Facies Associations and Successions in Amaseri Sandstones, Southern Benue Trough, Nigeria: Implications for Interpretation of Depositional Environments and Palaeogeography

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Abstract
The purpose of this study is to identify and describe sandstone facies and facies associations of Amaseri Sandstone and its succession as a means of assessing the depositional environments. The data set used consists of logged outcrop sections describing critical lithofacies parameters such as composition, lithology, paleoflow, photo montages of some bedding planes, textures, fossils and sedimentary structures including biogenic structures studied on outcropping vertical sections of the Amaseri Sandstones in the study area. The lithofacies interpreted from the Amaseri Sandstone consist of seven main types; some of which represent Bouma sequence ranging from Ta to Td. The interpreted lithofacies are: cryptobioturbated, conglomeritic, siliceous sandstone (Ta); bioturbated, shelly, conglomeritic, calcareous sandstones (Ta); bioturbated, conglomeritic, arenaceous sandstone (Ta); bioturbated, parallel laminated, calcareous sandstone (Tb); ripple/wavy laminated sandstone (Tc); cryptobioturbated mudstone (Td); and cross bedded, arenaceous sandstones. These lithofacies were integrated with physical sedimentary structures, biogenic structures, body fossils content and nature of bedding contacts to interpret facies associations. The facies associations interpreted are: proximal fan facies associations deposited by debris flows and represented by the conglomeritic sandstones (Ta); outer fan facies associations deposited by turbidity currents and represented by bioturbated, parallel, calcareous sandstone (Tb) and ripple/wavy laminated sandstone (Tc); mid-fan facies association represented by crptobioturbated mudstone (Td); and offshore to shoreface facies association represented by cross bedded arenaceous sandstone.The palaeoflows interpreted from the rose diagram constructed from the azimuths of the trough cross beds indicate two directional modes, the north-west and the south-west flows. The petrographic studies show that the grain shapes are dominantly sub-angular to sub-rounded, moderately sorted and texturally and compositionally immature indicating that the sediments were not long transported. The combined palaeoflow and petrographic results show that the Amaseri Sandstones were sourced from the nearby Calabar Flank and Oban Massif as indicated by the northwestery palaeoflow and from the Basement Complex in areas around Ogoja as indicated by the southwestery palaeoflow mode. The limestone cobble/boulders forming the rip-up clast in the conglomeritic sandstone may be sourced from the Mfamosing Limestone located within the Calabar Flank.
Keywords: Amaseri Sandstone, Facies Association, Palaeoenviroments, Palaeogeography and Benue Trough

1. Introduction

The study area is located within latitudes $7^0\ 53^1\ 21.9^{11}$ and $7^0\ 57^1\ 52.6^{11}$N and longitudes $5^0 53^1 50.9^{11}$E (Fig. 1). It is underlain by the Eze-Aku Shale and Amaseri Sandstone, formations within the Eze-Aku Group. The Eze-Aku Group is of Turonian age and belongs to southern Benue Trough. The exposures of the Amaseri Sandstone occur as NE – SW trending ridges separated by swales underlain by shales. Umeji (1984, 1985, 1988 and 1993) and Amajor (1992) established five lithofacies of Eze-Aku Group in the western flank of the Abakaliki Anticlinorium in areas around Nkalagu and Isinkpuma. In the eastern flank, Banerjee (1980) subdivided the Amasiri Sandstone of Eze-Aku Group into five lithofacies while Amajor (1987a) subdivided the sandstone facies into six lithofacies. Odigi (2012) described the conglomeritic sandstone facies in the eastern flank of the Abakaliki Anticlinorium and suggested that it belong to the Nkporo Formation. He interpreted the sandstones as alluvial fans and fluvial deposits. Okoro and Igwe (2014) identified eight lithofacies and grouped then into four lithofacies associations. They interpreted the depositional environment to vary from shallow shelf to deep water environments. However, no detailed study has been done on the Amasiri Sandstone as to interpret the depositional environments using trace fossil evidences, facies associations and successionsas well as palaeogeography. Ichnofacies analysis integrated with sedimentology, paleontology and stratigraphy of the succession emerges as a powerful tool for high-resolution reconstruction of depositional environments.

The purposes of this study are (1) to re-appraise and review the interpretations and depositional models of previous workers for the Amaseri Sandstone in using trace fossil evidence and facies associations (2) to interpret palaeogeography of the Amaseri Sandstone facies using rose diagram constructed from the cross beds azimuth and thin sections prepared from the indurated sandstones.

2. Regional Geologic Setting of the Study Area

The Benue Trough is a part of the extensive West and Central African Rift Systems that occur as a result of break- up of the Gondwana supercontinent. Based on tectonic, geographical and stratigraphic features, the Benue Trough has been subdivided into three: northern, central and southern (Murat, 1972 and Whiteman, 1982). Compressional folding during the Santonian tectonic episode affected the whole of the Benue Trough and was quite extensive, producing over 100 anticlines and synclines (Benkhelil, 1989). The Gboko line, which represents a wrench fault demarcates the southern Benue Trough from the central part, while the northern part is demarcated from the central by presence of Cretaceous sandstone and numerous Tertiary volcanic plugs (Nwajide, 2013).

The southern Benue Trough comprising mainly the Abakaliki Anticlinorium, Afikpo Synclinorium and the Calabar Flank is underlain by folded early to late Cretaceous rocks and numerous igneous intrusions. The study area is located at the southeastern limb of the Abakaliki Anticlinorium (Fig. 1). Following Santonian tectonism and magmatism, the Benue Trough was uplifted into a positive structure creating the Anambra Basin as a new depocenter westward and eastwards of the uplifted Abakaliki Anticlinorium (Nwajide, 2013; Obaje, 2013). Therefore, the post Santonian deposits that terminated with major marine flooding in the Danian/Palaeocene are referred to the Anambra Basin. Table 1 shows the stratigraphic framework of the southern Benue Trough and the Anambra basin and the stratigraphic positions of the Amasiri Sandstone and the Afikpo Sandstone in the study area.

Table 1: Lithostratigraphic framework of southern Benue Trough and Afikpo Sub-Basin, Nigeria

Age		Lithostratigraphic Units		Basin
Late Cretaceous	Late Maastrichtian	Nsukka Fm.		Afikpo Sub-basin/Anambra Basin
	Middle Maastrichtian	Ajali Fm.		
	Early Maastrichtian	Mamu Fm.		
	Late Campanian	Nkporo Group	Nkporo Shale	
			Afikpo Sandstone	
	Santonian	Angular Unconformity		Abakaliki Anticlinorium/Calabar Flank
	Coniacian			
	Turonian	Eze-Aku Group	Amasiri Sandstone	
			Ezeaku Shale	
	Cenomanian	Odukpani Group		
Early Cretaceous	Albian	Asu River Group		
PRECAMBRIAN BASEMENT COMPLEX				

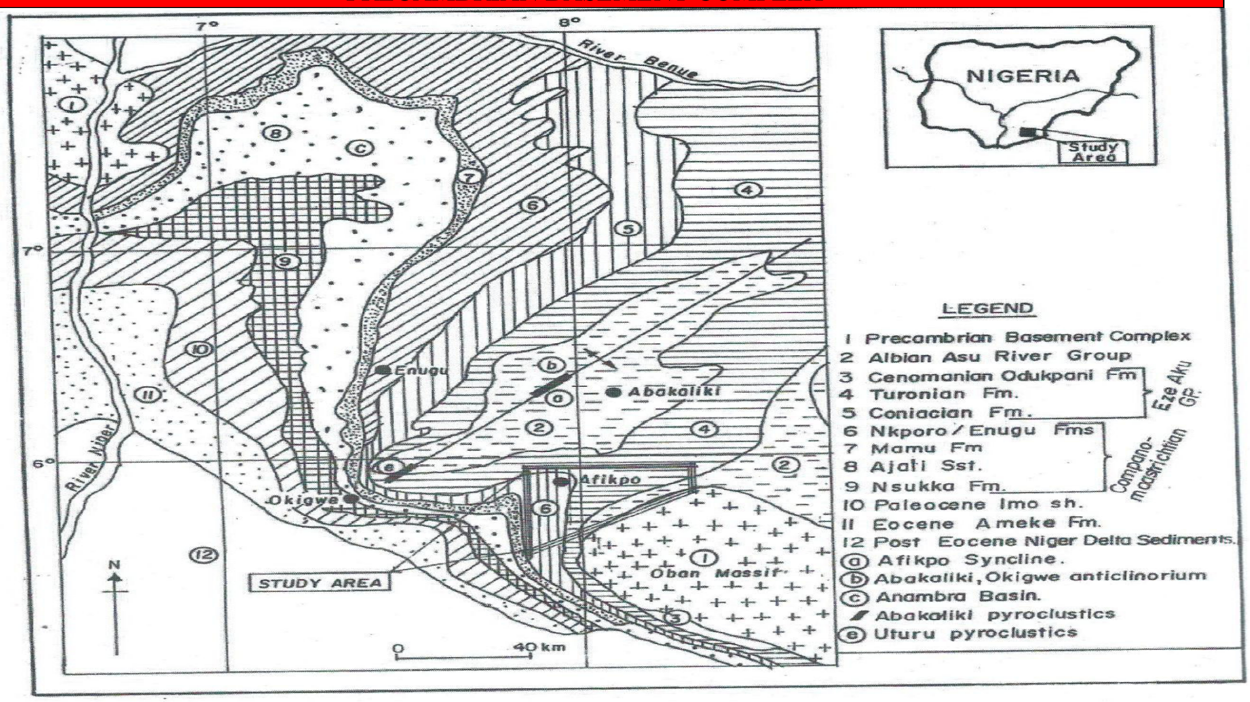

Figure 1. Regional geological map of southern Benue Trough and Anambra Basin showing the Abakaliki Anticlinorium and the study area.

