Journal of the Nigerian Association of Mathematical Physics
***Volume 29,* (*March, 2015*), pp 375 – 390**

Diagenetic Controls on Reservoir Quality of Tertiary Sandstones Ofameki Formation (Eocene), Southeast Nigeria

Okunuwadje S. E.[1] and Oti M. N.[2]

[1]Department of Geology, University of Benin, P.M.B 1154, Benin City, Nigeria
[2] Department of Geology, University of Port Harcourt, P.M.B 5323, Port Harcourt, Nigeria.

Abstract

Sandstone units on the southeastern flank of the Eocene Ameki Formation were studied petrographically and mineralogically by X-ray diffraction for their reservoir potential.The results obtained show that these sandstones are composed dominantly of quartz grains accounting for approximately 100% of the total detrital component sand are classified as quartz arenites. Reservoir quality of these sandstones rangesfrom poor to good with units in Ogbunike having the highest reservoir potential with preserved porosity value estimated at 15% while units in Umunya, Nsugbe, andNanka are considered as poor to fair (average estimated porosity < 5%). Important factors that influenced diagenesis include compaction, pressure solution at grain contacts, authigenic quartz overgrowth, hematite cementation, microfracturing and dissolution of quartz grains, while compaction, pressure solution, authigenic quartz overgrowth and hematite cementation are the main mechanism which have greatly resulted in porosity loss from its initial value at deposition to a preserved estimated value of about 2-15%. Three diagenetic phases were delineated: an early stage characterized by deposition, burial and early compaction; a second phase characterized by late compaction, pressure solution and precipitation of silica cementation in the form of authigenic quartz overgrowth around detrital quartz grains; and a late phase characterized by microfracturing, dissolution of quartz grains and infiltration of hematite cement. These diagenetic processes have greatly controlled the reservoir quality of these reservoir units.

Key words: Diagenesis; Reservoir quality;Sandstones; Eocene; Ameki Formation

1.0 Introduction

Diagenetic processes control the quality of reservoir rocks which is measured by its porosity and permeability. Etu-Efeotor [1] defined the porosity of a reservoir rock as the capacity of the rock to store or hold fluids and permeability as the capacity to transmit the stored fluid when penetrated by a well. The amount and distribution of porosity in sandstones control the migration pathway of hydrocarbon and ultimately the capacity of such a reservoir to produce hydrocarbon [2]. Though porosity and permeability are initially controlled by sedimentary conditions at the time of deposition but are subsequently altered through diagenesis [3]. Therefore, understanding the diagenetic history of a reservoir is an important step in developing meaningful reservoir models for hydrocarbon exploration and production.

The Eocene Ameki Formation is one of the outcrops of the Tertiary Niger Delta Basin[4-7].Several studies have been carried out on the Eocene Ameki Formation with emphasis on sedimentology, stratigraphy, structural characteristics, depositional environment, reservoir properties and geological significance [8-11]. However, very little is known about the diagenesis of the sandstone units of the Eocene Ameki Formation.

The present study is therefore aimed at investigating the controls of diagenesis on the reservoir quality of the sandstone units of the Eocene Ameki Formation exposed in parts of Southeast Nigeria covering an area of about 1500km^2 and lies between latitude $6^0$00N to $6^0$30N and longitudes $6^0$30E to $7^0$30E (Fig. 1).

Corresponding author: Okunuwadje S.E, E-mail: sunny_okunu@yahoo.com, Tel.: +2347038900349

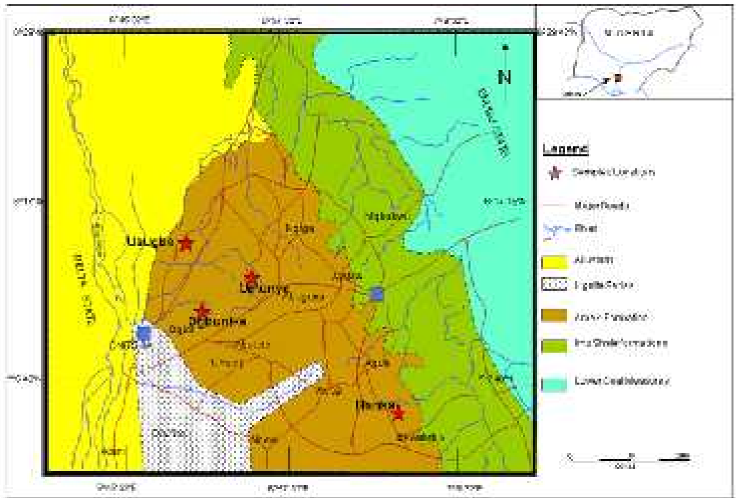


Figure 1: Geological Map of Onitsha, Awka and Environs showing sampled Locations (Sourced from Nigeria Geological Survey)

2.0 Methodology

Selected outcrops of the Ameki Formation (Fig.1) were carefully logged and interpreted. Representative samples collected at selected intervals from each of the outcrops were thereafter subjected to petrographic and XRD analyses.

For petrographic analysis, thin sections were prepared and analyzed petrographically using a polarizing microscope. For proper evaluation of the rock, the Glagolov Chayes' method which is based on grid point count and evaluation of percentages of framework elements and void fillers in the rock[12] was adopted and photomicrographs of the images were thereafter made.

For the mineralogical composition of the rock, the samples were dried @ 60^0c for 30mins, pulverized and X-rayed with the Schimadzu 6000 model X-ray diffractometer under the following conditions: CuKa radiation, 40V/30A, 1^0 auto slits, scanning speed =6 deg/min; for bulk analysis:samples were x-rayed from 2^0 to $60^0=2\theta$;while for orient analysis:samples were prepared for orient and x-rayed from 2^0 to $40^0=2\theta$

3.0 Lithological Description

Location A (Nanka Gully site)

The stratigraphic section in this location (Figs. 2 to 3) is about 40m thick and consists predominantly of bedded sandstones interleaved with mudstone horizons and generally showing a fining upward succession. The sandstone is generally friable and poorly sorted. Paleo current pattern is unimodal with foresets dipping between 10-40 degrees southwest. Five lithofacies were recognized from bottom to top of the section (Fig. 3).

Location B (Umunya)

The stratigraphic section in Umunya (Figs. 4 to 5) is about 20m thick and is characterized predominantly by a succession of bedded sandstones alternating with siltstone and shale horizons. The sandstone is also friable but moderately sorted. Paleocurrent pattern is unimodal with foresets dipping between 10-30 degrees northwest. Four main lithofacies were recognized from bottom to top of the section (Fig. 5).

