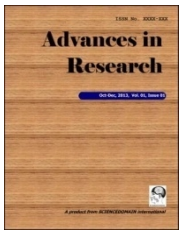

Advances in Research
2(12): 696-711, 2014, Article no. AIR.2014.12.001

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Calcareous Nannofossil Biostratigraphic Analysis of Well '*K-2*', Deep Offshore Niger Delta, Nigeria

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Author's contribution

Author SOA designed the study, performed the analysis and interpretation of the samples and also prepared the manuscript.

Original Research Article

Received 12th May 2014
Accepted 14th June 2014
Published 5th July 2014

ABSTRACT

A study on the calcareous nannofossil biostratigraphy has been carried out on sequences within the interval 1640m-1980m of well *'K-2'* located in the deep offshore of Niger Delta, Nigeria.

Lithologic description of the samples was done using a stereo-binocular microscope. Thirty-four slides of samples were prepared and studied for their calcareous nannofossil contents using Olympus Light Microscope in both plane-polarized and cross-polarized light.

The lithostratigraphic descriptions on the samples showed the abundance of shale and mudstone/siltstone with minor amount of thin intercalated units of sand bed. Seventeen calcareous nannofossil species were identified and used to predict the biostratigraphic deductions such as zonation, dating and a tentative sequence stratigraphic framework. With the aid of a standard zonation schemes, two major nannofossil zones (NN 19 and NN 18) were identified. These zones belongs to Pleistocene and Pliocene ages respectively. Two major zones of *Gephyrocapsa carribeanica* and *Gephyroca psaparallela* were identified for the studied well on the basis of the index taxa and fossil assemblage recorded. The insufficient amount of nannofossils in the lower part of the well precluded a definite zonation and made the zone to be indeterminable. One Condensed Section believed to be associated with 2.0Ma Maximum Flooding Surfaces was recognized.

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Keywords: Biostratigraphy; Gephyrocapsa carribeanica; Gephyrocapsa parallela; condensed section; maximum flooding surfaces.

1. INTRODUCTION

The focus on the Tertiary Niger Delta basin by various workers gained prominence following its discovery as a petroleum laden basin in the 1950's by Shell BP. Since then, Nigeria has been rated as the sixth largest oil producing country in the world with a proven ultimate reserve of about thirty four billion barrels of oil and two hundred and sixty trillion cubic feet of gas [1].

However, about 90% of the twenty six billion barrels recoverable oil reserve earlier estimated for the Niger Delta by [2] is said to be from the onshore areas of Niger Delta. This could have been due to the extensive exploration activities, which concentrates on the onshore areas of the Niger Delta compared to offshore regions.

Presently, attention has been directed to the offshore regions and so far prospects have been encouraging. The advancement in deep-water drilling technology and various exploration techniques have aided this development.

More recently, the integration of biostratigraphy with other methods like geophysics, well log reserve, sequence stratigraphy, have contributed immensely to hydrocarbon exploration in the offshore Niger Delta.

However, based on the biostratigraphy, three major fossil groups are focused on. These are foraminifera, pollen and spores and nannofossils. These three have proven very useful and complementary to each other but the use of nannofossils is becoming increasingly important because of the following:

a) They are planktonic, abundant, evolve rapidly and largely cosmopolitan.
b) They can be studied from minute rock chips because of their small size. This found application in hydrocarbon exploration and development, and scientific drilling.

Calcareous nannofossils therefore are defined as all calcareous fossils that are smaller than 30 microns (μm). They are exclusively marine fossils of great importance in deep water exploration and they have been used in various ways to assist in operational situation in the well site during drilling which include achieving a straight-forward age monitoring of wells where stratigraphy is uncertain and also in confirmation of terminal depth where there is commitment to drill to deposit of specific age and in coring point selection to mention a few. This means that a pragmatic approach to nannofossil biostratigraphy is required. Many researchers have worked on the calcareous nannofossils [3,4,5,6,7,8].

1.1 Location of the Study Area

Ditch cutting samples were obtained from well 'K–2' in the offshore deep-water Nigeria. The samples were given out by one of the deep water operators. The name and the exact location of the well were not made available for proprietary reasons.

However, the Nigeria deep-water region is believed to be roughly between water depth of 600m on the inboard side and 200m in the outboard side for an area of approximately 48,500Km^2 (Fig. 1) [9].

