

African Research Review

An International *Multidisciplinary Journal, Ethiopia*

Vol. 5 (6), Serial No. 23, November, 2011

ISSN 1994-9057 (Print)

ISSN 2070--0083 (Online)

DOI: <http://dx.doi.org/10.4314/afrrrev.v5i6.29>

Biostratigraphical Analysis and Palaeoenvironmental Reconstruction of Cenomanian-Turonian Boundary in Côte d'Ivoire Onshore Sedimentary Basin, West Africa

(Pp. 361-380)

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Abstract

The microfauna studied in this work was provided by the interval 1350-1590m of an onshore oil well Tiemié 1, located about 70 km West of Abidjan, in northern Gulf of Guinea. The residues of 23 samples of drill cuttings

washed with soapy water, dried and sorted, revealed fourteen of mainly planktonic foraminiferal species dominated by the Whiteinellids, Hedbergellids and Heterohelicids. The dominance of microplankton in the lower part of the interval (1390-1590 m), combined with the total absence of benthic foraminifera, reflects an environment of external platform with a thick water column probably responsible of reduced oxygenation over the seafloor. At the top (1350-1390 m), absence of any microfauna suggests a shallow shelf and on which a turbulent marine winnowing phenomenon would have probably prohibited their accumulation. This assemblage characterizing Turonian-Cenomanian transition in many geographical provinces bordering Atlantic Ocean, was discussed at both biostratigraphical and palaeoenvironmental and palaeogeographic plans.

Keywords: Foraminifera, Turonian, Cenomanian, Palaeoenvironment, Sedimentary basin, Côte d'Ivoire.

Introduction

The geology of Côte d'Ivoire is characterized by two distinct sets: a Precambrian basement representing approximately 97.5% of the territory and a sedimentary basin (2,5%) of Secondary-Tertiary age forming a coastal strip along the Atlantic over the Northern Gulf of Guinea (Guerin-Villaubreil, 1965; Spengler and Delteil, 1966; Affian, 1986; Digbehi, 1987). Stratigraphic syntheses of Ivorian basin proposed by Digbehi (1987) and by Chierici (1996) are summarized in four main phases: 1) a rifting phase (Barremian-Albian) with marginolittoral sediments, 2) an initial oceanic expansion phase with first frank marine transgressions (Cenomanian-Early Senonian), which allowed deposition of calcispherid limestones that will erode during Early Senonian, 3) a phase of active expansion and subsidence (Campanian-Maastrichtian) with transgressive marine clays over eroded surfaces affecting in some places Cenomanian series, 4) a phase of maximum expansion of Tertiary age during which occurred a major regressive phase lasting from Late Eocene to Oligocene.

Micropaleontological data published about Côte d'Ivoire Cenomanian and Turonian boundary deposits were evoked through a few works concerning mainly data from offshore wells (Chierici, 1996; Digbehi et al., 1997; Saint-Marc and N'da, 1997; Moullade et al., 1998) and rarely on onshore data. Jardiné and Magloire (1965) hypothesized that species *Heterohelix moremani* added to an abundance of *Heterohelix globulosa* indicated Turonian age in Côte d'Ivoire western sedimentary basin. Digbehi et al. (1997) linked

Turonian to the presence of *Whiteinella baltica*). This first study undertaken on data provided by an onshore oil well aimed to identify the microfaunas and discuss the biostratigraphic and palaeoenvironmental and palaeogeographical aspects of Cenomanian-Turonian boundary. It focusses on microfauna's study of the interval 1350-1590 m of oil well Tiemie 1, located in western Côte d'Ivoire sedimentary basin (Fig.1).

Materials and methods

Thirty grams of sediment each of 23 cuttings samples used to support this work were collected on variable depth depending on their availability along the interval of study.