The basin fills in the study area include the Amaseri Sandstones of the Eze-Aku Group and Afikpo Sandstone of the Nkporo Group. The Afikpo Sandstone unconformably overlies the Amaseri Sandstone in the study area (Table 1; Fig. 2). The Eze-Aku Group appears to be filled in cyclic form moving from transgression to regression with deposition of the Eze-Aku Shale and Amaseri Sandstones which exhibit different lithofacies.

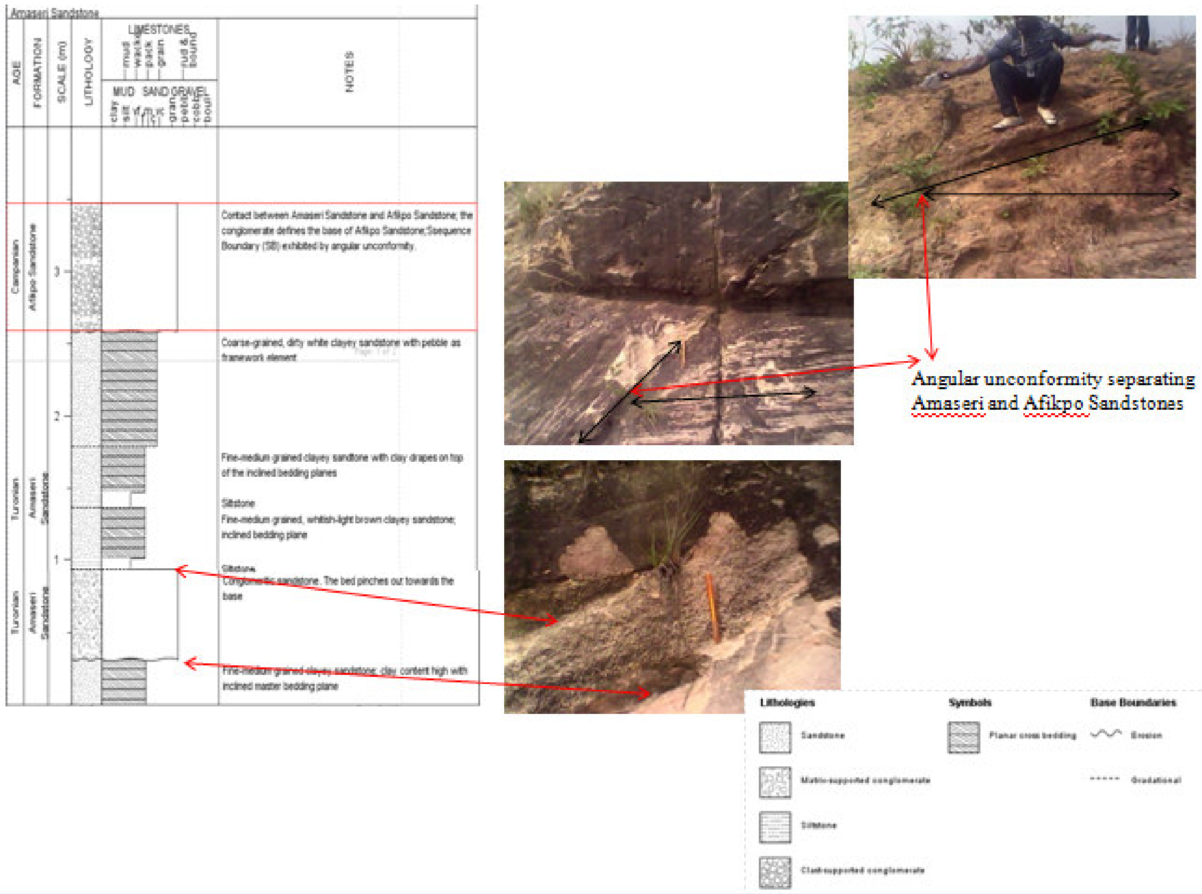

Figure 2. Litholog of the Amaseri Sandstone and the overlying Afikpo Sandstone showing angular unconformities in two places as shown by the two pictures at the top right hand corner.

3. Method of Study

The methodology adopted in this study encompasses description of outcrop sections of the Amasiri Sandstone and Afikpo Sandstones exposed on road cuts on the Okigwe – Amasiri – Afikpo and Abakaliki – Amasiri road. Exposed quarry sections were also described. The exposed rock sections were described and logged from their base to their top with emphasis on critical lithofacies definition parameters such as the lithology, texture, sedimentary structures and fossils. Particular attention was given to biogenic structures (trace fossils) and their descriptive geometries which were useful in interpretation of substrate character, paleobathymetry and depositional environments. The vertical transition pattern of the lithofacies was used to interpret depositional environments (Pemberton and MacEachem, 1992; Miall, 2000; Walker, 2006). Representative outcrop sections of the formation logged were noted at Amaseri Sandstone. These sections formed the basis for definition of the depositional model for the Formation.

4. Results and Discussion

The results of this study are presented as measured vertical sections of exposed road cuts and quarry sections. Others are paleocurrent directions, thin section analysis and photo montages of some bedding contacts, textures, fossils and sedimentary structures. Recorded geologic features such as lithology, texture, sedimentary structures (including trace fossils assemblages and bioturbation) and sedimentary architecture and their vertical transition patterns enabled the interpretation of lithofacies associations and environments of deposition. The interpreted palaeocurrent directions and petrographic studies gave credence to palaeogeography of the deposited sandstones.

4.1. Facies Associations of Amaseri Sandstone

Facies association is defined as collection of commonly associated sedimentary attributes such as gross geometry (thickness and areal extent), continuity and shape of lithologic units, rock types, sedimentary structures and fauna (Miall, 2000 p. 150). Therefore, the characteristics of an environment are determined by the combination of processes which occur there (Nichols, 2009 p. 81).

The facies associations interpreted in the Amaseri Sandstones were based on lithology, physical sedimentary structures, biogenic structures, nature of bedding contacts, bioturbation index (BI) and body fossils. The lithofacies interpreted in the Amaseri Sandstone consist of eight main types namely: bioturbated, shelly, calcareous sandstones; cryptobioturbated, conglomeritic, siliceous sandstone; bioturbated, matrix-supported, conglomeritic sandstone (Ta); bioturbated, parallel laminated, calcareous sandstone (Tb); ripple/wavy laminated sandstone (Tc); cryptobioturbated mudstone (Td); bioturbated, shelly, conglomeritic, arenaceous sandstone and arenaceous cross bedded sandstones. The interpreted lithofacies were grouped into facies associations, which are presented below.

4.1.1. Proximal Fan Facies Association

The processes that deposited these sediments are of debris flows and turbidity currents. Debris flow deposits (debrite) are defined as viscous mixtures of sediment and water in which the volume and mass of sediment exceeds that of water (Nichols, 2009). The texture of this sandstone consists of varying sizes of rip-up clasts floating in a fine to very fine-grained matrix. This arrangement forms a matrix-supported, conglomeratic sandstone facies. The lithofacies belonging to these facies associations are: bioturbated, conglomeritic, siliceous sandstone; bioturbated, conglomeritic arenaceous sandstone; bioturbated, shelly, conglomeritic, calcareous sandstone. The detail field descriptions and interpretations are presented below:

4.1.1.1. Bioturbated, matrix-supported, conglomeritic, arenaceous sandstone (Ta):

This is the lowest part of the sequence exposed in the outcrop section. It consists of poorly sorted massive sandstone with limestone floating as rip-up clasts. Fine-grained sandstone constitute the groundmass while the limestone clasts which are mainly of cobble/boulder sizes and are sub-spherical to circular in shape, forming holes in most of the places as a result of dissolution. The section is fully bioturbated with abundant Skolithos Ichnofacies which include *Ophiomorpha* isp., *Skolithos* isp., *Cylindrichnus* isp. and *Arenicolites* isp. There are equally some evidences of cryptic bioturbations in some locations. The arenaceous sandstones are well bedded with the rip-up clast of limestones aligning along the bedding planes. The beds dip in SE (140-150^0) while it strikes in NE-SW directions. The exposures of these natures can be found at three locations: (1) the base of a Bouma sequence located behind Government Technical College premises, Akpoha, (2) at abandoned quarry located between Government Technical College, Akpoha and Amoha Development Centre, and (3) at the premises of St. Gabriel Catholic Church, Amaseri located along Amaseri-Amunro Road.

