Cenozoic Planktonic Foraminiferal Biostratigraphy of well HAS-64, Coastal Swamp depobelt, Niger Delta, Nigeria

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ABSTRACT

This Niger Delta area ranks among the top ten most productive oil regions globally. Consequently, numerous advanced research techniques have been developed since the discovery of oil to enhance exploration and extraction processes, aiming to provide valuable information that makes these operations more cost-effective and provide data for academic purposes. One such technique is foraminiferal biostratigraphy. This study utilized one hundred and eleven ditch cutting samples and wireline logs from the HAS-64 well which is located in the Coastal Swamp Depobelt and spans a total depth of 4,530 ft. (2,400 ft. – 6930 ft.). A Meiji binocular stereoscope and wireline logs were employed for the lithologic description. Gamma ray log responses and sand/shale ratios supported by paleobathymetric data indicate that, within the studied interval, the HAS-64 well encountered three lithofacies unit of the Agbada Formation. These units which are the paralic, transitional paralic and continental transitional units. The recovered samples contain sparse to moderate recovery of foraminiferal species. Benthic foraminiferal species dominate the assemblage while planktic species are sparse and characterized by long ranging species. Four planktic foraminiferal biozones were erected for the well, and they include the *Orbulina universa- Globoquadrina nepenthes* partial range zone (N9-N10), *Globorotalia continuosa – Orbulina universa* concurrent zone (N10-N16), *Globoquadrina dehiscens – Globorotalia continuosa* interval range zone (N16-N17), and *Globigerinoides bulloideus – Globoquadrina dehiscens* interval range zone (N17-N18). Using the planktonic foraminiferal biozones erected, four informal benthic zones were developed, and they are the *Ammonia beccarii-Hanzawaia stratonii* interval range zone, *Quinqueloculina seminulum – Siphouvigerina auberiana attenuata* interval range zone, *Siphouvigerina auberiana attenuata – Uvigerina subperegrina* interval range zone, *Uvigerina subperegrina – Textularia* sp. interval range zone. Using the planktonic foraminiferal biozonation, the sediments penetrated by well HAS-64 have been age-dated to be Middle Miocene to Earliest Pliocene.

Keywords: Niger Delta, Miocene, Pliocene, Biostratigraphy, Biozones

INTRODUCTION

The Niger Delta Basin, situated on the West African Continental margin, spans between latitudes 4°00'00"N and 6°00'00"N, and longitudes 5°00'00"E and 8°00'00"E. This area ranks among the top ten most productive oil regions globally. Consequently, numerous advanced research techniques have been developed since the discovery of oil to enhance exploration and extraction processes, aiming to provide valuable information that makes these operations more cost-effective and provide data for academic purposes. One such technique is foraminiferal biostratigraphy.

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Numerous researchers have investigated the foraminiferal biostratigraphy of the Niger Delta Basin (Adeniran, 1997; Fadiya, 1999; Ozumba and Amjor, 1999; Boboye and Adeleye, 2009; Okosun *et al.,* 2012; Obiosio, 2013; Adegoke *et al.,* 2014; Fadiya, 2014; Olajide, 2015). However, the sediments of this study well have never been analysed micropalaeontologically, and academic access to the extensive body of data in the possession of the commercial companies on the Niger Delta foraminiferal biostratigraphy remains limited, as much of it is kept confidential by commercial exploration and exploitation companies for proprietary reasons (Evamy *et al.,* 1978).

This study aims to determine the age of the sediments penetrated by the well HAS-64, decipher the paleoenvironment in which the sediments were deposited, and delimit the stratigraphic surfaces using the faunal abundance levels complimented with litholog.

Figure 1: Map of the lease areas for petroleum exploration and extraction in the onshore and offshore Niger Delta showing the probable location of the study well HAS-64 in the Coastal Swamp Depobelt (Adegoke *et al.,* 2014)

THE NIGER DELTA BASIN

The evolution of the delta is controlled by pre- and synsedimentary tectonics (Evamy et al., 1978; Ejedawe, 1981; Knox & Omatsola, 1987; Stacher, 1995; Reijers, 2011). 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 the continents of South America and Africa in the late Jurassic (Whiteman, 1982).

