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The biostratigraphy of the offshore Niger delta during the Late Quaternary: Complexities and progress of dating techniques

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ABSTRACT

The Late Quaternary marine sediments from the Niger Delta lacks an age model using conventional radiocarbon dating due to the rarity of calcareous macrofossils. The proprietary nature of material drilled by companies prospecting for hydrocarbons in the Niger Delta basin, and in the rare cases when samples are available for study as well as freshwater dilution from continental runoff have contributed to this dearth of knowledge. The availability of three shallow marine (~3 m) gravity cores obtained from the eastern, central, and western parts of the Niger Delta provides the opportunity for biostratigraphy utilising well-preserved marker species of planktonic foraminifera and calcareous nannofossils in the sediments. The last occurrence (LO) of planktonic foraminiferal species *Globorotalia truncatulinoides* (late Pleistocene) (MIS 2) and the first occurrence (FO) of *Globorotalia tumida* (Holocene) (MIS 1) are used to identify two interval zones in the gravity cores. The presence of the calcareous nannofossil *Gephyrocapsa oceanica* (all <3 μm in size) supports a late Pleistocene age (NN19 Zone) for the lower interval. In addition, an increase in the abundance of *Emiliania huxleyi* up-section is an indication of early Holocene age (NN20-NN21) for the upper interval.

1. Introduction

The discovery of hydrocarbons in the Niger Delta in the 1950s and proprietary clauses of prospecting companies that own the concessions remain the main hindrances to data access in the basin (Ige, 2009; Reijers, 2011; Adojoh, 2017). Acquiring data for public research usually requires strict confidentiality and compliance with these companies's regulations, and hence the few published studies (mostly pre-Quaternary) for the region. For the Quaternary, the published studies include Allen (1964), Oomkens (1974) and Sowunmi (1981), Ige and Sowunmi (1997) andRiboulot et al. (2012). Until recently, exploration focused on the onshore section of the delta where older sediments are preserved· The last 20 ka (Late Pleistocene-Holocene) in the deep offshore where, exploration is continuing, serve as an analogue for the pre-Quaternary sedimentation (Riboulot et al., 2012). Understanding the stratigraphy, depositional conditions, and constraining the ages of the sequences are key to proper identification of reservoir and source rocks.

Different methods can be used to assign a time-frame to a depositional sequence. The dating method chosen depends on the timeframe being studied, depositional setting, depth of coring, sedimentation, bioturbation, material availability, tectonics, and structural deformation. For instance, sediments deposited in a stable or quiet environment probably experienced fewer sedimentary breaks or accumulation rate changes compared to those in an unstable environment. Thus, radiometric dates are, therefore, better applied to stable environments because of better stratification (if dateable materials are present), whereas biostratigraphic methods are more appropriate in the dating unstable environments with non known, or suspected, depositional hiatuses) (Bennett, 1994).

Several biostratigraphic, sequence stratigraphic and sedimentological studies of the Niger Delta (Ladipo, 1992; Stacher, 1995; Reijers et al., 1997; Owejemi and Willis, 2006; Magbagbeoloa and Willis, 2007; Reijers, 2011) indicate the combined controls of eustatic cyclicity, local tectonics, and subsidence on the complex sedimentation. Recent studies of the offshore delta (Bankole et al., 2014; Olayiwolaa et al., 2017) validate these controls and note the importance of the biostratigraphical

