Sedimentary Processes and Sedimentation in the Shallow Offshore, Eastern Niger Delta, Gulf of Guinea

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Abstract

The Cretaceous Afikpo sedimentary Basin in Southeastern Nigeria contains rocks of fluvial, deltaic and shallow marine origin. This study examines the role of sedimentary processes in sediment distribution in the various geologic environments. The outcrop sections and the Afikpo River were studied by visual observation and photographing of important features during a field mapping exercise. Well log data from the Niger Delta Basin were also used to infer depositional environments based on gamma ray log motifs. These outcrop sections consist of fluvial, deltaic and shallow marine sediments that occurred as braids, point-bars, mouth-bars and beach/regressive bars. Braids and point-bar deposits also occurred within the recent Afikpo River channel, a major conduit transporting sediments to the offshore area of eastern Niger Delta. Sandstone outcrops showing a mouth-bar architecture occurred at Akpoha Town east of Afikpo Town, with a shallow marine sequence at Amasiri area, west of Afikpo Town. The Amasiri sandstone is a massive outcrop with large lateral extent covering more than 8 kilometers. Gamma ray log trends observed on well log from offshore area in the eastern Niger Delta indicated deposits of fluvial, deltaic and shallow marine origin.

Keywords: Afikpo Basin, cross river, fluvial, sedimentation, Niger delta, shallow offshore

1. Introduction

The Gulf of Guinea has recently received tremendous attention from both the oil companies and the academia for several decades due to increasing hydrocarbon discoveries in the region. To maximize production from offshore reservoirs, there is the need to properly understand the processes of sedimentation and the consequent depositional architecture of facies and their distribution within the marine realm. The two major rivers (Niger and Benue rivers) in Nigeria are of significance in the distribution of sediments in the east and western offshore area of the country. The Niger River is active and supplies sediments toward the western part of the Niger Delta, whereas, the Benue River concentrates sedimentation in the eastern offshore (**Figure 1**) area. There are subsurface evidences of the occurrence of ancient river channels and canyons that served as conduits for transporting sediments from the continent to the Gulf of Guinea [1]. These sedimentation processes are still active today and sediments keep building out along the shores and on the continental shelf of the Niger Delta. We will look at the outcrop evidence of fluvial and marine sandstones at Afikpo Town, and trace the course of the Cross River from Afikpo (**Figure 2**) to the coastal town of Calabar where presently these sediments are deposited into the estuaries and open marine environments. The subsurface occurrence of shallow marine facies will serve as analogue to the outcrop exposures of marine sandstones in the Afikpo basin. The eastern offshore of the Niger Delta occurs within few kilometers away from the active volcanic line of the Cameroun Mountain. The geomorphic features and surface processes in this region are of interest to most researchers and enables the paleo-reconstruction of subsurface sediments of Tortonian age in the offshore area. The adjacent highland areas consisting of the Precambrian basement of the Oban Massif, Obudu Plateau and the Cameroun Mountain form the sources of weathered sediments that are transported through the Great Kwa and Calabar Rivers to the offshore area south of Calabar Town, South Eastern Nigeria [2]. These rocks are weathered, highly fractured, foliated, and exposed by stream channels cutting through them [2]. They from the major provenance of sediments deposited within the shallow to deep offshore through submarine canyons. In this paper, we will consider a major tributary

Figure 1. Map of Africa showing the location of Afikpo town and the Cross River flowing south-ward into the Gulf of Guinea.

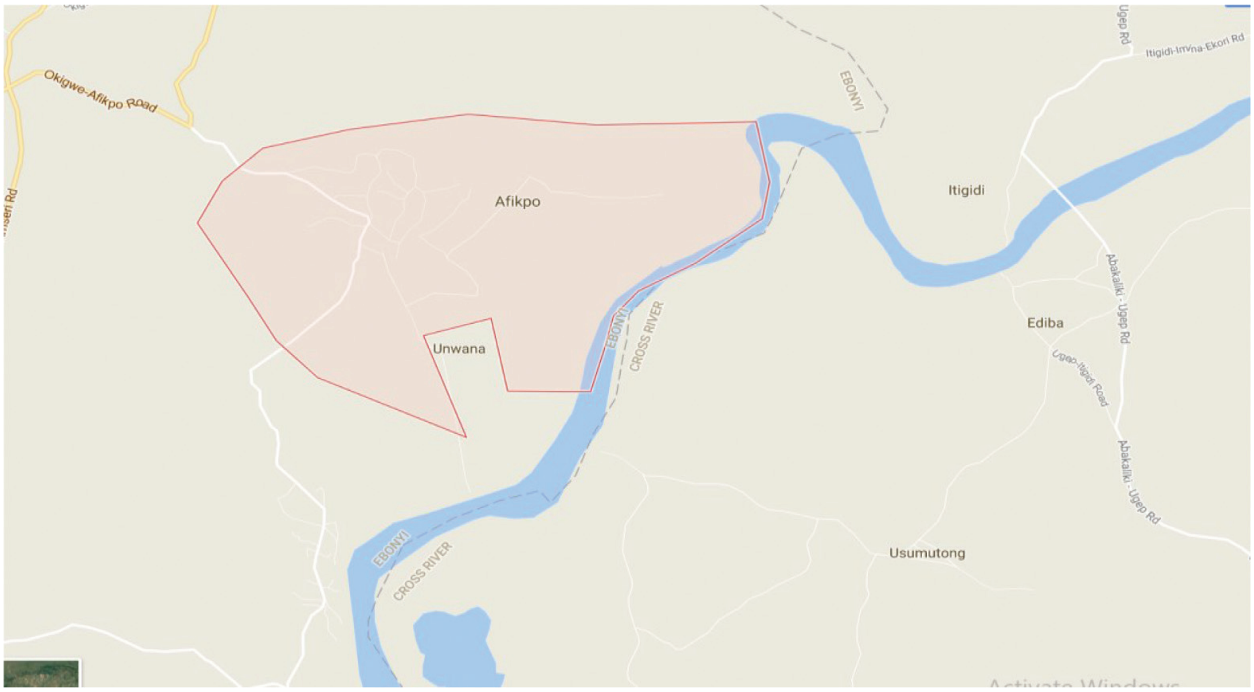

Figure 2. The river configuration within Afikpo town, SE Nigeria.

of the Benue River, the Afikpo-Cross River, which transport sediments from the hinterland in eastern Nigeria to the eastern offshore area of the Niger Delta. We will discuss the continental, deltaic and shallow marine processes, sediments and their responses from both outcrop and subsurface data. A consideration of the subsurface architecture of shallow marine sediments from the eastern part of the Tertiary Niger Delta sedimentary basin will also be made. The study and understanding of sedimentary processes and their responses have serious economic, environmental and mineral exploration significance.

