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Miocene Foraminifera Biostratigraphy and Interpretation North Deep Sea Block of the Congolese Atlantic Basin

Nehl Dorland Kobawila[1*], Hilaire Elenga[1,2], Louis Richard Ngatse[3]

[1]Department of Geology, Faculty of Science and Technology, Marien Ngouabi University, Brazzaville, Republic of Congo
[2]Geological and Mining Research Center, Brazzaville, Republic of Congo
[3]National Petroleum Society of the Congo, Brazzaville, Republic of Congo
Email: *kobawila_nehldo@hotmail.fr

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Abstract

This work is the subject of the biostratigraphic and palaeoenvironmental study of the North Deep Sea area of the Congolese Miocene Atlantic Basin. This study is made from samples of lateral cores, drill cuttings and electrical logs. Lithology generally exhibits an irregular alternation of weakly indurated grey clay, light grey siltstones, and whitish, quartzitic sand, medium to coarse-grained, sub-angular to rounded. The presence of glaucony indicates that sediments have been deposited in a calm and reducing environment. The entire formation is fossiliferous. Micropaleontological analysis revealed 120 species of foraminifera including 98 planktonic (81.67%) and 22 benthic (18.33%) species used for biozonation, dating and interpretation of palaeoenvironments. Similarly, the bio-events of plankton foraminiferal, characterized by the level of the first appearance of certain species, have made it possible to identify fifteen biozones (*Globorotalia plesiotumida*, *Globorotalia merotumida*, *Globorotalia acostaensis*, *Globorotalia menardii*, *Globigerina nepenthes*, *Globorotalia siakensis*, *Globorotalia fohsi*, *Globorotalia praefohsi*, *Globorotalia peripheroacuta*, *Globorotalia peripheroronda*, *Praeorbulina sicana*, *Catapsydrax dissimilis*, *Globigerinatella insueta*, *Paragloborotalia kugleri* and *Globorotalia kugleri*) corresponding to age between Aquitanian and Lower Pliocene. Biofacies analysis of foraminifera has identified palaeoenvironments that vary from open marine environments, bathyal to abyssal.

Keywords

Biostratigraphy, Foraminifera, Palaeoenvironments, Miocene, Congolese Atlantic Basin

1. Introduction

The history of the Congolese coastal sedimentary basin is linked to the Cretaceous opening of the South Atlantic between Africa and South America. The work of Desthieux *et al.* [1] presents a geodynamic evolution divided into three phases: antesaliferous, saliferous and post-saliferous. This basin, whose economic interest is linked to oil exploitation, has been the subject of numerous studies in the various fields of geology (tectonics, structural geology, stratigraphy, sedimentology, and micropaleontology) which provided interesting details on the lithological succession and the age of the facies. The biostratigraphic and micropaleontological studies, Kouyoumontzakis; M'Boro; N'Gatse; Massala; Giresse *et al.*; Giresse & Baloka; Mbani [2]-[9] carried out are mostly of Cretaceous age. Available data on Tertiary biostratigraphy, including Miocene biostratigraphy, are rare and fragmentary. Thus, few biostratigraphic studies have been carried out and published on the Miocene of the Congolese coastal basin. A large part of the existing studies on Miocene result from the correlation of the work carried out in the sub-region (Angola, Gabon and Cameroon). Although the Miocene was established during the oceanization, it is currently an interesting prospect in the oil exploration of the Congolese offshore. From the Oligocene to the Miocene, sedimentological data have prompted the search for ancient fluvial channels. These paleo-channels contain sands that have proven to be high-quality traps for migrating hydrocarbons. With a view to further exploration, a biostratigraphic study was carried out on four boreholes in the North Deep Sea block of the Congolese Atlantic Basin. This study area is located offshore in the Congolese Atlantic baisn with water depths varying from 500 m to 3000 m. The area is characterized by a thinning of the antesaliferous series and by the presence of chenalising structures (**Figure 1**). The objectives of this study are:

- To carry out a chronostratigraphic calibration from the biozones;
- To characterize the deposit environments based on lithological analysis and on the determination of biozones. This study presents the invotory of biozones, the chronostratigraphic calibration of remarkable biostratigraphic events at the scale of the interval studied, and the palaeoenvironmental interpretation of sedimentary deposits.

2. Material and Methods

Study material includes 92 samples of side cores, 120 drill cuttings and 5 electrical logs (Gamma Ray) from four wells called BM01, NM01, RM01 and SGM01, whose total depth varies between 1670 m and 3400 m.

The methodology consists in collecting the samples of loose sediment every 10 or 20 m for the foraminifera, and every 10 m for the nannofossils. Quantitatively, 30 grams of each sample are subjected to defloculation and sieving operations. Samples are carefully washed through a 63 μ sieve. The dried residue passes through a sieve set of 500 μ, 500 - 250 μ, 250 - 125 μ and less than 125 μ. Taxonomic analysis

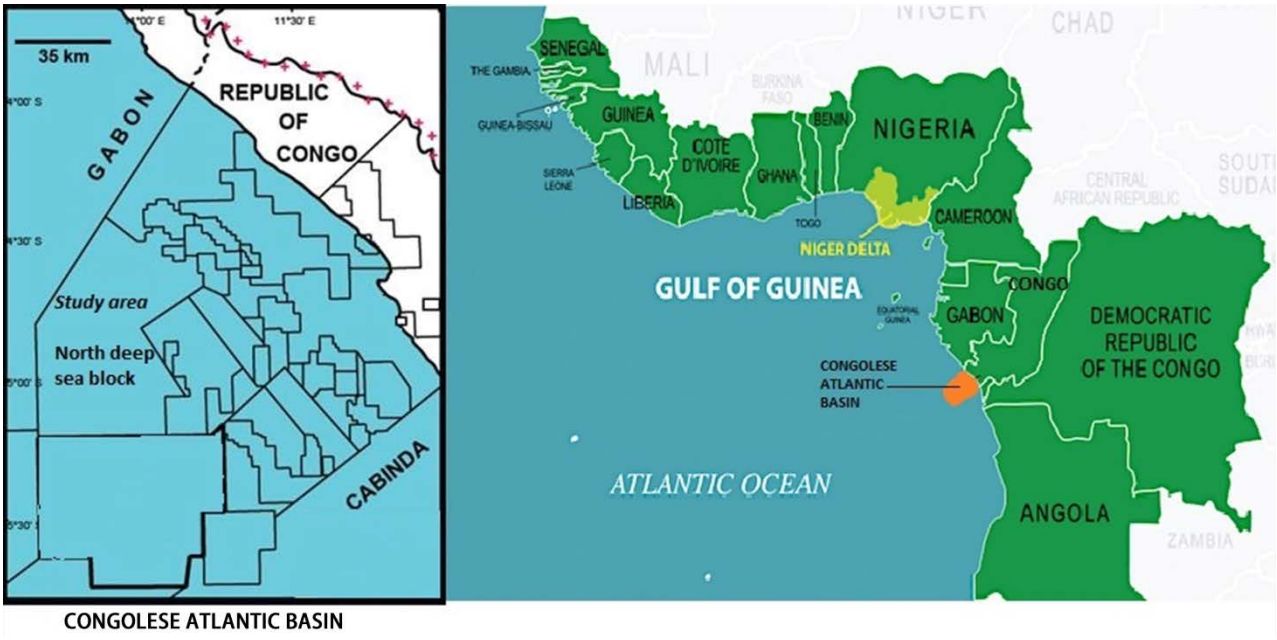


Figure 1. Location of the study area.

and identification of planktonic foraminifers are based on the documents and illustrations depicted in the work of Blow [10] [11] with modifications by Bolli & Saunders [12], Loeblich and Tappan [13], followed by recent amendments by Hardenbol *et al.* [14], Berggren *et al.* [15] and Olsson *et al.* [16], and in comparison to the work of Mboro *et al.* [17]. The micropaleontological preparations of the lateral cores were selected to study their total micropaleontological contents, and the samples of the drill cuttings were prepared for quantitative micropaleontological and nannofossil analysis. At the end of the biostratigraphic analyses, the results were integrated into the diagraph and lithofacie data in order to allow a strategic interpretation of the diagraphs, on which the stratigraphic and paleo-environmental cutting off the North Deep Sea block is based.

