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Reservoir Characterization of the Eze-Aku Formation, Lower Benue Trough, South-Eastern, Nigeria

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Abstract
The TuronianEze-Aku Formation of the Middle Cretaceous which outcrops at the eastern flank of the Abakaliki Anticlinorium, Southern Benue Trough Nigeria represents a potential reservoir rock for hydrocarbons. Representative outcrop samples of the sandstone unit of the Eze-Aku Formation were collected and analyzed in order to determine its reservoir characteristics. In order to achieve this aim, a comprehensive description of the sedimentological, geotechnical and petrographical characteristics of the sandstone unit of the TuronianEze-Aku Formation was carried out. Petrographic analysis shows quartz grains are the most abundant detrital components in the samples (both polycrystalline and monocrystalline), followed by feldspars. Quartz constitutes about 92-93% and feldspar ranges between 2-3% while rutile, garnet and tourmaline occur in trace quantities to about 1%. The polycrystalline quartz grains are well rounded with varied crystals boundaries. The sandstone shows moderate to very good sorting with mesokurtic-leptokurtic distribution and an average porosity of 38.4%. The permeability of the sandstone unit is of 6.2 $\times 10^{-3}$md. The shape and orientation of the sandstone ranges from angular to sub-angular, rounded to sub-rounded with a ratio of 54.38:34.25 respectively. The samples are fine skewed while some are very fine skewed. From the results, it shows that most of the samples are mesokurtic, only a few are leptokurtic this implies that the frequency has zero kurtosis and which indicates that the sediments are obtained from multiple sources.

Keywords: *reservoir,porosity, permeability, kurtosis,*

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I. Introduction

The TuronianEze-Aku Formation of the Middle Cretaceous which outcrops at the eastern flank of the Abakaliki Anticlinorium, Southern Benue Trough Nigeria represents a potential reservoir rock for hydrocarbons (Fig. 1). This study investigates the reservoir characteristics of the sandstone units of the Eze-Aku Formation using selected outcrop. Outcrop analogue studies in reservoir characterization have been demonstrated to be a powerful tool, supplementing sparse subsurface data and are commonly used to develop quantitative descriptions of sandstone architecture and rock properties at the reservoir scale (Dutton *et al,* 2000). The main aim of this study is to provide detailed analyses on the reservoir characteristics of the TuronianEze-Aku Formation. Indeed, despite the numerous documented works on the sedimentology, petrographic and depositional environment of the TuronianEze-Aku Formation (Igwe*et al.,* 2013; Ikoro D. O., 2014), currently only limited information is available on its reservoir characteristics. This limits our ability to understand its reservoir qualities. Consequently, this study is built upon these concerns and aims at providing a comprehensive understanding of the reservoir qualities of the sandstone unit of the TuronianEze-Aku Formation. In order toachieve this aim, a comprehensive description of the sedimentological, geotechnicaland petrographical characteristics of the sandstone unit of the TuronianEze-Aku Formation was carried out in order to investigate the tectonic setting,sediment transportation processes,source rock origin, and itsreservoir quality of the study. Results shows sandstones unit of Eze-Akucan be classified as a quartzarenite and quartz grains are the most abundant detrital components in the samples (both polycrystalline and monocrystalline)

