

# PETROGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE SANDSTONES IN AREAS AROUND ABUUL, IN USHONGO, SOUTHERN BENUE TROUGH, NIGERIA

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## ABSTRACT

The study focuses on the petrography and depositional setting of the sandstones in areas around Abuul, Ushongo; lower Benue Trough. The integration of outcrop, textural and petrographic studies aided the inference of the depositional framework of the sandstones in the area. Indurated sandstone samples were cut into thin sections for petrographic analysis while a total of 100 pebbles from OAM/1/Abuul were subjected to morphometric analysis. The thin section studies involved the determination of the texture and mineral/framework element compositions of the sandstones through point counting of about 100 constituent grains. The geologic mapping indicates that the sandstones are deposited proximal to the Basement Complex rocks. Thin section results show that the sandstones are coarse-grained and poorly sorted lithic arkoses, predominantly comprising of angular framework elements, with low textural and chemical maturity, possibly deposited in a fluvial setting. The result from pebble morphometry analysis also confirmed that the sands are fluvial. The bivariate plots of the pebble studies indicate a dominating population of fluvial-influenced pebbles in association with a subordinate population of beach influenced pebbles. However, minor grain compression is evident through the observed sediment compaction, stretched grains and presence of quartz overgrowths in some of the sandstones. This study has shown that the sandstones in the area are deposited by fluvial dominated processes, with the interaction of beach processes, though to a lesser degree.

**KEYWORDS:** textural analysis, sandstone petrography, depositional setting

## INTRODUCTION

The Benue Trough is a linear, northeast-trending depression in the eastern part of Nigeria. It tectonically evolved through transcurrent faulting in an axial fault system, where local compressional and tensional regimes resulted in basins and basement horsts (Benkhelil, 1989). Recently, many researches have been on the lower Benue Trough mainly because of the basin's mineral potentials and interesting geological features. Because of the basin's prospect for hydrocarbons and solid minerals, there is need for proper documentation of its stratigraphy and depositional framework. The diversity in rock lithology and stratigraphic heterogeneity occur as a result of many different depositional environments in which they are deposited. The study area covers about 76.5625sqkm and lies between N 07 05' and N 07 10' along latitude, and between E 008 55' and E 009 00' along longitude and covers towns like Abuul, Lessel, Wajir, Kiumbu and Tseghm (Figure 1). It extends from the extreme north-eastern end of the southern Benue Trough and transits into the northern Benue Trough. The stratigraphy of the Benue Trough, which the study area is part of, has been documented by Shell-BP (1957), Reymont (1965), and Najime (2011; 2014). The tectonomagmatism and regional metamorphism within the

trough have been studied on a regional scale by Akande and Erdtman (1998), Obiora and Charan (2010; 2011) etc. The study therefore, focuses on the petrography and depositional environment reconstruction of the sandstones in areas around Abuul, southern Benue Trough.

## Geologic Setting and Stratigraphy of the lower Benue Trough

The Benue Trough of Nigeria is a rift basin in central West Africa that extends NNE–SSW for about 800 km in length and 150 km in width (Obaje, 2009). The southern limit is the northern boundary of the Niger Delta, while the Northern limit is the southern boundary of the Chad Basin. The trough contains up to 6,000 m of Cretaceous – Tertiary sediments of which those predating the mid-Santonian have been compressionaly folded, faulted, and uplifted in several places. Sedimentation in the southern Benue Trough started with the marine Albian Arufu, Uomba, Gboko Formations, generally referred to as the Asu River Group (Offodile, 1976, Nwajide, 1990). The lithologic composition of the group comprises mainly limestones, shales, micaceous siltstones, mudstones and clays (Offodile, 1976); and the average thickness is estimated to be about 1,800 m. These are overlain by the Cenomanian Keana and Awe Formations and the Turonian Eze-Aku Formation (black shales,

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limestones and siltstones). The Keana Formation resulted from the Cenomanian regression which deposited fluvio-deltaic sediments and consists of cross-bedded, coarse grained felspathic sandstones with occasional bands of shales and limestones. The Awe Formation is also deposited as transitional beds during the late Albian to early Cenomanian regression, comprising medium to coarse grained calcareous sandstones, carbonaceous shales and clays. The Eze-

Aku Formation is the lateral equivalent of Konshisha Sandstone/Shale and the Wadata Limestone in the Makurdi area. The deposition of Eze-Aku Formation is attributed to the beginning of marine transgression in the late Cenomanian (Table 1). The sediments are made up of calcareous shales, micaceous fine to medium sandstones and beds of limestones which are in places shaley (Obaje, et al., 1999).