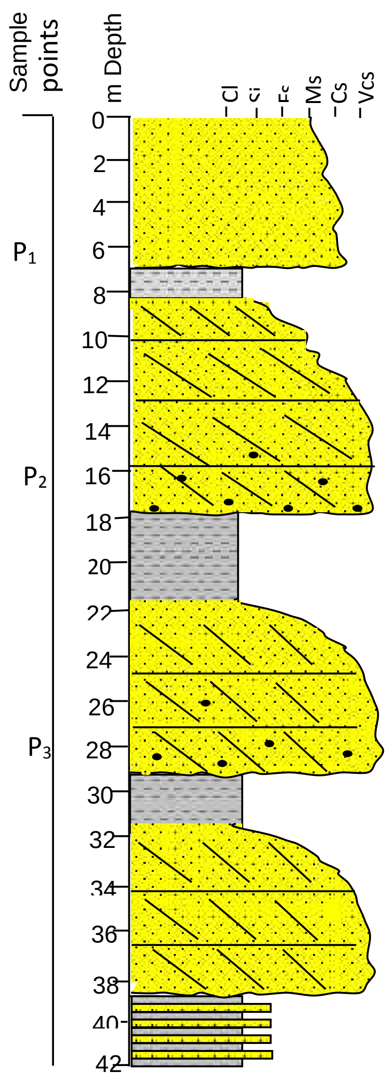
Location C (Ogbunike Cave)

The stratigraphic section in the Ogbunike Cave (Figs. 6) is about 5m thick and is characterized by a succession of relatively cross bedded, medium grained, well sorted, consolidated sandstones. Paleo current pattern is also unimodal with foresets dipping between 10-30 degrees southeast. Two main lithofacies were recognized (Fig. 6).

Location D (Nsugbe)

The stratigraphic section (Figs. 7 to 8) is about 20m thick and is characterized by a succession of friable sandstone that progressively grades upwards into heterolithic layers. Paleocurrent pattern is unimodal with foresets dipping between 10-30 degrees southwest. Six main lithofacies were recognized (Fig. 8).

Figure 2: Showing Overview of the Upper Section in the Nanka Gully site



LITHOLOGY	INTEPRETATION
Poorly sorted ferrugenized sandstone	Cyclic succession of fluvial channel fill
Brownish yellow, fine - coarse grained, locally granular and pebbly, poorly sorted, planar cross bedded sandstone with lag base and fining upwards into mudstone	
White, fine-coarse grained, locally granular and pebbly, poorly sorted, clay draped, planar cross bedded sandstone with erosive base and grading upwards into mudstone	
Fine – coarse grained, poorly sorted, clay draped, planar cross bedded sandstone, grading upwards into mudstone	
Reddish brown, ripple laminated, wavy, shaly heterolith with whitish streaks of siltstone	Tidal flat

Figure 3: Log and interpretation of the Nanka sandstone in the Nanka Gully site behind campus 3 primary school, Enugwu-Nanka Road, 20km south of Awka, (N 06º03′16.8″; E006º04′24″); P= petrographic analysis.

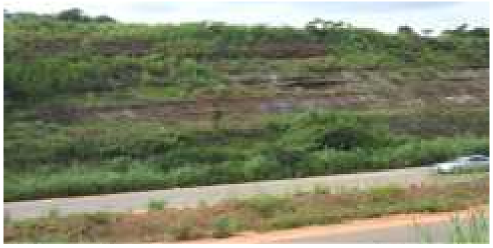
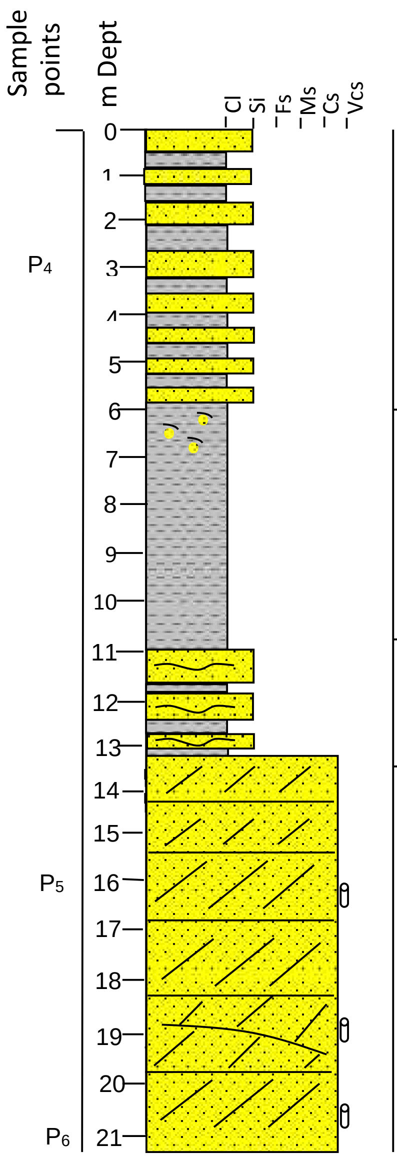
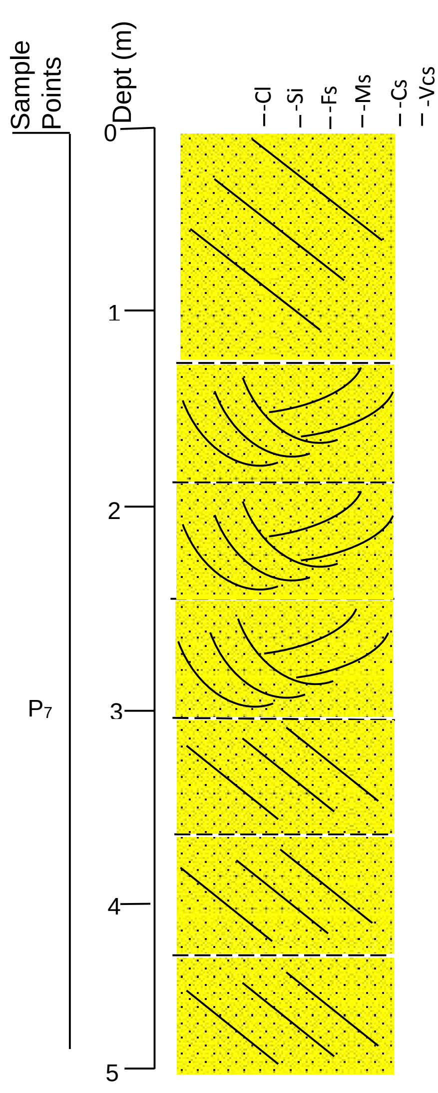


Figure 4: showing overview of the exposed section in Umunya, about 18km from Onitsha along the Enugu-Onitsha Expressway



LITHOLOGY	INTEPRETATION
Shaly heterolith consisting of claystone and wave ripple laminated siltstone	Tidal flat
Shale, brownish, becoming lenticular upwards Sandy heterolith consisting of wavy, ripple cross laminated ,fine sandstone with laminated whitish shale	
White, fine-medium grained, moderately sorted, clay draped, planar cross bedded sandstone with burrows of ophiomorpha, reactivation surfaces, and tidal bundle grading upwards into ripple laminated sandy heteroliths	Tidal (Estuarine) channel

