Research Article

Provenance Analysis of Sediments in ILU-TITUN and Environs, Eastern Dahomey Basin, Ondo State, Nigeria

O.B. Taiwo, A.B. Adeyemi and O.A. Ademeso
Department of Geology, Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria

Abstract: Twenty eight sediment samples were obtained from road cuts and stream cuts in Ilu Titun area of Ondo State, Nigeria and were subjected to Grain Size Distribution (GSD) analysis, from which statistical parameters were calculated and used to determine the environment of deposition of the sediments. Six representative samples were selected for petrographic studies to determine the heavy mineral content of the sediments with a view to establishing the sediments source of Ilu Titun and environs which mark the eastern margin of the Dahomey basin. The Graphic Mean (Mz) ranges from 0.700Φ to 1.667Φ while the Inclusive Graphic Standard Deviation (σi) range from 0.960 to 1.319. The Inclusive Graphic Skewness (SKG) of the samples ranges from -0.665 to 0.803 while Kurtosis range from 1.652 to 3.309. The bivariate plot of mean size against the Inclusive graphic standard deviation show that the sediments were deposited by river and beach processes. The plot of skewness against the Inclusive graphic standard deviation confirmed that the sediments were deposited by river processes. The results of the petrographic studies show that Slides EK 01 and EK 08 have Kyanite and Staurolite. Slides EK 13 and EK 24 have Staurolite, Tourmaline and Garnet. Slides EK 26 and 28 have Tourmaline and Zircon present in them. Bivariate plots using the statistical parameters show that the sediments were deposited by fluvial processes. The results from the petrographic studies indicate that the sediments were sourced from metamorphic rocks and pegmatites.

Keywords: Bivariate plots, graphic mean, graphic skewness, kurtosis, petrographic analysis, standard deviation

INTRODUCTION

Provenance questions must be answered in all sedimentary basins. In the case of ancient basins which have evolved through several regimes of tectonic upheavals, such provenance questions are answered without the benefit of obvious source regions for the sediments, due to either or both of the disappearance or dislocation of source rocks (through various processes such as tectonic movements, weathering and erosion). Proffering solutions to provenance determination problems is one of the most difficult exercises a petrographer must tackle (Pettijohn et al., 1972).

Despite the huge challenges associated with provenance determination, the lithology of the now-vanished sedimentary source can be deduced from the mineralogical composition of the present day sediments. The composition of sedimentary rock units is therefore important in provenance studies. However, the composition of sedimentary rocks is controlled by a complex system of factor which acts on the rock from the source location and lithology to the time of sedimentary rock formation. Some of these factors include weathering, erosion, hydrodynamic effects and diagenesis—all of which are affected by other contributing factors such as transport distance, time, energy and climate (Johnsson, 1993).

The knowledge of the provenance of sediments in the eastern Dahomey basin is little. There is a need for the provenance studies in this area because the area is underlain by vast deposit of bitumen in sandstone reservoir rock. Although bitumen is a heavy hydrocarbon, the reservoir characterization of the study area is important for the extraction of the bitumen. The environment of deposition of the sediments, derived from provenance studies, can be used to give a qualitative characterization of the sandstone reservoir rock.

LOCATION AND GEOLOGICAL SETTING

The area of study (IluTitun area, Okitipupa Local Government Area, Ondo State, Southwestern Nigeria) is located between latitudes 4°55′N and 5°00′N and longitudes 6°55′E and 6°59′E near the eastern boundary of the Dahomey basin. The area is underlain by coastal plain sands of Oligocene to recent age (Fig. 1).

The Dahomey basin belongs to one of the series of West African Atlantic margin basins initiated during the rifting phase in the late Jurassic to early Cretaceous (Omatola and Adegoke, 1981; Weber and Daukoru, 1975). The axis of the basin as well as its depo-centre lies slightly west of the Nigerian-Benin Republic...
The tectonic evolution, detailed geological setting, stratigraphy and hydrocarbon potentials of the basin are extensively described and documented by various workers such as Billman (1992), Hack et al. (2000), Jones and Hockey (1964), Okosun (1996), Omatsola and Adegoke (1981) and Reyment (1965).

