Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 311-324
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DEPOSITIONAL ENVIRONMENT AND STRATIGRAPHIC FRAMEWORK OF THE NS-1 WELL, COASTSL SWAMP DEPOBELT, NIGER DELTA BASIN: A FORAMINIFERAL PERSPECTIVE

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Received: 03-07-2024
Accepted: 24-07-2024

https://dx.doi.org/10.4314/sa.v23i3.29

Journal Homepage: http://www.scientia-african.uniportjournal.info
Publisher: *Faculty of Science, University of Port Harcourt.*

ABSTRACT

A comprehensive analysis of 102 ditch-cutting samples from the NS-1 well in Leuma Field, Coastal Swamp Depobelt, Niger Delta Basin, covering depths from 4730 ft to 7790 ft, is presented. Lithologic descriptions revealed eleven lithostratigraphic sub-units within the transitional-paralic sequence of the Agbada Formation, comprising alternating sandstone and shale. The foraminiferal analysis identified 58 species: 14 planktonic, 26 calcareous benthic and 18 agglutinated benthic. Key planktonic index species such as Globigerinoides sp. and Globorotaliacontinuosa indicates a Middle to Late Miocene age. The biozonation correlates with the Blow (1969) Scheme (N7-N9/N10/N11) placing the intervals within the Middle Miocene to Late Miocene epochs. The depositional environment transitioned from Coastal Deltaic to Inner Neritic and Middle Neritic, suggesting a shallow marine setting influenced by a warm, humid climate. The presence of calcareous foraminifera supports a shallow marine deposition above the carbonate compensation depth. This study provides valuable insights into the sedimentological, stratigraphic, and paleoenvironmental history of the NS-1 well during the Miocene.

Keywords: Planktonic, Benthonic, Calcareous, Lithostratigraphic, Paleoenvironment, Depobelt.

INTRODUCTION

The Niger Delta Basin, one of the most prolific hydrocarbon provinces in the world, offers a complex stratigraphic and sedimentological framework essential for understanding its geological history and resource potential. It is one of the Tertiary deltas that produces the most petroleum globally. The basin's petroliferous character has led to years of substantial, ongoing geologic research on it, conducted for both commercial and scholarly objectives (Avbovbo, 1978). Since the commercial quantity of oil was discovered in the Oloibiri-1 well in 1956, there has been intensive exploration and exploitation of hydrocarbon in the basin, which began in the early 1960s (Nwajide and Reijers, 1996). The majority of the Niger Delta Basin's significant hydrocarbon reservoirs are typically found in areas with complicated stratigraphy and structure (Short and Stauble, 1967). Many separate reservoirs with differing compositions and gas/oil ratios make up the majority of fields. The clastic portion of the Niger Delta Basin was produced along aulacogen that had previously advanced during the Late Jurassic plate tectonics, according to Burke (1972) and Whiteman (1982). Igbinigie and Aigbadon (2024) carried

out a biostratigraphic investigation of OSM well, Megbe Field, Niger Delta Basin. They observed four planktonic foraminifera zones, assigned late Miocene to middle Miocene age and established a coastal deltaic to inner neritic environment of deposition to the sediments. In order to identify maximum flooding surfaces (MFSs) and sequence boundaries (SB), Durugbo (2013) looked at the potentials of dinoflagellate cyst abundance and diversity in two wells in the Niger Delta. Six sequence boundaries and seven maximum flooding surfaces were found upon evaluation of his findings. Based on the analysis of dinoflagellate cysts found in the Igbomotoru-1 Well, Central Swamp Depo Belt, Niger Delta Basin, Oloto (2014) dated the well to be Upper Miocene to Pleistocene era. Based on the Foraminifera morpho group triangular cross-plot of the ratios between Textularina, Miliolina, and Rotalina, the ratio of planktic to benthic foraminifera (P/B ratio), and the presence of paleodepths indicator fossils, Obaje,and Okosun (2013) interpreted the Tomboy Field Offshore Western Niger Delta as shelf (inner to outer neritic) environment of deposition. The percentage ratios of calcareous benthic to arenaceous benthic foraminifera (FOBC/FOBA) in the five wells, along with lithofacies and fossil accessories, suggested a shallow marine paleoenvironment. Planktonic foraminiferal biostratigraphic investigations were conducted by Ajayi and Okosun (2014) on four wells offshore Niger Delta Basin. They observed three foraminifera zones, forty-two foraminifera species and assigned Late Miocene to Early Pliocene age to the sedimentary succession. Three wells (Benin West-1, ANL-1, and E-12) were worked on by Odedede and Lucas (2014), who determined the palaeoenvironment for each well. They stated that sediments penetrated by the wells were deposited in a distributory channel, shelf and marine environments. This study aims to contribute significantly to our understanding of the Niger Delta Basin's geological setting

Geologic setting

The Niger Delta, a prominent oil region in Nigeria, is situated on the border of West Africa. It is bounded by the Western African shield to the west and northwest, terminating at the Benin hinge line, and by the Calabar hinge line to the east. The Anambra Basin and the Abakaliki anticlinorium delineate its northern border. Its southern border is the Gulf of Guinea. According to Etu–Efeotor **(**1997), the Niger Delta is a vast arcuate delta of the destructive, wave-dominated type. It is composed of a mainly regressive clastic series that thickens to a maximum of around 12 km in the area of the basin center (Whiteman, 1982).