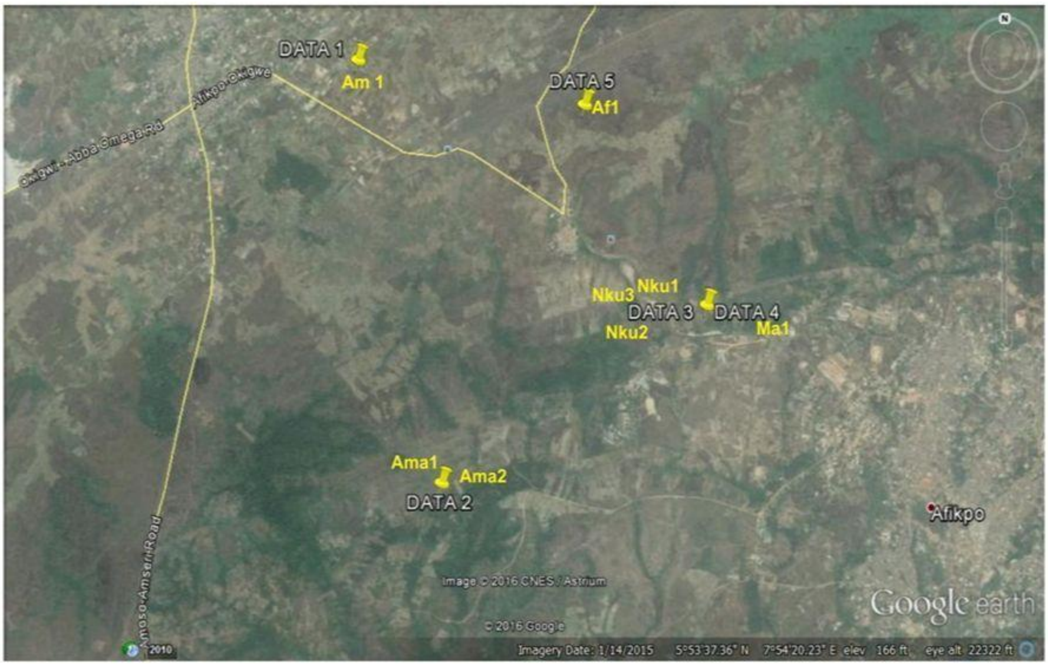

Fig. 1: Satellite Image of the study area showing sample locations

1.1 GEOLOGICAL SETTING

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 width. The southern limit is the northern boundary of the Niger-Delta, while northern limit is the southern boundary of the Chad basin. The trough contains up to 6000m of cretaceous-tertiary (Benkhelil, 1989).The sedimentary fill in the Afikpo basin in the southern limit of the Benue trough is divided into three tectonic -stratigraphic mega sequences the Asu River Group, Eze-Aku Group and proto-Niger Delta succession (Fig. 3). In the south-eastern Nigeria the oldest sedimentary rocks overlying the Precambrian Basement complex rocks are non-marine to marine sediments of Early-Mid Albian in age (Odigi and Soronnadi 2014). The AlbianAsu River Group is dominantly shale with siliclastic and calcareous sandstones. The oldest sedimentary sequence is of a conglomeratic to arkosic sandstone, overlain by shales, lower and upper regressive sandstones. The lower and upper sandstone bodies are regarded by Petters and Ekweozor (1982) as Awi and Awe Formations respectively. The Asu River Group is overlain unconformable by the EzeAkuGroup, while the Eze-Aku Group is also overlain by the proto-Niger Delta deposits. The proto-Niger Delta basin comprise of Campian-Maastrichtian and Paleocene sediments which are post-unconformity formations.

II. Methodology

Representative outcrop samples of the sandstone unit of the Eze-Aku Formation were collected and analyzed in order to determine its reservoir characteristics. Accessibility and collection of these samples were made possible by road cut exposure (Fig. 1). Selected samples were subjected to geotechnical, grain size and petrographic analysis (thin section). Eight samples collected were selected for thin section study in order to determine the structure and composition of the sandstones. The produced thin section slides were studiedusing a petrographic microscope. Petrographic classification was done using quartz (Q), feldspar (F) and rock fragment (RF).The falling head permeability test evaluated the permeability of the sandstone while the grain size analysis was used to ascertain the proportion of the various size fractions of the sandstone unit of the Eze-Aku Formation.

III. Results

3.1 LITHOLOGICAL DESCRIPTIONS

The Eze-AkuForamation is composed of calcareous shale, siltstone and thin sandy or shelly limestone as well as calcareous fine to medium grained sandstones [Reyment, 1965). Based on lithostratigraphy and field descriptions, the sandstones of Eze-Aku Formation in Amasiri area are grouped into two units: Nku sandstone andAmasiri-AfikpoAbakaliki road sandstone.The Amasiri sandstone is highly consolidated with the outcrop exposing as low lying sediments of about 5m. The Shale is highly weathered, it has been uplifted and intruding the sandstone. There is a ironstone in between the shale and the sandstone, this suggest the shale is older and there was a break in deposition which made the shale to be capped with ironstone.The sandstone unit of the EzeAku Formation is highly consolidated and medium grained (Fig. 2).