Stratigraphically, the Niger Delta is made up of three formations in the subsurface; the continental Benin Formation, the transitional Agbada Formation, and the paralic Akata Formation. These formations are characterised based on the sand/shale ratio, with the Akata Formation predominantly made up of shale and the Benin Formation predominantly composed of sand. The Agbada Formation is composed of an intercalation of sand and shale in almost equal amounts.

Varying rates of sedimentation and subsidence gave way to syn-sedimentary faulting, consequently forming the distinct depobelts. When further crustal subsidence could no longer be accommodated, sedimentation shifted seaward, creating additional depobelts through the same process (Doust and Omatsola, 1990; Tuttle *et al.*, 1999).

METHODOLOGY

The study utilizes ditch cutting samples and wireline logs from the HAS-64 well. These samples were kept in small, labeled polyethylene bags that specified the well name and sampling depth. In the laboratory, the bags were arranged in sequence on a wooden tray for lithologic analysis and foraminiferal recovery.

The lithologic description of the samples was done using a Meiji binocular stereoscope and wireline logs provided.

Foraminiferal recoveries were generally low to moderate and moderately well preserved. Some intervals are generally barren of foraminifera, while others contain sparse to moderate recovery of foraminiferal species. Benthic foraminiferal species dominated quantitatively while planktic species are generally sparse.

To begin the treatment process for the samples, a determined amount, specifically 25 grams, was placed into a labeled plate. Corresponding labels were attached to ensure accurate identification of each sample. Once labeled, the sample plates were placed securely on a hot plate and set to a temperature of approximately 80°C. The samples were allowed to dry on the hot plate for about 2 to 3 hours. After this drying period, the hot plate was switched off and the sample plates carefully removed and allowed to cool, and the dried samples weighed.

The samples were soaked in kerosene and allowed to sit overnight, which helps to disaggregate the material. The next day, the kerosene was carefully decanted, removing it from the samples. After decanting, the samples were covered with water and left to soak for an additional 5 hours. This soaking step further prepares the samples for subsequent procedures or analysis.

The foraminiferal biozonation of the HAS-64 was done with schemes of Berggren (1995) and Wade et al. (2011) as guides, which also provided estimates of the numerical ages in Ma. Condensed Sections/Maximum Flooding Surfaces were correlated with the Global Cycle Chart of Hardenbol et al. (1998).

RESULTS

Quantitative Analysis

After the ditch cuttings were processed, 222 planktics, 1125 benthics (1034 calcareous benthics and 91 arenaceous benthics), and 2 Ostracod sp were recovered from the study well.

Heterolepa pseudoungeriana, Lenticulina inornata, Florilus atlanticus (accepted as *Nonionella atlantica*), *Florilus costifernum* (accepted as *Florilus stellatus*), *Hanzawaia stratonii, Ammonia beccarii, Quinqueloculina microcostata, Marginulina costata,* and *Cibicorbis inflata* dominate in the calcareous benthics count. The other benthics recovered from the well are *Amphistegina lessonii, Heterolepa mckannai, Amphycorina scalaris caudata, Lenticulina calcar, Nonion commune (Florilus scaphum), Lenticulina rotulata, Bolivina isidorensis, Rectoglandulina comatula, Lagena straita, Epistominella vitrea, Quinqueloculina seminulum, Spiroloculina depressa, Lenticulina cultrata, Lenticulina curvisepta, Lagena costata, Nonionella turgidus, Bolivina scalprata mioceanica, Siphouvigerina*

auberiana attenuata, and *Uvigerina (8) subperegrina.*

The planktonic foraminiferal recovery was not substantial, albeit useful. Four *Globigerinoides* spp. dominate here; *Globigerinoides ruber, Globigerinoides trilobus immaturus, Globigerinoides bulloideus, and Globigerinoides obliquus obliquus.*

BIOSTRATIGRAPHY

By virtue of the importance of planktonic foraminifera in estimating the ages of rock units owed to their abundance, rapid evolutionary rates, and mostly short-ranging evolution, four planktonic biostratigraphic zones were established for the well HAS-64 throughout the 6,385 ft. depth of penetration.

The topmost unit from 2,490 ft. – 335 ft. could not be dated because it is barren of planktonics and only two indeterminate forms recovered. Micromolluscs were recovered too, but the entire unit is dominated by shell fragments (15 counts). All these were not useful for the purpose of the study.