Sample preparation followed standard procedures as recently described by Digbehi et al. (1997) and Bamba et al.(2011). They were washed with soapy water through three sieves (200 µm, 125 µm and 63 µm). The refusal of each sieve was oven-dried and sorted. Planktonic foraminifera common to rare and relatively well preserved were identified following Caron (1978; 1985), Robaszynski and Caron (1979, 1995), Loeblich and Tappan, (1988) and Bellier and Moullade (2002). This taxonomic determination allowed counting them and then to propose a biostratigraphy of the interval studied. Determination of depositional environments was based on the models of Masala (1993) and Massala et al. (1996), using essentially the ratio planktonic / benthic Foraminifera. Main marker species and the most common species (deposited in Laboratory of biostratigraphy, University of Cocody, Côte d'Ivoire) were illustrated in Plates 1 to 3.

Results and discussions

Biostratigraphy

The only lower part of the interval (1390-1590m) provided all the microfaunas exclusively planktonic (Fig.2) . A few badly conserved fragments of ostracods, bivalves and gastropods are observed. This microplankton are dominated by taxa of three families including Heterohelicids (61 %), Hedbergellids (31 %) and to a lesser extent Whiteinellids (7 %) and others (1 %). Any benthic forms are identified.

The main species identified are: *Hedbergella delrioensis* (Plate 1, figs 1 & 2), *Hedbergella* Gr. *simplex* (Plate 1, figs 3 & 4), *Hedbergella planispira* (Plate 2, figs 1 & 2), *Hedbergella* sp., *Heterohelix moremani* (Plate 2, fig.3e), *Heterohelix* cf. *moremani* (Plate 2, figs 3f, 3g), *Heterohelix reussi*, *Heterohelix glabrans*, *Heterohelix globulosa*, *Heterohelix* sp., *Whiteinella archaeocretacea* (Plate 3, fig. 1) and *Whiteinella* cf. *baltica* (Plate 3, fig.2).

The species *Guembeltria* cf. *cenomana*, *Achaeoglobigerina cretacea* (Plate 3, Fig.3) and *Marginotruncana* sp.(Plate 3, fig.4) are very rare.

Vertical distribution of the microfauna (Fig. 3) shows their concentration in the lower part (1390-1590 m) of the interval and their complete disappearance at the top (1590-1350 m).

Figure 4 shows a summary of the stratigraphic distribution of certain species commonly encountered in this study, supported by bibliographic data including work of Caron (1985). It shows in fact that most of these species occur in the transition zone between Cenomanian and Turonian. Therefore, such assemblage is thought to characterize the Cenomanian-Turonian transition despite its low frequency of taxa recorded, in contrary to Turonian age strictly assigned to it by number of previous works. Thus, as evoked above, Jardiné and Magloire (1965) hypothesized that species *Heterohelix moremani* added to an abundance of *Heterohelix globulosa* indicated Turonian age in Côte d'Ivoire western sedimentary basin whereas Digbehi et al. (1997) linked Turonian to the presence of *Whiteinella baltica*.

Furthermore, in Senegal River Basin, Klasz et al. (1995) identified an association with dominant *Whiteinella*, *Hedbergella* and *Heterohelix* attributed to Turonian. Elsewhere, Petrizzo (2003) argued that Marginotruncanids appear during Turonian and disappear at Early Campanian, and also showed that *Whiteinella archaeocretacea* is not older than Turonian. Similarly, Stanislay et al. (2005) showed that *Whiteinella archaeocretacea* appears at the base of Turonian.

However, many restrictions can be noted for the use of some species of this assemblage and that contraries this statement of only Turonian age. Thus, in Vocontian basin (South-Eastern France), Grosheny et al. (2006) identified and described *Whiteinella archaeocretacea* in Cenomanian-Turonian black shales. Moreover, the absence, in the present study, of *Rotalipora* so-called "zones" species due, according to Desmares et al. (2003, 2004, 2007), to the OAE2 anoxic event, resulted in the Cenomanian-Turonian boundary. This probably justifies the keeled forms (*Praeglobotruncana*, *Rotalipora*), occupying the deepest recesses, were virtually absent from all associations described by Saint-Marc and N'da (1997). In absence of such species, the assemblage described could not attribute with certainty, a Turonian age for this interval, because it could also correspond to Cenomanian. So, if the first occurrences of *Heterohelix reussi* begin conventionally in Turonian in various atlases, one however must be careful with these taxa. Indeed, for

