Ezeaku Formation Calcareenaceous Sandstone Facies at Abini, Cross River State, Nigeria

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ABSTRACT

Mineralogical and paleocurrent studies of Amasiri Sandstone, a member of Ezeaku Group outcropping as a ridge in Abini were done to determine the quantitative values of component minerals for proper designation of the facies of sandstone and the direction of paleocurrent. Sampling, paleocurrent measurements, petrographic and X-ray diffraction (XRD) analyses were employed to achieve results. Three highly indurated beds of white fine – medium, angular - subrounded grained sandstones were observed. The basal and second beds had thin laminations, whereas the third was massive. The sandstone is found to be hybrid facies, it is not a quartz arenite neither a calcareous sandstone. Calcite (CaCO_3) is the most abundant mineral ranging from 43% - 66%, with an average of 51.39%. Calcite is seen occurring as skeletal grains and sparry calcite, corroding, and replacing quartz grains. Quartz (SiO_2) ranges from 3% - 37.6% with an average of 17.22%, occurring as detrital quartz and authigenic quartz overgrowth. Monocrystalline and polycrystalline quartz occur, with monocrystalline dominating. Feldspars such as albite, plagioclase, sanidine and orthoclase occur, with the potassic feldspars dominating. Silica, calcite, and iron oxide were the observed cementing materials. The paleocurrent direction is in the SE. The angularity of the grains implies a source area with close proximity. Therefore, the source area could be inferred to be the Oban Massif or and the Cameroun Mountains.

Keywords: Authigenic, Calcareenaceous, Detrital, Hybrid sandstone, Skeletal grains.

Published Online: February 23, 2022

ISSN: 2684-446X

DOI : 10.24018/ejgeo.2022.3.1.247

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I. INTRODUCTION

Calcareenaceous sandstone is special sandstone that does not fall into the typical classes of sandstones, but it is hybrid between quartz arenite and calcarenitic limestone. They are a mixture of detrital quartz and detrital carbonates [1]. They are characterized by low quartz content and high carbonate grain content. The carbonate grains are typically non-clastic that are derived from within the basin - They are mainly skeletal particles and ooids. Calcareenaceous sandstones contain up to 50% CaCO_3 as carbonate grains. They occur in carbonate producing areas where there is a large influx of terrigenous clastic. They grade laterally into limestone or purer sandstone [2].

The Amasiri Sandstones is a member of the Ezeaku Group in the Afikpo Syncline, it occurs as series of parallel asymmetric ridges in the syncline. The study area is bounded by latitudes: $\text{N}5^{\circ}41'$ and $\text{N}5^{\circ}42'$ and Longitudes: $\text{E}8^{\circ}30'$ and $\text{E}8^{\circ}40'$ (Fig. 1).

The study was centered on the Amasiri Sandstone ridge in Abini, Cross Rivers State, which trends 310° NW-SE, it is about 8 m high. It is highly indurated and was observed to be calcarenaceous facies of the Ezeaku Group from this study based on the petrography and XRD analysis used to determine the mineralogy, their quantitative values and accompanying diffractogram.

Fig. 1. Location map showing study points.

II. LITERATURE REVIEW

Shell D' Archy geologists in the 1950s, studied the Ezeaku Formation, and erected a stratigraphic unit. They described the Formation as hard, flaggy, calcareous grey or black shales and siltstones with impressions of *Innoceramus* sp. common [3]. [4] Introduced the term "Ezeaku Shale Group" and included all the stratigraphic units deposited in the Late Cenomanian to Turonian in the southern Benue Trough. [5] Subdivided the Ezeaku Formation into several lithofacies, which are: calcareous and non-calcareous sandstones, siltstones, shales, and limestones. [6] Classified

the Amasiri Sandstone ridge at Abini as calcareous sandstone with fine to medium grains, fairly sorted and highly bioturbated.

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 [7].