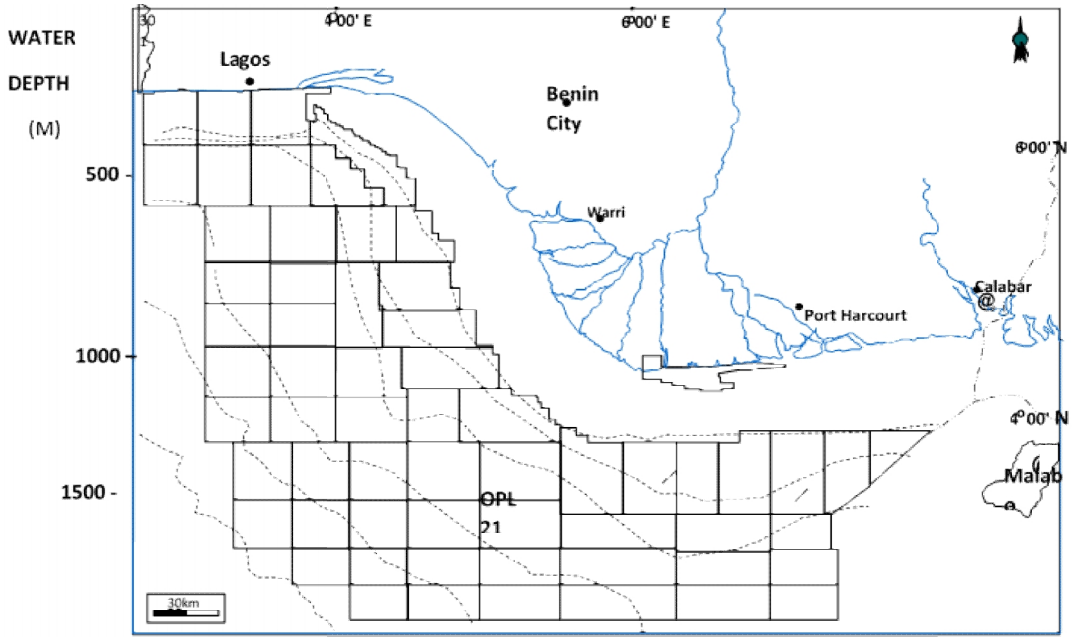

Fig. 1. Map showing the acreage of study area

The samples were obtained at 10m interval. This study covers an interval of 1640m to 1980m comprising thirty-four samples in all.

1.2 Objectives of the Study

The main objectives of the study are:

To identify the calcareous nannofossil species in the strata penetrated by the well and to identify new nannofossil species in the analyzed sequence (if any). Other objectives include.

- To establish the lithostratigraphic sequence of the section (same as the one below, so delete this)
- To establish the lithostratigraphic sequence of the section.
- To determine the age of the strata penetrated by the well.
- To determine a tentative sequence stratigraphic framework for the section.

1.3 Geology of the Niger Delta

The Niger Delta is one of the basins in West Africa formed as a result of basement tectonics related to crustal divergence and translation during the Cretaceous continental rifting of Gondwanaland. The Niger Delta is a thick prism of clastic sediments which has prograded down the Benue Trough into the Gulf of Guinea since Early Tertiary. These sediments began

to reach the continental slope by Late Eocene time and subsequent progradation has progressively enlarged the continental margin to its present position [2].

The results of numerous studies [1,2,9] of Tertiary Niger Delta indicate that the Delta consists of a thick sedimentary prism of about 12km. The overall succession in ascending order consists of over pressure continuous marine shales (Akata Formation) with interbedded thin bed of siltstone interpreted as slope channel fills. These are overlain by a paralic sequence of shales and sands (Agbada Formation) and thick continental sands and gravels at the top (Benin Formation).

2. MATERIALS AND METHODS

Materials used for this study were ditch cutting samples. The well is code-named as well 'K-2' for confidential reasons. These samples were supplied by one of the major Niger Delta deep-water operators.

Thirty-four samples were obtained at depth within the intervals of 1640-1980m andanalyzed. They were packed in small polythene bags which bear the name of the well and sampling depth. The bags were arranged serially in a tray in laboratory for lithologic description and sample processing for calcareous nannofossil analyses.

2.1 Lithologic Description

The lithologic description of the samples was done using a stereo-binocular microscope. A lithostratigraphic column for the well was then constructed based on the lithologic description of the samples and lithostratigraphic units penetrated by the well were delineated.

2.2 Preparation

Thirty four samples were processed for their calcareous nannofossil content according the standard preparation technique of [10]. The technique involves:

(i) Taking a fresh inner portion of the sample provided and spreading over a cover slip (22mmx40mm) of a glass slide (25.4mmx76mm).
(ii) Adding a few drop of distilled water and making a thick sediment suspension with the help of a flat– sided toothpick.
(iii) Smearing the suspension thinly across the surface of the cover-slip using a toothpick, and drying rapidly on a hot-plate at a temperature of about 60-70°C for few minutes.
(iv) Labeling a glass microscope slide, and affixing the coverslip (smear-side down) using a few drops of Norland optical adhesive mounting medium.
(v) Placing this under an ultraviolet light for about forty five minutes.

