Sedimentological Study and Heavy Mineral Analysis of Sediment Samples from Well-S, Niger Delta, Nigeria

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Abstract  Sedimentological study and petrographic analyses were carried out on thirty ditch cutting samples from well-S, Niger Delta, Nigeria, with the aim of determining the provenance and depositional environment of the sediments. The samples were subjected to soxhlet extraction for the removal of soluble organic matter from them and particle size analyses using Pipette and Emery sedimentation techniques in order to determine the grain size distribution of the sediments. Separation of heavy of mineral from the samples was done with the aid of bromoform to enable petrographic analyses of the heavy mineral suite, under the polarising microscope. The data obtained from the grain size analysis were used in preparing histograms, from which some simple statistical parameters were derived. Graphic mean values obtained range between 0.74 and 2.64 Ø, which implies that the sediments are predominantly fine-medium grained. The inclusive standard deviation values ranges from 0.53 to 1.24 Ø, indicating that the sediments are moderately well sorted to moderately sorted. Inclusive graphic skewness values of 0.29 to 0.70 indicate that the sediments ranges from finely skewed to strongly finely skewed and the graphic kurtosis values of 0.61 to 1.54 shows that the sediments are predominately very platykurtic which implies a low energy environment of deposition. The polymodal nature displayed by the histograms indicates that the sediments have been derived from various sources. The study concluded that the sediments were deposited in a fluvial environment. It also established that the sediments originate from metamorphic and acid igneous rocks of the Nigeria Basement Complex and mineralogically mature to sub-mature.

Keywords  Grain Size, Heavy Mineral, Provenance and Depositional Environment

1. Introduction

Sediments are derived from the pre-existing rocks that have been weathered, transported and deposited in basins. The Niger Delta is one of the depositional basins in Nigeria and it has been accommodating sediments since the Paleocene.

The understanding of the sedimentary processes most importantly the environmental factors that have influence on the weathering, transportation, deposition and subsequent modification of the sediments are crucial in knowing their source and reconstructing the environment in which they were. Sedimentologists are saddled with the responsibility of studying the properties of the sediments such as texture, structure, chemical and mineralogical composition to uncover the natural history of the sediments.

Although, the Niger Delta has been extensively studied by various workers, as regard the provenance of the sediments, heavy mineral suite and depositional environment (NERDECO (Netherlands engineering consultant, 1959 [1]); Evamy et al., 1978[2]; Adedokun 1981[3]; Mateawo 1995[4]), there is paucity of information on sedimentological and heavy mineral studies of sediments from deepwater wells in the Niger Delta.

The aim of the present work is to study the sedimentological properties of sediments from two deepwater Niger Delta wells penetrated in the sequence and subsequently establish the provenance and environment of deposition of the sediments.

2. Geology of the Study Area

The Niger Delta, which is the most important sedimentary basin in Nigeria, is one of the world’s major hydrocarbon prolific basin and largest delta complexes. It is located between latitudes 4° and 6° North and longitudes 4° and 9° East. It is bounded in the West by the Benin Flank and in the East by the Calabar Flank which is a subsurface continuation of the Oban Massif. The Delta covers an area in excess of 75,000km² (Avbovbo, 1978[5]). The Niger Delta occupies an area restricted by the Benin Flank, the Calabar Flank, the Anambra Basin and the Senonian Abakaliki Uplift. It is situated in the Gulf of Guinea on the west coast of Africa. Themodern Niger Delta is generally agreed to be built on an
oceanic crust. The supporting arguments came from the pre-continental drift reconciliation. This indicates an important overlap of NE Brazil on the present Niger Delta; and from a series of geological and geographical observations. The Delta has been very prolific in terms of hydrocarbon due to the association of source rock, structure, thermal histories and lithology type which are favourable conditions for the production, accumulation and retention of hydrocarbons.

3. Materials and Methods

Thirty (30) ditch cutting samples from 10700-11570m, collected at 30m in Well-S were obtained for sedimentological studies from a Nigeria deepwater operator (Oil Company). The name and location of the well was not made available for proprietary reasons. However approximate location of the study area as shown in (figure 1).

A soxhlet extraction was carried out to remove the soluble organic matter contained in the samples using mixture of n-hexane and toluene in ratio 2 to 3 as solvent. Thereafter, the samples were wet sieved using 63 µm mesh to separate the fine grained size fraction (silt/clay) from the coarse grained size fraction (sand particle) using the standard procedure of Carver (1971)[6] and Folk (1974)[7]. The clay/silt fraction of the sample was analysed for grain size distribution using pipette method, while Emery’s rapid sedimentation tube method was used for the grain size studies of the sand size fraction of the samples.