III. STRATIGRAPHY

Amasiri Sandstone occurs as series of parallel asymmetric ridges in the Afikpo Syncline. The Afikpo syncline is associated with the Benue Trough which is a north east – south west trending elongate Cretaceous rift. It is flanked on both sides by Basement rocks. It is believed that much of the lithic fill of the southern Benue Trough are derived from these Basement rocks [8]. Intracontinental conglomerate, sandstone and shales of fluvial origin of the Awi Formation rest on the Basement rock in the Calabar Flank. This was classified with the Asu River Group because of lithological similarities [9]. The first marine transgression deposited the Asu River Group in the Mid–Albian. This is a clastic sequence of shales, limestone, and sandstones. Shales dominate in the south and grade northwards into limestone platforms at Arufu and Gboko [9]. This was followed by a regressive phase that was restricted to the Calabar flank and the Odukpani Group made up of the Ekenkpon Shale and the New Netim Marl were deposited. The second marine transgression which occurred in the Turonian was the most extensive; it deposited the Ezeaku Group and Awgu Formation. In the Anambra basin, the Nkalagu limestone predominates, whereas the Amasiri Sandstone predominates in the Afikpo syncline. The third marine transgression in the Cretaceous stratigraphy of south- eastern Nigeria occurred in the Campanian – Maastrichtian. It deposited the proto Niger Delta Formations in the Anambra basin, Afikpo Syncline and the Nkporo Shale in the Calabar Area. The proto Niger Delta formations include the Nkporo Group, the Mamu Formation, Ajali Formation and the Nsukka Formation in the Cretaceous. The Nkporo Group include: Nkporo Shale and its lateral equivalents: The Afikpo Sandstone in Afikpo syncline, and the Owelli Sandstone and the Enugu Shale in the Anambra basin (See Table I).

IV. METHODOLOGY

The study involved outcrop analysis, paleo-current analysis, sampling of selective beds, petrographic analysis and XRD analysis for mineralogy and modal composition of the Formation. Measurements of inclinations of bed laminae were taken for paleo-current direction. Some of the selected samples were labeled and taken to the laboratory for preparation of thin sections for determination of light minerals by petrographic studies. The rock samples were cut, sliced, and smoothened on one side by carborundum. The slices were put on glass slip with heated basalm on it

for the purpose of gluing. For the XRD analysis, the samples received were crushed and split into two equal halves. One crushed portion was pulverized to 100% passing through 75 μm sieve, split into two portions with one portion further submitted for XRD Analysis while the other half was kept as reference sample. The pulverized fraction was analyzed using Rigaku Miniflex 600 XRD equipment employing Cu-K α radiation at 2 theta angle 2–70°.

TABLE I: STRATIGRAPHIC SUCCESSIONS IN THE ANAMBRA BASIN, AFIKPO SYNCLINE AND CALABAR FLANK

Age	Anambra Basin	Afikpo Syncline	Calabar Area
Campanian - Maastrichtian	Nsukka Formation	Nsukka Formation	Nkporo Shale
	Ajali Sandstone	Ajali Sandstone	
	Mamu Formation	Mamu Formation	
	Nkporo Group = Owelli Sandstone/ Enugu Shale	Nkporo Group = Afikpo Sandstone	
Santonian			???
Coniacian	Awgu Shale = Agbani Sandstone		New Netim Marl
Turonian	Ezeaku Formation = Nkalagu Limestone	Ezeaku Formation = Amasiri Sandstone	Ekenkpon Shale
Cenomanian			
Albian	Asu River Group = Abakaliki Shale	Asu River Group	Mfamosing Limestone
	[10]	Unknown?	Awi Formation [11]

V. PRESENTATION AND DISCUSSION OF RESULTS

A. Outcrop Analysis

The Ezeaku Sandstone ridge located at Abini trends 310° NW-SE, it is about 8 m high. It is highly indurated white fine to medium grain sandstone. Three major beds were observed: The basal bed, bed A, is about 0.8 m, it is overlain by thinly laminated bed B of about 1.5 m thick. The third bed C, which is about 6 m thick is massive and lies above the thinly laminated bed. The beds dip between 24° to 50° NE. See Fig. 2A and 2B.