2. Sedimentation processes

Generally, there are two major rivers in Nigeria that run through the country with several tributaries. They are; the Niger and Benue rivers. The Niger river empties into the Atlantic Ocean in the south- western axis of Nigeria, whereas the Benue River in the southeastern part. These rivers supply sediments to the Gulf of Guinea. The active river system controlled by climate and topographic landscapes accounts for sediment distribution within the continent and offshore areas. Along the stream and river channels there are serious mining of these sediments used for construction purposes. Generally, sites for sand deposition fall into three main categories: 1. the alluvial fan province which is an area proximal to the base of mountains and high-altitude rock outcrops which serve as the major sources of high sediment supply to the rivers. These outcrops include; the weathered Cretaceous rocks of Afikpo Basin and other basement rocks from Obudu Plateau, the Oban Massif and the Cameroun Mountain 2. channelized braided stream sediments and associated overbanks, and, 3. meandering stream province that finally discharges into the open sea. The alluvial fan sediments occurred in the hinterland proximal to the Afikpo Basin sedimentary rock outcrops and the basement rocks of the Oban Massif. The Afikpo-Calabar River south-east of Afikpo Town in the South-eastern part of Nigeria possesses high sediment loads that account for the braids deposited within the channel in this area. This area is highly prone to river bank erosion that claims parts of adjacent farmlands (**Figure 3**). This river maintains a straight course from Afikpo area through Adim town to Etono where the river meanders in the south-west direction as it flows towards Iyakpan. The general trend of the river from Afikpo to Calabar is in the NE-SW direction.

2.1. Braided stream

Braided stream sediments occur within Afikpo Town in both ancient outcrop section and within the recent Afikpo-Calabar River course (**Figure 4**). The formation of braids usually occurred in areas proximal to sediment provenance with high sediment supply and stream gradient. The channel within this region possesses steep gradient with variations in stream discharge′ eroding the river banks at Ndibe Beach (**Figure 3**) and adjacent lands along the entire river course. The river channel is constantly expanding due to this erosion and has exceeded 100 m in width within Ndibe Beach (**Figure 3**). The region generally possesses uneven topography due to tectonism and differential weathering of the basement rock along the river channel [2]. The Cretaceous sandstone outcrop in the Afikpo Basin revealed this multi-story braided sediments stacking into about eight braids (**Figure 4**). These braided stream deposits reflect high sediment supply within the stream channel, great proportions of suspended and bedload load sediments which are the main controlling factors on the development of the ancient river that transported the sediments. Fluvial sediments are widespread in outcrop exposures in Afikpo Town and the various stream sedimentary features at various points along the channel are obvious in the outcrop sections in the area.

2.2. Meandering channels

There are more than seven major meandering loops along this river from Afikpo to Calabar Area (**Figure 5**). The degree of meandering along this river course increases downstream as it

Figure 3. Ndibe Beach, Afikpo-Cross River area: latitude N05°50′30.4″; longitude E-007°56′55.6″; elevation is 17 m. The width of the river is more than 100 m. The banks of the river in this area is prone to constant erosion.

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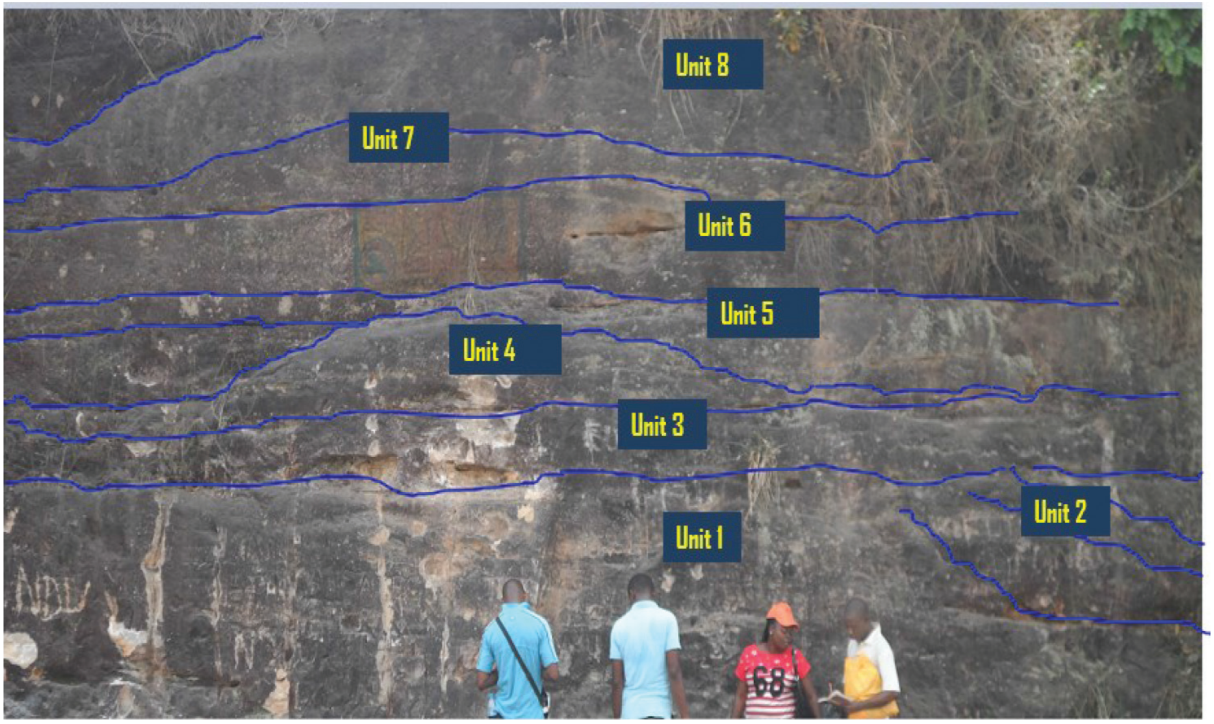

Figure 4. Stacked multi-story braided channel deposit at MacGregor Hill, Afikpo, SE Nigeria.