Zone 1: *Globigerinoides bulloideus* – *Globoquadrina dehiscens* Interval Range Zone

This zone spans from the penetration depth of 2,500 ft. – 3,500 ft., and falls within the Berggren (1995) N17-N18 biozone in the Late Miocene to Early Pliocene. This was done on the basis of the FDO of *Globigerinoides bulloideus* and the FDO of *Globoquadrina dehiscens.* The 5.9 Ma Last Occurrence of *Globoquadrina dehiscens* (M14 of Wade et al., 2011) was used to delimit the base of this zone. Other associated planktic foraminifera are *Globigerinoides trilobus trilobus, Globigerina plesiotumida, Globigerinoides ruber, Globigerinoides trilobus immaturus, Globigerinoides obliquus obliquus, Globigerinoides bolli, Globigerinoides* sp., *Globoquadrina altispira, Neogloboquadrina dutertrei, Orbulina universa, Globigerina nepenthes, and Globorotalia pseudopima.*

The earliest Pliocene age was justified by the highest occurrence of *Neogloboquadrina dutertrei* at 2,900 ft. which is a zone N18-N22 form (Chaisson and Pearson, 1997; Young *et al.,* 2019), marking the base of the N18 subzone.

Zone 2: *Globoquadrina Dehiscens* – *Globorotalia* continuosa Interval Range Zone

This zone is of Late Miocene age and falls within the N16-N17 of Berggren (1995) and at the depth range from 3,500 ft. – 5,100 ft. of the well. The zonation was done based on the FDOs of both *Globoquadrina dehiscens* and *Globorotalia continuosa.* The accompanying forms in this zone are *Globigerinoides trilobus trilobus, Globigerina plesiotumida, Globigerinoides ruber, Globigerinoides trilobus immaturus, Globigerinoides obliquus obliquus, Globigerinoides bolli, Globigerinoides* sp., *Neogloboquadrina dutertrei, Orbulina universa, Globigerina* sp. and *Globorotalia* sp. this zone also coincides with the 8.6Ma LDO bioevent of *Globorotalia plesiotumida.*

Zone 3: *Globorotalia continuosa* – *Orbulina universa* Concurrent Range Zone (5,100 ft. - 6,180 ft.)

This zone, at the depth interval of 5,100 ft. to 6,180 ft., is dated Middle Miocene to Late Miocene as it ranges from N10-N16 in the Berggren (1995) planktonic biozonation scheme. The base of this zone is placed at ~14Ma, which is about 0.22 fraction up of the Serravallian. It was established based on the FDO of *Globorotalia continuosa* at 5,100 ft. and the LDO of *Orbulina universa* at 6,150 ft. The other forms associated with this zone are *Globigerina praebulloides, Globorotalia* sp., *Globoquadrina dehiscens, Orbulina universa, Neogloboquadrina dutertrei, Globigerinoides ruber, Globigerinoides trilobus immaturus, Globigerinoides obliquus obliquus,* and *Globigerinoides bolli.* This zone is characterised by the 9.50Ma FDO of *Uvigerina subperegrina bioevent.* Adeola *et al.* (2021) used this bioevent to delimit the N16 zone of their X-Well in the deep offshore Niger Delta.

Zone 4: *Orbulina universa-Globoquadrina nepenthes* Partial Range Zone (6,180 ft. – 6,720 ft.)

