High-resolution Biostratigraphic Studies of Step-1 Well, Offshore, Western Niger Delta

Visoko resolucijske biostratigrafske preiskave morske vrtine Step-1 na območju zahodne delte reke Niger

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Abstract

A high-resolution biostratigraphic study of the STEP-1 well, offshore Western Niger Delta Basin, Nigeria, was carried out using foraminifera, calcareous nannofossils and palynomorphs. The study was aimed at identifying the biostratigraphic zones, age deductions as well as palaeoenvironmental and palaeoclimatic reconstructions. From the studied well section of 609 m (1,829–2,438 m), 50 ditch cuttings were used for foraminifera and calcareous nannofossils, while 25 samples were used for palynological studies at 12 m and 24 m intervals, respectively. Standard laboratory preparation techniques were employed for the three microfossil groups. Due to the occurrence of some forms such as *Globigerina praebuloides*, *Haplophragmoides spp*, *Bolivina scalprata miocenica*, *Valvulina flexilis* and *Cyclammina cf. minima*, two planktonic and one benthonic foraminifera zones were identified as follows: Lower N18, Upper N17 zone (early Pliocene, late Pliocene) and *Cyclammina minima* zone (late Miocene), respectively. Two biozones were recognized for the nannofossils and include NN12 (*Ceratolithus cristatus* zone) and NN11 (*Discoaster berggrenii* zone). These zones were assigned to early Pliocene and late Miocene, respectively. Other forms include *Discoaster pentaradiatus*, *Sphenolithus abies* and *Ceratolithus armatus*. *Echitricolporites spinosus*/P800zone has been assigned for the Palynomorph assemblages and was dated late Miocene due to the quantitative occurrence of *Cyperaceapollis spp*. Four identified major condensed sections include intervals at 1,926, 1,987, 2,097 and 2,316 m, which have been dated 5.0, 5.8, 6.3 and 7.0 Ma, respectively. Based on the benthonic foraminiferal species and Palynological Marine Index, a shallow marine environment is

deduced for the studied interval which was interpreted to be deposited under both wet and dry palaeoclimatic conditions. The findings, no doubt could serve as a template for a sequence stratigraphic model, generally beyond the resolution of seismic stratigraphy.

Keywords: drilling regime, roller cone bit, wear, reduced penetration rate, change of the material properties.

Izvešček

Z uporabo alg luknjičark, apnenčastih nanofosilov in palinomorfov so bile na območju zahodne delte reke Niger izvedene visoko resolucijske biostratigrafske preiskave morske vrtine STEP-1. Namen preiskave je bilo prepoznavanje biostratigrafskih območij, starosti ter paleookoljskih in paleoklimatskih rekonstrukcij. Iz 609 m dolgega preiskovanega odseka vrtine (1829–2438 m) je bilo uporabljenih 50 vzorcev za preiskave alg luknjičark ter apnenčastih nanofosilov ter 25 vzorcev za palinološke preiskave na intervalih dolžin 12 m in 24 m. Uporabljene so bile standardne laboratorijske tehnike priprave za tri skupine mikrofosilov. Zaradi pojavljanja nekaterih oblik, kot so *Globigerina praebuloides*, *Haplophragmoides spp*, *Bolivina scalprata miocenica*, *Valvulina flexilis* in *Cyclammina cf. minima* sta bili identificirani dve planktonski ter ena bentonska cona alg luknjičark. To sta coni: lower N18, Upper N17 (zgodnji Pliocen, pozni Pliocen) in cona *Cyclammina minima* (pozni Miocen). Za nanofosile sta bili prepoznani dve bioconi, in sicer NN12 (cona *Ceratolithus cristatus*) in NN11 (cona *Discoaster berggrenii*). Omenjeni coni sta bili dodeljeni zgodnjemu Pliocenu ter poznemu Miocenu. Ostale forme vključujejo: *Discoaster pentaradiatus*, *Sphenolithus*

