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The Biostratigraphical Interpretation and Sedimentological Analysis of Mn-003 Well, Central Swamp Depobelt, Niger Delta Basin, Southern Nigeria

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ABSTRACT

This study covers the biostratigraphical and sedimentological framework of MN-3 well. The well is located in central swamp depobelt of the Niger Delta Basin. Forty-Nine (49) ditch cutting samples at a depth interval of 8910ft- 11790ft were analyzed. The methods employed in the study are sedimentological analysis and biostratigraphic interpretation. The Niger Delta Chronostratgraphic Chart, Foram (F-Zone) data and the general foram association data chart were used to interpret the data. The study also entails using all the aforementioned parameters in the establishment of depositional environment. Three lithofacies were identified as shale, sandy shale, and sandstone. A total of thirty onelithozones were identified. Three maximum flooding surfaces and six sequence boundaries were estimated. The thick bottom shale interpreted to be possible source rock aligns with Bolivia 26 shale marker (23.2ma). The interpreted reservoir lies between 20.1-22.2 ma age range. The caprock lies above the Oghara shale marker. This connotes that the well is of the Miocene age. A total of one hundred and ninety-nine planktic foraminifera abundance was recorded in the well. Benthic abundance recorded in the well is three thousand four hundred and twenty-one. The ratio of planktic to benthic foraminifera in MN-3 Well is one to seventeen. The rock units were interpreted to be on the shelf environment as it is the point where the foram count starts.

1. Introduction

The Niger Delta lies in the Gulf of Guinea between latitudes 40 and 60 N and longitudes 30 and 90 E on the west coast of Central Africa. A detailed understanding of the stratigraphy and palaeoenvironmental evolution of the Niger Delta Region during the Priabonian to Rupelian (Late Eocene-Early Oligocene) is crucial for exploration front characterization and for detailed understanding of the stratigraphic architecture and basin evolution of the Niger Delta. The benthonic foraminifera are very abundant in the well sediments. These organisms have been proven to be of great importance in the determination of palaeoenviromental conditions in marine environment by considering their patterns of distribution which is based on their chemical and physical characteristics (Murray 1991; Murray, 2006).The use of lithofacies and biostratigraphy as tools and components in evaluating sedimentary pile and basin analysis has become increasingly important in recent times as seen in works by Bolli and Saunders (1985), Haq (1987), Kennet and Srinivasan (1983), Fadiya (1999) and Chiaghanam, et al. (2013).

Biostratigraphy is an essential tool for dating rocks and identifying the biotic record through time and is necessary for establishing temporal correlation, reconstructing paleogeography, paleoenvironmental reconstruction as well as recognition of oil and gas deposits and intervals. It is essential to the petroleum industry as a tool for defining geologic constraints on prediction of exploration risk and modeling reservoir simulation. Allmon (1993) stated that paleontology is still a necessary geologic tool because the geologic time scale is based on fossils, fossils are still the primary tool for dating sedimentary rocks and fossils record the history of life and environmental changes.

Foraminifera are found in all marine environments, they may be planktic or benthic in mode of life. Foraminifera have a geological range from the earliest Cambrian to present day. The earliest forms which appear in the fossil record (the allogromiina) have organic test walls or are simple agglutinated tubes. Foraminifera with hard tests are scarce until the Devonian, during which period the fusilinids began to flourish cumulating in the complex fusilinid tests of late Carboniferous and Permian times; the fusilinids died out at the end of the Palaeozoic. The miliolids first appeared in the early Carboniferous, followed in the Mesozoic by the appearance and radiation of the rotalinids and in the Jurassic. The earliest forms are all benthic. Planktic forms do not appear in the fossil record until the mid-Jurassic. The high sea levels and "greenhouse" conditions of the Cretaceous saw a diversification of the planktic foraminifera, and the major extinctions at the end of the Cretaceous included many planktonic foraminiferal forms. A rapid evolutionary burst occurred during the Palaeocene with the appearance of the planktic globigerinids and globorotalids and in the Eocene with the large benthic foraminifera of nummulites, soritids and orbitoids (Gabriel et al., 2014). The orbitoids died out in the Miocene, since which time the large foraminifera have dwindled. Diversity of planktonic forms has also generally declined since the end of the Cretaceous with brief increases during the warm climatic periods of the Eocene and Miocene (Raphael et al., 2021). Fossil foraminiferal assemblages are useful for hiostratigraphy and can accurately give relative dates to sedimentary rocks. Foraminifera can also be used in archaeology in the provenance of some raw material types.Foraminifera are classified primarily on the composition and morphology of the test. Three basic wall compositions are recognized; Organic (Protinaceous mucopolysaccharide); Agglutinated and Secreted Calcium Carbonate (or more rarely silica).Organic test; Composed of thin, non-rigid test of protinaceous mucopoysaccharides pseudochitinous matter generally termed "tectin" (Xiaobin et al., 2021).

The Allogrornina falls here. Agglutinated/Arenaccous; May be composed of randomly accumulated grains or grain selected on the basis of specific gravity, shape or size. Some forms arrange particular grains in specific parts of the test.Secreted Calcium Carbonate (calcareous); these are subdivided into three major groups: Microgram (Fusilinina), Porcelaneous (Milolina) and Hyaline (Gloigerinina). Microgranular walled forms (commonly found in the late Palaeozoic) are composed of equidimensional subspherical grains ofcrystalline calcite. Porcelaneous forms have a wall composed of thin inner and outer veneers enclosing a thick middle layer of crystal laths, they are imperforate and made from high magnesium calcite, The Hyaline foraminifera add a new lamella to the entire test each time a new chamber is formed. The objective of this research is to establish the paleodepositional environment of sedimentary succession penetrated by the drill in MN-3 Well, Central Swamp, Niger Delta Basin, Southern, Nigeria as shown in Fig. 1. Source of Data: Samples were made available by the Shell Petroleum Development Cooperation (SPDC).