The stratigraphy of the sediments in the Nigerian sector of the Benin basin is controversial. This is mainly because different nomenclatures have been proposed for the same formation in different localities in the basin (Olabode and Adekoya, 2008). Jones and Hockey (1964) confirmed both Cretaceous and Tertiary sediments while Billman (1992) subdivided the stratigraphy of the basin into three chronostratigraphic packages; pre-lower Cretaceous folded sediments, Cretaceous sediments and Tertiary sediments. In the Nigerian section of the Dahomey basin, the Cretaceous sequence based on outcrop and borehole records have been shown to consist of the Abeokuta Group which is subdivided into three formations; Ise, Afowo and Araromi Formations (Omatsola and Adegoke, 1981). The Tertiary sediments however consist of Ewekoro, Akinbo, Oshosun, Ilaro and Benin (coastal plain sand) Formations. The summary of the details about the stratigraphy of the sediments in the Nigerian section of the Dahomey basin has been recorded in Olabode and Adegoke (2008). The Dahomey basin has a high hydrocarbon potential. Evidences include the occurrence of large deposits of tar sands in the Nigerian sector of the basin. Also, there have been reported cases of hydrocarbon production in the Cretaceous and Tertiary sedimentary rocks in the Seme field offshore Benin Republic (Coker and Ejedawe, 1987).

**METHODS**

Samples were collected at road cuts, stream cuts and in present day river channels using hand trowels and were kept in labeled sample bags. Twenty eight samples were collected in all and subjected to laboratory analyses for provenance determination. The laboratory analyses carried out on the sediments are Grain size distribution and heavy minerals analyses.

**Grain size analysis:** Sieve analysis was carried out using the American Society for Testing and Materials (ASTM) C136 procedures. Details about the procedures of the analysis have been recorded in Adeyemi (2010) (Unpublished Report). The data from the grain size analysis are presented in the form of cumulative frequency curves (Ogive) and Bivariate plots. The approach employed in this preliminary research work was to carry out sedimentological studies by using statistical parameters to characterize the sediments. The
method employed to carry out the statistical analysis depended on results of the statistical parameters (such as Inclusive Graphic Mean, Inclusive Graphic Standard Deviation, Inclusive Graphic Skewness and Graphic Kurtosis) calculated from the percentile values derived from the cumulative curve of the grain size distribution of sediments.

The formulae used for the calculation of the statistical parameters include:

\[
M_z = \frac{\phi_{15} + \phi_{50} + \phi_{84}}{3}
\]

\[
\sigma_I = \frac{\phi_{84} - \phi_{16} + \phi_{95} - \phi_5}{6.6}
\]

\[
SK_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{5} + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_{5})}
\]

\[
K_I = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}
\]

where,

- \( M_z \) = Inclusive graphic mean
- \( \sigma_I \) = Inclusive graphic standard deviation
- \( SK_I \) = Inclusive Graphic Skewness
- \( K_I \) = Graphic Kurtosis
- \( \phi_n \) = Phi Unit at a given percentile

where, \( n \) represents a given percentile value such as 5, 16, 84 or 95 as shown in Eq. (1) to (4).

Heavy minerals analysis: The heavy minerals preparation procedures followed the methods described by Mange and Heinz (1992). The heavy minerals were separated from each of the sieved fractions using bromoform (density range of 2.88-2.9) and the residues were mounted in piperine (refractive index of 1.67). The heavy minerals comprise opaque and non-opaque minerals. The opaque minerals cannot be distinguished from one another during petrographic studies and as such they are not used in the heavy minerals analysis. Non-opaque minerals were identified and used in the provenance analysis based on the recommendation of earlier workers.