Fig. 2A. Calcareous facies of Amasiri Sandstone at Abini, Cross River State, Nigeria.

Fig. 2B. Calcarenaceous facies of Amasiri Sandstone at Abini, showing white fine grains.

B. Paleocurrent Analysis

Paleo-current direction was measured using the inclinations of the laminae in beds A and B. The following were the azimuth readings, all in the SE direction: 130, 130, 127, 131, 129, 141, 142, 140, 122, 125, 130, 136, 122, 124, 130, 131, 130 and 132 presented in Table II.

TABLE II: FREQUENCY TABLE OF AZIMUTH READINGS

Class interval	Frequency
120 - 129	6
130 - 139	9
140 - 149	3
TOTAL	18

The Sandstone ridge trends 310° NW – SE. Fig. 3 shows the rose diagram, which indicates a provenance source in the SE direction. This is suggestive of the Oban Massif and the Cameroun mountains which are in close proximity as the provenance. According to [12], the ridge has been attributed to storm dominated shallow shelf distributary mount submarine bar, and [5] opined that it accumulated along a transgressing Late Turonian – Coniacian epicontinental sea.

Fig. 3. Rose diagram For Calcarenaceous facies of Amasiri Sandstone in Abini, Cross River State Showing SE paleo-current direction.

C. XRD Analysis

The mineralogical assemblage of the Formation was studied using X-ray diffraction (XRD) method. The mineral phases detected by XRD for the various samples are listed in Tables III-IX with their quantitative values and

accompanying diffractogram which are shown in Fig IV-X. Calcite is the most abundant mineral ranging from 43-66%, with an average of 51.39%. Quartz (SiO_2) ranges from 3-37.6% with an average of 17.22%. Both sodic and potassic feldspars occur, such as Albite, plagioclase, Sanidine and orthoclase with potassic feldspars dominating.

TABLE III: RELATIVE ABUNDANCE OF THE MINERAL PHASES (%) AS DETERMINED BY XRD ANALYSIS MINERAL

Mineral	Chemical Formula	ABS 01 10276 (%)
Calcite	CaCO_3	53.0
Albite	$\text{Na(AlSi}_3\text{O}_8)$	2.0
Plagioclase	$\text{Ca}_{0.75}\text{Na}_{0.25}\text{Al}_{1.75}\text{Si}_{2.25}\text{O}_8$	5.0
Sanidine	KAlSi_3O_8	19.0
Quartz	SiO_2	18.0
Muscovite	$\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{F,OH})_2$	2.0
Chlorite	$\text{Mg}_2\text{Al}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{O})_8$	0.02
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	2.0

Fig. 4A. Pie chart of mineral phases for ABS 01.

TABLE IV: RELATIVE ABUNDANCE OF THE MINERAL PHASES (%) AS DETERMINED BY XRD ANALYSIS MINERAL

Mineral	Chemical Formula	ABS 02 10276 (%)
Calcite	CaCO_3	50.0
Quartz	SiO_2	24.0
Albite	$\text{Na(AlSi}_3\text{O}_8)$	9.5
Orthoclase	$\text{Al}_2\text{O}_3 \cdot \text{K}_2\text{O} \cdot 6\text{SiO}_2$	6.0
Sanidine	KAlSi_3O_8	5.0
Muscovite	$\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{F,OH})_2$	1.0
Chlorite	$\text{Mg}_2\text{Al}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{O})_8$	0.01
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	4.0

Fig. 4B. Pie chart of mineral phases for ABS 02.

