FACIES ARCHITECTURE AND RESERVOIR PROPERTIES ESTIMATION OF THE CAMPANIAN-MAASTRICHTIAN DEPOSITS IN ITUKU-OZALLA AREA, ANAMBRA BASIN, SOUTH-EASTERN NIGERIA.

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ABSTRACT

Facies architecture and reservoir studies were carried out using outcrop data from the Campanian-Maastrichtian succession in the Anambra Basin, south-eastern Nigeria. This research is aimed at identifying key depositional elements and their reservoir potential that will give insight into the geometry, continuity and lateral/vertical distribution of the sandstone bodies, as well as the reservoir qualities of the strata. Four (4) architectural elements identified include; (i) isolated and amalgamated channel (ii) sandy cross-stratified (iii) floodplain and (iv) heterolithic elements. Reservoir assessment of the sandstone shows permeability ranges from 7,925 to 160,793 mD while granular parameter ranges between 10.43 to 211.57 mm^2. The strata were not altered by intense diagenesis, so they gave a quantitative reservoir quality prediction. Studies suggest that net-to-gross varies considerably across the depositional facies ranging from moderately good to excellent (61 to 100%). In tidal channel deposits, the heterogeneities occur as mud drapes and mud laminae which act as baffles and barriers. The shales of the Nkporo Group and Mamu Formation act as potential source rocks while the Owelli Formation of the Nkporo Group acts as potential reservoir rock for the accumulation of hydrocarbon in the Anambra Basin.

Keywords: Depositional elements, heterogeneities, Net-to-Gross, Owelli Formation, permeability.
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INTRODUCTION

A well-exposed Campanian-Maastrichtian depositional system in south-eastern Nigeria provides analogue to sandstone and mudstones/shales of subsurface units that could be a potential reservoir and stratigraphic seals. The Owelli Formation (Campanian to Maastrichtian) have been interpreted as tidally influenced deposit in the study area while the exposed Mamu Formation (Maastrichtian) in the study area consists of swamp/floodplain deposit [1]. In Nigeria, numerous works are documented on reservoir studies of the Niger Delta [2-4] due to its hydrocarbon potential, however, there has been a new-fangled drive for hydrocarbon exploration in the inland basins of Nigeria [5-6].

The study covers parts of the Owelli and Mamu formations in the Anambra Basin. According to Mode [7], the prospective reservoirs of this basin include the Owelli sandstone (Campanian-Maastrichtian) and the Mamu sandstone (Maastrichtian). The Anambra Basin is considered as a petroliferous basin having all of the basic elements of a petroleum system [8-10], but the reservoir heterogeneity of the Campanian-Maastrichtian reservoirs is yet to be documented.

This paper aims to; i. investigates the sedimentological characteristics of Campanian-Maastrichtian deposits in Ituku-Ozalla region ii. Investigate petrophysical properties (such as permeability), and iii. Establish a relationship between the sandstones sedimentological and petrophysical properties. The reservoir characterization helps to understand the geometry, continuity and lateral/vertical distribution of siliciclastic sediments belonging to the Owelli Formation in the area of interest.

Regional geology

The megatectonic setting in the southern domain of the Benue Trough was a longitudinally faulted crust whose eastern half subsided preferentially to become the Southern Benue Trough [11]. The predominant depocentre in the Southern Benue Trough (Abakaliki area), after the Santonian folding and uplift became flexurally inverted, moving the depocentre to the west and northwest, the rate of the westward migration of the depoaxis was of the order of 10 km/My or 1 cm/year, and gradually affected the tectonic inversion between the Abakaliki region and the Anambra Basin leading to the existence of the Anambra Basin [12].

The lithostratigraphy of the Anambra Basin commenced with the Campanian-Maastrichtian depositional cycle of the Nkporo Group, Mamu Formation, Ajali Formation and Nsukka Formation in both the Afikpo Syncline and Anambra Basin (Figure 1). The Nkporo Group which includes the Nkporo Formation and its lateral equivalents- the Enugu and the Owelli formations, were deposited during the Campanian, the last of which were deposited during the early Maastrichtian. The Owelli Formation was interpreted as a fluvial sandstone succession, formed from the short rivers that flowed unto the shelf area [12]. From its stratigraphic position, the age is inferred to be Campanian to Maastrichtian [12]. The Enugu Formation consists of shale with fairly well-defined fissility and contains black carbonaceous shales which contain abundant plant debris deposited in a coastal swamp environment but there are two distinguishable sandstone bodies – the Otobi and the Okpaya Sandstones [12].

METHODOLOGY AND DATA SET

Twenty-nine outcrop sections (Figure 2) were logged in detail out of which data from four representative outcrop sections A – D each trending NE (updip) – SE (downdip), was used for sedimentological (grain size and sorting) and reservoir petrophysical (permeability) analyses. The unconsolidated reservoir sandstones were subjected to granulometric analyses using standard ASTM sieve mesh sizes 0.5 phi apart on a Ro-tap shaker to determine mean grain size distribution, sorting, skewness and kurtosis. Sieve data plotted on semi-log sheet were used to determine the 50th percentile or median diameter (d_{50}) and sorting (Table 1). Using empirical formula proposed by Krumbein and Monk [13] for calculation of permeability of reservoir intervals with formula:

$K = C_o d^2_m \, e^{-1.31\,\sigma ø}$, ………………………………… (i)

Where, K = permeability (millidarcies),

C_o = an empirical constant (760 darcies/mm^2)

D_m =median diameter (mm), $\sigma ø$ = sorting (in phi standard deviation).

The Granular Parameter gives a measure of the acceptability of the rock as a reservoir bed before any diagenetic change. The formula is given as:

$G = d_m^2 \, e^{-1.31\,\sigma ø}$ (1000 mm^2), ………………………(ii)

Where, G = granular parameter,

D_m = median diameter (mm), $\sigma ø$ = sorting (phi units).

Kriesa *et al.* [14] suggested that evaluation of permeability for reservoir units can be done using empirical formula since a general relationship between permeability and porosity in sandstones remains acceptable.

Detailed geological mapping and sedimentological description were carried out in the study area. Results from the outcrop description were used for identification of depositional architectural elements. For the purpose of reservoir development, bed-length and thickness statistics were individually and collectively compared for each architecture type. Based on net-to-gross distribution, the shale-bed and sand-bed thicknesses from the logged sections were used to characterize the reservoir units. The only challenge is that most of the outcrops in the study area were poorly exposed.