Nederbragt (1991), *Heterohelix reussi* would be managed in synonymy with *Heterohelix globulosa*; in his paper the author emphasizes a continuum between morphotypes of both *Heterohelix globulosa* and *Heterohelix reussi*. The first occurrences of *Heterohelix globulosa* are commonly identified from the Cenomanian (Keller et al. 2004; Grosheny et al, 2006, Desmares et al, 2007), so that it seems difficult to use this taxon as Turonian marker, despite its relatively strong representation (25 per cent) in the present study. Furthermore, an example of "Cenomanian *Heterohelix* event " is known in "Western Interior" basin, characterized by the proliferation of *Heterohelix globulosa* (Leckie et al. 1998; Desmares et al., 2007). Moreover, in many works, *Whiteinella archaeocretacea* was identified in Upper Cenomanian, and that, through different palaeogeographic provinces (Keller et al., 2004, Caron et al, 2006, Grosheny et al., 2006, Desmares et al, 2007). *Whiteinella archaeocretacea* Zone corresponds to a partial extension range between the last occurrence of *R. cushmani* and the first occurrence of *H. helvetica* (incidentally, the present study did not reveal any *R. cushmani* nor *H. helvetica*). The Cenomanian-Turonian boundary being included within this zone, it follows that the species *W. archaeocretacea* (3 %) of the plankton) could not be used as an only Turonian marker. Furthermore, according to Grosheny et al. (2006), the base of Turonian was best defined by the first occurrences of Marginotruncanids or by the "Zone species" *Helvetoglobotruncana helvetica*. They also argued that sedimentation of black shales, well defined in Vocontian basin, corresponded to profound changes in both assemblages (benthic and planktonic) which might reflect changes in oxygenation of bottom waters. Works of Desmares et al. (2008) on the ontogenetic relationships among *Rotalipora* indicated that the loss of the keel in some of younger *Rotalipora* was a selective advantage that allowed them to remain in surface waters, avoiding the expansion of anoxia at the Cenomanian-Turonian boundary. In total, only two but very rare specimens of *Archaeoglobigerina cretacea* and *Marginotruncana* sp. argued in favor of a Turonian in the present study.

Palaeoenvironmental context

Two sub-intervals are identified in this study and reflect roughly two distinct depositional environments (Fig. 4) . The first (1390-1590 m) consisting of laminated gray clays, is mainly composed of planktonic foraminifera and suggests an outer shelf (open sea). The second (1370-1390 m), composed of very sandy clays and sandstone contains no foraminifera. It evokes an inner continental shelf under nearshore influences. But the total absence of benthic

foraminifera (only a few badly preserved fragments of ostracods and bivalves are found), suggests a relatively thick water column, which could induce oxygen deficiency on the floor. However, in terms of environmental conditions of deposition and palaeogeography, this boundary was well documented in many global geographical provinces (Eicher 1969a, 1969b; Eicher and Worstell, 1970; Leckie, 1987; Kroon and Nederbragt, 1990; Saint-Marc and N'da, 1997; Bellier, 1998; Holbourn and Kuhnt, 1998; Holbourn and Moullade, 1998; Watkins et al., 1998; Noemi, 2003; Desmares et al., 2004; Noemi and Allison, 2005; Grosheny et al., 2006). They concluded that this boundary was strongly influenced by anoxia expanded on the ocean floor at that time.