TABLE V: RELATIVE ABUNDANCE OF THE MINERAL PHASES (%) AS DETERMINED BY XRD ANALYSIS MINERAL

Mineral	Chemical Formula	ABS 2B 10278 (%)
Calcite	CaCO_3	50.0
Quartz	SiO_2	5.4
Albite	$\text{Na}(\text{AlSi}_3\text{O}_8)$	17.0
Orthoclase	$\text{Al}_2\text{O}_3 \cdot \text{K}_2\text{O} \cdot 6 \text{SiO}_2$	2.3
Sanidine	KAlSi_3O_8	18.0
Muscovite	$\text{KA}(\text{AlSi}_3\text{O}_{10})(\text{F},\text{OH})_2$	3.0
Chlorite	$\text{Mg}_2\text{Al}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{O})_8$	0.01
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	5.0

Fig. 4C. Pie chart of mineral phases for ABS 2B.

TABLE VI: RELATIVE ABUNDANCE OF THE MINERAL PHASES (%) AS DETERMINED BY XRD ANALYSIS MINERAL

Mineral	Chemical Formula	ABS 4B 10280 (%)
Calcite	CaCO_3	49.0
Quartz	SiO_2	11.0
Albite	$\text{Na}(\text{AlSi}_3\text{O}_8)$	17.0
Orthoclase	$\text{Al}_2\text{O}_3 \cdot \text{K}_2\text{O} \cdot 6 \text{SiO}_2$	9.0
Sanidine	KAlSi_3O_8	5.0
Muscovite	$\text{KA}(\text{AlSi}_3\text{O}_{10})(\text{F},\text{OH})_2$	3.0
Chlorite	$\text{Mg}_2\text{Al}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{O})_8$	0.3
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	6.0

Fig. 4D. Pie chart of mineral phases for ABS 4B.

TABLE VII: RELATIVE ABUNDANCE OF THE MINERAL PHASES (%) AS DETERMINED BY XRD ANALYSIS MINERAL

Mineral	Chemical Formula	ABS 5B 10281 (%)
Calcite	CaCO_3	48.7
Quartz	SiO_2	37.6
Albite	$\text{Na}(\text{AlSi}_3\text{O}_8)$	1.0
Orthoclase	$\text{Al}_2\text{O}_3 \cdot \text{K}_2\text{O} \cdot 6 \text{SiO}_2$	1.5
Sanidine	KAlSi_3O_8	9.5
Muscovite	$\text{KA}(\text{AlSi}_3\text{O}_{10})(\text{F},\text{OH})_2$	0.8
Chlorite	$\text{Mg}_2\text{Al}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{O})_8$	0.2
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	0.6

Fig. 4E. Pie chart of mineral phases for ABS 5B.

TABLE VIII: RELATIVE ABUNDANCE OF THE MINERAL PHASES (%) AS DETERMINED BY XRD ANALYSIS MINERAL

Mineral	Chemical Formula	ABS 5MC 10282 (%)
Calcite	CaCO_3	43.0
Quartz	SiO_2	15.0
Albite	$\text{Na}(\text{AlSi}_3\text{O}_8)$	5.0
Orthoclase	$\text{Al}_2\text{O}_3 \cdot \text{K}_2\text{O} \cdot 6 \text{SiO}_2$	6.0
Sanidine	KAlSi_3O_8	6.0
Muscovite	$\text{KA}(\text{AlSi}_3\text{O}_{10})(\text{F},\text{OH})_2$	9.0
Chlorite	$\text{Mg}_2\text{Al}_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{O})_8$	2.0
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	15.0

Fig. 4F. Pie chart of mineral phases for ABS 5MC.

D. Diffractogram of Samples of Amasiri Sandstones in Abini

Fig. 5. Diffractogram obtained for ABS 01 102276.

Fig. 6. Diffractogram obtained for ABS 02 10277.

Fig.10. Diffractogram obtained for ABS 5B 10281.

Fig. 7. Diffractogram obtained for ABS 2B 10278.

Fig. 11. Diffractogram obtained for ABS 5MC 10282.

Fig. 8. Diffractogram obtained for ABS 3B 10279.

Fig. 9. Diffractogram obtained ABS 4B 10280.

