Geology and Stratigraphy of Middle Cretaceous Sequences Northeast of Afikpo Basin, Lower Benue Trough, Nigeria.

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ABSTRACT

The geology of northeast of Afikpo basin consists of two major lithostratigraphic units of sandstone ridges and low-lying shales, each of which forms significant component of the Middle Albian Asu River Group and Turonian Ezeaku Formation. The major folds in the area have northeast-southwest trend, south easterly dip and comprise both anticlines and synclines. The area is also marked by two significant angular unconformities; one interformational between the Asu River Group and Ezeaku Formation, and the other intraformational within the Ezeaku Formation. Mineral assemblages, poor to moderate sorting and angular to subrounded shapes of the minerals suggest a possible model in which sedimentary materials of northeast Afikpo basin were derived from proximal basement granites probably the Oban Massif and deposited in shallow to deep marine environments under fluctuating energy levels, with two major breaks in deposition in the Cenomanian and Turonian times.

(Keywords: Afikpo basn, lithostratigraphic units, geology, Asu river group, Turonian Ezeaku formation)

INTRODUCTION

The study area lies between longitudes 7°51'E and 8°00'E and latitudes 5°55'N and 6°00'N within the Afikpo syncline of the Cross River basin of the Benue Trough. The Benue Trough of Nigeria formed as a result of series of tectonism and repetitive sedimentation in the Cretaceous time when South America separated from Africa. Afikpo is located in the southern Benue Trough, between the Abakiliki Anticlinorium running northeast and the Cameroon Line in the southeast.

Ridges of sandstones, and plains and valleys of shales form prominent and extensive topographic features in the study area. Sandstones and shales are very important constituents of sedimentary processes and are therefore very crucial in the understanding of stratification history of their environments of deposition. Also the mineral and organic compositions, texture, and structure of the sedimentary sequences usually suggest their provenance characteristics.

The present work is aimed at examining the lithologies and their stratigraphic relationships with a view to drawing inferences on the geology, provenance, depositional history and environment of deposition of the sedimentary bodies in the area.

GEOLOGIC SETTING

The stratigraphy of the study area consists of Asu River Group and Eze-Aku Formation (Figure 1) deposited in alternating transgressive and regressive phases. The Asu River Group, consisting of shale, sandstone, and limestone, is the older lithostratigraphic unit in the area and was deposited during Albian transgressive phase. It is also the oldest dated sedimentary rock unit in southern Benue Trough (Whiteman, 1982). Simpson (1955), and Reyment and Barber (1956) were of the view that the Asu River Group was deposited in a moderately deep water environment during the Albian, with abundant ammonites, foras, radiolarian, and pollens.

According to Reyment (1965), the Albian sediments were moderately folded in many places with the fold axes trending NE-SW.