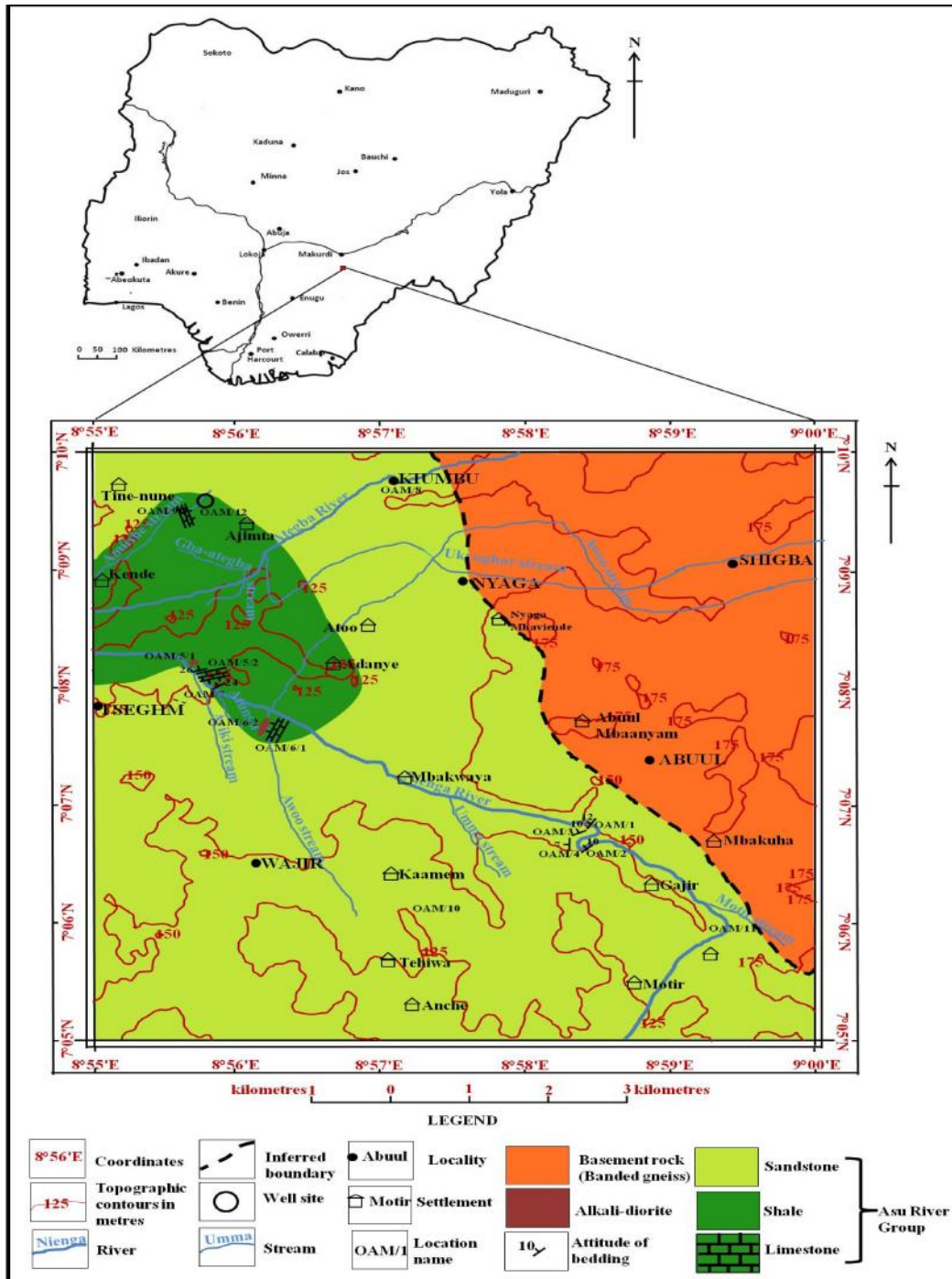


Figure 1: The location and geologic map of the study area

The Coniacian coal-bearing Awgu Formation lies conformably on the Eze-Aku Formation. In the Makurdi area, Makurdi Sandstone inter-fingers with the Awgu Formation. The mid-Santonian was a period of inversion

(folding) throughout the Benue Trough. The Campano-Maastrichtian Lafia Formation ended the sedimentation in the lower Benue Trough, after which widespread volcanic activities took over in the Tertiary.

**Table 1:** The Stratigraphic correlation across the Benue Trough (Modified from Reyment, 1965; Cratchley and Jones, 1965; Ojoh, 1992; Obaje, 2009; Nwajide, 1990)

