Research Journal of Environmental and Earth Sciences 7(3): 60-67, 2015
ISSN: 2041-0484; e-ISSN: 2041-0492

Submitted: February 16, 2015 Accepted: March 1, 2015 Published: August 20, 2015

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 (σ_i) range from 0.960 to 1.319. The Inclusive Graphic Skewness (SK_I) 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 $4^0 55^l$N and $5^0 00^l$N and longitudes $6^0 55^l$E and $6^0 59^l$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 (Omatsola 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

Corresponding Author: O.B. Taiwo, Department of Geology, Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria, Tel.: +234-813-641-1272

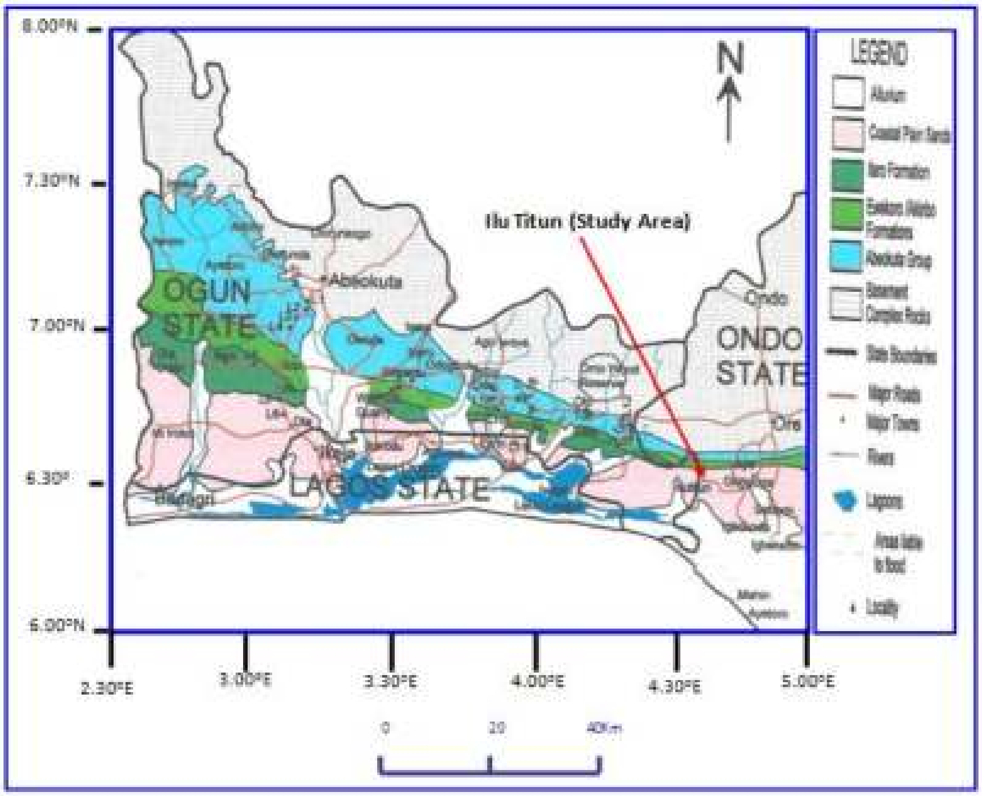


Fig. 1: Geological map of the Nigerian section of the Dahomey basin showing Ilu Titun (Modified after Olabode and Adekoya, 2008)

border. 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 Garphic 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:

$$M_z = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3} \quad (1)$$

$$\sigma_I = \frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{95} - \Phi_5}{6.6} \quad (2)$$

$$SK_I = \frac{\Phi_{16} + \Phi_{84} - 2\Phi_{50}}{2(\Phi_{84} - \Phi_{16})} + \frac{\Phi_5 + \Phi_{95} - 2\Phi_{50}}{2(\Phi_{95} - \Phi_5)} \quad (3)$$

$$K_G = \frac{\Phi_{95} - \Phi_5}{2.44(\Phi_{75} - \Phi_{25})} \quad (4)$$

where,
M_z = Inclusive graphic mean
σ_I = Inclusive graphic standard deviation
SK_I = Inclusive Graphic Skewness
K_G = Graphic Kurtosis
Φ_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_Z) ranges from 0.700 to 1.667Φ. 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