Twenty (20) sand sized fraction samples were selected for the heavy mineral separation and dry sieved with 200micron mesh in order to remove the coarse grains. The sample was introduced into a separating funnel containing bromoform in a fume cupboard and was properly stirred. The heavy minerals settled while the lighter fraction floated on the bromoform due to difference in their densities (Carver 1971). The heavy minerals obtained were sprinkled on a glass slide and covered with a cover slip using Canada balsam as a mounting medium. These slides were labelled properly and examined under petrographic studies.

Figure 1. Map of Niger Delta showing location of the study area (Modified after Whiteman 1982).
4. Results and Interpretation

The data obtained from the pipette and emery’s sedimentation tube analyses were used in plotting cumulative, histogram and probability curves. Quantitative graphical values for the various percentiles such as Ø5, Ø16, Ø25, Ø50, Ø75, Ø84 and Ø95 were obtained from these curves on the probability log paper and the results are presented in Table 1. The following Statistical parameters derived from the results include; graphic mean, inclusive graphic standard deviation, inclusive graphic skewness and graphic kurtosis for each sample. These parameters are defined by the equations that make use of the percentiles stated above as proposed by Folk and Ward (1957) [8].

The textural characteristics, mechanisms of deposition and depositional environment of the studied samples were inferred from the statistical parameters. The values obtained from graphic mean ranges between 0.74 and 2.64 ø. This shows that sediments are fine to coarse grained. On the average, about 63.3% of the sediments are fine grained, 33.3% are medium grained and 3.4% are coarse grained. This implies that the velocity of the transporting and depositing medium themselves environment with deposition in a predominantly low energy environment.

The inclusive graphic standard deviation values ranges from 0.53 to 1.24 ø which indicates that the sediments are moderately sorted to moderately well sorted. About 60% of the samples are moderately sorted while the remaining 40% were moderately well sorted. However the range of standard deviation values, predominantly in excess (0.80 – 1.4) implies a moderately agitated medium with a relatively constant energy of deposition. The range of standard deviation values of 0.50 to 0.80 ø is more typical of fluvial environments than inland dunes which indicate that the sediments were deposited by a river supplying the sea with sediments (Friedman, 1961)[9].According to Folk (1974), sediments that are deposited by a constant current will produce better sorting than sediments deposited by current that fluctuate rapidly. Therefore, the sediments analysed in the studied well section must have been deposited by constant to intermediate current strength.

The values of skewness and kurtosis, show how closely the grain size distribution approaches the normal Gaussian probability curve and the more extreme the values are, the more the size curves deviates from normal (Folk, 1974). Sediments from one source has fairly normal curves while sediments from more than one source deviate appreciably from the normal and show high values of skewness and kurtosis. The values of the graphic skewness ranges from 0.29 to 0.70 (i.e from fine skewed to strongly fine skewed). This shows that the energy of the environment is low as indicated by the prevailing positive skewness of the sediments. More than 96% of the sediments are strongly fine skewed while the remaining 4% are fine skewed.

The graphic kurtosis values obtained for the samples range from 0.61 to 1.54 (from very platykurtic to very leptokurtic). On average, more than 33% of the sediments are leptokurtic while 60% of the sediments were very platykurtic, platykurtic and mesokurtic at 20% each and the remaining 6.7% were very leptokurtic. This implies that they have the tails portions better sorted than the central part, although there are values that show better sorting at the central part.

The three principal modes of transport which are traction (rolling/sliding), saltation and suspension (Visher, 1969[10]; Visher and Howard, 1974[11]; Sagoe and Visher, 1977[12]) are generally represented by different line segments on a probability plot. Friedman (1967) showed that river sands commonly display these three modes of transportation while beach sands in contrast display only the saltation transportation components. Detail examination of most of the probability curves derived from the studied samples indicates three line segments which imply that the three modes of transportation were present. It means that the deposits were likely to be of fluvial origin. The most effective transport mechanisms of the sediments studied are saltation and suspension with saltation being the predominant while traction can be a subordinate mechanism of transportation (figure 3).

The histogram plotted for most of the samples analysed exhibit polymodal to bimodal distribution (figure 2). The histograms show similar grain size distribution.

The polymodal nature of the samples indicates that the sediments are from different sources. The uniformity of sands in this area is believed to be as a result of uniformity in the force transporting and depositing them. The histograms displayed both the primary and subsidiary modes. The primary mode is between 0.92 and 2.39 ø while subsidiary mode is between 3.00 and 3.84 ø.
Table 1. Percentile values for each sample