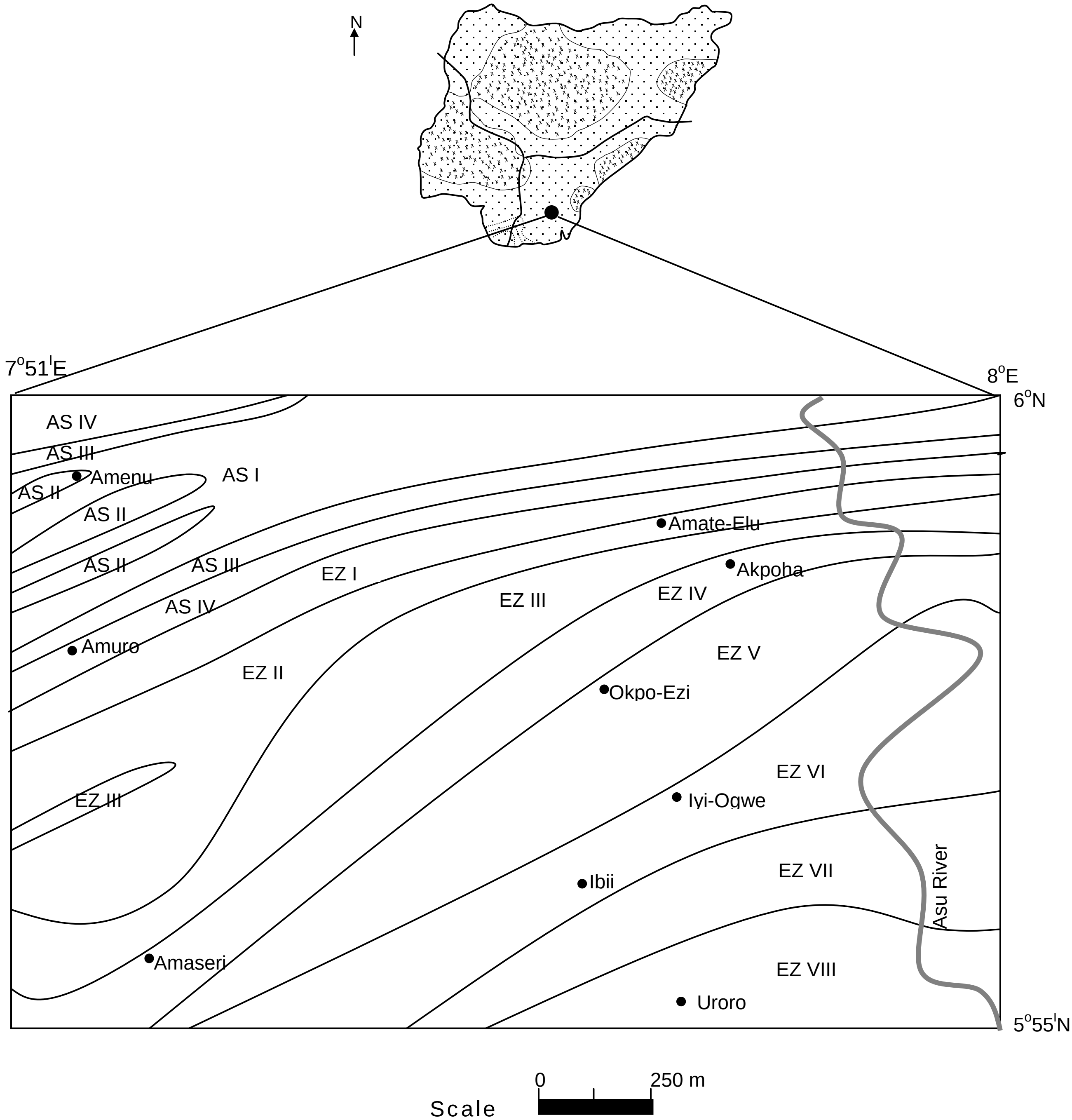

Figure 1: Generalized Geological Map of Northeast Afikpo Basin with Map of Nigeria Showing the Study Area. Symbols are Explained in Table 1.

On the other hand, the Ezeaku Formation is believed to represent typical shallow water deposit, consisting mainly of hard grey to black shales and siltstones. Facies changes to sandstones and sandy shales are common. The thickness of this Formation varies and locally may be up to 100 m thick and passes laterally into sandstone ridges at Amaseri sandstone, limestone, calcareous sandstone, and sandy limestone.

Murat (1972) was of the view that the Eze-Aku Shale shows deposits of marine condition in a tectonically controlled basin (the Abakiliki Trough). He believed that sandstone deposits mark a period of regression, while the shale deposits indicate a period of transgression. On the basis of the predominance of shale from Aba-Omege towards Abakiliki, Nwachukwu (1975) concluded that deep-sea conditions terminated at Aba-Omege from where a shallow marine condition commenced. He also believed that a distant metamorphic basement had contributed to the sediments in the Eze-Aku Shale because he found metamorphic minerals in the sandstone units, in addition to conclusions he drew from heavy mineral analysis.

The Eze-Aku Formation was deposited in the Turonian transgressive phase but in a shallow marine environment. The lithologies include shale, sandstones, and calcerous sandstones. The fossils in this Formation include vascocerastids, pelecypods, gastropods, echinoids, fish teeth, decapod, and plant fragments (Reyment, 1965).