Table 1: Percentile values determined from cumulative curves of each sample

Sample	Φ_5	Φ_{16}	Φ_{25}	Φ_{50}	Φ_{75}	Φ_{84}	Φ_{95}
EK01	-1.10	0.20	0.60	1.50	2.10	2.35	2.90
EK02	-0.80	0.30	0.80	1.40	2.10	2.40	2.90
EK03	-0.80	0.20	0.75	1.35	2.00	2.35	2.85
EK04	-1.30	0.20	0.55	1.30	2.00	2.20	2.90
EK05	-0.40	0.50	0.80	0.40	2.10	2.40	2.80
EK06	-1.15	-0.55	-0.20	0.70	1.45	1.95	2.90
EK07	-1.10	-0.25	0.20	1.00	1.80	2.05	2.75
EK08	-1.30	-0.50	0.20	0.90	1.70	2.05	2.80
EK09	-1.10	-0.40	0.00	0.80	1.55	1.75	2.75
EK10	-1.20	-1.45	-0.10	0.80	1.50	2.00	2.50
EK11	-1.25	-0.20	0.15	0.95	1.60	2.05	2.85
EK12	-0.40	-0.20	0.20	1.00	1.80	2.20	2.90
EK13	-0.45	-0.20	0.25	0.95	1.85	2.20	2.90
EK14	-1.15	-0.35	0.10	1.00	2.00	2.35	3.10
EK15	-1.15	-0.40	-0.05	0.75	1.65	2.10	2.90
EK16	-0.60	-0.30	0.65	1.35	2.00	2.30	2.90
EK17	-0.80	0.00	0.30	1.05	1.70	2.10	2.90
EK18	-0.20	0.60	1.00	1.70	2.40	2.70	3.10
EK19	-0.45	0.55	0.90	1.70	2.30	2.60	3.05
EK20	-0.90	0.00	0.40	1.10	1.70	2.00	2.70
EK21	-0.40	-0.10	0.30	1.10	1.70	2.00	2.70
EK22	-0.35	0.10	0.50	1.15	1.80	2.15	2.75
EK23	-0.30	0.20	0.50	1.20	1.85	2.20	2.80
EK24	-1.20	-0.30	0.20	1.90	1.75	2.20	2.75
EK25	-0.30	0.30	0.70	1.35	2.00	2.30	2.95
EK26	-0.30	0.30	0.60	1.40	2.00	2.40	2.90
EK27	-0.35	0.20	0.65	1.30	2.10	2.45	3.05
EK28	-0.80	0.30	0.80S	1.50	2.30	2.65	3.20

Table 2: Summary of the results from statistical analyses and their interpretation

Sample	Graphic Mean (M_Z)	Interpretation (Grain Size)	S.D (σ_I)	Interpretation (Sorting)	Graphic Skewness (SK_I)	Interpretation (Skewness)	Graphic kurtosis (K_G)	Interpretation
EK01	1.350	Medium Grained	1.144	Poorly sorted	-0.255	Coarse skewed	2.459	Very Leptokurtic
EK02	1.367	Medium Grained	1.086	Poorly sorted	-0.118	Coarse skewed	1.971	Very Leptokurtic
EK03	1.300	Medium Grained	1.091	Poorly sorted	-0.124	Coarse skewed	1.870	Very Leptokurtic
EK04	1.233	Medium Grained	1.136	Poorly sorted	-0.169	Coarse skewed	2.496	Very Leptokurtic
EK05	1.100	Medium Grained	0.960	Moderately sorted	0.083	Fine skewed	1.705	Very Leptokurtic
EK06	0.700	Coarse Grained	1.239	Poorly sorted	0.043	Nearly Symmetrical	2.739	Very Leptokurtic
EK07	0.933	Coarse Grained	1.158	Poorly sorted	-0.089	Nearly Symmetrical	2.525	Very Leptokurtic
EK08	0.817	Coarse Grained	1.259	Poorly sorted	-0.086	Nearly Symmetrical	2.520	Very Leptokurtic
EK09	0.717	Coarse Grained	1.121	Poorly sorted	-0.052	Nearly Symmetrical	2.446	Very Leptokurtic
EK10	0.783	Coarse Grained	1.173	Poorly sorted	-0.051	Nearly Symmetrical	2.426	Very Leptokurtic
EK11	0.933	Coarse Grained	1.184	Poorly sorted	-0.048	Nearly Symmetrical	2.436	Very Leptokurtic
EK12	1.000	Coarse Grained	1.100	Poorly sorted	0.076	Nearly Symmetrical	2.164	Very Leptokurtic
EK13	0.983	Coarse Grained	1.108	Poorly sorted	0.103	Nearly Symmetrical	2.197	Extremely Leptokurtic
EK14	1.000	Coarse Grained	1.319	Poorly sorted	-0.006	Nearly Symmetrical	3.309	Very Leptokurtic
EK15	0.817	Coarse Grained	1.239	Poorly sorted	0.071	Nearly Symmetrical	2.822	Very Leptokurtic
EK16	1.317	Medium Grained	1.030	Poorly sorted	-0.082	Nearly Symmetrical	1.936	Very Leptokurtic
EK17	1.050	Medium Grained	1.086	Poorly sorted	0.000	Nearly Symmetrical	2.123	Very Leptokurtic
EK18	1.667	Medium Grained	1.025	Poorly sorted	-0.100	Nearly Symmetrical	1.893	Very Leptokurtic
EK19	1.617	Medium Grained	1.043	Poorly sorted	-0.175	Coarse skewed	2.008	Very Leptokurtic
EK20	1.033	Medium Grained	1.045	Poorly sorted	-0.106	Coarse skewed	1.918	Very Leptokurtic
EK21	1.000	Coarse Grained	0.995	Moderately sorted	-0.055	Nearly Symmetrical	1.779	Very Leptokurtic
EK22	1.333	Medium Grained	0.982	Moderately sorted	0.004	Nearly Symmetrical	1.652	Very Leptokurtic
EK23	1.200	Medium Grained	0.970	Moderately sorted	0.016	Nearly Symmetrical	1.715	Very Leptokurtic
EK24	1.267	Medium Grained	1.223	Poorly sorted	-0.665	Strongly Coarse skewed	2.509	Very Leptokurtic
EK25	1.317	Medium Grained	0.992	Moderately sorted	-0.033	Nearly Symmetrical	1.732	Very Leptokurtic
EK26	1.367	Medium Grained	1.010	Poorly sorted	-0.055	Nearly Symmetrical	1.836	Very Leptokurtic
EK27	1.317	Medium Grained	1.078	Poorly sorted	0.026	Nearly Symmetrical	2.020	Very Leptokurtic
EK28	1.483	Medium Grained	1.194	Poorly sorted	-0.086	Nearly Symmetrical	2.459	Very Leptokurtic