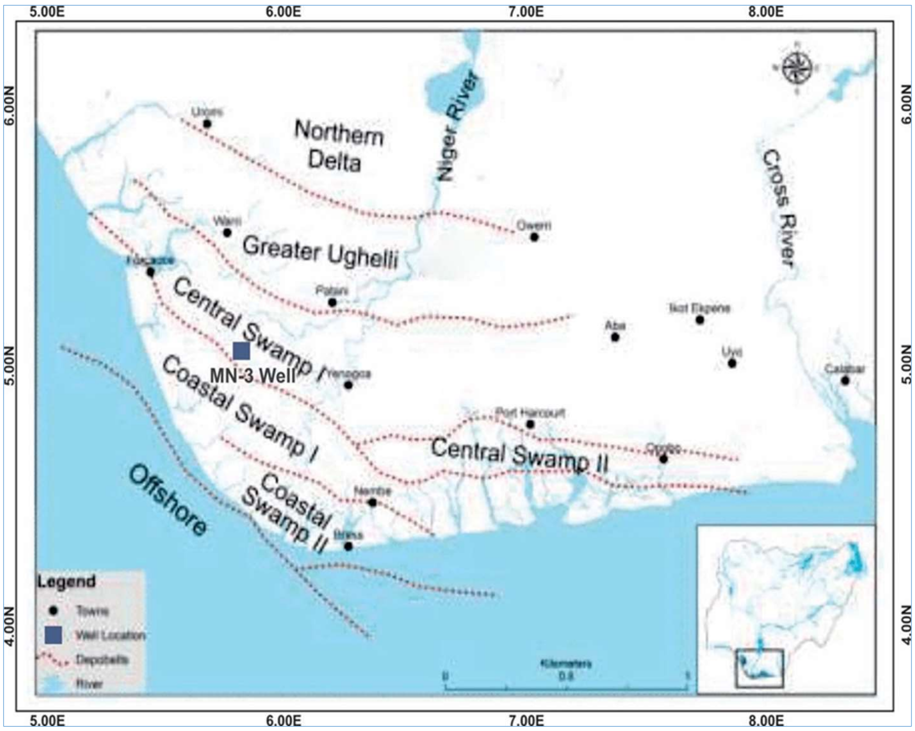

Fig. 1. Dahomey Basin is shown on a regional Gulf of Guinea map in respect to other basins (Adapted from Brownfield et al., 2006)

2. Regional Geology of the Study Area

The Niger Delta basin is located in the Equatorial region of the South Atlantic margin. The delta developed at the triple junction of the Gulf of Guinea, the South Atlantic Ocean and the Benue depression at the point where South America separate from Africa in the Upper Cretaceous (Burke et al., 1972; Corridor et al., 2005). Growth faults were used to define "depobelts', which succeeded one another in time and space as the delta prograded southward with each depobelt determining a seaward sequential movement of the delta (Doust and Omatsola, 1990).

Niger Delta stratigraphy consists of Cretaceous to Holocene marine clastic strata that overlie oceanic and some continental crust fragments (Corridor et al., 2005). The Cretaceous section is yet to be penetrated beneath the Niger Delta Basin; it has been inferred from the nearby Anambra basin (Reijers et al., 1997; Corridor et al., 2005). The sediments of the Niger Delta span a period of 54.6 million years during which, worldwide, some thirty-nine-eustatic sea level rises have been recognized (Adesida et al., 1997). Correlation with the chart of Galloway (1989) confirms the presence of nineteen of such named marine flooding surfaces in the Niger Delta.

Eight of these are locally developed. Adesida et al. (1997) defined eleven lithological mega sequences marked at the base by regional mappable transgressive shales (shale markers) that are traceable across depobelt boundary faults and proposed these as the genetic sequences that can be used as the basis for lithostratigraphy of the Niger Delta as shown in Fig. 2.

The Benin Formation is characterized by high percentage (70–100%) of Sand and forms the top layer of the Niger Delta depositional sequence. The massive sands were deposited in continental environment comprising the fluvial realms (braided and meandering systems) of the upper delta plain.

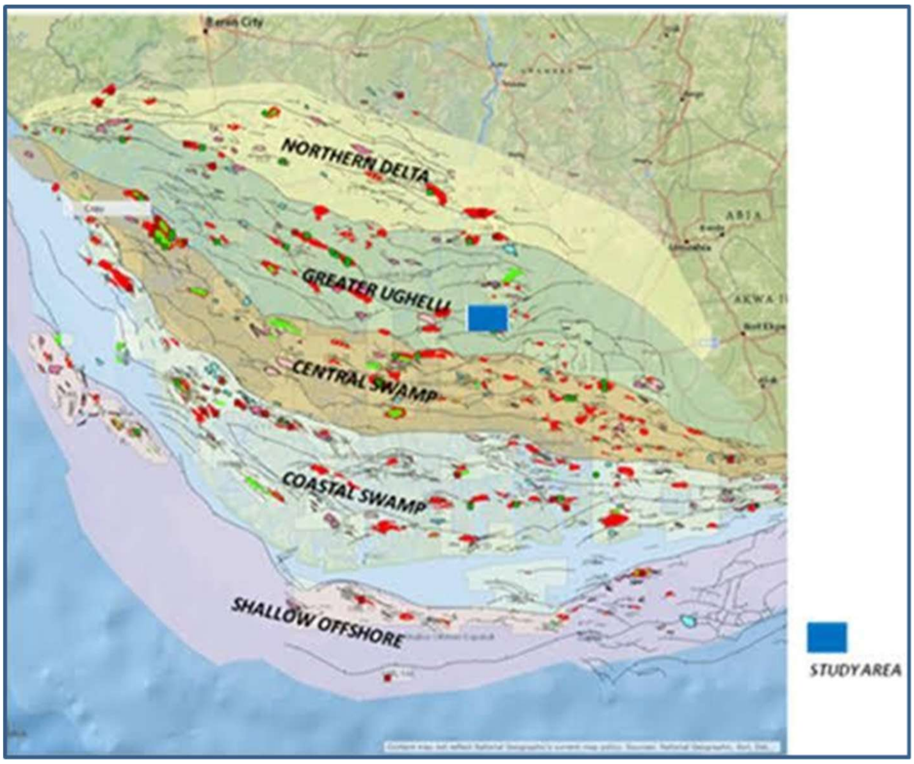

Fig. 2. Depo belts of the Niger Delta (Adopted from Lucas and Omodolor, 2018)

3. Materials and Methods

3.1. Materials

Forty-nine (49) ditch cuttings were collected from MN-3 Well at central swamp depobelt of the Niger Delta Basin, Southern, Nigeria at depth interval of 8910ft-11790ft and Gamma ray log data were provided by Shell Petroleum Development Company (SPDC).