The predominantly Albian-Cenomanian marine depositional cycle was terminated by a phase of folding (Nwachukwu, 1975; Olade, 1978), which affected the Asu River Group in the area. The second transgressive-regressive phase of deposition in Turonian to Santonian was terminated again by a phase of folding and faulting in the early Santonian times, which affected all the sediments deposited before the tectonism and this produced the Afikpo syncline.

METHOD OF STUDY

Detailed field mapping of the study area was undertaken during which the contacts of the different structures and lithologies were identified and delineated. Sandstone samples were collected from good exposures for petrographic studies. Photomicrographs of these thin sections were taken to illustrate their mineralogy, mineral associations, grain sizes, roundness, sorting, and alterations.

LOCAL GEOLOGY

The study area consists of highly undulating alternations of sandstone ridges and shale low lands, trending in a NE-SW direction. However, the northern section of the study area is generally low land, rising from sea level to some 30 m above sea level, except northeast of Asu River Bridge, where it attains a height of about 45 m above sea level. The highest sandstone ridges are the Amaseri-Okpo-Ezi sandstones (about 120 m high), Ibii sandstone (about 75 m high), and Akpoha sandstone (about 75 m high). The sandstone ridges have been subjected to prolonged and intense weathering, producing huge blocks of boulders and rock falls.

The Asu River Group: The Asu River Group is a major stratigraphic unit in the study area, consisting of dark micaceous shale, fine grained and calcareous sandstone bodies. It is poorly bedded, and dip range is 46^{o} to 72^{o} Azimuth. The beds, rich in ammonite fauna, indicate Albian age. The geology of the different lithostratigraphic facies of the Asu River Group in the study area is highlighted below.

Amenu Shale: Amenu Shale is the oldest lithologic unit of the Asu River Group in the study area (Table 1). Its contact with the younger Amenu Sandstone is very sharp, and the shale unit has a southwest strike with dip amount of 46^{o} to 70^{o} in a southeast direction. The shale is fissile, and dark-bluish grey or pure grey in colour. It is intercalated in places with yellowish brown coloured ferruginized lamina. It also contains some concretions, which are reddish-brown on the surface but grade through light grey coloured clay to dark or grey-coloured mud at the core.

Amenu Sandstone: Amenu Sandstone conformably overlies the Amenu Shale. It outcrops within the anticlinal fold at a distance of about half a kilometre from Asu River bridge towards Amaseri (Figure 1). The contact between this unit and the underlying older Amenu Shale is sharp, grading through coquina and back to shale. The sandstone has a northeasterly strike and a southwesterly dip, and is generally greyish in colour when fresh but brown when ferruginized.

Table 1: Stratigraphic Sequence of the Study Area.

AGE	LITHOSTRATIGRAPHIC UNITS				
	Group	Formation	Member	Symbol	Thickness (m)
Turonian		Eze-Aku	Ururo Shale	EZ VIII	200
			Ibii Sandstone	EZ VII	150
			Iyi-Ogwe Shale	EZ VI	75-120
			Okpo-Ezi Sandstone	EZ V	130
			Akpoha Sandstone Amaseri Shale	EZ IV	55-80
			Amaseri Sandstone	EZ III	150
			Amate-Elu Shale	EZ II	40-150
			Amate-Elu Sandstone	EZ I	40
Albian	Asu River	Amauro Shale		AS IV	35
		Amauro Sandstone		AS III	40
		Amenu Sandstone		AS II	35
		Amenu Shale		AS I	400

It is highly indurated, with no fresh surface for measurements.

Microscopic analysis of some samples of the sandstone shows average mineralogical composition of quartz (40%), feldspar (30%), calcite as cement (29%) and muscovite and sphene (1%). The grains are sutured, coarse, not very compacted with much of the pores filled up by calcite cement. Figure 2 is a photomicrograph of a sample of the sandstone showing abundance of quartz and feldspar minerals. Thus, based on the classification scheme of Pettijohn (1975), the Amenu Sandstone is feldspathic. The sandstones of the Asu River Group display effects of the Cretaceous deformations in their slight mineral lineations (Figures 3 and 4).

