International Journal of Science and Technology
ISSN 2049-7318

International Journal of Science and Technology Volume 2 No. 9, September, 2013

Paleoenvironmental Interpretation of Tomboy Field, Offshore Western Niger Delta, Nigeria

S. O. Obaje[1], E. A. Okosun[2]
[1]Nigerian Geological Survey Agency, P.M.B. 1423, Fate, Ilorin, Kwara State, Nigeria.
[2]Department of Geology, Federal University of Technology, P.M.B. 65, Minna, Niger State, Nigeria.

ABSTRACT

The aim of the study is to delineate the paleoenvironments of deposition in the study area using identified foraminifera specimens and lithofacies. The area of study is located in the Tomboy field of the offshore western Niger Delta area of Nigeria. The ratios between Textulariina, Miliolina and Rotaliina plotted in a foraminiferal morphogroup triangular cross-plot and the biometric analysis of foraminifera's abundance and diversity indicated shelf paleoenvironment of deposition. Also, the ratio of planktic to benthic foraminifera (P/B ratio) of 25.92%/74.08% corroborated the paleodepths of inner to outer neritic (shelf) environment of deposition. In addition, the calculated average of 82.51%/17.49% percentage ratios of calcareous benthic to arenaceous benthic foraminifera (FOBC/FOBA) in the five wells indicated shallow marine paleoenvironment. Three paleodepths of inner neritic, middle neritic and outer neritic were characterised by indicator fossils such as *Cassidulina neocarinata* THALMANN, *Textularia* sp. DEFRANCE, *Eponides eshira* DE KLASZ & RÉRAT, *Quinqueloculina seminulum* LINNÉ, *Uvigerina auberiana* D'ORBIGNY, *Ammonia beccarii* LINNÉ, *Nonionella* sp., *Globocassidulina subglobosa* BRADY, *Cancris auriculus* FITCHTEL & MOLL, *Amphicoryna scalaris caudata* BATSCH, *Spiroplectammina carinata* CUSHMAN and *Quinqueloculina microcostata* NATLAND, *Uvigerina peregrina* CUSHMAN, *Uvigerina subperegrina* CUSHMAN & KLEINPELL, *Bulimina aculeata* BROTZEN and *Florilus* ex. gr. *N. costiferum* CUSHMAN, etc. Finally, the assessed lithofacies such as clay, silt, poorly to well sorted fine- to coarse- grained sands and the presence of fossil accessories such as micro-mollusc and echinoid remains, etc., also agreed with the paleodepths of inner neritic to outer neritic.

Keywords: *Paleoenvironmental interpretation, Tomboy Field, western Niger delta, Nigeria*

1. INTRODUCTION

The area of study is located in the Tomboy field of the offshore western Niger Delta area of Nigeria (Fig. 1). The Niger Delta is situated in the Gulf of Guinea on the west coast of Central Africa. Niger Delta lies between latitudes 4° and 6° N and longitudes 3° and 9° E in the south-south geo-political region of Nigeria [18]. The Cenozoic Niger Delta is situated at the intersection of the Benue Trough and the South Atlantic Ocean where a triple junction developed during the separation of South America and Africa in the Late Jurassic [24]. The aim of this study is to identify foraminifera specimens, record their abundance and diversity for biometric analysis as well as the assessment of the lithofacies with a view to delineate the paleoenvironments of deposition in the study area.

2. GEOLOGICAL SETTING

Three main formations have been recognised in the subsurface of the Niger Delta[5], [20], [23], [1], [11], [22]. These are the Akata, Agbada, and Benin Formations. These formations were deposited in marine, transitional and continental environments, respectively; together they form a thick, overall progradational passive-margin wedge [5]. The Akata Formation is Paleocene to Pliocene in age and it is the basal unit composed mainly of marine shales believed to be the main source rock within the basin. The Agbada Formation is made up of alternating sandstone, siltstone and shale sequences that constitute the petroleum reservoirs of the basin. Agbada Formation is Eocene to Quaternary in age (Figs. 2 and 3). On the other hand, the Benin Formation is Oligocene to Recent in age and it is mainly made up of non-marine fine to coarse-grained sands with a few mudstone and shaly intercalations [5].

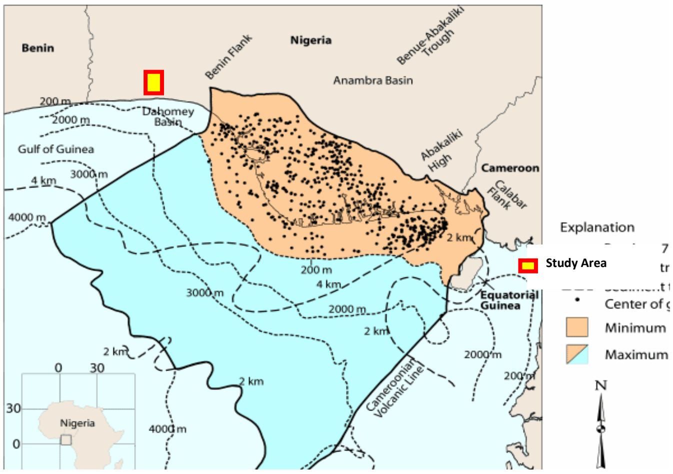


Fig. 1. Location Map of the Study Area (Source: Tutle et al. [22])