approaches Calabar area in the Niger Delta (**Figure 5**). This river and its tributaries forms the major sediment transporting conduit to the offshore area in the south-eastern Niger Delta and to the Gulf of Guinea. Site for more sediment accumulation within the meandering system is the point bar characterized by poorly sorted, coarse to very coarse-grained sands with gravels deposited in the deeper parts of the meander belt by a slow-moving water along the curve (**Figure 6**). It grades upward into a very fine grained well-sorted sediment from the deeper part of the channel towards the shallow section with reduced current flow. The amount of suspended sediments guaranteed the deposition of fine grained sands along the meandering curve prompting a swift transition from braided deposition to a meandering configuration. The areas experiencing high degree of meandering along the river course include; south of Afikpo Town, Etono area, Iyakpan, Itu and Ayadeghe with waning energy as it approaches Calabar Town where the river empties into the open sea to deposit its sediments. These sediments are moved oceanward into the Gulf of Guinea through canyon. Some are distributed within the shores by waves, longshore currents and other marine energy fluxes to form beaches as can be seen in Ibeno Beach south of Eket Town in Akwa Ibom State, west of Calabar Town. The ancient river deposits within the shallow offshore in the eastern Niger Delta have been identified from subsurface data [3].

2.3. Deltaic deposits

The marine portion of the outcrops in Afikpo marks a transition from a more fluvially influenced sedimentation to a deltaic process. This is evident in the isolated lobes of sandstone outcrops that occur within Akpoha area west of Afikpo Town (**Figure 7**). It may possibly be a

Figure 5. Meandering points along the river course from Afikpo town to Calabar. The degree of meandering increases in the south-east direction as the river approaches the sea.

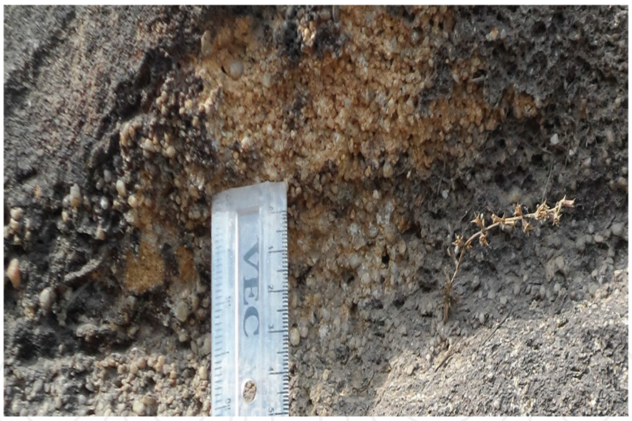

Figure 6. Meandering channel deposit: Fining upward point bar channel deposits showing lag base with very coarse grained, pebbles and gravels (cretaceous sandstone of Afikpo Basin, south-eastern Nigeria).

mouth-bar deposit that occurred towards the end of a distributary channel. It consists of two facies units: a massive planar bed overlying a mega trough cross-beds facies of between 250 and 300 cm thick (**Figure 7**). The sandstone is underlain by mudstones and shale portraying a coarsening upward sequence in grain size typical of a deltaic environment. A shoreface shallow marine section is observed in the Cretaceous age Amasiri sandstone (Afikpo Basin) showing a large lateral extent of more than 8 km with thickness greater than 100 m (**Figure 8a** and **b**).

Figure 7. Massive planar beds underlain by cross-bedded sandstone (250–300 cm thick). The sandstone is underlain by marine shale—Deltaic environment.

(a)

(b)

Figure 8. (a) Regressive barrier bars (Amasiri, Afikpo Basin, SE Nigeria). Thickness: over 100 m; width: 3 m; length: (more than 8 km). These regressive bars are underlain by marine shales, (b) shallow marine regressive Amasiri sandstone in Afikpo Basin, SE Nigeria. It is laterally extensive and runs parallel to paleo-coastline. The thickness is above 70 m, more than 3 m in width. N05°53′09.9″; longitude E-007°52′15.4″. Elevation is 67.8 m.

3. Subsurface sedimentary analogue of eastern offshore Niger Delta

Stratigraphically, the Niger Delta Basin has three formations. They include; Akata Formation, a prodelta marine shale which is the basal unit; the Agbada Formation, a paralic sequence of shale and sandstone beds occurring in almost equal proportions, which forms the hydrocarbon habitat in the basin, and finally the youngest continental Benin Formation comprising of loose fluvial sands and gravels [4–10]. There are four unique Members that occur within the Agbada Formation in the eastern offshore Niger Delta. They include; the Qua Iboe Shale, Biafra Member, the Rubble Bed, and the D-1 Sand [3]. The Qua Iboe Shale (QIS) is identified on well log as the first continuous shale interval that occurred towards the base of the continental Benin Formation. The well data used for this study were taken from an oilfield located in the shallow offshore area in the eastern part of the Niger Delta sedimentary basin. The location is about 4 km away from the Calabar Town, just at the mouth of the major estuary where most sediments from the continent are deposited and consequently transported to the deep sea in the Gulf of Guinea.

Studies of modern sedimentary environments revealed that vertical profiles of grain size from a specific environment have certain log characteristics [11–14]. For instance, prograding deltas and barrier bars deposit display an upward-coarsening grain size profiles (**Figure 9**). Three prominent trends identified on well log that helped to delineate the various depositional settings are: coarsening upward trend representing deltaic facies (**Figure 10**, number 4).; fining upward trend showing transgressive facies (**Figure 10**, number 1 and 5), boxcar gamma ray log motif of regressive barrier bar/beach deposits (**Figure 10**, number 2 and 3).