The formation and genesis of the Niger Delta can be traced to the opening of the South Atlantic in the Aptian following the breakup of South America and African plates. Short and Stauble (1967) reported that the coastal sedimentary basin of Nigeria has undergone three depositional cycles. The first began with a marine intrusion in the middle Cretaceous and ended with a small folding phase in the Santonian epoch. The second cycle resulted in the establishment of a proto-Niger Delta in the late Cretaceous and a major marine transgression during the Paleocene. During the third cycle, which covered the Eocene to Recent era, the major Niger Delta kept growing (Burke, 1972).

Studies conducted in the Niger Delta have identified three vertical lithostratigraphic subdivisions or Formations (Short and Stauble, 1967): The Agbada Formation, which contains the hydrocarbon reservoirs, the Benin Formation, which is an upper delta top lithofacies, and the lower Akata Formation, which is the source of the hydrocarbon generation and contains overpressured shales (Short and Stauble, 1967). Together, the three diachronous units of Paleocene to Recent age that make up the Niger Delta's sediments are dispersed throughout onshore and offshore depobelts, forming a vast regressive cycle (Avbovbo, 1978). The thickest unit is the Benin Formation, which is made up of

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continental, backswamp, and with fluviatile deposits and has a thickness of up to 2500 meters. The Agbada Formation, comprising paralic, brackish to marine, coastal, and fluvio-marine deposits arranged in coarsening upward cycles, is situated underneath them. The marine pro-delta that descends to a depth of 6500 meters makes up the Akata Formation below. The deformed and overpressured shale deposits of the Akata Formation are a consequence of the delta's progradation (Short and Stauble, 1967).

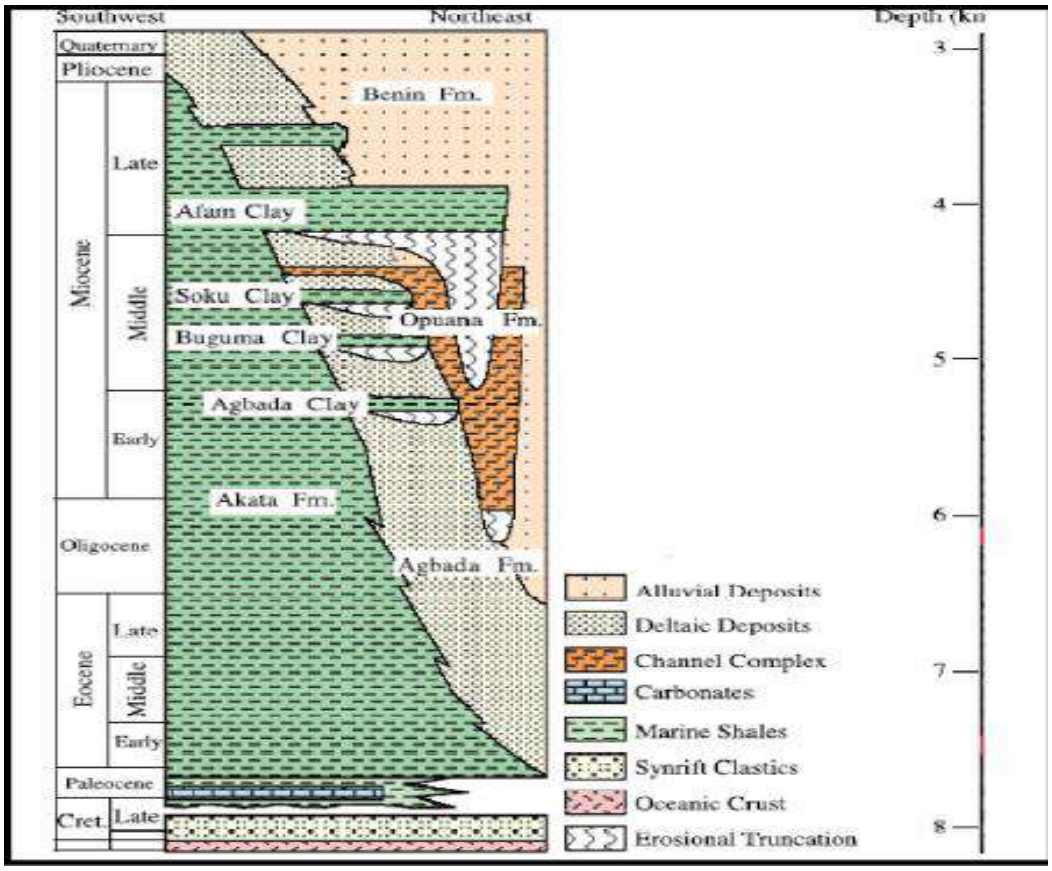

Figure 1: Stratigraphic column showing the three formations of the Niger Delta. Modified from Shannon and Naylor (1989); and Doust and Omatsola. (1990).