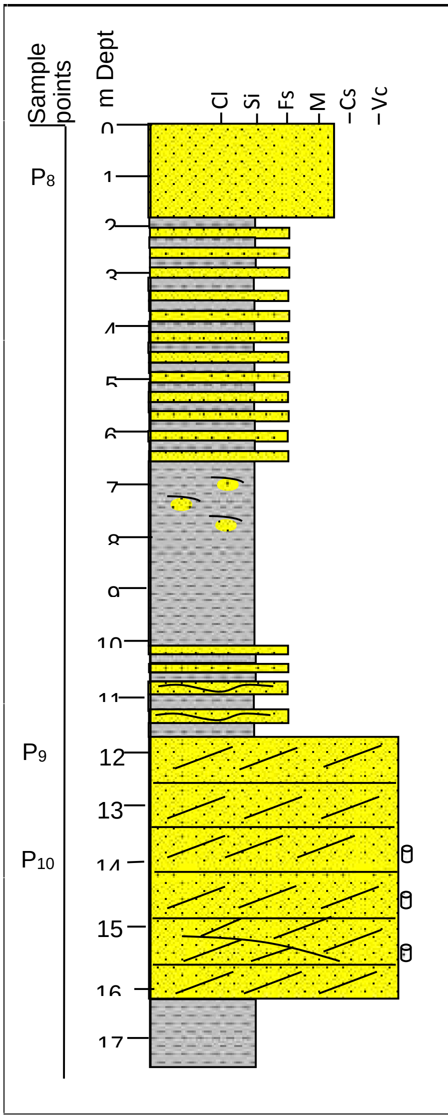
Figure 5: Log and interpretation of the Nanka Sandstone at Umunya about 18km from Onitsha along the Enugu-Onitsha Expressway (N 06º12$^{|}$18$^{||}$; E006º53$^{|}$55$^{||}$); P=petrographic analysis



LITHOLOGY	INTEPRETATION
White, medium grained, well sorted, consolidated, planar cross-bedded sandstone with clay drapes	Tidally influenced estuarine channel fill
White, medium grained, well sorted, consolidated, trough-cross bedded sandstone with reactivation surfaces	
White, medium grained, well sorted, consolidated, planar cross-bedded sandstone with clay drapes	

Figure 6: Log and interpretation of the Nanka Sandstone in Ogbunike cave (N 06º11ǀ06.3ǁ; E06º54ǀ90.0ǁ); P=petrographic analysis

Figure 7: Showing overview of the lower section in Nsugbe



LITHOLOGY	INTEPRETATION
Ferruginized clayey sandstone with sharp base and burrows of Ophiomorpha	Tidal (Estuarine) channel
Shaly heteroliths consisting of claystone and wavy ripple laminated fine sandstone, ferrugenization increasing upwards	Tidal flat
Mudstone, slightly brownish, becoming lenticular upward	
Sandy heteroliths, wavy and ripple cross laminated	Tidal (Estuarine) channel
White, fine to coarse grained, poorly sorted, clay draped, planar cross bedded sandstone with reactivation surfaces and burrows of Ophiomorpha, becoming clayey and flat bedded upwards	
Light gray shale	Tidal flat

Figure 8: Log and interpretation of the Nsugbe Sandstone in Nsugbe along Nsugbe-Umuleri Road (N 06º16ǀ17ǁ; E006º49ǀ30; P=petrographic analysis

4.0 Petrographic Analysis

Results of petrographic analysis of representative samples collected at selected intervals from each of the outcrops are shown on Table 1. Figures 9-12show the photomicrograph while Figure 13 is the ternary plot showing the composition of the sandstone based on point count of twenty-two (22) thin sections.

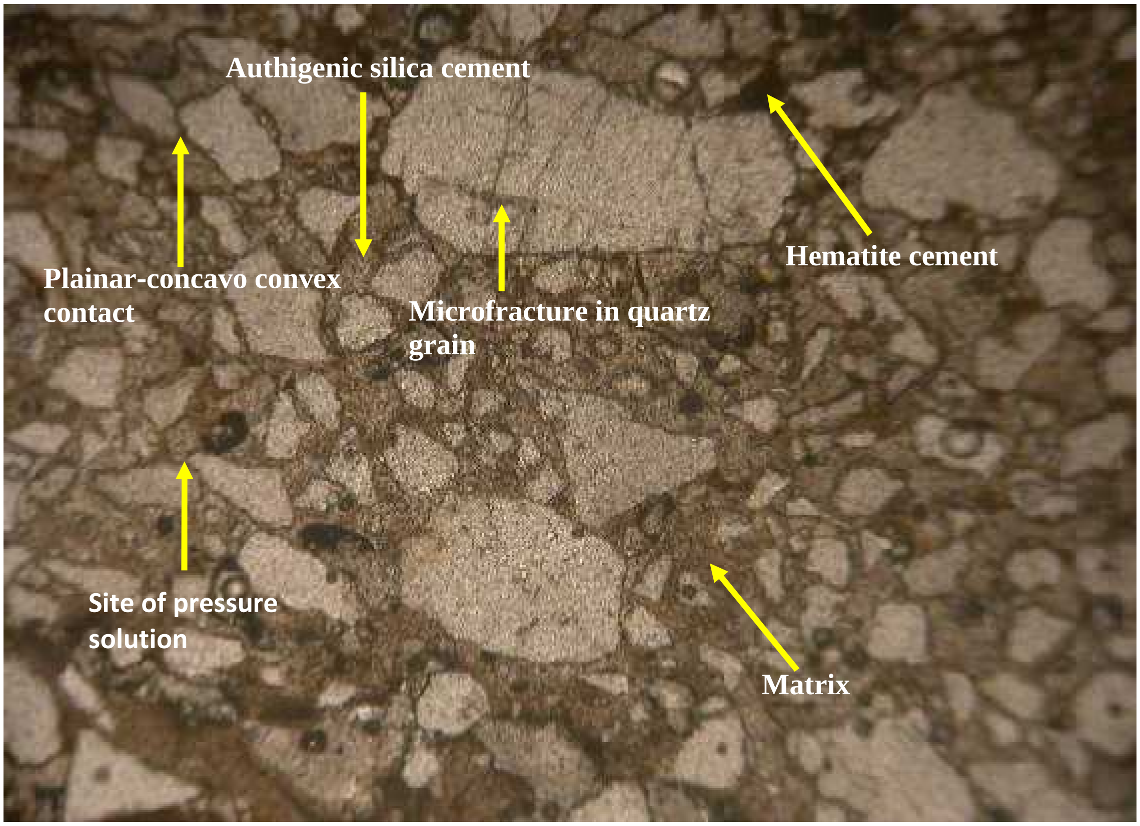


Figure 9: Photomicrograph of sandstone sampled from location 1 (Nanka Gully site, 28m on log)