3. Results

1) LITHOSTRATIGRAPHY

The lithological description of the core samples and cuttings associated with the analysis of the Gamma Ray logs shows that the interval drilled concerns the Paloukou formation (clay-silty, sandy and limestone). The sections studied generally consist of three units in the direction of drilling:

- Unit 1: Upper Miocene (1816 m - 2556 m)
  It generally has an alternation of greenish grey to dark grey clay, silty, transparent to opaque sand, very fine to coarse, and light grey siltstone. This unit is very fossiliferous with a good diversity of fossils. Its thickness varies from 250 m to 740 m approximately.
- Unit 2: Medium Miocene (2556 m - 2926 m)
  This section is dominated by an irregular alternation of greenish grey clay,

weakly indurated, brown grey siltstone, loosely consolidated more or less clayey, and translucent sand with fine to locally coarse, sub-rounded quartz grain. The medium Miocene is moderately fossiliferous and contains abundant glauconite. This interval is between 130 m and 370 m thick.

- Unit 3: Lower Miocene (2926 m - 3400 m)

  This interval is composed of grey to beige clay, silty to sandy silto-sandy, little to well indurated; followed by grey to whitish siltstone; of whitish-white sand, quartzitic, medium to coarse grained, sub-angular to rounded. This unit is low fossil and has a reduced diversity of fossil species. It is about 450 m thick.

2) BIOSTRATIGRAPHY

120 species of foraminifers, including 98 planktonic (81.67%) and 22 benthic (18.33%), have been identified and used for dating, biozonation and palaeoenvironmental interpretation. From the different species of foraminifers collected in the North Deep Sea block, the different stratigraphic cuts of the Miocene are defined on the basis of the Blow [10] [11] classification (**Table 1**).

Upper Miocene Limit—Lower Pliocene

In the Deep North Sea block, the upper Miocene—lower Pliocene boundary is marked by the first appearance of *Globorotalia plesiotumida* and the last appearance of *Globorotalia margaritae* located at 1816 m of depth. The foraminifers *Globorotalia juania*, *Globorotalia conoide* and *Globorotaloides variabilis* are also recorded slightly below this depth.

a) Upper Miocene (1816 m - 2556 m)

- **Messinian (1816 m - 2150 m)**

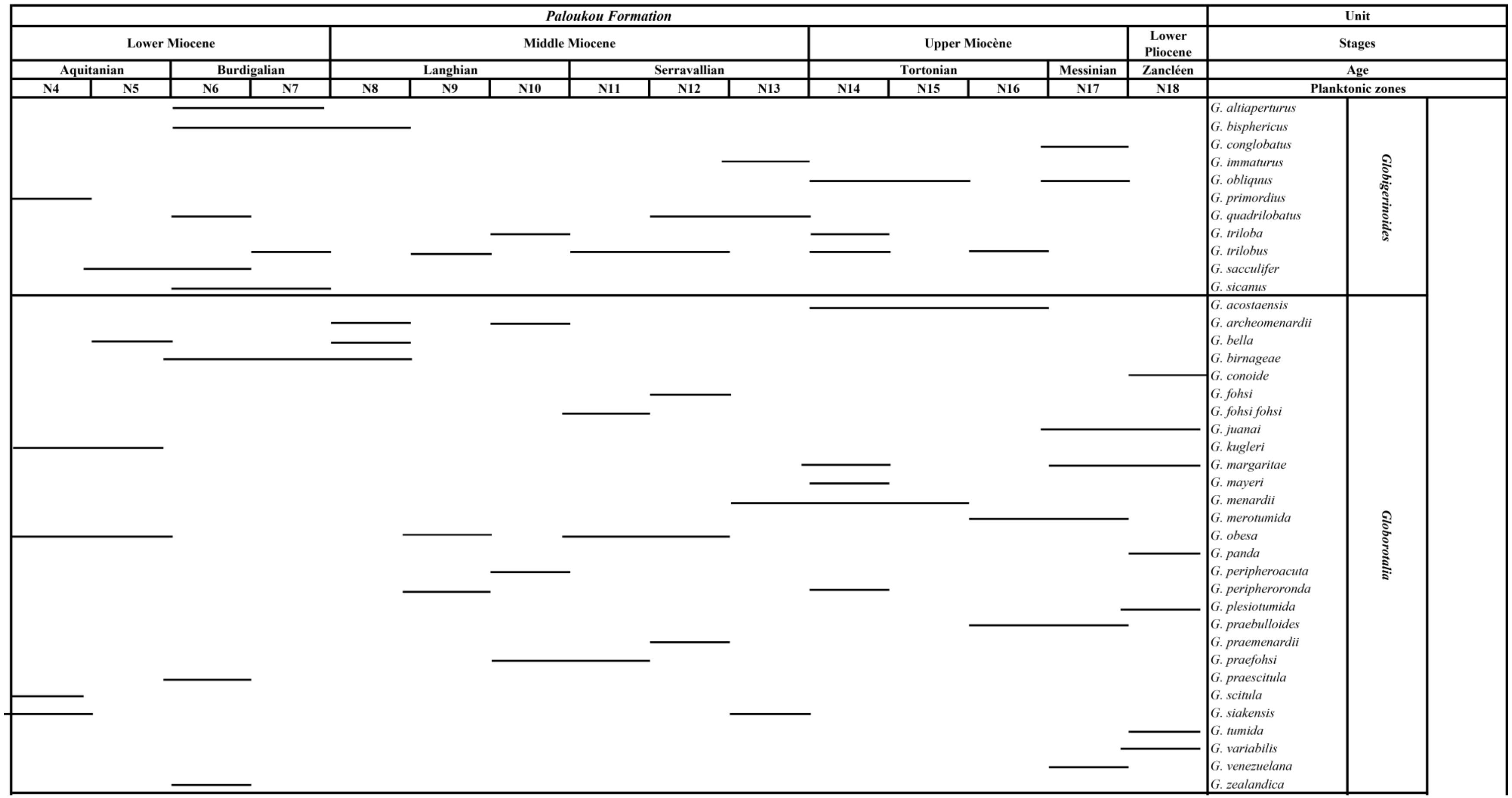
It is found in three wells. In the direction of drilling, the summit of the Messinian is encountered at 1816 meters of depth by the first appearance of *Globorotalia tumida plesiotumida*. The base of this interval is marked by the appearance of *Globorotalia merotumida* at 2150 m depth. The fossil harvest is abundant and makes it possible to distinguish in the direction of drilling, the presence of planktonic foraminifers *Globorotalia tumida*, *Globorotalia panda*, *Globorotalia venezuelana*, *Neogloboquadrina acostaensis*, *Globigerina angustiumbilicata*, *Globigerina obesa*, *Orbulina suturalis*, *Praeorbulina glomerosa*, *Globigerinoides conglobatus*, *Orbulina universa*, *Neoglobigerina pachyderma*, and *Neogloboquarina acostaensis*, all characteristics of this interval.