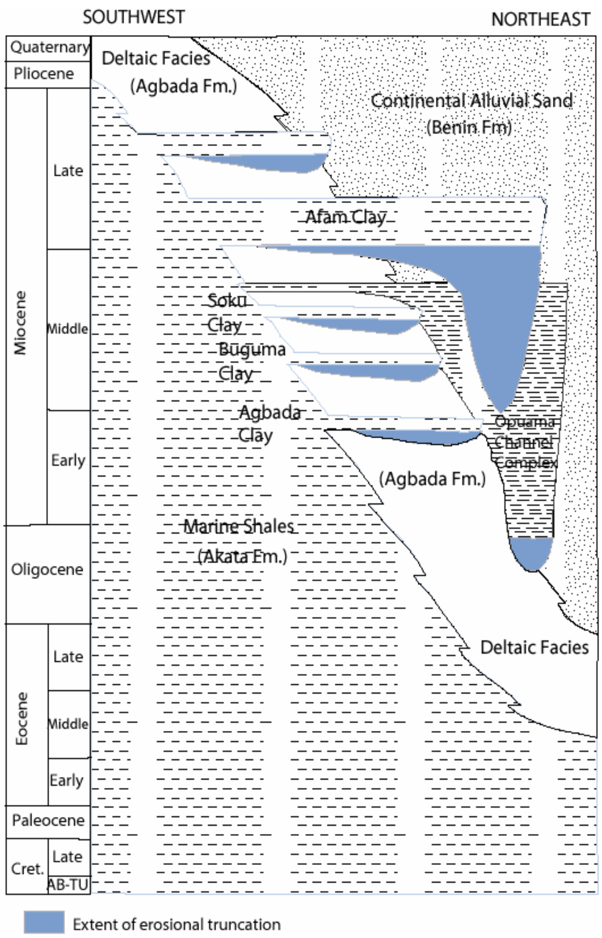


Fig. 2. Stratigraphic column showing the three formations of the Niger Delta (after Tuttle et al.[22]; modified from Doust and Omatsola [6])

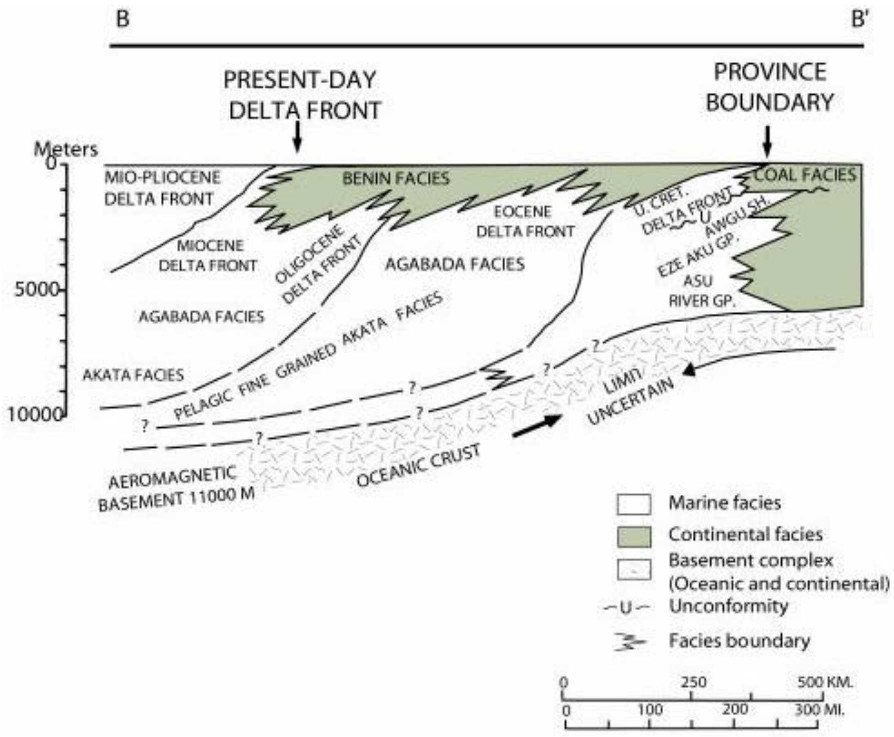


Fig. 3. Southwest-Northeast (B-B') cross-section through the Niger Delta (modified from Whiteman [24])

3. METHODS OF STUDY

In all, 550 ditch cuttings samples constituted by 113, 106, 111, 108 and 112 samples were retrieved at 18.29 meter intervals from the five wells studied (TMB-1, TMB-2, TMB-4, TMB-5 and TMB-6), respectively. The standard micropaleontological preparation technique for foraminiferal samples was employed. The unwashed ditch cutting samples were initially rinsed to remove drilling mud and then dried. Twenty grams of each dried sample was soaked for four hours in kerosene and then detergent solution water overnight. The disaggregated samples were then washed under running faucet water over a 63 µm sieve mesh. The washed residues were then dried over a hot electric plate, and then sieved into three size portions: coarse, medium and fine. They were then put in labelled sample bags. Their foraminiferal contents were then identified under binocular microscope and recorded. The complete micropaleontological and statistical data of the specimens were recorded. The sediments were also studied under reflected light binocular microscope for lithofacies assessment of each well depth.

4. RESULTS AND DISCUSSION

4.1 Paleoenvironmental Analysis

The categories of the benthic foraminifera in the five wells have different abundances, viz: the calcareous species have average population density of 82.51% and range of 80.14% - 84.41%, while the arenaceous benthics have average population density of 17.49% and range of 15.86% - 19.59% (Table 1). The calcareous benthics are dominated by *Spirosigmoilina oligoceanica* CUSHMAN, *Uvigerina sparsicostata* CUSHMAN & LAIMING, *Uvigerina subperegrina* CUSHMAN & KLEINPELL, *Eponides eshira* DE KLASZ & RÉRAT, *Brizalina* sp. LOEBLICH & TAPPAN, *Bulimina aculeata* BROTZEN, *Florilus* ex. gr. *N. costiferum* CUSHMAN, *Lenticulina inornata* D'ORBIGNY, *Marginulina costata* BATSCH, *Lagena costata* WILLIAMSON, etc.