Age		Southern Benue Trough-Anambra Basin-Niger Delta Basin				Central Benue Trough		Northern Benue Trough	
						Lafia-keana-awearufu Area	Basharmuri-amarzurak Area	Gombe Area	Lau Area
Eocene		Ameki Formation/Nsugbe Formation/Nanka Formation/Orlu Formation				Volcanics		Keri-Keri Formation	
Paleocene		Imo Shale				Volcanics		Volcanics	
		Nsukka Formation							
Maastrichtian	Late	Mamu Formation				Lafia Formation		Gombe Formation	
	Middle								
	Early								
Campanian		Nkporo Shale/Enugu Shale/Owelli Sandstone		Nkporo Group				Fika Shale	
Santonian									
Coniacian		Awgu Formation/ Agbani Sandstone							
Turonian		Eze-aku Shale/Agala Sandstone/ Amaseri Sandstone/ Makurdi Sandstone/ Agu Ojo Sandstone/ Agala Sandstone/ Igumale Sandstone/ Konshisha Group		Eze-aku Group		Keana Formation, Makurdi Formation, Wadatta Limestone (Eze-aku Group)		Zurak Formation	
								Gongila and Pindiga Formations	
								Sekuliye Formation	
Cenomanian	Upper	Ezillo Formation		Mfamosing Limestone		Awe Formation		Kumberi Formation	
	Lower	Abakalki Formation	Ibri And Agala Sandstones						
			Ngbo Formation						Yolde Formation
Albian	Upper	Ekegheligwe Formation		Awi Formation		Arufu, Uomba and Gboko Formations		Asu River Group	
	Lower					Muri Sandstone			
Pre-Albian						Ogoja Sandstone		Bima Sandstone	
Precambrian		Crystalline Basement Complex							

**METHOD AND MATERIALS**

The study involved the detailed petrographic description of sandstone units within the study area and four outcrop locations were studied and sampled for petrographic/granulometric analysis. Four indurated sandstone samples from locations OAM/1, OAM/2, OAM/3 and OAM/4 were cut into thin sections for petrographic analysis while a total of 100 pebbles from OAM/1/Abuul were subjected to pebble morphometric analysis. The thin section petrographic analysis involved the determination of the texture and mineral/framework element compositions of the sandstones through point counting of about 100 constituent grains. The texture and framework elements of the sandstones are

indicative of the depositional environments. The classification of the sandstone samples was also done based on the framework elements composition of Folk (1968). The pebble morphometric analysis involved measuring the long (L), intermediate (I) and short (S) axes of the pebbles. They were used to determine parameters such as form (Zingg, 1935), mean roundness (Shepard and Young, 1961) and form indices (Dobkins and Folk, 1970; Stratten 1974). These parameters have evaluated ranges which indicate certain depositional environments. The bivariate plots derived from the form indices, which are environment indicators are used to determine the influence of some processes that are characteristic of certain environments of deposition.



**Figure 2:** Sandstone outcrops at locations 1 (A: OAM/1) and 2 (B: OAM/2)



**Figure 3:** Sandstone outcrops at locations 3 with fractures (A: OAM/3) and 4 (B: OAM/4)

## RESULTS AND DISCUSSION

### Petrography

The results from the petrographic analysis show that the mineral compositions of all the rock samples include quartz, feldspars and rock fragments with accessory muscovite mica (Table 2). The micas were observed in the first three samples and the feldspars present are less altered, compared to sample OAM/4. The samples (OAM/1, OAM/2, OAM/3 and OAM/4) are generally coarse-grained and poorly sorted on the thin

section, with high amounts of angular grains and polycrystalline quartz (80% and 72% respectively). The constituent grains of the polycrystalline quartz had mostly suture contacts. Samples OAM/1, OAM/2 and OAM/3 (Figure 4) are matrix supported, and have angular grains, which make up about 70% of the rock, set in a very fine matrix (Table 3). Sample OAM/4 (Figure 5) is made up of very closely-packed grains with line and point contacts; which are cemented by quartz overgrowths, though some of the grains are separated by thin layers of matrix.