abies in *Ceratolithus armatus*. *Echitricolporites spinosus*/ *cona* P800 je bila dodeljena sklopom palinomorfa in je bila datirana kot pozni Miocen zaradi kvantitativnega pojavljanja *Cyperaceapollis* spp. Štiri identificirani glavni zgoščeni odseki vključujejo intervale 1926 m, 1987 m, 2097 m in 2316 m, ki so bili datirani kot 5.0 Ma, 5.8 Ma, 6.3 Ma in 7.0 Ma. Na osnovi bentonske vrste alg luknjičark in palinološkega morskega indeksa, je

plitvo morsko območje izbrano za preučevan interval ki je nastal pod mokrimi in suhimi paleoklimatskimi pogoji. Izsledki preiskave lahko brez dvoma služijo kot osnova za zaporedni stratigrafski model, ki v splošnem presega ločljivost seizmične stratigrafije.

Ključne besede: biostratigrafija, paleoklima, paleookolje, palinološki morski indeks

Introduction

The Niger Delta Basin is one of the rift-generated sedimentary basins on the continental margin of the Gulf of Guinea in Nigeria [1]. The study area lies approximately between latitudes 4°23'30"N and 6°24'00"N and longitudes 2°45'30"E and 6°46'30"E (Figure 1). As the Niger delta basin matures, most of its subsurface uncertainties lie at reservoir scale, and hence the need for application of biostratigraphy. Oil companies which invest hugely in this high-risk business of oil exploration have undoubtedly gained much from biostratigraphic studies. Apart from assigning ages to rocks, the prediction of water depths and palaeodepositional environments is vital for the understanding and deduction of depositional models with reasonable productiveness [2]. Previous studies include those on foraminifera biostratigraphy from offshore Western Niger Delta [3]. Fajemila [3] recognized five foraminiferal zones and inferred that the sediments were of normal salinity and belonged to early Pliocene to late Miocene age.

Sanuade [4] carried out calcareous nannofossil biostratigraphy of Well 'K-2', in the deep offshore, Niger Delta. Two major zones were identified, while one condensed section was believed to be associated with 2.0 Ma maximum flooding surface (MFS).

Aturamu [6] reported on integrated biostratigraphic studies using foraminiferal and palynomorph assemblages within the Niger Delta. They established two planktonic foraminiferal zones, *Globigerinoides obliquus* and *Globigerinoides ruber*, aged Miocene–Pliocene and four benthic foraminiferal biozones. They proposed *Echiperioporites* cf. *estelae*, *Psilatricolpites okeizeis* and *Foeveotricolpites* sp. palynological zones which are correlatable with the Pantropical zones. Ukpabi and Osterloff [7]

integrated microflora and nannoflora for biostratigraphic and palaeoenvironmental study of the Niger Delta sediments. They documented the occurrence of *Belskipolliselegans* which revealed the influence of climate, sea-level changes and/or sediment influx in the Niger Delta during the middle Miocene. The transgressive and regressive trends were interpreted and correlated based on the general distribution of *Belskipolliselegans* within the palynological zones in the middle Miocene Agbada Formation of the Niger Delta Basin.

The present study gives an account of integrated foraminiferal, calcareous nannofossils and palynostratigraphy of the STEP-1 well, offshore western Niger delta, in order to deduce the age of the penetrated interval, and provide detailed information on the paleoenvironment of deposition and palaeoclimatic conditions of the sediments. Such information, no doubt, could serve as a sequence stratigraphic model, generally beyond the resolution of seismic stratigraphy.

Geologic setting and stratigraphy

The Niger Delta basin is situated between latitudes 3° and 6°N and longitudes 5° and 8°E in the Gulf of Guinea on the margin of West Africa, and is one of the largest deltaic systems in the world. Doust and Omatsola [8] and Short and Stauble [9] classified the subsurface Niger Delta into three stratigraphic units from the oldest to the youngest: Akata, Agbada and Benin Formations (Figure 2). The Akata Formation is the basal unit of the Tertiary Delta Complex and comprised shales, clays and silts at the base of the known delta sequence. They contain a few

Figure 1: Geological map of Western Niger Delta showing the approximate study area (modified from [5]).