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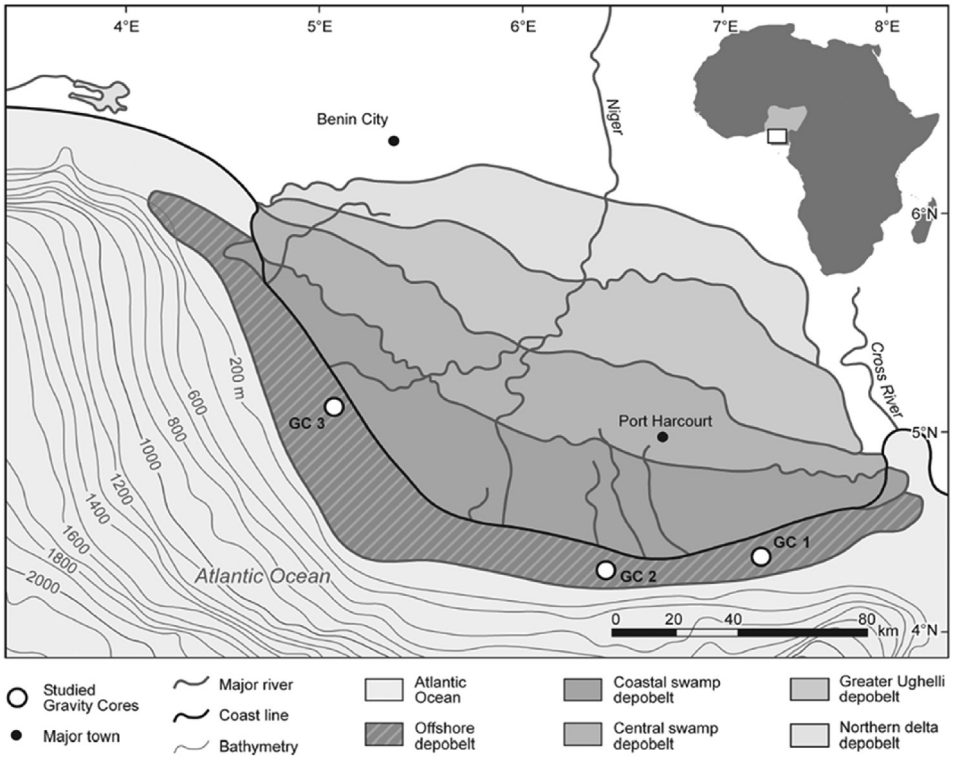

Fig. 1. The study location showing strategically positioned GC1, GC2 and GC2 gravity cores (Adojoh et al., 2017).

methods utilised. Efforts have been made to refine the biostratigraphical zonation scheme by Evamy et al. (1978) (e.g., Reijers, 2011; Oboh-Ikuenobe et al., 2017; Olayiwolaa et al., 2017), but the zonation for the Quaternary is still an issue.

This study provides a biostratigraphical age model for the last ~20 ka (Late Pleistocene to Holocene) from planktonic foraminiferal and calcareous nannofossil data obtained from three gravity cores (GCs, ~3 m long) in the shallow offshore eastern (GC1), central (GC2), and western parts (GC3) of the Niger Delta (Fig. 1). Specimens of planktonic foraminifera or broken shells of macrofossils suitable for radiocarbon dating are insignificant in the samples, a similar situation noted in another Niger Delta study by Kim et al. (2010). This study also highlights the important research gaps and challenges researchers have faced in dating the Late Quaternary (MIS 1 and MIS 2) of the Niger Delta.

2. The Niger delta

The stratigraphy of the Niger Delta was initiated by the diachronous interaction between rates of sediment supply and subsidence (Reijers, 2011), with the primary controls on the sedimentary succession being eustasy (global sea level), tectonism and climatic variations from the catchment area. The subsidence was essentially triggered by basement morphology and differential sediment loading on the unhinged and ductile shale (Doust and Omasola, 1990), and triggered synsedimentary and post-sedimentary normal faults (Fig. 2). These sequential events followed the sedimentation of each depo belt (sedimentary cycles) which resulted to development of the last 20 ka structural and stratigraphic successions of the Niger Delta (Reijers, 2011). The Niger Delta developed through pulses of prograding sedimentation into the Gulf of Guinea (Fig. 1). A 12,000-m thick sequence of overall off-lapping, regressive sediments developed, comprising three diachronous siliciclastic units: the deep-marine pro-delta Akata Formation (shale), the shallow marine delta front Agbada Formation (paralic sediments), and the continental delta plain Benin Formation (silty sand). The configuration of the subsurface Benin Formation is similar to the modern day Quaternary shallow offshore delta (Fig. 1).