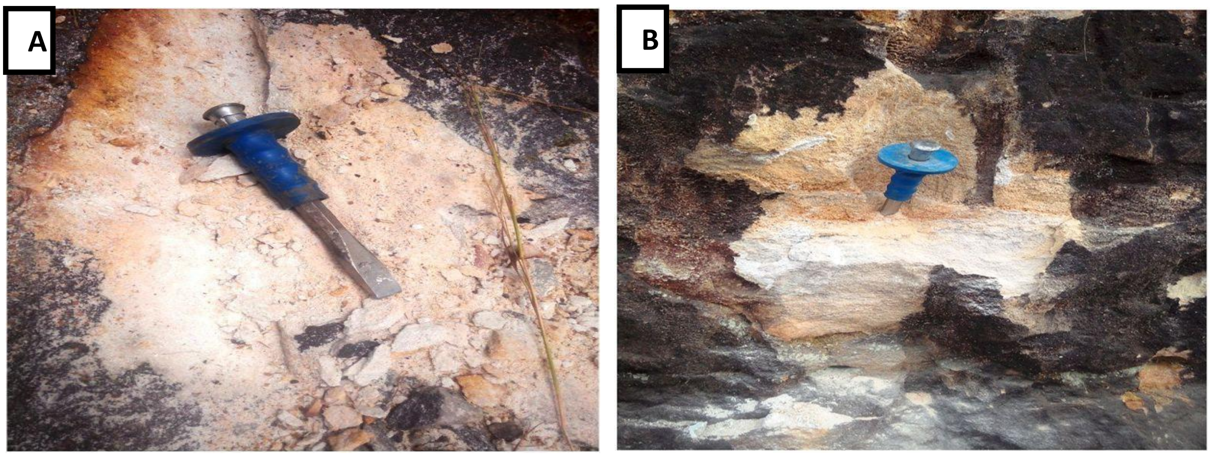

Fig. 2: (A) highly consolidated sandstone (B) massive- medium grained sandstone with clasts

3.2 GRAIN SIZE DISTRIBUTION

The grain size distribution of rocks gives detailed texture as well as descriptive properties of rocks, thus reflecting depositional environment (Olugbemiro and Nwajide, 1997). The sandstone unit of the Eze-Aku formation were subjected to grain size analysis. From the data obtained, cumulative curves were plotted. These were valuable in estimating statistical parameters such as graphic mean, standard deviation, skewness, kurtosis. Quantitative graphical values for the various percentile and quartiles were obtained from the cumulative curves from various samples (Tables 1 and 2).The grain-size analysis revealed that the sandstone are admixture of mainly sand-size (< 0.01 - 2.00 mm) along with minor amount of silt and clay size (<0.1 mm).The sandstone shows moderate to very good sorting with mesokurtic-leptokurtic distribution (Table 2), only NKU3 sample is poorly sorted and this is likely as a result of the high energy of transport and close proximity to its source. Fluctuation in energy of the depositional medium and moderate winnowing may have produced the moderate to very good sorting of the sandstones. The mesokurtic-leptokurtic distribution of the sandstone unit of the Eze-Aku formation suggests multiple source of derivation.

Table 1: Percentile value for analysed samples from cumulative curves

Sample No	ϕ16	ϕ50	ϕ84	ϕ95	ϕ5	ϕ85	ϕ75	ϕ25	mean	Sorting	skewness	Kurtosis
NKU3	0.55	1.18	2.0	3.0	0.30	2.2	1.72	0.70	1.24	1.05	1.41	1.1
AF1	0.31	0.56	1.16	1.4	0.15	0.18	0.86	0.36	0.68	0.48	0.1	1.0
MA1	0.35	0.62	1.20	3.4	0.21	1.22	0.42	1.16	0.72	0.69	0.56	1.8
AMA1	0.30	0.55	1.0	1.5	0.21	1.1	0.35	0.84	0.62	0.52	0.45	1.1
AMA2	0.50	1.15	2.35	3.4	0.18	2.37	1.32	0.43	1.33	0.95	0.35	1.48
AM1	0.33	0.60	0.90	1.30	0.15	1.00	0.85	0.40	0.58	0.42	0.22	1.05
NKU2	0.50	0.90	1.70	2.35	0.25	1.72	1.20	0.60	1.03	0.62	0.37	1.43
NKU1	0.40	1.16	1.14	0.45	1.20	0.25	0.85	0.50	0.66	0.32	0.71	1.11