| SAMPLE NO | Ø5  | Ø16 | Ø25 | Ø50 | Ø75 | Ø84 | Ø95 |
|-----------|-----|-----|-----|-----|-----|-----|-----|
| 1         | 0.80| 1.36| 1.60| 2.06| 2.80| 3.20| 3.61|
| 2         | 0.92| 1.80| 2.03| 2.48| 2.87| 3.40| 3.68|
| 3         | 1.67| 1.00| 1.41| 1.80| 2.19| 2.40| 2.83|
| 4         | 0.0 | 0.00| 0.21| 1.68| 2.50| 2.82| 3.50|
| 5         | 0.87| 1.81| 1.87| 2.35| 3.02| 3.30| 3.63|
| 6         | 1.18| 1.64| 2.00| 2.52| 3.20| 3.38| 3.72|
| 7         | 0.82| 1.28| 1.53| 2.20| 2.77| 3.31| 3.59|
| 8         | 0.88| 1.82| 2.08| 2.62| 3.10| 3.40| 3.71|
| 9         | 0.70| 0.91| 1.00| 2.00| 2.62| 3.00| 3.70|
| 10        | 0.82| 1.73| 2.07| 2.68| 3.18| 3.52| 3.61|
| 11        | 1.23| 1.49| 1.71| 2.48| 3.39| 3.61| 3.77|
| 12        | 0.22| 0.87| 1.68| 2.53| 2.91| 3.20| 3.68|
| 13        | 0.91| 1.20| 1.50| 2.33| 2.89| 3.27| 3.70|
| 14        | 0.87| 1.28| 1.60| 2.42| 3.10| 3.31| 3.87|
| 15        | 0.00| 0.75| 1.22| 2.00| 2.58| 2.85| 3.42|
| 16        | 0.00| 0.2 | 0.57| 1.47| 1.83| 2.03| 2.43|
| 17        | 0.00| 0.00| 0.00| 0.53| 1.30| 1.68| 2.00|
| 18        | 0.48| 0.80| 1.49| 2.02| 2.58| 2.88| 3.51|
| 19        | 0.00| 0.00| 0.00| 1.01| 1.80| 2.10| 2.91|
| 20        | 0.00| 0.00| 0.12| 1.80| 2.31| 2.60| 3.28|
| 21        | 0.27| 1.58| 0.87| 2.43| 1.83| 2.87| 3.20|
| 22        | 1.20| 1.62| 1.69| 2.28| 2.71| 2.80| 3.08|
| 23        | 0.00| 0.80| 1.42| 1.91| 2.28| 2.59| 3.00|
| 24        | 0.58| 1.47| 1.70| 2.23| 2.60| 2.87| 3.42|
| 25        | 0.41| 1.29| 1.63| 2.22| 2.37| 2.68| 3.32|
| 26        | 0.72| 1.68| 1.89| 2.43| 2.81| 3.01| 3.48|
| 27        | 1.12| 1.51| 1.70| 1.97| 2.38| 2.92| 3.39|
| 28        | 0.60| 1.30| 1.58| 2.00| 2.30| 2.70| 3.30|
| 29        | 0.78| 1.02| 1.20| 1.68| 2.01| 2.31| 3.02|
| 30        | 1.02| 1.52| 1.72| 1.98| 2.40| 2.59| 3.30|
Figure 2. Showing the histogram plots for some Samples
4.1. Depositional Environment

Sahu (1964) [13] proposed some equations that are useful for the confirmation of the depositional environment. One of these equations is used to differentiate between shallow marine and fluvial sediments. It is mathematically expressed as:

\[ Y_{sh.mari \ flu} = 0.2852Mz - 8.76040 \sigma - 4.8432SKI + 0.0482Kg \]

Where:
- \( Mz \) = Graphic mean
- \( \sigma \) = Square of the average graphic standard deviation
- \( SKI \) = Average graphic skewness
- \( Kg \) = Average graphic kurtosis

Figure 3. Showing the probability Plots for some samples.
He further proposed a limit value which he used to distinguish the environments, thus:

- $Y_u < -7.1490$ indicates fluvial environment
- $Y_u > -7.4190$ indicates shallow marine environment.

The value derived for the analysed samples is $-8.0471$ which indicate that they are fluvial sediments.

### 4.2. Results of the Heavy Mineral Analysis

The heavy minerals present in the sediments analysed are listed in Table 2. According to Carver (1971), heavy minerals are accessory minerals present in concentrations of less than 1%. They are chiefly silicates and oxides, many of which are very resistant to mechanical abrasion and chemical weathering.

### 4.3. Petrography

The heavy mineral assemblages were dominated by opaque minerals in the samples analysed. It has been noted by Friedman and Sanders (1978)[14] that opaque minerals typically predominate in a heavy mineral suite. Emphasis is placed on non-opaque minerals in this study because the opaque minerals are of little importance in provenance determination. They are anhedral in shape with very irregular outlines. The non-opaque minerals include Tourmaline, Staurolite, Rutile, Zircon, Apatite, Kyanite, Amphibolite, Monazite and Olivine. A brief description of the textural and optical characteristics of each heavy mineral type is as shown in Table 3. The photomicrographs of some of the heavy minerals as shown in figure 4.