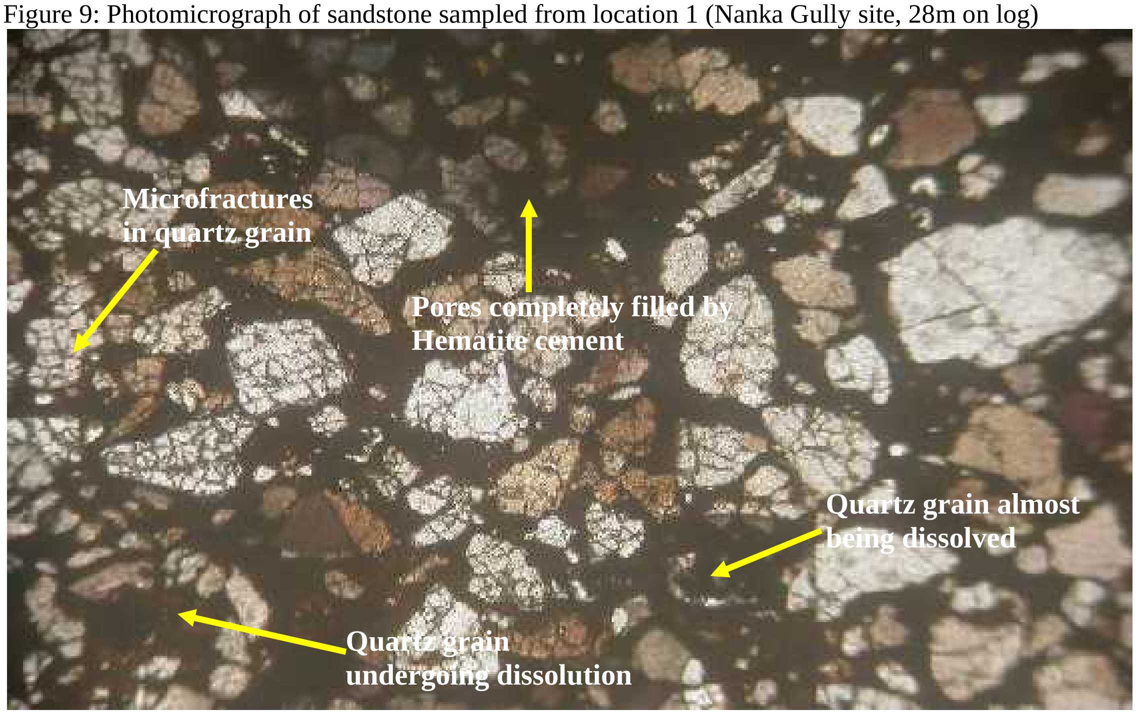


Figure 10: Photomicrograph of sandstone sampled from location 2 (Umunya section, 3mon log)

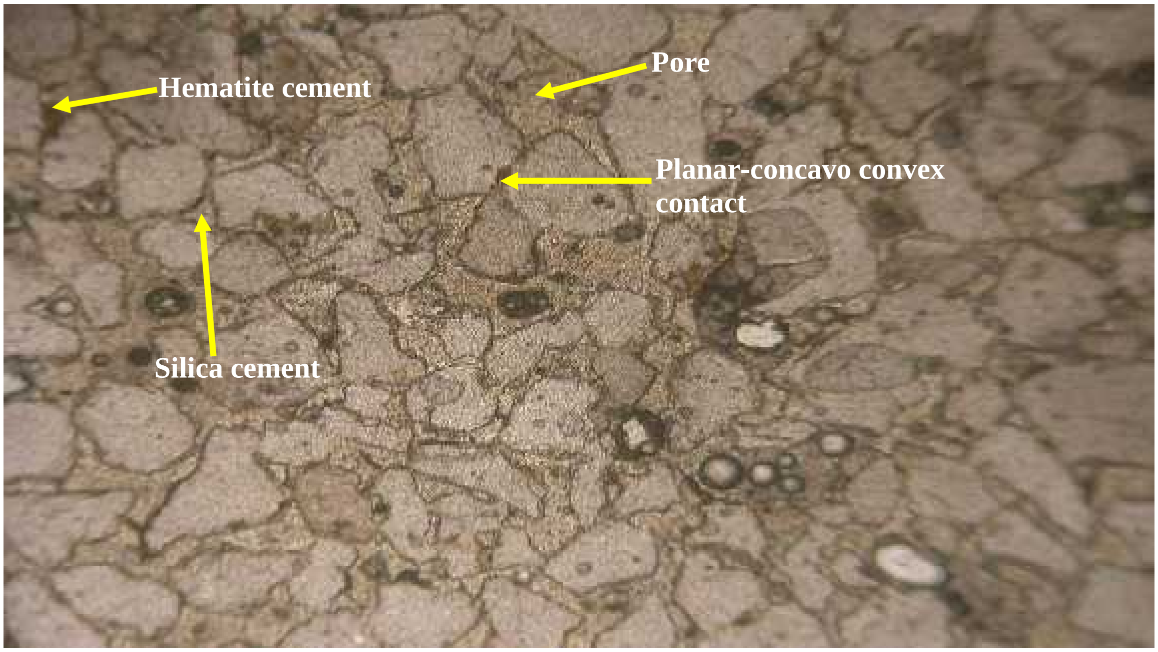


Figure 11: photomicrograph of sandstone sampled from location 3 (Ogbunike cave, 3mon log)

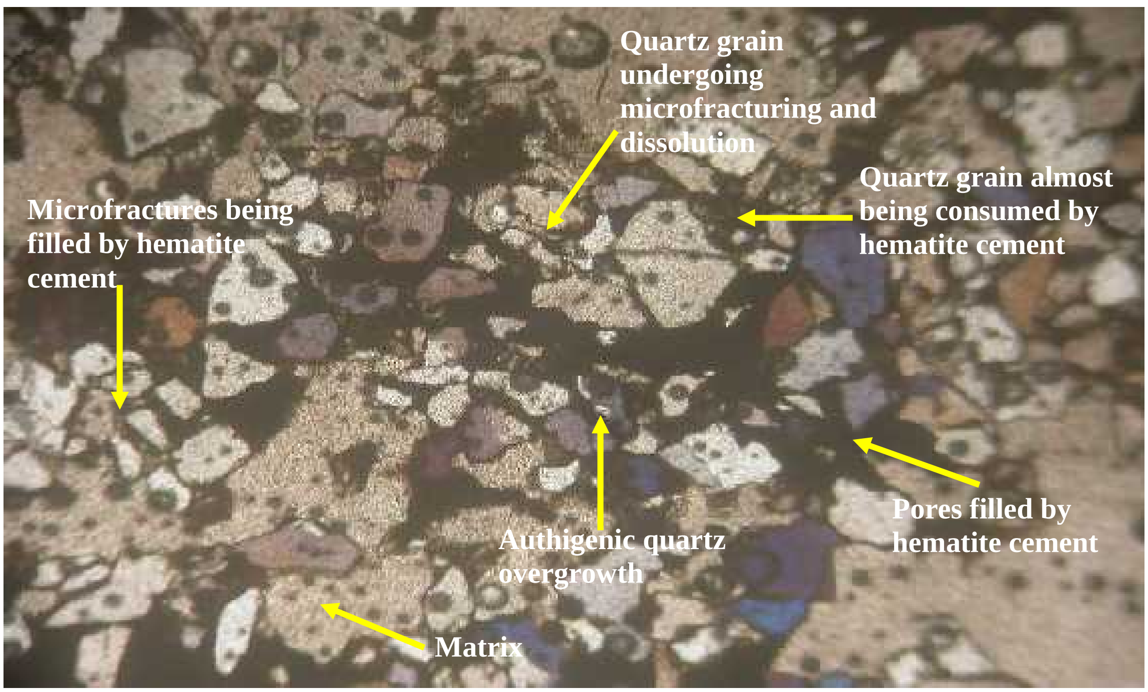


Figure 12: Photomicrograph of sandstone sampled from location 4 (Nsugbe, 6m on log)

Table 1: Petrographic Analysis of the Sandstone Unit of Ameki Formation From Locations A-D