The arenaceous benthics are dominated by *Eggerella scabra* WILLIAMSON, *Textularia* sp. DEFRANCE, *Haplophragmoides* cf. *H. hausa* PETTERS, *Trochammina* cf. *T. pacifica* CUSHMAN, *Ammobaculites* cf. *A. jarvisi* CUSHMAN & RENZ, *Reophax* cf. *R. morrisoni* CUSHMAN & ELLISOR, *Saccammina complanata* FRANKE, *Spiroplectammina carinata* CUSHMAN, etc. The benthic foraminifera in TMB-1 well are made up of 1,188 calcareous benthic and 224 arenaceous benthic specimens, respectively. In TMB-2 well, there are 739 calcareous benthic specimens and 180 arenaceous benthic specimens. TMB-4, TMB-5 and TMB-6 wells have 1,171, 1,099 and 1,325 calcareous benthic specimens and 250, 244 and 257 arenaceous benthic specimens, respectively (Table 1 and Fig. 4). The calculated average percentage of planktic foraminiferal specimens in the five wells is 24.40%. The numbers of planktic foraminifera are 522, 278, 508, 477 and 580 specimens in TMB-1, TMB-2, TMB-4, TMB-5 and TMB-6, respectively. The dominant planktic foraminifera are *Globorotalia continuosa* BLOW, *Globorotalia mayeri* CUSHMAN & ELLISOR, *Globigerinoides subquadratus* (BRÖNNIMANN), *Globorotalia foshi lobata* BERMUDEZ, *Globigerina bulloides* D'ORBIGNY, *Orbulina universa* D'ORBIGNY, *Orbulina suturalis* BRÖNNIMANN, *Globigerina praebulloides* BLOW, *Globigerinoides sacculifer* BRADY, *Globigerinoides trilobus* REUS and *Globigerinoides extremus* BOLLI & BERMUDEZ. Other very useful markers present in low numbers are *Globorotalia obesa* BOLLI, *Globigerinoides quadrilobatus* D'ORBIGNY, *Globigerinita naparimaensis* BRÖNNIMANN, etc. [16]. The non-foraminiferal fossils referred as accessories are the shell fragments of echinoids, ostracods, pelecypods and micro-mollusc species, etc. The numbers of the accessories in the five wells are 111, 91, 109, 109 and 135 in TMB-1, TMB-2, TMB-4, TMB-5 and TMB-6, respectively; and their average population density is 5.87% with range of 5.34% - 7.06% relative to the percentages of foraminifera (Table 1 and Fig. 4). It is inferred that the low population density of the accessories is indicative of marine environment devoid of turbulent, high energy currents.

The ratios between Textulariina, Miliolina and Rotaliina plotted in a foraminiferal morphogroup triangular cross-plot and foraminiferal abundance/diversity enable the discrimination of a range of paleoenvironments of deposition [13], [14], [15]. Planktic foraminifera are depth-stratified because they are very sensitive to certain environmental factors such as salinity, turbidity, temperature, etc. [2], [4]. Thus, their thanatocoenoses (death assemblages) have higher diversity in deeper marine environment than in shallower water environment. Consequently, the ratio of planktic to benthic foraminifera (P/B ratio) provides useful paleoenvironmental guide and the higher the percentages of planktic foraminifera, the deeper the paleodepth of deposition [2], [8], [3], [4]. Fig. 5 shows the ratio of planktic to benthic foraminifera in the study area.

Boersma [3] outlined the following criteria for paleoenvironmental analysis:

(a) The marshes and lagoon environments are characterised by lower numbers or absence of calcareous genera in relation to the population of the agglutinated/arenaceous forms.
(b) The shallow shelf is characterised by a numerically small fauna dominated by a few species, very few of which are agglutinated/arenaceous and none of which are pelagic. The agglutinated/arenaceous tests have simple interior.
(c) The inner shelf is characterised by coarse-grained, clear, well sorted sands containing abundant rounded shell fragments. The faunas are usually highly dominated by a few species. Tests are small and not strongly ornamented. A few pelagic species, usually of the genus *Globigerina* may be present.
(d) The deeper inner neritic/shelf contains fine- to medium- grained sand, silt, clay, with common glauconite and micro-mollusc and echinoid remains. Pelagic types are more numerous and the agglutinated/arenaceous foraminifera increase in abundance, but still have simple interior.
(e) The middle neritic/shelf are composed of clay, silt, poorly sorted sands and abundant glauconite. The species are often highly ornamented, large and robust. The pelagic planktic foraminifera make up 15-30% of the micro-fauna populations. The arenaceous forms have more complex interior structures.
(f) The outer neritic/shelf is characterised by fine-grained sediments such as clay and some glauconite. Species number is high and ornamentation is strong. The planktics constitute approximately 50% of the faunas.
(g) The upper continental slope/bathyal strongly resembles the outer neritic. Smooth slope to submarine canyons are common with varying amounts of allogenic or transported materials. The planktic foraminifera's populations range from 50-85% of the microfauna.
(h) The lower slope/bathyal is like the abyssal plain in its fine-grained calcareous marls and clays. The number of benthic species is large on the abyssal plain. Though there is a dilution effect from dead planktic tests. The planktic foraminifera range 75-90% of the micro-fauna. The agglutinated forms have very complex labyrinthic interior structures.

In the Hayward [9] chart (Fig. 6), the variations in P/B ratios in percentages are placed on the y-axis, while the paleodepths in metres are given on the x-axis. Also, inside the chart are two distinct figures of bar and dark curves which are positively skewed. The percentage of planktics in the P/B ratio is used to draw horizontal line along its calculated values on both sides of the y-axis. A diagonal line originating from zero % P/B ratio value on the left-hand side of the y-axis is drawn to intercept the percentage of benthics in the P/B ratio marked on the right-hand side of y-axis. The point of interception of the drawn horizontal line on the bar and dark curves and the diagonal line are noted and projected to the x-axis to infer the paleodepths of deposition in metres. In Table 1, the average calculated P/B ratio in this study is 25.92%/74.08%. On the left-hand side of the y-axis, 25.92% was marked and a horizontal line was drawn therefrom to intercept its corresponding value on the right-hand side of the y-axis in Fig. 6. From the 0% P/B ratio on the left-hand side of the y-axis, a line was drawn to intercept 74.08% on the right-hand side of the y-axis. The points of interceptions of the bar and dark curves with the drawn horizontal and diagonal lines were marked and projected to intercept the x-axis. The interceptions on the x-axis were noted and used to deduce paleodepths of inner to outer neritic (shelf) environment of deposition. Also, using the triangular cross-plot of foraminiferal morphogroups [13], [14], [15] in the study area indicated paleoenvironment of "most shelf seas" (Fig. 7).