2.3Identification of Calcareous Nannofossils

The prepared slides were studied for their calcareous nannofossils content under a high power Olympus Light Microscope in plane-polarized and cross-polarized light.

The abundance and diversity of the assemblages were made by consulting the works of [11] and [12].

2.4 Sequence Stratigraphy

The basic procedure of sequence stratigraphic interpretation according to [13] involves the following steps:

(i) Lithology to be interpreted from log character (gamma ray and sonic ray and ditch cuttings).
(ii) Deduction of depositional environment from *Foraminifera* data and characters.
(iii) Interpretation of condensed section from faunal abundance and diversity peaks.
(iv) Determination of sequence boundaries and system tracts from log character.
(v) Age dating of well sequence from biostratigraphic data.

3. RESULTS AND DISCUSSION

3.1 Lithostratigraphy of Well 'K-2'

The samples analyzed in this well from intervals 1640m to 1980m have been found to have similar lithology. The sequences in the well correspond to the lower units of the Agbada paralic facies described by [14]. Most of the lithofacies are composed of shale and siltstone mudstone with thin intercalated units of sand beds. This is revealed in the lithologic description of ditch cutting samples. A summary of the lithologic log is given in Table 1.

The shales and mudstones are mostly grey to dark grey and black in colour. The sands range from coarsed to fine grained, angular to rounded and poor to well sorted. Accessory minerals occurring in high abundances include ferruginous materials and pyrite. Common to few occurrences of glauconite, mica flakes and carbonates are found within certain intervals of the studied sections.

3.2 Calcareous Nannofossils

The result shows highly abundant and diverse calcareous nannofossils. A total of seventeen nannofossils species comprising mainly of coccoliths, placoliths and nannoliths were identified. Of these, *Gephyrocapsa carribeanica* is the most abundant. *Helicosphaera carteri* occur almost throughout the entire analyzed section. Influxes of *Gephyrocapsa carrribeanica* were noticed within interval 1660-1680m and at depth 1720m and 1790m. *Gephyrocapsa oceanica* also occurs in high abundance within the upper part of the studied section.

The family *Noelaerhabdacea* is represented by the genera Gephyrocapsa and *Reticulofenestra* with predominant species *Reticulofenestra productella* mainly at depth 1670m. Three species of genus Gephyrocapsa namely *Gephyrocapsa carribeanica, Gephyrocapsa oceanica* and *Gephyrocapsa parallela* are all in abundance within the studied section. These *Gephyrocapsa* species are important stratigraphically and are commonly employed as zonal markers. They are also of chronostratigraphic value in the Neogene andused to delineate the two major zones proposed for the studied section of well 'K-2'.

Helicosphaera carteri and *Helicosphaera selli* are the well represented species of the familyHelicosphaera in the studied section. *Helicosphaera carteri* are very abundant and diverse while *Helicosphaera selli* shows a rare occurrence in the studied section.

The *Calcidiscaceae* family is also represented by two species which are *Calcidiscus leptoporus* and *Calcidiscusmacintyrei. Calcidiscusmacintyrei* reveals a rare occurrence only at depth 1660m. *Calcidiscus leptoporus* shows high abundance and diversity occurring within the interval 1680m-1760m and also at depths 1780m, 1810m and 1840m within the studied section.

Other nannofossil assemblages of high abundance and diversity are *Pseudoemiliana lacunosa* and *Thoracosphaera spp*. Other nannofossils with rare occurrence in the studied section include *Ceratolithuscristatus, Coccolithus pelagicus, Scyphosphaeraglobulata, Scyphosphaeraapsteinii* and *Pontosphaera multipora.*

Table 1. Summary of Lithologic Log of Well 'K-2'