The interpretation tools employed includes: Biofacies data, Biostratigraphical data, Niger delta chronostratigraphic chart, Sequence Stratigraphic data, Laptop, Microsoft excel software package, Microsoft word, Ruler, Pencil.

3.1.1. SPDC Chronostronatigraphy Chart

Chronostratigraphy is the element of stratigraphy that deals with the relative time relations and ages of rock bodies. The Chronostratigraphy chart (Fig. 3) was used in the identification and matching of the p-zones in line with the Epoch, and Age/stage and Niger Delta shale marker.

3.1.2. The Foraminifera Abundance Chart

Foraminifera range chart with the total abundance of benthic. The diverse foraminifera chronostratigraphic schemes used by the major operators in the Niger delta, in particular Shell, Mobil, ELF, Nigerian Agip Oil Company Limited (NAOC), and Chevron. Each company had its individual nomenclature that is confidential for internal use only. These diverse schemes were harmonized in this work and an integrated Niger Delta-Wide Zonal Scheme was developed.

3.1.3. Sequence Stratigraphic Chart

The diverse foraminifera stratigraphic schemes used by the major operators in the Niger delta, in particular Shell, Mobil, ELF, Nigerian Agip Oil Company Limited (NAOC), and Chevron. Each company had its individual nomenclature that is confidential for internal use only. Microsoft Excel Software was used to compute dates from the well.

3.2. Methods

The method adopted in the interpretation of the ditch cutting samples on MN-3 Well Data is stratigraphic (biostratigraphy and sequence stratigraphy) method.

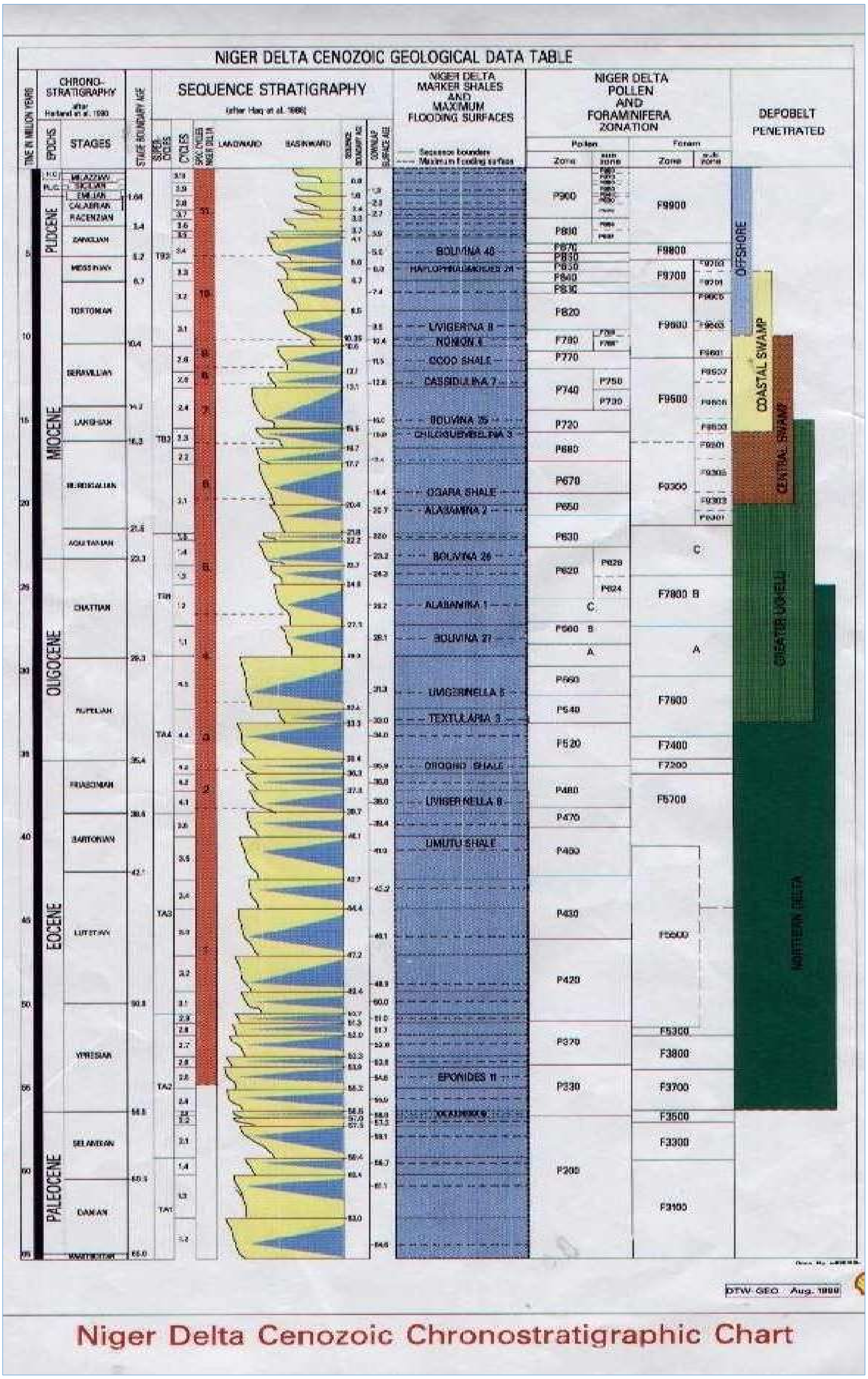

Fig. 3. Niger-Delta-Cenozoic-Chronostratigraphic-Chart (Sources: SHELL)

