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Composition and Textural Characteristics of Turonian Ezeaku Formation: Implication for Depositional Environment

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Abstract
The depositional environment of the Ezeaku Sandstone outcropping as Amasiri Sandstone in Afikpo Basin in the southeastern part of the Benue Trough was studied using the composition and textural characteristics of the Sandstone. Samples were collected from the Ibii, Ozara-Ukwu, Akpoha, Amasiri-Akpoeze ridges for petrographic and chemical analyses. The results show that the sandstones are feldspathic arenites with matric content less than 15%. Quartz is the most ubiquitous mineral with micro fractures; also, grain margins and surfaces are corroded and altered by calcite. Euhedral quartz overgrowth is seen with dust rim. The grains are angular to sub rounded, elongate grains were also common. Sorting is poor. Plagioclase and alkaline feldspars were observed, they have a modal composition of about 10 – 12%. Rock fragments were not common in the Ezeaku Formation. The grains were seen to be cemented mainly by calcite cement, silica cement also occur as quartz overgrowth and microcrystalline aggregates. Clay minerals and iron oxides are seen coating grains. The sandstone is compositionally and texturally sub mature. The chemical analysis shows the depletion of silica as a result of calcite replacement in the calcareous sandstone and concretions. Al_2O_3 value is high and it ranges from 9.766% to 23.55%. The sandstone is richer in K_2O than in N_2O, which is typical of arkoses. The results show that the Amasiri Sandstone was deposited in a shallow marine environment under humid conditions that allowed the segregation of calcite minerals into concretions within the Sandstone.
Keywords: Petrography, Calcareous sandstone, Calcareous concretions, Diagenesis, Paragenetic sequence, Sandstone composition, Plate Tectonics

1. Introduction

The Turonian Ezeaku Formation is one of the prominent formations of the Anambra and Afikpo Basins was formed during the Santonian tectonism and uplift of the Abakaliki Anticlinorium in the Lower Benue Trough. The Ezeaku Formation lies unconformably on the Aptian – Albain Asu River Group. The Ezeaku Formation is made up of calcareous and non-calcareous sandstones, shales and limestones. The outcrop is highly indurated and sedimentary structures such as ripples, swaley cross stratification, planar crossbeds and bioturbation occur. Weathering on exposed surface is also intense giving a reddish colour due to the presence of oxidized iron minerals.

The depositional environment of a sedimentary rock could be inferred from its composition and textural characteristics. The depositional environment of the Ezeaku Formation has been a subject of various researches. Reyment, (1965) described the Ezeaku Formation as comprising of dark grey to black shales, sandstone, surbodinate limestone and siltstone deposited in shallow marine environment. Amajor (1987) observed that there are northeast – southwest trending sand bodies forming prominent sandstone ridges which are parallel to the Trough in the southeastern part of the Benue Trough. He also postulated that the Sandstones of Ezeaku Formation are storm dominated and not tide dominated based on facies analysis of the Sandstones (Amajor, 1987).

The Ezeaku Formation occurs as the Amasiri Sandstones in the Afikpo Basin, the sandstone occurs as Northeast-Southwest trending ridges. The study area is bounded by latitudes N5^0 53' and N5^{0}59' and Longitudes E7^{0}52' and E7^{0}59' (Figure 1) and covers the areas around Akpoha, Ozara-Ukwu, Amasiri, Ibii and Afikpo in Afikpo North Local Government Area, Ebonyi State of South Eastern Nigeria. Access to the area is primarily through the East-West Okigwe –Afikpo - Abakaliki roads, passing through Akaeze, Aamasiri, Akpoha and Abomega. Same road connects Afikpo community at Amasiri Junction. Other access to the study area is made possible through the minor roads linking the various towns and communities around the area. Samples were collected at Akpoha, Uzara-ukwu, Ibii, Amasiri/Akpoeze and Afikpo where the Amasiri Sandstone outcrops.

The textural characteristics and composition of the Sandstone were studied from petrographic analysis and the concentration of major oxides respectively to infer the depositional environment. Based on the results, shallow marine environment was deduced for the Turonian Ezeaku Formation in agreement with Amajor (1987).