Interpretation

The limestones clasts are irregular in shape and showed no pattern of grading while the grains of the groundmass are fine with light brown colour. The basal contact of this section is undulating showing evidence of scouring. There were no obvious physical sedimentary structures, suggesting that the intensity of bioturbations may have completely obliterated the structures. The association of low diversity but highly abundant of the ichnogenera of Skolithos, Ophiomorpha, Cylindrichnus and Arenicolites showed evidence of archetypal Skolithos Ichnofacies. This shows a high energy environment. Fedonkin (1994) showed that Skolithos Ichnofacies may appear in slightly to substantially deeper water deposits wherever energy levels, food supplies and hydrographic and substrate characteristics are suitable. Sediments of this nature were interpreted as debris flow deposits which were deposited in proximal fan channel environment. The upper boundary showed sharp erosional features with turbidite deposits overlying it. This arrangement formed debris-turbidite couplet (Einsele, 1992, p.212).

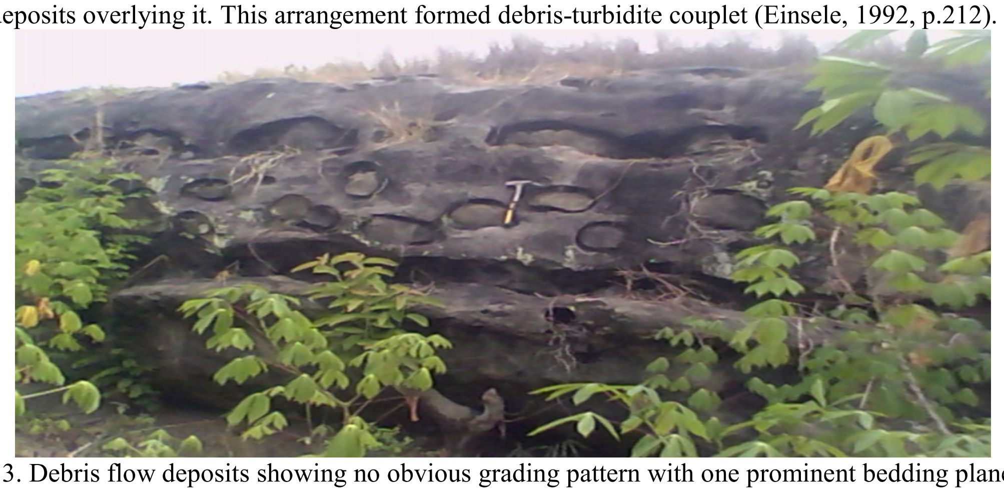

Figure 3. Debris flow deposits showing no obvious grading pattern with one prominent bedding plane. The exposure is behind Government Technical College, Akpoha

4.1.1.2. Matrix-supported conglomeritic, bioturbated, shelly, calcareous, sandstone (Ta):
The grains are dominantly fine, well sorted and light grey. It contained some rip-up clasts of limestone and carbonaceous (black woody) materials. The limestone clasts are circular in shape and majority of them have been dissolved off forming circular holes while the carbonaceous materials are irregular in shape and disoriented. The clasts of both the limestone and carbonaceous materials are not touching one another; hence this arrangement formed a matrix-supported conglomerate. This facies normally contain body fossils, mainly molluscs. In the old abandoned quarry, the shells were preserved in form of casts of ammonites and pelecypods which may be due to dissolution of calcite/aragonite shells (Fig. 4). However, in the newly exposed quarries (around Crushed stone Company and St. Gabriel Catholic Church, Amaseri), the entire body fossils were found intact. The biogenic structures identified were dwelling structures of suspension/passive carnivorous feeding organisms such as Ophiomorpha, Skolithos and Arenicolites. This facies appeared to be massive when there exist alone but at St. Gabriel Catholic Church, premises Amaseri, and Amate-Enu (Fig. 4c) outcrops this lithofacies was found to be bedded. It is gently dipping with dip amount of 2^0 and direction of 132^0.

Interpretation

The geometry of this sandstone is mounded. It contains rich molluscs preserved in form casts and shells of ammonites, gastropods and pelecypods (Fig. 4a). The cementing material binding the grains of these sands is mainly calcite. The grey colour of the sandstone showed that the sediments were relatively poorly oxygenated which allowed preservation of some organic matter (Nichols, 2009). The entire exposures of sandstone produces effervescence when tested with 10% dilute hydrochloric acid and are much indurated. This facies is called matrix-supported conglomeritic, bioturbated, shelly, calcareous sandstone. The co-occurrence and concentration of carbonaceous materials, shells and rip-up clasts of limestone in this calcareous sandstone facies showed that the sediments were deposited as debris flows by storm action. Deposition of sediments in this zone occurred as a result of constant supply of sediments to the shelf in which case continuous deposition of sediments build up layers on the sea bed and the water becomes shallower. This means that shelf areas that were formerly below storm wave base experienced the effects of storms and become part of the offshore transition zone.

Figure 4a. Cast of some mollusks showing concentration of shells due to storm action

The lithofacies exhibits intense degree of cryptic and obvious bioturbation with burrows of the Cruziana and Skolithos Ichnofacies, such as *Asterosoma* isp., *Rosselia* isp., *Arenicolites* isp and *Ophiomorpha nodusa* dominating the assemblages (Fig.4b). The co-occurrence of *Asterosoma* and *Rosselia* suggest that the sediments may have been deposited in the upper lower shoreface environment (Pemberton *et al*., 2012). The absence of physical sedimentary structures may be due to the intense bioturbation which may have completely obliterated these structures.

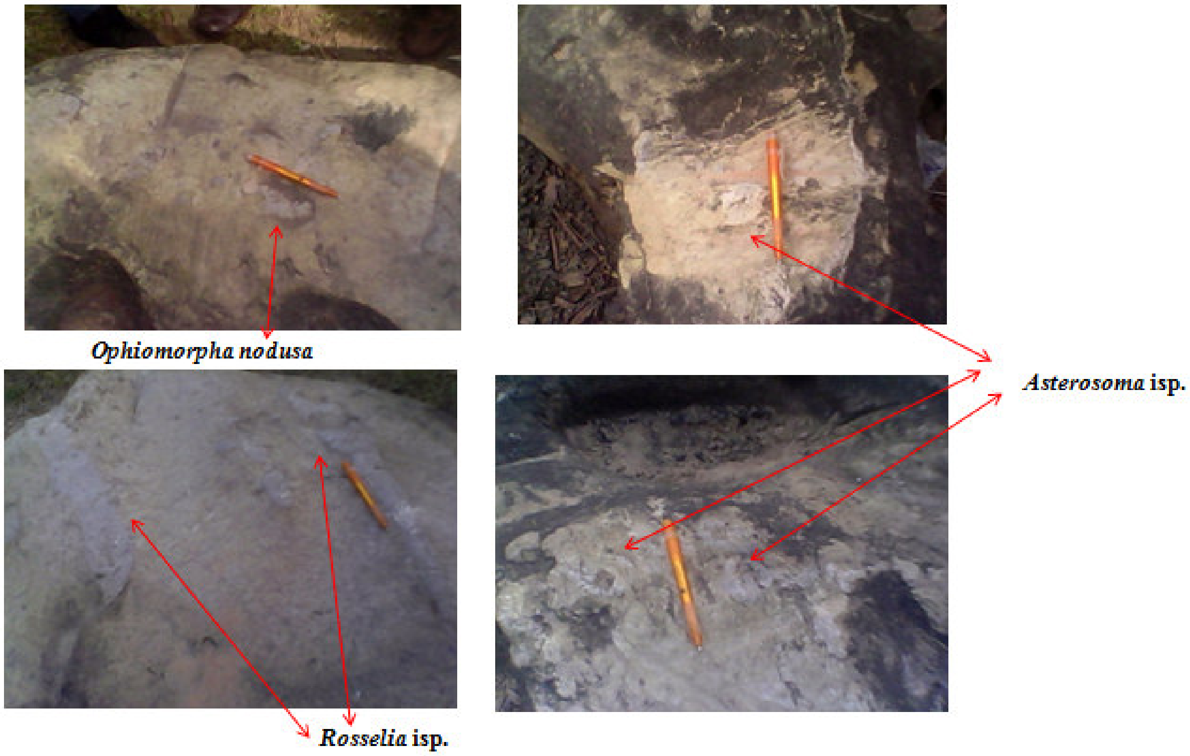

Figure 4b. Some of the biogenic structures belonging to Cruziana Ichnofacies identified at calcareous sandstone exposed at Central School, Amaseri