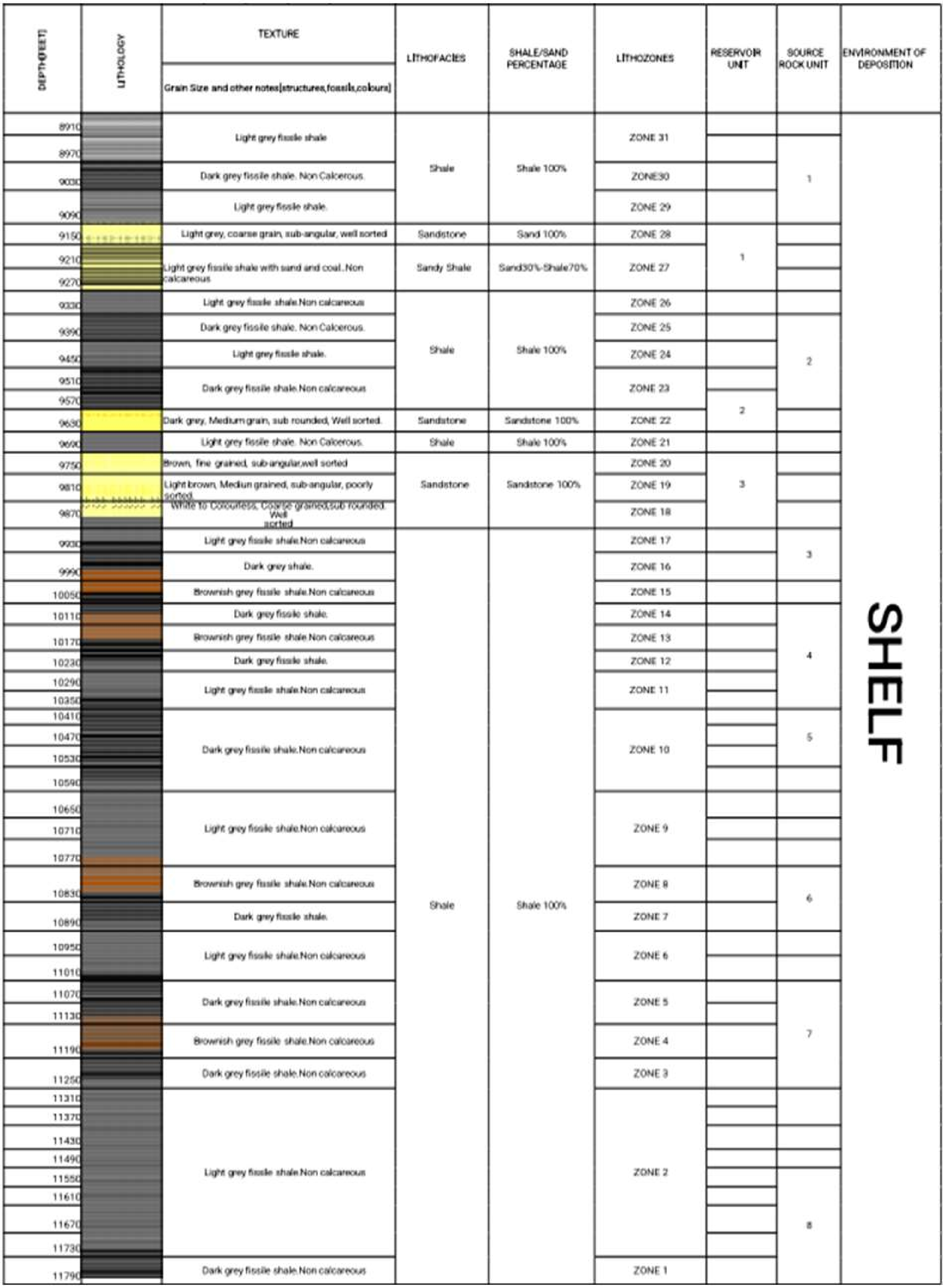

Fig. 4. Lithology of MN-3 Well

Table 1. Summary of Lithozones Description

Units	Depth Interval	Interpretation
Lithozone 1	11790 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are dark grey fine and fissile.
Lithozone 2	11310 ft to 11730 ft	It is completely shale. Its grain is light grey fine and fissile. It is also non-calcareous shale.
Lithozone 3	11250 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are dark grey fine and fissile.
Lithozone 4	11190 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are brownish grey fine and fissile. It is also non-calcareous shale. The brownish colour in this lithozone is indicative of iron hydroxide.
Lithozone 5	11070 ft to 11130 ft	It is completely shale. Its grain is dark grey, fine and fissile. It is also non-calcareous shale. It is made up of mica, feldspar and clay as it is associated with mineral units.
Lithozone 6	10950 ft to 11010 ft	It is completely shale. Its grain is light grey fine and fissile. It is also non-calcerous shale.
Lithozone 7	10890 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are dark grey fine and fissile.
Lithozone 8	10830 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are brownish grey fine and fissile. It is also non-calcerous shale. The brownish colour in this lithozone is indicative of iron hydroxide.
Lithozone 9	10650 ft to 10770 ft	It is completely shale. Its grain is light grey fine and fissile. It is also non-calcerous shale.
Lithozone 10	10410 ft to 10590 ft	It is completely shale. Its grain is dark grey, fine and fissile. It is also non-calcerous shale. It is made up of mica, feldspar and clay as it is associated with mineral units.
Lithozone 11	10290 ft to 10350 ft	It is completely shale. Its grain is light grey fine and fissile. It is also non-calcerous shale.
Lithozone 12	10230 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are dark grey fine and fissile.
Lithozone 13	10170 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are brownish grey fine and fissile. It is also non-calcerous shale. The brownish colour in this lithozone is indicative of iron hydroxide.
Lithozone 14	10110 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are dark grey fine and fissile.
Lithozone 15	10050 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are brownish grey fine and fissile. It is also non-calcerous shale.
Lithozone 16	9990 ft	It is completely shale, made up of mica, feldspar and clay as it associated mineral units. Its grains are dark grey fine and fissile.
Lithozone 17	9930 ft	It is completely shale. Their grains are light grey fine and fissile. It is also non-calcerous shale.
Lithozone 18	9870 ft	It is sandstone with quartz and feldspar associated mineral units. It is White to colourless in color, with coarse, sub-rounded, well-sorted grains, with plant materials present.
Lithozone 19	9810 ft	It is sandstone with quartz and feldspar associated mineral units. It is light brown in color, with medium grained, sub-angular, poorly sorted grains, with plant materials present.
Lithozone 20	9750 ft	It is sandstone with quartz and feldspar associated mineral units. It is brown in color, with fine grained, sub-angular and well-sorted grains.
Lithozone 21	9690 ft	It is completely shale. Its grain is dark grey, fine and fissile. It is also non-calcerous shale. It is made up of mica, feldspar and clay as it is associated with mineral units.
Lithozone 22	9630 ft	It is sandstone with quartz and feldspar associated mineral units. It is dark grey in color, with medium grained, sub- rounded and well-sorted grains.
Lithozone 23	9510 ft- 9570 ft	It is completely shale. Its grain is dark grey, fine and fissile. It is also non-calcerous shale. It is made up of mica, feldspar and clay as it is associated with mineral units.
Lithozone 24	9450 ft	It is completely shale. Its grain is light grey fine and fissile. It is also non-calcerous shale.
Lithozone 25	9390 ft	It is completely shale. Its grain is dark grey, fine and fissile. It is also non-calcerous shale. It is made up of mica, feldspar and clay as it is associated with mineral units.
Lithozone 26	9330 ft	It is completely shale. Its grain is light grey fine and fissile. It is also non-calcerous shale.
Lithozone 27	9210 ft to 9270 ft	It is sandy shale because it's composed of a higher percentage of shale, say about 70% to just about 30% of sand. Light grey in color and the grains are medium to coarse in size, sub-angular to angular in shape and are moderately sorted. Streak of lignite and plant material are present, with quartz and mica as the associated mineral units. It also consists of coal and sand.
Lithozone 28	9150 ft	It is sandstone with quartz and feldspar associated mineral units. It is light grey in color, with coarse grained, sub- angular and well-sorted grains.
Lithozone 29	9090 ft	It is completely shale. Their grains are light grey fine and fissile. It is also non-calcerous shale.
Lithozone 30	9030 ft	It is completely shale. Its grain is dark grey, fine and fissile. It is also non-calcerous shale. It is made up of mica, feldspar and clay as it is associated with mineral units.
Lithozone 31	8910 ft to 8970 ft	It is completely shale. Its grain is dark grey, fine and fissile. It is also non-calcerous shale. It is made up of mica, feldspar and clay as it is associated with mineral units.