2.Literature Review

The study area is replete of geological literature from several researchers among whom are Murat (1972), Reyment (1965), Offodile (1976), Amajor (1987) and others. Murat (1972) described the paleogeography of the Cretaceous and Lower Tertiary rocks in the southern Nigeria to have resulted from three main tectonic episodes.

Kogbe (1976) and Offodile (1976) have contributed to the recognition of the sedimentary units within the

Benue trough. While Reyment (1965) and Banerijee (1980) posited that the Turonian

Ezeaku Formation of the Lower Benue Trough is dominated by shale and sandstones with subordinate limestone and the environment of deposition was postulated to be shallow marine environment and the deposits were possibly tidal deposits.

However, in the Southeastern part of the Trough, a number of Northeast-Southwest trending sand bodies forming prominent sandstone ridges which are parallel to the axis of the Trough were recognized by Amajor (1987).

Also, Amajor (1987) claims the Sandstones of Ezeaku Formation are storm dominated and not tide dominated based on facies analysis of the Sandstones. The sandstone was observed to be texturally and compositionally immature feldspathic arenites based on petrographic studies Hoque (1977) and Amajor (1987).

2.1Geology And Stratigraphy Of The Area

The geology of Northeast Afikpo consists of lithostratigraphic units of parallel and asymmetric sandstone ridges and low lying shales, each of which forms significant component of the Middle Albian Asu River Group and Turonian Ezeaku Formation (Odigi 2007). Ukaegbu and Akpabio (2009) designated these ridges as EZi – Ezviii. The highest sandstones ridge in the area is the Amasiri-Akpoeze Sandstones (about 120m high) followed by the Ibii and Akpoha Sandstones ridges which are about 75m high.

Three main Cretaceous lithostratigraphic units have been recognized in the Afikpo Basin, they are; the Asu River Group, the Ezeaku Group and the Post Santonian Proto-Niger Delta succession (Odigi, 2007). Asu River Group (Late Albian–Early Cenomanian) forms the base with a maximum thickness of about 1500 m (Shell 1957). It consists of the Ogoja Sandstone, Awi Formation/Mamfe Formation and Abakaliki Formation in the Southern Benue Trough (Nwajide 2013). They are non-marine to marginal marine deposits, and comprise of sandstones and dark shales with ammonites. The Asu River Group represents deposits of the first transgressive – regressive marine depositional cycle in the area (Petters, 1980).

Unconformably overlying the Asu River Group are 200m thick, Late Cenomanian – Early Santonian sediments of the Ezeaku Group. The Ezeaku Formation in the Afikpo Basin is called Amasiri Sandstone. The Ezeaku Formation consists of shales, limestones and sandstone ridges which strike on the average, NW 40^o SE with dip ranging from 20^o to 68^o. The sandstone bodies are parallel and are elongate features. The Ezeaku Formation represents the second trangressive depositional cycle that occurred during the Upper Cretaceous (Murat, 1972).

The major folds in the area have Northeast-Southwest trend and comprise of both anticlines and synclines. The Asu River Group experienced both the Cenomanian and the Early Santonian folding which is reflected by the higher dip magnitude of 46^o to 72^o as against the effect of only the Early Santonian folding on the Ezeaku Formation with dip magnitude of 16^o to 38^o. (Odigi 2007).

The Ezeaku Group is unconformably overlain by Post Santonian sediments of the Proto Niger Delta beds. The end of the Turonian was marked by a regressive phase which was terminated by a third sedimentation cycle of the Campanian – Maastrichtian transgression and regression which led to the deposition of the Post Santonian, (Campanian – Maastrichtian) Proto Niger Delta sequence in the broad and gentle depression of the Afikpo Basin. These beds comprise of alluvial, fluvial-shallow marine conglomerates and sandstones, mudstone and shale which show a NE – SW trend (Odigi 2007).

3.0 Study Methods

3.1 Sampling

Fresh samples were collected according to standard sample collection procedures from outcrops at Akpoha, Ibii and Amasiri/Akpoeze and Afikpo communities for petrographic and chemical analysis.