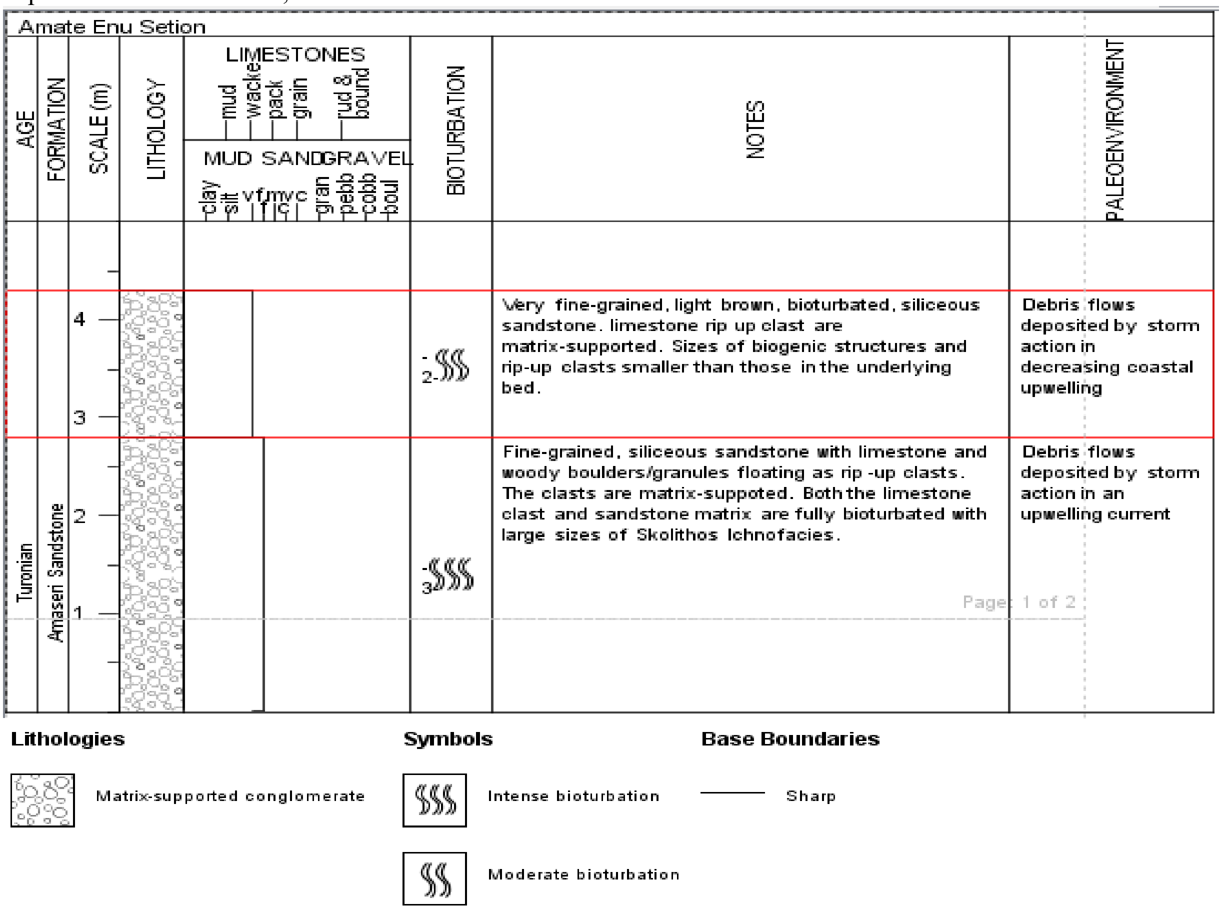

Figure 4c. Amate-Enu litholog showing the fining upward sequence of calcareous sandstone. The conglomeritic sandstone shows evidence of fining upward sequence with matrix, rip-up clasts and biogenic structures becoming smaller in size upward.

4.1.1.3. Bioturbated, matrix-supported conglomeritic siliceous sandstone (Ta):
Light grey, fine-grained sandstone with limestone rip-up clasts of pebble to boulder size. The limestone rip-up clasts are matrix-supported (Fig.5). The sediments contain quartz and feldspars as framework minerals while silica is the cement. Two siliceous sandstone facies have been noticed. (1) cryptic-bioturbated siliceous sandstone associated with irregular shaped limestone clast and (2) Large size and intense bioturbated, siliceous sandstone with large circular limestone cobbles/boulders. The beds are well-defined, dipping at angles of 10 - 20^0 to the southeast. Some of the bedding planes are defined/lined by limestone rip-up clasts.

Interpretation

The abundance of dwelling structures of suspension-feeding passive carnivorous biogenic structures exhibited by large size Arenicolites isp. with limestone cobbles/boulders within fine-grained dominated siliceous sandstone showed that the sediments were deposited in zones of coastal upwelling. At these zones the nutrient supply from the intermediate waters is concentrated on the upper slope and outer shelf (Einsele, 1992 p. 192). The siliceous sediments were produced by diatoms possibly radiolaria which extract much silica from ocean waters in the basin rather than rivers and volcanic activity. According to Einsele, 1992, highly siliceous or bio-siliceous sediments can only be found in area of (1) high primary productivity (in this case radiolaria), (2) where the influx of river-borne material is very low and (3) where the carbonate production is low or lysocline and carbonate compensation depth (CCD) are so high that most of the carbonate is dissolved in the water column or within the sediments. This factors support the field observations as most of the limestone boulders have been dissolved, remaining only as holes. The sediment of this type is deposited by debris flows under storm actions in a coastal upwelling condition.

Figure 5. Outcrop of boiturbated, siliceous sandstone

4.1.2. Outer Fan Facies Association

This facies overlie the conglomeritic sandstones facies and are found to represent a cyclic sequence representing a Bouma sequence. A typical example is represented by an outcrop exposure behind Government Technical College, Akpoha (Fig. 6).

Bouma (1962) recognised five divisions within the sequence namely: “a” to “e” and annotated as Ta, Tb, Tc, Td and Te. These divisions described the internal sedimentary structures in sandy turbidites. Four of these divisions were interpreted in our study area and they range from Ta to Td with repetition of Ta after Td. The detailed lithofacies interpretations are presented below.

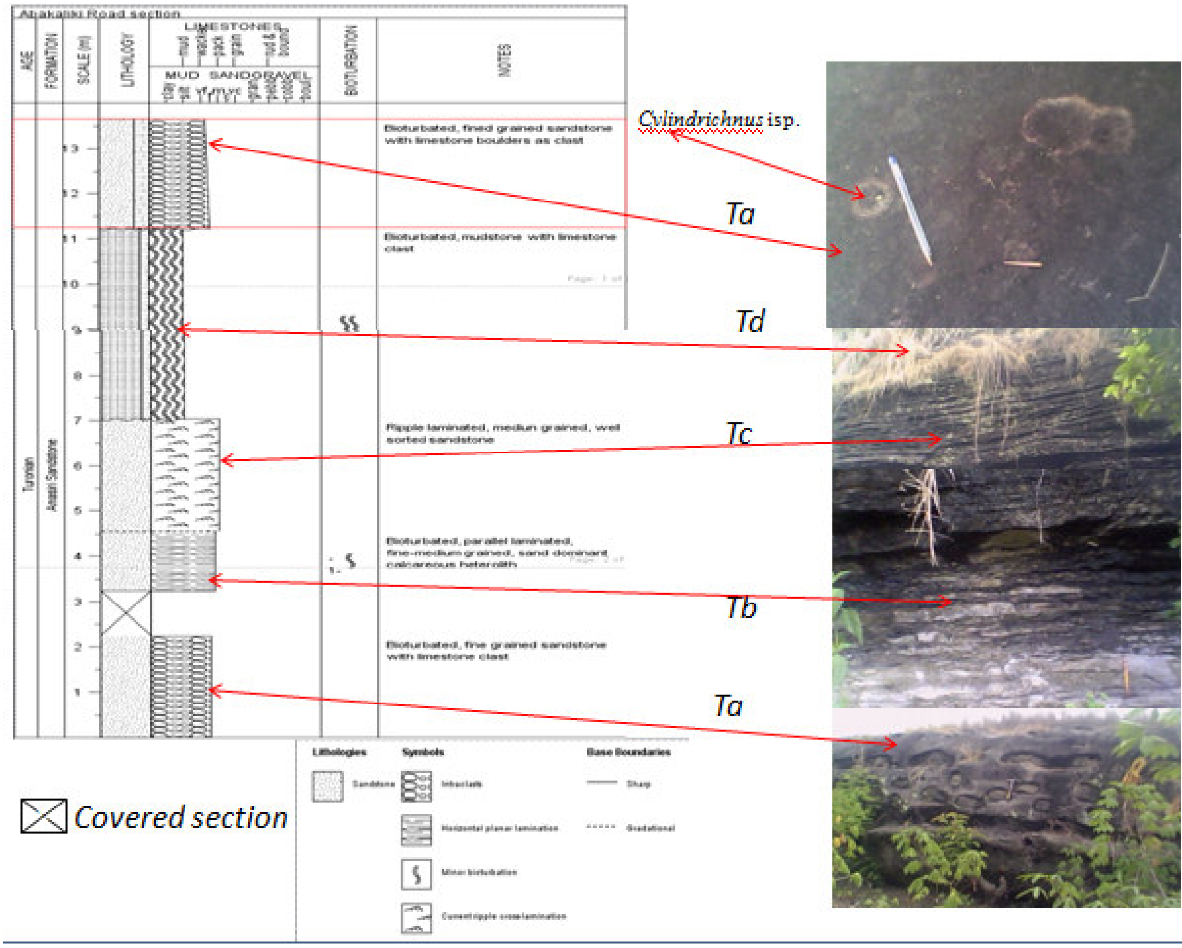

Figure 6: Typical Bouma sequence interpreted behind Government Technical College, Akpoha

4.1.2.1. Bioturbated, parallel laminated (heterolithic), calcareous sandstone (Tb):

This lithofacies are characterized by parallel laminated, fine to medium – grained, bioturbated calcareous sandstone. The parallel lamination is as a result of sand/mud heterolith but sand is dominant over mud. The geometry is mounded while the bioturbation is mainly Skolithos Ichnofacies dominated by *Ophiomorpha* isp. The sediments of this nature occurred in high energy regime while the parallel laminae are generated by the separation of grains in upper flow regime transport.