Amauro Sandstone: The Amauro Sandstone member is within the Amenu Shale unit. It maintains the same mineralogical composition and textural characteristics with the host and older Amenu Sandstone. However, both have different stratigraphic positions. The sandstone, which is grey in fresh surfaces or brown when weathered, is about 30 m high. Under the microscope, the percentage mineralogical compositions are quartz (45%), feldspar (30%), calcite (24%) and rock fragments (1%). Figure 5 is a photomicrograph of a sandstone sample showing crushing of quartz crystals. The grains are moderately sorted, and the rock is well compacted and coarse-grained. It is also feldspathic.

Figure 2: Photograph of a Sample of Amenu Sandstone, Taken Under Crossed Polars, Showing Abundance of Quartz and Feldspar. Magnification X28.

Figure 3: Photograph of a Sample of Amenu Sandstone, Taken Under Crossed Polars, Showing Weak Mineral Alignments (N-S). Magnification X28.

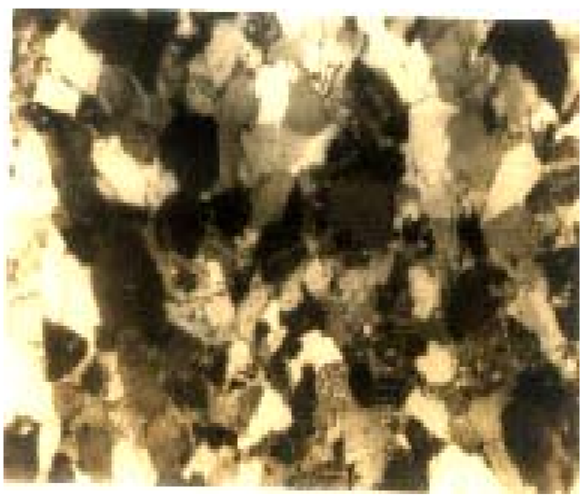

Figure 4: Photograph of a Sample of Amenu Sandstone, Taken Under Crossed Polars, Showing Weak Mineral Alignments (N-S) due to Deformation Effect. Magnification X30.

Amauro Shale: Amauro Shale is the youngest unit of the Asu River Group, and it is unconformably overlain by the oldest Eze-Aku unit; Amate-Elu Sandstone member (Table 1). The shale is fissile and grey in colour except that it assumes reddish-brown to dirty-brown colours when weathered. It has a northeasterly strike and a southwesterly dip as the older Amenu Sandstone. An unconformity between this unit and the Amate-Elu Sandstone is marked by basal conglomerate covering the top of this shale unit, and the base of the Amate-Elu Sandstone.

Figure 5: Photograph of a Sample of Amenu Sandstone, Taken Under Crossed Polars, Showing Crushing of Quartz Grains at Inter-Grain Boundaries. Magnification X25.

EZE-AKU Formation: The Eze-Aku Formation unconformably overlies the Asu River Group in the study area. It consists of alternating sandstone/siltstone and hard grey to black shale. The contacts between the lithologies appear sharp or gradational; where it is gradational the shale is sandy, silty or calcareous, before passing into siliceous or calcareous sandstone. This is exemplified at Amaseri where it passes into the Amaseri Sandstone. The thickness of the units varies from 100 m to 45 m above sea level. The dip range of the Formation is 16^{o} to 38^{o} Azimuth. The lithostratigraphic facies descriptions of this Formation are presented below.

Amate-Elu Sandstone: This is the oldest lithologic unit of the Eze-Aku Formation that unconformably overlies the Amauro Shale of the Asu River Group, in the study area. The interformational angular unconformity here is shown by basal conglomerates covering the top of Amauro Shale of the Asu River Group and the base of Amate-Elu Sandstone of the Eze-Aku Formation. This unconformity strikes southwest northwest with dip amount of 14^{o} to 40^{o} Azimuth. Amate-Elu Sandstone is grey coloured when fresh but turns reddish brown or dark brown when weathered. The thickness of the beds ranges from about 35 m to slightly less than 1.5 m from base to top. The grains are angular to sub-rounded, fine to medium grained.