DEPTH [m]	lithology	Age	Formation
1640-1650	Shale	Pleistocene	Agbada
1650-1660	Shale	Pleistocene	Agbada
1660-1670	Shale	Pleistocene	Agbada
1670-1680	Shale	Pleistocene	Agbada
1680-1690	Shale	Pleistocene	Agbada
1700-1710	Shale	Pleistocene	Agbada
1710-1720	shale	Pleistocene	Agbada
1720-1730	Shale	Pleistocene	Agbada
1730-1740	Shale	Pleistocene	Agbada
1740-1750	Shale	Pleistocene	Agbada
1750-1760	Shaly sand	Pleistocene	Agbada
1760-1770	Sand	Pleistocene	Agbada
1770-1780	Shale	Pleistocene	Agbada
1780-1790	Shale	Pleistocene	Agbada
1790-1800	Shale	Pliocene	Agbada
1800-1810	Sandy shale	Pliocene	Agbada
1810-1820	Shaly sand	Pliocene	Agbada
1820-1830	Shaly sand	Pliocene	Agbada
1830-1840	Shaly sand	Pliocene	Agbada
1840-1850	Shaly sand	Pliocene	Agbada
1850-1860	Shaly sand	Pliocene	Agbada
1860-1870	Shaly sand	Pliocene	Agbada
1870-1880	Shaly sand	Pliocene	Agbada
1880-1890	Sandy shale	Pliocene	Agbada
1890-1900	Shaly sand	Pliocene	Agbada
1900-1910	Argillaceous sandstone	Pliocene	Agbada
1910-1920	Argillaceous sandstone	Pliocene	Agbada
1920-1930	Argillaceous sandstone	Pliocene	Agbada
1930-1940	Argillaceous sandstone	Pliocene	Agbada
1940-1950	Argillaceous sandstone	Pliocene	Agbada
1950-1960	Sandy mudstone	Pliocene	Agbada
1960-1970	Shaly sand	Pliocene	Agbada
1970-1980	Sandy mudstone	Pliocene	Agbada

Nannofossils observed are well preserved with minimum effect of dissolution. A nannofossil distribution chart plotted with depth on the vertical axis and recorded taxa on the horizontal axis includes the interpretations made from this work (Fig. 2 and Table 2)

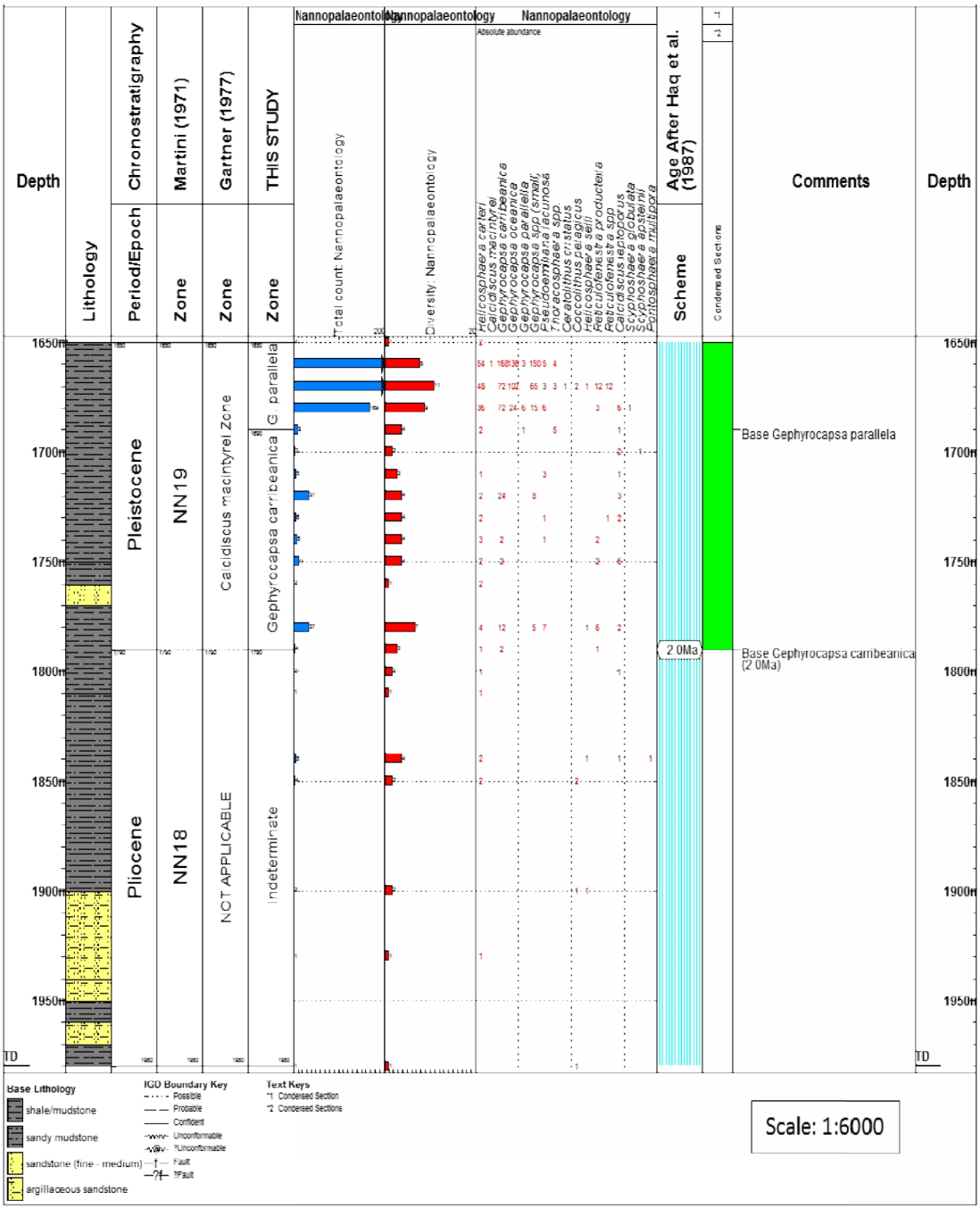

Fig. 2. Calcareous nannofossil distribution chart of well 'K-2'