3.2 Laboratory Analysis

3.2.2 Petrographic Analysis

The samples collected from the study area were analysed using a petrographic microscope. The purpose of the analysis was to determine the light mineral contents of the samples such as quartz, feldspars etc. Chips of rock slices were cut and smoothened on the side by the use of carborundum powder. Each slice was glued to a glass slip by adding heated basalm. The specimen was washed with water and left to dry, and a thin slide was produced into thin sections.

3.2.2 Chemical analysis

The chemical analysis involved oxide analysis of six samples of Amasiri Sandstone outcropping at Akpoeze, Ibii, Ozara-ukwu and Afikpo communities. The pan fraction of the sandstone samples after grinding and sieving were analysed by a x-ray fluorescent spectrography. The required filters for each element were selected accordingly and probed. The initial results of concentration of the element selected were shown in diffractions, which were then converted to concentration in weight percentage of oxides. The result is presented in Table 2

4.0 Presentation And Discussion Of Results

4.1 Petrography

Framework material

The quartz grains are the most ubiquitous minerals and they form the framework minerals. They are detrital and are mainly monocrystalline, they form about 60 – 80 % of the total grains. The quartz grain size range from very fine to coarse grains and exhibit very few euhedral quartz overgrowth. The overgrowth are separated by dust rims. They are mainly monocrystalline with edges and surfaces which are corroded by calcite (Figure 2). The matrix content is less than 15%, the grains are sub angular to sub round. Elongate grains are also common.

Plagioclase and alkaline feldspars were observed, they have a modal composition of about 10 – 12%. Rock fragments were not common in the Ezeaku Formation. The grains were seen to be cemented mainly by calcite cement, silica cement also occur as quartz overgrowth and microcrystaline aggregates (Figures 2 – 5). The sandstone is compositionally sub mature.

Texture

The grains are poorly sorted to moderately sorted, sub angular to sub-rounded and are mainly monocrystaline grains. Tangential, sutured and concave – convex grain contacts were observed but concave convex is more prominent. Deformational structures such as fractures on grains were observed (Figures 2 – 7). The sandstone is texturally sub mature.

Diagenesis

Silica cement is present in the form of microcrystalline aggregates filling pores and as well as overgrowth around detrital quartz grains which may have resulted from the solution and recrystallization at the grain contacts. Calcite cement is the most abundant but is considered more recent because it fills pores, dust rim and grain margins, contacts and surfaces as alteration product (Figure 2-8).

Clay minerals occur mostly as unoriented microcrystalline aggregates. They are seen around quartz grains and around calcite cement as alteration products (Figure 4 and 6).

Iron Oxide occurs as coating on detrital grains of quartz, feldspars and rock fragment.

The sequence of decreasing abundance for the Ezeaku Sandstones is in the following order: Calcite, silica, clay and iron oxide.

Paragenetic sequence

Textural relationship of the grain and cement in the Ezeaku Sandstones indicate four stages of chemical diagenesis in the following order:

Develpoment of iron oxide coating on grains margins and surfaces.

Solution and recrystallization of silica as microcrystalline quartz and quartz overgrowth

Development of clay cement

Calcite development

4.2 Chemical Analysis

Chemical analysis of the studied sandstone was carried out using the following parameters, SiO_2, K_2O, Al_2O_3, Na_2O, Fe_2O_3, TiO_2, MnO, MgO and CaO. The result in Table 2 shows slight variation in element composition of all the samples analysed. This variation reflects changes in the chemical and mineralogical composition of the sediment, especially in the quartz-feldspar ratio and Cao abundance.

SiO_2 abundance ranges from 32.30% to 88.90%; the value is lowest in the calcareous concretions where it is 32.30% and 42.16% and lower in the host calcareous sandstones where it ranges from 53.00% to 88.90.14%. This is mainly due to calcite replacement. Figure 11 explicitly displays the inverse relationship of silica to CaO. The higher the SiO_2, the lower the CaO and the lower the SiO_2 the higher the CaO.