The unit shows massive and well-indurated features. Analysis of the thin sections of samples shows average mineralogical composition of quartz (60%), feldspar (15%), silica as cement (20%), calcite and anhydrite (4%), rock fragment, muscovite, biotite, and sphene (1%). The muscovite crystals are bent, broken or compressed within the other phenocrysts. The sandstone is poorly to moderately sorted, and classifies as feldspathic.

Amate-Elu Shale: This is the blue-black fissile and laminated shale conformably overlying the older Amate-Elu Sandstone. Weathered components of this shale lack fissility and are brown or yellow or red in colour. The contact between this shale unit and the Amate-Elu Sandstone is gradational.

Amaseri Sandstone: This unit extends from Amaseri to Ugwu Okporo through Amate-Elu to Asu River (Figure 1). It rises from Amaseri (about 45 m above sea level) to a maximum height at Ugwu Okporo (about 120 m above sea level). It overlies conformably the Amate-Elu Shale, and the contact between the two units is gradational. Fresh samples of this unit are deep grey, and since the sandstone is calcareous the deep greyish colour is attributed to abundant calcite. However, on strong weathering the sandstone is dark brown and develops caves, potholes and huge boulders. It is medium to coarse grained, sub angular and moderately sorted. The thickness of the beds is in the range of 35 cm to 2.5 m; the beds are massive.

Mineralogical compositions of samples of the sandstone in thin section studies show the following averages: quartz (40%), feldspar (microcline and plagioclase) (15%), calcite (44%), rock fragment (1%) and accessory minerals (muscovite and biotite) (1%). Figure 2 shows a photomicrograph of a sandstone sample showing microcline, quartz and calcite crystals. Amaseri sandstone is both feldspathic and calcareous. The unit is discontinuous, probably due to weathering.

Amaseri Shale: Amaseri Shale is fissile and conformably overlies the Amaseri Sandstone. It is blue-black when fresh and yellow to reddish-brown when weathered. The two units maintain gradational contacts. The amount of dip is between 8^{o} and 14^{o} Azimuth. This shale unit is continuous and extensive. Figure 6 is a photograph of highly fissile Amaseri Shale at the base of Okpo-Ezi Sandstone.

Figure 6: Photograph of a Sample of Highly Fissile Amaseri Shale.

Akpoha Sandstone: This is a highly indurated lens within the Amaseri Shale. The maximum height is 75 m with thickness of the beds ranging from 90 cm to 210 cm. Fresh surfaces show dark-grey to grey colours but dirty brown when weathered. The grains are sub angular to sub rounded in shape (Figure 7) and moderately sorted. Microscopic analysis of Akpoha Sandstone shows the following average mineral compositions: quartz (50%), feldspar (30%), calcite (19%) and rock fragments (1%). Akpoha Sandstone is feldspathic. Cross stratifications with NE-SW strike and dip range of 26^{o} to 32^{o} occur in parts of the sandstone lenses and caves. Joints with attitudes of 194^{o} to 198^{o} also occur.

Okpo-Ezi Sandstone: Okpo-Ezi Sandstone unconformably overlies the Amaseri Shale with the contact between the two gradational from coquina to silty shale to siltstone then to sandstone. The silty shale grades into siltstone of 7 cm to 10 cm thick intercalated with grey to dark shale of thickness approximately 2 cm to 3.5 cm. The sandstone is grey when fresh but turns brown when weathered and bioturbated. It has a thickness of 1m to 1.5m. Incorporated within the sandstones are well-rounded pebbles and cobbles, which measure about 3cm to 11cm in diameter. These are believed to have been transported from older sedimentary units under high-energy current condition.

Figure 7: Photograph of a Sample of Akpoha Sandstone, Taken Under Crossed Polars, Showing Poor Sorting and Sub-Angular to Aub-Rounded Shape of the Rock. Magnification X25.

The sandstone unit shows coarsening upward sequence. Vertical to near vertical joints, which strike NE-SW with dip range of 68° to 89° Azimuth abound in the sandstone. Average mineralogical compositions from microscopic studies are quartz (40%), feldspar (9%), calcite as cement (50%), and rock fragment (1%). The grains are moderately to well sorted and compacted. The sandstone is feldspathic.