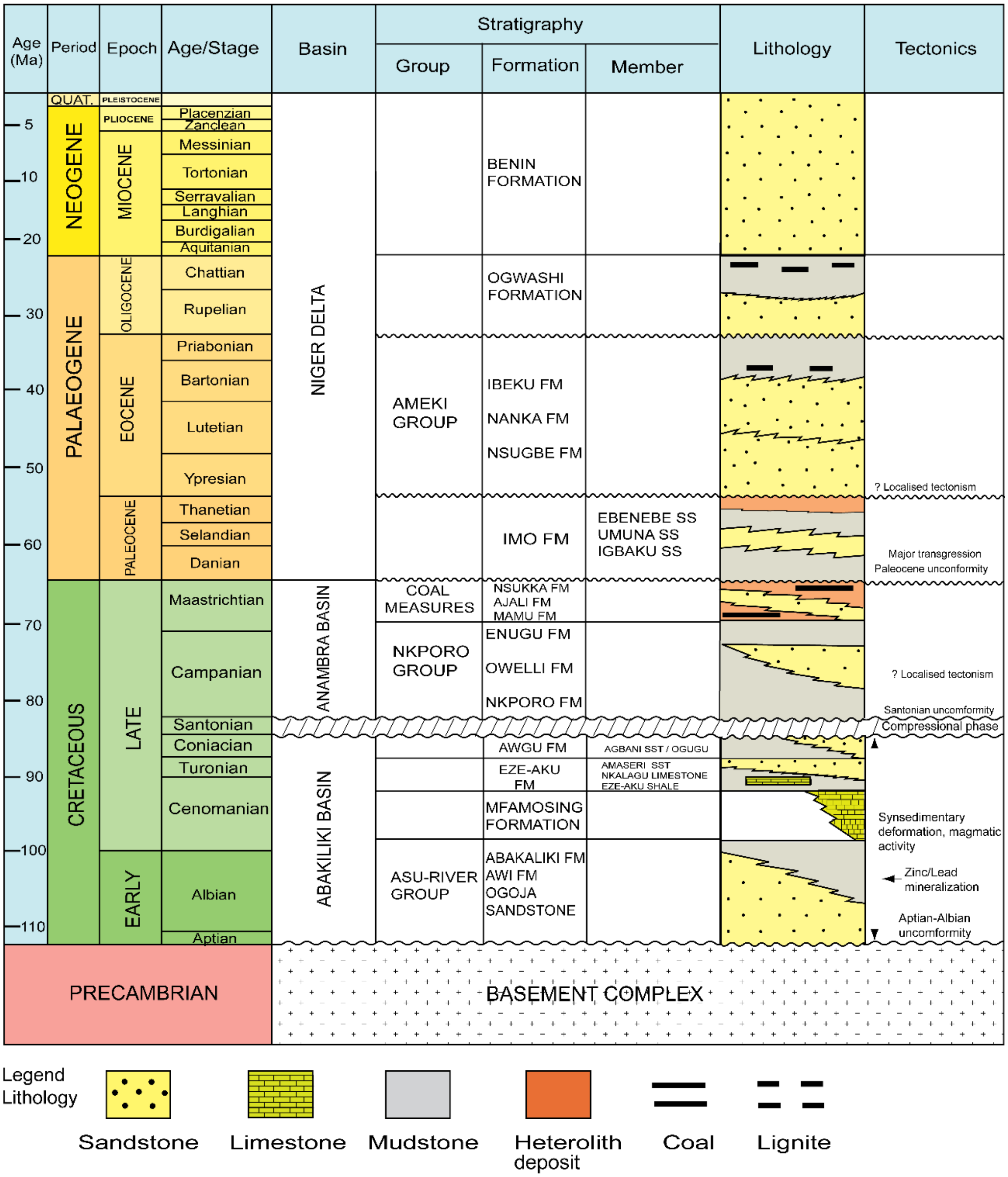
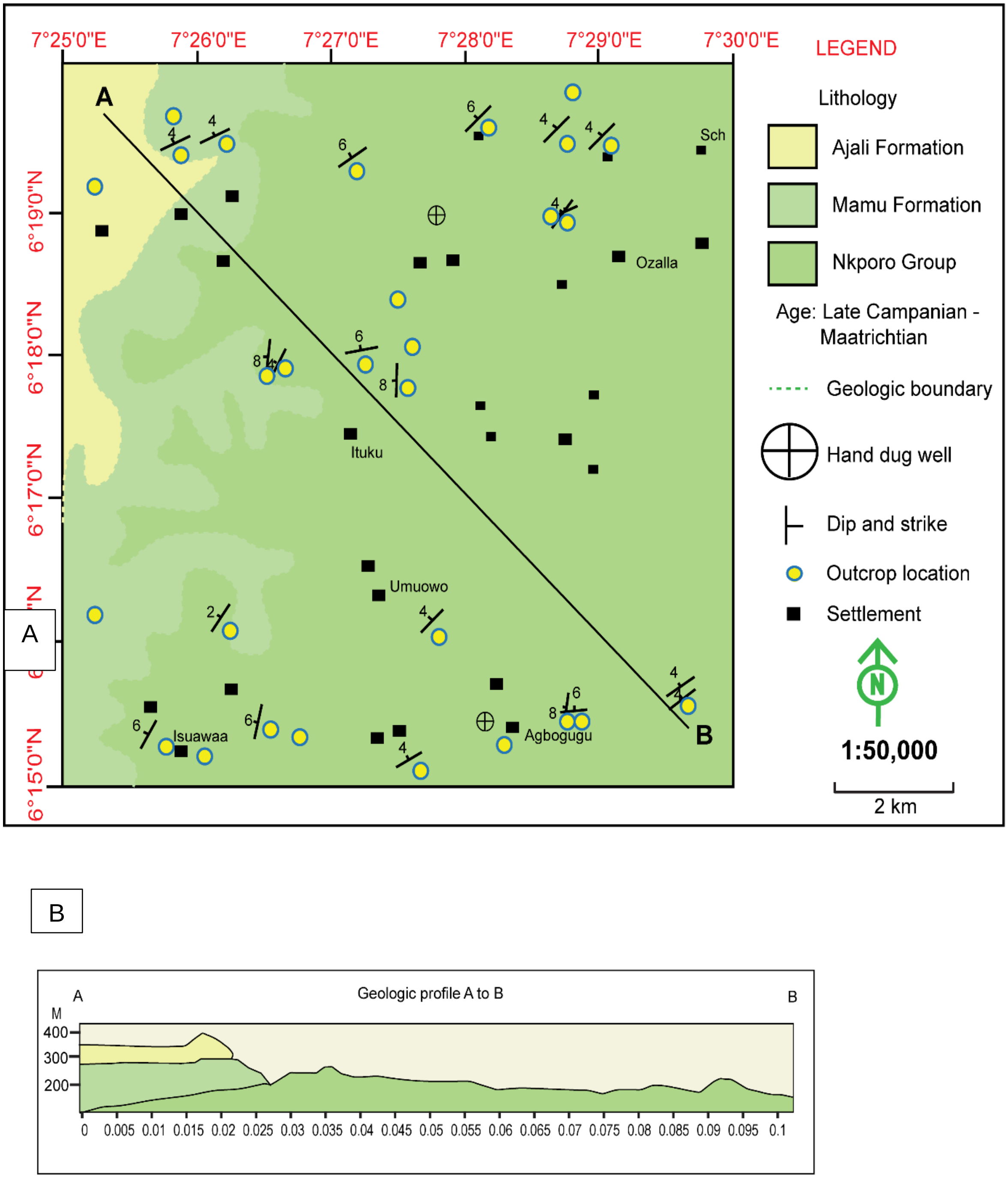