AGE	FORMATION	LITHOLOGY	THICKNESS	SEDIMENTARY CYCLE	ENVIRONMENT
HOLOCENE	BENIN	SAND	max 2100m	REGRESSION	CONTINENTAL
PLEISTOCENE					
NEOGENE					
PLIOCENE	AGBADA	SAND	3000m	REGRESSION	TRANSITIONAL TO MARINE
MIOCENE					
OLIGOCENE					
PALEOGENE	AKATA	SHALE	600 - 6000m	TRANSGRESSION	MARINE
EOCENE					
PALEOCENE					

Figure 2: Stratigraphic succession of the Niger Delta [7].

streaks of sand, possibly of turbiditic origin [10]. The Agbada Formation is the hydrocarbon-prospective sequence, a paralic clastic sequence which lies above the Akata Formation. The upper part of the Agbada Formation often has sand percentages ranging from 50% to 75%, becoming increasingly sandy towards

the overlying Benin Formation, while the basal part is more of shale sequence [8]. The Benin Formation is the freshwater-bearing formation in the Niger Delta. It comprises the top part of the Niger Delta Basin, from the Benin-Onitsha area in the north to beyond the present coastline [9].

Materials and methods

Materials used in this study include ditch cuttings and gamma ray log. Because of the proprietary nature of the well, the exact location information was not provided, hence it was code-named STEP-1 well. The samples were selected and composited at intervals of 12 m and 24 m, respectively, which was then prepared and analysed based on fauna and flora contents. The biostratigraphic analyses were carried out while the other analysis was achieved using the STRATABUG software.

Lithologic description

The lithologic description was carried out by examining the samples under a hand lens in order to identify the constituents, describe and name the lithology. This was supported by the GR log to complement the lithologic description based on its deflection away from the Shale Baseline (SBL).

Sample preparation

The ditch cuttings were prepared for foraminifera, calcareous nannofossils and palynomorph contents using standard preparatory methods. Fifty samples were selected at 12 m intervals for foraminifera preparation; the standard weight (20 g) of each sample was soaked overnight to ensure proper disaggregation and liberation of microfossils present within the cuttings. The disaggregated samples were then washed under a shower of water over a 63 μ m sieve, rinsed in liquid detergent to remove drilling mud and dried over a hot plate. The forms were picked with a picking needle under an Olympus binocular microscope. Preparation and identification of individual foraminifera were guided following the works of [11–13], among others.

Fifty samples were selected at 12 m interval for calcareous nannofossils; about 2 g of each of the samples were scraped onto a glass microscope slide. The slides were labelled sequentially and two blobs of Norland Optical Adhesive were affixed onto the cover-slip. The slides were dried and later studied under a transmitting light microscope in polarized light. This was done following Martini [14].

Twenty-five samples were selected and composited at 24 m intervals for palynological analysis. A constant weight (30 g) of each sample was initially given a 5% dilute hydrochloric acid treatment to remove carbonates prior to complete digestion in concentrated hydrofluoric acid (HF) under a fume cupboard. The samples were decanted thrice at an interval of 1 h each through the Branson Sonifier and with the aid of a 5 μ m sieve to filter away the inorganic matter. A LOCTITE mounting medium was used for the residues, which are the palynomorphs. Identification and preparation of the specimen was done following Germeraad et al. [15].

Results and discussion

Lithologic description

The lithostratigraphic section of the studied well was produced from ditch sample descriptions and the deflection away from the shale base line on the gamma ray log. The total thickness of the analysed sample is 609.6 m (i.e. between 1,828.8 m and 2,438.4 m intervals). From the lithologic description, the samples are mainly shale with a little sand. The shale is fissile, greyish to black, while the sand is fine to medium grained. The observation revealed that the studied well is largely made up of a sequence of fine-grained shale alternating with fine- to medium-grained sandstone in the lower part while the upper part is mainly shale (Figure 3).