3.2.1. Biostratigraphy Interpretation

The Biostratigraphy abundance chart, zones, total plankatic, total benthic foraminifera and total foraminifera abundance.

i. Bio-zonation: The zones were determined based on the presence of marker species and correlated with the published by SPDC chronological chart.

ii. The F-Zones: The P-Zones are useful tools in recognizing maximum flooding surface and sequence boundary in the cycle concept as well as sequence stratigraphy. Maximum foraminifera abundance peaks were also employed to assist in correlation of the determined horizons in global existence on the Shell Petroleum Development Company (SPDC) global cycle chart.

3.2.2. Sequence Stratigraphic Interpretation

Using the sequence Stratigraphic data charts, the maximum flooding surfaces of sequence boundary in the wells were determined. The sequence Stratigraphic was done on over a Stratigraphic chart of OFT to Shell Petroleum Development Company (SPDC) 2010 chronostratigraphic chart procedure was adopted for this study.

i. Interpretation of stratigraphic data
ii. Interpretation of depositional environment
iii. Interpretation of condensed section from peak fauna counts to identify maximum flooding surface
iv. Recognizing sequence boundary from biostratigraphy abundance chart by identifying firming or coarsening upward units based on relative positions, distally or proximally.

Procedure: Step By Step Method on Foraminifera Model Generation STEP 1: Open the laptop; STEP 2: Go to Microsoft excel and insert the data in the columns and rolls putting the depth on the left-hand side. STEP 3: Highlight the inserted data and go to insert on the tittle bar and then click on the chart (scatter with straight line); STEP 4: The graph will be formed and then go to plus sign to add the axis title and chart title; STEP 5: Click on the lines and then delete them; STEP 6: After the graph has been formed, use ctrl-c to copy the graph and then take it to Microsoft word and then paste it; STEP 7: Click insert on the Microsoft and then click on table and select 5 columns and 1 roll and STEP 8: Then paste the copied graph in the table as a picture.

3.2.3. Foraminifera Identification

The identification of the various foraminifera taxa (both planktonic and benthonic forms) was based on comparison with publications on foraminifera and those defined by Petters (1982), Loeblich and Tappan (1987) and Bolli and Saunders (1985). The statistical data (foraminifera count) acquired was computerized by means of the Microsoft Excel spread sheet. Area plots of the abundance were made to represent the assemblage count recovered from the well as shown in Fig. 4.

4. Presentation and Interpretation of Results

Detailed description of ditch cutting samples provided was carried out mainly by visual examination, taking note of textural (grain size and shape) characteristics, color and associated mineral. The major lithofacies encountered were Shale, Sandstone, Sandy-Shale and Shaly-Sand as shown in Table 1.

The Sequence stratigraphy recognizes three (3) Maximum Flooding Surfaces (M.F.S) at depths 9270 ft, 10350 ft and 10710 ft respectively and six (6) Sequence Boundaries (S.B) as shown in Table 2.

4.1. Biostratigraphy Interpretation

The Biostratigraphy interpretation of MN-3Well was section into three (3) zones namely:

- Foraminifera Zones (F–Zones); Foraminifera Zone of Non-diagnostics Top (8910 ft.) to non-diagnostics Base (8970 ft)
- Foraminifera Zone of 9300 Top (9030ft.) to 9300 Base (10350 ft) and (10410 ft.) to F9300–F7800 Base (11790 ft), respectively as shown in Table 2.

The entirely samples at 8910 ft to 11790 ft depth are composed of ditch cuttings (CU). There were no foraminifera at depth 9750 ft while an abundance of foraminifera was recorded from 10170 ft to 10830 ft with depth 10710ft recording the highest foraminifera abundance. Planktonic foraminifera were recorded majorly from depth 9090ft to 11670 ft with depth 10770 ft recording the highest number of foraminifera. Depth 11730ft to 11790 ft marked an absence of planktic foraminifera (Table 2).

4.1.1. Foraminifera Zones

Non-diagnostic Top to Non-diagnostic Base (8910 ft to 8970 ft): The F-Zone is a non-diagnostic top at 8910 ft and non-diagnostic base at 8970 ft. It is Middle Miocene age to Langham stage at about 15.0 Ma. The shale marker is Bolivina'25 (Table 2).