#### Table 2. Showing heavy minerals present in the sediments analysed

| Sample | Label | Heavy Minerals Present |
|--------|-------|------------------------|
| 1      |       | Staurolite, Zircon, Rutile, Garnet, Amphibole and Opaque ores |
| 2      |       | Tourmaline, Kyanite, Staurolite, Garnet and Opaque ores |
| 3      |       | Rutile, Staurolite, Amphibole, Olivine and Opaque ores |
| 4      |       | Tourmaline, Zircon, Garnet and Opaque ores |
| 5      |       | Rutile, Kyanite, Staurolite, Zircon, Garnet and Opaque ores |
| 6      |       | Tourmaline, Staurolite, Zircon, Kyanite and Opaque ores |
| 7      |       | Staurolite, Zircon, Rutile, Garnet, Olivine and Opaque ores |
| 8      |       | Zircon, Rutile, Olivine and Opaque ores |
| 9      |       | Tourmaline, Staurolite, Zircon, Rutile, Monazite and Opaque ores |
| 10     |       | Tourmaline, Staurolite, Zircon, Rutile, Kyanite, Garnet, Amphibole and Opaque ores |
| 11     |       | Staurolite, Zircon, Rutile, Garnet and Opaque ores |
| 12     |       | Zircon, Rutile, Kyanite, Garnet and Opaque ores |
| 13     |       | Staurolite, Kyanite, Tourmaline, Zircon, Garnet and Opaque ores |
| 14     |       | Staurolite, Tourmaline, Zircon, Rutile, Monazite and Opaque ores |
| 15     |       | Tourmaline, Staurolite, Kyanite, Rutile and Opaque ores |
| 16     |       | Staurolite, Tourmaline, Kyanite, Rutile, Zircon, Garnet and Opaque ores |
| 17     |       | Tourmaline, Staurolite, Zircon, Kyanite, Garnet and Opaque ores |
| 18     |       | Tourmaline, Staurolite, Zircon and Opaque ores |
| 19     |       | Staurolite, Kyanite, Garnet, Amphibole and Opaque ores |
| 20     |       | Tourmaline, Rutile, Zircon, Kyanite and Opaque ores |

#### Table 3. Showing optical properties of heavy minerals in the sediments

| Optical Properties | tourmaline | staurolite | rutile | zircon | garnet | apatite | kyanite | monazite | olivine |
|--------------------|------------|------------|--------|--------|--------|---------|---------|----------|--------|
| Colour             | Greenish Brown | Yellow to brown | Reddish brown | Colourless to light brown | Dark brown | colourless | Yellow to brown | Pale greenish yellow | colourless |
| Relief             | High       | High       | High    | High   | High   | High    | High    | High     | Moderate |
| Pleochroism        | Strongly pleochroic | Pleochroic | Non-pleochroic | Non-pleochroic | Non-pleochroic | None    | None    | Pleochroic | None    |
| Form               | euhedral and sub-rounded | Anhedral | Prismatic, euhedral and rounded | Prismatic and subhedral | Rounded to sub-rounded | Prismatic | Anhedral | Sub-rounded | Rounded |
| Extinction         | Parallel   | Parallel   | Parallel | Parallel | Parallel | Parallel | Inclined with twinning | Inclined with twinning | None    |
| Inclusion          | Quartz     | None       | None    | None    | None    | None    | None    | None     | Quartz  |
| Birefringence      | High       | Low        | High    | High    | High    | Low     | Low     | Weak     | Low     |
Figure 4a. Photomicrograph of sample 1

Figure 4b. Photomicrograph of sample 2
Figure 4c. Photomicrograph of sample 6

Figure 4d. Photomicrograph of sample 7
5. Conclusions

The data obtained from the statistical parameters show that the sands from well-S are predominantly fine grained, moderately sorted to moderately well sorted, strongly fine skewed and very platykurtic. This implies that the sediments were deposited in a relatively low energy fluvial environment.

It was revealed by the statistical parameters that the sediments were transported mainly by saltation and suspension with a greater population of the sediments transported by saltation. The sediments in the sequence studied have been found to be deposited in a predominantly low energy medium under fluviatile conditions as deduced from the application of Sahu’s (1964) equation to the

**Keys:** Amph- Amphibole, Kyan- Kyanite, Stau- Stauroilite, Tour-Tourmaline, Ruti-Rutile, Zirc- Zircon, Oli-Olivine, Gar-Garnet.
The heavy mineral suite indicates that the sediments of the study area are likely to have been derived from acid igneous and metamorphic rocks which form part of the Basement Complex rocks of Nigeria. The co-occurrence of stable heavy minerals like Tourmaline, Zircon, Rutile, and Garnet indicate that the sediments are mineralogically mature.

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