Table 2: Description of statistical parameters for analysed samples

Sample No	Mean	Sorting	Skewness	Kurtosis	Description
NKU3	1.24	1.05	1.41	1.1	Medium sand, poorly sorted, strongly fined skewed, mesokurtic
AF1	0.68	0.48	0.1	1.0	Coarse sand, moderately well sorted, fine skewed, very mesokurtic
MA1	0.72	0.69	0.56	1.8	Coarse sand, moderately well sorted, strongly fined skewed, mesokurtic
AMA1	0.62	0.52	0.45	1.1	Coarse sand, moderately well sorted, fined skewed, mesokurtic
AMA2	1.33	0.95	0.35	1.48	Medium sand, well sorted, fine skewed mesokurtic.
AM1	0.58	0.42	0.22	1.05	Coarse sand, moderately well sorted , fine skewed, mesokurtic
NKU2	1.03	0.62	0.37	1.43	Very coarse sand, moderately well sorted, fine skewed, leptokurtic
NKU1	0.66	0.32	0.71	1.11	Coarse sand, very well sorted,fine skewed, leptokurtic

3.3 MINERALOGICAL DESCRIPTION

Weathering processes and provenance are the main factors determining sandstone features and composition (Arribas*et al*., 2013; Perri, 2014). Thin section studies show the presence of quartz, feldspar, rutile, garnet, tourmaline and rock fragment in the studied samples. Quartz grains are the most abundant detrital components in the samples (both polycrystalline and monocrystalline), followed by feldspars (Table 3). The polycrystalline quartz grains are well rounded with varied crystals boundaries (Fig. 4). In all studied samples, the monocrystalline quartzranges from 22 to 48% which is lower when compared to that of the polycrystalline quartz (42 to 61%). Most of the particles are sub angular to sub-rounded, super matured (>90% quartz) and moderately sorted (Table 4). This is likely to be associated with the impact of weathering and abrasion during a relatively short transportation from source. The feldspars in the studied samples are characterized by low birefringence, colourless, and occasionally looks cloudy compared to quartz in its true form. It can be differentiated from quartz by cleavage, twining, refractive indices and stained slide with a sodium cobalt nitrate solution (Makeen, *et al.* 2016). Orthoclase and Plagioclase are the most common feldspar type with relative abundance ranging from 1 to 2% (Table 3; Fig. 3). Rutile, garnet and tourmaline occur in much of the samples ranging from trace quantities to 1%. Rock fragments present ranges from 2 to 3%. The compositional maturity of the samples is super mature (Table 4).