F9300 Top to F9300 Base (9010 ft–10350 ft): The Foraminifera Zone is F9300 top at 9010 ft and F9300 ft at 10350 ft early Miocene age to Aquitanian stage. The shale marker is Alabammina'2 Ma (Table 2).

F9300 to F7800 Top (10410 ft.) and F9300 to F7800 Base (11790 ft.): The F9300 to F7800 Top is at depth 10410 ft. and F9300 to F7800 Base at 11790 ft. It is from the Late Oligocene age to Chattian stage at about 26.0 Ma. The shale maker is Alabammina'1 (Table 2).

4.1.2. Foraminifera Abundance

At depths 8910 ft to 10110 ft, a total number of one thousand, eight hundred and sixty-one (1861), out of which five (24) were planktic foraminifera and one thousand, eight hundred and thirty-seven (1837) were benthic foraminifera. At depths 10170 ft to 10830 ft., a total of two thousand, two hundred and seventy-four (2274) foraminifera were recorded, out of which one hundred and fifty-nine (159) were planktic foraminifera and two thousand, one hundred and fifteen (2115) were benthic foraminifera. At depth 10890 ft and 11790 ft., a total of one thousand, three hundred and eighty-five (1,385) foraminifera were recorded, out of which one thousand, three hundred and sixty-nine (1369) were benthic foraminifera while sixteen (16) were planktic foraminifera (Table 2).

4.1.3. Planktic Abundance

A total of one hundred and ninety-nine (199) planktic foraminifera abundance was recorded in MN-3 Well. Benthic Abundance: a total of three thousand, four hundred and twenty-one (3421) of Benthic abundance was recorded in MN-3 Well (Table 2).

Ratio of Planktic to Benthic Foraminifera: the ratio of planktic to benthic foraminifera in MN-3Well is one to seventeen.

$$199\ FOP = 3421\ FOB;\ 1FOP : 17FOB \quad (1)$$

Total foraminifera=Benthic foraminifera+Planktic foraminifera The total foraminifera in OG-1 well, is seventy-six thousand four hundred and twenty-two (76422) (Table 2).

$$FOB + FOP;\ 73880 + 2542 = 76422 \quad (2)$$

4.2. Maximum Flooding Surface

Three (3) Maximum flooding surfaces were delineated at depth 9270 ft, 10350ft, and 10710 ft. respectively. At depth 9270 ft. the first maximum flooding surface was delineated. Oghara Shale Marker was recorded. It is 19.4 Ma and is of Miocene age. At a depth of 10350ft., the second maximum flooding surface was delineated. The Shale markers recorded at this surface includes Alabammina'2 and Bolivina'26. It is of Late Oligocene to Early Miocene age. It is 20.7 Ma to 23.2 Ma. The third maximum flooding surface was delineated at 10710ft. The Shale markers are Bolivina'26. It is of Late Oligocene to Early Miocene age. It is 23.2 Ma (Table 2).

4.3. Environmental Deposition

Due to the paucity of abundant planktic foraminifera in MN-3 Well, the depositional environment is delineated majorly at Shelf environment. Also, the ratio 1:17, planktic to benthic foraminifera in MN-3 Well, (8910 ft–11790 ft), suggest a shelf environment of deposition as shown in Table 2.

Table 2. Summary of Biostratigraphy and Sequence Stratigraphy interpretation

The Foraminifera Distribution and Abundance			
Depth (ft)	**Total Plantic Abundance**	**Total Benthic Abundance**	**Total Foram Abundance**
8910-10110	24	1837	1861
10170-10830	159	215	2274
10890-11790	16	1369	1385
Total	199	3421	5520
Foraminifera Zones and Environment of Deposition			
Depth (ft)	**F- Zones**		**Environment of Deposition**
8910	Non-diagnostics Top and Non-diagnostics Base		Not known
9030 10350	F9300 Top F9300 Base		Shelf
10410 11790	F9300–F7800 Top F9300–F7800 Base		Shelf
Maximum Flooding Surface (MFS) and Environment of Deposition			
Depth (ft)	**Maximum Flooding Surface**		**Environment of Deposition**
9270	Shale marker; Ogara Shale, 19.4 Ma and It is of the Miocene age.		Shelf
10350	Shale markers are Alabammina'2 and Bolivina'26. It is of Late Oligocene to Early Miocene age. It is 20.7–23.2 Ma		Shelf
10710	Shale markers; Bolivina'26, 23.2Ma and. It is of the Late Oligocene to early Miocene age.		Shelf
Sequence Boundary and Environment of Deposition			
Depth (ft)	**Sequence Boundary**		**Environment of Deposition**
8910	17.7 Ma		Shelf
9690	20.4 Ma		Shelf
9810	21.8 Ma		Shelf
10970	23.7 Ma		Shelf
11790	24.9 Ma		Shelf

Table 3. Sequence boundaries were delineated at depth 8910 ft to 11790 ft in MN-3 Well

Depth (ft)	Explanation
SB–8910 ft	The first sequence boundary was delineated at depth 8910 ft and it is 17.7 Ma
SB–9690 ft	The second sequence boundary was delineated at depth 9690 ft and it is 20.4 Ma
SB–9810 ft	The third sequence boundary was delineated at depth 9810 ft and it is 21.8 Ma
SB–10970	The fifth sequence boundary was delineated at depth 10970 ft and it is 23.7 Ma
SB–11790	The sixth sequence boundary was delineated at depth 11790 ft and it is 24.9 Ma

4.4. Sequence Boundary

The sequence boundary is delineated into five (5) boundaries from a depth of 8910 ft to 11790 ft as shown in Table 3.

5. Conclusion

The studied MN-3 Well, Central Swamp Depobelt lies in the Niger Delta Basin, Southern Nigeria. The age is Oligocene to Miocene. There were no foraminifera at depth 9750 ft. and 9870 ft. Abundance of foraminifera was recorded at depths 10170 ft–10830 ft, with depth 10710 ft recording the highest foraminifera abundance, three hundred and fifty-five (355). Planktonic foraminifera were found majorly from depth 9090ft – 11670 ft. with depth 10770 ft. recording the highest foraminifera, thirty-seven (37). Depth 8910 ft, 8970 ft, 11730 ft and 11790 ft. marked an absence of planktic foraminifera. Three (3) maximum flooding surfaces and five (5) sequence boundaries were encountered in the well. The shelf environment of deposition was delineated for the well.