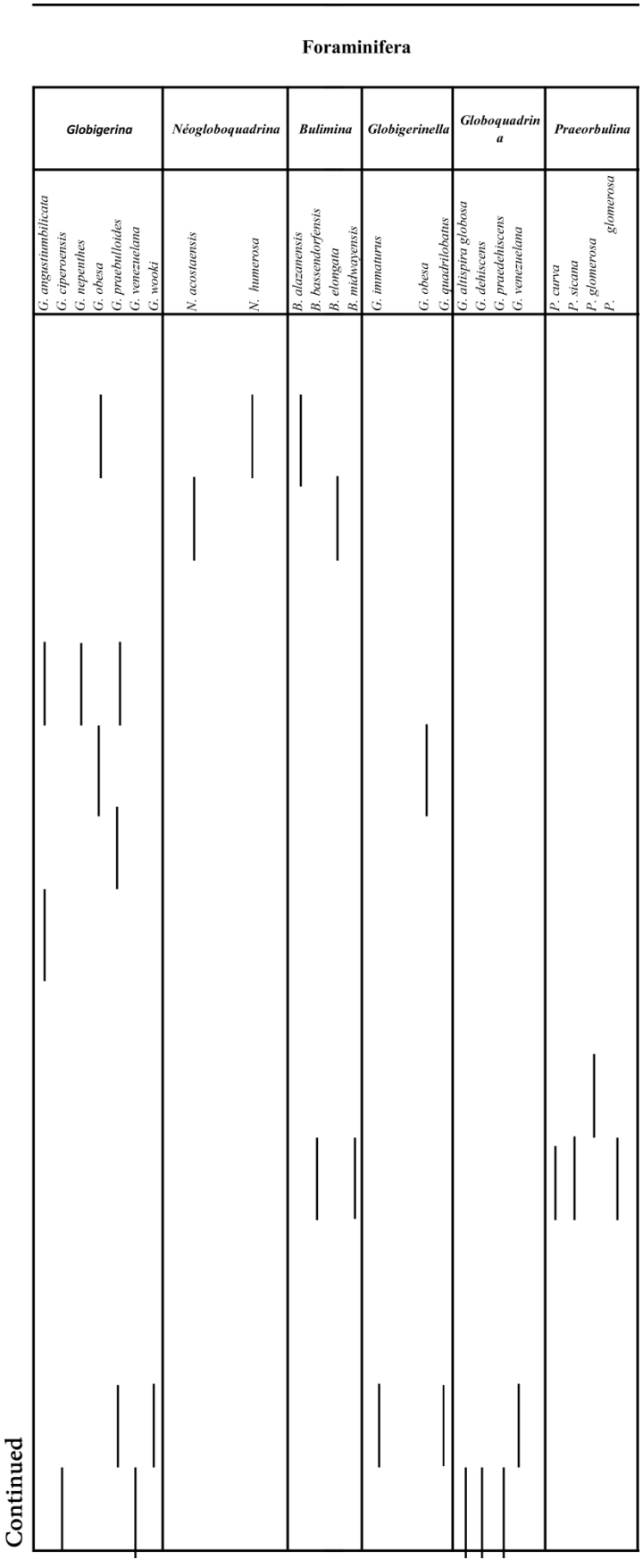
Benthic foraminifera *Martinotiella communis*, *Sphaeroidinellopsis disjuncta*, *Heoglundina elegans*, *Pullenia bulloides*, *Cibicidoides pseudoungerianus*, *Bulimina alazanensis* are also collected in this interval. In addition, we also note the subsequent appearance at the descent of the fossils *Discoaster quiqueramus* at 2060 m and *Discoaster berggrenii* at 2100 m of depth.

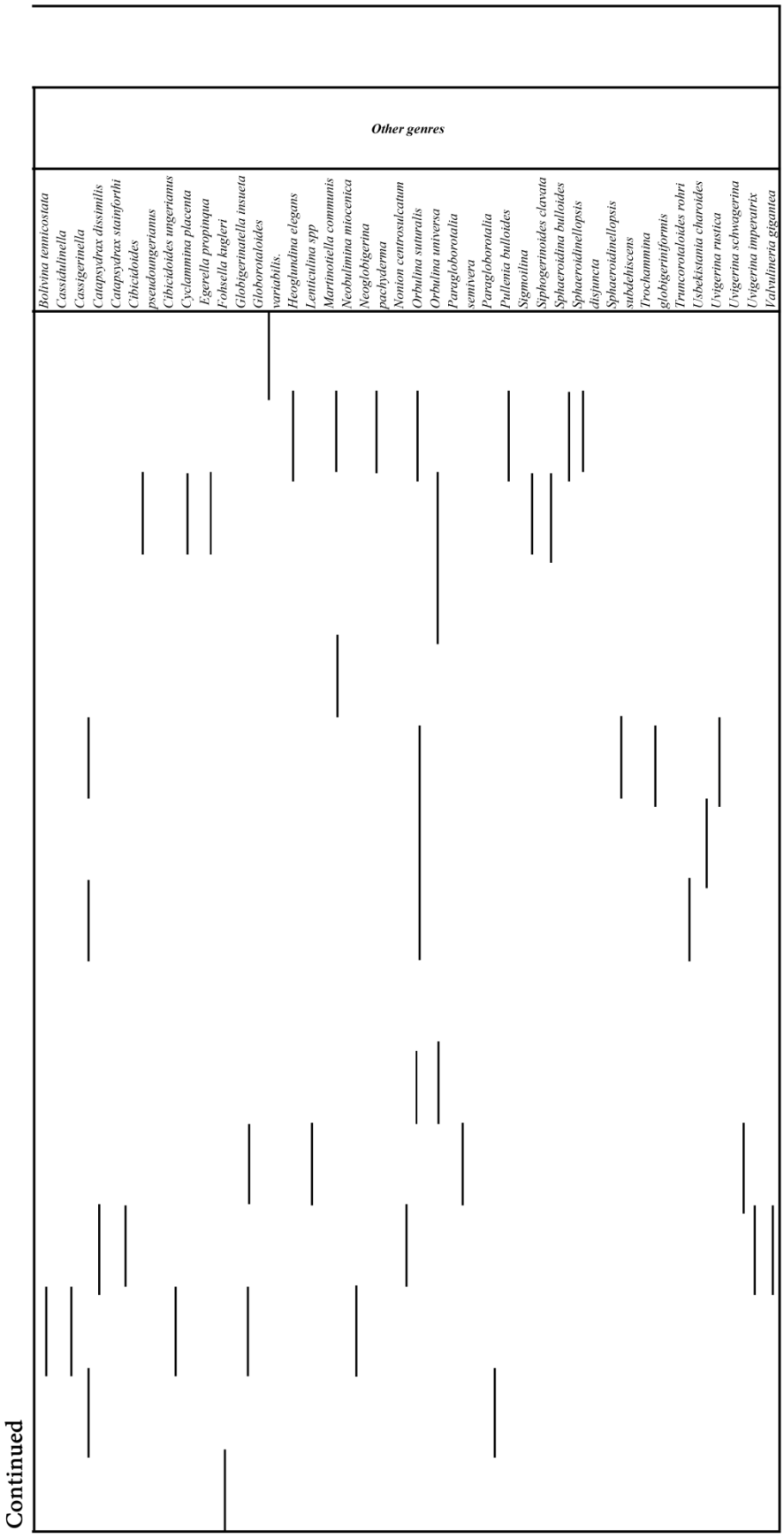
- **Tortonian (2150 m - 2556 m)**

Micropaleontological harvest is good. In the direction of drilling, the top is marked by *Globorotalia merotumida* at 2298 m depth and the base is at 2556 m depth with the first appearance of *Globigerina nepenthes*. This area is also characterized by the first appearance of *Globorotalia mayeri*, *Globorotalia acostaensis*

Table 1. Stratigraphic distribution of planktonic foraminifers established on Deep Sea North block.