VI. PETROGRAPHY

Under thin sections, it was observed that the Sandstone is made up of fine to medium grains which are elongate, angular to sub-rounded grains of majorly quartz forming the clast, and skeletal particles. See Fig. 11 A–G, which are photomicrographs of the samples under the microscope.

The modal composition of minerals using the Point Counter is given in Table X and Fig. 12 A–G. That of quartz is from 15.6% to 29.6%. The average modal composition is 23.37%. The quartz grains are mainly monocrystalline which show few euhedral quartz overgrowths. The overgrowth is separated from the detrital quartz with a dust rim. It is also observed that some of the edges of the quartz grains are corroded or etched as shown by the irregular embayed contact with calcite, and calcite is seen replacing quartz.

Feldspars were observed but, the potassic feldspars: orthoclase and microcline are most common. They range from 5.6% to 20.4%. The average modal composition is 13.26%. Rock fragments are not common in the sandstone.

Calcite is seen occurring as skeletal particles and as sparry calcite corroding and replacing quartz grains at grain contacts and within the mineral quartz. The average modal composition is 58.8%

A. Texture

The grains are fine-medium grains that are poorly sorted. They are sub-angular to sub –rounded, which indicate short distance of travel. The quartz grains are mainly monocrystalline, but, polycrystalline quartz do occur. Tangential, sutured and concave–convex grain contacts were

observed. Also observed were deformational structures such as fractures on the grains.

B. Diagenesis

Silica cement which may have resulted from the solution and recrystallization at grain contacts occurs as microcrystalline and crystalline aggregates filling pores as well as overgrowth on detrital quartz.

Calcite cement is the most abundant but is more recent than the silica. This is because it fills the pore created by microcrystalline quartz grains and fills the dust rims as alteration products. Iron oxide occurs as coating on the detrital grains. The average modal composition is 4.57%. The sequence of decreasing abundance is in the following order: Calcite, Silica and Iron oxide.

TABLE X: MODAL COMPOSITION OF SANDSTONE FROM POINT COUNTER AT 250X UNDER XPL

Samples	Quartz	Orthoclase/ Microcline	Calcite	Iron Oxide
ABS1	28	14	54.4	3.6
ABS2	26.8	17.2	48.4	7.6
ABS2B	15.6	10.8	70	3.6
ABS3B	19.6	5.6	68.4	6.4
ABS4B	16.8	9.6	70	3.6
ABS5B	29.6	15.2	51.2	4
ABS5MC	27.2	20.4	49.2	3.2
Average	23.37	13.26	58.8	4.57

C. Paragenetic sequence

Textural relationship of the grains and cement in the Formation indicate the following order:

- 1) Development of iron oxide coating on quartz grains and quartz boundaries.
- 2) Solution and recrystallization of silica as microcrystalline quartz and quartz overgrowth
- 3) Calcite development.

(a)

(b)

Fig. 12A. Photomicrograph of ABS 1 under PPL (40X) (a) and XPL (40X) (b).

(a)

(b)

Fig. 12B: Photomicrograph of ABS 2 under PPL (40 X) (a) XPL (40X) (b).

(a)

(b)

Fig. 12C. Photomicrograph of ABS 2B under PPL (40X) (a) and XPL (40X) (b).

(a)

(b)

Fig. 12D. Photomicrograph of ABS 3B under PPL (40X) (a) and XPL (40X) (b).

(a)

(b)

Fig 12F. Photomicrograph of ABS 5B under PPL (40X) (a) and XPL (40X) (b).

(a)

(b)

Fig. 12E. Photomicrograph of ABS 4B under PPL (40X) (a) and XPL (40X) (b).

(a)

(b)

Fig. 12G. Photomicrograph of ABS 5mc under PPL (40X) (a) and XPL (40X) (b).