**Table 2:** Percentage Frequencies of frame work elements of the samples

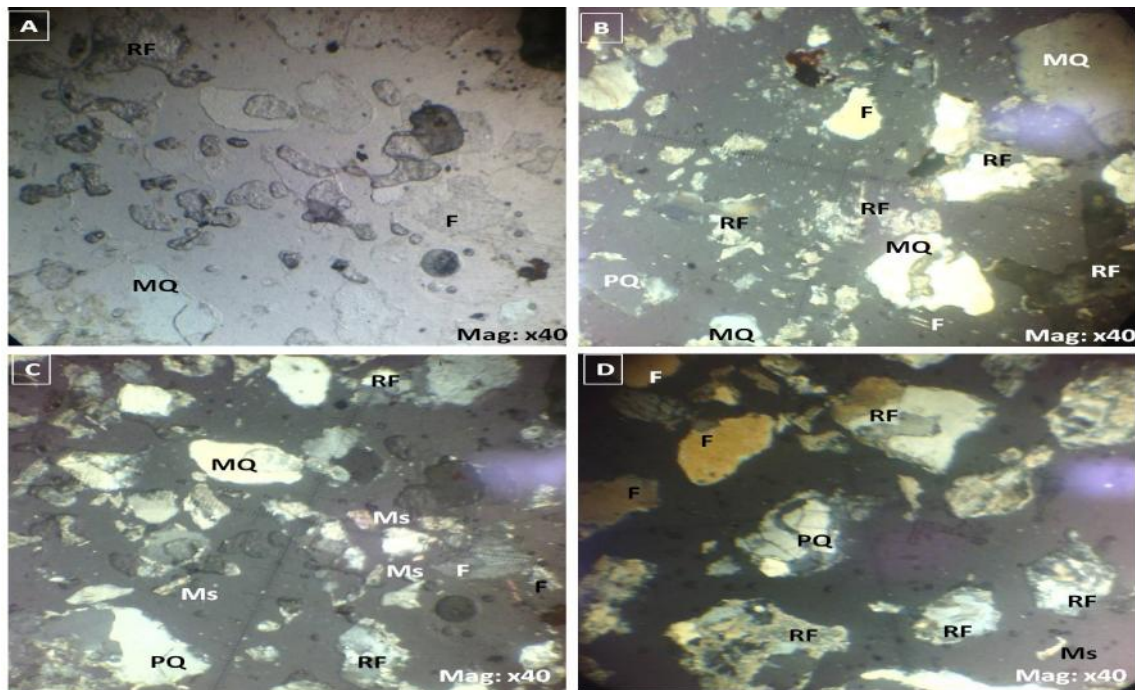
Framework element	Quartz (%)	Feldspars (%)	Micas (%)	Metamorphic rock fragments (%)
% frequency (Sample OAM/1)	31	37	5	27
% frequency (Sample OAM/2)	32	38	2	28
% frequency (Sample OAM/3)	29	35	6	30
% frequency (Sample OAM/4)	27	46	-	27

**Table 3:** Percentage Frequencies of Roundness Image sets of the samples.

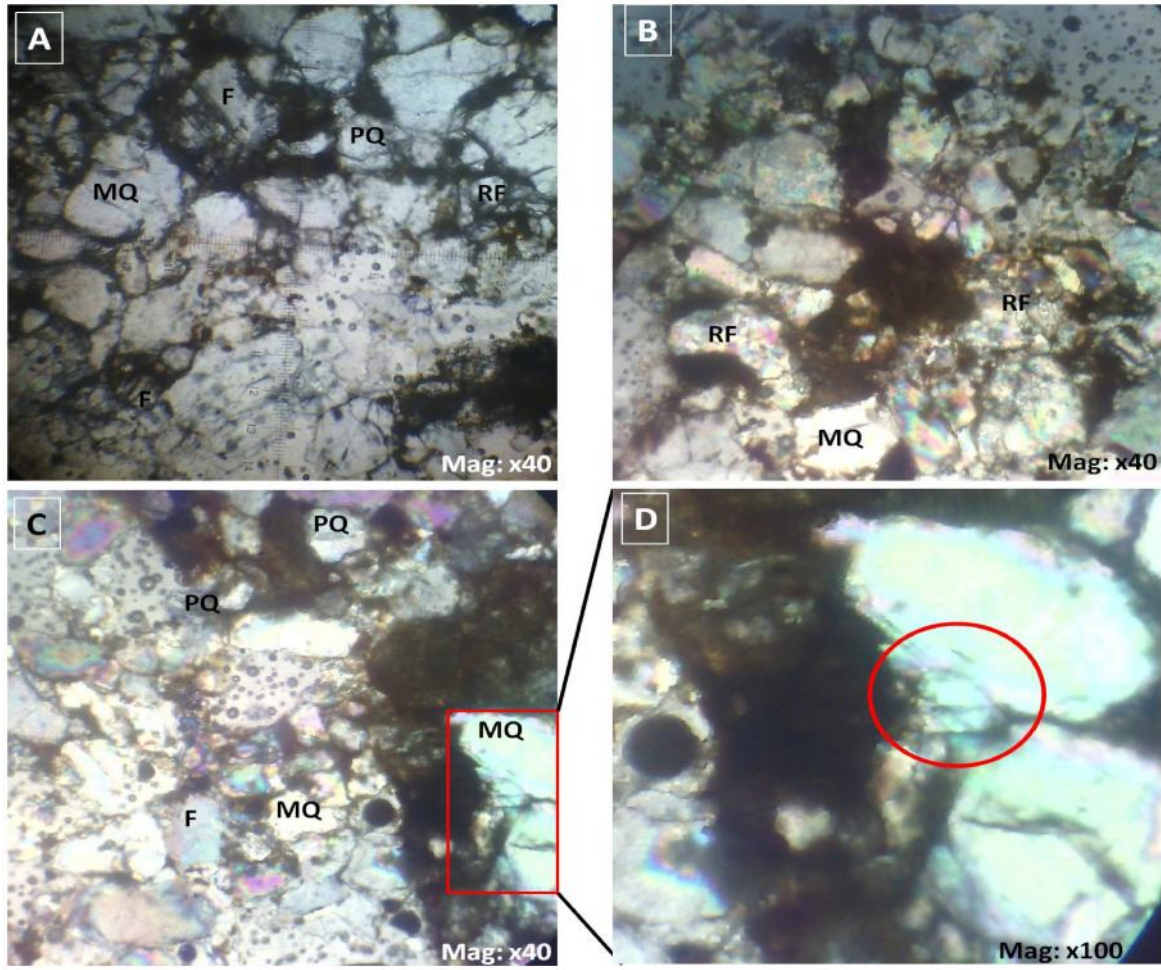
Mean roundness	Angular grains	Sub-angular grains	Sub-rounded grains	Rounded grains
% frequency (Sample OAM/1)	29%	35%	32%	4%
	(Total angular grains = 61%)		(Total rounded grains= 39%)	
% frequency (Sample OAM/2)	28%	37%	30%	5%
	(Total angular grains = 65%)		(Total rounded grains= 35%)	
% frequency (Sample OAM/3)	26%	35%	33	6
	(Total angular grains = 64%)		(Total rounded grains= 36%)	
% frequency (Sample OAM/4)	25%	44%	25	6
	(Total angular grains = 69%)		(Total rounded grains= 31%)	