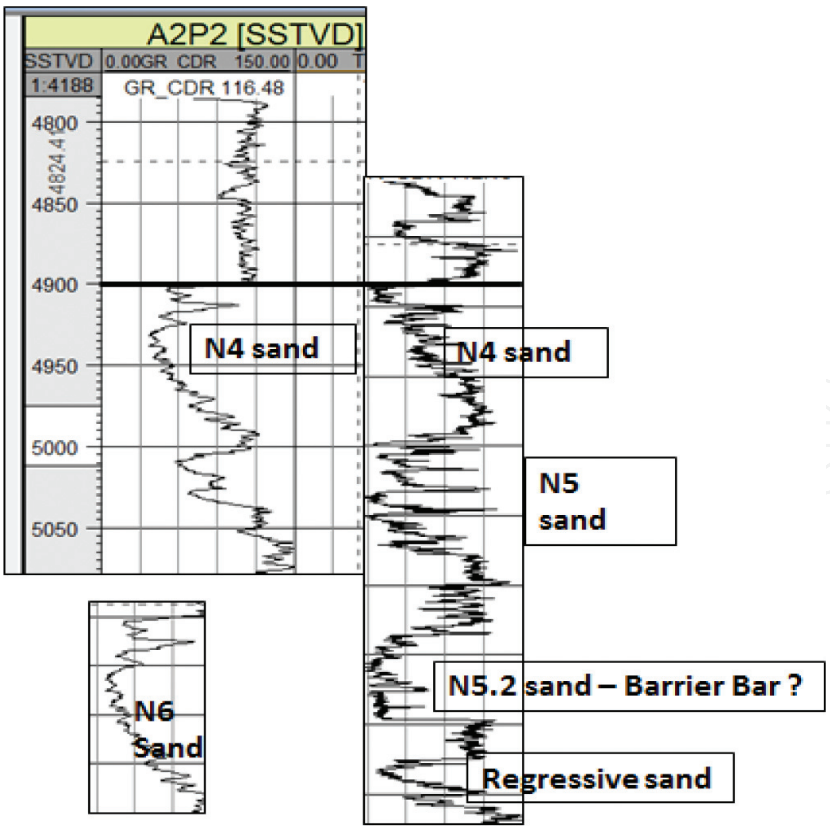

Figure 9. Electrofacies patterns showing some distinct depositional environments.

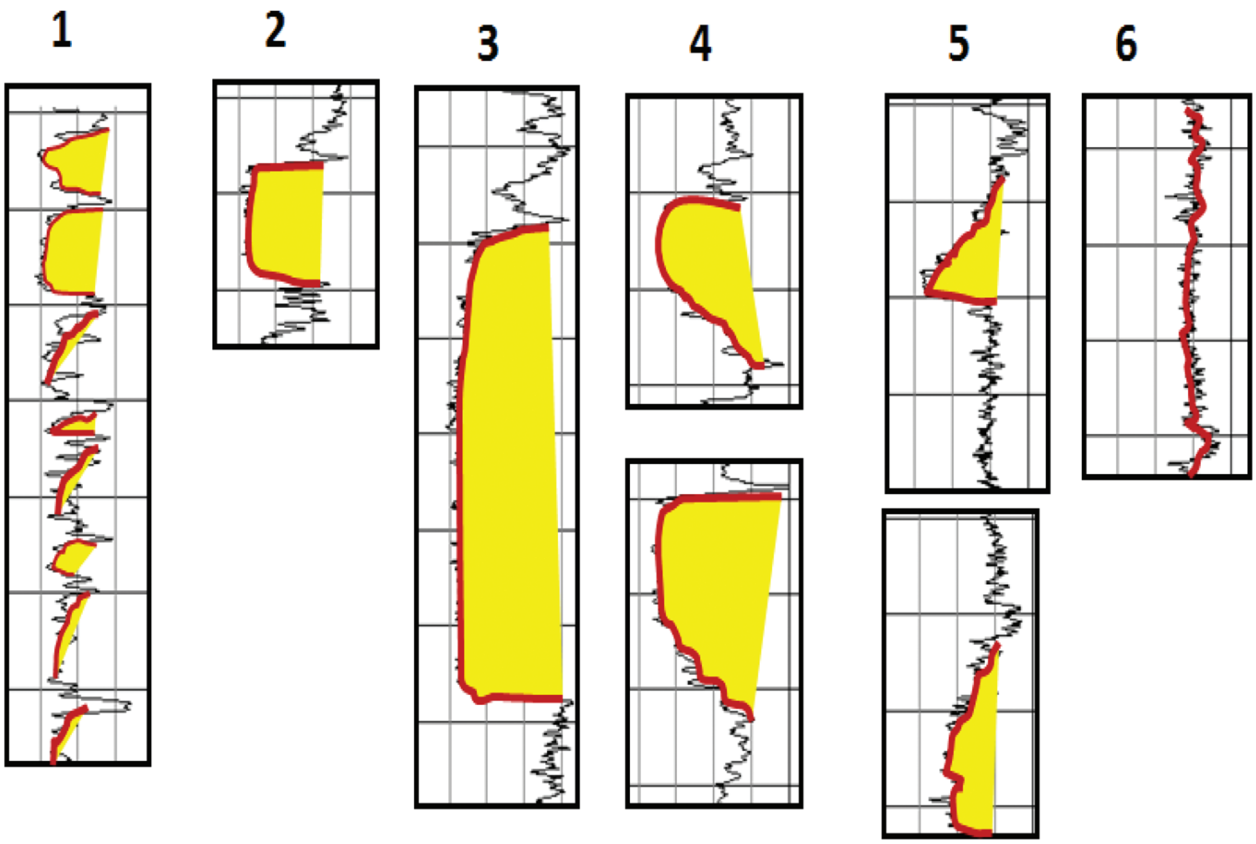

Figure 10. Specific gamma ray log trends in the study area.

3.1. Gamma ray log facies description

Seven main gamma-ray log characteristics (**Figure 11**) have been established using gamma-ray log trends; (1) spiky or mixed (2) blocky and coarsening-upward (3) blocky and fining-upward (4) coarsening upward (5) fining upward (6) erratic and (7) blocky [3]. The log facies descriptions below are used to infer genetically related environments. The gamma-ray electrofacies patterns represent environments that range from deltaic front to shallow marine setting.

Electrofacies 1: This facies is characterized by spiky or mixed gamma ray log signature, which may represent middle or lower deltaic plain environment (**Figure 11**).

Electrofacies 2: This facies consists of both a blocky pattern in association with a coarsening-upward trend. The repeated blocky pattern may represent amalgamated fluvial (distributary) or estuarine channels, whereas coarsening upward shows seaward progradation of continental sediments (**Figure 11**).

Electrofacies 3: This unit has a sharp lower contact with a weak fining upward trend at the upper boundary displaying a blocky shape typical of distributary channel or tidally influenced delta (**Figure 11**) [3].