Furthermore, the percentage ratio of calcareous benthic to arenaceous benthic foraminifera (FOBC/FOBA ratio) provides useful paleoenvironmental guide and the higher the % FOBC ratio, the shallower the paleodepths, conversely, the higher the % FOBA, the deeper the paleodepths [8], [10, [3], [4]. The FOBC/FOBA ratios in the five wells have the following distributions: (80.41% - 84.14%)/(15.86%-19.51%) with calculated average of 82.51%/17.49% (Table 1). The calculated average value of 82.51% for calcareous benthics and 17.49% for the arenaceous benthics in the samples are indicative of shallow marine environment.

Benthic foraminifera of the Niger Delta contain paleobathymetric indicators of varying environments of sediment deposition from coastal to bathyal depths [19]. The indicator foraminiferal assemblages and individual specimens [2], [21], [8], [10], [13], [14], [3], [4], [12], [19] were used to characterise the paleobathymetric environments of deposition in the studied wells. Three paleodepths of inner neritic, middle neritic and outer neritic (shelf) were characterised by indicator fossils such as *Cassidulina neocarinata* THALMANN, *Textularia* sp. DEFRANCE, *Eponides eshira* DE KLASZ and RÉRAT, *Quinqueloculina seminulum* LINNÉ, *Uvigerina auberiana* D'ORBIGNY, *Ammonia beccarii* LINNÉ, *Nonionella* sp., *Globocassidulina subglobosa* BRADY, *Cancris auriculus* FITCHTEL & MOLL, *Amphicoryna scalaris caudata* BATSCH, *Spiroplectammina carinata* CUSHMAN and *Quinqueloculina microcostata* NATLAND, *Uvigerina peregrina* CUSHMAN, *Uvigerina subperegrina* CUSHMAN & KLEINPELL, *Bulimina aculeata* BROTZEN and *Florilus* ex. gr. *N. costiferum* CUSHMAN and *Nodosaria* sp. LAMARCK, etc. Fig. 8 shows photomicrographs of the paleobathymetric indicator species used in the study.

Besides, in accordance with Boersma's [3] criteria for paleoenvironmental analysis, the paleobathymetric environments of inner neritic to outer neritic are inferred from the under-listed interpretation of the results on the studied wells:

(a) The calculated average percentage of the calcareous benthic foraminifera individuals in the samples (82.51%) in relation to the population of the arenaceous/agglutinated forms,
(b) The presence of highly ornamented species such as *Quinqueloculina seminulum* LINNÉ, *Uvigerina auberiana* D'ORBIGNY, *Globocassidulina subglobosa* BRADY, *Amphicoryna scalaris caudata* BATSCH, *Spiroplectammina carinata* CUSHMAN and *Quinqueloculina microcostata* NATLAND, *Uvigerina peregrina* CUSHMAN and *Uvigerina subperegrina* CUSHMAN & KLEINPELL, etc.,
(c) The average percentage ratio of planktic foraminifera in the P/B ratio in the samples (25.92%), which is in the Boersma's [3] range of 15–30% for middle neritic paleodepths.
(d) The lithofacies in the wells such as clay, silt, poorly to well sorted fine- to coarse- grained sands and the presence of fossil accessories such as micro-mollusc and echinoid remains, etc. are indicative of inner neritic to outer neritic paleodepths.

4.2 Lithostratigraphy

The study area has two lithostratigraphic units, namely: the paralic Agbada and the continental Benin Formations that are recognised in the onshore and offshore Niger Delta basin [20, [18]. The assessment of the ditch cutting samples from the five wells corroborates the fact that the Agbada Formation is a sequence of sandstones alternating with shales/mudstones with sands predominating in the upper section [16]. The binocular microscopic assessment of the samples indicated that the Agbada Formation is largely made up of a sequence of shale/mudstone alternating with variable, thickly-bedded sands. The Benin Formation consists of fluviatile sands with clay, shale/mudstone interbeds [5]. In the Agbada Formation, the shallowest depth penetrated was 2,268.93 m in TMB-1 well, while the deepest of 3,962.40 m was penetrated in TMB-6 well (Table 2). Also, in the Agbada Formation, the lithostratigraphic thicknesses in the well depth intervals ranged from 1,014.07 m in TMB-6 to 1,510.59 m in TMB-1 wells, while TMB-2, TMB-4 and TMB-5 wells lie within the above range of values (Table 3). In the study area, the shallowest depth penetrated in the Benin Formation was 731.52 m in TMB-4 well while the deepest depth of 2,948.33 m was in TMB-6 well (Table 2). Lastly, the lithostratigraphic thicknesses in the well depth intervals ranged from 741.88 m in TMB-1 to 1,726.08 m in TMB-6 wells, while TMB-2, TMB-4 and TMB-5 wells lie within the above-mentioned range of values (Table 3). Fig. 9 shows the lithostratigraphic log of the five wells in the study area.

Table 1. Statistical Distribution of Foraminiferal Morphogroups (Source: Obaje [16])

S/N	WELL NAME	FOP	FOBC	FOBA	ACC.*	TOTAL DIV.	FOP : (FOBC + FOBA)		BENTHICS RATIO	
							FOP	FOBC & FOBA	FOBC	FOBA

1	TOMBOY-1	522	1,188	224	111	2,045	26.99%	73.01%	84.14%	15.86%
		25.53%	58.09%	10.95%	5.43%	100%				
2	TOMBOY-2	278	739	180	91	1,288	23.23%	76.77%	80.41%	19.59%
		21.58%	57.38%	13.98%	7.06%	100%				
3	TOMBOY-4	508	1,171	250	109	2,038	26.33%	73.67%	82.41%	17.59%
		24.93%	57.46%	12.27%	5.34%	100%				
4	TOMBOY-5	477	1,099	244	109	1,929	26.21%	73.79%	81.83%	18.17%
		24.73%	56.97%	12.65%	5.65%	100%				
5	TOMBOY-6	580	1,325	257	135	2,297	26.83%	73.17%	83.76%	16.24%
		25.25%	57.68%	11.19%	5.88%	100%				
6	AVERAGE % VALUES	24.40%	57.52%	12.21%	5.87%	100%	25.92%	74.08%	82.51%	17.49%