<u>Iyi-Ogwe Shale</u>: This unit unconformably overlies the Okpo-Ezi sandstone. Intraformational unconformity exists within the Eze-Aku Formation marked by basal conglomerate that separates the top of Okpo-Ezi sandstone and the base of Iyi-Ogwe Shale. This second unconformity in the study area also strikes NE-SW with dip values of 10° to 40° Azimuth. The shale is grey to mottled yellow when fresh but turn pink when weathered and ferruginized. The shale is laminated with thickness of the lamina about 2mm. These laminations have been attributed to tidal differences (Reyment, 1965).

<u>Ibii Sandstone</u>: This sandstone unit conformably overlies the Iyi-Ogwe Shale and both follow the same NE-SW trend. It is structurally massive and laterally extensive, covering about 250m. The thickness of the beds averages about 1.3m, while the over all average height of the unit is about 15m. On fresh surfaces the colours are from dirty white to light grey but these turn brown to red on weathering. This sandstone is very friable due to poor cementation. Dip values of this unit range from 24° to 32° in a SE direction. Vertical and near vertical joints also occur in the area. Grain size analysis shows that the sandstone is poorly sorted and has fine to medium grain sizes. Figure 8 shows the fine grain nature of the sandstone.

Figure 8: Photograph of a Sample of Ibii Sandstone, Taken Under Crossed Polars, Showing the Fine Grained Nature of the Sandstone. Magnification X32.

<u>Uroro Shale</u>: This is the youngest unit of the Eze-Aku Formation in the study area. It directly conformably overlies the Ibii Sandstone, and trends NE-SW. The shale is grey when fresh but turns dirty brown to dark-brown on weathering.

STRUCTURES

The structural elements of northeast Afikpo Basin possess important attributes, which can be utilized to make useful projections on the tectonic history of the study area. The Asu River Group dips at higher magnitude (46° to 72° Azimuth) than the Eze-Aku Formation (16° to 38° Azimuth) in the study area. Also there is an unconformity between the Asu River Group and Eze-Aku Formation, marked by basal conglomerate along the contact that runs NE-SW and parallel to Amaseri-Okpo-Ezi Shale with dip magnitude ranging from 40° to 70° Azimuth. Similarly, an intraformational angular unconformity occurs within the Eze-Aku Formation, between Iyi-Ogwe Shale and Okpo-Ezi Sandstone, with dip amount ranging from 10^o to 40^o Azimuth. The Lower (Older) Eze-Aku Formation is characterized by siliceous sandstones and black fissile shales as opposed to the calcareous sandstone and grey shales that dominate the sedimentary history of the Upper (Younger) Eze-Aku Formation.

Some of the sandstone units show vertical joint systems. Joints in Amenu Sandstone member range from straight to irregular patterns, and where the joints are open, quartz crystals form infillings. All the joints strike NE-SW of the study area, and in some cases, are extensive to about half a kilometre in length. The pattern of the Asu River suggests a fault-controlled river channel.

Three distinct fold were mapped within the Asu River Group, at Ogo Ubi (about 500 m south of Asu River Bridge) along Amaseri-Okposi road, and two at Amenu, after Asu River (about 2 km from bridge). The axes of the folds run in the same direction (NE-SW). Most of the sandstones show graded features, and fine upwards, except in few cases that show reverse sequences.

There are well-developed ripple marks at Okpo-Ezi, Akpoha and some parts of Amaseri. The shales show conspicuous laminations. Cross beds are common features in Okpo-Ezi, Ugwu Okporo, and Akpoha, and can be extensive in some cases. Pits and points are also very common especially at Amaseri and some parts of Akpoha.

DISCUSSION

Stratigraphy: The geology of northeast Afikpo consists of two major lithostratigraphic units of sandstone ridges and low-lying shales, each of which forms significant component of the Middle Albian Asu River Group and Turonian Ezeaku Formation. The major folds in the area have northeast-southwest trend, and comprise both anticlines and synclines. These mega-tectonic structures developed in response to crustal solidification processes linked to the opening of the South Atlantic and the post-Santonian structural frame as a result of these processes (Whiteman, 1982).