Foraminifera
Globigerina
Néogloboquadrina
Bulimina
Globigerinella
Globoquadrina
Praeorbulina
G. angustiumbilicata
G. ciperoensis
G. nepenthes
G. obesa
G. praebulloides
G. venezuelana
G. wooki
N. acostaensis
N. humerosa
B. alazanensis
B. bassendorfensis
B. elongata
B. midwayensis
G. immaturus
G. obesa
G. quadrilobatus
G. altispira globosa
G. dehiscens
G. praedehiscens
G. venezuelana
P. curva
P. sicana
P. glomerosa
P. glomerosa
Continued


Continued
Other genres
Bolivina temicostata
Cassidulinella
Cassigerinella
Catapsydrax dissimilis
Catapsydrax stainforthi
Cibicidoides
pseudoungerianus
Cibicidoides ungerianus
Cyclammina placenta
Egerella propinqua
Robsella kugleri
Globigerinatella insueta
Globorotaloides
variabilis.
Heoglundina elegans
Lenticulina spp
Martinottiella communis
Neobulimina miocenica
Neoglobigerina
pachyderma
Nonion centrosulcatum
Orbulina suturalis
Orbulina universa
Paragloborotalia
semivera
Paragloborotalia
Pullenia bulloides
Sigmoilina
Siphogerinoides clavata
Sphaeroidina bulloides
Sphaeroidinellopsis
disjuncta
Sphaeroidinellopsis
subdehiscens
Trochammina
globigeriniformis
Trancorotaloides rohri
Usbekistania charoides
Uvigerina rustica
Uvigerina schwagerina
Uvigerina imperatrix
Valvulineria giguntea

with the disappearance of *Neogloboquadrina acostaensis* and *Neogloboquadrina humerosa*. We record the presence of planktonic foraminifera *Globorotalia praebulloides*, *Globigerina praebulloides*, *Globigerina angustiumbilicata*, *Globigerinoides trilobus*, *Globigerinoides triloba*, *Globigerinoides obliquus*, *Globigerinoides immaturus*, *Orbulina universa*, as well as the presence of benthic foraminifera such as *Bulimina elongata*, *Cibicidoides pseudoungerianus*, *Sigmoilina schlumbergeri*, *Martinottiella communis*, *Cyclammina placenta*, *Egerella propinqua*, *Siphogerinoides clavata* and *Sphaeroidinellopsis subdehiscens.*

b) Middle Miocene (2556 m - 2926 m)

- **Serravalien** (2556 m - 2720 m)

The summit is marked by the first appearance of *Globigerina nepenthes* at a depth of 2556 m. The foraminifera *Globorotalia praefohsi* and *Truncorotaloides rohri* represent the base of the Serravalien at 2720 m. The micropaleontological harvest in this area is moderate. Some samples are not very fossiliferous, while others contain casts of broken foraminifera. This section records, still in the direction of drilling, by the presence of the assemblages of *Globorotalia acostaensis*, *Globorotalia praemenardii*, *Globorotalia scitula*, *Globorotalia fohsi*, *Globorotalia obesa*, *Globorotalia menardii*, *Globorotalia siakensis*, *Globigerinoides trilobus*, *Globigerinoides obliquus*, *Globigerinoides quadrilobatus*, *Globigerinoides immaturus*, *Globigerina praebulloides*, *Globigerina nepenthes*, *Usbekistania charoides*, *Uvigerina rustica*, *Orbulina suturalis*, *Trochammina globigeriniformis* and *Sphaeroidinellopsis subdehiscens.*

- **Langhien** (2720 m - 2926 m)

The roof and base of this section are characterized respectively at 2720 m and 2926 m depth by the first appearance of *Globorotalia praefohsi* and *Praeorbulina sicana*. The interval is moderately fossiliferous and increasingly calcareous with an increase in planktonic foraminifers and calcareous nannofossils. The basal part is also defined by an increase in the number of agglutinating and radiolar foraminifera. In the direction of the borehole, we can count the presence of *Globorotalia peripheroronda*, *Globorotalia birnageae*, *Globorotalia bella*, *Globorotalia archeomenardii*, *Globorotalia fohsi fohsi*, *Globorotalia Obesa*, *Globorotalia praemenardii*, *Globorotalia scitula*, *Globigerinoides trilobus*, *Globigerinoides triloba*, *Globigerinoides bisphericus*, *Globigerinatella insueta*, *Praeorbulina glomerosa*, *Praeorbulina curva*, *Praeorbulina sicana*, *Praeorbulina glomerosa glomerosa*, *Paragloborotalia semivera*, *Orbulina suturalis*. The lower part differs from the previous one by the abundance of arenaceous foraminifera and by an assemblage of *Bulimina midwayensis*, *Bulimina bassendorfensis*, *Buliminella aff. Sp*, *Lenticulina spp Uvigerina schwagerina*.

c) Lower Miocene (2926 m - 3400 m)

- **Burdigalian (2926 m - 3195 m)**

This interval is weakly fossiliferous. It is nevertheless characterized by the abundance of benthic foraminifers and by a small quantity of planktonic foraminifera. The top is marked by the first appearance of *Praeorbulina sicana* while the

base is marked by the first appearance of *Globigerinatella insueta*. In the direction of the borehole, this interval records the presence of the foraminifera *Globorotalia birnagae*, *Globorotalia bella*, *Globorotalia praescitula*, *Globorotalia zealandica*, *Globorotalia obesa*, *Globorotalia peripheroronda*, *Globigerinoides triloba*, *Globigerinoides sacculifer*, *Globigerinoide sicanus*, *Globigerinoides altiaperturus*, *Globigerinoides trilobus*, *Globigerinoides quadrilobatus*, *Globigerinoides bisphericus*, *Globigerina woodi*, *Globigerina praebulloides*, *Globigerina angustiumbilicata*, *Globoquadrina venezuelana*, *Catapsydrax dissimilis*, *Catapsydrax stainforthi*, *Sphaeroidina bulloides*, *Valvulineria gigantea*. The Burdigalien is also characterized by the presence of *Bolivina tennicostata*, *Nonion centrosulcatum*, *Cassidulinella pliocenica*, *Cibicidoides ungerianus*, *Neobulimina miocenica*, *Cassigerinella chipolensis* and *Uvigerina imperatrix.*

- **Aquitanian (3195 m - 3400 m):**

The first appearance of the foraminifera *Globigerinatella insueta* and *Globigerinoides primordius* respectively characterize the roof and the base of this interval at heights 3195 m and 3400 m. In addition, this zone includes the presence of the foraminifera *Globorotalia obesa*, *Globorotalia bella*, *Globigerina praebulloides*, *Globigerina wooki*, *Globigerinoides sacculifer*, *Globigerinoides primordius*, *Globigerinella obesa*, *Globigerinella immaturus*, *Globigerinella quadrilobatus*, *Globoquadrina venezuelana*, *Globoquadrina dehiscens*, *Cassigerinella chipolensis*, *Paragloborotalia kugleri*, *Uvigerina rustica* and *Trochammina globigeriniformis*.