The sandstone samples (dark grey in colour) are classified as lithic arkose (Figure 6) and they are texturally immature because of the high percentage of matrix, dominance of angular grains, abundance of polycrystalline quartz/feldspar and poor sorting. The ratio of quartz to feldspars and rock fragments in all the samples gave indices that range from 0.37 to 0.45. This means that the chemical maturity of both rock samples is at the extremely immature stage (Folk, 1951). The dominance of polycrystalline grains suggest that the grains are still in transit and are undergoing mechanical and thermodynamic stress which fractures the grains and eventually bring about monocrystalline quartz grains as sediments travel down current. The high percentage

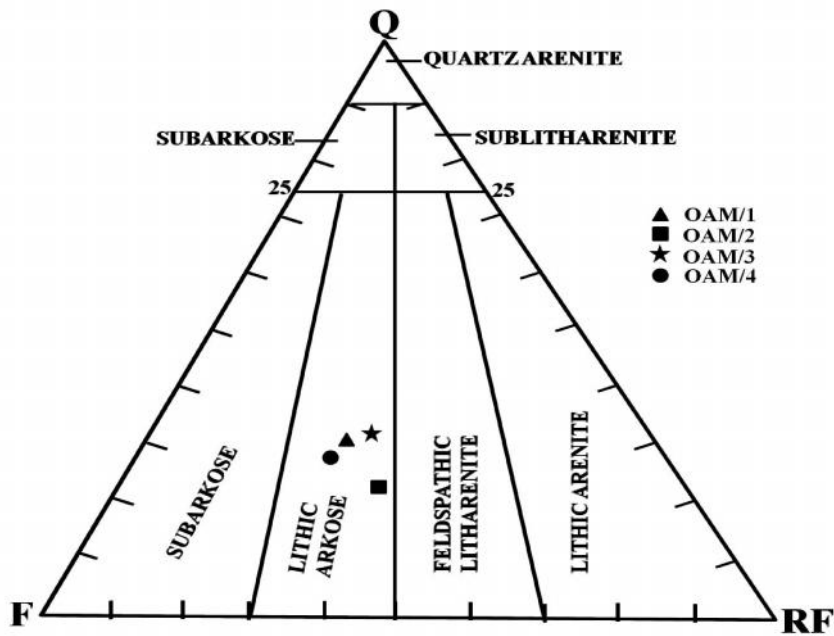
frequency of angular grains also suggests that the grains are still in transit. These angular sediment grains will gradually be transformed by corrasion and attrition into rounded grains as they travel down current. The high amounts of angular grains in all the samples suggest the possibility of deposition in a fluvial environment, where attrition is less due to a unimodal current direction. This is supported by the poorly sorted nature of the grains and the presence of matrix in both samples; signifying poor to moderate winnowing action characteristic of fluvial setting. On the other hand, the abundance of polycrystalline quartz, sutured grain contacts and stretched grains are evidence of an imposed compressive stress on the rocks.



**Figure 4:** Photomicrographs of samples (A) OAM/1 (plane polars), (B) OAM/1 (cross-polarized light), (C and D) OAM/2. (PQ) polycrystalline quartz, (MQ) monocrystalline quartz, (F) feldspar, (Ms) muscovite, (RF) rock fragments.



**Figure 5:** Photomicrographs of (A) OAM/3 (plane polars) (B) OAM/3 (cross-polarized light) (C and D) OAM/4 (PQ) polycrystalline quartz, (MQ) monocrystalline quartz, (F) feldspar, (RF) rock fragments. 'D' is an up-close photo of two quartz grains in 'C'. The red circle in (D) highlights a quartz overgrowth.