**RESULTS AND DISCUSSION**

This result of the derived phi units at various percentiles of the cumulative curve is presented in Table 1. The statistical parameters derived from the results of the grain size distribution are discussed below:

**Statistical parameters:** Table 2 shows the calculated values of Inclusive Graphic Mean, Inclusive Graphic Standard Deviation, Inclusive Graphic Skewness and Graphic Kurtosis from the grain size analysis. The values of the graphic mean (\( M_I \)) ranges from 0.700 to 1.667\( \Phi \). Thus, the grain size of the sediments range from medium grained to coarse grained sand. 39% of the overall sediment samples are coarse grained while 61% are medium grained. This indicates that the sediments were deposited in medium to high kinetic energy environment since very high kinetic energy of the transporting medium will result in non-deposition of...
Processes. Deviation (σ) samples were poorly sorted while the remaining 18%
mechanism is likely to be of either marine or fluvial elimination the possibility of the aeolian transport.

EK27 1.317 Medium Grained Medium 1.078 Poorly sorted 0.026 Nearly Symmetrical 2.020 Very Leptokurtic
EK26 1.367 Medium Grained Medium 1.010 Poorly sorted -0.055 Nearly Symmetrical 1.836 Very Leptokurtic
EK25 1.317 Medium Grained Medium 0.992 Moderately sorted -0.033 Nearly Symmetrical 1.732 Very Leptokurtic
EK24 1.267 Medium Grained Medium 1.223 Poorly sorted -0.665 Strongly Coarse skewed 2.509 Very Leptokurtic
EK23 1.200 Medium Grained Medium 0.970 Moderately sorted 0.016 Nearly Symmetrical 1.715 Very Leptokurtic
EK22 1.333 Medium Grained Medium 0.982 Moderately sorted 0.004 Nearly Symmetrical 1.652 Very Leptokurtic
EK21 1.000 Coarse Grained 0.995 Moderately sorted -0.055 Nearly Symmetrical 1.779 Very Leptokurtic
EK20 1.033 Medium Grained Medium 1.045 Poorly sorted -0.106 Coarse skewed 1.918 Very Leptokurtic
EK19 1.617 Medium Grained Medium 1.043 Poorly sorted -0.175 Coarse skewed 2.008 Very Leptokurtic
EK18 1.667 Medium Grained Medium 1.025 Poorly sorted -0.100 Nearly Symmetrical 1.893 Very Leptokurtic
EK17 1.050 Medium Grained Medium 1.086 Poorly sorted 0.000 Nearly Symmetrical 2.123 Very Leptokurtic
EK16 1.317 Medium Grained Medium 1.030 Poorly sorted -0.082 Nearly Symmetrical 1.936 Very Leptokurtic
EK15 0.817 Coarse Grained 1.184 Poorly sorted 0.076 Nearly Symmetrical 2.164 Very Leptokurtic
EK14 1.000 Coarse Grained 1.100 Poorly sorted 0.103 Nearly Symmetrical 2.197 Very Leptokurtic
EK13 0.983 Coarse Grained 1.108 Poorly sorted 0.086 Nearly Symmetrical 2.250 Very Leptokurtic
EK12 1.000 Coarse Grained 1.319 Poorly sorted 0.006 Nearly Symmetrical 3.309 Very Leptokurtic
EK11 0.933 Coarse Grained 1.184 Poorly sorted 0.048 Nearly Symmetrical 2.436 Very Leptokurtic
EK10 0.783 Coarse Grained 1.173 Poorly sorted 0.051 Nearly Symmetrical 2.426 Very Leptokurtic
EK9 0.717 Coarse Grained 1.121 Poorly sorted -0.052 Nearly Symmetrical 2.446 Very Leptokurtic
EK8 0.817 Coarse Grained 1.259 Poorly sorted -0.086 Nearly Symmetrical 2.520 Very Leptokurtic
EK7 0.933 Coarse Grained 1.158 Poorly sorted 0.089 Nearly Symmetrical 2.525 Very Leptokurtic
EK6 0.700 Coarse Grained 1.239 Poorly sorted 0.043 Nearly Symmetrical 2.739 Very Leptokurtic
EK5 1.100 Medium Grained 0.960 Moderately sorted 0.083 Fine skewed 1.705 Very Leptokurtic
EK4 1.233 Medium Grained Medium 1.136 Poorly sorted -0.169 Coarse skewed 2.496 Very Leptokurtic
EK3 1.300 Medium Grained Medium 1.091 Poorly sorted -0.124 Coarse skewed 1.870 Very Leptokurtic
EK2 1.367 Medium Grained Medium 1.086 Poorly sorted -0.118 Coarse skewed 1.971 Very Leptokurtic
EK1 1.350 Medium Grained Medium 1.144 Poorly sorted -0.255 Coarse skewed 2.459 Very Leptokurtic
EK0 0.700 Coarse Grained 1.239 Poorly sorted 0.043 Nearly Symmetrical 2.739 Very Leptokurtic
Table 2: Summary of the results from statistical analyses and their interpretation