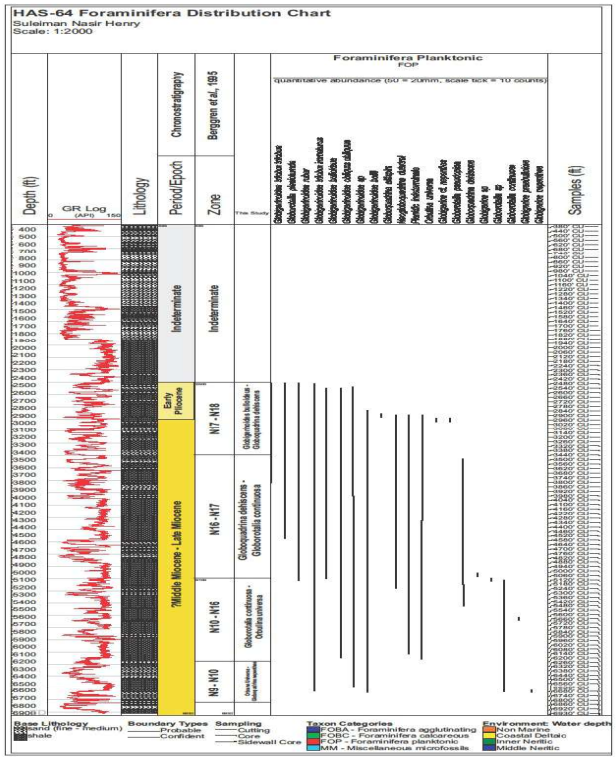

Figure 2: Planktonic foraminifera range chart for the study well showing the biozones.

This zone is arbitrary as the global FAD range of *Orbulina universa* is inferred for this zone which is within N9-N10 of Berggren *et al.* (1995) (Young *et al,* 2019), therefore placing this zone within the Middle Miocene (Late Langhian to Early Late Serravallian). *Globigerinoides* sp., *Globigerinoides bolli, Globigerinoides trilobus immaturus,* and *Globorotalia continuosa* all have their Last Downhole Occurrences within this zone.

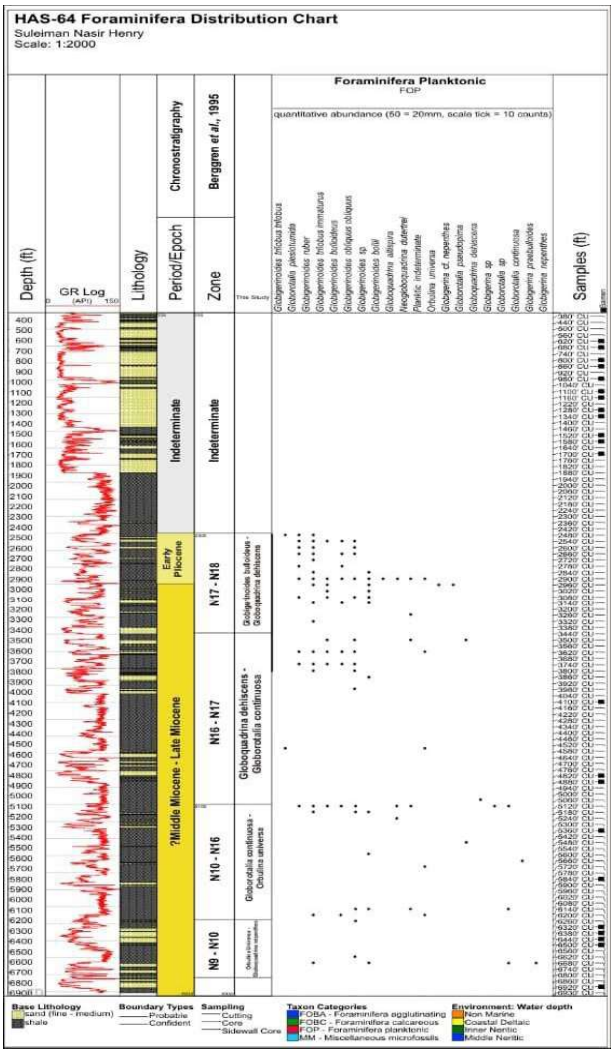

Figure 3: Planktonic foraminifera distribution chart showing the delimited biozones.

Proposed Benthic Foraminiferal Zones

Four benthic zones have been delimited for the sediments through their unique distribution pattern, and using the planktonics to constrain the age of the sediment because of the unreliability of benthic foraminifera in the aspect of sediment age determination. All four zones correspond with all four planktic zones, respectively. The zones are as follows:

Zone 1: *Ammonia beccarii/Hanzawaia stratonii – Quinqueloculina seminulum* Interval Zone

This zone, spanning the entirety of the planktic Zone 1 of this work, is delineated at its top by the FDOs of *Ammonia beccarii* and *Hanzawaia stratonii* at 2,520 ft., and the base at the FDO of *Quinqueloculina seminulum* at 3,500 ft. This zone is dated Late Miocene to Early Pliocene and corresponds with the planktic zone of N17 – N18 (Berggren et al., 1995) and N17-N19 of Wade et al., 2011.