According to Eicher (1969a, 1969b) and Eicher and Worstell (1970), dominance of *Whiteinella*, *Hedbergella* and *Heterohelix* was a well known phenomenon in Mid-Cretaceous marine deposits of Western United States . These organisms live near the surface, grow and invade the continental neritic shelf and where they fit to withstand variations in salinity and temperature (Leckie, 1987). For Leckie (1987) and Kroon and Nederbragt (1990), the microfauna is the main association of planktonic foraminifera that colonized pelagic environments (slope) during the Cretaceous. In southern Mexico, Noemi (2003) recognized *Helvetoglobotruncana helvetica* Zone (Lower-Middle Turonian) associated to many taxa of Hedbergellids and Whiteinellids characterizing an open sea deposit. Other works of Noemi and Allison (2005) lead to interpret *Whiteinella archaeocretacea* Zone as characteristic of organic facies in the same area, in connection with the low oxygenation of the seafloor at this time. In Turonian-Santonian hemipelagic of Ghana-Côte d'Ivoire Ridge, Watkins et al. (1998) suggested a low rate of food in surface waters at that time, with prevailing anoxic conditions in the basin.

According to Saint-Marc and N'da (1997), lack of or inadequate mixing of waters by oceanic currents resulted in the Gulf of Guinea, a poor oxygenation of the sea floor and an oxygenation of superficial column. Moreover, in laminated black shales provided by an Ocean Drilling Project Campaign carried off Southeast Côte d'Ivoire offshore basin, Holbourn and Kuhnt (1998) identified in Turonian, benthic foraminifera dominated by two associations of Buliminids. They suggested that endemism observed in these forms was stronger during Turonian, when the water circulation was probably more restricted and when the relations between Equatorial basins and Atlantic were limited. Holbourn and Moullade (1998), during that same

campaign ODP, showed a high level of dissolution of planktonic forms, a virtual absence of benthic foraminifera and radiolarian abundance within Cenomanian deposits. They interpreted this as a reflect of a high productivity in surface waters and a severe anoxia at the sediment-water interface, thus making the deeper waters corrosive, causing this dissolution. On the topographic existing shoals reported in this region of Ivorian Basin by Digbehi (1987) and then by Chierici (1996), erosive submarine current, probably due to winnowing phenomenon would have prohibited accumulation of benthic forms.

Conclusion

The lower laminated black clays of the interval studied yielded a planktonic foraminiferal assemblage dominated by Whiteinellids, especially Hedbergellids and Heterohelicids. This assemblage characterizes Cenomanian-Turonian transition and reflects a depositional environment of marine outer shelf (base) and progresses to the inner continental shelf at the top. Predominance of planktonic foraminifera (98%) reflects a slice of oxygenated surface water. But the absence of agglutinated benthic forms is interpreted as related to anoxic conditions unfavorable to their life on ocean floor. In the upper part of the interval, the absence of any specimen of foraminifera is thought to be linked to probable winnowing phenomenon due to erosive submarine currents that would have prohibited accumulation of benthic forms on probably topographic existing shoals. This assemblage, known in many geographical provinces bordering Atlantic Ocean, has been discussed at both biostratigraphical and environmental and palaeogeographic plans.

In any case, and at the end of this discussion, we observe that: (i) the number of processed data is quite insufficient (23 cutting samples for 240 m thick sequence) to claim a solid biostratigraphic division. To overcome this lack of fauna characteristic of the Cenomanian-Turonian boundary recorded in many parts of the globe, biostratigraphic allocation proposed in this work could be consolidated through the present results in comparison with other data (sedimentology, geochemistry, data well ...) and/or by providing correlations with other sections at the regional level. (ii) Similarly, under the sampling step not very tight, low time pressure, lack of descriptions of facies, microfacies and high-resolution study of microfossil assemblages, this has made it difficult to interpret a valid palaeoenvironmental reconstruction. But given the desire to better understanding of the OAE2 event in the

sedimentary basin, this first study in the terrestrial part of the Ivorian basin should be encouraged and pursued.

Acknowledgements

The authors wish to thank Société Nationale des Opérations Pétrolières de Côte d'Ivoire (PETROCI) for having entrusted this study.