MATERIALS AND METHODS

The study well (NS-1 well) with a geographic coordinates of Latitude $N5^{0}45'12''$ and Longitude $E4^{0}$ 52'09''is located in Leuma Field, Coastal Swamp Depobelt of the Niger Delta Basin. For this study, one hundred and two (102) ditch-cutting samples were acquired from the NS-1 well and were processed for sedimentological study. The studied interval of the NS-1 well penetrated sedimentary succession from 4730ft to 7790ft. Lithologic description involved sequential sample preparation, washing, drying, and visual inspection using a reflected light binocular microscope to determine lithology, color, and texture. The presence of carbonate was found by chemical testing using diluted hydrochloric acid. Two grams of each sample were soaked in kerosene for the foraminifera examination, then the samples were dried and run through a 63-micron sieve. Sorting and identification of the coarse, medium, and fine fractions were done under a microscope, using type collections and albums, after the dried residues were sieved. Photomicrographs of the foraminifera were shot with a Sony digital camera that was placed on a microscope, and statistical data analysis was carried out using Stratabug 2.0 software.

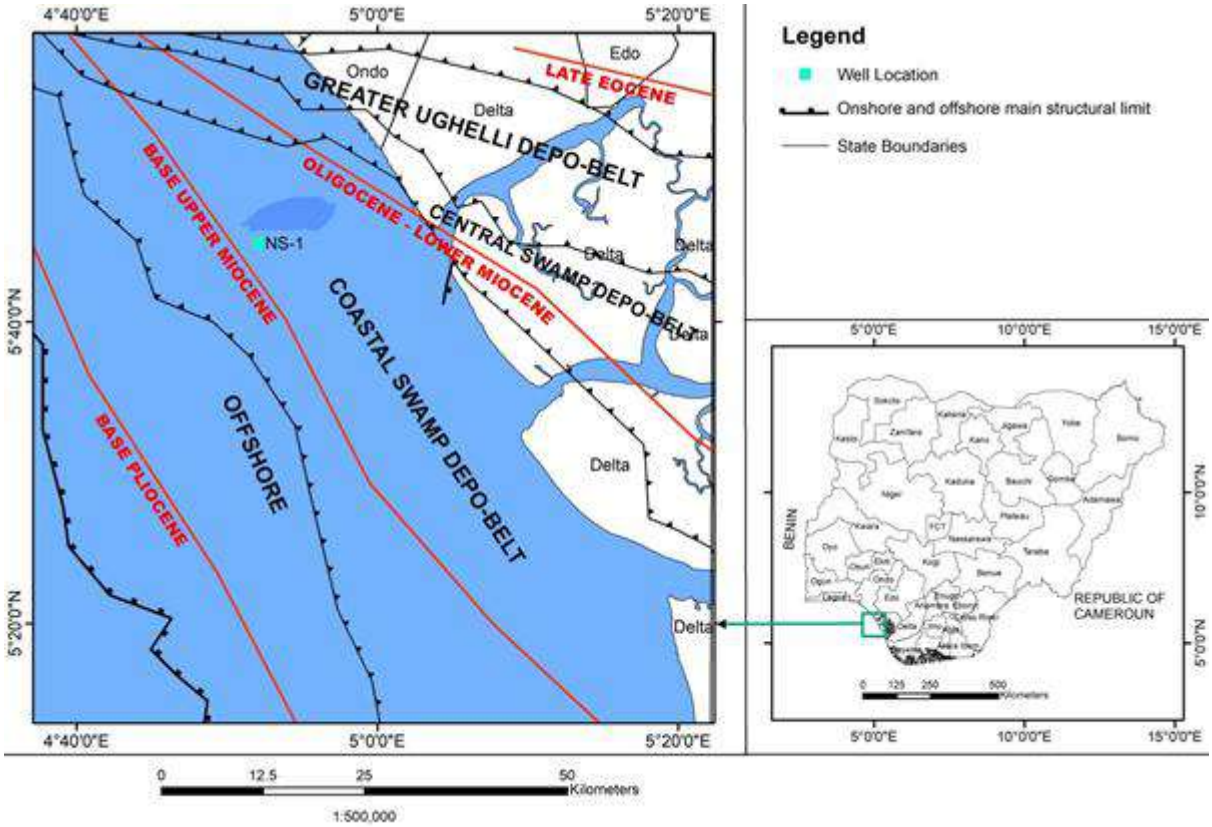

Figure 2: Niger Delta Depobelts Map showing Location of NS-1 well

RESULTS AND DISCUSSION

Lithostratigraphic Units

The lithologic characteristics of the analyzed section of the NS-1 well are discussed within the framework of the identified lithofacies units. The studied section of the NS-1 well was classified as a transitional-paralic sequence (4730ft – 7790ft). Eleven informal sedimentary units were delineated from the analysis. These lithofacies units with their corresponding depths are sub-unit one: (4730 ft - 5090 ft), sub-unit two: (5090 ft - 5360 ft), sub-unit three: (5360 ft - 5510 ft), sub-unit four: (5510 ft - 5900 ft), sub-unit five: (5900 ft - 6110 ft), sub-unit six: (6110 ft - 6470 ft), sub-unit seven (6570ft-6740ft), sub-unit eight (6740 ft - 7070 ft), sub-unit nine (7070ft-7340ft), sub-unit ten (7340ft-7550ft) and sub-unit eleven (7550ft-7790ft) respectively. Sub-Unit one (4730ft–5090ft) contained sandy shales and shaly sands with light grey, poorly sorted sands and grey fissile shales. Sub-unit two (5090ft–5360ft) was dominated by grey fissile, moderately hard shales. Sub-unit three (5360ft–5510ft) had alternating sands and shales, with sands being subangular to subrounded. Sub-unit four (5510ft–5900ft) was predominantly shale, as is sub-unit six (6110ft–6470ft) and sub-unit eight (6740ft–7100ft), each with light grey, moderately hard shales. Sub-unit five (5900ft–6110ft) and sub-unit nine (7100ft–7340ft) featured alternating sands, shales, and sandy shales. Sub-unit seven (6470ft–6740ft) includes alternating beds of sands, shaly sands, and shales, while sub-unit ten (7340ft–7550ft) was mainly shale. Sub-unit eleven (7550ft–7790ft) consisted of alternating shales and shaly sands.