The values of the Inclusive Graphic Standard Deviation (σ) range from 0.960 to 1.319. 82% of the samples were poorly sorted while the remaining 18% were moderately sorted. The results show that the energy of the transporting medium fluctuated randomly thus resulting in the poor sorting of the sediments.
The Inclusive Graphic Skewness of the samples range from -0.665 to 0.803. 71% of the samples are nearly symmetrical, 21% are coarse skewed and 4% are fine skewed while the remaining 4% of the samples are strongly coarse skewed.
Of the overall calculated skewness values, 68% of the samples are negatively skewed. Negative skewness
is usually as a result of the turbulence in the transport medium which has a predominantly unidirectional flow. This gives an indication that the transport medium is likely to be of fluvial origin.

The calculated values of kurtosis, as shown in the table of summary of results, range from 1.652 to 3.309. The samples are essentially very leptokurtic since 96% of the samples belong to this distribution while 4% of the samples are extremely leptokurtic. It can therefore be concluded that the sediments are very leptokurtic; implying that the sediments are from the same source.

The environment of deposition for the sediments was determined using the bivariate plots by plotting one statistical parameter against another. Figure 2 shows the plot of the Inclusive graphic Skewness against the mean size of the sediments. When compared with plots from Friedman (1961) and Stewart (1959), this plot indicates that the data points do not plot in the dune or wave processes area. The data plots within the river processes area. This confirms the unidirectional flow of the transporting medium which is a non-eolian mechanism.

The bivariate plot of mean size against the Inclusive graphic standard deviation (Fig. 3) also confirms that the sediments were deposited by river and beach processes when compared with plots from Friedman (1961, 1967). The bivariate plot of skewness against the Inclusive graphic standard deviation (Fig. 4) was meant to discriminate the environment of deposition due to either beach or river processes. This plot shows that the sediments were deposited by river processes when compared with plots from Friedman (1967).

Table 3: Summary of results showing the heavy mineral suites in each petrographic slide

<table>
<thead>
<tr>
<th>Minerals present /Slide</th>
<th>KYANITE</th>
<th>STAUROLITE</th>
<th>TOURMALINE</th>
<th>ZIRCON</th>
<th>GARNET</th>
<th>RUTILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM EK 01</td>
<td>Pale bluish-brown</td>
<td>Yellow-brown and irregular</td>
<td>Pale brown and Sub-hedral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HM EK 08</td>
<td>Colorless to pale bluish-brown</td>
<td>Yellow to Yellow brown and round.</td>
<td>Anhedral – subhedral, high relief, light brown and blue variety</td>
<td>Grey to pale brown and irregular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HM EK 13</td>
<td>Yellow to Yellow brown, high relief and irregular</td>
<td>Anhedral – high relief.</td>
<td>Light brown, high relief and euhedral in form.</td>
<td>Light grey and high relief</td>
<td>Light brown and sub-hedral.</td>
<td></td>
</tr>
</tbody>
</table>

- Mineral present/Petro graphic slide
- "No mineral present.
- Mineralogical description

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Heavy minerals: Six of the samples were selected for the petrographic analysis such that the result can be representative of the entire area of investigation. The photomicrographs for petrographic studies are shown in Appendix 1. Table 3 shows a summary of the results of the heavy minerals suites observed in the photomicrographs of the petrographic analysis.