Figure 1: Stratigraphic succession in the Anambra Basin and Niger Delta (redrawn and modified after Nwajide [15], Ekwenye *et al.* [16].


A
7°25'0"E
7°26'0"E
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7°28'0"E
7°29'0"E
7°30'0"E
6°19'0"N
6°18'0"N
6°17'0"N
6°15'0"N
A
B
Sch
Ozalla
Ituku
Umuowo
Isuawaa
Agbogugu
LEGEND
Lithology
Ajali Formation
Mamu Formation
Nkporo Group
Age: Late Campanian - Maatrichtian
Geologic boundary
Hand dug well
Dip and strike
Outcrop location
Settlement
N
1:50,000
2 km
B
Geologic profile A to B
A
B
M
400
300
200
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
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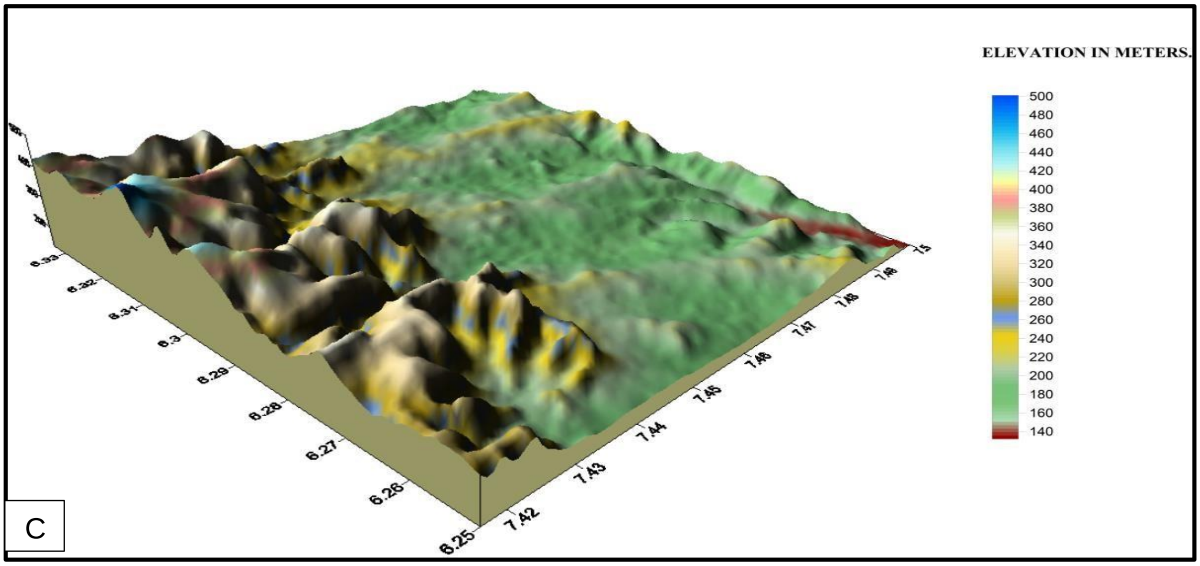


Figure 2: (A) Geologic map of the study area showing the outcrop locations. (B) Geologic profile (A-B) of the study area showing the distribution of the studied formations. (C). Elevation map showing the study area and environs.