Al_2O_3 value is high and it ranges from 9.766% to 23.55%, it is lowest in sample 6 from the non-calcareous sandstone member of the Ezeaku Formation. K_2O value ranges from 2.832 to 4.59%; Na_2O value ranges from 1.834 to 3.936%. The values of Na_2O and K_2O in sample 6 are insignificant compared to others. The sandstone is richer in K_2O than in N_2O, which is typical of arkoses (Figures 12 and 13). Fe_2O_3 value ranges from 0.9915 to 1.521%; MgO value ranges from <0.0034 to 2.545%; TiO_2 value ranges from 0.0453% to 0.775% and MnO value ranges from 0.0039% to 0.082%. CaO value ranges from 3.222 to 19.55%, it is highest in the concretions where it is 13.44% and 19.55%. CaO is a major component of Calcite.

The precipitation of calcite is evidence of a pH of at least 7.8, which is an alkaline environment. Silica dissolves in an alkaline environment and precipitates in an acid environment. The presence of recrystallized quartz in the form of quartz overgrowth and calcite cement and calcarous concretions indicate a warm temperature and alkaline environment with a pH just slightly above 7.0.

The calcarous concretions are the product of localized precipitation of carbonate mineral in the pores of sediment about a nucleus or centre (Fuhrman, (1968). They are generally spherical and spheroidal. They vary in size from small objects of 1cm in diameter to great spheroidal bodies as much as 9m in diameter. The size is predominantly determined by the permeability of the rock; those in sandstones are larger than those in siltstone.

These concretions contain a great deal of host rock material. The bedding planes of the host rock pass through them, which indicates that these bodies were formed after deposition of the enclosing sediment. They are phenomenon of localized cementation. Such cementation may have been relatively early, Fuhrman (1965). The calcareous concretions in the Amasiri Sandstones conform to Fuhrman (1965, 1968). The sizes range from 3cm - 2m. (Figures 8 -10). It is therefore inferred that these concretions were formed in the studied area and not transported as suggested by Amajor (1987) and Odigi (2007). It can also be inferred from the above discussion that the Amasiri Sandstone was deposited in a shallow marine environment under humid conditions that allowed the segregation of calcite minerals.

The occurrence of angular to sub rounded quartz grains and weathered feldspar imply the significance of both mechanical and chemical weathering in the sandstone and proximity to provenance. It suggests a textural and compositional sub maturity of the sandstones, probably due to the short distance of transport with relatively low relief and multiple cycle of sedimentation respectively.

4.3 Sandstone Composition And Plate Tectonics

It has been repeatedly shown that there is a relationship between sandstone composition and tectonic setting (Middleton et al 1972; Schaw, F. L.1971a). Sedimentary provenance usually affects and influences the character and composition of sandstones found in them. The key relationship between provenance and depositional basin is provided by plate tectonics which ultimately controls the distribution of different types of sandstones. (Dickson et al, 1979).

1. Quartzose sand from continental craton are very common within interior basin, platform successions, miogeoclinal wedges and opening ocean basins.
2. Arkosic sands from uplifted basement block are present locally in rift trough and in wrench basin related to transform ruptures.
3. Volcaniclastic lithic sands derived from magmatic arcs are present in trenches, forearc basins and marginal seas.
4. Recycled orogenic sands rich in quartz or chert and other lithic fragments are derived from subduction complexes, collision orogen and foreland uplift are present in closing ocean basins (Dickson et al, 1979).

Crook (1974) showed the following in his studies.

Quartz rich (>65%), average S_iO_2 (70%) and K_2O/Na_2O (>1) are associated typically with passive continental margins. Quartz intermediate (15%-65%) average, SiO_2 (15%-65%) K_2O/Na_2O (< or =1) are associated with mainly active continental margin or other orogenic belts. Quartz poor (<15%) average, SiO_2 (55%) K_2O/Na_2O (<1) occur mostly in volcanic magmatic arc. Using the oxide values in Table 2, we can deduce Table 3.