Electrofacies 4: This unit displayed a spiky and coarsening upward gamma ray log motif that may represents a prograding deltaic or a delta front facies (**Figure 11**) [3]. The environments

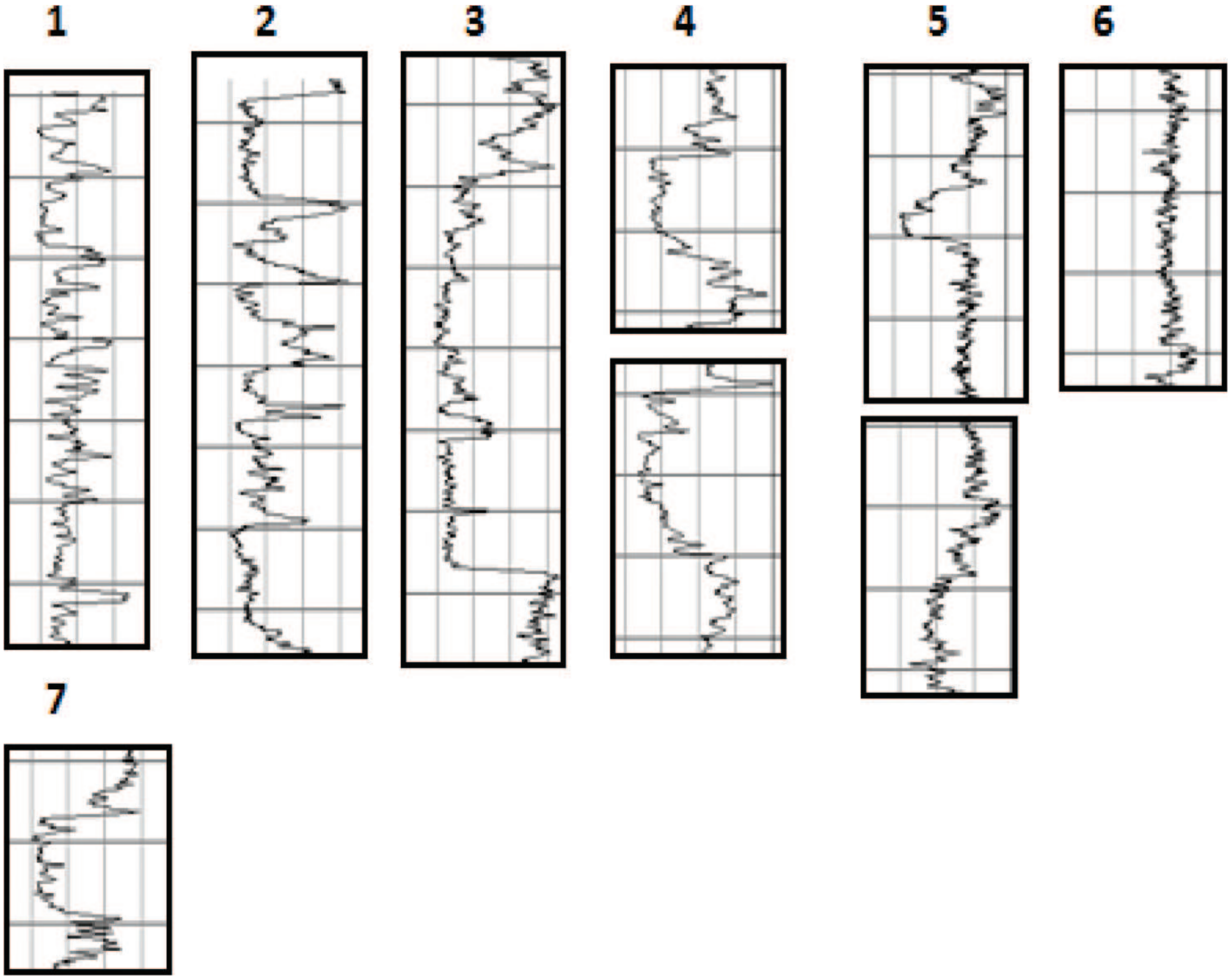

Figure 11. Gamma ray log motifs in association.

depicted by this trend could be shoreface, tidal or mouth bar. By the methods reported in [15], the environments of coarsening upward successions can be classified into three general categories: (1) prograding submarine fans (2) regressive barrier bars, and (3) prograding deltas or crevasse splays [3]. Prograding submarine fans and regressive barrier bars are commonly associated with glauconite and shell debris [3, 11, 15, 16]. Glauconite debris occurred in all the samples from about 1800 ft. in all the wells, consequently, there is the possibility of the first two environments (regressive barrier bars or prograding submarine fans) occurring in the field. Deductively, the paleoenvironments of funnel shape facies can be attributed to shallow marine and deltaic front environments. One of the major difference between a prograding delta and a crevasse splay is the scale of deposition; the scope of a prograding delta is comparatively large. The work of [11, 15], shows that environments of funnel-shaped successions with the presence of carbonaceous detritus may be depicted a prograding delta or a crevasse splay [3]. The average thickness of the thin funnel-shaped successions in this work is less than 800 cm, which suggests that the paleoenvironment could be a crevasse splay associated with a deltaic channel. A scale of less than 800 cm is comparatively small to be classified as a prograding delta [3].

Electrofacies 5: The unit characteristically displayed sharp lower contact with a gradational upper boundary (**Figure 11**). It is a transgressive unit. The bell-shaped succession usually occurs in three types of environments: tidal channels, turbidite fills and fluvial or deltaic channels. Tidal channels and turbidite fills also commonly include glauconite and shell debris [16]. The only bell-shaped successions with carbonaceous detritus are deposited in environments of fluvial or deltaic channels [11].

Electrofacies 6: This is erratic in nature. It may represent a lower deltaic plain to shallow marine shelf deposits.

Electrofacies 7: The electrofacies of this unit shows sharp upper and lower contact (blocky) [3]. The thickness of the boxcar gamma ray log motifs in all the studied intervals is less than 25 m [3]. Mudlog report indicates that the lithologies of these sections are mostly sandstones (off white to creamy white, gray in part, translucent to transparent, very fine to fine, occasionally medium grained, sub-rounded to rounded, sub-spherical, primarily calcareous cement, argillaceous in part poorly to moderately sorted [3], very good porosity and permeability) (**Table 1**) [3]. In the Yowi field, the boxcar shaped gamma-ray log occurred in all the wells with average thickness of 58 ft. in well A2P2 between the intervals of 3357–3412 ft., 5286–5344 ft., 5750–5813 ft., 6047–6110 ft. and 6848–6903 ft. Carbonaceous matter, mica and glauconitic materials are also present in the successions (**Table 1**). The presence of glauconite depicts a marine environment, whereas mica and carbonaceous detritus showed that the sediments were deposited within the shallow marine/coastal realm.