4.1.2.2. Ripple, wavy laminated sandstone (Tc):

This lithofacies are characterized by ripple laminated, medium – grained, well sorted sandstone. The thin laminae are made of mud, which separate the medium-grained sandstones from one another. The thickness of the sandstone beds appears to decrease upwards (graded lamination). The contact between the facies (Tc) and underlying facies (Tb) showed a well developed solemark. This deposit is interpreted to be deposited in outer fan fringe.

Interpretation

The bioturbated, parallel laminated, calcareous sandstone (Tb) and the ripple, wavy laminated sandstone (Tc) are product of turbidity current. Turbidite deposits are gravity-driven turbid mixture of sediment deposited from suspension. Such deposits are particularly important in deep basins adjacent to continents (Einsele, 1992). The Tb and Tc are interpreted to be submarine fans deposited by high energy in outer fan environment dominated by channel and levee complexes.

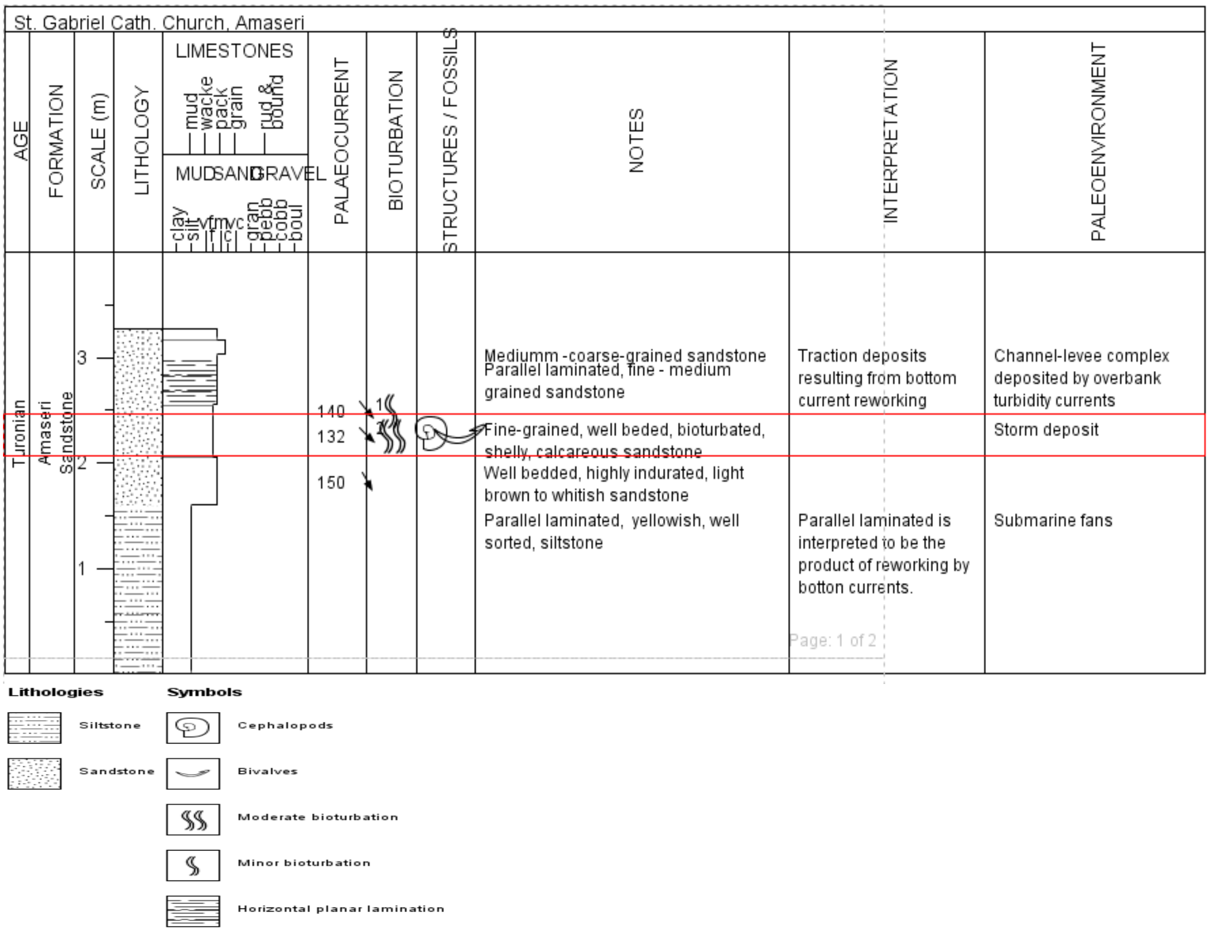

Figure 7. Litholog of the Amaseri sandstone showing succession from arenaceous sandstone to calcareous sandstone

4.1.3. Mid-fan Facies Association

4.1.3.1. Cryptobioturbated mudstone facies (Td)

This lithofacies are characterized by very fine grained sandstone to siltstone and can be described to be dominantly mud. It is light grey in colour and showed evidence of parallel lamination. The bioturbations are cryptic and that tend to obscure the parallel lamination structure (Fig. 7).

Interpretation

The cryptobioturbated mudstone facies is overlain by conglomeritic sandstone facies, which is a coarsening-up succession capped by a channelized conglomerate sandstone unit. Nichols, 2009 interpreted the sequences of this nature as a succession built up by depositional lobe progradation. This facies is interpreted to be deposited in a mid - fan environment.

4.1.4. Shefal (Offshore to Shoreface) Facies Association

This facies association is characterised by cross-bedded arenaceous sandstone lithofacies. The lithofacies is further classified into: planar cross bedded and trough cross- bedded, arenaceous sandstones.

4.1.4.1. Planar cross-bedded, arenaceous sandstone:

Fine-grained, well sorted, massive, cross bedded clayey sandstone. The sandstone is friable and whitish in colour containing quartz, clay, mica as minerals. The ridges are elongated and arranged parallel to one another.

Figure 8. Planar cross bedded sandstone

4.1.4.2. Trough cross-bedded pebbly sandstone:

Coarse-grained, trough cross-bedded, matrix supported pebbly sandstone. The cross-beds showed mud drapes which align with the axis of the cross beds.

Figure 9. Trough cross bedded sandstone

Interpretation

The arenaceous sandstone facies of the Amaseri Sandstone is tectonically disturbed showing evidences of folding and faulting in various locations. At the northwestern portion of the study area (towards calcareous sandstone lithofacies at Ozara-Ukwu section) the ridges are massive while towards the southeastern portion (towards the Amaseri and Afikpo Sandstones boundary at the shattered zone), they are well bedded. The Lithology is dominated by conglomerates and sandstones with minor siltstone beds

There is minimal evidence of tide, thus it may only be affected by a microtidal setting with few clay drapes on top of large scale cross beddings. The vertical sequence of Ozara-Ukwu outcrop is shown in Fig. 10a depicts environments of deposition interpreted ranging from offshore/lower shoreface to tempestite at the base with the overlying upper shoreface. The arenaceous facies of Amaseri Sandstone located at the shattered zones towards Macgregor College depict environments of deposition ranging from offshore with the facies interpreted as offshore sand ridges with interwoven facies interpreted as channel lag. The offshore sand ridges are overlain by Upper shoreface facies with the upper contact marked by erosional features and overlain by clast-supported conglomerate (Fig. 10b).