4. Interpretation

1) BIOZONATION

The biozonation of Cenozoic planktonic foraminifera has been the subject of several reviews including: Berggren [18] [19] [20] [21]; Blow [10]; Bolli [22]; Bolli and Bermudez [23] [24]; Premoli-Silva and Bolli [25]; Lamb and Beard [26]; Stainforth *et al.* [27].

The biozones used here are those of Bolli [22] and Blow [10]. The chronostratigraphic framework is taken from Berggren *et al.* [15]. Across the Congolese Atlantic basin, the observation of certain planktonic and benthic bioevents led to the establishment of 15 biozones (**Table 2**). These biozones were recognized on the basis of the levels of the first appearance of foraminifera which mark their lower limit. This method, which defines the level of first appearance and the level of extinction of marker species, avoids the contamination problem resulting from collapse which is very common with drill cuttings. However, the level of the first appearance of the supra-adjacent species marks the top of each zone.

It is thus proposed, after international calibration, the following biozonation:

a) Upper Miocene—lower Pliocene limit

- ***Globorotalia plesiotumida*** **(N18) zone**

The presence of the planktonic foraminifera *Globorotalia conoides* and

Table 2. Correlation of established biozones.

AGE	BOLLI, 1966	BLOW, 1969	Proposed In this study	ZONE	DEPTH (m)
LOWER PLIOCENE	*Globorotalia margaritae*	*Globorotalia tumida tumida - Spaeroidinellopsis subdehiscens paenedehiscence*	*Globorotalia margaritae*	N18	1816
MESSINIAN	*Globorotalia humerosa*	*Globorotalia tumida plesiotumida*	*Globorotalia merotumida*	N17	2150
TORTONIAN	*Globorotalia acostaensis*	*Globorotalia acostaensis - Globorotalia merotumida*	*Globorotalia acostaensis*	N16	2265
	Globorotalia menardii	*Globorotalia continuosa*	*Globorotalia menardii*	N15	2307
	Globorotalia mayeri	*Globigerina nepenthes - Globorotalia siakensis*	*Globigerina nepenthes*	N14	2556
	Globigerinoides ruber	*Globorotalia siakensis*	*Globorotalia siakensis*	N13	2600
SERRAVALLIAN	*Globorotalia foshi robusta*	*Globorotalia fohsi*	*Globorotalia fohsi*	N12	2681
	Globorotalia foshi lobata	*Globorotalia praefohsi*	*Globorotalia praefohsi*	N11	2720
	Globorotalia fohsi fohsi	*Globorotalia peripheroacuta*	*Globorotalia peripheroacuta*	N10	2785
LANGHIAN	*Globorotalia fohsi peripheroronda*	*Orbulina surturalis - Globorotalia peripheroronda*	*Orbulina suturalis*	N9	2860
	Praeorbulina glomerosa	*Praeorbulina glomerosa curva*	*Praeorbulina sicana*	N8	2926
BURDIGALIAN	*Globigerinoides altiaperturus*	*Praeorbulina glomerosa sicana*	*Catapsydrax dissimilis*	N7	3195
	Catapsydrax stainforthi	*Globigerinatella insueta/ Globigerinita dissimilis*	*Globigerinatella insueta*	N6	3290
AQUITANIAN	*Catapsydrax stainforthi*	*Globoquadrina dehiscens praedehiscens/ Globoquadrina dehiscens dehiscens*	*Paragloborotalia kugleri*	N5	3324
	Globorotalis kugleri	*Globigerinoides quadrilobatus primordius/Globorotalia kugleri*	*Globorotalis kugleri*	N4	3400

Globorotalia tumida at 1670 m indicates the lower Pliocene. The first occurrence of *Globorotalia margaritae* (Figure 2(a)) and *Globorotalia plesiotumida* at the 1816 m level mark the limit between the upper Miocene and the lower Pliocene, then confirms an age corresponding to the Blow [10] zone N18. The taxon *Globorotalia margaritae* is considered to be a very important biostratigraphic boundary separating the Miocene from the Pliocene [27] [28]. The species *Globorotalia margaritae* therefore characterizes the base of the Lower Pliocene [10] and is correlated with the *Globorotalia crassaformis* zone of Mboro *et al.* [17]. Subsequent to descent, the presence of plantonic foraminifera *Globorotaloides variabilis, Globorotalia padan* and *Globorotalia juanai* is recorded.

b) Upper Miocene

i) Messinian

- ***Globorotalia merotumida*** **(N17) zone**

The first occurrence of *Globorotalia merotumida* (Figure 2(b)) is located at a depth of 2150 m, thus marking the base of the Messinian. The upper limit is at a

depth of 1816 m, defined by the first occurrence of *Globorotalia margaritae*. This interval corresponds to zone N17 of Blow [10] and, of Mboro *et al.* [17]. This space which covers the Messinian is also characterized by the first occurrence of *Globigerinoides obliquus, Neogloboquadrina humerosa, Martinottiella communis* and by the presence of *Globigerinoides conglobatus*, *Globorotalia praebuloides, Globigerina obesa, Globorotalia venezuelana, Globorotalia juanai Pullenia bulloides* and *Orbulina saturalis.*

ii) Tortonian

- ***Globorotalia acostaensis* (N16) zone**

The base of this interval is delimited at the level of 2265 m by the first occurrence of *Globorotalia acostaensis* (**Figure 2(c)**) while its top is located at a depth of 2150 m by the occurrence of *Globorotalia merotumida*. In this biozone, also exist *Globigerinoides trilobus*, *Orbulina universa, Cibicidoides pseudoungerianus*, *Globorotalia praebulloides*, *Neogloboquadrina acostaensis*. The *Globorotalia acostaensis* biozone is correlated with the N16 biozone (*Globorotalia acostaensis*) of Bolli [17], Blow [10], Postuma [29] and Mboro *et al.* [17].

- ***Globorotalia menardii* (N15) zone**

The level of first occurrence of *Globorotalia menardii* (**Figure 2(d)**) is located at 2307 m depth, thus marking the base of this interval. The top is at 2265 m marked by a first occurrence of *Globorotalia acostaensis*. This area is characterized by the presence of *Orbulina universa* and *Globigerinoides obliquus*. This interval is correlated with the N15 (*Globorotalia menardii*) zone from Bolli [22], Postuma [29], Mboro *et al.* [17] and the *Globorotalia continuosa* (N15) zone from Blow [10].

- ***Globigerina nepenthes* (N14) Zone**

The base is delimited at 2556m depth by the first occurrence of *Globigerina nepenthes* (**Figure 2(e)**) and *Globorotalia mayeri* and the top is marked by the first occurrence of *Globorotalia acostaensis* at 2265 m depth. This interval is also characterized by the occurrence of *Globorotalia menardii*, *Globigerina angustiumbilicata*, and the presence of *Globorotalia margaritae*, *Martinottiella communis*, *Globigerinoides triloba*, *Globigerinoides obliquus*, *Globigerinoides trilobus* and *Globigerina praulleboides*. This zone is correlated with the *Globorotalia mayeri* (N14) zone of Bolli [22] and Mboro *et al.* [17].

c) Middle Miocene

i) Serravallien

- ***Globorotalia siakensis* (N13) zone**

The base of this interval is marked by the first occurrence of *Globorotalia siakensis* (**Figure 2(f)**) at 2600 m depth. The top is characterized by the first occurrence of *Globigerina nepenthes* at 2556 m depth. This zone is characterized by the occurrence of *Cassigerinella chipolensis*, *Globigerinoides quadrilobatus*, *Globigerinella obesa*, *Globorotalia menardii*, *Globigerinoides immaturus*, *Sphaerodinelopsis subdehiscens*, *Orbulina suturalis*, *Uvigerina rustica* and *Trochammina globigeriniformis*. This zone is correlated with the *Globorotalia siakensis*

(N13) zone by Blow [10] and the *Globigerinoides ruber* (N13) zone by Bolli and Saunders [12].