**Figure 6:** Triangular Diagram of framework composition of the samples (Folk, 1968)

**Pebble Morphometry**

Results from pebble morphometric analysis of the sandstones at OAM/1 show that 38% of the pebbles are equiaxial, 37% are oblate, 12% are prolate, while 13% are bladed. Based on mean roundness, 29% of the pebbles have a mean roundness of 0.145 (i.e. very angular), 25% have a mean roundness of 0.210 (i.e. angular), while the percentages of sub-angular and sub-rounded pebbles are 31% and 13% respectively (Table 4). The mean roundness for sub-angular grains is 0.300 while that of sub-rounded is 0.420. Only 2% of the pebbles are rounded, with a mean roundness of 0.595. It is also observed that 99% of the pebbles have Oblate-Prolate index (OPI) values greater than -1.5; the percentage of pebbles with Maximum Projection Sphericity (MPS) values greater than 0.65 is 75%, while 65% of the pebbles have Flatness Index (FI) values greater than 45% (Table 4).

The high percentages of angular (very angular, angular and sub-angular) pebbles indicate a lesser degree of attrition, due to the influence of a unidirectional current flow typical of fluvial environment. Roundness of pebbles tend to increase from rivers to beaches, hence with the low percentage of round pebbles (sub-rounded and rounded), it is likely that the pebbles have been affected mainly by fluvial processes. The equiaxiality of grains indicates a greater tendency towards sphericity, which decreases from rivers to beaches, hence the high amount of equiaxial pebbles indicate a fluvial influence. The occurrence of higher amount of pebbles which have values less than the critical values for the form indices (Oblate-Prolate Index, OPI; Maximum Projection Sphericity, MPS; and Flatness Index, FI) of fluvial and shallow marine environments according to Dobkins and Folk (1970) and Stratten (1974), indicates the prevalence of fluvial processes (Table 4).

**Table 4:** Univariate pebble morphometric parameters and their interpretations

Sample/Location name	Univariate parameters	Amount of pebbles (%)					Interpretation
		Equiaxial	Oblate	Prolate	Bladed		
OAM/1/ Abuul	Form	38%	37%	12%	13%		Fluvial
	Mean roundness	Very angular 29%	Angular 25%	Sub-angular 31%	Sub-round 13%	Rounded 20%	Fluvial
	Form indices	OPI		MPS		FI	
		(>1.5) 99%	(<1.5) 1%	(>0.65) 75%	(<0.65) 25%	(>45) 75%    (<45) 25%	Fluvial

The bivariate plot of the form indices, Maximum Projection Sphericity (MPS) vs Oblate-Prolate Index (OPI) shows 73% of the plots in the fluvial portion; 1% in the beach portion, while 26% plots in the lower non-diagnostic portion of the graph (Figure 7).

Similarly, the bivariate plot of the form indices, Flatness Index (FI) vs Maximum Projection Sphericity (MPS) shows 66% of the plots in the fluvial portion; 27% in the beach portion; while 7% plots in the lower part of non-diagnostic portion of the graph (Figure 8, Table 5). On the other hand, the bivariate plots of Maximum Projection Sphericity (MPS) vs. Oblate-Prolate index (OPI) and Flatness Index (FI) vs. Maximum Projection Sphericity (MPS) indicate the influence of fluvial processes. This is observed in the higher amounts of plots in the portions of the graphs which correspond to fluvial processes.

The plot of Mean Roundness (MR) against Elongation Ratio (I/L) shows 1% of the pebbles within the portion of littoral environment, 9% plotted in the transitional portion, while 90% of the pebbles correspond to the fluvial portion of the graph (Figure 9). The high proportion of fluvial plots indicates the

dominance of fluvial processes. Similarly, the low percentages of mean roundness (i.e. 31% and below) of majority of the pebbles (Table 4) indicate low degree of attrition commonly associated with rivers as opposed to a transitional or littoral environment.

Also, the Sphericity Form plot of the pebbles shows that 14% of the plots correspond to the compact, while the percentages of points that correspond to the compact platy, compact bladed and compact elongate portions are 10%, 18% and 13% respectively (Figure 10 and Table 6). The platy, bladed and elongate pebbles constitute 7%, 25% and 6% of the total number of pebbles respectively, while 7% of the total number of grains make up the very platy, very bladed and very elongate pebbles in the proportion of 2:4:1 (Table 6). The prevalence of compact, compact bladed and compact elongate pebbles (45%) indicates fluvial dominated process as opposed to the 13% of platy, very platy and very bladed that indicate beach action (Dobkins and Folk, 1970). This higher percentage of pebbles that indicate fluvial action confirmed the dominance of the fluvial processes in the area.