LOCATION	Dept (m)	Det %	Mat %	Detrital Framework Components Recalculated to 100%			Texture						Cement				Porosity	Other Diagenetic features	
				Qtz	Fel dspars	RKF	Size	Spher	Roundness	Sorting	Grain Packing	Grain contact type	Silica %	Hematite %	Total %	Degree		Micro-fractures	Dissolution by hematite
Nanka	6	65	18	100	-	-	F-VC	L-H	Sub rnd-Ang	Poor	Tight	Planar-Concavo convex	5	10	15	moderate	tr	moderate	Tr
	28	68	20	100	-	-	F-VC	L-H	Sub rnd-Ang	Poor	Tight	"	5	5	10	Low	tr	low	-
	36	70	20	100	-	-	F-VC	L-H	Sub rnd-Ang	Poor	Tight	"	5	Tr	8	Low	tr	low	-
Umunya	3	66	10	98	Tr	-	F-C	L-H	Sub rnd-Ang	Poor	Tight	“	Tr	20	22	High	tr	High	High
	16	78	6	100	-	-	F-M	Mo-H	Sub Ang-rnd	Moderate	Tight	“	5	5	10	Low	6	low	-
	21	78	6	100	-	-	F-M	Mo-H	Sub Ang-rnd	Moderate	Tight	"	5	5	10	Low	6	Low	-
Ogbunike	3	75	Tr	100	-	-	M	Mo-H	Subrnd-rnd	Well	Tight	"	10	tr	12	Moderate	15	low	-
Nsugbe	1	70	12	100	-	-	F-C	L-H	Sub rnd-Ang	Poor	Tight	"	tr	13	15	Moderate	3	moderate	tr
	12	72	8	100	-	-	F-M	Mo-H	Subang-Rnd	“Moderate	Tight	"	5	10	15	Moderate	5	moderate	tr
	15	72	8	100	-	-	F-M	Mo-H	Subang-Rnd	“	Tight	"	5	10	15	“	5	“	“

.

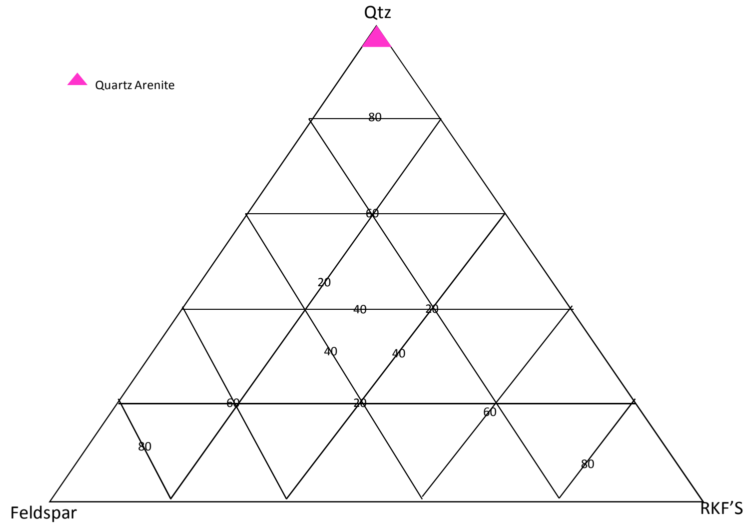


Figure 13: Ternary plot showing composition of sandstones from locations A-D based on pointcount of 22 thin sections. Classification system is that of Pettijohn [13]

As shown, the framework grains of the Ameki sandstones from locations (A-D) are dominantly quartz grains (Fig.13) accounting for almost 100% of the total detrital components. The quartz grains are monocrystalline with undulose extinction patterns. They are generally angular to rounded with low to high sphericity. The grains are generally tightly packed with characteristic planar – concavo convex contact types. Microfractures and dissolution of the quartz grains, though generally ranges from low to moderate but are unexpectedly high at the upper section of location B (Umunya).The matrix is between 2-20% and is composed of clay (kaolinite and illite). Most of the matrix filled the pore spaces and reduced the porosity which range from about 2-15%. Silica and hematite constitute the cement which range from 10-22%.

From the recalculated detrital framework composition, the sandstones in location (A-D) are classified as quartz arenite [12-14]and are therefore compositionally mature [15]. However, sandstones of locations A, B and D have high matrix content (>5%), poor sorting and are sub angular to angular and are therefore texturally immature whereas, location C sandstones have low matrix content (< 5%), well sorting and are sub rounded to rounded and are therefore texturally mature [16].

5.0 X-ray Diffraction Analysis

Results of x-ray diffraction analysis of representative samples collected at selected points from each of the outcrops are shown on Figures 14-15 while Table 2 shows the relative amounts of clay minerals in the study area.

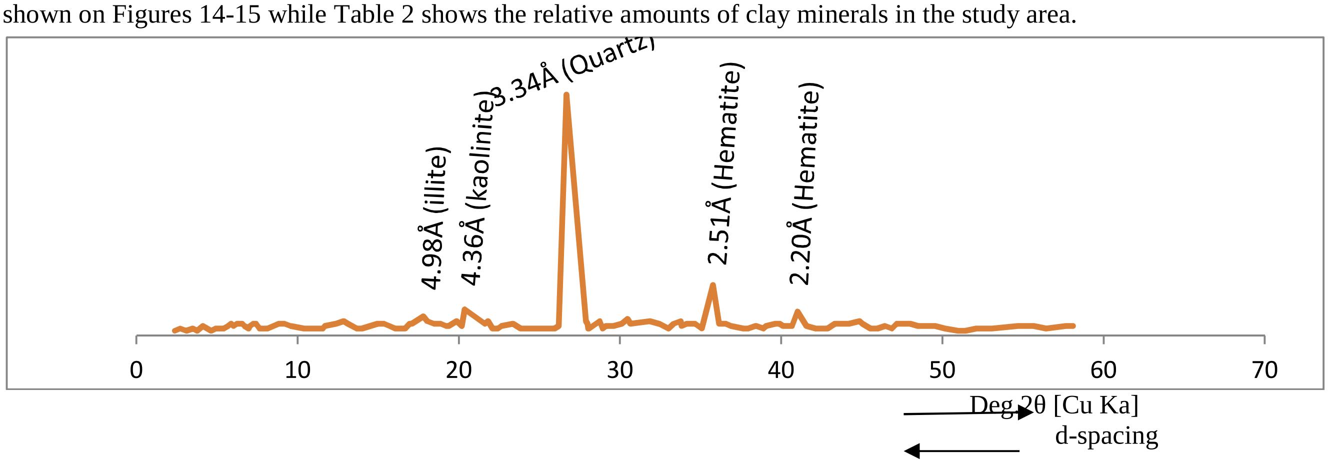


Figure 14: X-ray diffractogram (Bulk analysis) of sandstone sample from location B (Umunya)