The lithostratigraphic units of the analysed intervals of the NS-1 well were interpreted as the transitional-paralic sequence of the Agbada Formation (alternation of sandstone and shale) in the study well section. The transitional-paralic is also a heterogeneous succession of alternating sand and shale, with abundant occurrence of foraminiferal and dinoflagellate cysts units. The alternating sequences of sandstones and shales are cyclic

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sequences of marine and fluvial deposits. The transitional-paralic sequence is made up of a succession of sandstone and shale. The sand/shale ratio is approximately 65/35 %. Lithologically, the sands are light to dark brown, light to dark grey, milky white to white, fine to medium-grained, subangular to subrounded and poorly to moderately sorted. The shales are grey, platy and hard to moderately hard. Index minerals are dominated by mica flakes, carbonaceous detritus and ferruginous materials.

Table 1: Summary of the Lithofacies Sub-Units of NS-1 Well Transitional-paralic sequence

Interval (feet)	Sub-units	Depth Interval	Formation	Lithofacies Sequence	Diagnostic Criteria
4730 – 7090	One	4730 ft - 5090 ft	Agbada	Transitional - paralic	• Sand/shale ratio of approximately 65:35 over the 4730ft -7090ft interval • Association largely with transitional and shallow marine biofacies • Alternation of sands and shales. .
	Two	5090 ft - 5360 ft			
	Three	5360 ft - 5510 ft			
	Four	5510 ft - 5900 ft			
	Five	5900 ft - 6110 ft			
	Six	6110 ft - 6470 ft			
	Seven	6570 ft - 6740 ft			
	Eight	6740 ft - 7070 ft			
	Nine	7070 ft - 7340 ft			
	Ten	7340 ft - 7550 ft			
	Eleven	7550 ft - 7790 ft			

Foraminiferal Studies for NS-1 Well

Foraminiferal analysis was carried out on fifty (50) ditch cutting samples from 4,730 – 7,790ft. Foraminiferal recoveries were generally poor to moderate and poorly preserved. Some intervals were generally barren of foraminifera, while others contained sparse to moderate recovery of foraminiferal species. A total of fifty-eight (58) foraminiferal species were recovered from the well. The species recovered were classified into planktonic, calcareous benthonic and agglutinated benthonic foraminifera. Fourteen (14) planktonic foraminifera species, twenty-six (26) calcareous benthonic foraminifera species and eighteen (18) agglutinated benthonic foraminifera species were recorded. The percentage proportion of the various foraminifera species is as follow: planktonic foraminifera (24.1%), calcareous benthonic foraminifera (44.9%), agglutinated benthonic foraminifera (31%).

The recovery of foraminifera from the well was generally moderate. High recovery was observed in predominantly shaly units. This is probably due to the nature of the environment in which shales are deposited. There was paucity of foraminiferal species in predominantly sandy intervals and this is probably due to the rapid and high energy associated with the deposition of sands. The Stratigraphic interval 4,730–5,240ft **i**s characterized by benthonic forms like *Heterolepa pseudoungeriana, Lenticulina inornata, Alveolophragmium crissum, Cyclammina cancellata, Florilus costiferum* and *Ammobaculites agglutinans.* The stratigraphic interval 5,240 –5,480ft is characterized by Planktonic foraminifera like *Globigerinoides immaturus, Globigerinoides trilobus, Globigerinoides sp* and *Orbulina universa,* and associated benthonic foraminiferal species include *Lenticulina inornata, Lenticulina clacar, Florilus costiferum, Poritextularia panamensis, Alveolophragmium crassum, Haplophragmoides narivaensis, Quinqueloculina microcostata, Heterolepa pseudoungeriana and Heterolepa crebbsi.* The stratigraphic interval 5,480 –6,740ft is characterized by the presence of planktonic

foraminiferal species like *Globorotalia continuosa, Globorotalia mayeri, Globigerinoides immaturus,* and *Globigerinoides sp.* and associated benthonic foraminiferal which include *Spirosigmoilina oligocaenica, Lenticulina inornata, Valvulina flexilis, Haplophragmoides narivaensis, Poritextularia panamensis, Haplophragmoides sp,* and *Alveolophragmium crasum.* The stratigraphic interval 6,740 –7,790ft is characterized by the presence of planktonic foraminiferal species: *Globigerinoides trilobus, Orbulina universa, Globorotalia continuosa,* and *Globigerina praebulloides,* and associated benthonic foraminiferal assemblage include *Bolivina scalprata miocenica, Saccamina complanata, Alveolophragmium crassum, Lenticulina inornata, Heterolepa pseudoungeriana, Cyclamminacf minima,* and *Trochammina sp.*

Planktonic foraminiferal for NS-1 Well

Fourteen planktonic foraminiferal species belonging to six genera and four families were identified. Species diversity was moderate with fairly low frequency. The planktonic foraminiferal assemblages found in the well were moderately preserved. The exceptionally abundant species is *Globigerinoides*sp.