List of main planktonic foraminifera recorded in this interval.

Achaeglobigerina cretacea (Pessagno, 1967)

Guembelitria cf. *cenomana* (Keller, 1935)

Hedbergella Gr. *simplex* (Morrow, 1934)

Hedbergella delrioensis (Carsey, 1826)

Hedbergella planispira (Tappan, 1940)

Hedbergella sp.

Heterohelix cf. *moremani* (Cushman, 1946)

Heterohelix glabrans (Cushman, 1934)

Heterohelix globulosa (Ehrenberg, 1840)

Heterohelix moremani (Cushman, 1946)

Heterohelix reussi (Cushman, 1938)

Heterohelix sp.

Marginotruncana sp.

Whiteinella archaeocretacea (Pessagno, 1967)

Whiteinella baltica (Douglas et Rankin, 1969)

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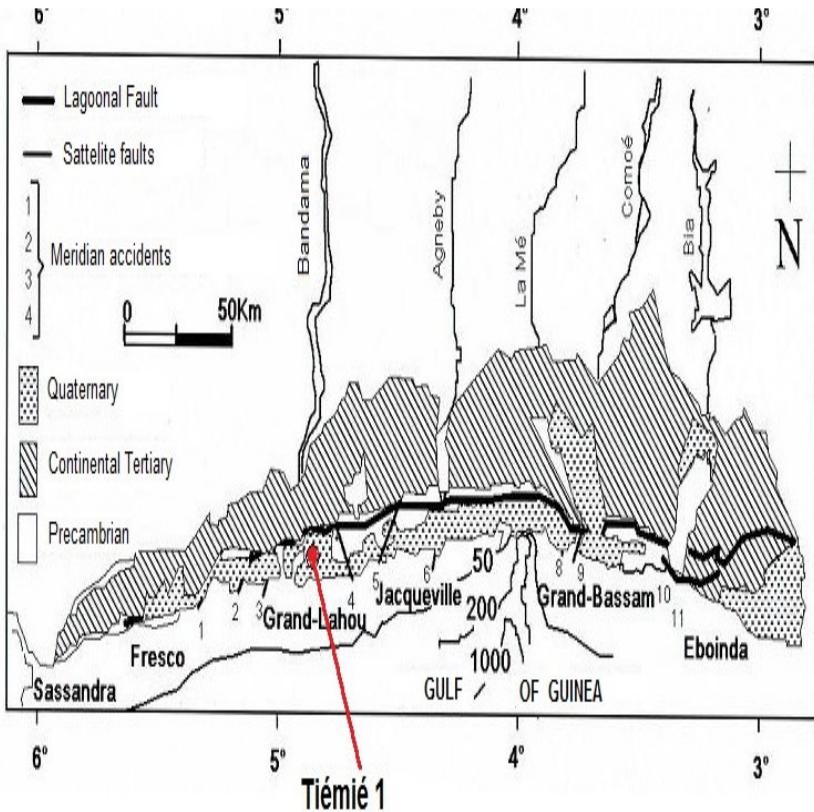