Wright *et al.* (1985) had stated that "no break has yet been discerned between the marine Albian and Turonian strata in the Benue Trough". Contrary to this view, a break in deposition between these two units, which represents Cenomanian age, is represented by the unconformity between the Asu River Group and Eze-Aku Formation, and is marked by basal conglomerate along their contact running NE-SW. Furthermore, the combined effect of the Cenomanian and Early Santonian folding on the Asu River Group as against only the effect of the Early Santonian folding on the Ezeaku Formation in the study area is demonstrated by the higher dip magnitude in the Asu River Group (46^o to 72^o Azimuth) than the Eze-Aku Formation (16^o to 38^o Azimuth). The two lithostratigraphic units have north-easterly strike and south-easterly dip.

The Cenomanian folding episode caused the interformational non-deposition between the two sedimentary units, while the intraformational angular unconformity within the Eze-Aku Formation suggests a break in deposition within the Turonian sedimentary activities, probably as a result of dissolution/erosion in calcite components of the Upper (Younger) Eze-Aku Formation. The calcareous components of the earlier calcareous sandstones suffered dissolution/erosion probably due to high energy level in the environment that was warm. The low angles of dip of this unconformity do not suggest folding in the Turonian.

Provenance and Environment of Deposition: The mineral assemblages of the sandstone units at Amenu, Amauro, Akpoha, Ibii, Okpo-Ezi, Amate-Elu, and Amaseri consist predominantly of quartz and feldspar. This indicates granitic source, which probably is the nearby Oban Massif, situated southeast of Afikpo (Reyment, 1965), or the basement rocks north of the Benue Trough. However, the fairly large amount of feldspar in the sediments suggest relatively close provenance such as the Oban Massif. This is in conformity with the view expressed by Odigi and Amajor (2008), though the authors disagree with their view that 'basaltic volcanics' and 'mafic igneous source rocks' were significant source materials for the sandstones. Also the poor to moderate sorting and angular to sub-rounded nature of the minerals support high-energy environment and short history of transportation. However, ubiquitous fine lamination in both rock units is suggestive of fluctuations in energy levels during the transportation of the sediments.

Previous researchers had suggested that the Asu River Group was deposited in a moderately deep sea, while the Eze-Aku Formation was deposited in a shallow marine environment (Reyment, 1965; Murat, 1972; Nwachukwu, 1975). Findings from this work confirm these views. For instance, the predominance of black fissile shale of the Asu River Group in the study area suggests moderately deep environment. The laminations in the shales indicate either rapid deposition that prevented bioturbation or acidic environment.

The shallower marine condition of the Eze-Aku Formation is indicated by the predominance of sandstone units in the Formation, abundance of burrowing organisms, widely distributed pebbles and cobbles, predominance of calcareous sandstone, massive beddings and cross-stratification. These suggest deposition in a shallower marine environment during transgressive/regressive phases in Turonian times. The rapid alternations of sandstone and shale units in the Eze-Aku Formation suggest two conditions of depositions: transgressions and regressions.

CONCLUSION

Two lithological units of the Asu River Group and Eze-Aku Formation were mapped in the study area. The Asu River Group is marked by black fissile and laminated shale, deposited in a deep marine environment during a transgressive phase in the Albian times. Generally, it trends NE-SW with dip range of 46^o to 72^o in a south-easterly direction. The Eze-Aku Formation, on the other hand, is marked by the predominance of sandstone units, burrowing organisms, wide distribution of coarse-grained sandstone and calcareous sandstones.

These suggest deposition in a shallower marine environment during transgressive/regressive phases in Turonian times. It has the same NE-SW strike direction as the Asu River Group with dip range of 16^o to 38^o. The poor to moderate sorting, subangular to subrounded nature of the sediments of the area suggest short transport. Also the abundance of feldspar in the sediments of these units indicates short transport. Two angular unconformities marked by basal conglomerates trend in the same NE-SW direction as the Asu River Group and Eze-Aku Formation.

The possible model of the geology of northeast of Afikpo is that its materials were derived from proximal basement granites, probably the Oban Massif and deposited in shallow to deep marine environments under fluctuating energy levels, with two major breaks in the Cenomanian and Turonian times.

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