Table 2: Planktonic foraminifera recovered from NS-1 well

PLANKTONIC FORAMINIFERA	TOTAL COUNT
Globigerinoides bulloideus	1
Globorotalia sp	1
Globigerinoides obliquus	4
Globigerinoides sp	8
Planktonic indeterminate	8
Globigerinoides tribolus	1
Globigerinoides subquadratus	1
Globorotalia continuasa	3
Globigerinoides immaturate	7
Orbulina universa	3
Globorotalia mayeri	1
Globoquadrina sp	1
Sphaeroidinellopsis sp	1
Globigerina praebulloides	1
TOTAL	**41**

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Benthonic foraminiferal for NS-1 Well

The benthonic foraminiferal species is composed of consistent and diverse occurrence of foraminiferal and generally preserved compared to the planktonic forms. The diversity is moderate to high with very good frequency. Forty-four benthonic foraminiferal species were identified. The calcareous benthonic were dominated by *Heterolepa pseudoungeriana, Lenticulina inomata, Calcareous indeterminate, Marginulina costata, Lenticulinar calcar, Rectogladulina comatula, Quinqueloculina microcostata.* The remaining species were rare and, in many instances, occured in few samples. The agglutinating benthonic foraminiferal are dominated by species of*Haplophragmoidessp, Reophaxsp, Bathysiphon, Trochammina, Ammobaculitesagglutinans*.

Table 3: Calcareous benthonic foraminifera recovered from NS-1 well

CALCAREOUS BENTHONIC FORAMINIFORA	TOTAL COUNT
Placentammina sp	1
Heterolopa pseudoungeriana	78
Florilus atlanticus	5
Lenticulina calcer	4
Lenticulina inomata	107
Rectoglandulina comatula	3
Ammonia beccari	1
Amphycorina scalaris caudata	3
Lenticulina costata	1
Florilus ex. gr costiferum	10
Calcareous indeterminate	10
Quinqueloculina sp	3
Heterolepa mkkannai	1
Floritus scaphum	1
Heterolepa crebbsi	2
Uvigerina subperegrina	5
Bolivina scalprata mioceanica	3
Marginulina costata	11
Nodosaria sp	1
Bulmina sp	1

Quinqueloculina microcostata	3
Heterostegina sp	2
Stilostomella sp	2
Eponides cf. eshira	1
Uvigerina sp	1
Lenticulinacfgrandis	1
TOTAL	**261**

Table 4: Agglutinated benthonic foraminifera recovered from NS-1 well

AGGLUTINATED BENTHONIC FORAMINIFERA	TOTAL COUNT
Foraminifera indeterminate	181
Heplophragmoides sp	59
Bathysiphone sp	29
Vulvulina flexilis	8
Textularia sp	8
Textularia elegans	1
Ammobaculites agglutinans	7
Haplophragmoides compressa	9
Cyclammina cancellate	2
Alveolophragmium crissum	31
Haplophragmoides narivaensis	10
Poritextularia panamensis	2
Reophex sp	64
Trochammia sp	6
Eggerella scabra	1
*Ammobaculites*sp	3
Saccammina complanate	2
Trochamminoides sp	1
TOTAL	**424**