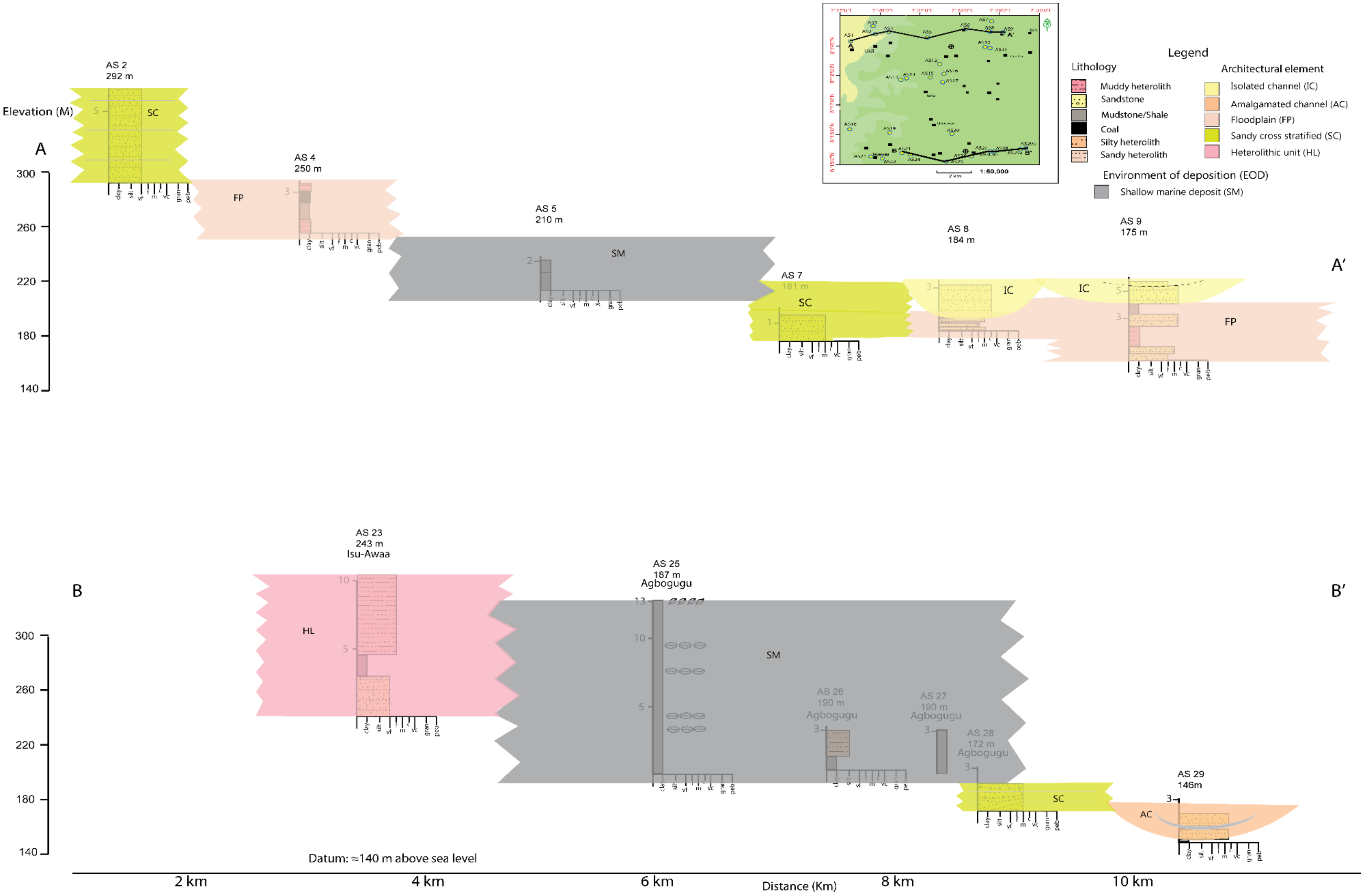


Figure 3: The architectural elements (Fig. 3) are identified in the study area showing lateral and vertical facies changes.

RESULT AND INTERPRETATION

Facies architecture

Four (4) architectural elements (Figure 3) are identified in the Campanian-Maastrichtian deposits based on their sediment textures, sedimentary structures, geometry and lateral and vertical arrangement of lithofacies and juxtaposition with other lithofacies [17].

Channel deposits

Isolated channels in Agbogugu is associated with tidal channel environment. It occurs as a simple, single-storey sandstone body and contains no internal scour surfaces (Figure 3). It is characterised by low angle (8^o) large scale planar cross-beds, having a tabular geometry with a thickness of 1.6 m. The characteristics of these single-story channelized sandstone bodies imply an asymmetric fill of a single episode of sedimentation whereby the channel was blocked by sand transported during relatively high stage flow and there was lateral migration of the channel [18-19]. The channel deposit in Akaegbe-Ugwu (SA 8) is characterized by planar cross-laminations and having sharp boundaries with mudstone (0.8 to 1.4 m thick) that has desiccation cracks, the sandstone is 22 cm to 1.64 m thick. This element records slow sedimentation within largely inactive channels as fill deposits [20]. Soft sediment structures occur just after deposition usually in places where water is flowing and carrying a lot of sediment. This structure forms where the sediment is either deposited on a slight slope or where there is a shear stress on the material due to flow of overlying fluid [21].

Amalgamated channels are found in tidally influenced fluvial channel deposits. They occur as multi-channel sandstone units characterised by scour and fill structures Individual sand-bodies vary in thickness from 33.2 to 99 cm (Figure 4a). The multi-storey sandstone bodies are composed of stacked sets of epsilon cross-beds, arranged into fining-upward packages and characterised by planar cross-beds at AS 29. Other common structures are ripple laminations with mud drapes, small-scale trough cross-beds and sparsely burrowed with *Skolithos* ichnofacies. The ripple lamination may be attributed to the downcurrent migration of straight and sinuous trains of asymmetrical ripples under controlled conditions of sediment supply in a lower flow regime of low intensity [22]. The impoverished *Skolithos* ichnofacies are dwelling structure of suspension feeders, which indicates high-energy condition in a stress brackish-water condition [23]. Mud drapes on cross-laminations are deposited during slack water conditions in response to semi-diurnal tidal fluctuation [24].

Sandy cross-stratified deposits

The sandy cross-stratified deposits are characterised by cosets of trough-cross beds (Sbt) that are stacked on each other as observed in AS 28 and amalgamated hummocky and swaley cross stratified sandstone as observed in AS 7 and 8. The trough cross-bed deposits are characteristically coarse-grained whereas the hummocky cross-bed deposits are dominantly fine to medium grained and well sorted sandstones. The thickness of the sandy cross-bedded element is about 1.7- 3 m having a sheet-like to lobe geometry. These elements represent the migration of dune-scale bedforms on middle-upper estuarine environments for the tidal deposits and storm-dominated bayhead delta for the hummocky cross-stratified deposit. Halfar *et al.* [25] suggested that when the scale of the cross-bedded sets reduce in a downstream direction, there is a possibility of downstream changes from dune- to ripple-scale bedforms, likely indicates a local decrease in transport energy and channel depth. The trough cross-bedded sandstone unit is moderately burrowed, with the presence of vertical shafts of *Ophiomorpha nodosa* (Figure 4b), which is associated with higher energy environments [26].

Floodplain elements

The floodplain is associated with multi-channel structureless sandstone is characterized by 1.5 to 3.5 m thick successions of very fine-grained and well sorted (white) sandstone (Figure 4c). These elements can be traced laterally for distances in excess of 1000 m. The overall geometry of these elements is tabular. The floodplain is fine grained, variegated in colour with grey mudstone. According to Mrinjek *et al.* [27] fine grain size, extensive nature and tabular geometry of these elements indicates deposition over a wide area that was distal to the main channel. The thick, tabular geometry, the reddish-brown colour may indicate deposition in a semi-arid, oxidizing environment or tropical condition. The absence of carbonaceous root material indicates the occurrence of oxidizing near-surface conditions [19].