KEY: ACC.* = Accessories such as pelecypods, micro-molluscs, shell fragments, ostracods, echinoderm remains, etc.
FOP = Planktic Foraminifera; FOBC = Calcareous Benthic Foraminifera; FOBA = Arenaceous Benthic Foraminifera

Table 2: Lithostratigraphic Data of XY-1 Field (Source: Obaje and Okosun [17])

FORMATION	TMB-1 DEPTH (M)	TMB-2 DEPTH (M)	TMB-4 DEPTH (M)	TMB-5 DEPTH (M)	TMB-6 DEPTH (M)
BENIN	1,527.05- 2,268.93	1,527.05 - 2,282.95	731.52 - 2,273.81	1,219.20 - 2,417.98	1,222.25 - 2,948.33
AGBADA	2,268.93 - 3,779.52	2,420.11 - 3,791.71	2,273.81 - 3,489.96	2,417.98 - 3,535.68	2,948.33 - 3,962.40

Table 3: Lithostratigraphic Thicknesses of Well Depth Intervals of XY-1 Field (Source: Obaje and Okosun [17])

FORMATION	TMB-1 THICKNESS (M)	TMB-2 THICKNESS (M)	TMB-4 THICKNESS (M)	TMB-5 THICKNESS (M)	TMB-6 THICKNESS (M)
BENIN	741.88	755.90	1,542.29	1,198.78	1,726.08
AGBADA	1,510.59	1,371.60	1,216.15	1,117.70	1,014.07

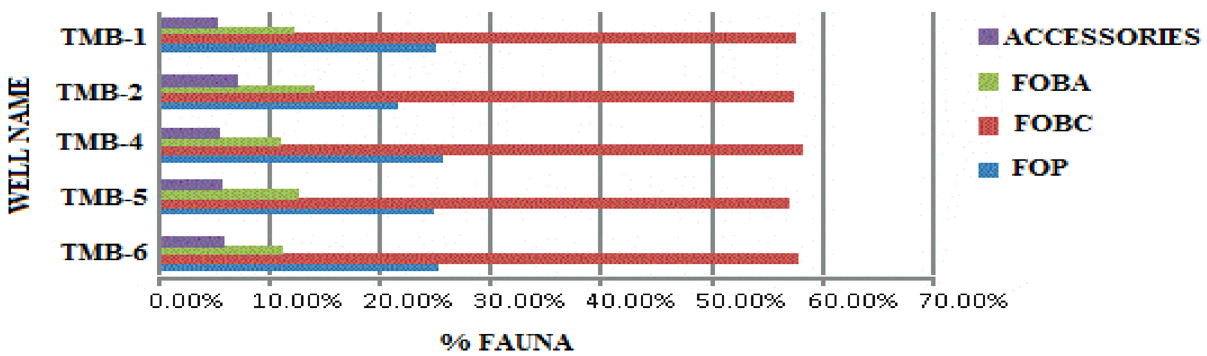


Fig. 4. Distribution Chart of Foraminifera Morphogroups in Tomboy Field

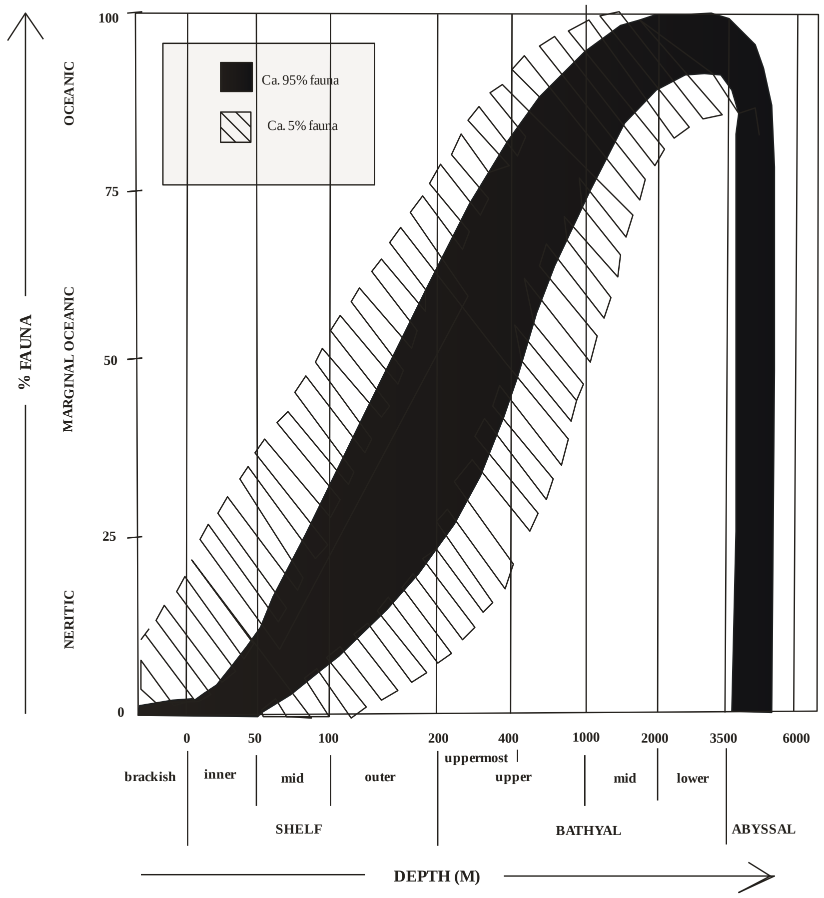


Fig. 6. Variation in the ratio of planktic to benthic foraminifera with depth (after Hayward [9])