(a)

(e)

(b)

(f)

(c)

(g)

(d)

Fig. 13. Pie charts of mineral percentages under XPL:
(a) ABS 1; (b) ABS 2; (c) ABS2B; (d) ABS3B; (e) ABS4B; (f) ABS5B;
(g) ABS 5mc.

VII. SUMMARY

Based on the results from XRD and the petrographic analysis, it is shown that the Amasiri Sandstone ridge outcropping at Abini has very high content of calcite, with an average calcite value of 51.39%. Calcite occurs as skeletal particles and as sparry calcite that occurs as replacement for the quartz grains as well as cementing material in the Formation. Silica occurring as monocrystalline and polycrystalline quartz has an average value of 17.22%. The point counter readings from the petrographic analysis also confirm this mineralogy. The quantitative analysis of the components of the Formation was done using the point counting mechanism which gave the values in percentages of the component minerals -

quartz, calcite, orthoclase, microcline and iron oxide. Their various values are listed in Table X. Calcite has an average of 58.8%, quartz has an average value of 23.37%, orthoclase and microcline have a value of 13.26% and Iron Oxide has a value of 4.57%. This mineralogy qualifies the Amasiri Sandstone occurring in Abini to be designated as Calcareneous Sandstone instead of Calcareous Sandstone as was proposed by [6]. According to [2], calcarenaceous sandstones occur in carbonate environment where there is a lot of influx of clastic materials and they would grade laterally into limestone or purer sandstone. [12] had opined that the Amasiri Sandstone ridge in Abini must have been deposited in a storm dominated shallow shelf distributary mount submarine bar, which is a favourable carbonate environment, and terrigenous clastic materials may have been derived from the Oban Massif and the Cameroun mountains in the SE as was indicated from the paleocurrent direction. The angularity of grains also confirms a short distance of transport.

REFERENCES

- [1] Pettijohn FJ. *Sedimentary rocks*, Third edition, CBS publishers and distributors, 2004.
- [2] Doyle Larry J. Roberts, Harry H. Editors. *Carbonate clastic transition (Developments in sedimentology)*. Published by Elsevier Science Publishers., Amsterdam, Oxford et. al. (1988) ISBN 10: 044429042 ISBN 13: 978044429049.
- [3] Simpson, A. The Nigerian coalfield: Geology of parts of Onitsha, Owerri and Benue provinces. *Bull. GSN*, 1995;24:85.
- [4] Murat RC. Stratigraphy and paleogeography of Cretaceous Lower Tertiary in southern Nig. African Geol. TFJ. Dessauvague and MD. Whiteman (Ed), University of Ibadan press, 1972, 251-268.
- [5] Umeji OP. Ammonite palaeoecology of the Ezeaku Formation, southeastern Nigeria. *Journal of Mining and Geology*, 1984, vol. 21, pp 55-59.
- [6] Ekueme BN, Nyong EE, Peters, SW. *Geological excursion guidebook to Oban Massif, Calabar Flank and Mamfe Embayment*. Dec-Ford Publishers, Calabar, 1995.
- [7] Akpofure E. and Didei SI. Sedimentology of the Turonian Ezeaku Sandstone in the Afikpo Basin, Nigeria. *International Journal Geology and Mining*, 2018; 4(2):211-223.
- [8] Hoque M. Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, South Nigeria. *Journal of Sedimentary Geology*, 1977;17:235-245.
- [9] Reyment RA. *Aspects of geology of Nigeria*. Ibadan university press, 1965, p. 133.
- [10] Nwajide CS. *Geology of Nigeria's sedimentary basins*. Lagos, CSS Press, 2013.
- [11] Peters SW, Nyong EE, Akpan EB, Essien NU. Lithostratigraphic revision for the Calabar Flank, SE Nigeria. In *Proc. of the 31st Ann. Conf. of NMGS*.
- [12] Amajor LC. The Eze-Aku Sandstone ridges (Turonian) of southeastern Nigeria. A re-interpretation of their depositional origin. *Nigerian Journal of mining and Geology*, 1987;23(1&2):19-26.