3.2. Depositional environments

Sedimentary deposits identified using well log motifs helped in reconstructing sediments that were deposited within the open sea and reworked to confer the various architecture and

Reservoir interval	Core description	Remarks
5018–5021	Sandstone: Light to medium brown, friable, clear, translucent, light brown, quartz grains, very fine, slightly silty, sub rounded to rounded, well sorted, glauconitic, carbonaceous speckles, micaceous, good porosity and permeability. Oil Shows: Very light brown oil stain, very dull yellow fluorescence, weak diffuse white cut fluorescence, no residue, faint Hydrocarbon odor.	A regressive bar
5027–5033	Silty Sandstone: Light to medium gray, friable, clear, translucent, Lower part of opaque, quartz grains, very fine, silty in part, with thin Siltstone laminae, sub rounded to rounded, well sorted, micaceous, glauconitic, carbonaceous speckles, traces of pyrite, moderate to good porosity and permeability. Oil Shows: Very light brown oil stain, moderate yellow white fluorescence, slow streaming to weak diffuse white cut fluorescence, no residue, faint hydrocarbon odor.	Lower part of a regressive bar
5042–5045 Well A2P2, N5.2 sand	Sandstone: Medium to dark brown oil saturated sandstone, clear, translucent, medium brown, friable to loose quartz grains, very fine to fine, predominantly very fine, sub rounded to rounded, very well sorted, excellent porosity and permeability, micaceous, trace glauconite, trace carbonaceous speckles. Oil Shows: Medium brown oil stain, intense bright yellow fluorescence, instant blooming milky white cut fluorescence, light brown residue. Very strong hydrocarbon odor.	Top of 5.2 sand, a regressive bar

Table 1. Ditch-cutting description of rock samples [3].

configurations of the deposits [3, 17]. Well log correlation revealed sand bodies displaying lateral continuity across the field (**Figures 12** and **13**). The Qua Iboe Shale (QIS) forms a key stratigraphic marker across the field that delimits the marine sediments from the continental deposits. The top and base of key sand units are used for correlation base on gamma ray trends (**Figure 12**). Each depositional stack (parasequence) is unique to guide sand body correlation thereby complementing the traditional lithostratigraphic correlation. High gamma ray (with a cut-off of 75 ^{0}API value and above) corresponding to the shale base line indicates shale lithology. In the sequence of the various major environments, there is swift transition from fluvial to marine. The fluvial section occurred at the top of the Qua Iboe Shale which demarcated the continental sediments from the marine section (**Figure 13**). The marginal marine segment comprises of the coastal plain sands, whereas delta front sandstones occurred within the shallow marine realm (**Figure 13**). The delta front sandstone is characterized by thicker, cleaner and more shale-free sandstones than the coastal plain sands (**Figure 13**).

From the perspective of facies models, layer-caked shore-parallel facies have been assumed to form homogenous, uniform reservoirs with high production capacities. Wave-influenced coastline

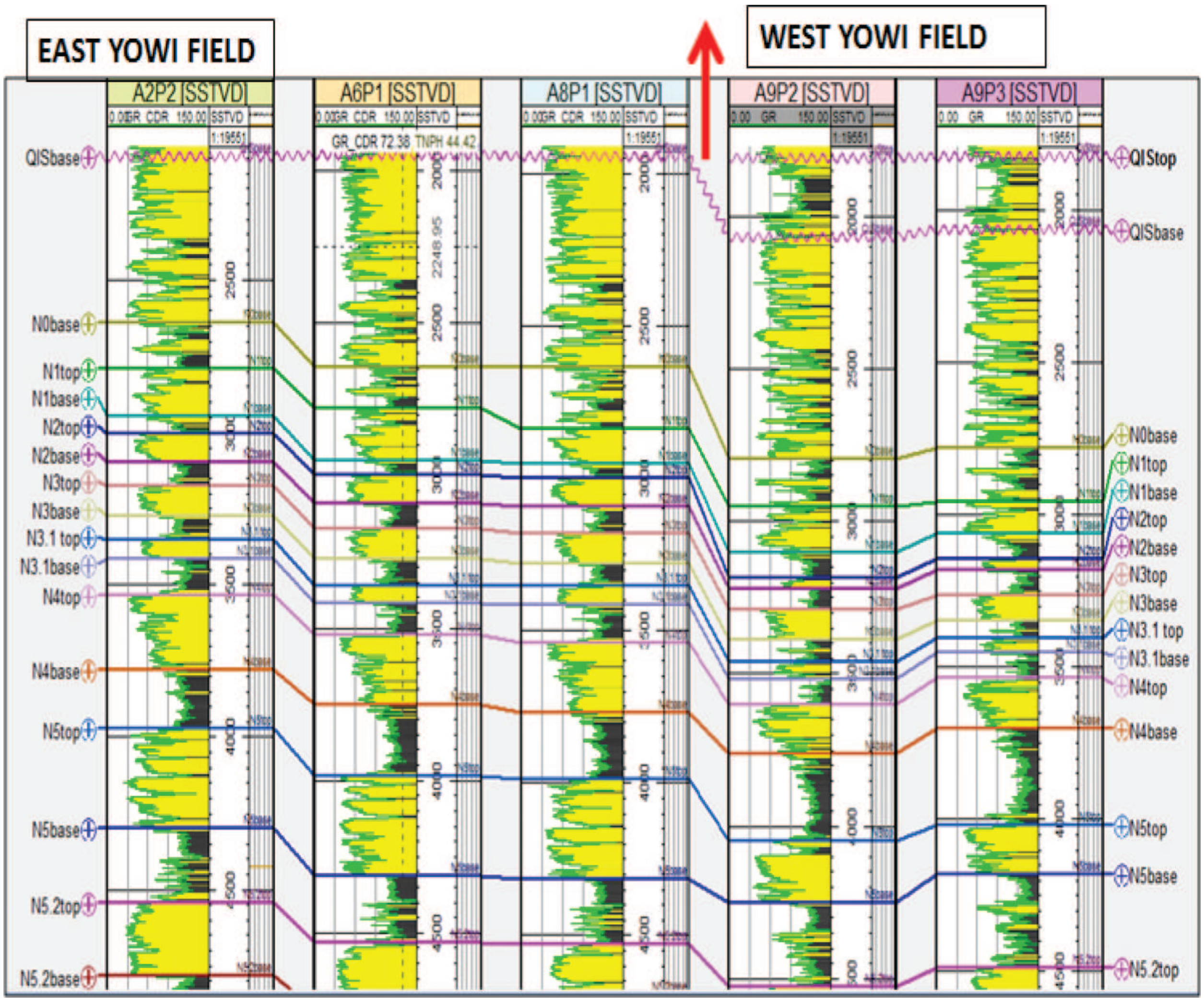

Figure 12. E-W Litho-correlation of key sand bodies across the field.