Heterolithic units

The heterolithic units are tabular or sheet geometry, the internal architecture consists of thin (7 cm to 80 cm thick) continuous sheets of medium to coarse-grained sandstone alternating with cm-scale continuous lenses of shale, which stack vertically to produce a maximum of about 2.3 m thickness heterolithic units. Basal and upper bounding surfaces are sharp and gradational. The intercalation of cm-scale medium to coarse-grained sandstone with cm-scale mudstone is interpreted as a cyclic accumulation of vertical sediment, referred to as tidal rhythmites [28] which are typical of an intertidal flat environment.

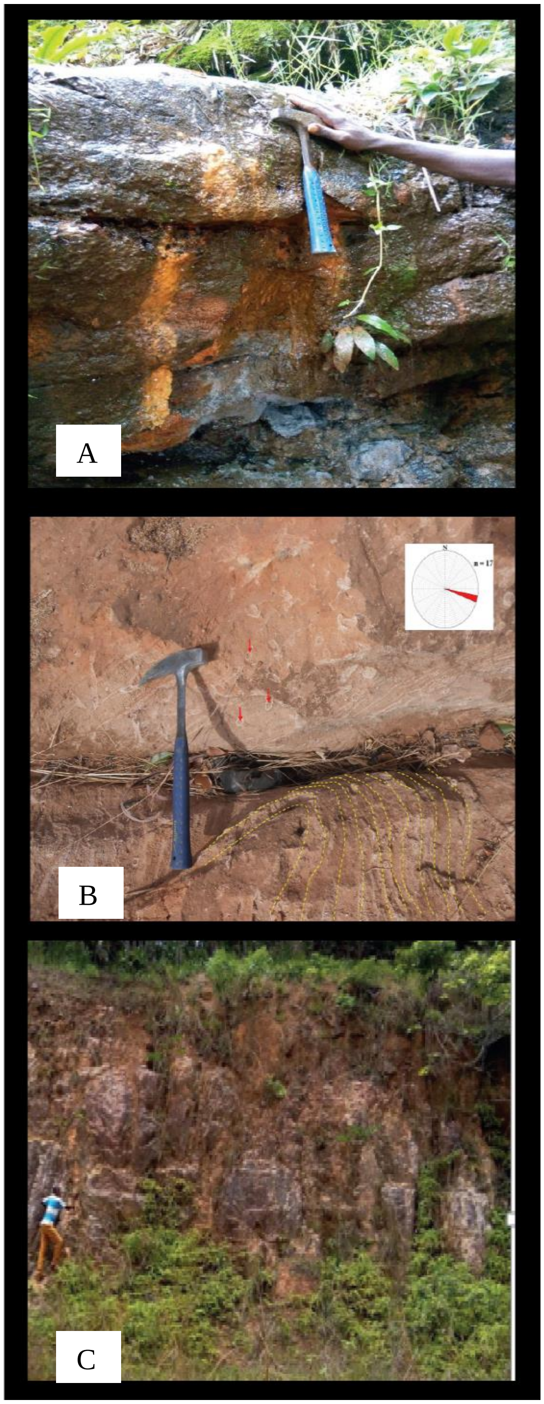


Figure 4: Selected outcrop photographs of some architectural elements. A. Close up view of multi-channel sandstone with erosive based and sole mark at the base of a channel set and organic debris B. Burrowed mud-draped trough cross-bedded sandstone (St) with mud-filled *Ophiomorpha* burrows (red arrows) at Agbogugu. C. Variegated fine-grained sandstone that depict floodplain occurs in associated with multi-channel structureless sandstone.

RESERVOIR ASSESSMENT OF THE STUDY AREA

Permeability*:* The permeability data obtained from the study area, using empirical formula is showed in table 1. The average permeability values are 62,209 mD with lowest recorded value of 7295 mD and highest value of 160,793 mD. According to Levorsen [29] and Shepherd [30], oil fields with permeability's 1000 mD plus are exceptional reservoirs. For recently deposited unconsolidated petroleum reservoirs at low confining pressures, permeability is determined using the formula formulated [13]; statistical correlations of sedimentological data (grain size and sorting) and reservoir-engineering data (permeability) relating permeability to lithology and compaction [31].

Table 1: Textural data and reservoir parameters of selected sandstone units in the study area obtained by the use of empirical formula (after Krumbien and Monk [13]; Hsu [31]).

SAMPLE	MEDIAN SIZE (d_{50})	SORTING $(\sigma\emptyset)$	GRANULAR PARAMETER (mm^2)	PERMEABILITY (mD)
AS 28-29/1	0.87	0.97	211.57	160,793
AS 28-29/3	0.76	0.95	164.81	125,257
AS 28-29/6	0.66	0.81	150.05	114,036
AS 28-29/8	0.62	1.10	89.57	68,075
AS 28-29/9	0.78	0.99	165.53	125,805
AS 8/1	0.33	0.87	34.77	26,423
AS 8/2	0.33	0.88	34.45	26,182
AS 7/1	0.35	0.98	34.76	26,417
AS 7/3	0.18	0.66	13.25	10,070
AS 7/5	0.16	0.73	10.43	7,925
AS 7/7	0.5	0.66	105.31	80,032
AS 9/2	0.15	0.44	13.31	10,114
AS 9/4	0.33	0.84	36.30	27,590

Mode [32] pointed out that the empirical formula was used for assessing the permeability of recently deposited sediments at low confining pressures. Based on this study the values are comparatively high when measured up to most reservoirs, which occur at relatively high overburden and confining pressures (Figure 5). Therefore, effective porosity could not be calculated as proposed by Wu and Berg, [33], which was applied to Middle Jurassic Brent Group sandstones from the Norwegian sector of the North Sea. From the data set above permeability is dependent on median size and independent of sorting.