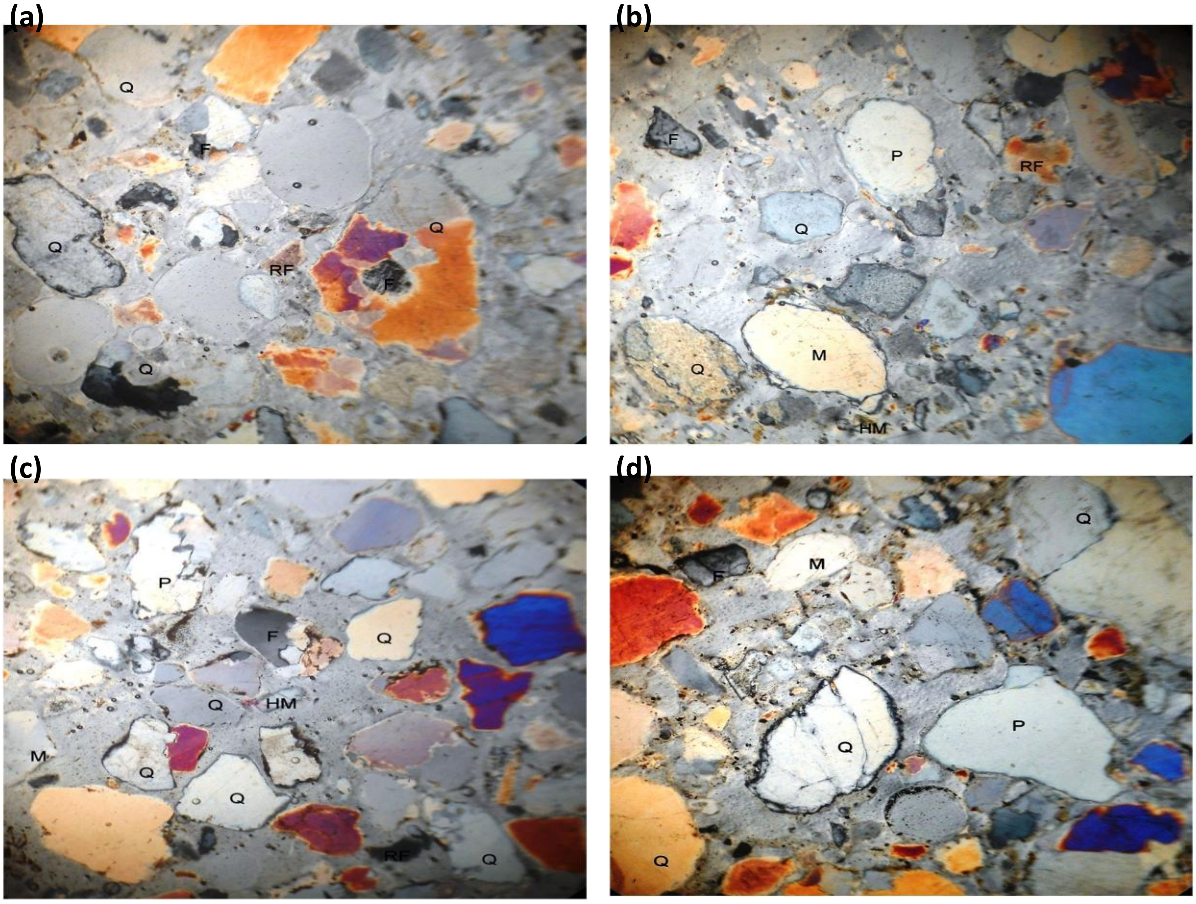

Fig. 4. (a), (b), (c) and (d) showing common polycrystalline quartz with less amount ofmonocrystallinequartz, subordinate quantities of feldspars and minor heavy minerals(Q: Quartz, F: Feldspar, RF: Rock fragments, P: Plagioclase, HM: Heavy mineral)

Table 3: Average modal analysis

SAMPLE NO	Q (%)	F (%)	R (%)	G (%)	T (%)	RF (%)
AMA1	93	2	1	1	1	2
MA1	92	2	2	1	1	2
AMA2	93	3	1	--	1	2
NKU2	92	3	--	1	1	3
AM1	92	2	1	1	1	3
AF1	92	3	1	1	1	2
NKU1	93	2	1	1	1	2
NKU3	93	2	1	1	1	2

Table 4: Compositional maturity of the sandstone unit of the EzeAku Formation

Sample No	Quartz (grain type)	Angular/Boundary	No of Count	Ratio of PQ to MQ	CM
AMA1	Qp Qm	Angular to sub-angular Rounded to sub-rounded	58 22	58:22	Super mature (93%quartz)
MA1	Qp Qm	Angular to sub-angular Rounded to sub-rounded	54 39	54:39	Super mature (92%quartz)
AMA2	Qp Qm	Angular to sub-angular Rounded to sub-rounded	61 31	61:31	Super mature (93%quartz)
NKU2	Qp Qm	Angular to sub-angular Rounded to sub-rounded	58 32	58:32	Super mature (92%quartz)
AF1	Qp Qm	Angular to sub-angular Rounded to sub-rounded	52 32	52:32	Super mature (92% quartz)
NKU1	Qp Qm	Angular to sub-angular Rounded to sub-rounded	51 42	51:42	Super mature (93%quartz)
NKU3	Qp Qm	Angular to sub-angular Rounded to sub-rounded	42 28	42:28	Super mature (93%quartz)
AM1	Qp Qm	Angular to sub-angular Rounded to sub-rounded	59 48	59:48	Super mature (92%quartz)