The Amasiri Sandstone does not fall in exactly into any of Crooks (1974) pigeonhole. The Sandstone has quartz ranging from 50 – 80%, SiO_2 average of 55.52% and K_2O/Na_2O average of 1.518. SiO_2 in the concretions is very low due to silica replacement by calcite. It can then be inferred that, the Sandstone was deposited in environment that ranged between Crooks (1974 type 1 and type 2 environment. That is, passive continental margins with intermittent tectonic activity in a warm environment.

5.0 Conclusion

The Ezeaku Formation, known as the Amasiri Sandstone in Afikpo Basin occur as NE-SW trending elongate sand ridges which alternate with Shale swales. They are mainly Arkosic, The most common mineral is quartz. The quartz grains are mainly monocrystalline, they range from very fine to coarse grains and exhibit very few euhedral quartz overgrowth. The over growth are separated by dust rims. Feldspars are few and lithic fragments are almost non-existent. Tangential, sutured and concave – convex grain contacts were observed but concave convex is more prominent. Deformational structures such as fractures on grains were observed. The grains show corrosion and alteration at grain contact and surface. Calcite is seen replacing silica at pore spaces and at grain margins and surfaces. Clay mineral and iron oxide also occur in places. The paragenetic sequence is as follows: Development of iron oxide coating on grains margins and surfaces; solution and recrystallization of silica as microcrystalline quartz and quartz overgrowth; Development of clay cement and calcite development.

The Sandstone was deposited in a warm alkaline, but slightly acidic environment that favoured the dissolution and recrystallization of silica at grain contact and the formation of calcite cement and diagenetic segregation of calcite in to concretions which are randomly emplaced within mainly the basal bioturbated beds. This is typical of the shallow marine environment. Therefore, the shallow marine environment can be inferred for the sandstone.

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TABLE 1: Stratigraphic Successions In Anambra and Afikpo Basins in the Lower Benue Trough.

SYSTEM	**SERIES**	**STAGE**	**LOWER BENUE TROUGH**	**LOWER BENUE TROUGH**
			ANAMBRA BASIN	**AFIKPO BASIN**
TERTIARY	Eocene		Ameki Fm.	Ameki Fm
	Paleocene		Imo Shale	Imo Shale
CRETACEOUS		Maastrichtian	Nsukka Fm.	Nsukka Fm.
			Ajali Sandstone	Ajali Fm.
			Mamu Fm.	Mamu Fm.
	Senonian	Campanian	Enugu Shale	Nkporo Fm.
		Santonian	Awgu Fm.	Ezeaku Fm.
		Coniacian		
		Turonian	Ezeaku Fm.	
		Cenomanian	Odukpani Fm.	
		Albian	Asu River Group	Asu River Group
PRECAMBRIAN			BASEMENT COMPLEX	
			Hoque, 1977	**Odigi, 2007**

Table 2: Chemical Composition Of The Studied Sandstone

Sample no	Location	SiO_2	K_2O	Al_2O_3	Na_2O	Fe_2O_3	TiO_2	MnO	MgO	CaO
AM1	Ibii calc Sst	50.67	4.54	17.34	1.834	1.312	0.775	0.029	0.318	3.222
AM2	Ibii calc nodule	32.30	2.832	9.766	2.089	0.992	0.5758	0.082	0.246	19.55
AM3	Ozara-Ukwu calc nodule	42.16	3.084	16.39	1.964	1.277	0.4780	0.0607	2.545	13.44
AM4	Ozara-ukwu calc Sst	66.14	4.59	23.55	3.936	1.521	0.5895	0.0796	0.940	0.672
AM5	Akpoeze calc Sst	53.00	3.270	12.05	2.154	1.046	0.290	0,0179	0.470	2.972
AM6	Amasiri non Calc. Sst.	88.90	0.0815	13.86	0.137	0.414	0.0453	0.0039	<0,0034	0.0327

Table 3: Showing K_2O/Na_2O values.