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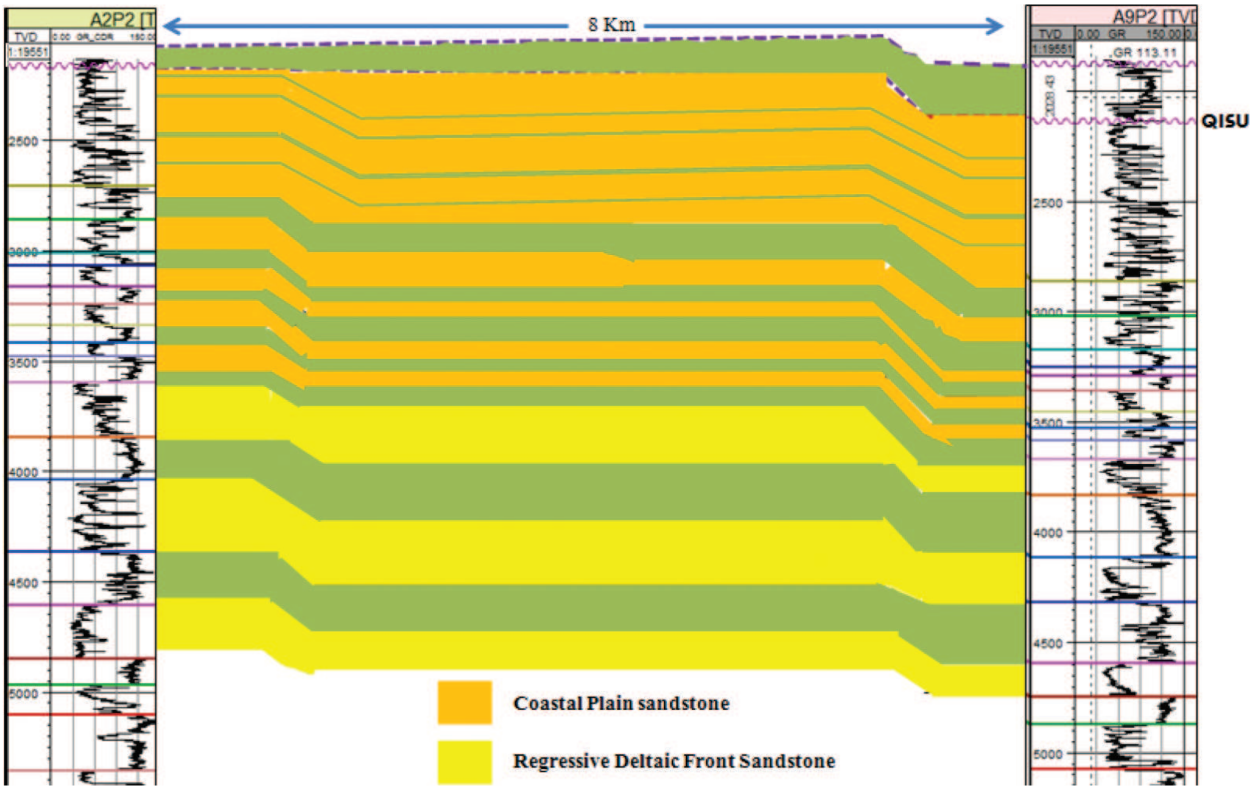

Figure 13. E-W correlation showing increasing shale thickness towards the west (A9P2) and increasing thickness of coastal plain/deltaic front sandstones towards the east.

deposits possess distinct facies with homogenous beach and shoreface sands accumulating on the updrift side of the river mouth with significantly more heterogeneous facies on the downdrift side. The heterogeneous unit is noticed towards the lower parts of the reservoirs (N4, N5, and N5.2) in wells A2P2 and A9P2 (**Figure 9**). The thick shale segments within each sequence are interpreted to be shelf or deep marine deposits.

3.2.1. Fluvial sediments

The well log signature of the continental fluvial environment of the Benin sand shows a jagged log motif, a typical characteristic of siliciclastic fluvial environment [3]. It occurred above the top of Qua Iboe Shale Member (QISM) at 1850 ft. (**Figure 13**) [3]. Different subenvironments that occurred within the Benin Formation include; braided stream, channel fills, flood plain, meandering channels, point-bar, etc. [3]. For example, sand beds that indicate meandering channel system consist of an alternation of fining-upward (**Figure 11**), channel fills and mud dominated floodplain deposits [3]. Braided fluvial systems are often composed of amalgamated channel fills, which confer a blocky pattern to the well logs [3]. In contrast, other types of rivers, including fine grained meandering or flashy ephemeral, produce a more irregular, jagged type of motif on well logs (**Figure 11**, number 1) [3]. Relatively thin-bedded (±m scale) coarsening-upward sand units may also occur in fluvial successions relative to crevasse splays in a low-energy and confined meandering system [3, 18]. The ditch cutting description for the sandy section shows sand dominated by Quartz grains (**Table 1**) after [3].

3.2.2. Deltaic and shallow marine sediments

The deltaic front environment is highly unstable due to the variety of processes operating within this realm. A combination of marine and fluvial influences account for the depositional styles within the marginal marine. Studies on modern sedimentary environments revealed that vertical profiles of grain size from a specific environment have certain log characteristics [3, 11]. Hence, prograding deltas and barrier bar deposits have coarsening upward grain size trends (**Figure 12**, number 4) [3, 19]. Gamma ray motifs with a bell-shape reflects a gradual vertical transition from shale to sandstone, whereas an upward increase in sand-size is indicative of a gradual change in the energy level of the depositional milieu, and no unique SP-curve pattern is representative of any specific depositional environment [12]. However, when these patterns are integrated with the presence or absence of glauconite and/or carbonaceous detritus from cuttings, a more meaningful and reliable interpretation emerges [20]. The presence of glauconite is observed in ditch-cutting samples from studied wells in the field at about 1800 ft., which is the base of Benin Formation and the beginning of the marine sequence. The highest occurrence of glauconite is reported at 2005 ft. It has been consistently recorded from the uppermost part of the Agbada sand sequence down hole, signifying a more marine influence than fluvial or deltaic. The associated environments based on log shapes and the presence of glauconite within this interval in the study area include [3]; beach, barrier foot, offshore/regressive bars, and shoreface deposits.