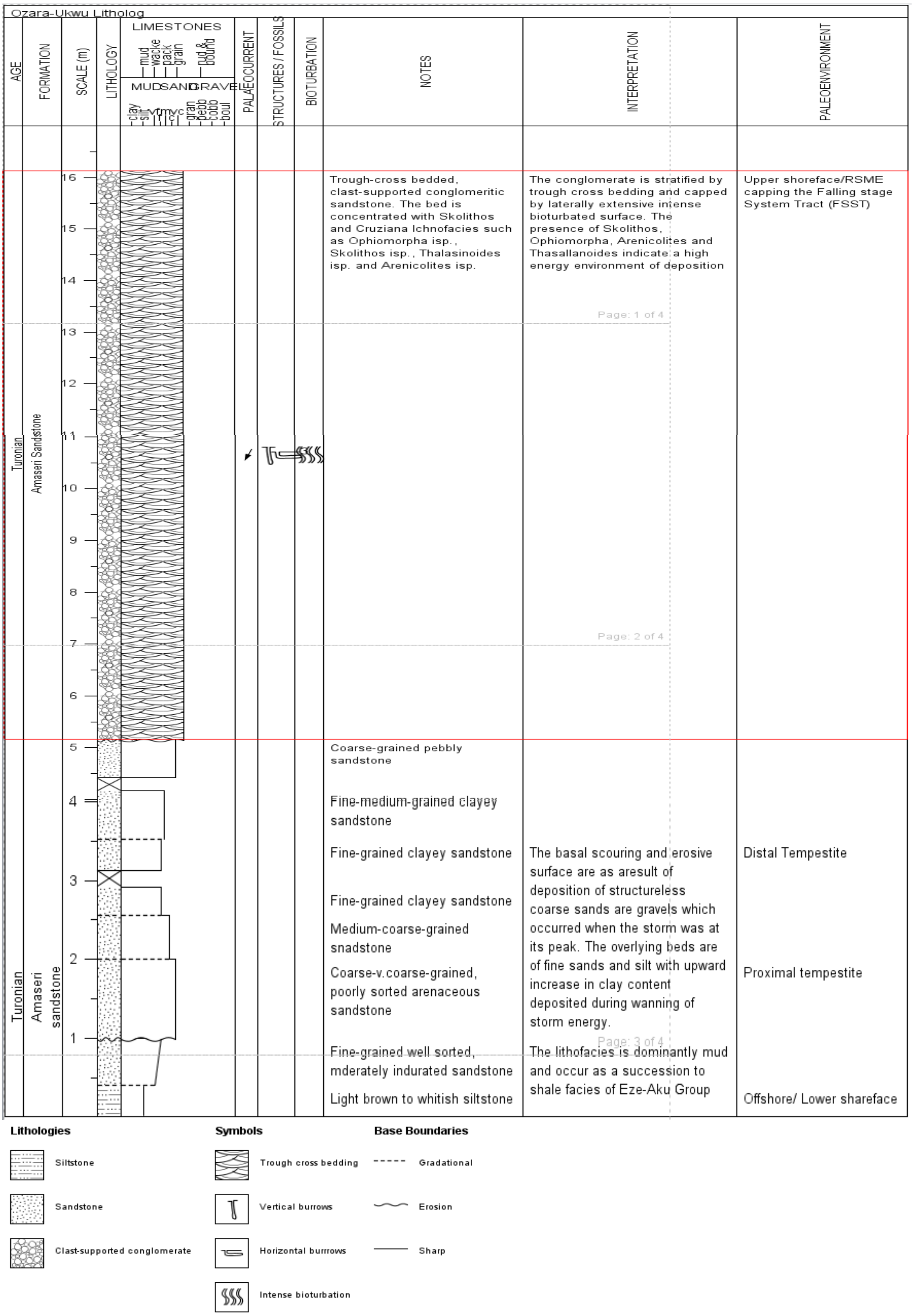

Figure 10a. Ozara-Ukwu outcrop showing sequence boundary at the upper section

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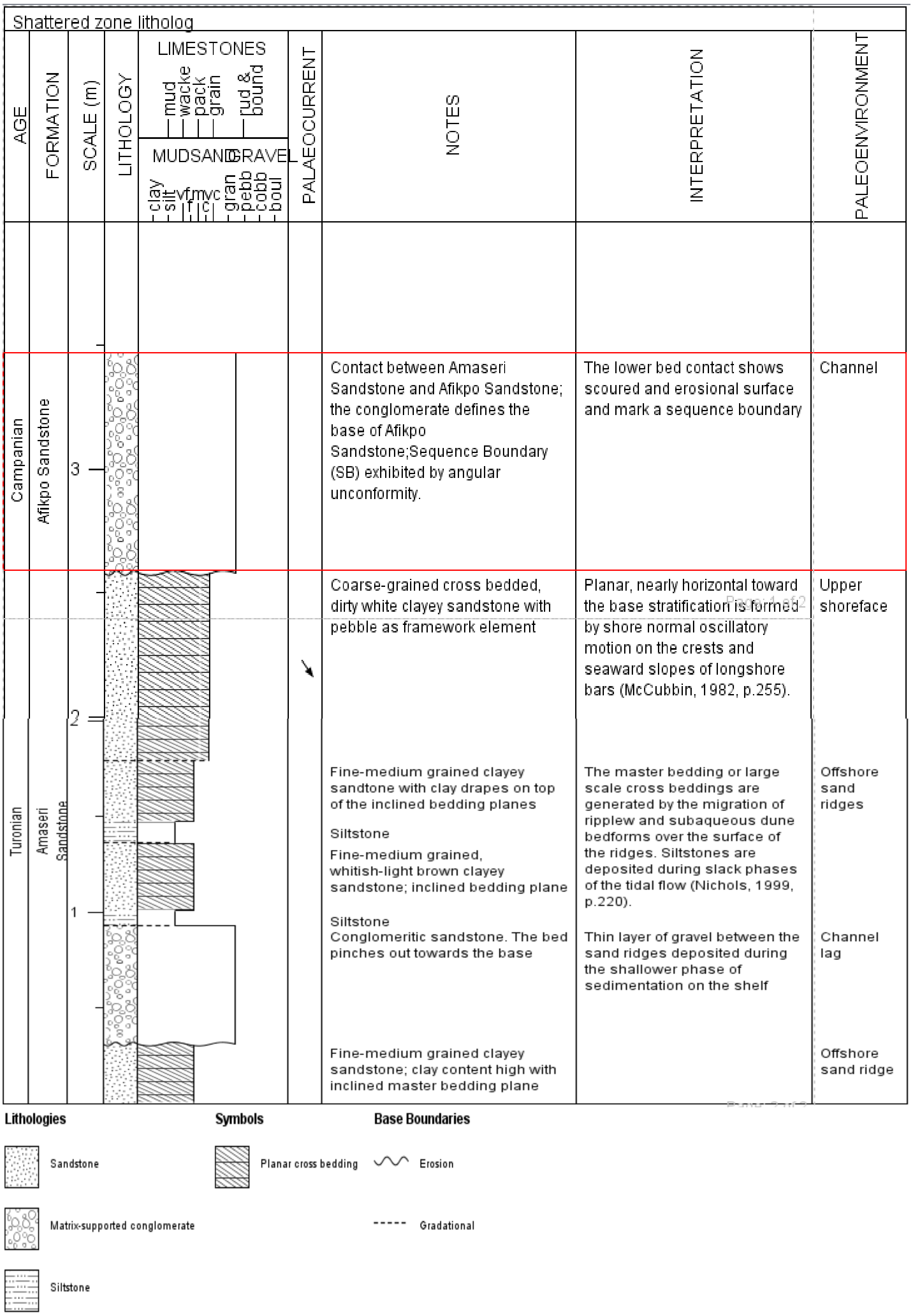

Figure 10b. Macgregor (shattered zone) outcrop showing sequence boundary at the upper section

5. Facies Succession in Amaseri Sandstone

The Eze-Aku Group showed a well varied lithofacies which begins with the Eze-Aku Shale and grade to facies of the Amaseri Sandstone. The Amaseri Sandstone facies succeed one another following Walther's law of facies succession in which vertical variations in facies corresponds to lateral variations. The sandstone facies started with deep water sandstone facies and terminated with shallow water sandstone facies. The deep water facies normally start with bioturbated siliceous sandstone followed by the bioturbated calcareous sandstone which is normally capped by bioturbated arenaceous sandstone facies (Fig. 11). Most of the deep water sediments form matrix-supported conglomeritic sandstone

The shallow water facies varies from offshore sand ridges to tempestite and terminated with upper shoreface facies. In general, the sequence shows a shoaling up and shallowing in palaeobathymetry. The geologic map (Fig. 12) also shows a sequence that start with siliceous sandstone to calcareous sandstone and finally to arenaceous sandstone with Eze-Aku Shale occurring as swales between the sandstones.

6. Palaeogeography

The dip azimuths of the bisectrix of the trough cross beds were measured in order to interpret the direction of the current (palaeoflow) that deposited the Amaseri Sandstones. The bisectrix of the trough cross stratification, on the a-b plane indicates the palaeocurrent direction (Okoro, 2009, p. 197). Igwe *et al* (2013) interpreted a southwesterly, westerly and northwesterly directed palaeocurrent mode and suggested that the Amaseri Sandstones were derived from Oban Massif. Nwajide (2013, p. 160) suggested that the Amaseri Sandstones together with the adjoining Konshisha River Group deposits were largely derived from the Basement Complex areas around Ogoja.

However, our rose plot of the Amaseri Sandstone facies (Fig. 13) shows that the sediments were derived from two main sources with north-west and south-west directed palaeoflows. The north-west directed palaeoflow was the results of dip azimuths measured from the cross beds of the conglomeritic sandstone facies where the limestone cobbles/boulders float as rip-up clast. The thin section (Fig. 14) of the same conglomeritic sandstones shows that the grain shape is sub-angular to angular indicating that the sediments were not long transported. The integrated results from the rose diagram and thin section show that the conglomeritic sandstones were derived the nearby Calabar Flank and Oban Massif located in the south-east portion of the study area. The limestone rip-up clasts are from the Mfamosing Limestones which was remoulded and remobilized by storms and deposited together with some woody fragments to form the matrix-supported conglomeritic sandstones of the Amaseri Sandstone.

The south-west directed palaeoflow is measured from the friable, cross bedded, arenaceous sandstones. A synthesized litholog (Fig. 11) of the Amaseri Sandstone shows that this facies occurred at upper section. Since the palaeoflow is in southwesterly direction, it means that the current that deposited the sandstone facies comes from the northeasterly direction indicating a source from Basement Complex in areas around Ogoja as suggested by Nwajide (2013).