Zone 2: *Quinqueloculina Seminulum – Siphouvigerina auberiana attenuata* Interval Zone

The FDOs of both *Quinqueloculina seminulum* and *Siphouvigerina auberiana attenuata* mark the top and base of the interval, respectively. Its correspondence with the *Globoquadrina Dehiscens – Globorotalia continuosa* Interval Range Zone constrains the age of the zone to Late Miocene. The zone is characterised by low overall foraminifera count species and richness and a general scarcity of planktonics, indicating a coastal deltaic to inner neritic paleobathymetry for this section. The litholog for this section indicates cyclic transition from a deepening upward sequence to a shallowing upward sequence.

Zone 3: *Siphouvigerina auberiana attenuata – Uvigerina subperegrina* Interval Zone

The top of this biozone was delimited using the respective

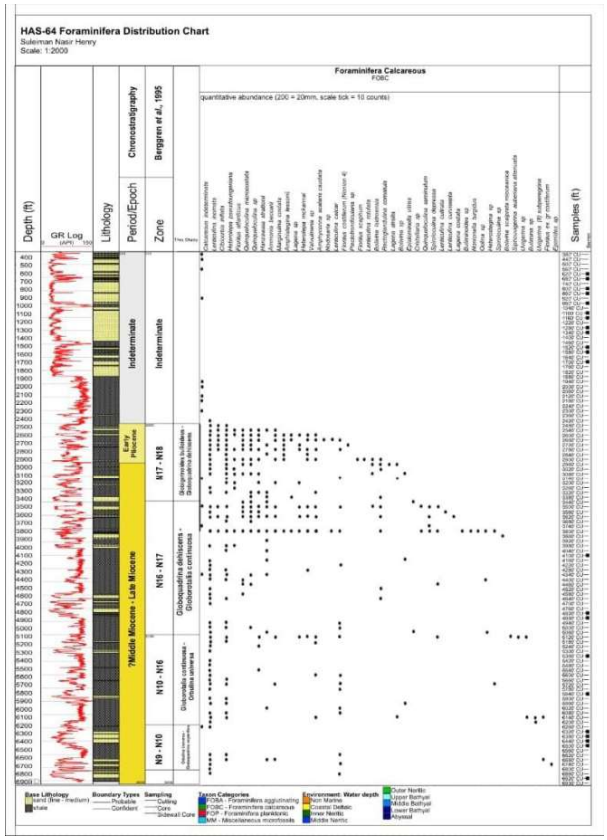

Figure 4: Benthic foraminifera distribution chart for HAS-64 well.

FDOs of *Siphouvigerina auberiana attenuata* and *Uvigerina subperegrina.* It corresponds with N10-N16 of the planktic zone 3 *(Globorotalia continuosa – Orbulina universa* Concurrent Range Zone). The zone is dated Middle to Late Miocene.

Zone 4: *Uvigerina subperegrina – Textularia* sp. Interval Zone

The Middle Miocene age is proposed for the benthics of this zone using the planktics that constrained the age of this zone to the N9-N10 biozone of Berggren (1995).