the sediments. The presence of coarse grains sediments eliminates the possibility of the aeolian transportation mechanism. Therefore the sediment transportation mechanism is likely to be of either marine or fluvial processes.

The values of the Inclusive Graphic Standard Deviation (σ_I) 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

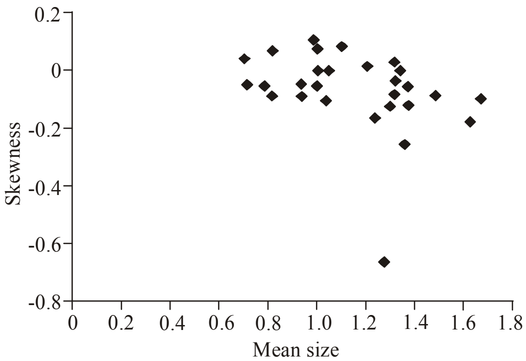


Fig. 2: Bivariate plots of Skewness against Mean size in Ilu Titun Sandstone

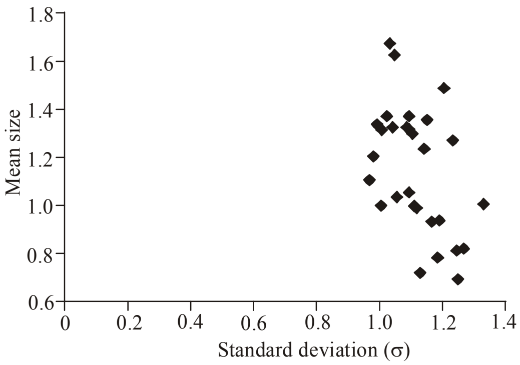


Fig. 3: Bivariate plots of Mean size against Standard deviation in Ilu Titun Sandstone

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.

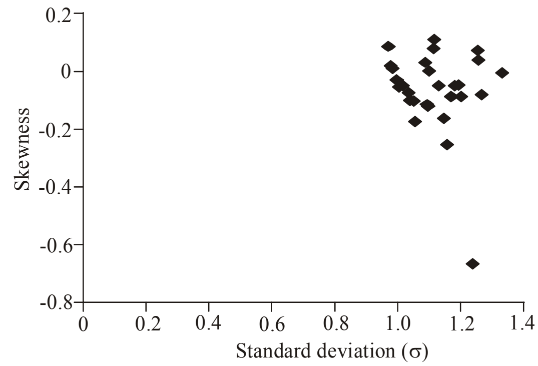


Fig. 4: Bivariate plots of Skewness against Standard deviation in Ilu Titun Sandstone