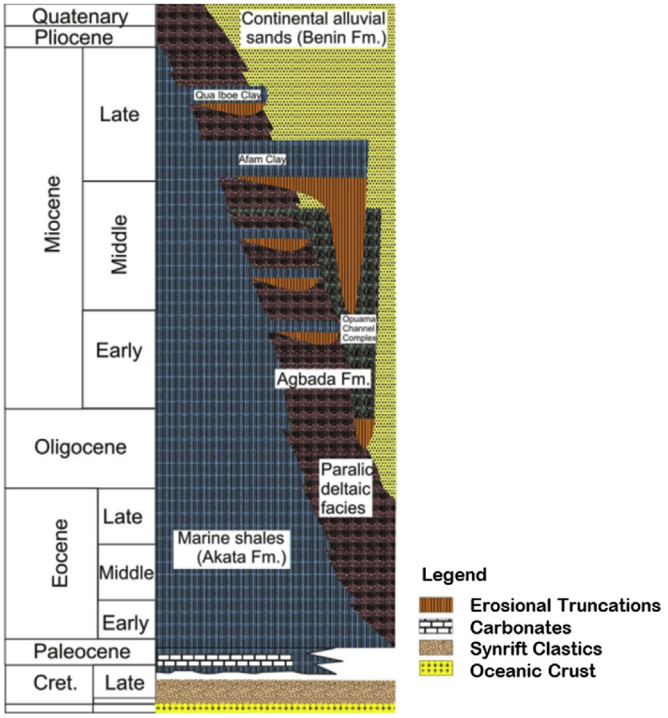

Fig. 2. The stratigraphy of Niger Delta (after Doust and Omatsola, 1990).

3. Materials and methods

The three gravity cores (GCs) used for this study were collected by Fugro Geotechnical Company for Shell Petroleum Development Company of Nigeria in 2002. The cores were obtained from the seabed within the shallow marine realm of the Niger Delta, at approximately 40 m

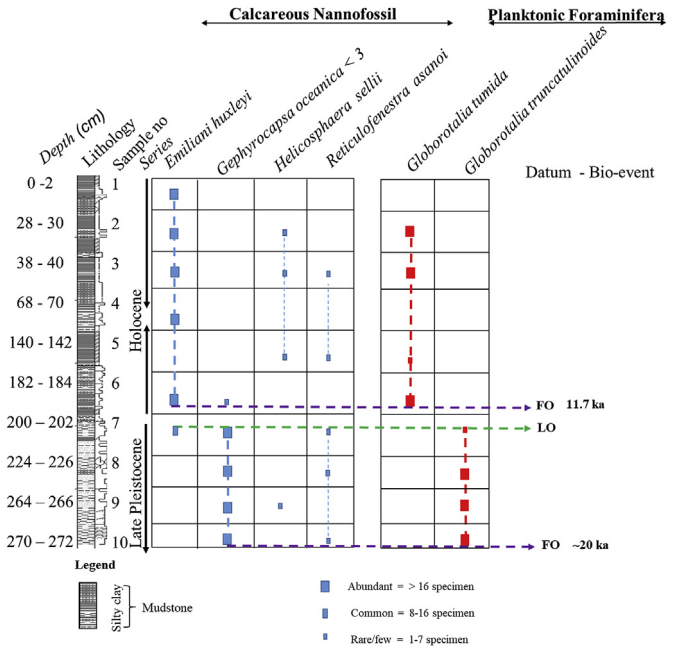

Fig. 3. Distribution of the calcareous nannofossil and planktonic foraminiferal markers species in the GC1 and its estimated biostratigraphy. **Note**: Between 0 and 40 cm is increasing upwards (*Emiliania huxleyi*) for the three GCs.

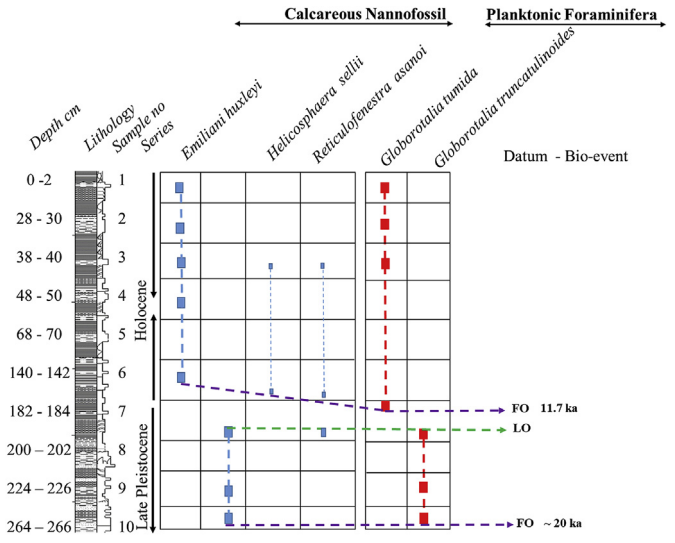

Fig. 4. Distribution of the calcareous nannofossil and planktonic foraminiferal markers species in the GC2 and its estimated biostratigraphy. Legend same as in Fig. 3.

water depth. They were strategically positioned in the eastern (GC1 = Latitude - 4°49′43 N, Longitude - 5°20′20″ E), central (GC2 = Latitude - 4°05′08″ N, Longitude - 6°33′30″ E) and western (GC3 = Latitude - 4°11′59″ N, Longitude - 7°21′29″ E) parts of the delta (Fig. 1). For each GC, approximately 3 m of core was collected and sampled at 2 cm intervals for detailed stratigraphic, chronostratigraphic and palaeoenvironmental investigation.