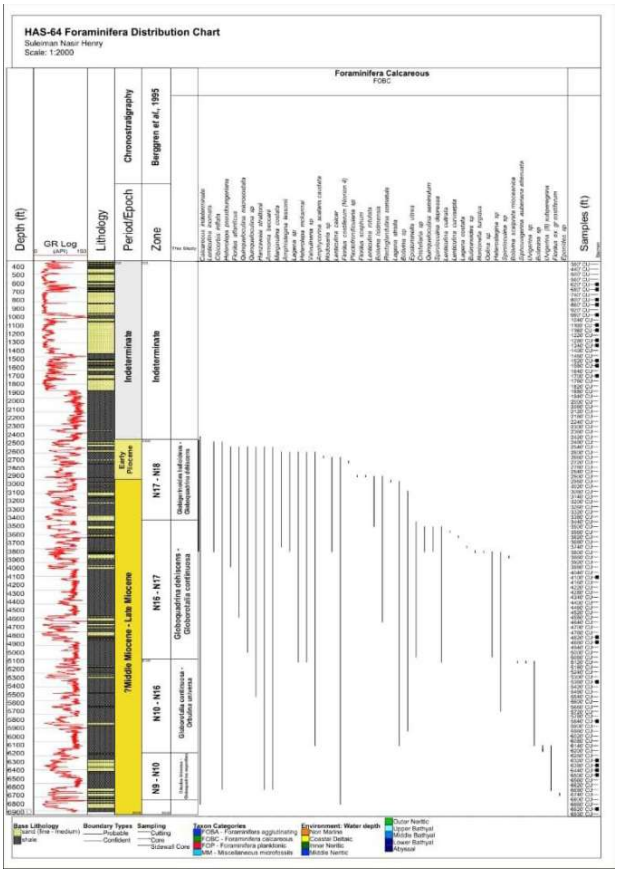

Figure 5: Benthic foraminifera range chart for HAS-64 well.

Age determination

The entire datable section on which biozones establishment was possible, the sediments were estimated to have been deposited from around ~15Ma to ~4.8Ma (from around Late Langhian in Middle Miocene to Earliest Pliocene) spanning the N9-N18 biozonation scheme of Berggren (1995).

Lithofacies and Associated Paleobathymetry

Three lithostratigraphic units were identified in the sediments of the Agbada Formation penetrated by the well using the sand/shale ratios, gamma ray logs, and associated paleobathymetric biological indicators. The units are the paralic, transitional-paralic, and continental-transitional units.

- **The paralic unit (4,010 ft. – 6,930 ft.):** the shales in this unit are generally thicker than the sands and is characterised by moderately hard blocky to flaggy grey-brown shale and milky white sands that are predominantly fine grained and occasionally medium-grained and sub-angular. Some parts of the units are characterised by shell fragments, indicating occasional high-energy depositional environment.

Paleobathymetry was delimited using the benthonic fauna to be predominantly outer neritic depth of deposition with some occasional shift through middle neritic to coastal deltaic depositional depth indicated by the low-count occurrence of Ammonia beccarii which is intolerant of a depositional environment outside the coastal-deltaic to inner neritic.

The calcareous benthonic foraminifera that characterise this unit are dominated by *Lenticulina inornata* and *Heterolepa pseudoungeriana.* The other associated forms are *Quinqueloculina microcostata, Quinqueloculina* sp., *Hanzawaia stratonii, Ammonia beccarii, Marginulina costata, Heterolepa mckannai, Amphycorina scalaris caudata, Florilus costifernum, Rectoglandulina comatula, Epistominella vitrea, Lenticulina cultrata, Siphouvigerina auberiana attenuata, Uvigerina subperegrina, Eponides* sp.

The arenaceous benthonic foraminifera in this unit are dominated, albeit scanty, by *Cyclammina minima* with other lesser occurrences of *Haplophragmoides (24) narivaensis, Haplophragmoides* sp., *H. compressa, Alveolophragmium crassum, Ammobaculites agglutinans, and Poritextularia panamensis.*

- **The paralic-transitional unit (1,875 ft. – 4,010 ft.):** This unit is dominantly composed of sands alternating with subordinate proportions of shales. Its sand/shale ratio is approximately 65:35. The sands are generally thicker than the shales. The shales grey, brown and brownish red in colour. They are predominantly blocky to flaggy and moderately hard. The sands are milky white to glassy, predominantly fine, occasionally medium to coarse-grained, moderately- to well-sorted, occasionally poorly sorted, predominantly sub-angular.

The fauna that characterise this unit are *Heterolepa pseudoungeriana, Cibicorbis inflata, Amphistegina lessonii, Ammonia beccarii, Bolivina isidorensis, Poritextularia panamensis, Marginulina costata, Lenticulina inornata, Florilus atlanticus, Quinqueloculina microcostata, Hanzawaia stratonii, Rectoglandulina comatula, Plectofrondicularia* sp., *Lenticulina calcar, Epistominella vitrea, Valvulineria* sp., and species of planktic dominated by *Globigerinoides* genus characterized this interval suggesting deposition fluctuating between inner neritic to middle neritic setting.

The upper part of this unit is completely barren of planktonic foraminifera and is characterised by high count (15) of indeterminate benthonics and some shell fragments which are altogether indicative of high energy environment of deposition. Which further confirms the inner neritic paleodepth.