Foraminifera biostratigraphy

The well recorded fairly rich and diverse assemblages of planktonic and benthonic foraminifera at the upper part (1,902–2,109 m), with 55 species recorded. Of these, 22 (40%) species are calcareous, while 27 (49%) are arenaceous. Two foraminiferal “zones” were recognized in the studied section. The Cenozoic chronostratigraphic scheme of Berggren et al. [13] and the Global Sequence Cycle Chart of Hardenbol et al. [16] were adopted for this study. The zones are characterized briefly below.

Figure 3: Lithological description of STEP-1 well.

1. *Globorotalia tumida/Cyclammina minima* zone

Stratigraphic interval: 1,841–1,987 m

Equivalent planktic foraminiferal zone: “Lower” N18–“Upper” N17 zone.

Age: Late Miocene (5.99–5.47 Ma)

Diagnosis: The top of this zone is placed at the 5.47 Ma MFS, recognized at 1,926 m, while the base is defined by the 5.8 Ma MFS, recognized at 1,987 m (Figure 4). The First Downhole Occurrence (FDO) of the zonal marker, *Cyclammina cf. minima* was recorded at 1,926 m (Table 1). The zone correlates with the “Lower” N18–“Upper” N17 planktic foraminiferal zone of Berggren et al. [13] and Hardenbol et al. [16]. The age is late Miocene.

2. *Globoquadrina dehiscens/Haplophragmoides narivaensis* zone

Stratigraphic interval: 1,987–2,438 m.

Equivalent planktic foraminiferal zone: “Middle-Lower” N17 zone.

Age: Late Miocene

Diagnosis: Undiagnosed

Calcareous nannofossil biostratigraphy

The results of calcareous nannofossil analysis show high abundance and diversity of species (Figure 5). Biozonation and age determination of the well was based largely on calcareous nannofossils assemblages, abundance and diversity. The chronostratigraphic scheme adopted follows the usage of the worldwide zonation schemes of Okada and Bukry [17] and Haq et al. [18]. Considerable effort was made to identify and define zonal tops with the FDOs of diagnostic marker species, abundance and species diversity peak as these form the most reliable events [14]. The highest nannofossil peaks were dated using important marker species such as *Sphenolithus abies*, *Discoaster pentaradiatus*, *Ceratolithus cristatus*, *Ceratolithus armatus*, *Discoaster quinqueramus* and *Discoaster berggreni* (Table 2). The stratigraphic distribution of the recorded species along with the significant datum, MFSs, nannofossil zones and age interpretations are presented in distribution charts (Figure 5). The highlights of the results are summarized below.

Figure 4: Foraminiferal distribution chart of STEP-1 well.

Table 1: Foraminiferal biostatigraphy of STEP-1 well

Depth (m)	Age	Planktonic zone	Benthonic foram zone	Bioevents
1,853	Early Pliocene	N18	Indeterminate	FDO <i>Valvulina flexilis</i>
1,926				Cyclamina cf. minima 5.0 Ma MFS
1,987				
2,097	Late Pliocene	N17 and older	<i>Cyclamina cf. minima</i>	Peak fauna abundance 5.8Ma MFS
2,438			Indeterminate	

1. Interval: 1,841–1,926 m

Zone: NN12

Age: Early Pliocene

Diagnosis: This interval is dated based on the presence of *Ceratolithus cristatus* at 1,902 m and the presence of *Ceratolithus armatus* at 1,914 m. These records of nannofossils represent the early Pliocene.

2. Interval: 1,926–2,438 m

Zone: NN11

Age: Late Miocene

Diagnosis: This interval is characterized by an increase in nannofossil abundance and diversity. Its nannofossil peak at 1,963 m represents the 5.8 Ma MFS [18] late Miocene NN11 zone. This is confirmed by the FDO of *Discoaster quinquerramus* at 1,939 m. The

presence of *Discoaster berggrenii* at 2,292 m further confirmed the 7.0 Ma MFS [18] age assigned to the lower section.