A detailed lithological description was undertaken for each GC at the scale of 1:10 cm (interval per unit length) (Figs. 3–5). Upon drying, the GCs were assessed for grain size distribution, accessory minerals (siderite, pyrite), shell fragments, and bioturbation before selecting samples for foraminiferal and nannofossil analyses.

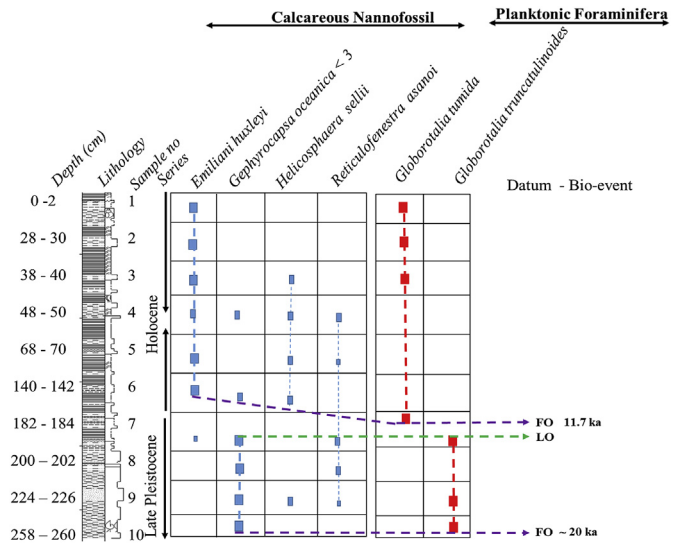

Fig. 5. Distribution of the calcareous nannofossil and planktonic foraminifera markers species in the GC3 and its estimated biostratigraphy. Legend same as in Fig. 3.

3.1. Foraminifera

About 2.5 g of material (mostly mudstone with some silty sandstone) were collected from 20 samples for each GC (60 total) for foraminiferal extraction. The samples were soaked in a clean, dry aluminium bowl containing warm water and left for 24 h to disaggregate as completely as possible. Disaggregated sample materials were washed through a 63 μm sieve to remove coagulated particles, and the fine residues were placed on the filter papers to drain the before being left in an aluminium bowl in the oven to dry at 40 °C for 24 h. Dried samples were weighed and then sieved through 250 μm, 125 μm and 63 μm sieves fractions and quantitatively analysed. The <63 μm residues were stored in plastic vials. For most samples, fewer than the standard minimum of two hundred and fifty (250) specimens (Smart, 2002) were picked using an eyelash sable brush under a binocular microscope. All the picked specimens were then mounted on gummed micropalaeontological grid slides (Chapman Slides). The quantitative data (Tables 1–3) were used to establish the first occurrence (FO) and last occurrence (LO) datums of key taxa for biostratigraphic interpretation.

3.2. Calcareous nannofossils

Ten samples were selected from each of GC (thirty total) for nannofossil preparation using the pipette and smear methods. During these preparations, precautions were taken at all stages to avoid cross-sample contamination. Although standard preparations require 30 g of sample, 35 g were used in this study to improve the chances of accurate and higher recovery of nannofossil species in the samples. Following the routine procedures of Harland et al. (1989), Yildiz and Toker (2006), and Self-Trail et al. (2017), the samples were disaggregated using distilled water. Small quantities of Sodium hexametaphosphate solution were added to disperse the clay content which ensured an even distribution of particles in the final mounts. Glass pipettes were used subsequently to extract the suspended liquids from beakers which were then carefully pippetted onto glass cover slips (22 mm × 22 mm). After a few minutes, little drops of distilled water were added to the cover slips and then dried on a hot plate. Each dried cover slip was mounted on a glass slide using two drops of Norland Optical Adhesive (index~1.56) and the slide analysed using an high-powered optical microscope for biostratigraphic interpretation (Tables 1–3).