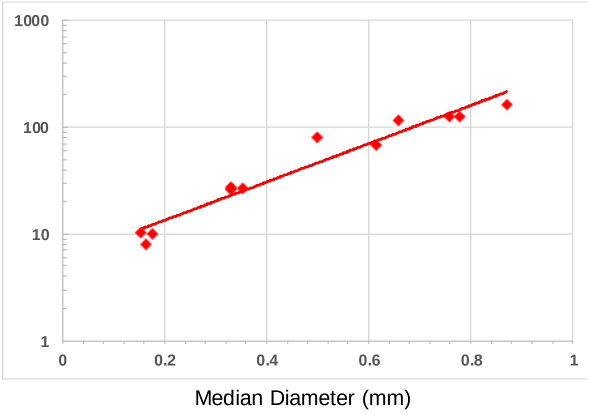


Figure 5: Cross-plot showing permeability vs median diameter.

Reservoir heterogeneity

Reynolds *et al.* [34] suggested that heterogeneities in reservoir properties are caused by permeability changes that affect local sweep efficiency. In the study area, the reservoir heterogeneities are controlled by bedding, facies change and bioturbation. Two types of heterogeneities were noted in this study as proposed by Mode and Obi [35]. Megascale Heterogeneities (1 - >10 m): Lateral or vertical facies changes are its major control accompanied by the juxtaposition of facies with different permeability. Figure 3 shows clear lateral changes in facies from channelized sandstone to bayhead delta and mudstone facies as well as vertical changes in facies from tidal flats to tidal channels. Mesoscale Heterogeneities (5 cm – 2 m): Bedding units, mud drapes, mud lamina are examples of heterogeneities at this scale, as observed during field studies and detailed lithologic description and interpretation of outcrops (Figure 4).

DISCUSSION

The architectural elements encountered were delineated to project the reservoir geometries and continuity as well their spatial distribution. These advanced sedimentological tools along with the statistical parameters were employed to access the reservoir potential of the study area.

Reservoir potential

The reservoir potential in the study area are arranged into two major facies /architectural elements. They include the amalgamated channel intervals that are less than 1 m as well as sandy cross-stratified deposits with high net-to-gross (98 –100%) and the heterolithic element which has its internal architecture consisting of thin (7 cm to 80 cm thick) continuous sheets of medium to coarse-grained sandstone alternating with cm-scale continuous lenses of shale. The heterolithic elements are interpreted as mixed flat of intertidal flat with average to relatively high net-to-gross (77 – 100%). Reservoir studies across the area show that net-to-gross is moderately good to excellent, varying from 61 to 100%

(0.61 – 1.00). There is an increase of net-to-gross in the SE section and a corresponding decrease in the NE section of the study area (Figure 6-7). In the reservoir architectural element, the shale-bed thickness could appear as baffles and barriers leading to compartmentalization alongside the reduction in net-to-gross.

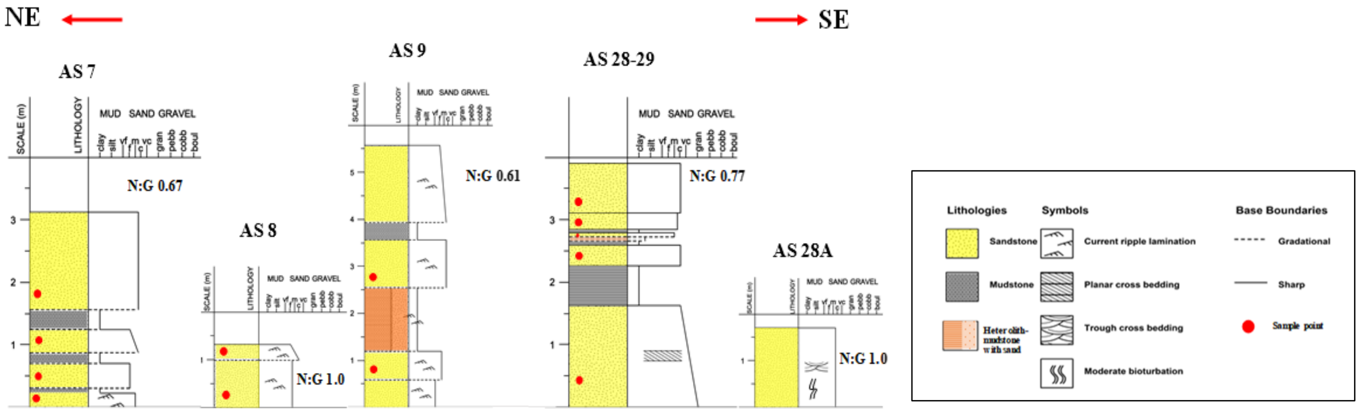
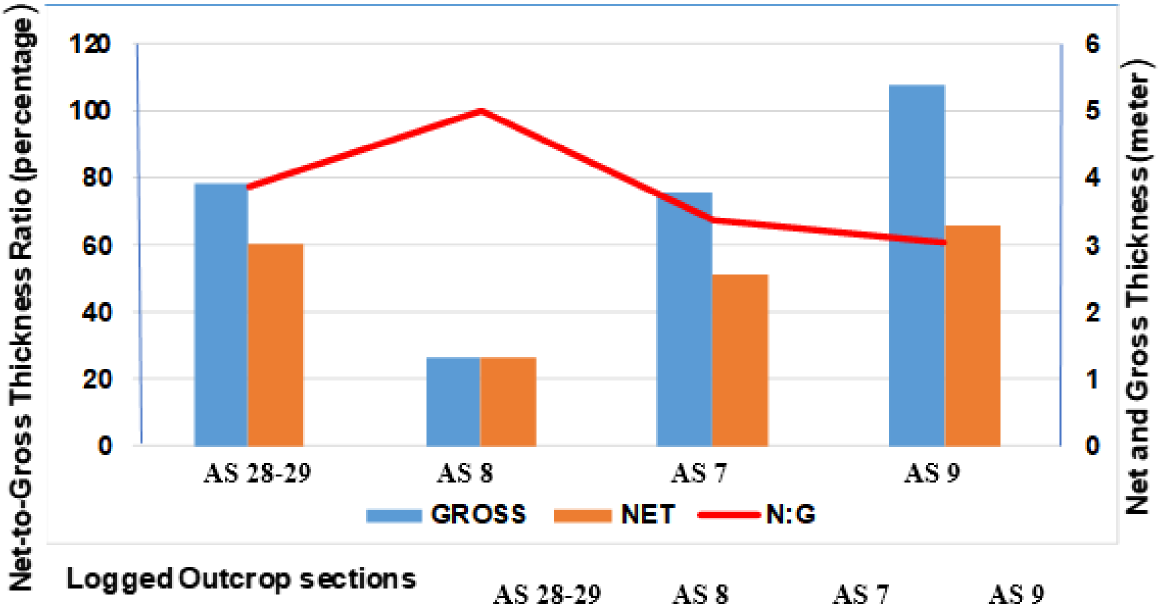


Figure 6: Representative section of outcrop across the study area (NE – SE), and their corresponding the Net-to Gross.