	LOCATION	**SiO_2**	**K_2O**	**Na_2O**	**K_2O/Na_2O**
AM1	Ibii calc sst	50.67	4.54	1.834	**2.475**
AM2	Ibii calc nodule	32.30	2.832	2.089	**1.356**
AM3	Ozara-Ukwu calc nodule	42.16	3.084	1.964	**1.570**
AM4	Ozara-ukwu calc sst	66.14	4.59	3.936	**1.166**
AM5	Akpoeze calc sst	53.00	3.270	2.154	**1.518**
AM6	Amasiri non calc sst	88.90	0.0815	0.137	**0.594**
	Average	55.52	3.066	2.019	**1.518**

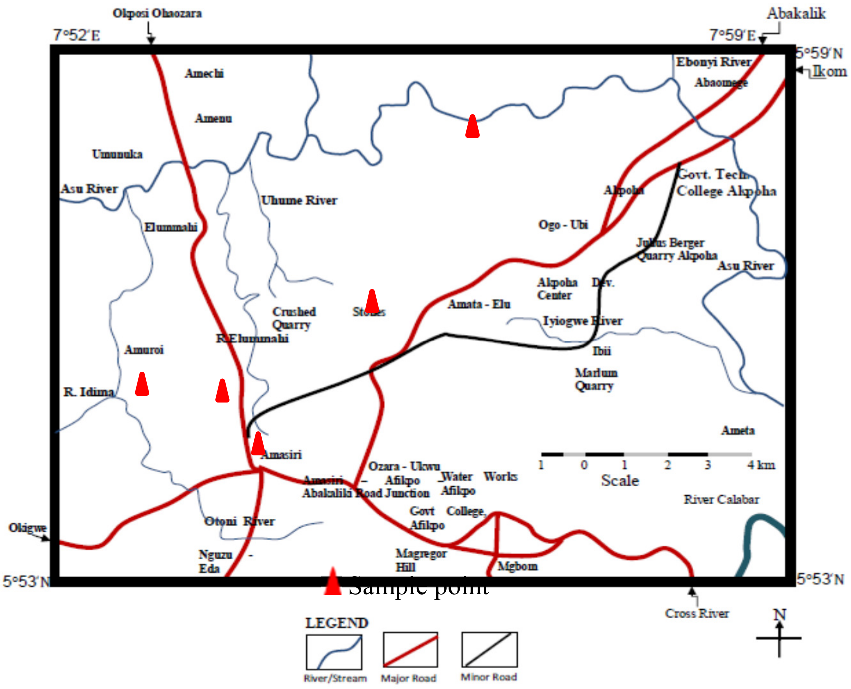

Figure 1: Location and Accessibility Map of Study Area and Its Environs.

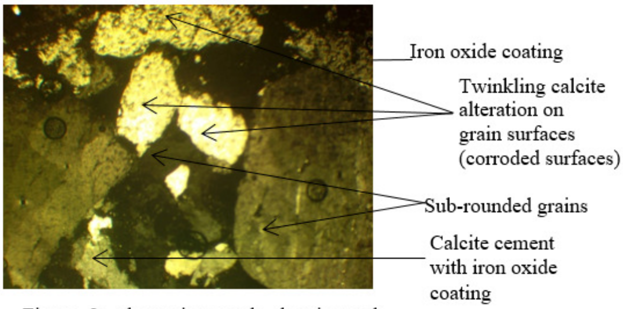

Figure 2: photomicrograph showing sub rounded - angular framework grains and their poorly sorted nature, calcite cement as alteration product and iron mineral coating in Amasiri Sandstone.

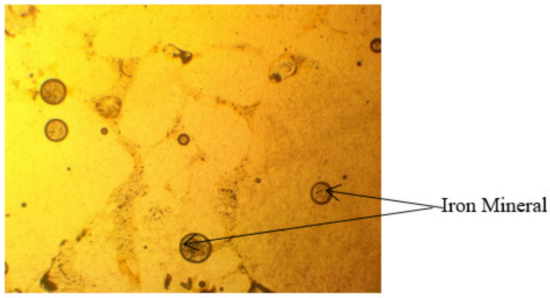

Figure 3: Photomicrograph (PPL) showing rounded grains, calcite cement and iron minerals in Amasiri Sandstone.