Table 1
Biostratigraphic quantitative counts of Nannofossils and Planktonic foraminifera for GC1. **Note**: Between 0 and 40 cm is increasing up section (*Emiliania huxleyi* "E") for the three GCs, column with "G" (*Globorotalia*) represents the foraminiferal count for the GCs and *Truncorotalia trucatulinoides is the full species name for Globorotalia truncatulinoides* (d' Orbigny, 1839). " *G. trucatulinoides"* is used to maintain the uniformity of the species as applied in the region."G" = *Gephyrocapsa oceanica* (<3 μm), "H" = *Helicosphaera sellii* and "R" = *Reticulofenestra asanoi*.

Depth (cm)	*E.huxleyi*	*G.oceanica*	*H.sellii*	*R.asanoi*	*G.tumida*	*G.truncatulinoids*
0–2	50	0	0	0	35	0
28–30	45	1	4	0	0	0
38–40	42	0	2	3	40	0
48–50	32	0	0	0	0	0
68–70	0	0	3	4	0	0
140–142	36	2	0	14	41	0
182–184	0	35	0	10	0	4
202–204	0	34	0	0	0	35
224–226	0	40	5	0	0	40
270–272	0	38	0	3	0	47

Table 2
Biostratigraphic Quantitative counts of Nannofossils and Planktonic foraminifera for GC2. Note: This legend and species count is applicable to 3.2–3.2.

Depth (cm)	*E. huxleyi*	*G. oceanica*	*H. sellii*	*R. asanoi*	*G. tumida*	*G. truncatulinoides*
0–2	48	0	0	0	35	0
28–30	46	0	0	0	40	0
38–40	40	0	2	3	44	0
48–50	31	0	0	0	0	0
68–70	0	0	2	4	0	0
140–142	33	4	4	0	0	0
182–184	0	35	0	10	35	0
200–202	0	32	3	11	0	42
224–226	0	40	0	2	0	45
264–266	0	38	0	0	0	40

Table 3
Biostratigraphic Quantitative counts of Nannofossils and Planktonic foraminifera for GC3.

Depth (cm)	*E. huxleyi*	*G. oceanica*	*H. sellii*	*R. asanoi*	*G. tumida*	*G.truncatulinoides*
0–2	47	0	0	0	32	0
28–30	46	0	0	0	32	0
38–40	43	0	2	0	34	0
48–50	3	11	11	13	0	0
68–70	34	0	3	3	0	0
140–142	37	3	4	0	0	0
182–1847	4	36	0	14	36	0
200–202	0	46	0	10	0	32
224–226	0	40	13	3	0	34
258–260	0	35	0	0	0	35

4. Results

4.1. Foraminiferal biochronology

Of the twenty samples analysed for each GC, four to ten samples were productive and yielded benthic and planktonic foraminiferal taxa. The benthonic forms are poorly preserved and, few in number; therefore, unsuiatble for further analysis. The planktonic forms, although better preserved, are few and not diverse. Among the 21 foraminiferal species recovered, two marker species, *Globorotalia* truncatulinoides and *Globorotalia tumida,* can be used for a biostratigraphic age model (Figs. 3–5). The presence of these marker species in tropical sediments are indicative of the late Pleistocene to Holocene (Kennett and Srinivasan, 1983; Hine et al., 2002; Wade et al., 2011; Wall-Palmer et al., 2014; Suganuma et al., 2018).

A standard reference count of >30 but <50 specimens was adopted to define the datum and age range for the sections analysed (Smart, 2002). The quantitative format used is as follows: few/rare (1–7 specimens); common (8–16 specimens); and abundant (>16 specimens). Identification of the key biostratigraphic datums established are based on the first occurrence (FO) and last occurrence (LO) of the marker species. Three stratigraphic distribution charts of each marker species were erected based on the quantitative data and sample depths of the GCs to determine the age zonation (Tables 1–3; Figs. 3–5). The abundances of the two species observed at different intervals (Sections 4.1.1-4.1.3) were cross-referenced with global zonation schemes of Cita (1975), d'Orbigny (1983), Berggren et al. (1995), Mikkelson et al. (1997), Stefano (1998), Wall-Palmer et al. (2014), and Suganuma et al. (2018) (see Fig. 7).