Table 2. Calcareous nannofossil zones recognized in well 'K-2'

Depth(m)	Epoch	Age (ma)	Zones[15]	Zones[16]	Established Zones (well 'K-2')	Bio-events	
1650 1660 1670 1680 1690 1710 1720 1730 1740 1750 1760 1770 1780 1790	PLEISTOCENE	2.0	NN 19	*CALCIDISCUS MACINTYRE I*	*G. CARRIBEANICA* *G. PARALLELA*	← base of *Gephyrocapsa parallela*	1690 1790
1800 1810 1820 1830 1840 1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990	PLIOCENE	NN 18	NOT APPLICABLE	INDETERMINATE		Base of *G. Carribeanica* (2.0Ma)	

3.3 Calcareous Nannofossil Zonation

The stratigraphic interval studied in well 'K-2' has been sub-divided into biostratigraphic zones on the basis of their calcareous nannofossils. The well section was zoned using the globally recognized calcareous nannofossil zonation scheme of [15] and [16]. [15] zones were tagged NN zones (Neogene Nannofossils). [16] established his zones based on the index taxa.

Two major zones belonging to Pleistocene and Pliocene ages were established in the studied section of well 'K-2' as shown in the table above. These are the NN19 and NN18 zones of [15].

3.4 Zonal Description

3.4.1 *Pseudoemiliana lacunosa* zone

Stratigraphic interval: 1640 – 1790m
Age: Pleistocene
Nannofossilzone: NN 19
Top: The top of this zone is believed to be shallower than the first sample analysed.
Base: The base of this zone is marked by the base of *Gephyrocapsa carribeanica* at depth 1790m.

Description: Zone NN 19 is otherwise known as *Pseudoemiliana lacunosa* zone according to [15] and it is divided into four sub-zones which are *Pseudoemiliana lacunosa* Zone, small *Gephyrocapsa* Zone, *Helicosphaera selli* Zone and *Calcidiscusmacintyrei* Zone by [16]. The sub-zone that fall within the studied well is *Calcidiscusmacintyrei* zone. This zone is characterized by abundant and diverse nannofossil assemblage at the upper half. The lower half is characterized by a slight reduction in fossil diversity and abundance. Index taxa recognized in the section which are in abundance include *Gephyrocapsa carribeanica, Gephyrocapsa oceanica, Gephyrocapsa parallela, Calcidiscus macintyre I* and *Pseudoemiliana lacunosa*. Other nannofossils in the zone include *Helicosphaeracarteri*, *Thoracosphaera spp.*, *Calcidiscus leptoporus, Reticulofenestra spp., Coccolithus. pelagicus* and *Ceratholithuscristatus.*

3.4.2 Zone NN 18

Stratigraphic Interval: 1790 –1980m
Age: Pliocene
Description: This interval is marked by rare occurrences of nannofossils. This precludes a definite zonation of the interval. However the interval has been assigned Zone NN18 based on the stratigraphic position below the positively recognized zone NN 19 above. Some of the nannofossil species in this zone are *Helicosphaera carteri*, *Coccolithus pelagicus, Helicosphaera selli*, *Calcidiscus leptoporus* and *Pontosphaeramultipora*. These assemblages comprises mainly of long range, non-age diagnostic species. However, [16] zonation scheme is not applicable to this age.

3.5 Zonation Based on this Study

Two major zones were erected for the studied section of well 'K–2'. No subzones were delineated.

The erected zones are:

(i) Gephyrocapsa carribeanica zone
(ii) Gephyrocapsa parallela zone
(iii) Intervals 1790-1990m has been designated indeterminate zone based on lack of index taxa.