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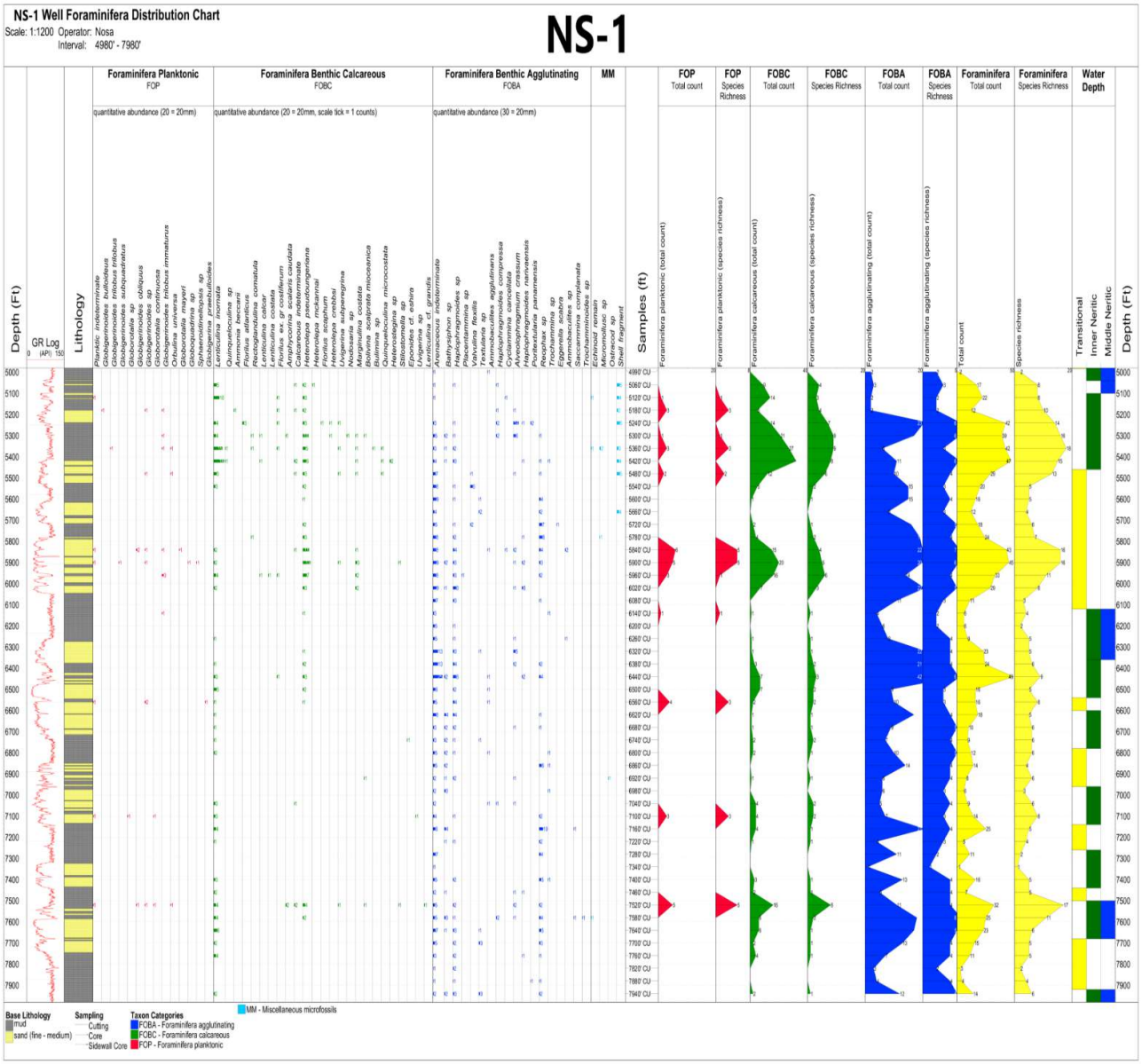

Figure 3: Foraminifera distribution chart for NS-1 well

Age determination and biozonation of NS-1 well

The recovered foraminiferal species' index forms have been used to date and zone the intervals. The concept of Blow (1969, 1979) and our understanding of the stratigraphic distributions of foraminiferal species in the Niger Delta served as the foundation for the foraminiferal zonation of the NS-1 well. The works of Gradstein and Ogg (2004), and Vail and Wornardt (1991) served as the foundation for the numerical ages (Ma).

Planktonic foraminiferal species are generally rare in this well, zonation on the basis of planktonic species could not be well established but were inferred using the endemic benthonic foraminiferal marker species whose stratigraphic distributions have been well established in the Niger Delta and have been calibrated with the planktonic foraminifera. The important foraminifera dating events used are first downhole occurrence (FDO) of chronostratigraphically significant planktonic/benthonic foraminiferal species, last downhole occurrence (LDO) of planktonic/benthonic foraminiferal marker species, foraminiferal abundance and diversity peaks dated with foraminiferal markers

species whose stratigraphic ranges are well established in the Niger Delta and worldwide.

Stratigraphic Intervals and Zonation

Interval 4,730 – 5,240 Ft: This interval corresponds to the Planktic Zones N17 – N16 as defined by Blow (1969, 1979). The benthic foraminifera zone is F9600, with the benthic zone characterized by the presence of *Ammobaculites agglutinans* and *Florilus costiferum*. The age of this interval is identified as Late Miocene, with an estimated numerical age ranging between 7.72 to 9.50 million years ago (Ma). The age determination for this interval is based on the First Downhole Occurrence (FDO) of key species: *Florilus*ex. gr. *costiferum* at 4,780 ft., *Ammobaculites agglutinans* at 4,990 ft., and *Globorotalia continuosa* at 4,900 ft.

Interval 5,240 – 5,480 Ft: This stratigraphic interval is placed within the Planktic Zones N16 – N15 as per Blow's classification. The benthic zone defined by the presence of *Uvigerina subperegrina*, was placed at F9600 to F9500. This interval belongs to the Middle Miocene epoch, with an estimated numerical age between 9.50 to 12.26 Ma. The determination of this interval's age relies on the FDO of *Uvigerina subperegrina* at 5,240 ft. and *Spirosigmoilina oligocaenica* at 5,480 ft., marking the lower limit of this zone.

Interval 5,480 – 6,740 Ft: Within this interval, the Planktic Zones are N15 – N14. The benthic zone is characterized by *Spirosigmoilina oligocaenica*,falls under the F9500 zone. The Middle Miocene epoch is represented here, with an estimated numerical age of 12.26 to 13.68 Ma. The age determination is based on the FDO of *Spirosigmoilina oligocaenica* at 5,480 ft. The occurrence of *Globorotalia mayeri* at 5,840 ft. confirms the Middle Miocene. The lower boundary is marked by the FDO of *Eponides eshira* at 6,740 ft.