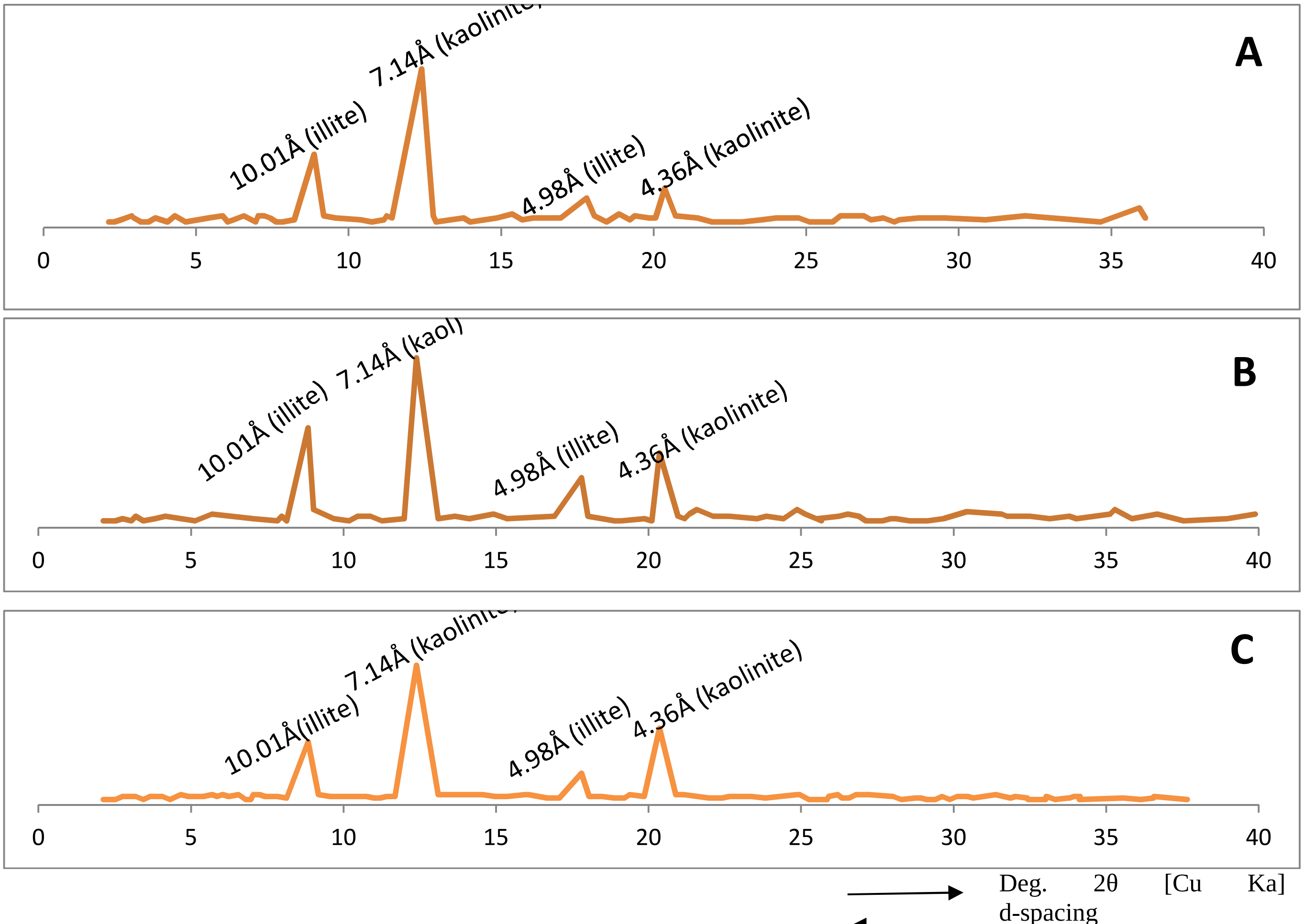


Figure 15: X-ray diffractogram (orient analysis) of sandstone sample from the study area: A (Nanka); B (Umunya) and C (Ogbunike)

Table 2: Relative Amounts of clay minerals in the <2µm fractions of sandstone units in the study area

Locations/clay minerals	Kaolinite	Illite	Smectite
A (Nanka)	68	32	-
B(Umunya)	70	30	-
C(Ogbunike)	65	35	-

X-ray diffraction studies of the Ameki sandstones in the study area show that the sandstones are composed of quartz (76%), clay (including kaolinite and illite, 13%), hematite (6%) and others (including silica cement, 5%). The clay matrix or cement in the sandstone units of the study area consists dominantly of kaolinite (about 70%) and illite (about 30%). In sandstone, authigenic kaolinite commonly occurs as pore-filling whereas illite occurs as pore-bridging; and consequently reduces the petrophysical characteristics of the sandstone [14].

6.0 Discussion

7.0 Reservoir Quality

Reservoir quality which is measured by porosity and permeability [1 & 17] varies across the area studied. In locations A (Nanka), the sandstones are predominantly fine to coarse grained and are poorly sorted. They are compositionally mature but texturally immature based on the classification of [16 & 18]. The very high matrix content (consisting of kaolinite and illite) should drastically occlude pores and reduces permeability. In locations B and C (Umunya and Nsugbe), the sandstones,particularly at the lower section, are predominantly fine to medium grained and are moderately sorted. However, they are compositionally mature but texturally immature based on Folk’s classification [16].

Though porosity value of these sandstones is estimated at 5%, it is however believed to be very low relative to freshly deposited sands which have porosity values between 40-45% [15]. In addition, the high matrix content (consisting of kaolinite and illite)would drastically reduce the petrophysical characteristics of these sandstone units. Based on these characteristics, reservoir quality of locations A, B, & D is considered as poor to fair.

In location C (Ogbunike Cave), the sandstones are medium grained and well sorted. They are both compositionally and texturally mature. Inspite of the low matrix content (consisting of kaolinite and illite), the sandstone generally has a good preserved porosity estimated at about 15%. However, this favourable reservoir property can be drastically reduced by a strong compaction relative to deeper burial.

8.0 Diagenesis

9.0 Compaction

Compaction is a diagenetic process involving the squeezing together of sediments during burial owing to the weight of overlying sediments. Compaction forces grains into closer contact and causes changes in types of grain-to-grain contacts and in the process, porosity is drastically reduced [15].

As shown on Table 1 and in Figures 9-12, evidence of compaction from the study is suggested by grain packing, grain contact type and porosity reduction. The sandstones are predominantly tightly packed with planar-concavo convex grain contact type with preserved porosity estimated between 2-15%. The relative abundance of concavo convex grain type to other grain contact types and the packing of the grains are indicative of compaction at some great depths.

10.0 Cementation

Cementation is a diagenetic process involving the precipitation of mineral into the pore spaces of sediments, thereby reducing porosity and bringing about lithification [15]. Evidence of cementation from the study is suggested by the presence of authigenic quartz and hematite cements.

Authigenic quartz occurs as syntaxial overgrowth around quartz and constitute between 2-10% of the total rock composition (Table 1). Quartz-cemented sandstones have been suggested to have low porosities and permeabilities [2, 19-20] and therefore influence reservoir quality. From the study, authigenic quartz cement is believed to have been generated by pressure solution of detrital quartz grains at grain contacts (Figs.9-12) and is consistent with the submission of [15 & 21]. Dissolution of the grains preferentially occurs along these high pressure areas and the dissolved ions migrate away from the point of contact towards areas of lower pressure where the dissolved ions are re-precipitated as cement.

Hematite cement on the other hand is the dominant iron oxide cement in the area. It occurs as thin coatings on detrital grains to massive infilling of pores and constitutes between 2-20% of the total rock composition. Hematite cement has been suggested by [22 – 23] to have been formed by the dehydration of goethite/limonite at a burial temperature range between 200-250^{o}C. The presence of hematite cement is responsible for the reddish colouration (ferrugenization) of the sandstone beds. Effect of hematite cementation is greatest at the upper section of the outcrops but reduces down-section. Generally, it passes downwards into a red-white mottled zone and then into white to off-white sandstone. This distribution suggests that hematite grain coatings that produced the reddish brown beds are more extensive at the upper section than the lower section. The presence of hematite cement indicates an oxidizing environment during diagenesis [21].