Logged Outcrop sections	AS 28-29	AS 8	AS 7	AS 9
🟦 Gross Thickness	3.91	1.32	3.78	5.38
🟧 Net Thickness	3.02	1.32	2.54	3.27
━ Net-to-Gross Thickness (%)	77	100	67	61

Figure 7: The distribution of net-to-gross thickness ratio in representative outcrop sections across the study area.

The reservoir potential is based on the description of the internal architecture of the sandstone bodies. The heterogeneities observed in the tidal channel are due to the varying amounts of mud present, occurring in the form of mud drapes and mud laminae. Low heterogeneity in the strata of amalgamated channels is due to lack of mud deposits. Taylor and Ritts [36] suggested that the thickness and amalgamation of the channels would produce vertically- and laterally-connected sandbody complexes, thus this would imply good connectivity and high lateral continuity and low vertical compartmentalization. The bulk of tidal channels consist of bedsets that are heterogeneous reservoir units, due to the presence of mud draped planar and trough cross-beds and hence may act as small scale permeability barriers or create flow baffles [36, 37]. The presence of mud-filled vertical trace fossils can act as baffles to fluid flow. Isolated channels bounded below and above by tidal mudflat deposits may result in poor lateral continuity and high vertical compartmentalization. Isolated channels are characterized by fine-grained infill, heterolithic units, and mud clasts which relates to poor vertical connectivity. The heterolithic beds consist of alternating sand-shale, these internal heterogeneities, therefore, would result in poor lateral continuity and high vertical compartmentalization. The alternation of sand-shale would act as flow barriers.

CONCLUSION

The sandstones are surface reservoir analogues of subsurface deposits. The geometry of the sandstone bodies varies from channels, both isolated channels enclosed in fine-grained flood plain deposits that portray stratigraphic traps, multistorey channels that indicate connectivity of reservoirs; extensive tabular and sheet-like forms which are potential reservoirs. Permeability values especially for these reservoirs have excellent correlation with median grain diameter but have poor correlation with the sediment sorting. For the estimation and prediction of reservoir heterogeneity, the median diameter of the sand grains is more dependable. Two major heterogeneities were observed: firstly, at the megascale, where major control was the juxtaposition of facies with different permeability, and secondly for mesoscale, where the reservoir heterogeneities were observed on lithofacies, bedding and lamina-scale variation. In terms of reservoir quality, the sand bodies of the Nkporo Group are medium-grained, well-moderately sorted, this relates to good porosity and permeability which could be of good reservoir quality as that will act as a potential reservoir system for the hydrocarbon that may be sourced within the basin.

REFERENCES

1. AGBAETUO, S.C. (2016). The Geology of Areas around Ituku-Ozalla, Anambra Basin South-eastern, Nigeria. Unpublished B.Sc. thesis. University of Nigeria, Nigeria; 167pp.
2. EVAMY, B.D., HAREMBOURE, J., KAMERLING, P., KNAAP, W.A., MOLLOY, F.A. & ROWLANDS, P.H. (1978). Hydrocarbon habitat of Tertiary Niger Delta. *American Association of Petroleum Geologists Bulletin*, **62**: 1–39.
3. DOUST, H. (1989). The Niger Delta: Hydrocarbon potential of a major Tertiary delta province, in coastal lowlands, geology and geotechnology, in Proceedings of the Kon. Nederl. Geol. Mijnb. Genootschap, p. 203-212.
4. TUTTLE, M.L.W., CHARPENTIER, R.R. & BROWNFIELD, M.E. (1999). The Niger delta petroleum system: Niger delta province, Nigeria, Cameroon, and Equatorial Guinea, Africa: USGS Open-file report 99-50-H.
5. NWACHUKWU, U.E.D., ANYIAM, O.A., EGBU, O.C. & OBI, I.S. (2010). Sedimentary controls on the reservoir properties of the Paleogene fluvio-tidal sands of the Anambra Basin, south-eastern Nigeria- implication for deep water reservoir studies. *American Journal of Scientific and Industrial Research,* **2**(1): 37 - 48.
6. ANYIAM, O.A., ONUOHA, K.M. & JOLLY, B.A. (2014). Hydrocarbon Generation Potentials of the Awgu Shale, Lower Benue Trough, Nigeria. *Journal of Geological Society India*, **83**(3): 303 - 310.
7. MODE, A.W., ANYIAM, O.A. & ANIGBOGU E.C. (2016). The Effect of Diagenesis on Reservoir Quality of Mamu Sandstone, Anambra Basin, Nigeria. *Journal Geological Society of India,* (**87**): 583 - 590.
8. AVBOVBO, A.A., & AYOOLA, E.O. (1981). Petroleum prospects of southern Nigeria's Anambra Basin. *Oil and Gas Journal*, **79**: 334 - 347.
9. OBAJE, N.G., WEHNER, H., SCHNEEDER, G., ABUBAKAR, M.B. & JAURO, A. (2004). Hydrocarbon prospectivity of Nigeria inland basins: from the view point of organic geochemistry and organic petrology. *American Association of Petroleum Geoscientists Bulletin,* **88**(3): 325 - 353.
10. AKANDE, S.O., LEWAN, M.D., EGENHOFF, S., ADEKEYE, O., OJO, O.J. & PETERHANSEL, A. (2015). Source rock potential of lignite and interbedded coaly shale of the Ogwashi-Asaba Formation, Anambra

Basin as determined by sequential hydrous pyrolysis. *International Journal of Coal Geology*, **150 – 151**: 224 - 237.

