancient Greek cities off Egypt's Nile Delta-A cautionary tale. GSA TODAY, 14(1): 4-10. Doi:10.1130/1052 5173(2004)0142.0.CO;2

Stewart, H.B Jr. (1958). Sedimentary reflections on depositional environments in San Migue Lagoon, Baja, California, Mexico. American Association of Petroleum Geologists Bulleti,; 42:2567–2618.

Waugh, D. (1995).Geography: an integrated approach. 2nd ed. Nelson, Glasgow, UK, , p. 593.

Weber, K.J., (1971), Sedimentological aspects of oil fields in the Niger Delta. Geologic En Mijnbouw, Vol. 50, p. 559-576.

Weber, K.J., and Daukoru, E.M., (1975), petroleum Geology of the Niger Delta. Proceedings of the Ninth World Petroleum Congress, vol.2, Geology: London, Applied Science Publishers, Ltd., p. 210-221.

Whiteman, A.J., (1982), “Nigeria its Petroleum Geology Resources and Potential I & IT” Edinburgh, Graham and Tortman, 166pp.