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

Minerals present /Slide	KYANITE	STAUROLITE	TOURMALINE	ZIRCON	GARNET	RUTILE
HM EK 01	Pale bluish-brown	Yellow-brown and Irregular	Pale brown and Sub-hedral			
HM EK 08	Colorless to pale bluish-brown	Yellow to Yellow brown and round.				
HM EK 13		Yellow to Yellow –brown, high relief and irregular	Anhedral – subhedral, high relief, light brown and blue variety		Grey to pale brown and irregular	
HM EK 24		Yellow–brown with high relief	Light brown, high relief and euhedral in form.		Light grey and high relief	Light brown and sub-hedral.
HM EK 26			Yellowish–brown and irregular shape. High relief.	Colourless and high relief. Sub–rounded to rounded.		
HM EK 28		Yellow to yellowish–brown and rounded.	Brown. High relief. Anhedral to sub–herdral.	Pale grey and euhedral .		

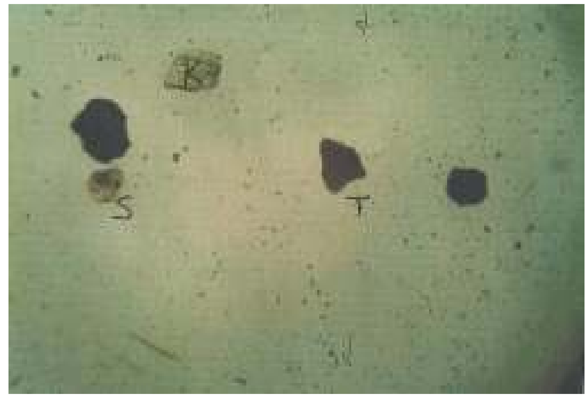
Mineral present/Petro graphic slide; No mineral present; Mineralogical description

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.

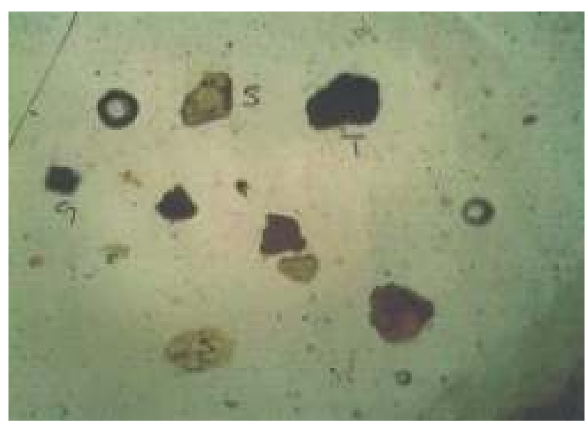
Slide EK 26 has Tourmaline and Zircon. The Tourmaline shows that the source of the sediments is of low grade metamorphism. The properties of the Zircon in this slide indicate that this heavy mineral has been reworked. Slide EK 29 has Staurolite, Tourmaline and Zircon. The Staurolite is indicative of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



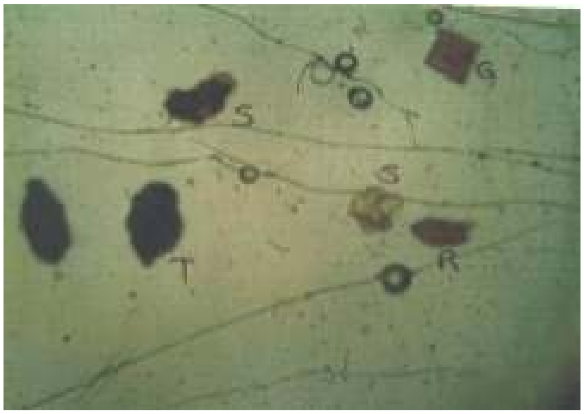
Slide 1: Photomicrograph of Sample EK 01 showing Kyanite (K), Staurolite (S) and Tourmaline (T) in Plane Polarized Light. *x*40

Slide 2: Photomicrograph of Sample EK 08 showing Kyanite (K) and Staurolite (S) in Plane Polarized Light. *x*40