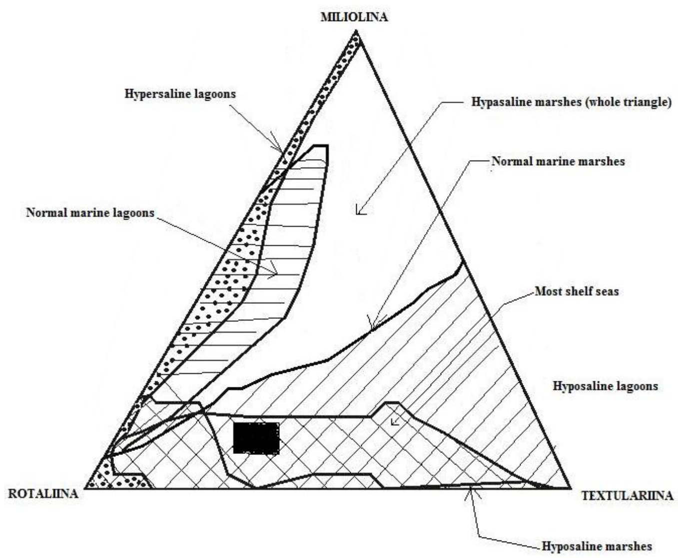
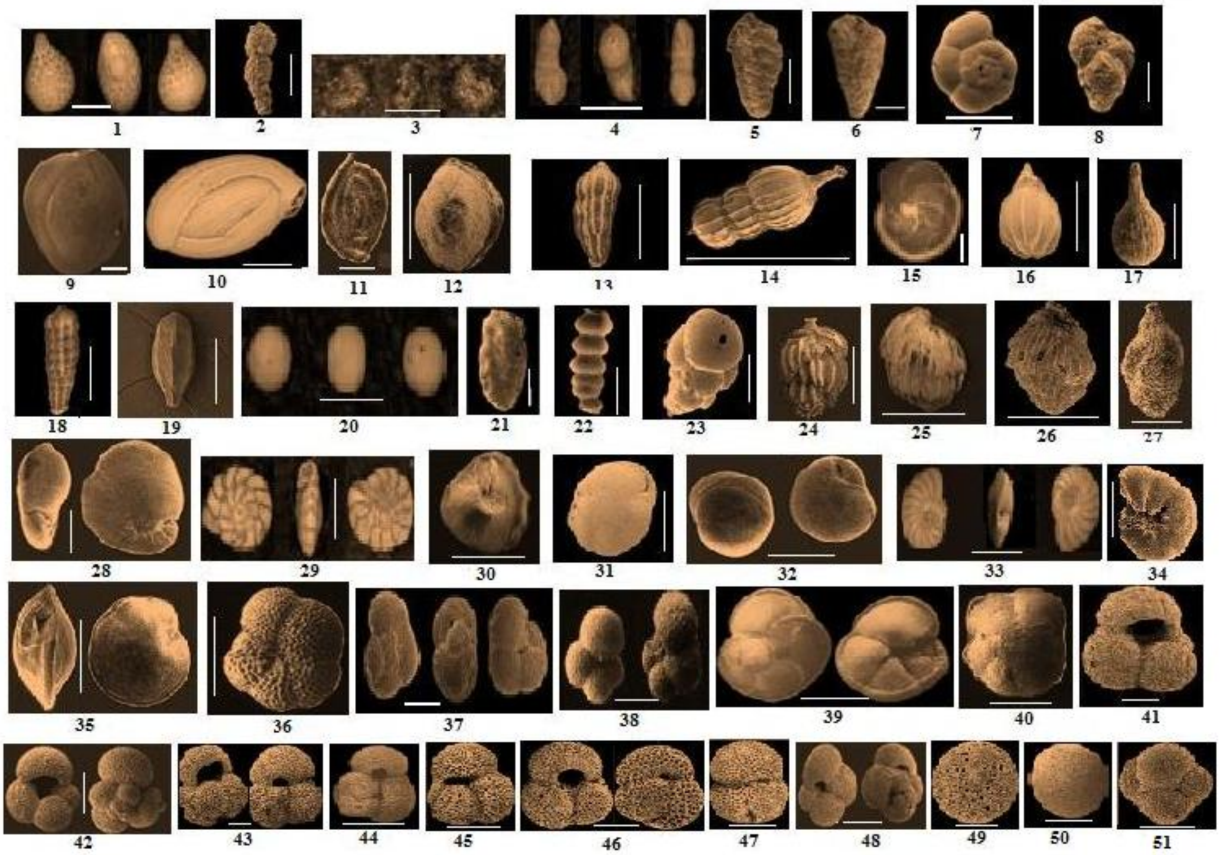