Interval 6,740 – 7,700 Ft: This interval corresponds to the Planktic Zones N11/N10 – N9. The benthic zone features *Eponides eshira* and *Lenticulina grandis* was placed under F9500 to F9300 zones. The Middle Miocene epoch is indicated here, with an estimated numerical age from 14.20 to 15.60 Ma. The age determination is based on the FDO of *Eponides eshira* at 6,740 ft., with a lone occurrence of *Lenticulina cf. grandis* at 7,540 ft. The upper limit of this zone is marked by the FDO of *Eponides eshira* at 6,740 ft., with an erosional surface or unconformity suggested at this depth, potentially causing the absence of N13 to N12 zones that would typically be above this interval. The lower boundary is tentatively placed at approximately 7,790 ft., marking the terminal depth of the study interval.

The study interval from 4,720 ft. to 7,700 ft. of the NS-1 well spans the Middle Miocene to Late Miocene epochs. The estimated numerical age ranges from 6.0 Ma to 13.68 Ma, covering Planktic Zones N17 to N9/N10/N11 as defined by Blow (1969, 1979). This extensive interval reflects significant geological and paleoenvironmental changes, indicated by the succession of various foraminiferal species and the presence of an erosional unconformity, suggesting dynamic depositional conditions during the Miocene epoch. The detailed stratigraphic and biostratigraphic data provide a comprehensive understanding of the sedimentary and paleoenvironmental history of the NS-1 well area during this period

Table 5: The age and biozones established in NS-1 well using foraminifera. Correlated with zonal scheme demarcated by Blow (1969, 1979) **and SPDC Niger Delta Fauna Zonal Schem**

Epoch	Age (Ma)	Planktic Foraminifera Blow (1969, 1979)]	Benthic Faunal Zone	Benthic foraminifera zone of the study	Bioevent
Depth Interval (ft)					

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4720-5240	Late Miocene	7.72-9.50	N17 – N16	F9600	*Ammobaculitesagglutinans-Floriluscostiferum*	FDO of *Globorotaliacontinuosa* at 4,900ft.
5240-5480	Middle Miocene	9.50-12.26	N16- N15	F9600-F9500	*Uvigerinasubperegrina*	FDO of *Uvigerinasubperegrina* at 5,240ft.
5480-6740	Middle Miocene	12.26-13.68	N15 – N14	F9500	*Spirosigmoilinaoligocaenica*	FDO of *Spirosigmoilinaoligocaenicca* at 5,480ft.
6740-7700	Middle Miocene	14.20-15.60	N11/N10 – N9	F9500-F9300	*Eponideseshira-Lenticulinagrandis*	FDO of *Eponideseshira*at 6,740ft

Paleoenvironment of Deposition

Micropaleontologically, paleoenvironmental deductions were based on the presence of planktic and benthic foraminiferal assemblage. The abundance and diversity of foraminiferal species were also taken into consideration. Micropaleontologically, the foraminiferal assemblage within this depositional environment fluctuates between Coastal Deltaic to Inner Neritic and occasional deepening to Middle Neritic. The interval shows a progressive deepening in the depositional environment. Foraminiferal species that characterized this depositional unit includes: *Haplophragmoides sp., Ammobaculites sp., Reophaxsp, Trochamminasp, (*Coastal Deltaic), *Poritextularia panamensis, Bathysiphon sp., Eponides cf. eshira,* (Inner Neritic), *Saccammina complanata, Alveolophragmium crassum, Uvigerina subperegrina, and Stilostomella sp. (*Middle Neritic)**.** From the above, it is clear that NS-1 sediments were not deposited in a deep water environment. Deposition took place in a shallow water environment. The ratio of agglutinated to calcareous foraminifera was also applied to determine the paleoenvironment. According to Berggren (1995), it is a well-known fact that acidity increases as we go down an ocean. With depth, calcareous foraminifera completely disappear. Below the carbonate compensation depth (CCD), calcareous foraminifera are not found at all. Calcareous foraminifera do not exist at deep ocean depth (Nwajide, and Reijers, 1996). The fact that the NS-1 well has a high amount of calcareous foraminifera depicts deposition in a shallow marine environment.

Paleoclimate

The detailed analysis of foraminiferal assemblages from the NS-1 well reveals significant insights into the paleoenvironment and paleoclimate of the region during the Middle to Late Miocene. Initially, the presence of species such as *Haplophragmoides* sp., *Ammobaculites* sp., *Reopha*x sp., and *Trochammina* sp. indicates a Coastal Deltaic environment, suggesting a warm and humid climate that supported substantial riverine input and delta formation, driven by high rainfall and a robust hydrological cycle (Murray, 2006). As the environment transitioned to the Inner Neritic zone, marked by species like *Poritextularia panamensis*, *Bathysiphon* sp., and *Eponides cf. eshira*, the climate likely remained warm, fostering a stable shallow marine ecosystem with clear waters typical of temperate to subtropical regions Leckie *et al*. (1993). Further deepening to Middle Neritic conditions, indicated by species such as *Saccammina complanata, Alveolophragmium crassum, Uvigerina subperegrina,* and *Stilostomella* sp., suggests a continued warm climate with stable sea levels, supporting a diverse benthic community and reflecting a broader Miocene warming trend and associated sea level rise (Flower and Kennett, 1994). The idea of a constantly warm

marine environment is supported by the prevalence of calcareous foraminifera throughout the well, which suggests deposition above the carbonate compensation depth and points to warm surface waters and high carbonate saturation. (Lutze, 1986). Overall, the stratigraphic progression from Coastal Deltaic to Middle Neritic settings reflects a transgressive sequence driven by global climatic influences, with a warm, humid climate initially supporting dynamic coastal systems that transitioned to stable, warmer shallow marine conditions as sea levels rose. This comprehensive interpretation aligns with global Miocene climatic patterns, characterized by generally warm conditions with periodic cooling events, and highlights the dynamic interplay between sea level changes and climatic conditions in shaping the depositional history of the NS-1 well (Zachos *et al.*, 2001)