4. Conclusions

The Cretaecous exposure in Afikpo Basin South Eastern Nigeria comprises of sediments of fluvial, deltaic and marine origin. Ancient fluvial deposits in the area contains both braided stream and point bar channel sedimentary units. These deposits are also observed in the recent fluvial process that is continuously transporting sediments from the highland into the open sea in the offshore of the eastern Niger Delta through the Afikpo-Cross River. This has significant implications for paleo-environmental reconstruction of the subsurface formations of the Niger Delta. Subsurface data from an offshore field south of Calabar Town revealed the architecture of sediments probably of fluvial, deltaic and marine origin.

The overall stacking pattern of these sedimentary units as reconstructed from gamma ray log within the Agbada section shows a coarsening upward succession. This is typical of a deltaic and shallow marine depositional setting. Within the Agbada sequence in the field, stacked regressive sand occurred between 2000 and 3300 ft., and may indicate rapid sedimentation and progradation on adjacent shelf (**Figure 9**). This interval contains stacked highstand parasequence sets. The generalized subsurface depositional model for this field will show different environments affected by variety of processes ranging from wave action, long shore currents, tidal action and fluvial process, [3]. These sediments were derived from the continent and deposited within the shallow marine environment through distributary channels. The sediments upon arrival within the shores are reworked by wave action to form beach ridges/dunes [3]. Longshore currents reworked the sediments into longitudinal bars [3] running parallel to coastline. Subaqueous migration of regressive sands forms the offshore bars. Most of the log facies units displaying erratic/fining upward motifs are representatives of tidal events. The ancient and recent sediments identified in the area form the major sources of sand used for construction purposes. Some essential minerals are also concentrated in these sedimentary units. In the subsurface, the sediments form reservoirs for hydrocarbon accumulation.

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Conflict of interest

The author declares that no conflict of interest exists.

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References

[1] Petters SW. An ancient submarine canyon in the Oligocene-Miocene of the western Niger Delta. Sedimentology. 1984;**31**:805-810. DOI: 10.1111/j.1365-3091. 1984.tb00887

[2] Momta PS, Essien NU. The geology and structural evolution of the Aningeje Metasediment in the lower part of the Oban massif, SE Nigeria. Journal of Geography, Environment and Earth Science International. 2015, 2016;**4**(1):1-16. DOI: 10.9734/JGEESI/2016/19888 ISSN: 2454-7352

[3] Momta PS, Odigi MI. Reconstruction of the depositional setting of Tortonian sediments in the Yowi field, shallow offshore Niger Delta, using Wireline logs. American Journal of Geoscience. 2015, Science Publication (under review)

[4] Short KC, Stauble AJ. Outline geology of the Niger Delta. American Association of Petroleum Geologists Bulletin. 1967;**51**:761-779

[5] Reijers TJA, Petters SW, Nwajide CS. The Niger Delta Basin. In: Selley RC, editor. African Basins. Sedimentary Basins of the World. Vol. 3. Amsterdam: Elsevier; 1997. pp. 145-168

[6] Allen JRL. Sediments of the modern Niger Delta: A summary and review. In: Morgan JR, Shaver RH, editors. Deltaic Sedimentation. Soc. Econ. Paleontologists and Mineralogists, Spec. Publ.15, Tulsa, Okla. 1970. pp. 138-151

[7] Evamy DDJ, Haremboure P, Kamerling WA, Knaap F, Molloy A, Rowlands MH. Hydrocarbon habitat of the tertiary Niger Delta. American Association of Petroleum Geologists Bulletin. 1978;**62**:1-39

[8] Ejedawe JE. Patterns of incidence of oil reserves in Niger Delta basin. American Association of Petroleum Geologists Bulletin. 1981;**65**:1574-1585

[9] Doust H, Omatsola E (1990). Niger Delta. In: Edwards JD, Santogrossi PA (Eds.), Divergent/Passive Margin Basins American Association of Petroleum Geologists Memoir, vol. 48, pp. 201-238

[10] Reijers TJA. Stratigraphy and sedimentology of the Niger Delta. Geologos. 2011;**17**(3): 133-162

[11] Selley RC. Elements of Petroleum Geology. New York: W. H. Freeman and Company; 1985. p. 448

[12] Amajor LC, Agbaire DW. Depositional history of the reservoir sandstones, Akpor and Apara oilfields, eastern Niger Delta, Nigeria. Journal of Petroleum Geology. October 1989; **12**(4):453-464

[13] Chow JJ, Ming-Chung L, Fuh SC. Geophysical well log study on the Paleoenvironment of the hydrocarbon producing zones in the Erchungchi formation, Hsinyin, SW Taiwan. TAO. 2005, August 2005;**16**(3):531-545

[14] Asquith GB, Gibson CR. Basic well log analysis for geologists: AAPG, Methods in Exploration Series No. 3; 1982. 216 p

[15] Selley RC. Elements of Petroleum Geology. Imperial College, London United Kingdom: Department of Geology; 1998. pp. 37-145

[16] Nelson CS, James NP. Marine cements in mid-tertiary cool-water shelf limestones of New Zealand and southern Australia. Sedimentology. 2000;**47**:609-629

[17] Momta PS, Odigi MI. Geobody architecture and petroleum potential of the Yowi field, offshore eastern Niger Delta, Nigeria. American Journal of Geosciences. 2015. DOI: 10.3844/ajgsp2015

[18] Catuneanu, O. (2006). Principles of sequence stratigraphy. Elsevier, the Netherlands: pp. 89-159

[19] Momta PS, Omoboh JO, Odigi MI. Sedimentology and depositional environment of D2 sand in part of greater Ughelli Depobelt, onshore Niger Delta, Nigeria. American Journal of Engineering and Applied Sciences. 2015;**8**(4). DOI: 10.3844/ajeassp.2015.556.566

[20] Selley RC. Concept and methods of subsurface facies analysis Cont. Edu. Course; 1978

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