Palynostratigraphy

Twenty-five palynomorphs were selected at 24 m intervals. The palynomorphs are well preserved and fairly diverse (Figure 6). These include *Zonocostites ramonae*, *Monoporites annulatus*, *Sapotaceae*, *Retitricolporites irregularis*, *Pachydemites diderixi*, *Acrostichum aureum*, *Pteris spp*, *Laevigatosporites spp*, *Verucatosporites spp*, *Stereisporites spp*, *Cyperaceapollis spp*, *Sapotaceae* and *Psilatricolporites crassus*. Dinoflagellate cysts recorded are *Selenopemphix spp*, *Polysphaeridium zoharyi* and *Leiosphaeridia spp*.

Figure 5: Calcareous nannofossil distribution chart of STEP-1 well.

Table 2: Calcareous nannofossils biostratigraphy of STEP-1 well

Depth (m)	Downhole occurrence of calcareous nannofossils	Age (Ma) Haq et al. (1988)	NP zones (Martini, 1971)	Inferred relative ages	
1,841	First sample analysed				
1,902	Presence of <i>Ceratolithus cristatus</i>		NN 12		
1,914	Presence of <i>Ceratolithus cristatus</i>				
1,926					
1,939	FDO: <i>Discoaster quinquaramus</i>	5.8		Late Miocene to early Pliocene	
1,963	Maximum flooding surface				
2,292	FDO: <i>Discoaster berggrenii</i>		NN 11		
2,316	Maximum flooding surface, Presence: Discoaster quinquaramus	7.0			
2,438 TD					

The STEP-1 sediments are assigned to the section within the Pantropical *Echitricolporites spinosus* zone of Germeraad et al. [15] and the P800 zone of Evamy et al. [1]. The zone was further subdivided into P840 and P830 sub-zones. Details of the zone and sub-zone identified are represented in Tables 3 and 4, and explained briefly below.

1. Zone: P800
Sub-zone: P840
Interval: 1,829–2,204 m
Discussion: The top of this sub-zone is placed at 1,829 m of the first sample analysed. The base is defined by the quantitative occurrence of *Cyperaceapollis spp* at 2,204 m. The P840 sub-zone is further confirmed and characterized by the presence of *Stereisporites*

Figure 6: Palynomorphs distribution chart of STEP-1 well.

Table 3: Palynostratigraphy of STEP-1 well

Depth (m) series	Sub-series	Gemeraad et al. (1968)	Evamy et al. (1978)		Bioevents
			Zone	Sub-zone	
1,829	Miocene	Late	P 800	P 840	Quantitative base occurrence of <i>Cyperaceapollis</i> spp
1,981	Miocene	<i>Echitricolporites</i> <i>Spinosus</i> zone			
2,134				P 830	
2,204					
2,286					
2,438					

spp, abundant mangrove pollen *Zonocostites ramonae* and *Monoporites annulatus*. The age assigned to this sub-zone is late Miocene.

2. Zone: P800

Sub-zone: P830

Interval: 2,204–2,438 m

Discussion: The top of this sub-zone is placed at 2,204 m defined by the quantitative base occurrence of *Cyperaceapollis* spp while the base was not penetrated. This sub-zone is further characterized by the presence of *Cyperaceapollis* spp, *Stereisporites* spp and *Racemonocolpites* hians. The age of this sub-zone is late Miocene.

Age deductions

The ages for this well were established using three bioevents (Table 5): these include recorded peak faunal abundance (MFS), sequence boundary (SB) and the occurrence of some index fossils such as *Cyclammina* cf. *minima* and *Discoaster* *beggrenii*. The chronostratigraphic position of STEP-1 well is given in Table 6.