3.4 PROVENANCE

Weathering processes and provenance are the main factors determining sandstone features and composition (Arribas et al., 2013; Perri, 2014). In order to ascertain the provenance of the sediments, percentagesof various grains from modal analysis of sandstones are presentedon ternary diagrams (Fig. 5 and 6). This ternary diagram (QFR) is an important tool indifferentiating sandstones from major tectonic area.In the QFR ternary diagram, the compositional framework grain data plots in the cratoninterior (Fig. 5). Sandstones plotting in the craton interior field are mature sandstones derived from granitoids and gneissic sources, supplemented by recycled sands from associated platform or passive margin basins(Dickinson, 1985). The relative relief and moderate transport distance sandstones gives rise to typically quartzo-feldspathic sandstones of subarkosic classic character. Petrographic evidences of the Eze-Aku sandstones such as the presence offeldspar andsub angular to sub-rounded grains of quartz demonstrates the activities of both mechanical andchemical weathering in the grains of the sandstone.The sandstones unit of Eze-Akucan be classified as a quartzarenite (Fig. 6).

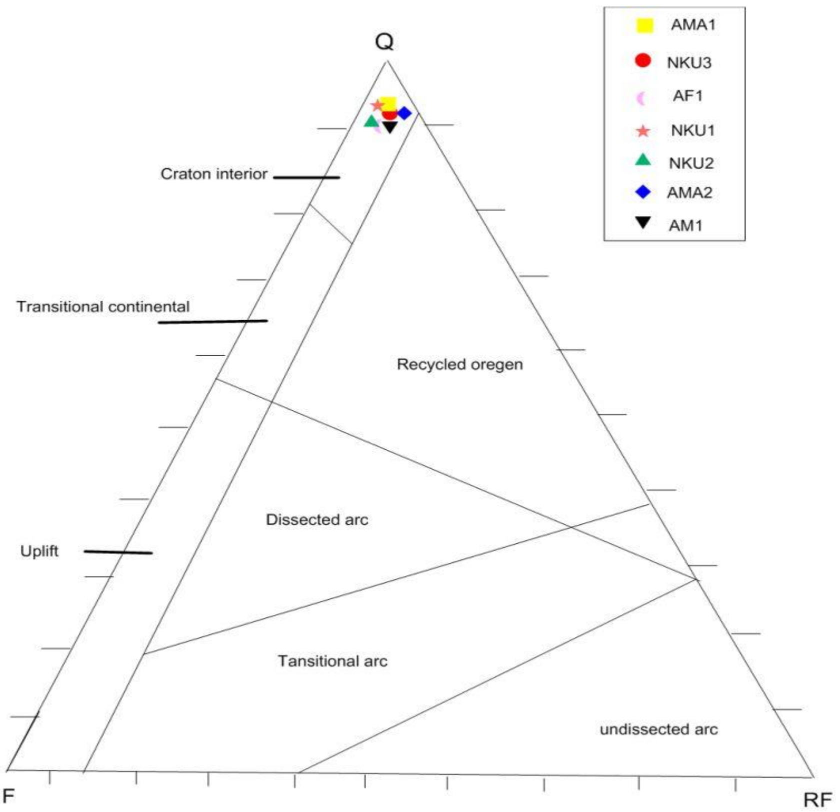

Fig. 5. QFR diagram: Inferred tectonic setting of the studied sandstone (afterDickinson, 1985).

3.5 RESERVOIRQUALITY

Porosity and permeability are very important factors whenaccessing the economic viability of hydrocarbon accumulation, and thus need to be quantitatively determined to ascertain thereservoir quality (Hakimi*et al*., 2012).The relationship between porosity and permeability (degree of interconnectedpores) control hydrocarbon accumulation and expulsionin a sedimentary terrain. Porosity is the amount of void spaces in a rock sample while the permeability is the ability of the rock to transmit fluids.The porosity of the Eze-Aku sandstone unit was calculated from the result of the bulk density and specific gravity in order to ascertain the void ratio (Table 5). The Permeabilityresult was calculated using the falling head permeability test method. Porosities values of the Eze-Aku sandstone unit ranges between 35%- 44 % and permeability values between 5.2×10^{-3}-8.1×10^{-3} (Tables 5). The average mean of the porosity is 38.4% and permeability is 6.2×10^{-3}.md