- ***Globorotalia fohsi* (N12) zone**

The base and top of this area are marked by the occurrence and disappearance of *Globorotalia fohsi* (**Figure 2(g)**) at 2681 m (base) and 2600 m (top) respectively. This area also has the presence of *Globorotalia praemenardii*, *Orbulina suturalis*, *Globorotalia obesa*, *Usbekistania charoides*, *Globigerina praebulloides*, *Globigerinoides quadrilobatus* and *Globigerinoides trilobus*. It is correlated with the *Globorotalia fohsi* (N12) zone of Blow [9].

- ***Globorotalia praefohsi* (N11) zone**

The level of first occurrence of *Globorotalia praefohsi* (**Figure 2(h)**) is at a depth of 2720 m thus marking the base of this zone. The summit is defined by the first occurrence of *Globorotalia fohsi* at 2681 m depth. This area is characterized by the presence of *Globorotalia fohsi fohsi*, *Orbulina suturalis*, *Cassigerinella chipolensis*, *Globorotalia obesa*, *Globigerina praebulloides*, *Globigerinoides trilobus* and *Globigerina angustiumbilicata*. It is correlated with the *Globorotalia praefohsi* (N11) zone of Blow & Banner [30] [31].

ii) Langhien

- ***Globorotalia peripheroacuta* (N10) zone**

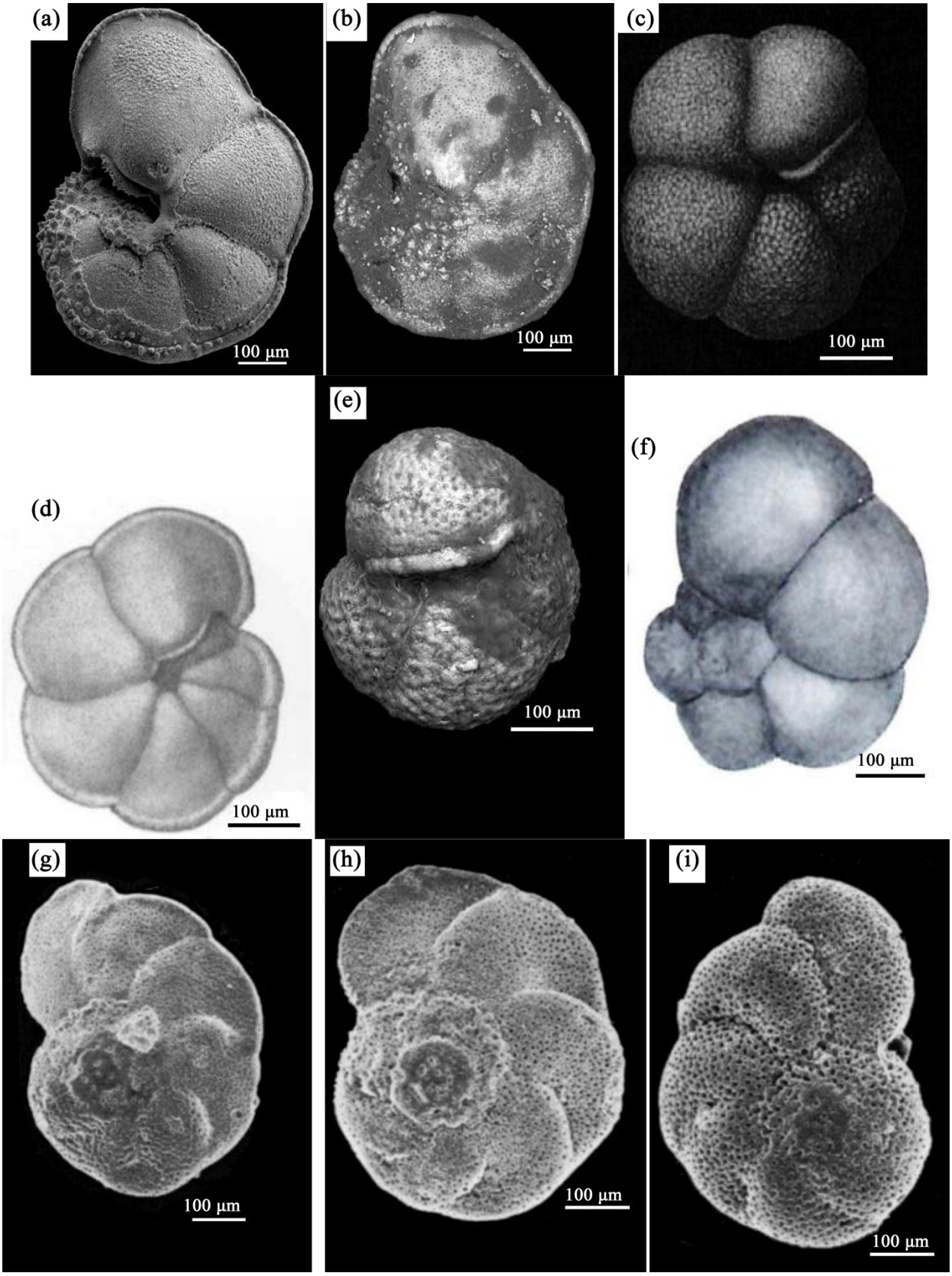
The base of the area is delimited by the level of first occurrence of *Globorotalia peripheroacuta* (**Figure 2(i)**) at 2785m depth and the summit is defined by the first occurrence of *Globorotalia praefohsi* at a depth of 2720 m. This area is also marked by the first occurrence of *Globigerinoides triloba* and *Globorotalia archeomenardii.* It is correlated with the *Globorotalia peripheroacuta* (N10) zone of Blow [10].

- ***Orbulina suturalis* (N9) zone**

The top of this zone is defined by the level of the first occurrence of *Praeorbulina glomerosa* at a depth of 2785 m, while the base is marked by the first occurrence of *Orbulina suturalis* (**Figure 2(j)**) at a depth of 2860 m. This area is characterized by the first appearance of *Globorotalia peripheroronda* and then by the presence of *Globorotalia Obesa, Orbulina universa and Globigerinoides trilobus*. The zone with *Orbulina universa* is equivalent to the zone *Globorotalia peripheroronda* (N9) of Blow [10].