Palaeoenvironment of deposition

1. The presence of some benthonic foraminifera such as *Uvigerina auberiana*, *Lenticulina* spp, *Valvulineria* spp, *Haplophragmoides* spp, *Cyclamina* cf. *inina* and *Bolivina scalprata*

Table 4: Harmonized biostratigraphic chart of STEP-1 well

Depth (m)	Epoch	Age	P zone	B zone	N zone	Pa zone	Pa zone and sub-zone	Bioevents
1,900								FDO <i>Valvulina flexilis</i>
1,950								Presence of <i>Ceratulithus cristatus</i>
2,000	Early Pliocene	ZANCLEAN	N18		NN 12		P840	Presence of <i>Ceratulithus armatus</i>
2,050								FDO <i>Cyclamina cf. minima</i> (5.0Ma MFS)
2,100								FDO <i>Discoaster quinqueramus</i>
2,150				<i>Cyclamina minima</i>		<i>Echitricolporites spinosus</i>	P800	5.8 Ma MFS
2,200								Peak faunal abundance (5.8 Ma MFS)
2,250			N 17 and older					6.3 Ma SB
2,300	Late Miocene	MESSIAN			NN 11		P830	Quantitative base occurrence of <i>Cyperaceapollis spp</i>
2,350								<i>Discoaster beggrenii</i>
2,400								7.0 Ma MFS

indicates a shallow marine environment (inner neritic).

2. With land-derived palynomorphs such as *Monoporites annulatus*, *Laevigatosporites spp*, *Zonocostites ramonae*, *Acrostichum aureum*, *Pachydemites diderixi*, *Pteris spp*, *Striatricolpites catatumbus* and *Cyperaceapollis spp* (from 1,853–2,438 m). It can be deduced that the sediments were deposited within a shallow marine environment.

Palaeoclimatic deductions

Palynofossils are preserved mainly in continental basins. The characteristics of great quantity, wide distribution and different preserved lithofacies are the unique advantage of these fossils [19]. For this reason, palynomorphs are now very important for reconstructing palaeoclimatic conditions at the time of sediments deposition. The climate of an area is reflected by its vegetation type [20]. The three important palynomorphs used for this study are *Monoporites annulatus*, *Zonocostites ramonae* and *Acrostichum aureum*. *Monoporites annulatus* abundance is often used as an indicator of a large degree of landscape openness [21, 22], and increased aridity [23, 24]. *Zonocostites ramonae* has been used as an indicator for mangrove vegetation and hence, wet climatic condition [25]. *Acrostichum aureum* is used as an indicator of wet climatic condition [26].

From Figure 7, the dominance in abundance of *Monoporites annulatus* over the relative abundance of *Acrostichum aureum* favours a dry climatic condition for the interval 1,853–2,048 m. While the sediments are believed to have been deposited in the Savanna setting, interval 2,073–2,146 shows alternating wet and dry climate.

From Figure 8, the dominance in abundance of *Acrostichum aureum* over *Monoporites annulatus* from interval 2,170–2,438 m indicates a wet climatic condition; hence, they are of mangrove species, although interval 2,243–2,265 m relatively shows alternating wet and dry climatic conditions. Figure 9 shows photomicrographs of foraminifera, calcareous nanofossil and Palynomorphs recovered from the STEP-1 well.

Table 5: Age deductions for STEP-1 well

Depth (m)	Age (Ma)	Microfossil	Bioevents
1,926	5.0	Foraminifera	FDO <i>Cyclamina cf. minima</i>
1,963	5.8	Nannofossils	Maximum flooding surface (MFS)
1,987	5.8	Foraminifera	Peak faunal abundance (MFS)
2,097	6.3	Nannofossils	Sequence boundary
2,316	7.0	Nannofossils	MFS

Table 6: Chronostratigraphic position of STEP-1 well

Standard chronostratigraphy				
Ma	Period	Epoch	Age/stage	This study
1	Quaternary	Holocene	Taranian	STEP-1 well
2		Pleistocene	Ionian	
3			Calabrian	
4		Pliocene	Gelasian	
5	Piacenzian			
6	Zanclean			
7	Neogene	Miocene	Messinian	
8		Tortonian		
9				
10				