11. MURAT, R.C. (1972). Stratigraphy and paleogeography of the Cretaceous and lower Tertiary in Southern Nigeria. In: T.F.J., Dessauvagie, and A.J. Whiteman, (Eds.), African Geology. Ibadan University Press, Ibadan: pp. 251 – 266.
12. NWAJIDE, C.S. (2013). Geology of Nigeria's sedimentary basins. CSS Bookshops Ltd., Lagos; 518p.
13. KRUMBEIN, W.C. & MONK, G.D. (1942). Permeability as a function of the size parameters of unconsolidated sand. Petroleum Technology, **5**: 153 - 163.
14. KREISA, R.D., UNOMAH, G.I., JOINER, S.D., OLUWALE, Y.R. & LEININGER, S.C. (1999). Improved reservoir description and development through quantitative integration of core data. *Nigerian Association of Petroleum Explorationists Bulletin*, **14**(2): 1 - 17.
15. NWAJIDE, C.S. (2005). Anambra Basin of Nigeria: Synoptic basin analysis as a basis for evaluating its hydrocarbon prospectivity. In: C.O. Okogbue, (Ed.) Hydrocarbon potentials of the Anambra Basin: geology, geochemistry and geohistory perspectives. Proceedings of the 1st seminar organized by Petroleum Technology Development Fund Chair in Geology, University of Nigeria, Nsukka, pp.1-46.
16. EKWENYE, O.C., OKEKE, K.K., OTOSIGBO, G. & ONYEMESILI, O. (2020). A Re-evaluation of the Stratigraphic and Palaeogeographic Evolution of the Paleogene Sedimentary Successions of the Niger Delta. *Jordan Journal of Earth and Environmental Sciences*, **11**(2): 146-156.
17. MIALL, A.D. (1985). Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. *Earth Science Revolution*, **22**: 261 - 308.
18. FRIEND, P.F., SLATER, M.J. & WILLIAMS, R.C. (1979). Vertical and Lateral Building of River Sandstone bodies, Ebro Basin, Spain. *Journal of the Geological Society*, **136**(1): 39-46.
19. GHAZI, S. & MOUNTNEY, N.P. (2009). Facies and architectural element analysis of a meandering fluvial succession: The Permian Warchha Sandstone, Salt Range, Pakistan. *Sedimentary Geology*, **221**: 99 - 126.
20. MIALL, A.D. (1996). The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis, and Petroleum Geology. Springer-Verlag, New York; 582p.
21. LEEDER, M.R. (1999). Sedimentology and Sedimentary Basins: from Turbulence to Tectonics. Blackwell Science, Oxford.
22. ALLEN, J.R.L. (1963). The classification of cross-stratified units with notes on their origin. *Sedimentology*, **2**: 93 - 114.
23. BUATOIS, L.A., GINGRAS, M.K., MACEACHERN, J., MANGANO, M.G., ZONNEVELD, J.P., PEMBERTON, S.G., NETTO, R.G. & MARTIN, A. (2005). Colonization of brackish-water systems through time: Evidence from the trace-fossil record. Palaios, **20**(4): 321 - 347.
24. SHANLEY, K.W., MCCABE, P.J. & HETTINGER, R.D. (1992). Tidal influence in Cretaceous fluvial strata from Utah, USA: a key to sequence stratigraphic interpretation. *Sedimentology*, **39**(5): 905 - 930.
25. HALFAR, J., RIEGEL, W. & WALTHER, H. (1998). Facies architecture and sedimentology of a meandering fluvial system: a Palaeogene example from the Weisselster Basin, Germany. *Sedimentology*, v. 45: 1 - 17.
26. FREY, R.W., HOWARD, J.D. & PRYOR, W.A. (1978). *Ophiomorpha*: its morphologic, taxonomic, and environmental significance. *Palaeogeography, Palaeoclimatology and Palaeoecology*, **23**: 199 - 229.
27. MRINJEK, E., SREMAC, J. & VELIC, J. (2006). Pliocene alluvial sediments in the Drava Depression of the Virovitic–Slantina area, Northern Croatia. *Journal Geological Society of Croatia*, **59**: 65 - 84.
28. KVALE, E.P. (2006). The origin of neap–spring tidal cycles. *Marine Geology*, **235**(1 – 4): 5 – 18.
29. LEVORSEN, A.I. (1967). Geology of Petroleum: San Francisco, Freeman and Company, 724p.
30. SHEPHERD, M. (2009). Oil Field Production Geology. *American Association of Petroleum Geologist*s, Memoir **91**: 348p.
31. HSU, K.J. (1997). Studies of Ventura Field, California, II: Lithology, Compaction, and Permeability of Sands. *American Association of Petroleum Geologists Bulletin*, **61**(2): pp. 169 - 191.
32. MODE, A.W. (2002). Hydrocarbon evaluation of Campanian–Maastrichtian strata within a sequence stratigraphic framework, South Eastern Anambra Basin, Nigeria. Unpublished Ph.D. Thesis, University of Nigeria, Nsukka, p 225.
33. WU, T. & BERG, R.R. (2003). Relationship of reservoir properties for shaly sandstones based on effective porosity. *Petrophysics*, **44**(5): 328 -

341.

34. REYNOLDS, A.D., SIMMONS, M.D., BOWMAN, M.B. J., HENTON, J., BRAYSHAW, A.C., ALI-ZADE, A.A., GULIYEV, I.S., SULEYMANOVA, S.F., ATAEVA, E.Z., MAMEDOVA, D.N. & KOSHKARLY, R.O. (1998). Implications of Outcrop Geology for Reservoirs in the Neogene Productive Series: Apsheron Peninsula, Azerbaijan. *American Association Petroleum Geologists Bulletin*, **82**(1): 25 - 49.
35. MODE, A.W. & OBI, I. (2006). Surface Reservoir Analog – an example of Reservoir Scenarios and Trapping Mechanisms on Braid Fluvial Channel Deposits of the Ugwunwanne Ridge, Abakaliki Basin, SE Nigeria.
36. TAYLOR, A.W. & RITTS, B.D. (2004). Mesoscale heterogeneity of fluvial lacustrine reservoir analogues: examples from the Eocene Green River and Colton Formations, Unit A Basin, Utah, USA. *Journal of Petroleum Geology*, **27**(1): 3 - 25.
37. FENIES, H. & TASTET, J.P. (1998). Facies and Architecture of an estuarine tidal bar (the Trompeloup bar, Cironde Estuary, South-western France. *Marine Geology*, **150**(1): 149 - 169.