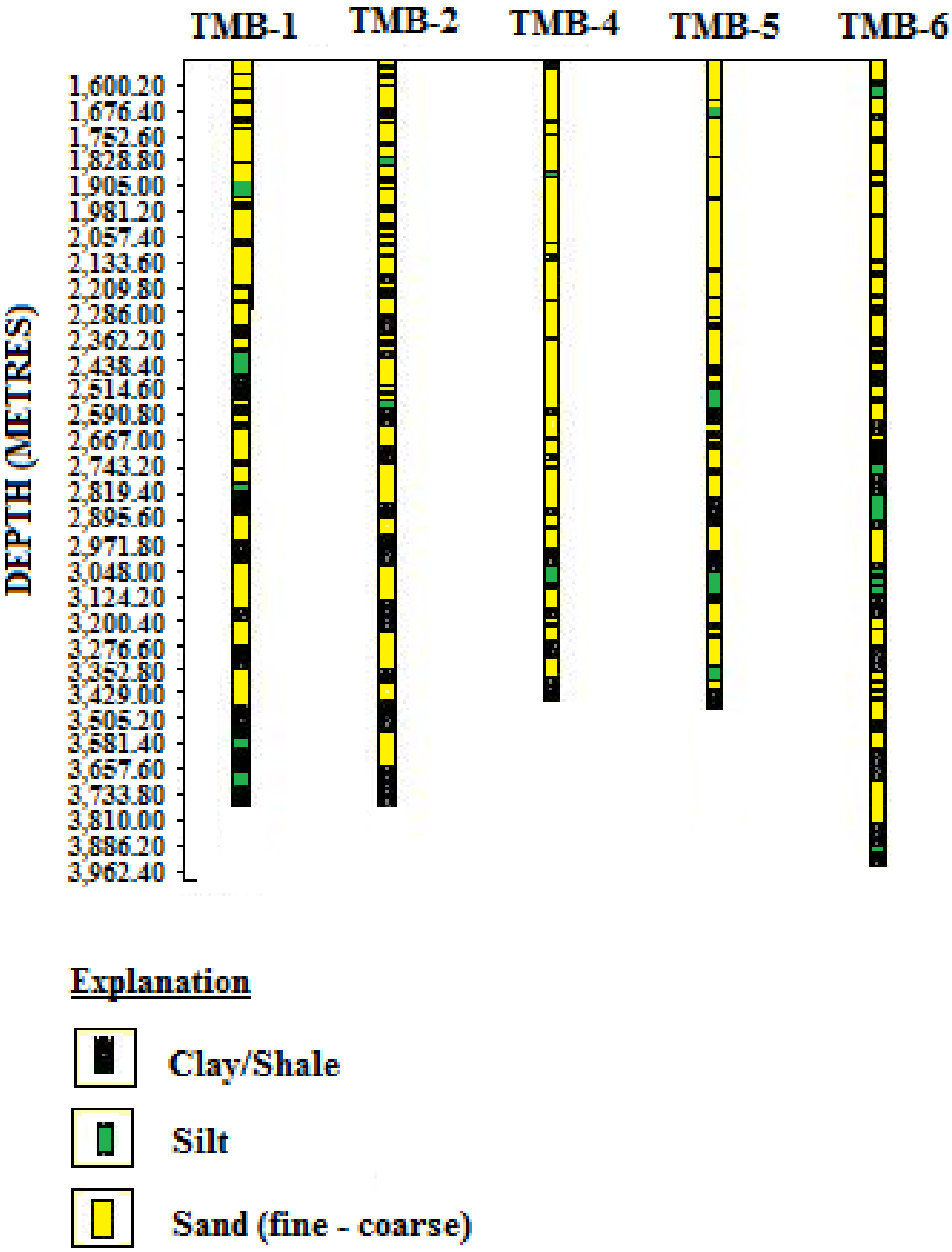
Fig. 7. Tomboy Field Foraminiferal Morphogroups Triangular Plot (based on Murray [13]). Black rectangle is indicative of samples in "Most shelf seas" paleoenvironment



1. *Saccammina complanata* FRANKE
2. *Reophax* cf. *R. morrisoni* CUSHMAN & ELLISOR
3. *Haplophragmoides* cf. *H. hausa* PETTERS
4. *Ammobaculites* cf. *A. jarvisi* CUSHMAN & RENZ
5. *Spiroplectammina carinata* CUSHMAN
6. *Textularia* sp. DEFRANCE
7. *Trochammina* cf. *T. pacifica* CUSHMAN
8. *Eggerella scabra* WILLIAMSON
9. *Quinqueloculina seminulum* LINNÉ
10. *Quinqueloculina microcostata* NATLAND
11. *Sigmoilina tenuis* CŽJŽEK
12. *Spirosigmoilina oligoceanica* CUSHMAN
13. *Nodosaria* sp. LAMARCK
14. *Amphicoryna scalaris caudate* BATSCH
15. *Lenticulina inornata* D'ORBIGNY
16. *Lagena striata* D'ORBIGNY
17. *Lagena costata* WILLIAMSON
18. *Marginulina costata* BATSCH
19. *Rectoglandulina comatula* LOEBLICH & TAPPAN
20. *Oolina* sp. D'ORBIGNY
21. *Brizalina* sp. LOEBLICH & TAPPAN
22. *Stilostomella* sp. GUPPY
23. *Bulimina aculeata* BROTZEN
24. *Uvigerina peregrina* CUSHMAN
25. *Uvigerina subperegrina* CUSHMAN & KLEINPELL
26. *Uvigerina sparsicostata* CUSHMAN & LAIMING
27. *Uvigerina auberiana* D'ORBIGNY
28. *Cancris auriculus* FICHTEL & MOLL
29. *Ammonia beccarii* LINNÉ
30. *Eponides eshira* DE KLASZ & RÉRAT
31. *Cassidulina neocarina* THALMANN
32. *Globocassidulina subglobosa* BRADY
33. *Florilus* ex. gr. *N. costiferum* CUSHMAN
34. *Nonionella* sp. CUSHMAN
35. *Hoeglundina elegans* D'ORBIGNY
36. *Globorotalia mayeri* CUSHMAN & ELLISOR
37. *Globorotalia continuosa* BLOW
38. *Globorotalia obsea* BOLLI
39. *Globorotalia menardii* 'A' BOLLI
40. *Globorotalia foshi lobata* BERMUDEZ
41. *Globigerina praebulloides* BLOW
42. *Globigerina bulloides* D'ORBIGNY
43. *Globigerina obliquus* BOLLI
44. *Globigerinoides extremus* BOLLI & BERMUDEZ
45. *Globigerinoides quadrilobatus* D'ORBIGNY
46. *Globigerinoides subquadrilobatus* (BRÖNNIMANN)
47. *Globigerinoides trilobus* REUSS
48. *Globigerinoides sacculifer* BRADY
49. *Orbulina suturalis* BRÖNNIMANN
50. *Orbulina universa* D'ORBIGNY
51. *Globigerinita naparimaensis* BRÖNNIMANN

Scale bars: 100 µm

Fig. 8. Photomicrographs of Paleobathymetric Indicator Species



Fi.g. 9. Lithostratigraphic Logs of Five Wells in the Tomboy Field

5. CONCLUSION

The aim of the study was realised using foraminifera specimens and lithofacies data. Foraminiferal morphogroup triangular cross-plot based on the ratios between Textulariina, Miliolina and Rotaliina indicated most shelf paleoenvironment. Also, the ratio of planktic to benthic foraminifera (P/B ratio) of 25.92%/74.08% corroborated the paleodepths of inner to outer neritic (shelf) environments of deposition. In addition, the percentage ratios of calcareous benthic to arenaceous benthic foraminifera (FOBC/FOBA) in the five wells with calculated average of 82.51%/17.49% indicated shallow marine paleoenvironment. The presence of paleodepths indicator fossils also confirmed the paleodepths of inner neritic, middle neritic and outer neritic. The assessed lithofacies and fossil accessories also established paleodepths of inner neritic to outer neritic. Paleoenvironmental interpretation is very useful for determining environments of deposition, which is a valuable cost-effective input into petroleum exploration and development.