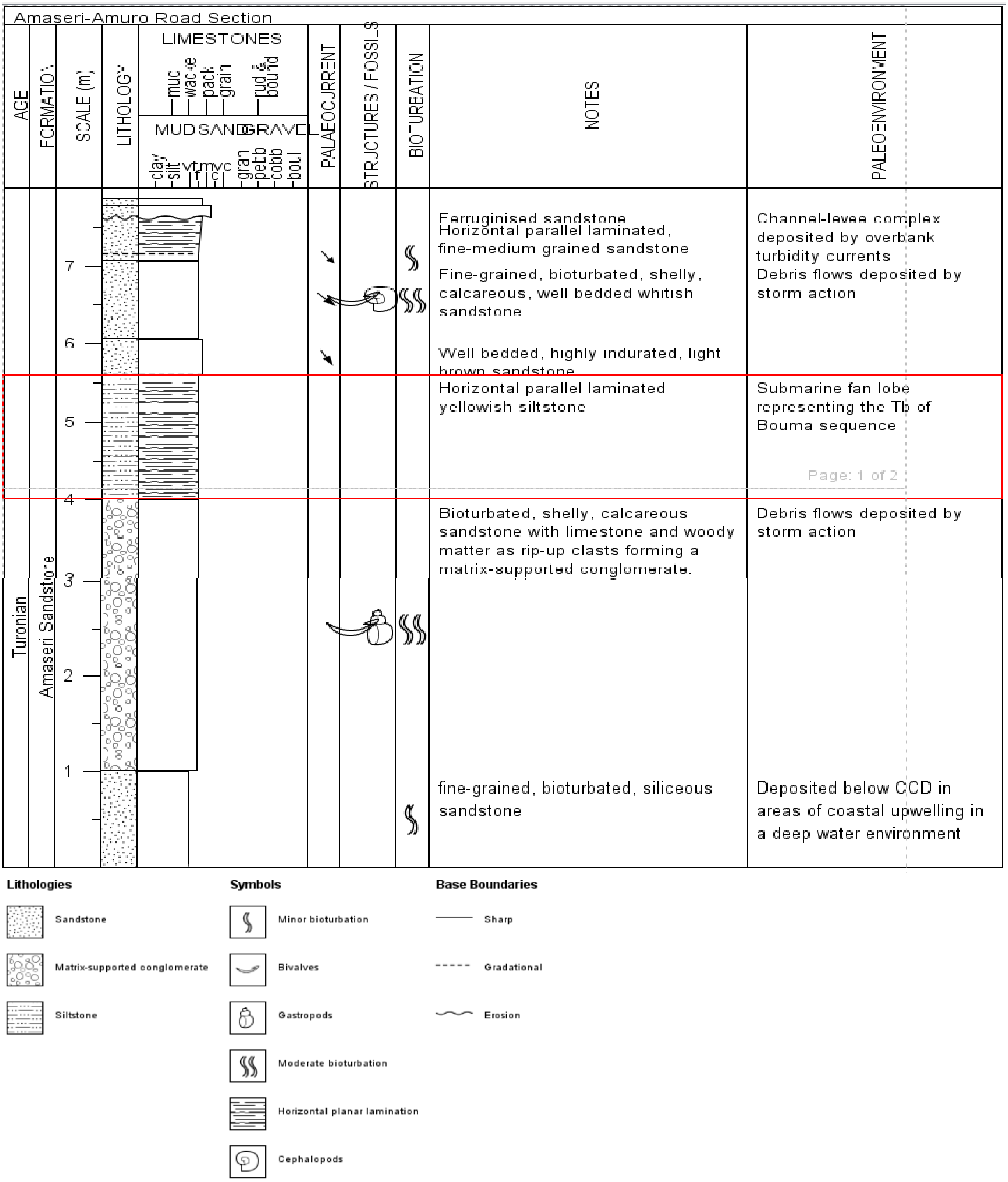

Figure 11. Synthesized litholog of Amaseri Sandstone facies showing the facies succession from siliceous sandstone to calcareous sandstone and finally to arenaceous sandstone.

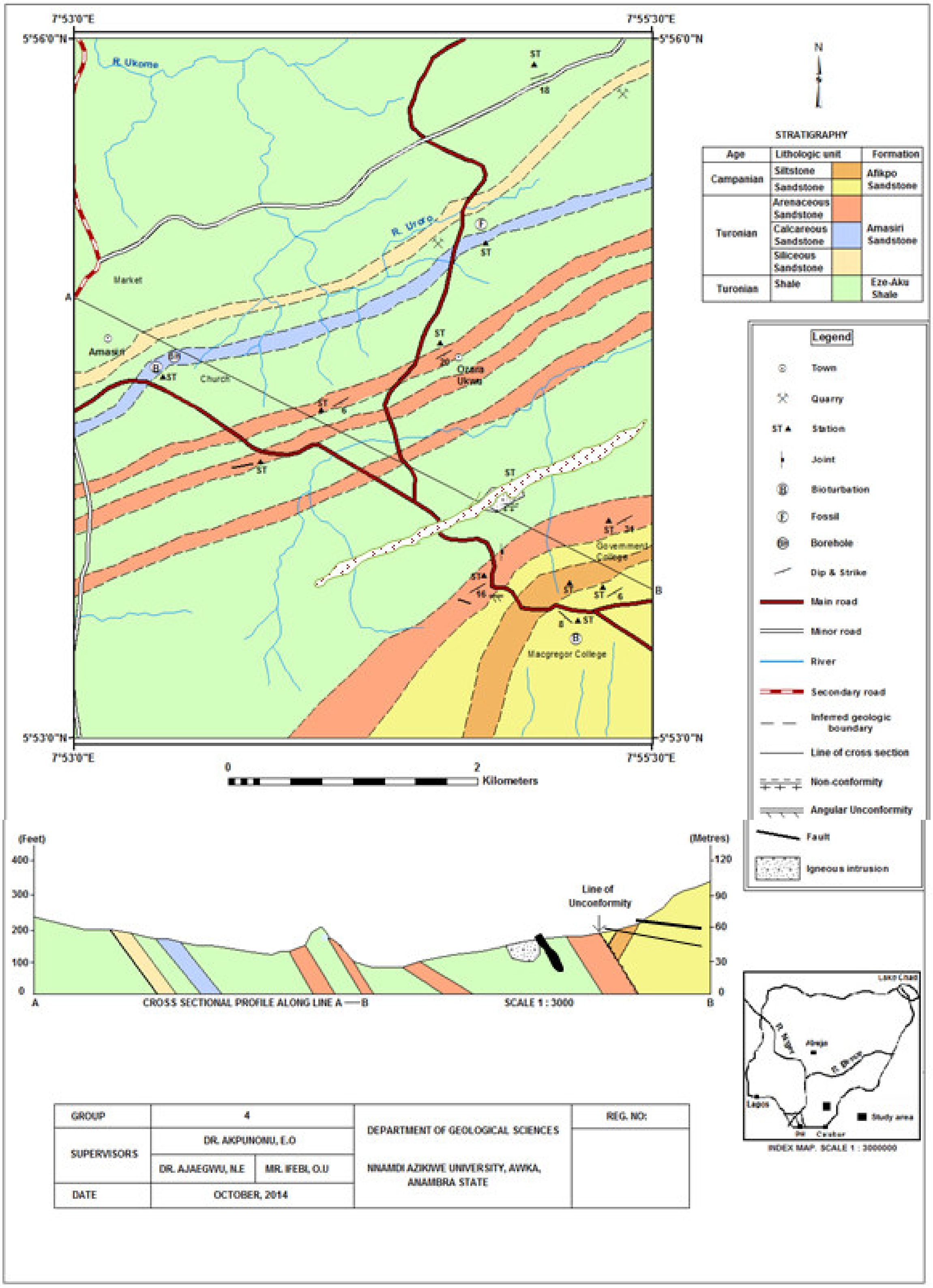

Figure 12. A geologic map of the Eze - Aku Group with the adjoining Afikpo Sandstone