- **The Continental-Transitional Unit (335 ft. – 1,875 ft.):** This interval is characterised by little to no occurrence of foraminiferal species, with only rare occurrences of arenaceous and calcareous indeterminates and complete absence of planktonic forms. This complete barrenness of foraminiferal within this interval suggests deposition in conditions that were generally unfavourable for foraminiferal colonization. This, together with the general shallowing shown by the litholog, is consistent with deposition in continental/marginal marine environments where the waters were somewhat brackish. Lithologically, the unit is made up predominantly of milky white to glassy sands that range from fine- to coarse-grained, poorly- to moderately-sorted, and angular to moderately sub-rounded. These sands make up about 90% of the whole lithology, with the remaining 10% made up of grey to reddish brown shales that are blocky and moderately hard.

SEQUENCE STRATIGRAPHY

Integrating gamma ray log and faunal abundance and species richness peaks as proposed by Armentrout (1990), four sequences were recognised. Furthermore, identifiable systematic variations in foraminiferal abundance and diversity correlated with similar variations in stacking patterns as seen on the available gamma ray log as well as the paleobathymetric data acquired over the analysed section aided the recognition of systems tracts. The proposed sequence stratigraphic framework for the well is briefly highlighted below:

Sequence 1 (6930 - 4775ft)
This depositional sequence began its development with a Transgressive Systems Tract (TST) composed of sediments presenting a regressive profile. The TST terminates at a Maximum Flooding Surface (MFS) marked by a Gamma Ray peak and associated with faunal abundance and diversity peaks at 5020ft. This MFS is proposed to be related to the 9.50Ma MFS based on the First Downhole Occurrence (FDO) of the benthonic foraminifera species *Uvigerina subperegrina* at 5120 ft. The progradational unit over the interval 5020 – 4775ft is interpreted as a Highstand Systems Tract (HST). The Sequence Boundary (SB) caps the HST at 4775 ft.

Sequence 2 (4775 - 3970ft)
This sequence is bounded at the base by the proposed SB at 4775ft. A fining-upward succession of sediments laid down on the SB over the interval 4775 – 4210ft is interpreted as representing a Transgressive Systems Tract (TST). The Gamma Ray positive deflection at 4210 ft. within a Condensed Section is proposed as the MFS capping the TST. This MFS is correlated to the 8.80Ma MFS of Hardenbol *et al.* (1998). Above the MFS, a progradational succession of mudstones/shales, capped by a sand body constitutes the HST laid down as the shoreline apparently receded. The SB bounding this sequence at the top has been defined at the point of change-over from a coarsening-upward to a fining-upward profile at 3970ft. The SB has been assigned an age of 9.26Ma based on correlation with the Global Sea Level Cycle Chart of Hardenbol *et al.* (1998).

Sequence 3 (3970 - 3375ft)
This sequence is composed of a fining-upward, or deepening-upward, profile of sediments over the interval 3970 – 3580ft. This is interpreted as a Transgressive Systems Tract (TST). This terminates at a Maximum Flooding Surface (MFS) marked by a Gamma Ray peak at 3580ft. The MFS is proposed as the 8.80 Ma MFS of Hardenbol *et al.* (1998). This age has been assigned on the basis of the stratigraphic position of the MFS between the proposed 9.50 Ma MFS and the 7.3 Ma MFS of Hardenbol *et al.* (1998). Above the MFS is a progradational unit of lower deltaic plain deposits. This constitutes the Highstand Systems Tract (HST). The top of the sequence is defined at the erosional top of a sand body at 3375ft. The SB has been assigned an age of 8.60 Ma based on correlation with the Global Sea Level Cycle Chart of Hardenbol *et al.* (1998).

Sequence 4 (3375 - 2920ft)
The proposed 8.60 Ma Sequence Boundary (SB) underlies this sequence which began its development with a 415ft-thick Transgressive Systems Tract composed of sands and shales/mudstones. The Gamma Ray peak at 2960ft, which is associated with a Condensed Section characterized by a faunal peak abundance and diversity, is interpreted as the Maximum Flooding Surface (MFS) terminating the TST. This MFS is suggested to be the 7.30 Ma MFS of Hardenbol *et al.* (1998). The progradational succession of marine mudstones/shales and silts over the interval 2960 –2920ft overlying the MFS is inferred as the Highstand System Tract (HST). The Sequence Boundary (SB) at the top of this sequence is marked at 2920ft to coincide with a point of change-over from a coarsening-upward to a fining-upward profile. The SB has been dated 6.98 Ma based on correlation with the Global Sea Level Cycle Chart of Hardenbol et al. (1998).