11.0 Microfractures

Microfractures are diagenetic features associated with compaction during burial [24] and can only be detected with magnification [25].

As shown on Table 1 and in Figures 9-12, the sandstones from the study area are microfractured though varies in degrees across the area. In locations A and D (Nanka and Nsugbe), the quartz grains are moderately microfractured and poorly filled by hematite cement. The microfractures are mainly intragranular with straight to curvilinear traces (Fig. 9) and increase upsection with increase in ferruginization. In location B (Umunya), the quartz grains are deeply microfractured and are well filled by hematite cement (Fig 10). The microfractures are also dominantly intragranular with straight to curvilinear traces and also increase upsection with increase in ferruginization. In location C (Ogbunike Cave), the quartz grains are both poorly microfractured and filled by hematite cement.

These microfractures are believed to have been produced due to intense compaction disequilibrium and are consistent with the view of [3, 26-27]. However, the dehydration of limonite/goethite to hematite may have also influenced the process based on the view of [22-23]. Infilling of these microfractures by hematite cement suggest that microfracturing of quartz grains predates episode of hematite cementation. The presence of hematite cement within and around these microfractures may also suggest a diagenetic event associated with uplift or basin unroofing and exposure to meteoric fluids in an oxidizing condition based on the view of [26-27 & 28]. However, it is important to emphasize as noted by [27] that microfractures contribute only an insignificant amount or minor portion of total secondary porosity.

12.0 Dissolution of Quartz Grains

Dissolution is a diagenetic feature that occurs along grain contacts without creating porosity [27].
Evidence of quartz dissolution is also shown on Table 1 and Figures 9-12. In locations A and C, dissolution of quartz grains is mild but appears higher in locations B and D. Dissolution of the quartz grains is believed to be due to pressure solution at grain contacts in consistent with the view of [27] and precipitation of hematite cementation through goethite/limonite dehydration. Dissolution perhaps produced pores that were subsequently filled by hematite cement. It is however important to emphasize as noted by [27] that dissolution of silicate mineral such as quartz generally creates little or no secondary pore.

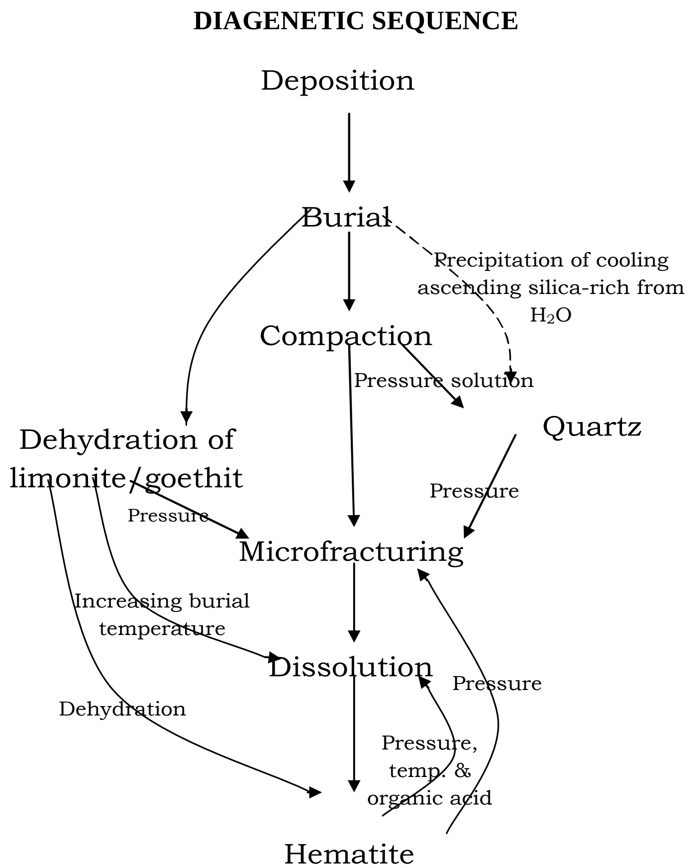


Figure 16: Schematic flow diagram showing interpreted diagenetic sequence of the Ameki Formation from locations1-4 based. Dash lines indicate uncertainty with regards to the study.

Based on the textural relationships of grains and diagenetic features, it is possible to interprete the relative sequence of diagenetic events in the study area. Figure 16 is a graphic representation of the diagenetic sequence.
The first major event was the deposition of the sediments in a subsiding basin. With further deposition of newer and younger sediments as basin subsidence increased, earlier or older sediments were buried and subjected to forces of compaction and forced grains into closer contact. This triggered pressure solution at grain contacts, dissolving the grains along these pressure areas and precipitating authigenic quartz cement around detrital grains as syntaxial overgrowths. Compaction of the sediments due to burial may have also induced upward movement of silica-rich formation waters which precipitated quartz cement around detrital grainsin the view of [15], though evidence of this could not be ascertained in the course of this study. This diagenetic phase reduced pores in the views of [2, 15, 19 – 21].
The second major phase of diagenesis in the area was the microfracturing and further dissolution of the quartz grains consequent on the dehydration of limonite/goethite to hematite and further mechanism of compaction disequilibrium. As shown in figure 16, while microfracturing is a product of pressure action on the grains, dissolution is produced by the combine action of temperature, pressure and organic acid. These two processes may have produced secondary pores in the views of [3, 21 & 27]

The third phase is the infilling of the microfractures and dissolution pores by hematite cement which further sealed up these pores and thereby reduced their secondary porosity potential.

13.0 Conclusion

Reservoir quality of the sandstone units of the Eocene Ameki Formation ranges from poor to good with the sandstone unit in location C (Ogbunike) having the highest reservoir potential and is followed by those in locations B, D and A (Umunya, Nsugbe and Nanka) as the poorest. Porosity loss is highest in location A (preserved porosity estimated as traces; less than 2%) where there is relative higher content of immature constituents in relation to other locations studied where compositional and textural maturity are relatively higher. Location C has the highest preserved porosity estimated at 15% because porosity loss during the compaction in subrounded to rounded, medium grained sands is low.

Important factors that influenced the course of diagenesis in the study area include compaction, pressure solution at grain contacts, authigenic quartz overgrowth, hematite cementation, microfracturing and dissolution of quartz grains of which compaction, pressure solution, authigenic quartz overgrowth and hematite cementation are the main mechanism which have greatly resulted in porosity loss from its initial value at deposition to a preserved estimated value of about 2-15%.

Compaction of the sediments started with burial and progressively increased with depth. The relative abundance of planar to concavo-convex grain boundaries is suggestive of compaction at some great depths. Physical compaction of the sediments resulted in tighter grain packing with concomitant loss of porosity while chemical compaction resulting from increased pressure at the contact points between grain, produced partial dissolution of silicate grains, authigenic quartz overgrowth and drastic loss of primary porosity.

The cementation of the sediments may have been brought about by chemical precipitation of pore solution under different ph conditions and temperature. The silica cement in the form of quartz overgrowth around detrital quartz grains and the infilling of ferruginous (dominantly hematite) cements may have significantly influenced the reservoir quality.