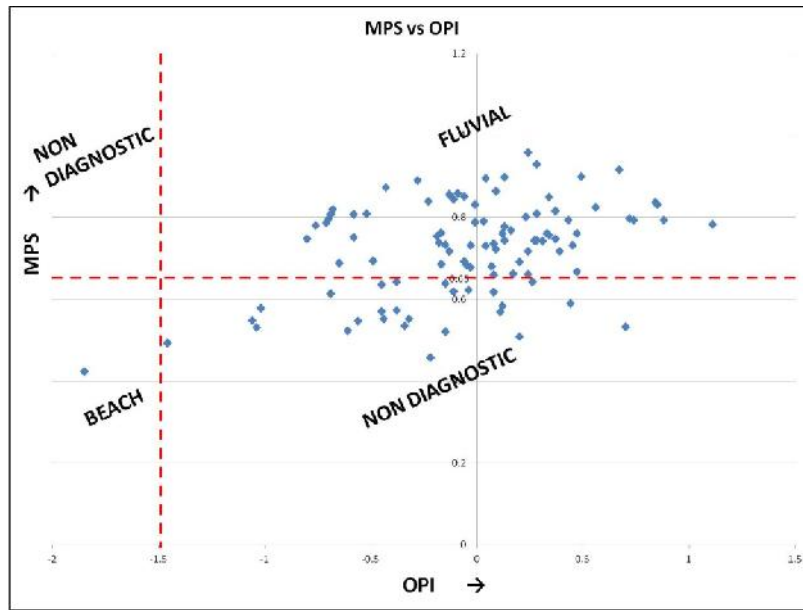


Figure 7: Bivariate plot of MPS vs. OPI of pebbles at location 1 (Dobkins and Folk, 1970)

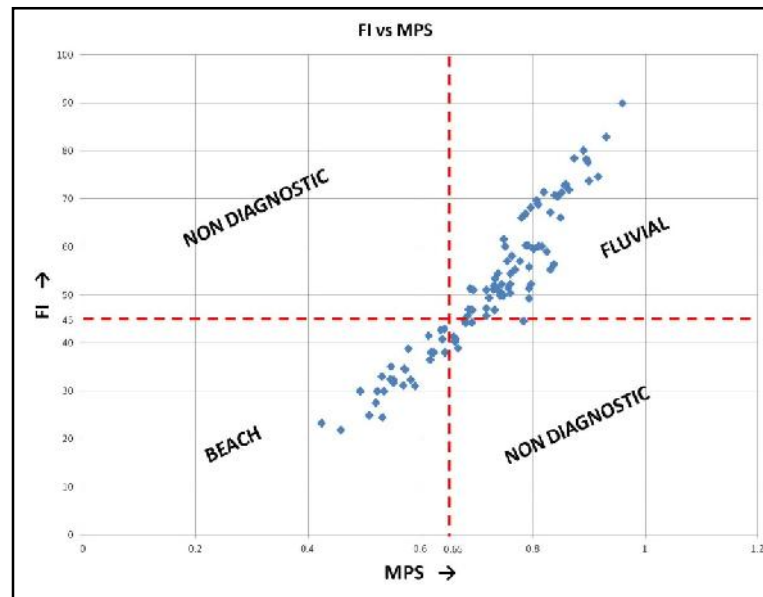
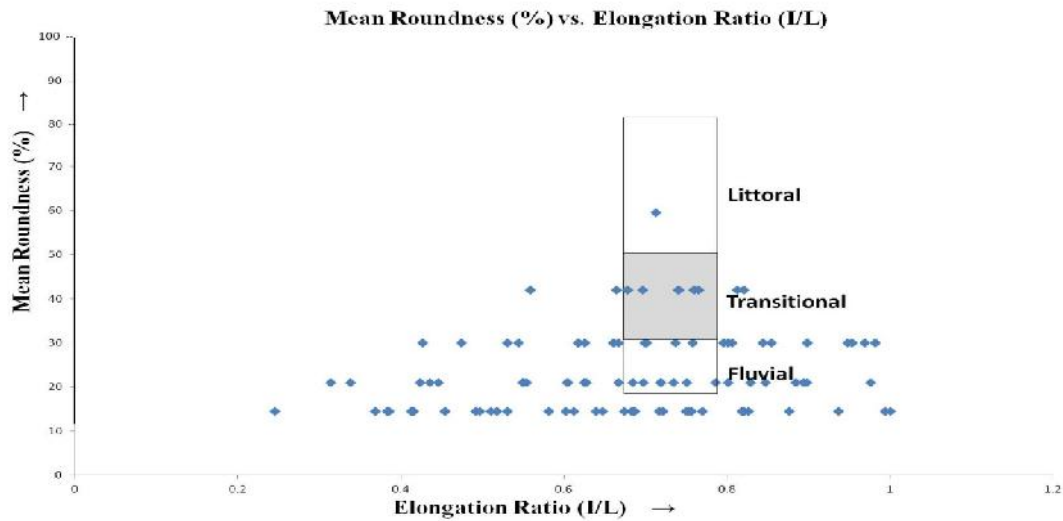