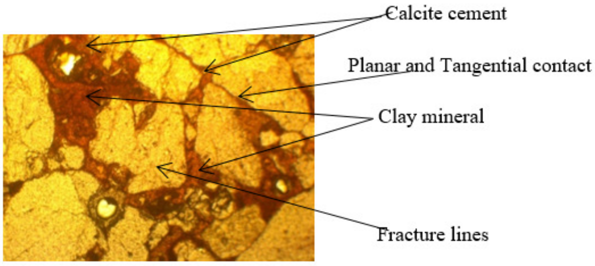

Figure 4: Photomicrograph showing planar and tangential contact, subangular grains, fracture lines, calcite cement and clay minerals in Amasiri Sandstone

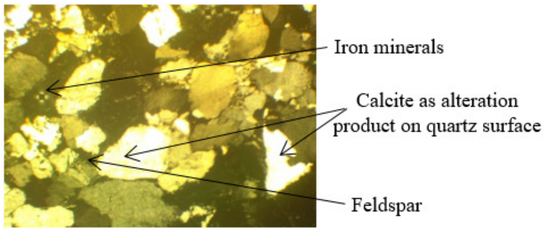

Figure 5: Photomicrograph (CPL) showing angular grains that are moderately sorted, calcite as alteration product and iron mineral coating in Amasiri Sandstone.

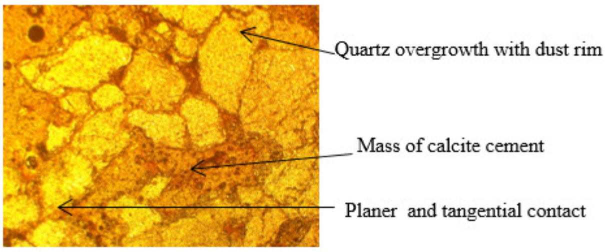

Figure 6: Photomicrograph showing poorly sorted grains, angular to sub angular grains, iron oxide coating on calcite cement, with planer and tangential contact in Amasiri Sandstone.

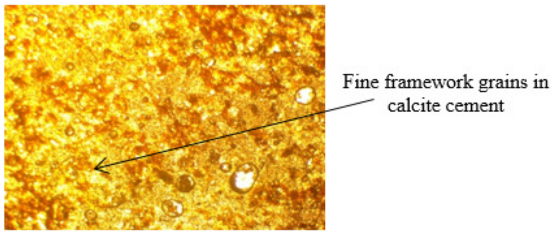

Figure 7: Photomicrograph showing fine grains in groundmass of calcite with iron oxide coating.

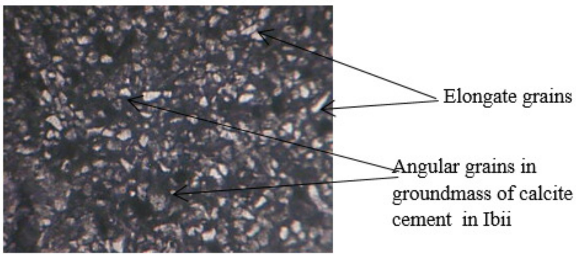

Figure 8: Showing angular and elongate grains

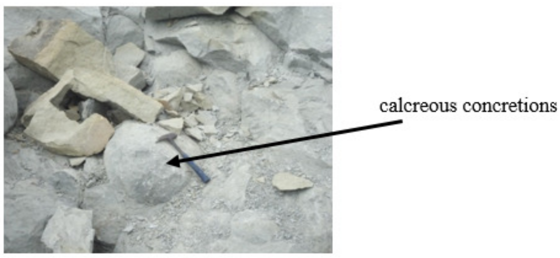

Figure 9: Amasiri Sandstone at Ibii showing calcareous concretions

Figure 10: Amasiri Sandstone at Ibii showing calcareous concretions in bioturbated host rock. Concretions and host rock have the same colour and grain size.