4.1.1. Lower interval

Definition. The lower interval in GC1 (272-200 cm), GC2 (266-200 cm) and GC3 (260-200 cm) is defined by the abundance of *Globorotalia truncatulinoides*, and its LO in GC2 and GC3.

Remarks. The presence of *Globorotalia truncatulinoides* and absence of the *Globorotalia tumida* suggest that the top of this interval cannot be younger than the Late Pleistocene (i.e., >11 ka) in age (Wade et al., 2011; Wall-Palmer et al., 2014, Suganuma et al., 2018).

4.1.2. Upper interval

Definition. The base of the upper interval in all three GCs (200-0 cm) is defined by the LO of *Globorotalia truncatulinoides*. *Globorotalia tumida* is

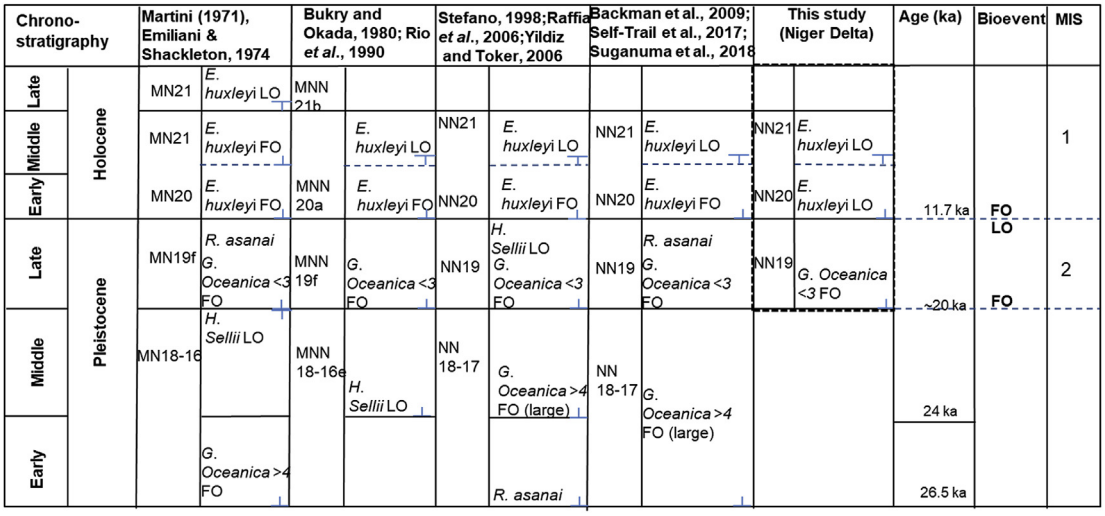

Fig. 6. Correlation of the global nannoplankton age zonation with the GCs age constrained and the marine isotope stages (MIS). MNN = Mediterranean Nannoplankton, FO = first occurrence, LO = last occurrence. Note: FO = first occurrence and continuous occurrence, LO = last appearance datum and discontinuous occurrence (Backman et al., 2009; Okada and Bukry, 1980; and Morley and Richards, 1993).