Microfracturing and dissolution of quartz grains on the contrary may have produced secondary pores but the infilling of these pores by hematite cement has significantly influenced the viability of the pores to enhance the reservoir potential of these sandstones.

Three diagenetic phases were delineated: an early stage characterized by deposition, burial and early compaction; a second phase characterized by late compaction, pressure solution and precipitation of silica cementation in the form of authigenic quartz overgrowth around detrital quartz grains; and a late phase characterized by microfracturing and dissolution of quartz grains and infiltration of hematite cement throughout the sandstones. These diagenetic processes have greatly controlled the reservoir quality of these reservoir units.

It is however recommended that further examination of these sandstonesunits involving XRD and SEM analyses be carried out to authenticate the authigenic clay minerals as well as the paragenesis. Additionally, further examination of these sandstone units involving cathode luminescence petrography, SEM, pore cast examination microprobe analysis and stable isotope analysis for detailed analysis of the petrological attributes of primary and secondary porosity is also recommended.

14.0 Acknowledgements

The first author wishes to thank the second author, Professor M.N Oti for mentoring and supervising this work as part of his MSc project;the University of Benin for providing some financial assistance through the ETF fund during the study at the University of Port Harcourt; Professor W.O Emofurieta for his encouragement during the course of this work;and ProfessorE.G Imeokparia who critically read the manuscript and made useful suggestions.

15.0 References

[1] Etu-Efeotor, J.O (1977): The fundamentals of Petroleum Geology: paragraphics publc, Port Harcourt, p51-63.

[2] Eherberg S.N. (1990): Relationship between Diagenesis and Reservoir Quality in Sandstones of the Garn Formation, Haltenbanken, Mid, Norwegian continental shell. AAPG Bulletin, volume 74, No 10, p1538-1558.

[3] Ali, S.A., Clark W.J. and Dribus J.R. (2010): Diagenesis and Reservior Quality. Oil field summer, 22, No. 2.

[4] Short K.C. and Stauble A.J. (1967): Outline of Geology of Niger Delta, Bull. Ame. Assoc. Petr. Geol. Vol 5, No 5, p761-779.

[5] Nwajide C.S. and Reijers T.J.A. (1996): Geology of the southern Anambra Basin: In: Reijers T.J.A. (ed): Selected chapters on Geology, SPDC Publ, p131-148.

[6] Nwajide C.S. (1979): A lithostratigraphic analysis of the Nanka sands, south eastern Nigeria: Journal of Mining and Geology, Vol 16, 100-110.

[7] Nwajide C.S (2005): Anambra Basin of Nigeria: Synoptic Basin Analysis as a Base for evaluating its hydrocarbon perceptivity. In: Okogbue, C.O. (ed); Hydrocarbon potentials of the Anambra Basin: Geology, Geochemistry and Geohistroy perspectives, Great AP EXP Publ. Ltd, 3-46.

[8] Arua, I (1986): Paleoenvironment of Eocene deposits in the Afilkpo Syncline, Southern Nigeria, Journal of African Earth Sciences, Vol 5, 279-284

[9] Reijers T.J.A., Peters S.W. and Nwajide C.S. (1996): The Niger Delta Basin. In: Reijes T.J.A.: Selected chapters on Geology, SPDC Publ, p103-117.

[10] Lambert A, Coker, S.J.L. Nwajide C.S., Oteze G.E., Akujieze, C, Arthur E., Anyadike E, and Okoro (2005): Establishing Geological Boundaries for Cenozoic formational units across the Sedimentary Basins of Southern Nigeria, Cenozoic project for Geological survey of Nigeria Agency, Unpubl, pp15.

[11] Nwachukwu, U.E.D; Anyiam, O.A; Egbu, O.C. and Obi, I.S. (2011): Sedimentary controls on the reservoirs properties of the paleogene-fluvio-tidals sands of the Anambra Basin Southeastern Nigeria. Implication for deep water reservoir studies: Ame. Journ. Sci and Ind. Res. Vol 2, p37-48.

[12] Okoro A.U (2009): Data Analysis and presentation: A sedimentological perspective. In: Lambert-Aikhionbare and Olayinka A. I (ed): Proceedings of field mapping standardization workshop; Ibadan Univ. Press, 181-208.

[13] Pettijohn F.J. (1973). Sedimentary Rocks. 3rd ed, New Dehic, CBS publ, p628.

[14] Odigi M.I. (2011): Diagenesis and Reservoir Quality of Cretaceous Sandstones of Nkporo Formation (Campanian) Southern Benue Trough, Nigeria; journal of Geology & Mining Research, Vol. 3 (10), pp 265-280

[15] Boggs, S (2001): Principles of Sedimentary and stratigraphy. Prentice Hall, Upper Saddle River, New Jersey, 3rd ed, p59-415.

[16] Folk, R.L (1951): Stages of textural maturity in sedimentary rocks. J.Sed. Pet. V.21, p127-136

[17] Gluyos, J. and Swarbrick, R. (2004): Petroleum Geoscience; Blackwell sci. ltd, p228.

[18] Hoque, M. and Nwajide, C.S (1985): Application of Markov Chain and entropy analysis to lithologic successions: an example from the Cretaceous of the Benue trough (Nigeria). Geol. Rndsh., 74, p. 165-177

[19] Wescott W.A. (1983): Diagenesis of Cotton Valley sandstone (Upper Jurassic), East Texas: Implications for Tight Gas Formation Pay Recognition: AAPG Bulletin, V 67, No 6, p1002-1013.

[20] Brown D.M., McAlpine K.D. and Yole R.W (1989): Sedimentology and sandstone Diagenesis of Hibernia formation in Hibernia oil Field Grand Banks of New Foundland. AAPG Bulletin, V73, No5, P557-575.

[21] McBride E.F. and Earle F. (1989): Quartz cement in sandstones: a review. Earth Sci. Rev., Vol 26, p69-112.

[22] Adamovic,J., Ulrych J. and Peroutka, J. (2001): Geology of occurrences of ferruginous sandstone. In: Bohemia N: famous localities revisited. Goel. Saxonica-Abh. Mus. Miner. Geol. Dresden 46/47: 105-123.

[23] Walter D; Buxbaum G., and Laque W (2001): The mechanism of the thermal transformation from Geothite to hematite. Journ. Thermal Analysis and Calorimetry, Vol. 63, p733-748.

[24] Zeng L. (2010): Microfractuing in the Upper Triassic Sichuan Basin tight-gas sandstone: Origin. AAPG Bulletin, V. 94, No 12, p1811-1825.

[25] Laubach S.E. (1997): A method to detect natural fracture strike in sandstones. AAPG Bulletin, 81, 604-623.

[26] Perez R.J. and Boles J.R. (2005): Interpreting fracture development from diagenetic mineralogy and thermoelatic contraction modeling. Tectonophysics, 400, 179-207.

[27] Schmidt V. and McDonald D.A. (1984): Secondary porosity in the course of sandstone Diagenesis; AAPG continuing education course Note series, pp125.

[28] Walderhaug O. (1992): Magnitude of uplife of the Sto and Nordmela Formations in the Hammerfest Basin-a diagenetic approach. Norsk Geologist Tidesskrift 22, 321-333.