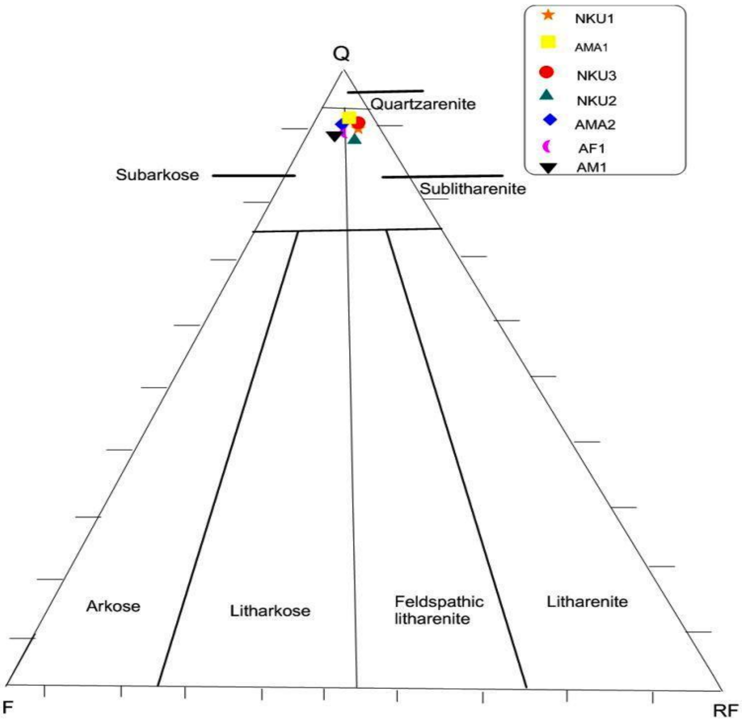

Fig. 6. QFR (Quartz – Feldspar-Rock Fragment)diagram showing classification of the Eze-Aku sandstone unit (modified after Pettijohn*et al*., 1987)

Table 5: Permeability and porosity values for samples from the Eze-Aku formation

Sample No	H1(mm)	H2(mm)	H1(mm)	H2(mm)	K (md)	Porosity (%)
AMA1	180	69	175	75	5.3×10^{-3}	41
MA1	180	55	156	44	7.2×10^{-3}	44
AMA2	160	50	160	55	6.5×10^{-3}	35
NKU2	160	55	170	60	6.2×10^{-3}	35
AM1	160	75	140	70	4.3×10^{-3}	40
AF1	155	140	150	135	6.1×10^{-4}	39
NKU1	160	65	175	65	5.6×10^{-3}	39
Ma1	150	75	155	75	4.2×10^{-3}	37
NKU1	170	40	165	45	8.1×10^{-3}	39

SG – Specific Gravity; K – Permeability

3.6 IMPLICATION FOR RESERVOIR QUALITY

Reservoir quality is a function of depositional environmentwhich controls the grain size, sorting, matrix and diagenetic processes (Makeen, *et al.* 2016).The two essential attributes of any reservoir are the porosity and permeability. The porosity and permeability of a rock are closely related to its texture. The various textural parameters of sediments which control the aforementioned include the shape of the grains, their roundness, sorting and grain size.The sandstones unit of theEze-Aku formation is well sorted and has medium to coarse grains in texture which indicates that the grains provides a clean frame work with little fine grained materials filling the pore spaces.Petrographic analysis of the sandstone suggests that they are mineralogically mature and are essentially quartz arenites. The textural parameters fromthe sandstone unit of theEze-Akuformation show good potential for reservoir rock.

IV. Conclusion

Results on thereservoir qualities of the sandstone unit of the TuronianEze-Aku Formationlead to the following conclusions;

- The sandstone are admixture of mainly sand-size (< 0.01 - 2.00 mm) along with minor amount of silt and clay size (<0.1 mm) and shows moderate to very good sorting with mesokurtic-leptokurtic distribution and an average porosity of 38.4%.
- The sandstones unit of Eze-Akucan be classified as a quartzarenite
- Quartz grains are the most abundant detrital components in the samples (both polycrystalline and monocrystalline), followed by feldspars. The polycrystalline quartz grains are well rounded with varied crystals boundaries
- Most of the particles are sub angular to sub-rounded, super matured (>90% quartz) and moderately sorted
- Eze-Aku formation has a good reservoir potential.

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