3.5.1 Zonal description

3.5.1.1 Gephyrocapsa parallela zone

Stratigraphic interval: 1640–1690m
Age: Pleistocene
Nannofossil zone: *Gephyrocapsa parallela*
Top: The top of the zone is probably shallower than the first analyzed sample.
Base: The base of this zone is marked by the base of *Gephyrocapsa parallela* at depth 1690m.
Description: This zone is marked by abundant and diverse occurrence of nannofossil assemblages. The top is probably shallower than the first analyzed sample in the studied section of well 'K–2'. It has been observed that *Gephyrocapsa parallela* occurs shallower in this study than observed by earlier authors who placed the base of *Gephyrocapsa parallela* at a relatively younger age. The base of *Gephyrocapsa parallela* was used by [16] to delineate his younger subzone (*Pseudoemiliana lacunosa*) of the NN19 zone earlier subdivided by [15]. Other index taxa found in this zone include *Gephyrocapsa carribeanica, Gephyrocapsa oceanica* and *Pseudoemiliana lacunosa* . Other nannofossil species in this zone include *Helicosphaera carteri, Calcidiscusmacintyrei, Pseudoemiliana lacunosa, Coccolithus pelagicus, Helicosphaeraselli* and *Reticulofenestra productella.*

3.5.1.2 Gephyrocapsa carribeanica zone

Stratigraphic interval: 1690 – 1790m
Age: Pleistocene
Nannofossil zone: *Gephyrocapsa carribeanica*
Top: The top of the zone is marked by the base of *Gephyrocapsa parallela* at depth 1690m.
Base: The base of the zone is marked by the base of *Gephyrocapsa carribeanica.*
Description: This zone is characterized by fairly abundant and diverse nannofossil assemblage. This interval is delineated based on the continuous occurrence of *Gephyrocapsa carribeanica* within the section. Other index taxa occurring in high abundance within this zone include *Gephyrocapsa oceanica, Gephyrocapsa parallela* and *Pseudoemiliana lacunosa*. Other nannofossils in common but few abundance within this zone include *Helicosphaera carteri, Calcidiscusmacintyrei, Thoracospharea spp., Ceratolithuscristatus, Coccolithus pelagicus, Helicosphaera selli, Reticulofenestra productella, Calcidiscus leptoporus, Scyphosphaera globulata* and *Scyphosphaeraap steinii*.

The base of *Gephyrocapsa carribeanica* at depth 1790m is dated 2.0Ma, hence, the observed condensed interval 1650-1790m is believed to be associated with 2.0Ma Maximum Flooding Surface.

3.6 Sequence Stratigraphy

Due to the absence of steps (ii) and (iv) in section 2.4, an attempt was made of a tentative sequence stratigraphic interpretation for the well section based on the available information. The absence of e-logs and palaeobathymetric data from *Foraminifera* studies prevent a detailed sequence stratigraphic interpretation of the well sequence.

The tentative interpretation therefore led to the identification of dated Condensed Section.

3.7 Condensed Section and Maximum Flooding Surfaces

Based on nannofossil abundance and diversity patterns, calibrated with chrono-stratigraphically important bio-events, one condensed section has been identified and correlated with the Global Cycle Chart of [17] as shown in Table 3. This is believed to be associated with the 2.0Ma Maximum Flooding Surface.

Table 3. Condensed section recognized in well 'K-2'

Condensed section	Interval (metres)	Age (Ma) After [17]	Dating criteria
1	1650–1790	2.0	• Base *Gephyrocapsa carribeanica* at depth 1790m (2.0Ma). • Base *Gephyrocapsa parallela* at depth 1690m

4. CONCLUSION

A calcareous nannofossil biostratigraphy has been undertaken on sequences within intervals 1640–1980 m of well 'K-2' in the deep offshore area of the Niger Delta, Nigeria.

A lithostratigraphic description made on the ditch cuttings revealed sandy mudstone and hemipelagic shale and the accessory minerals in them.

The results of the analysis revealed moderately abundant and diverse nannofossil assemblages. Seventeen calcareous nannofossil species identified were used to make biostratigraphic deduction including zonation, dating and a tentative sequence stratigraphic framework for the sequences studied.

Two major nannofossil zones (NN19 and NN18) belonging to Pleistocene and Pliocene, respectively were recognized based on the standard zonation schemes of Martini (1971) and Gartner (1977) respectively. Two major zones were erected for the studied well: the*Gephyrocapsa carribeanica* zone and *Gephyrocapsa parallela* zone. The Pleistocene portion of the well section based on this study was characterized by abundant and diverse occurrence of nannofossils. The Pliocene portion of this interval was characterized by rare and scattered occurrences of nannofossils which preclude a definite zonal and age assignment to the interval.

Nannofossil abundance and diversity patterns calibrated with chrono-stratigraphically important bio-events enhanced the identification of only one condensed section correlated to the Global Cycle Chart of Haq et al. [17]. This is thought to be associated with the 2.0Ma Maximum Flooding Surface.

It is recommended that a local nannofossil zonation scheme be erected for the Niger Delta Pleistocene age.

ACKNOWLEDGEMENTS

The author wish to thank Dr. S. L. Fadiya of Crystal Age Limited, Ikorodu, Lagos for his technical assistance in the preparation and analysis of samples.