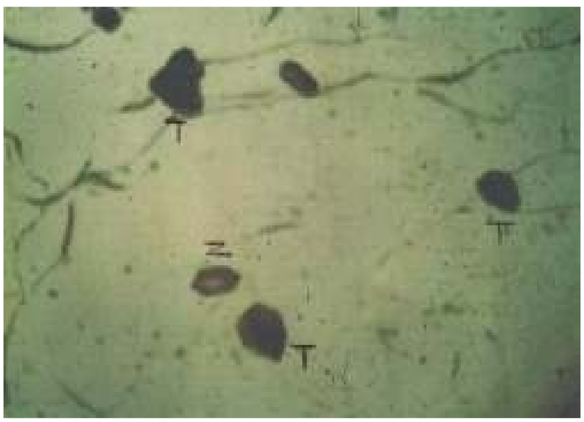


Slide 3: Photomicrograph of Sample EK 13 showing Garnet (G), Staurolite (S) and Tourmaline (T) in Plane Polarized Light. *x*40

The sediment logical analysis did not investigate the properties of the sediments samples such as rounding and sphericity. The rounding and spehricity was done on the heavy mineral suites using the photomicro graphic slides. It might be better to carry out such analysis on all the detrital materials both on



Slide 4: Photomicrograph of Sample EK 24 showing Garnet (G), Staurolite (S), Rutile (R) and Tourmaline (T) in Plane Polarized Light. *x*40



Slide 5: Photomicrograph of Sample EK 26 showing Zircon (Z) and Tourmaline (T) in Plane Polarized Light. *x*40

Slide 6: Photomicrograph of Sample EK 28 showing Zircon (Z), Staurolite (S) and Tourmaline (T) in Plane Polarized Light. *x*40

the samples and in the petrographic slides. Analysis on all detrital particles of sediments is important due to the stability of the heavy minerals against weathering and erosion processes. The sediments could be inferred to have been deposited close to the source rock because 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 petographic 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

Adeyemi, A.B., 2010. Sedimentological and provenance study of stream sediments in Ilu Titun area, Okitipupa Local Government, Ondo State, Nigeria. B.Sc. Thesis, Adekunle Ajasin University, Ondo State, Nigeria, pp: 54.

Billman, H.G., 1992. Offshore stratigraphy and paleontology of Dahomey (Benin) Embayment. NAPE Bull., 70(2): 121-130.

Coker, S.J.L. and J.E. Ejedawe, 1987. Petroleum prospect of the Benin basin Nigeria. J. Min. Geol., 23(1): 27-43.

Friedman, G.M., 1961. Distinction between dune, beach and river sands from their textural characteristics. J. Sediment. Petrol., 31: 514-529.

Friedman, G.M., 1967. Dynamic processes and statistical parameters compared for size frequency distinction of beach and river sands. J. Sediment. Petrol., 37: 327-354.

Hack, R.C., P. Sundaraman, J.O. Diedjomahor, H. Xiao, N.J. Gant, E.D. May and K. Kelsch, 2000. Niger Delta Petroleum Systems. In: Melle, M.R. and B.J. Katz (Eds.), Petroleum Systems of South Atlantic Margins. AAPG Memoir, Nigeria, 73: 213-231.

Johnsson, M.J., 1993. The System Controlling the Composition of Clastic Sediments. In: Johnsson, M.J. and A. Basu (Eds.), Processes Controlling the Composition of Clastic Sediments. Geol. Soc. Am. Spec. Pap., 284: 1-19.

Jones, H.A. and R.D. Hockey, 1964. The geology of part of southwestern Nigeria. Geol. Surv. Niger. Bull., 31: 101.

Mange, M.A. and F.W.M. Heinz, 1992. Maurer Heavy Minerals in Colours. Springer, Netherlands.

Okosun, E.A., 1996. Review of the early Tertiary stratigraphy of southwestern Nigeria. J. Min. Geol., 34(1): 27-35.

Olabode, S.O. and J.A. Adekoya, 2008. Seismic stratigraphy and development of Avon canyon in Benin (Dahomey) basin, southwestern Nigeria. J. Afr. Earth Sci., 50: 286-304.

Omatsola, M.E. and O.S. Adegoke, 1981. Tectonic evolution and Cretaceous stratigraphy of the Dahomey basin. Niger. J. Min. Geol., 18(1): 130-137.

Pettijohn, F.J., P.E. Potter and R. Siever, 1972. Sand and sandstones. Springer-Verlag, New York.

Reyment, R.A., 1965. Aspects of the Geology of Nigeria. Ibadan University Press.

Stewart, H.B. Jr., 1959. Sedimentary reflections of depositional environments in San Miguel Lagoon, Baja California, Mexico. AAPG Bull., 42: 2567-2681.

Weber, K.J. and E. Daukoru, 1975. Petroleum geology of the Niger Delta. Proceeding of the 9th World Petroleum Congress, 2: 209-221.