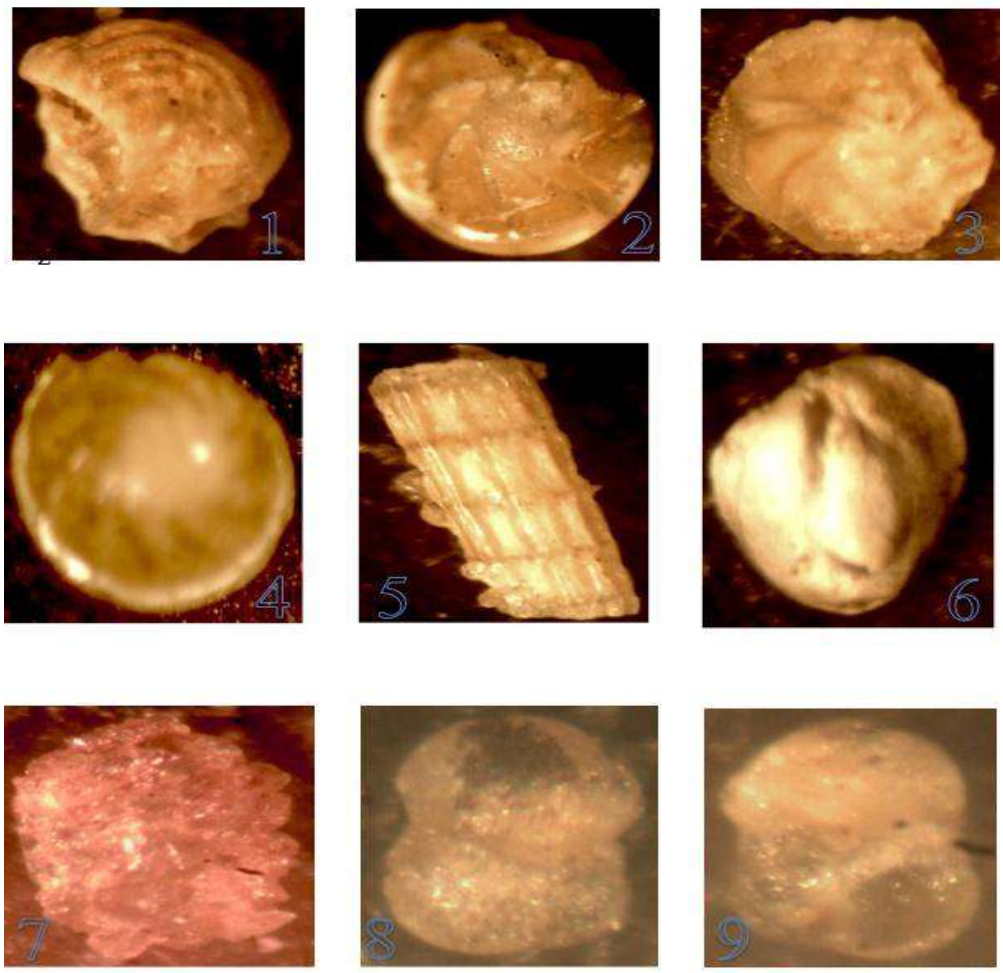

Figure 4: Photomicrographs of some important foraminifera species from NS-1 well

Photomicrograph explanation

1. Lenticulina costata
2. Lenticulina grandis
3. Lenticulina calcar
4. Lenticulina inornata
5. Marginulina costata
6. Spirosigmoilina oligocaenica
7. Ammobaculites agglutinans
8. Globigerinoides subquadratus - umbilical side
9. Globigerinoides subquadratus - spiral side

CONCLUSION

The lithologic and foraminiferal analysis of the NS-1 well in Leuma Field, Coastal Swamp Depobelt, Niger Delta Basin, reveals

Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 311-324
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significant insights into the geological history and depositional environment of the area. The identification of eleven lithostratigraphic sucb-units within the Agbada Formation, composed of alternating sandstones and shales, reflects the dynamic sedimentary processes in a transitional-paralic sequence. The foraminiferal assemblage, comprising 58 species including key planktonic index species such as *Globigerinoides* sp. and *Globorotalia continuosa*, establishes Middle to Late Miocene age for the strata.

The biozonation, correlating with Blow (1969) scheme (N7-N9/N10/N11) further delineates the temporal context of sediment deposition, spanning the Late Miocene to Middle Miocene epochs. The transition from Coastal Deltaic to Inner and Middle Neritic environments suggests a shallow marine setting, likely influenced by a warm, humid climate. The prevalence of calcareous foraminifera indicates deposition above the carbonate compensation depth, affirming a shallow marine origin.

Overall, this study enhances the understanding of the stratigraphic and paleoenvironmental evolution of the NS-1 well area, contributing valuable data for future geological and exploration endeavors in the Niger Delta Basin.

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