Figure 11: Amasiri Sandstone at Ibii showing calcareous concretions

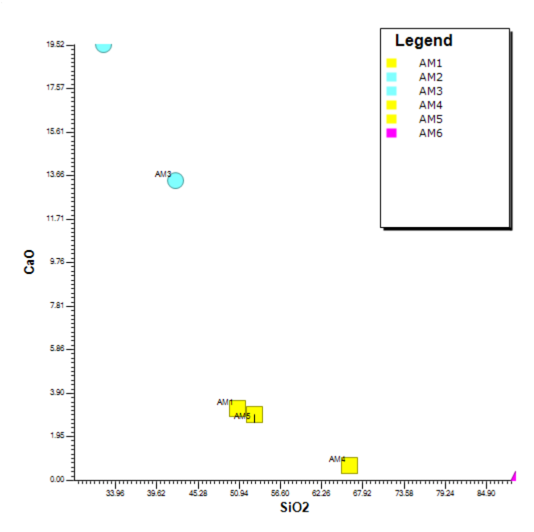

FIG 12: XY PLOT OF SiO_2 VS CaO OF AMASIRI

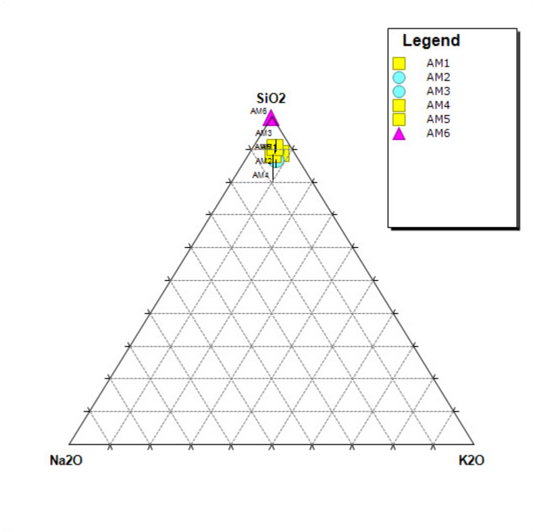

FIG 13: PLOT OF TOTAL ALKALI VS SiO_2

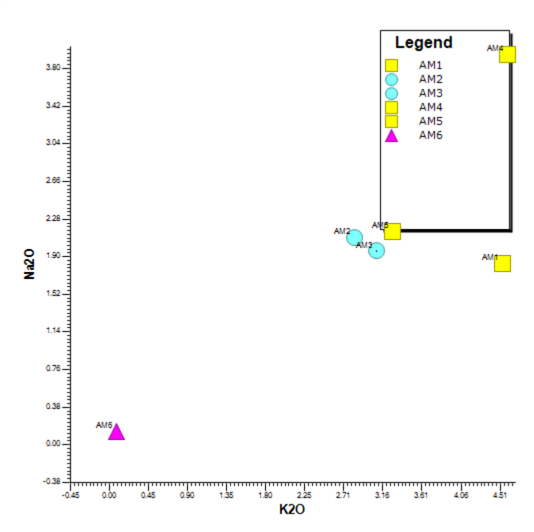

FIG. 14: PLOT OF Na_2O VS K_2O IN AMASIRI SANDSTONE

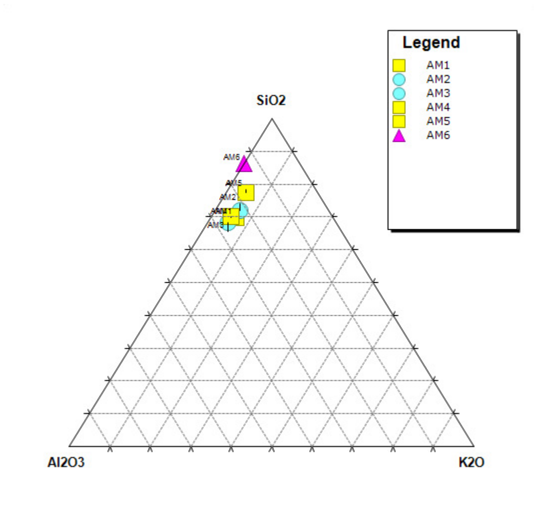

FIG 15: PLOT OF SiO_2, AL_2O_3 AND K_2O OF AMASIRI SANDSTONE