Figure 8: Bivariate plot of FI vs. MPS of pebbles at location 1 (Stratten, 1974)

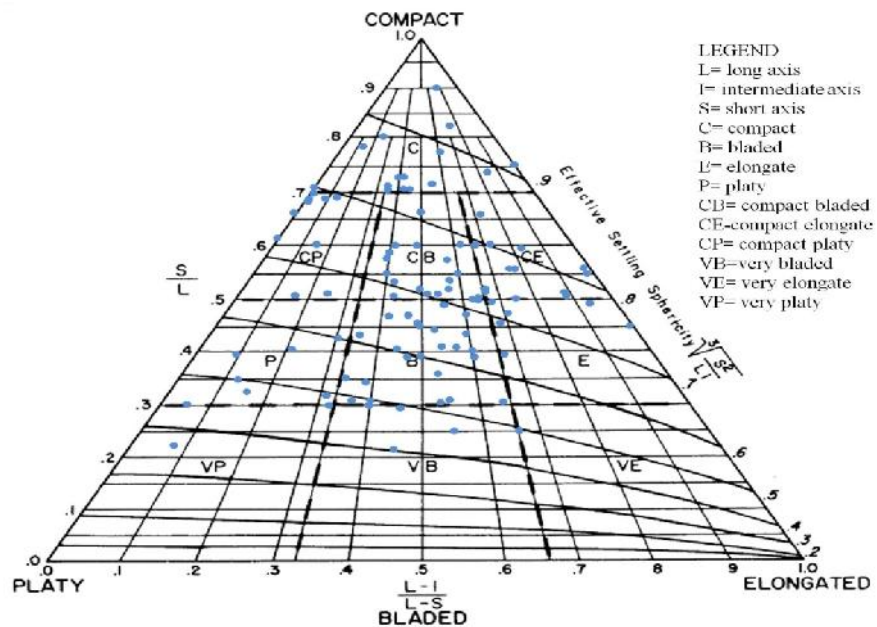


**Table 5:** Bivariate pebble morphometric parameters and their interpretations

Sample	Bivariate plots	Amount of pebbles (%)			Interpretation	
OAM/1/ Abuul	MPS vs. OPI	Fluvial 73%	Beach 1%	Non-diagnostic		Fluvial
				Upper -	Lower 26%	
	FI vs. MPS	Fluvial 66%	Beach 27%	Non-diagnostic		Fluvial
				Upper -	Lower 7%	



**Figure 9:** Plot of Mean Roundness (MR) vs. Elongation Ratio (I/L) for OAM/1/Abuul (Sames, 1966).



**Figure 10:** Sphericity Form Plot for OAM/1/ Abuul (Sneed and Folk, 1958)

**Table 6:** Percentage frequencies of the Sphericity Forms of the Pebbles at OAM/1/Abuul

Sphericity form	% frequency
Compact	14%
Compact platy	10%
Compact bladed	18%
Compact elongate	13%
Platy	7%
Bladed	25%
Elongate	6%
Very platy	2%
Very bladed	4%
Very elongate	1%

However, there seems to be a trend in the plots, where a higher proportion of the pebbles occur in the fluvial portion of the graph but narrows down to a lesser amount of pebbles on the beach portion. This suggests that there is a likely intervening action of beach process on the pebbles despite the dominance of the fluvial process.

## CONCLUSIONS

This study has shown that the sandstones in the area are deposited by fluvial dominated processes, with the interaction of beach processes, though to a lesser degree. Indications from pebble morphometric analysis also show high percentage frequencies of angular and equiaxial pebbles typical of a fluvial setting. These are buttressed by the data obtained from calculation of the form indices of the pebbles, where the individual as well as average OPI, MPS and FI values fall within the limiting ranges for a fluvial-dominated environment. Bivariate pebble morphometric plots also suggest a fluvial domination on the sediments. However, the plots show a trend, such that there is a movement from river to beach processes. This suggests that some of the pebbles bear imprints of beach processes.

The coarse-grained and poorly sorted nature of the lithic arkose sandstones indicates high energy deposition, with variable current velocities. The presence of up to 30% matrix in the samples suggests that the current direction may be unidirectional such that winnowing and attrition is to a lesser degree. This is also evident in the dominance of labile minerals (such as feldspars) as opposed to more resistant quartz minerals; typical of a fluvial environment. The predominant angularity of the grains in the sandstones suggests a lesser degree of attrition. It is important to note that the angularity and high amounts of labile minerals in the sandstone sediments encountered in the study area are as result of proximity to a source, which is most likely basement rock. The sandstones may be regarded as fluvial facies which represent a regressive phase. This facies probably was deposited during the regressive packages, as a result of rejuvenation of streams and rivers that eroded the elevated basement rocks, transported the sediments down-current for a few distances and deposited them at the base of the basement.

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