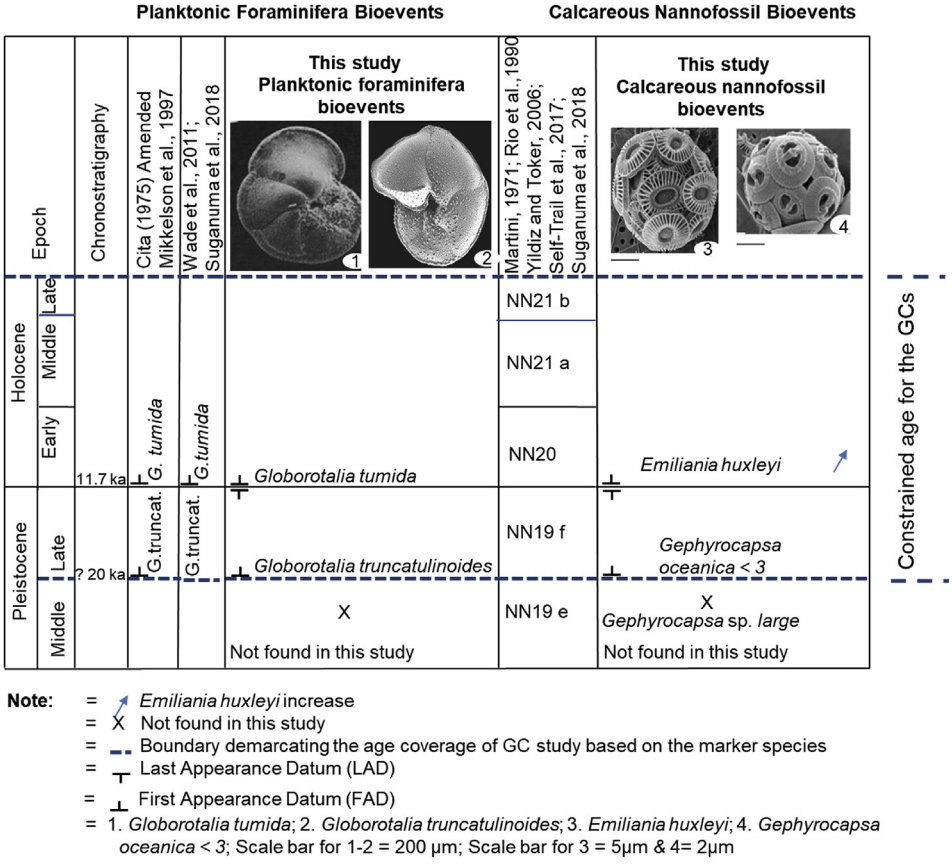

Fig. 7. Age model constrained for the GCs based on planktonic foraminiferal and nannoplankton marker species (This is placed in context with globally defined zonation).

recorded for the first time (FO) at the base of this interval. However, it occurs more prominently in the last three samples (40-0 cm).

Remarks. The absence of *Globorotalia truncatulinoides* and presence of *Globorotalia tumida* suggest that this interval is Early Holocene and younger (<11.7 ka) based on the local sedimentation rates (Adojoh et al., 2017). On the global records, this definition varies according to the regional settings (Wade et al., 2011; Wall-Palmer et al., 2014; Suganuma et al., 2018).

4.2. Nannofossil biochronology

Thirty samples (ten for each GC) were analysed for calcareous nannofossils based on a semi-quantitative method to confirm their reliability

for further detailed age determinations. The quantitative format for assigning the markers species to the three GCs is similar to that for foraminifera (Section 4.1). The specimens are well preserved with a higher diversity and abundance than planktonic foraminifera. This is because much recovery is usually obtained from a very small amount of material. In addition, in well-preserved sediments recovered away from upwelling areas, nannofossils are habitually more abundant than the planktonic foraminifera (especially the monospecies). They are more resistant to diagenetic changes over time (dissolution and overgrowth) (Raffia et al., 2006). Thus, they are present in the shallow water column and so minimise potential bias between sites, both locally and globally.

Among the six species recovered in the samples, four marker species are identified: *Emiliania huxleyi*, *Gephyrocapsa oceanica*, *Helicosphaera sellii*, and *Reticulofenestra asanoi* (Figs. 3–5). The specimens of *Gephyrocapsa oceanica* are all <3 μm in size, suggesting a late Pleistocene age (NN19 Zone) for the lower interval of the GCs (see Fig. 6; Martini, 1971; Yildiz and Toker, 2006; Kameo et al., 2006, 2016; Suganuma et al., 2018). In addition, there is an increase in the abundance of *Emiliania huxleyi* up-section. This is an indication of early Holocene age (NN20-NN21) for the upper interval of the GCs (Stefano, 1998; Yildiz and Toker, 2006; Self-Trail et al., 2017). *Helicosphaera sellii* and *Reticulofenestra asanoi* were rarely represented up-section.

Some authors use the relative size changes of specimens and abundance of marker species to delineate the Pleistocene-Holocene boundary (e.g., Emiliani and Shackleton, 1974; Castradori, 1993; Stefano, 1998; Raffia et al., 2006; Yildiz and Toker, 2006; Kameo et al., 2006, 2016; Suganuma et al., 2018). In addition, abundant increase in *Emiliania huxleyi* (*E. huxleyi* Zone of Gartner, 1977 and Yildiz and Toker, 2006) in the early Holocene up-section was noted in Tethyan (Mediterranean) regions, where the most comprehensive nannofossil biostratigraphic record has been published (e.g., Raffi and Rio, 1979; Rio et al., 1990a,b; Wall-Palmer et al., 2014, Suganuma et al., 2018). These microfossils are, therefore suitable for obtaining high-resolution biostratigraphy during the Quaternary.