COMPETING INTERESTS

Author has declared that no competing interests exist

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APPENDIX

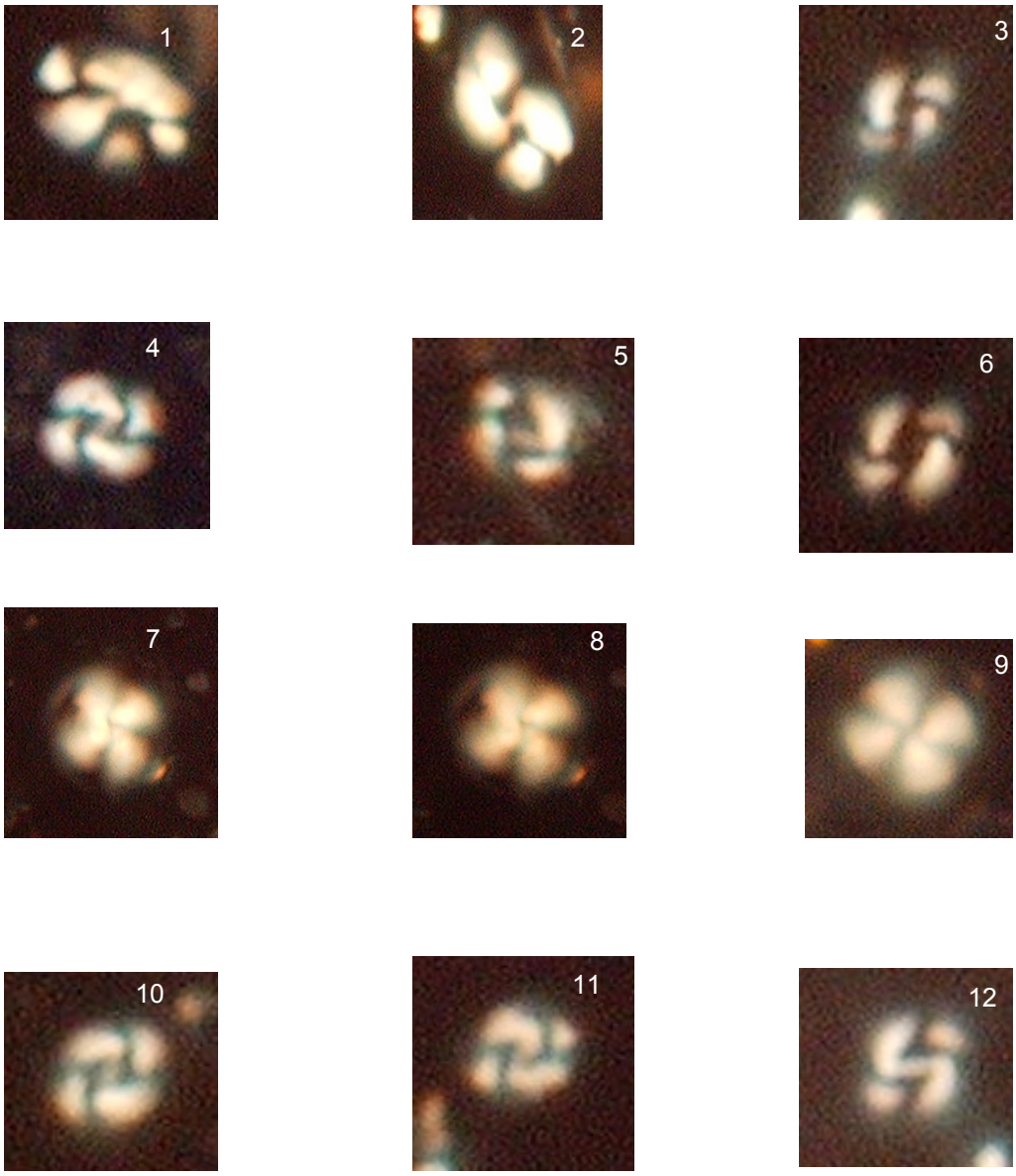


Plate 1. *Helicosphaera carteri* (Figs. 1-2) [18], *Gephyrocapsa carribeanica* (Figs. 3-6)[19].*Calcidiscus leptoporus* (Figs. 7-9) [18].*Gephyrocapsa oceanica* (Figs. 10-12) [18]