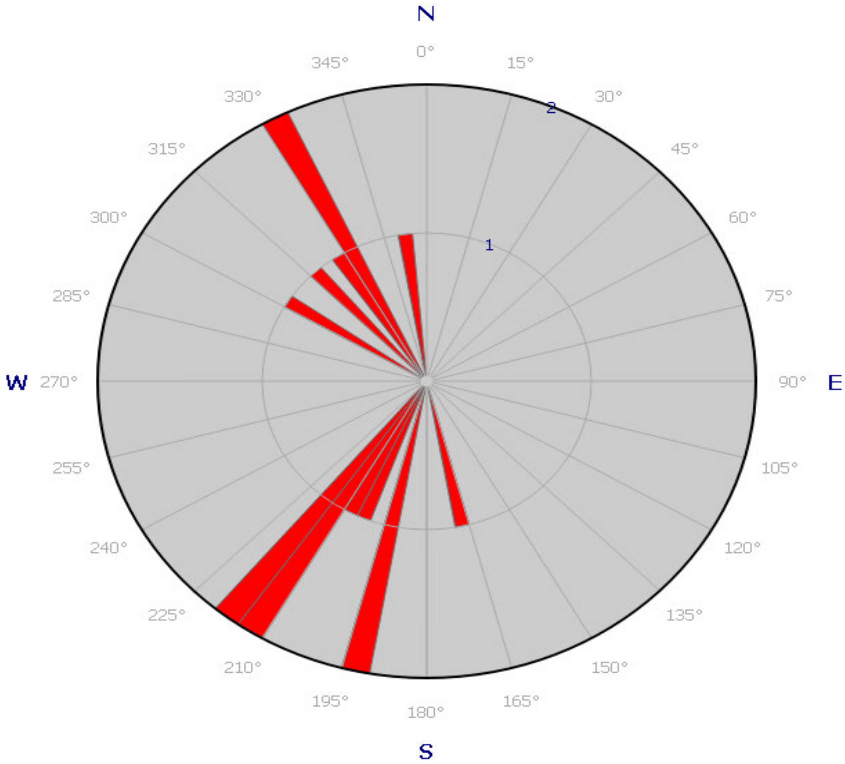

Figure 13. A rose diagram of Amaseri sandstone showing north-west and south-west directed palaeoflow

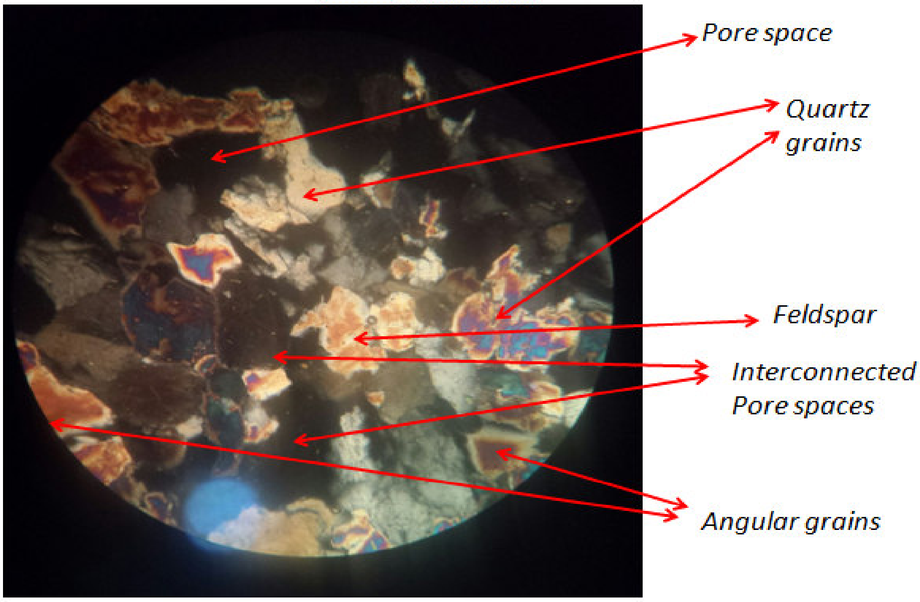

Figure 14. Photomicrograph of the Amaseri Sandstone

7. Conclusion

The lithofacies interpreted from the Amaseri Sandstone consist of seven main types; some of which represent Bouma sequence ranging from Ta to Td. The interpreted lithofacies are: cryptobioturbated, conglomeritic, siliceous sandstone (Ta); bioturbated, shelly, conglomeritic, calcareous sandstones (Ta); bioturbated, conglomeritic, arenaceous sandstone (Ta); bioturbated, parallel laminated, calcareous sandstone (Tb); ripple/wavy laminated sandstone (Tc); cryptobioturbated mudstone (Td); and cross bedded, arenaceous sandstones. These lithofacies were integrated with physical sedimentary structures, biogenic structures, body fossils content and nature of bedding contacts to interpret facies associations. The facies associations interpreted are: proximal fan facies associations deposited by debris flows and represented by the conglomeritic sandstones (Ta); outer fan facies associations deposited by turbidity currents and represented by bioturbated, parallel, calcareous sandstone (Tb) and ripple/wavy laminated sandstone (Tc); mid-fan facies association represented by crptobioturbated mudstone (Td); and offshore to shoreface facies association represented by cross bedded arenaceous sandstone.

The palaeoflows interpreted from the rose diagram constructed from the azimuths of the trough cross beds indicate two directional modes, the north-west and the south-west flows. The petrographic studies show that the grain shapes are dominantly sub-angular to sub-rounded, moderately sorted and texturally and compositionally immature indicating that the sediments were not long transported. The combined palaeoflow and petrographic results show that the Amaseri Sandstones were sourced from the nearby Calabar Flank and Oban Massif as indicated by the northwestery palaeoflow and from the Basement Complex in areas around Ogoja as indicated by the southwestery palaeoflow mode. The limestone cobble/boulders forming the rip-up clast in the conglomeritic sandstone may be sourced from the Mfamosing Limestone located within the Calabar Flank.

References

Amajor, L.C., (1992), "Storm-induced turbiditelike deposit: an example from the Turonian Eze-Aku Formation at Nkalagu, southeastern Nigeria", Journal of mining and Geology, **28**, 7– 17.

Banerjee, I., (1980), "A subtidal bar model for the Eze-Aku Sandstones, Nigeria", Journal of Sedimentary Geology, **30**, 133-147.

Benkhelil, J., (1989), "The evolution of the Cretaceous Benue Trough, Nigeria", Journal of African Earth Sciences, **8**, 251-282.

Bouma, A.H., (1962), "Sedimentology of some flysch deposits; a graphic approach to facies interpretation", Elsevier, 168p.

Einsele, G., (1992), "Sedimentary basins evolution, facies and sediment budget", Springer-Verlag, 206 -231.

Fedonkin, M. A. (1994), "Vendian body fossils and trace fossils", *in* S. Bengtson, ed., Early Life on Earth, Columbia University Press, New York, 370 –388.

Igwe, E.O., Igweaja, J.U., Obasi, A.I. and Edene, E.N., (2013), "Geochemistry and petrographic analysis of sandstone facies of Eze-Aku Formation in Amasisri area, Lower Benue Truogh, Nigeria: Implications for provenance and tectonic setting", Journal of Natural Sciences Research, **3** (9), 166-174.

Miall, A.D., (2000), "Principles of sedimentary basin analysis", Springer-Verlag, Berlin, 3rd ed., 163.

Murat, R.C. (1972), "Stratigraphy and palaeogeography of the Cretaceous and Lower Tertiary in South Nigeria", *in* T.F.J. Dessauvagie and A. Whiteman, eds., African Geology: University of Ibadan Press, 635 – 641.

Nichols, G, (2009), "Sedimentology and stratigraphy", Wiley-Blackwell, 2nd ed., 267 – 262.

Nwajide, C.S., 2013, Geology of Nigeria's sedimentary basins, CSS Bookshop Limited, 131 – 161.

Obaje, N.G., 2013, Updates on the geology and mineral resources of Nigeria, Onaiyi Printing & Publishing Co. Ltd., 49.

Odigi, M.I., (2012), "Sedimentology of the Nkporo Campanian-Maastrichtian Conglomeratic Formation, Afikpo Sub-basin, Southern Benue Trough, Nigeria", Journal of Mining and Geology, **48,** no. 1, 45 – 55.

Okoro, A.U. and Igwe, E.O. (2014), "Lithofacies and depositional environments of the Amasiri Sandstone, southern Benue Trough, Nigeria", Journal of African Earth Sciences, 179 – 190.

Okoro, A.U., (2009), "Data analysis and presentation: a sedimentological perspective", *in* D.O. Lambert-Aikhionbare and A.I. Olayinka, eds., Proceedings of field mapping standardization workshop: Ibadan University Press, 180 – 200.

Pemberton, S.G., MacEacham, J.A., Frey, R.W., (1992), "Trace fossil facies models: environmental and allostratigraphic significance", *in* R.G. Walker and N.P. James, eds., Facies Models: Response to sea level change, Geological Association of Canada, 47–72.

Umeji, O.P., (1984), "Ammonite palaeoecology of the Eze-Aku Formation, southeastern Nigeria" Journal of Mining and Geology, **21,** 55 - 59.

Umeji, O.P., (1985), "Subtidal shelf sedimentation: an example from the Turonian Eze – Aku Formation in Nkalagu area, southeastern Nigeria", Journal of Mining and Geology, **22,** 119 – 124.

Umeji, O.P., (1988), "Trace fossils in the Eze-Aku Formation (Turonian), southeastern Nigeria", Journal of Mining and Geology, **24,** 79 - 80.

Umeji, O.P., (1993), "Hummocky cross-stratification in the Turonian Eze-Aku sandstones of southeastern Nigeria: sedimentological significance", Journal of Mining and Geology, **29,** 71 - 76.

Walker, R.G., (1992a), "Turbidites and submarine fans", *in* R.G. Walker and N.P. James, eds., Facies Models: Response to Sea Level Change: Geological Association of Canada, 239–263.

Whiteman, A, (1982), "Nigeria: its petroleum geology, resources and potential", London, Graham & Trotman Ltd., **1,** 131-132.