Slide EK 01 have mineral suites (Kyanite and Staurolite) characteristic of high grade metamorphic source. The colour of the Tourmaline however matches that of low grade metamorphic source. Slide EK 08 has Kyanite and Staurolite which are diagnostic of high grade metamorphic source rocks. Slide EK 13 has Staurolite which is diagnostic of high grade metamorphic source rocks. The presence of Garnet in this slide may be due to either high grade metamorphic or pegmatitic source rocks. Tourmaline, in this slide, based on the colour is diagnostic of pegmatitic rocks. Slide EK 24 has Garnet, Rutile, Staurolite and Tourmaline. The presence of Garnet may be due to either high grade metamorphic or pegmatitic source rocks. The Staurolite is diagnostic of high grade metamorphic source. The colour and shape of the Tourmaline is indicative of low grade metamorphic source. The presence of Rutile may be due to basic igneous rocks or reworked sediments. The result of the analysis shows that the Rutile is sub-hedral. This form indicates that the source of the Rutile is likely to be of basic igneous origin.

Slide EK 26 has Tourmaline and Zircon. The Tourmaline shows that the source of the sediments is of low grade metamorphism. The properties of the Zircon in this slide indicate that this heavy mineral has been reworked. Slide EK 29 has Staurolite, Tourmaline and Zircon. The Staurolite is indicative of high grade metamorphic source rocks. Tourmaline in this slide is diagnostic of Low grade metamorphic sources. The properties of the Zircon in this slide indicate acidic igneous source rocks.

The presence of Staurolite in almost all the samples indicates that the sediments were sourced from high metamorphic source rocks. This inference is also supported by the presence of Kyanite and Garnet in the slides. Although the presence of Garnet may indicate that the sediments were sourced from pegmatitic source rocks. A variety of Tourmaline indicative of pegmatitic source rocks was also found in the slide. This might be a confirmation that the sediments have a pegmatite source. An imprint of low grade metamorphic source rocks was also implied by the presence and abundance of Tourmaline in the sediments. Igneous, both acidic and basic, may be implied by the presence of the Zircon and Rutile respectively. Since the Rutile is only found in one of the slides, it is anomalous to make conclusions based on this mineral. Also since the presence of Zircon may be an indication of more than one source, an acidic igneous source origin will not be concluded in this study.

The sediment logical analysis did not investigate the properties of the sediments samples such as rounding and sphericity. The rounding and sphericity was done on the heavy mineral suites using the photomicrographic slides. It might be better to carry out such analysis on all the detrital materials both on
the examination of the petrographic slides show that most of the minerals are angular to sub-angular which indicates a short distance of travel of the sediments. The rounded minerals in the slides are those that indicate reworking of sediments. Therefore the rounding observed is likely to be due to the reworking of the sediments.

**CONCLUSION**

The sediments in the area investigated have been shown to be medium to coarse grained, moderately to poorly sorted, very leptokurtic and in most cases negatively skewed. These sediments have been concluded to be deposited by a fluctuating and turbulent, unidirectional flow mechanism which exhibit medium to high kinetic energy of transporting medium. The bivariate plots have shown that the sediments were deposited by fluvial processes which are consistent with the characteristics described above for both the sediments and the transporting medium.

The results of the petrographic analysis using the heavy mineral suites indicate that the sediments were sourced mainly from the metamorphic sources (both high and low grade metamorphic rocks), pegmatites as well as some reworked sediments. The evidences of igneous sources for the sediments are not quite convincing because the heavy minerals suggesting the possible igneous source are non-diagnostic and occur only in one of the slides observed.

**REFERENCES**