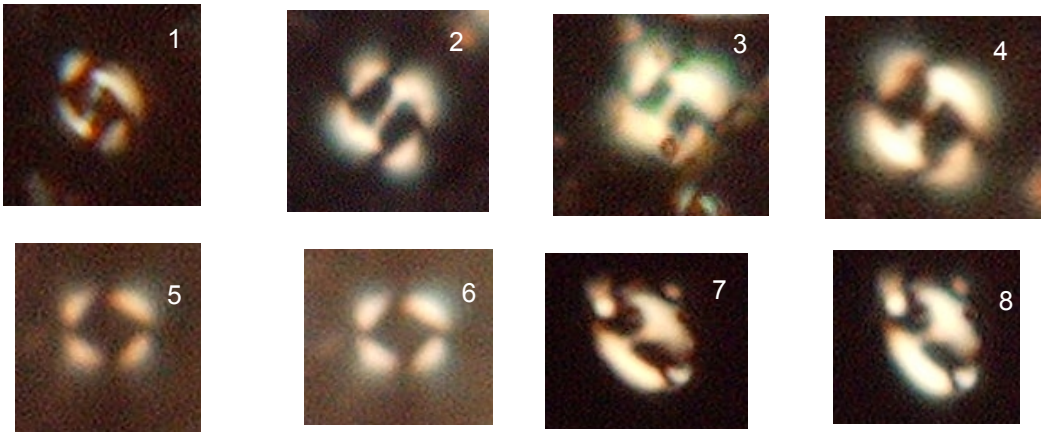


Plate 2. *Gephyrocapsa parallela* (Figs. 1-4) [20]. *Pseuso emiliana lacunosa* (Figs. 5-6) [18]. *Helicosphaera selli* (Figs. 7-8) [21]

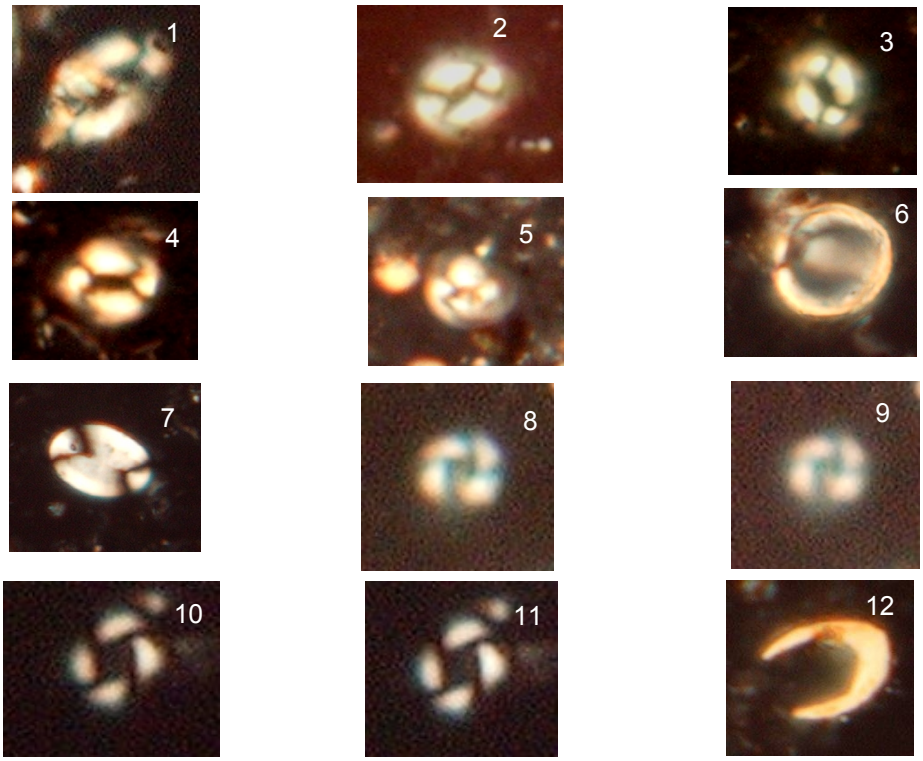
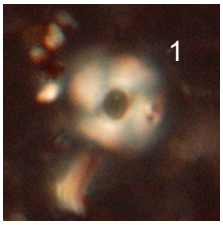
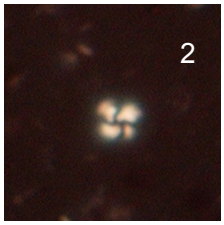


Plate 3. *Helicosphaera selli* (Fig. 1) [21], *Coccolithus pelagicus* (Figs. 2-5) [18] *Scyphosphaeraglobulata* (Fig. 6) [22],*Pontosphaeramultipora* (Fig. 7) [18] *Reticulofenestra productella* (Figs. 8-11) [23]. *Ceratolithuscristatus* (Fig. 12) [18]





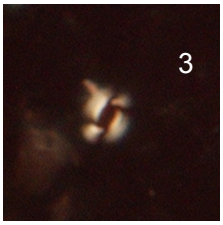


Plate 4. *Calcidiscusmacintyrei* (Fig. 1) [21]. *Reticulofenestra spp*. (Figs. 2-3) [21]

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