Source of Data: Samples were made available by the Shell Petroleum Development Cooperation (SPDC).

References

Adeniran, B.V., 1997. Quantitative Neogeneplanktic foraminiferal biostratigraphy of Western Niger Delta, Nigeria. Nigerian Association of Petroleum Explorationists Bulletin 12, 54-59.

Adesida, A.A., Reijers, T.J.A., Nwajide, C.S., 1997. Sequence stratigraphic framework of the Niger Delta. Paper presented at the AAPG international conference and exhibition, Vienna, Austria.

Avbovbo, A.A., Ayoola, E.O., Osahon, G.A., 1986. Depositional and structural styles in the Chad Basin of northeastern Nigeria. AAPG Bulletin 70, 1787-1798.

Beka, F.T., Oti, M.N., 1995. The distal offshoreNiger Delta: frontier prospects of a mature petroleum province, In M. N Oti and G. Postma (eds.), Geologyof Deltas: Rotterdam, A.A. Balkema, pp. 257-267.

Bolli, H.M., Saunders, J.B., 1985. Oligocene and Holocene Low Latitude Planktic Foraminifera. In: Bolli, H.M., Saunders, J.B. and Perch- Nielsen, K., Eds., Planktonic Stratigraphy, Cambridge University Press, Cambridge, Earth Science Series, Pp. 155-262.

Burke, K.C., Dewey, J.F., 1972. Orogeny in Africa. In: Dessauvagie

TFJ, Whiteman AJ (eds), Africa geology. University of Ibadan Press, Ibadan, Pp. 583-608.

Bustin, R.M., Cameron, A.R., Grieve, D.A., Kalkreuth, W.D., 1983. Coal petrology–its principles, methods and applications. Geological association of Canada, short course notes, 2nd end, Pp. 230.

Chiaghanam, O., Chiadikobi, K., Ikegwuonu, O., Omoboriowo, A., Onyemesili, O., Acra, E.J., 2013. Palynofacies And Kerogen Analysis Of Upper Cretaceous (Early Campanian to Maastrichtian) Enugu Shale And Mamu Formation In Anambra Basin, South-Eastern, Nigeria. Vol. 2, Pp. 225- 229.

Doust, H., Omatsola, E., 1989. Niger Delta. AAPG Memoir 48, 201-238.

Durand, J., 1995. High-resolution sequence stratigraphy (genetic stratigraphy) reservoir sedimentology: examples from the Niger Delta. The bulletin of the Nigerian Association of Petroleum Explorationists 1, 65-73.

Ejedawe, J.E., 1989. The Eastern Niger Delta: geological evolution and hydrocarbon occurrences. SPDC Internal Report, Exploration Note 89, 002.

Ekweozor, C.M., Okoye, N.V., 1980. Petroleum Source-Bed Evaluation of Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin 64, 1251-1259.

Evamy, B.D., Haremboure, J., Kameling, P., Knaap, W.A., Molloy, F.A., Rowlands, P.H., 1978. Hydrocarbon habitat of tertiary Niger Delta. AAPG Bulletin 62, 1-39.

Fadiya, S.L.,1999. Foraminifera and Calcareous Nannofossil biostratigraphy and well log sequence stratigraphic analysis of Opolo-5 and Opolo-9 wells, Niger Delta. Unpub. M.Sc. Thesis, Department of Geology, Obafemi Awozxdlowo University, Ile-Ife, Abstract Published – American Association of Petroleum Geologists Bulletin 82 (11), 2162.

Fayose, E.A., 1970. Stratigraphic Paleontology of Afiwo Well, Southwestern Nigeria. Journal of Mining Geology 5, 1-99.

Frankl, E.J., and Cordry, E.A., 1967. The Niger Delta Oil Province: Recent Developments On-Shore and Off-Shore. 7th World Petroleum Congress, Mexico City, 2-9 April, 195-209.

Galloway, W.E. 1989. Genetic stratigraphic sequences in basin analysis 1: architecture and genesis of flooding-surface bounded depositional units. AAPG Bulletin 73, 125-142.

Gabriel, J.B., Maibauer, B.J., Kraus, M.J., Röhl, U., Westerhold, T., Steimke, A., Gingerich, P.D., William, Sl.W., Clyde, C., 2014. Two massive, rapid releases of carbon during the onset of the Palaeocene–Eocene thermal maximum. Nature Geosciences Journal 8, 44-47.

Haq, B.U., Hardenbol, J., Vail, P.R., 1987. Chronology of Fluctuating Sea Levels since the Triassic. Science 235, 1156-1167.

Hospers, J. 1965. Gravity Field and Structure of the Niger-Delta, Nigeria, West Africa. Geological Society of America Bulletin 76, 407-422.

Hunt, J.M., 1979. Petroleum geochemistry and geology. Freeman and Company, San Francisco, Pp. 617.

Hunt, J.M., 1991. Generation of gas and oil from coal and other terrestrial organic matter. Organic Geochemistry 17, 673-680. https://doi.org/10.1016/0146-6380(91)90011-8.

Kennet, J.P., Srinivasan, M.S., 1983. Neogene planktonic foraminifera: a phylogenetic atlas; Stroudsburg, Pa: Hutchinson Ross; New York, NY:Van Nostrand Reinhold.

Knox, G., Omatsola, M.E., 1989. Development of the Cenozoic Niger delta in terms of the escalator regression model. Proceedings, Coastal Lowlands and Geomorphology, Kon. Nederl. Geol. Mijnb. Genootschap Pp. 181-202.

Lehner, P., De Ruiter, P.A.C., 1977. Structural History of Atlantic Margin of Africa. American Association of Petroleum Geologists Bulletin 61, 961-981.

Loeblich, A.R., Tappan, H., 1987. Foraminiferal Genera and Their Classification. New York: Van Nostrand Rienhold Co.