Sequence 5 (2920 - 335ft)
This sequence is bounded at the base by the proposed 6.98 Ma SB at 2920ft. A fining-upward succession of sediments laid down on the SB over the interval 2920 – 2120ft is interpreted as representing a Transgressive Systems Tract (TST). The Gamma Ray peak associated with faunal abundance and diversity peaks at 2120ft is proposed as the MFS capping the TST. This MFS is inferred to be related to the 6.0 Ma MFS of Hardenbol *et al.* (1998).This age is based on the association of the MFS with the planktonic foraminifera zone N17 and its stratigraphic position above the proposed 7.30 Ma MFS. Above this MFS, the Highstand Systems Tract (HST) composed essentially of multistory channel sands steps out. The top of this sequence probably lies shallower than 335ft, the top of the studied section of the Nas-113 well.

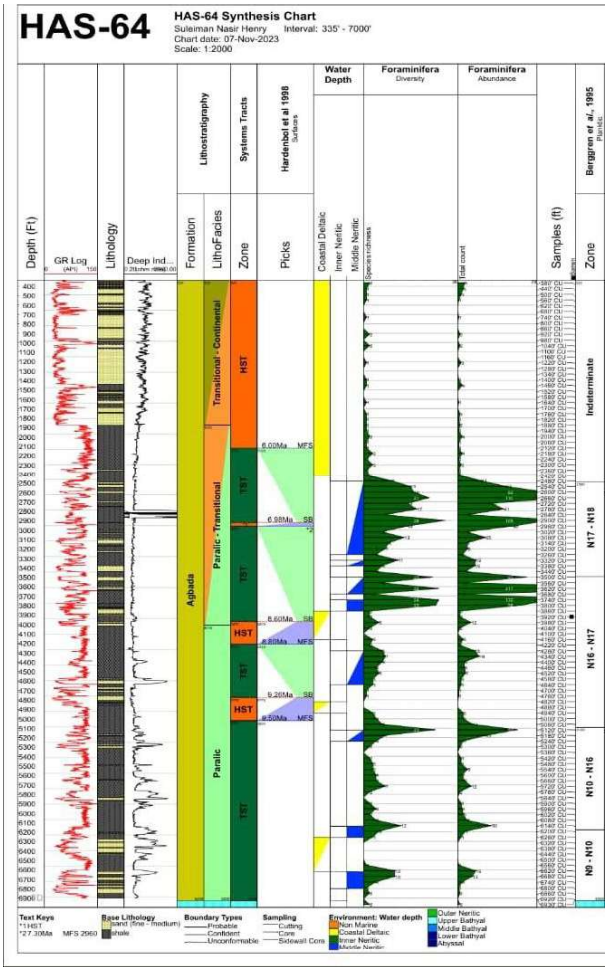

Figure 6: Sequence stratigraphy chart for Has-64 well.

CONCLUSION

Integrating gamma ray log, foraminiferal samples recovered from the well, and lithology log, age dating of well HAS-64 was done, and the paleoenvironment of deposition was determined. Three lithostratigraphic units were identified for the sediments of the Agbada Formation penetrated by the well using the sand/shale ratios, gamma ray logs, and associated paleobathymetric biological indicators; the paralic unit, the paralic-transitional unit, and the continental transitional unit. Four planktonic foraminiferal biozones were established for the sediments ranging from N9-N18 of Berggren (1995) scheme, and four benthonic foraminiferal biozones proposed, using the planktonics to constrain the ages of the zones. The paleobathymetric analysis indicates a coastal deltaic to middle neritic depth of deposition, confirmed using the lithology and associated fauna. The gamma ray log peaks, faunal abundance and species richness, and lithological analysis were integrated to decipher five depositional sequences characterised by four Maximum Flooding Surfaces (MFS) and bounded by three Surface Boundaries (SB).

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