- ***Praeorbulina sicana* (N8) zone**

The base of the area is defined by the level of first occurrence of *Praeorbulina sicana* (**Figure 2(k)**) at 2926m depth, and the summit is marked by the first occurrence of *Globorotalia peripheroronda* at 2860m depth. This interval is also characterized by the presence of *Praeorbulina curva* and *Globigerinatella insueta* which correspond to zone N8 (*Praeorbulina sicana*) of Blow [10]. The *Praeorbulina sicana* area is also marked by the presence of *Globorotalia birnageae*, *Globorotalia bella*, *Praeorbulina glomerosa glomerosa*, *Globorotalia archeomenardii*, *Paragloborotalia semivera* and *Globigerinoides bisphericus.*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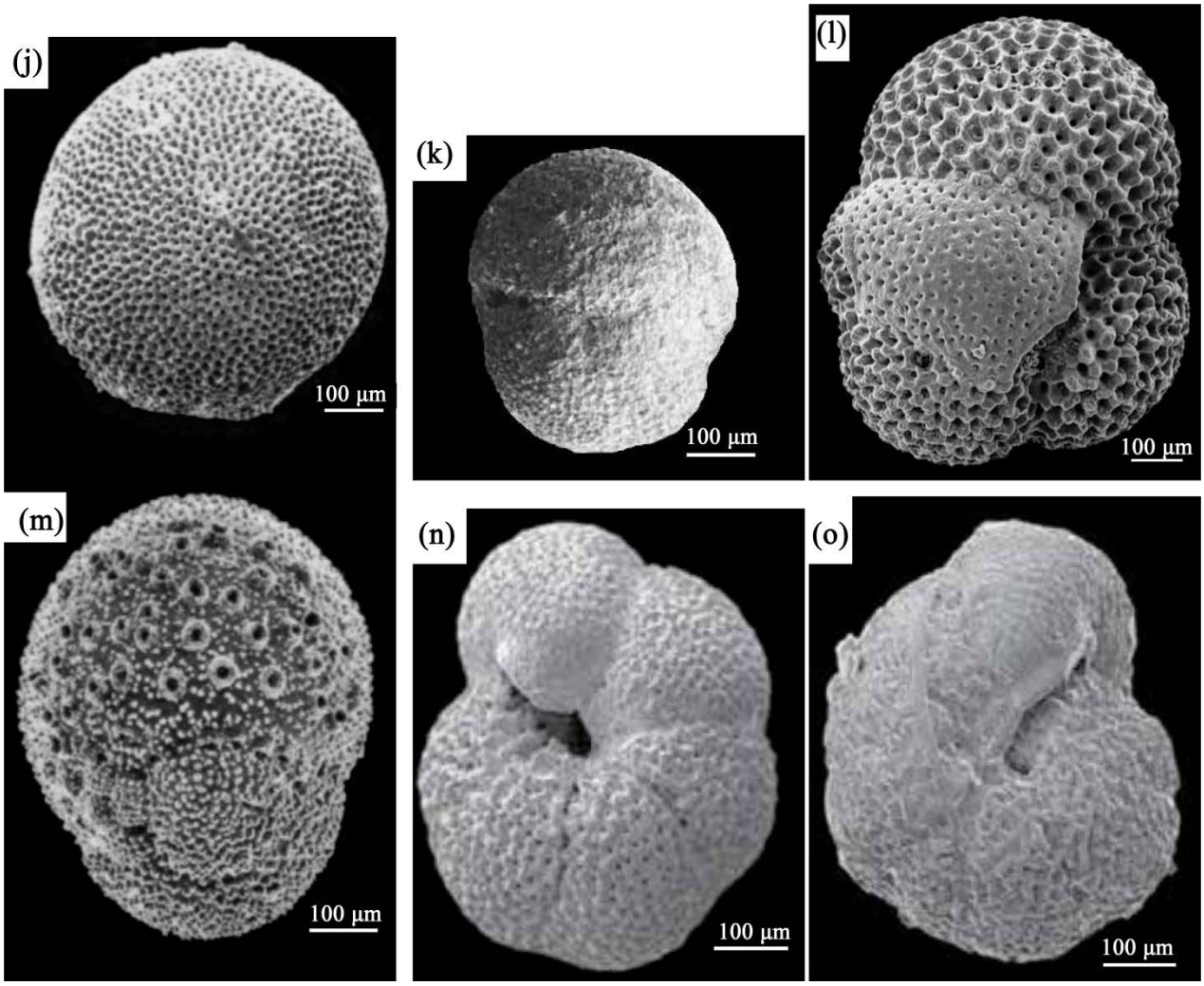

Figure 2. (a) Globorotalia plesiotumida; (b) Globorotalia merotumida; (c) Globorotalia acostaensis; (d) Globorotalia menardii; (e) Globigerina nepenthes; (f) Globorotalia siakensis; (g) Globorotalia fohsi; (h) Globorotalia praefohsi; (i) Globorotalia peripheroacuta. (j) Orbulina suturalis; (k) Praeorbulina sicana; (l) Catapsydrax dissimilis; (m) Globigerinatella insueta; (n) Paragloborotalia kugleri; (o) Globorotalia kugleri. All of these images are taken at size 100 µm.

d) Lower Miocene

i) Burdigalien

- ***Catapsydrax dissimilis* (N7) zone**

The level of first occurrence of *Catapsydrax dissimilis* (**Figure 2(l)**) is at a depth of 3195 m thus marking the base of this area. The summit is defined by the first occurrence of *Globorotalia peripheroronda* at a depth of 2926 m. This area is characterized by the presence of *Globigerinoides altiaperturus, Globigerinoides bisphericus*, *Globigerinoides trilobus*, *Globorotalia birnagae*, *Catapsydrax stainforthi*. This interval is correlated with the N7 zone at *Catapsydrax dissimilis* of Blow [10].

- ***Globigerinatella insueta* (N6) zone**

The base of the area is delimited by the level of first occurrence of *Globigerinatella insueta* (**Figure 2(m)**) at 3290 m depth and the summit is defined by the

first occurrence of *Catapsydrax dissimilis* at a depth of 3195 m. This area is characterized by the presence of *Globorotalia birnageae, Globigerinoides bisphericus, Globorotalia praescitula, Globigerinoides sacculifer, Globigerinoides altiaperturus* and *Globigerinoides quadrilobatus*. It is correlated with the N6 zone caused by *Globigerinatella insueta* by Blow [10].

ii) Aquitanian

- ***Paragloborotalia kugleri* (N5) zone**

The level of first occurrence of *Paragloborotalia kugleri* (**Figure 2(n)**) is at a depth of 3324 m marking the base of this zone. The summit is defined by the first occurrence of *Globigerinatella insueta* at 3290 m depth. This area is characterized by the presence of *Globorotalia obesa*, *Globorotalia bella*, *Globigerinoides sacculifer*, *Globigerina wooki*, *Globoquadrina venezuelana*, *Globigerina praebulloides* and *Cassigerinella chipolensis*. It is correlated with the N5 zone at *Globorotalia kugleri* by Blow [10].

- ***Globorotalia kugleri* (N4) zone**

This zone is defined at its base by the first occurrence of *Globigerinoides primordius* at the 3400 m level and by the last appearance of *Globorotalia kugleri* (**Figure 2(o)**) marking the summit at 3324 m. This zone is also characterized by the presence of the planktonic foraminifera *Fohsella kugleri*, *Globigerina ciperoensis*, *Globorotalia siakensis*, *Globorotalia obesa*, *Globigerina venezuelana*, *Globoquadrina praedehiscens*, *Globoquadrina altispira globosa* and *Globoquadrina dehiscens*. This interval is correlated with the N4 zone at *Fohsella kugleri* by Blow [10].

2) DEPOSIT PALEOENVIRONMENTS

The environment containing planktonic foraminifers is very complex and its description includes many parameters such as temperature, salinity, mixing depth of the water column, turbidity, nutrient composition, type and abundance of prey. (Hemleben *et al.* [32], 198; Kemle-von Mücke and Hemleben, [33]) indicating a strong link between planktonic foraminifera and hydrological parameters. It is recognized that the size of planktonic foraminifers varies with temperature and primary production [34]-[39]. Temperature is therefore considered to be one of the major factors influencing the size and growth of planktonic foraminifera [35] [39] [40] [41]. However, the definition of Miocene paleoenvironments in relation to the various biozones raised is based on three criteria:

- The relationship in the abundance and diversity of species;
- The planktonic/benthic ratio (P/B);
- limestone/Arenaceous tests report.