5. Discussion

The planktonic foraminifera and calcareous nannofossils in the samples proved to be the most useful microfossils for constraining the biostratigraphy of the GCs. Although pollen and spores are even more diverse and abundant than foraminifera and nannofossils in the samples (e.g., *Verrucatosporites usmensis* [Polypodiaceae], *Stereisporites* sp., [Sphagnaceae], Poaceae, *Zonocostites ramonae* [Rhizophoraceae], *Podocarpidites* sp. [Podocarpaceae], *Laevigatosporites* spp. [Pteridophyta], their long ranges render them unsuitable for dating (Adojoh, 2017). In addition, pollen and spores have not been successfully used in dating sediments older than mid-Pleistocene (Morley and Richards, 1993; Rull, 2002; Adeonipekun et al., 2015; Adojoh, 2017; Adeonipekun and Sowunmi, 2019).

Various studies have noted that the preservation and abundance of marine microfossils (foraminifera, calcareous nannofossils, dinoflagellate cysts, acritarchs) in shallow offshore parts of deltas are impacted by freshwater dilution (Simmons et al., 1999; Pospelova et al., 2004; Bankole et al., 2014; Adeonipekun et al., 2015; Adojoh, 2017; Adojoh et al., 2019). This affected the recovery of the planktonic foraminiferal and dinoflagellate cysts specimens in this study.

Species of *Globorotalia* have been used to date the Late Quaternary sedimentary succession locally and globally (Murray, 1991; Wade et al., 2011; Wall-Palmer et al., 2014; Suganuma et al., 2018). Specifically, *Globorotalia truncatulinoides* and *Globorotalia tumida* evolved in the latter part of the late Pleistocene and early Holocene, respectively in the Gulf of Guinea (Martinson et al., 1987; Riboulot et al., 2012). They have integrated calcareous nannofossil data to constrain the age of the studied cores as Late Pleistocene to Holocene (Figs. 3–7). Four globally recognised nannofossil marker species, *Gephyrocapsa oceanica* <3 μm in size (NN19), *Helicosphaera sellii*, *Reticulofenestra asanoi* (NN20), and *Emiliania huxleyi* (NN20 & NN21) (Rio et al., 1990a,b; Raffia et al., 2006; Yildiz and Toker, 2006; Kameo et al., 2006, 2016; Suganuma et al., 2018) were used. In a similar study, Dalibard et al. (2014) used *Gephyrocapsa oceanica <3 μm and Emiliania huxleyi* to date Core KZai 02 in nearby Congo deep sea fan. Thus, these two studies are the first in Africa to use nannofossil and planktonic foraminiferal data to date complex Late Quaternary deltaic sequences.

6. Conclusions

Three gravity cores (GC1-GC3) from the shallow offshore Niger Delta provided useful planktonic foraminiferal and calcareous nannofossil data for age constraints of the drilled sequences. Two planktonic foraminiferal intervals were identified based on the abundance of *Globorotalia truncatulinoides* in GC1, and its LO in GC2 and GC3 (lower interval, Late Pleistocene), and the FO of *Globorotalia tumida* (upper interval, Holocene). Among the four calcareous nannofossil marker species identified, the presence and abundance of Gephyrocapsa oceanica (<3 μm) age (NN19 Zone) and increase in the abundance of *Emiliania huxleyi* up-section (NN20-NN21) were used to further confirm the age assignments from planktonic foraminifera. *Helicosphaera sellii* and *Reticulofenestra asanoi* were also present in the upper interval in the cores. For the first time in the West African passive margin (Gulf of Guinea), these results have produce the first biostratigraphic zonation for the Late Quaternary.

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Erratum

Erratum regarding missing Declaration of Competing Interest statement in a previously published article

A Declaration of Competing Interest statement was not included in the published version of the following article that appeared in a previous issue of *Quaternary Science Advances*.

The appropriate Declaration/Competing Interest statement, provided by the Authors, is included below.

"The biostratigraphy of the offshore Niger Delta during the Late Quaternary: complexities and progress of dating techniques" [*Quaternary Science Advances,* 2020; Vol. 1, 100003] DOI: 10.1016/j.qsa.2020.100003.

Declaration of competing interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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