REFERENCES

[1] Avbovbo, A.A., 1978. Tertiary lithostratigraphy of Niger Delta, AAPG *Geol. Notes*, pp. 296-300.

[2] Bandy, O.L., 1964. General correlation of foraminiferal structure with environment, in: Imbrie, J. and Newell, N. D. (eds.), *Approaches to paleoecology*, John Wiley, New York, pp. 75 – 90.

[3] Boersma, A., 1978. Foraminifera, *in:* Haq, B.U. and Boersma, A. (eds.), *Introduction to Marine Micropaleontology*, Elsevier North Holland Inc., New York, pp. 19–77.

[4] Brasier, M. D., 1979. *Microfossils*. Univ. Hull Press, Kingston-upon-Hull, UK, 193 pp.

[5] Esan, A.O., 2002. High resolution sequence stratigraphic and reservoir characterization studies of D-07, D-08 and E-01 sands, Block 2 Meren Field, Offshore, Niger Delta,'' Publ. M.S. Geology Thesis, Texas A & M University, Texas, USA, 115 pp.

[6] Doust, H. and Omatsola, E., 1990. Niger Delta. In Edwards, J.D. and Santogrossi, P.A. (Eds.), Divergent/Passive Margin Basins, *American Association of Petroleum Geologists Memoir 48*, pp. 201-239.

[7] Frankl, E.J. and Cordy, E.A., 1967. The Niger Delta Oil Province Recent Development Onshore and Offshore, *7th World Petroleum Congress Proceedings, Mexico City, IB*, pp. 195-209.

[8] Funnel, B.M., 1967. Foraminifera and radiolarian as depth indicators in the marine environment, *Mar. Geol., vol. 5*, pp. 333 – 347.

[9] Hayward, B.W., 1990. Use of foraminiferal data in analysis of Taranaki Basin, New Zealand. *Journal of Foraminifera Research*, *vol. 20, no. 1*, pp. 71–83.

[10] Kafesioglu, I.A., 1971. Specific diversity of planktonic foraminifera on the continental shelves as a paleobathymetric tool, *Micropaleont., vol. 17*, pp. 455 –470.

[11] Knox, G.J. and Omatsola, E.M., 1989. Development of the Cenozoic Niger delta in Terms of the "Escalator Regression" Model and Impact on Hydrocarbon Distribution. In. van der Linden, W.J.M. et al. (Eds.), *Proceedings, KNGMG Symposium on Coastal Lowlands, Geology, Geotechnology*, Dordrecht, Kluwer Academic Publishers, pp. 181-202.

[12] Morkhoven, F.P.C.M. Van, Berggren, W.A. and Edwards, A.S., 1986. Cenozoic cosmopolitan deep-water benthic foraminifera. *Bull. Centr. Rech. Expl.-Prod., Elf-Aquitaine, no. 11*, 421pp.

[13] Murray, J.W. (1973): *Distribution and ecology of living benthic foraminiferids*. Crane, Russak & Co., New York, 244 pp.

[14] Murray, J.W. (1991): *Ecology and paleoecology of benthic foraminifera*, Longmans Scientific & Technical, Harlow, 397pp.

[15] Murray, J.W. and Wright, C.A. (1974): *Paleogene foraminiferida and palaeoecology, Hampshire and Paris Basins and the English Channel.* Paleont. Assoc. London, Spec. Papers Palaeont., no. 14, pp. 1–129.

[16] Obaje, S.O., 2011. Sequence Stratigraphy and Biostratigraphy of XY-1 (Tomboy) Field, Offshore Western Niger Delta, Nigeria. Unpublished PhD Geology dissertation, Federal University of Technology, Minna, Nigeria, 254pp.

[17] Obaje, S.O. and Okosun, E.A., 2013. Planktic Foraminiferal Biozonation and Correlation of XY-1 Field, Offshore Western Niger Delta, Nigeria. *Int. J. Sci. Techn., vol. 3 no. 3*, pp. 160-167.

[18] Ojo, E.A., Fadiya, L.S. and Ehinola, O.A., 2009. Biozonation and correlation of BDX-1 and BDX-2 wells of deep offshore Niger Delta using calcareous nannofossils, *Search and Discovery Article (AAPG) no. 50194*, 8 pp.

[19] Okosun, E.A., 2003. Taxonomic review of SPDC Niger Delta benthic foraminiferal type collection. Unpubl. SPDC Records, 62 pp.

[20] Short, K.C. and Stäuble, A.J., 1967. Outline of Geology of Niger Delta,'' *American Association of Petroleum Geologists Bulletin 5, vol. 51*, pp. 761-779.

[21] Stehli, F.G. and Creath, W.B., 1964. Foraminifera ratios and regional environments, *Bull. Am. Assoc. Petrol. Geol., vol. 48*, pp. 1810 – 1827.

[22] Tuttle, L.W.M., Charpentier, R.R. and Brownfield, E.M., 1999. The Niger Delta Petroleum System: Niger Delta Province, Nigeria Cameroon, and Equatorial Guinea, Africa, *U.S. Geological Survey Open-File Report 99-50-H*, Denver, Colorado, 70 pp.

[23] Weber, K.J. and Daukoru, E., 1975. Petroleum Geology of the Niger Delta, *Proceedings of the 9th World Petroleum Congress*, Tokyo, *vol.2*, pp. 202-22.

[24] Whiteman, A., 1982. *Nigeria- Its Petroleum Geology, Resources and Potential*, London, Graham and Trotman, p. 394.