Deposition environments vary from bathyal to abyssal glacis with the direct influence of the sea. A paleo-environmental model of deposition related to bathymetry is proposed (**Figure 3**).

a) Upper Miocene (1670 m - 2556 m)

Messinian-Tortonian

The interval is characterized by a good content in abundance and diversity of

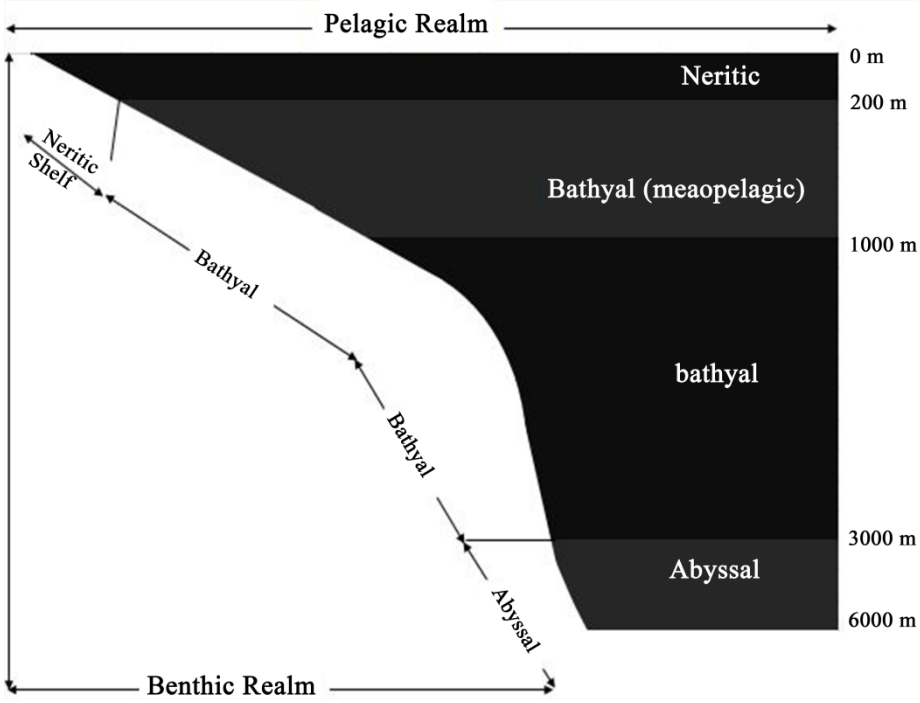

Figure 3. Paleobathymetric and paleoenvironmental zonation.

calcareous benthic and planktonic foraminifera between 1670 m and 2556 m. The recorded P/B values are high and here testify to a considerable increase in sea level caused by a transgression [17]. The abundance of planktonic foraminifera indicates an open marine environment. From 1670 m to 1890 m, the presence of the benthic foraminifera *Martinottiella communis, Pullenia bulloides* and *Sphaeroidina bulloides* characterize an upper bathyal environment [42]. Between 1890 m and 2330 m the microfauna is entirely made up of *Martinottiella communis* and radiolarians, which reveals a relatively deeper bathyal environment. Below 2330 m, the microfauna is dominated by agglutinating non-calcareous foraminifera up to 2470 m, indicating a deep marine deposition environment. Between 2470 m and 2521 m, a rich microfauna comprising abundant benthic and planktonic species suggests an outer shelf to upper bathyal environment [42]. Samples collected below 2521 m are rich in assemblages of agglutinating foraminifera with abundant radiolaria, indicating a deeper bathyal environment. The presence of *Globigerinoides bulloides* specimens often considered as a marker of upwelling environment at low attitudes, Bé and Hutson [43] found in deep water, in symbiosis with the genus *Neogloboquadrina pachyderma* indicate a relatively nutrient-rich lower bathyal environment [44]-[51]. The Foraminifera *Orbulina universa* is considered a warm-water species and lives in symbiosis with dinoflagellates [32] [52]. The *Globigerinoides trilobus* species preferentially lives between 21 and 29˚C [41] [44] [53] [54].

The association of *Globigerinoides trilobus* and *Orbulina universa* in constant symbiosis with dinoflagellates characterizes a photic environment [32] [55]. *Globorotalia* species are commonly considered to be deep species [43] [32]. How-

ever, the mixture of the foraminifera *Globigerinoides bulloides*, *Obulina universa*, *Globigerinoide trilobus*, *Neogloboquadrina pachyderma* and the genus *Globorotalia* can be considered as the effect of a post-mortem transport of species living in the shallow environment to the deep environment or simply by the bioturbation effects [17].

b) Middle Miocene (2556 m - 2926 m)

Serravalien-Langhian

The Middle Miocene is moderately fossiliferous. The interval is characterized by low abundance and diversity of species. The low values of P/B and C/A reflect a shallow marine environment. The presence of abundant glauconite contained in some samples confirms a shallower deposition environment, therefore from the outer platform to the upper bathyal. The presence of *Cibicidoides* at 2720 m, species characteristic of a muddy environment of shallow water with low tolerance of salinity and oxygen deficiency [56] [57]; Hanzawaia epipelic from Murray [42] and *Pullenia bulloides*, endopelic from Murray [58], characteristic of marine conditions of good oxygenation, external platform to bathyal [59]; these benthic foraminifera characterize well a shallow deposition environment. Samples collected between 2800 m and 2926 m are weakly fossiliferous composed of a high number of benthic foraminifers with a reduced number of planktonic foraminifers thus marking a shallow bathyal deposition environment.

c) Lower Miocene (2926 m - 3400 m)

Burdigalien-Aquitanien

The Lower Miocene samples are generally weakly fossiliferous, reflecting the dysaerobic nature of the deposit in relatively deeper water. The Burdigalian section, from 2926 m to 3195 m, is made up of mixed assemblages of planktonic, benthic, calcareous and agglutinating foraminifers which characterize an upper bathyal environment with an oxygenated bottom. Between 3195 m and 3400 m, although weakly fossiliferous, the Lower Miocene is composed of a high number of agglutinating foraminifers, with very low recovery of planktonic foraminifera. The majority of the samples collected are weakly calcareous and indicate a deeper to abyssal bathyal environment.

5. Conclusion

The North deep sea block was the subject of a study using sediments collected from four wells. This study made it possible to define the lithological characteristics, to carry out a micropaleontological inventory based on planktonic foraminifera, to establish the age of the sediments, biozones and deposit environments of the Miocene. This study shows a lithological variation in the sediments dominated by dark clays, but marked by an alternation of dark clays, more or less clayey siltstones, fine to coarse sands and limestone. On the basis of the foraminifera collected, the biostratigraphic analysis revealed several bioevents of planktonic foraminifera making it possible to identify fifteen (15) biozones (*Globorotalia plesiotumida*, *Globorotalia merotumida*, *Globorotalia acostaensis*, *Glo-*

borotalia menardii, *Globigerina nepenthes*, *Globorotalia siakensis*, *Globorotalia fohsi*, *Globorotalia praefohsi*, *Globorotalia peripheroacuta*, *Globorotalia peripheroronda*, *Praeorbulina sicana*, *Catapsydrax dissimilis*, *Globigerinatella insueta*, *Paragloborotalia kugleri* and *Globorotalia kugleri*) corresponding to age between Aquitanian and Messinian. The micropaleontological harvest is progressively excellent, moderate and weak depending on the sedimentation medium. The biofacies analysis of foraminifera has made it possible to define the palaeoenvironmental characteristics which vary from open marine environments, bathyal to abyssal. The biostratigraphic and biozonation results obtained make it possible to resolve the questions of sequential stratigraphy.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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