Lucas, F.A., Omodoler, H.E., 2018. Lithofacies Characterisation of Sedimentary Succession from Oligoture to early Moisture as inWell-2, Greater Depobelt Niger Delta Nigeria. Journal of Geoseute and Geoimates 6 (2), 77-84. https://doi.org/10.12691/jgg-6-2-5.

Merki, P., 1972. Structural geology of the Cenozoic Niger Delta. (ed. T.F.J. Dessauvagie and A.J. Whiteman). African Geology, Ibadan University Press, Pp. 635-646.

Michele, L.W.T., Ronald R.C., Michael, E.B., 1999. The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa: U.S. Geological Survey World Energy Project, Pp. 65.

Mitchum, R.M., Sangree, J.B., Vail, R.P. Wornardt, W.W. 1994. Recognizing Sequences and systems tracts from well logs, seismic data and biostratigraphy: Examples from the Late Cenozoic of the Gulf of Mexico. In P. Weimer, and H. Posamentier (Eds): Siliciclastic Sequence Stratigraphy: Recent Developments and Applications. AAPG Mem 58, 163-197.

Murray, J.W., 1991. Ecology and Palaeoecology of Benthic Foraminifera. Logman Scientific & Technical, London, Pp. 1-397.

Murray, J.W., 2006. Ecology and Applications of Benthic Foraminifera. Cambridge University Press, New York, Pp. 1-426.

Nwachukwu, J.I., Chukwurah, P.I., 1986. Organic Matter of Agbada Formation, Niger Delta, Nigeria. American Association of Petroleum Geologists Bulletin 70, 48-55.

Nwachukwu, S.O. 1972. The Tectonic Evolution of the Southern Portion of the Benue Trough, Nigeria. Geological Magazine 109, 411-419.

Obaje, N.G., 2000. Sand Fairways across the Shallow Offshore Niger Delta. Shell Internal Report, BXE-GEO.

Obaje, N.G., 2005. Fairways and reservoir potential of Pliocene–Recent sands in the shallow offshore Niger Delta. Journal of Mining Geology 40, 25-38.

Obaje, N.G 2009. The Geology and Mineral Resources of Nigeria, Springer-Verlag Berlin Heidelberg, Pp. 221.

Obaje, N.G., 2013. Updates on the Geology and Mineral Resources of Nigeria, Tetfund, Pp. 250.

Okosun, E.A., Liebau, A., 1999. Foraminiferal Biostratigraphy of Eastern Niger Delta, Nigeria. Journal of Nigerian Association of Petroleum Explorationist 14 (2), 136 -156.

Ola-Buraimo, A.O., 2010. Well-log sequence stratigraphy and paleobathymetry of well-X, offshore western Niger Delta, Nigeria. World Applied Sciences Journal 10 (3), 276-287.

Onyekuru, S.O., 2012. Sequence Stratigraphic Analysis of "XB Field", Central Swamp Depobelt, Niger Delta Basin, Southern Nigeria. International Journal of Geosciences 3 (1), 237-257. http://dx.doi.org/10.4236/ijg.2012.31027.

Ozumba, M.B., Amajor, L.C., 1999. Evolutionary Relationships in some Benthic Foraminifera of the Middle to Late Miocene, Niger Delta. Journal of Nigeria Association of Petroleum Explorationist14, (2), 157- 167.

Peter, K.L., 1979. Structural geology applied to petroleum exploration. S.N ISBN-13, 978 0894190476.

Petters, S.W., 1982. Central West African Cretaceous-Tertiary benthic foraminifera and stratigraphy. Palaeontographica Abt A 179, 1-104.

Petters, S.W., 1986. Foraminiferal biofacies in the Nigerian rift and continental margin deltas. In: Oti MN, Postma G (eds) Geology of deltas. AA Balkema, Rotterdam, Pp. 219-235.

Reijers, T.J.A., Nwajide, C.S., 1998. Geology of the Southern Anambra Basin. Unpublished Report for Chevron Nigeria Limited. Field Course Note, Pp. 66.

Reijers, T.J.A., Nwajide, C.S., Adesida, A.A., 1997. Sedimentology and Lithostratigraphy of the Niger Delta. Abstract, 15th International Conference of the Nigerian Association of Petroleum Explorationist (NAPE), Lagos, Nigeria.

Raphaël, M., Hassenrück, C., Greco, M., Fernandez-Guerra, A., Rigaud, S., Douady C.J., Kucera, M., 2021. Renewal of planktonic foraminifera diversity after the Cretaceous Paleogene mass extinction by benthic colonizers. Nature Communication 3, 7135.

Short, K.C., Stauble, J., 1967. Outline geology of the Niger Delta. AAPG Bulletin 5, 761-779.

Stacher, P., 1995. Present understanding of the Niger Delta hydrocarbon habitat. In: Oti MN, Postma G (eds) Geology of Deltas. AA Balkema, Rotterdam, Pp. 257-267.

Vail, P.R., 1987. Seismic stratigraphy interpretation, using sequence stratigraphy. Part 1: Seismic Stratigraphic Procedure. In: Balley AW (ed) Atlas of Seismic Stratigraphy. AAPG Studies in Geology 27, 1-10.

Weber, K.J., 1972. Sedimentological aspects of oil fields in the Niger Delta. Geologeen Mijnbouw 50, 559-576.

Weber, K.J., 1986. Hydrocarbon distribution patterns in Nigerian growth fault structures controlled by structural style and stratigraphy. AAPG Bulletin 70, 661-662.

Weber, K.J., Daukoru, E., 1975. Petroleum geology of the Niger Delta. In: Proceedings, 9th World Petroleum Congress. Applied Science Publishers, London 9, 209-221.

Whiteman, A., 1982. Nigeria:its petroleum geology, resources and potential. Graham and Trotman, London, Pp.381.

Xiao, H., Suppe, J., 1992. Origin of Rollover. American Association of Petroleum Geologists Bulletin 76, 509-229.

Xu, X., Hu, Q., Liu, D., Qiu, H., Shameem, M., Li, N., 2021. Characterization of Proteinaceous Particles in Monoclonal Antibody Drug Products Using Mass Spectrometry. Journal of Pharmaceutical Sciences 110 (10), 3403-3409.