Summary and conclusions

Foraminifera, calcareous nannofossils and palynomorph integrated biostratigraphic studies of the STEP-1 well in the offshore of Niger Delta Basin has resulted in the identification of biostratigraphic zones, determination of ages as well as reconstruction of the palaeoenvironment and palaeoclimatic conditions. The presence of some benthonic foraminifera such as *Uvigerina auberiana*, *Lenticulina spp*, *Valvulineria spp*, *Haplophragmoides spp*, *Cyclamina cf. inina* and *Bolivina scalprata* indicates a shallow marine environment of deposition (inner neritic). Two nannofossil zones subdivided into late Miocene and early Pliocene are confirmed by the FDO of *Discoaster quinquerramus* at 1,939 m. The presence of *Discoaster berggrenni* at 2,292 m further confirmed the 7.0Ma MFS age assigned to the interval. The late Miocene age also corroborates with the appearance of the zonal marker, *Cyclamina cf. minima*, which was recorded

Figure 7: Plot of *A. aureum*/*M. annulatus* against depth (1,853–2,146 m).

at 1,914 m. The Palynological Zonation of the well and their stratigraphic distribution based on the zonation schemes of Germeraad et al. [15] and Evamy et al. [1] are broadly assigned to the *Echitricolporites spinosus* and P800 zone, respectively. The latter was further subdivided into P840 and P830 sub-zones. The assigned age is late-late Miocene. The boundary between P830 and P840 was at 2,204 m, which was marked by the Quantitative base

Figure 8: Plot of *A. aureum*/*M. annulatus* against depth (2,170–2,438 m).

occurrence of *Cyperaceaepollis* spp. The four major condensed sections identified within the studied section of the well which include intervals at 1,926, 1,987, 2,097 and 2,316 m have been dated 5.0, 5.8, 6.3 and 7.0 Ma, respectively, based on the identified foraminiferal and calcareous nannofossil zones with their equivalent bioevents. This study reveals that the well penetrated a major sedimentary formation in the Niger Delta, which conforms to the paralic

1. <i>Uvigerina peregrina</i>	4. <i>Cyclammina cancellata</i>	7. <i>Planulina arinimensis</i>	10. <i>Cyclammina</i> cf. <i>minima</i>
2. <i>Bolivina scalpttrata miocenica</i>	5. <i>Lenticulina</i> sp.	8. <i>Lenticulina inornata</i>	11. <i>Globigerina praebuloides</i>
3. <i>Lagena</i> sp.	6. <i>Cibicides</i> sp.	9. <i>Valvulineria</i> spp.	

- (1) *Leiosphaeridia* sp (2) *Acrostichum aureum* (3) *Pachydermites diderixi*
 (4&5) *Psilatricolporites crassus* (6) *Microforaminiferal wall linings* (7) *Laevigatosporites* sp
 (8) *Monoporites annulatus* (9) *Pteris* sp (10) *Verrucatosporites* sp

Figure 9: Continued

(1) *Discoaster quinqueramus* (2) *Discoaster pentaradiatus* (3) *Discoaster brouweri*
 (4) *Sphenolithus abies* (5) *Discoaster berggrenii* (6) *Pontosphaera multipora*
 (7) *Helicosphaera carteri* (8) *Reticulofenestra pseudoumbilicus* (9) *Ceratolithus armatus* (10)
Ceratolithus cristatus (11) *Discoaster quinqueramus* (12) *Pontosphaera japonica*

Figure 9: Photomicrographs of foraminifera, calcareous nannofossil and Palynomorphs recovered from STEP-1 well.

sequence of Agbada Formation. The palynoflora *Monoporites annulatus*, *Laevigatosporites* sp. among others suggests a shallow marine environment of deposition, while the palaeoclimatic setting indicated both wet (1,853–2,146 m) and dry (2,170–2,438 m) conditions. The integration of the three microfossil groups for biostratigraphic studies has produced a detailed analysis in the recognition and interpretation of absolute biosignals.

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