Figure 1: Location map of the oil well Tiemie 1 studied

Depth (m) and relative frequency of Planktonic Foraminifera identified											
	1590	1570	1550	1530	1500	1480	1460	1410	1390	1370	1350
Total											
1								1			
1				1							
108	55	20	2	5	7	5	4	6	1		
18	4	6	0	3	2	0	0	2	1		
11	4	2	0	2	3	0	0	0	0		
34	12	12	0	5	0	2	2	1	3		
3	2	1	0	0	0	0	0	0	0		
23	2	5	2	2	0	0	2	5	5		
4	0	1	0	1	0	0	2	0	0		
37	12	4	1	3	3	2	4	5	3		
132	55	23	8	8	5	4	9	14	6		
147	69	38	7	5	5	2	6	9	6		
1	1	0	0	0	0	0	0	0	0		
18	2	2	2	4	3	0	2	3	0		
19	2	2	2	5	3	0	2	3	0		
558	165	93	16	36	26	11	24	35	19		
1	0	0	0	1	0	0	0	0	0		
2	0	0	0	0	0	1	1	0	0		
3	0	0	0	0	0	0	0	0	3		
										Barren	
											Archaeoglobigerina cretacea
											Guembelitra cf cenomana
											Hedbergella delrioensis
											Hedbergella planispira
											Hedbergella simplex
											Hedbergella sp
											Heterohelix glabrans
											Heterohelix moremani
											Heterohelix cf moremani
											Heterohelix reussi
											Heterohelix globulosa
											Heterohelix sp
											Marginotruncana sp
											Whiteinella archaeocretacea
											Whiteinella baltica
											Debris of bivalves
											Debris of gastropods
											Ostracods

Figure 2: Vertical relative abundance distribution of the main Planktonic Foraminifera identified in this interval studied

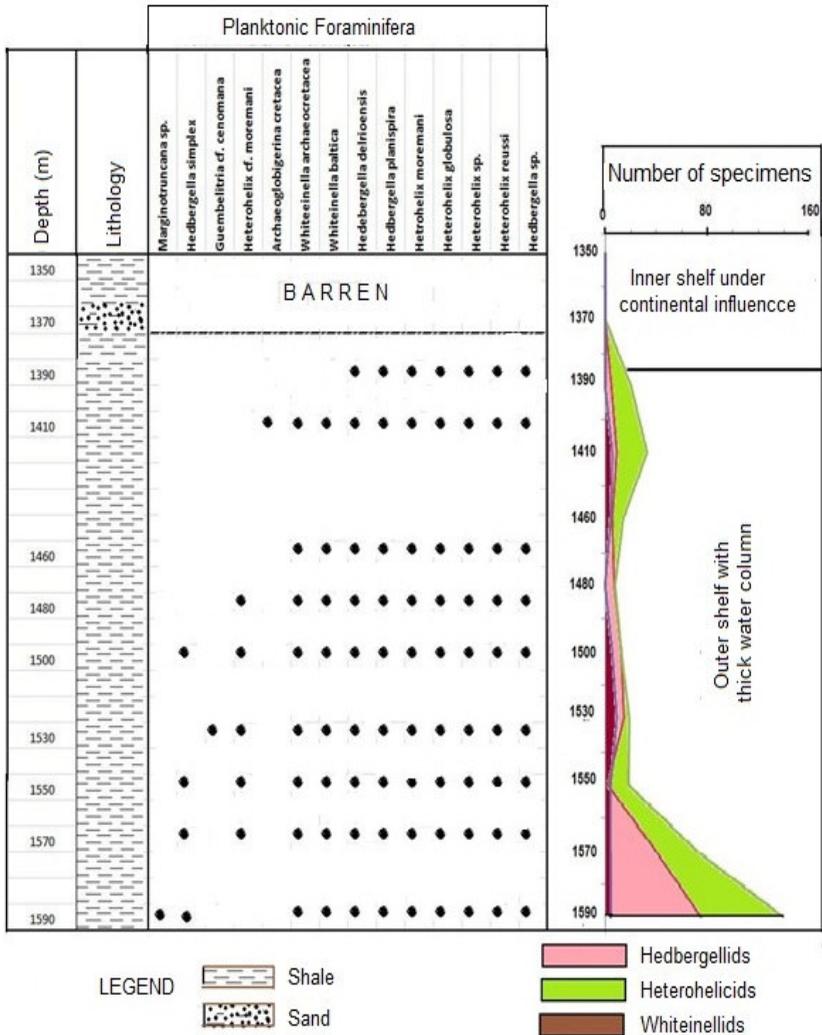


Figure 3: Vertical distribution according the depth, of the main Planktonic Foraminiferal families (Hedbergellids, Heterohelicids and Whiteinellids) in the studied interval of Tiemie 1 oil well

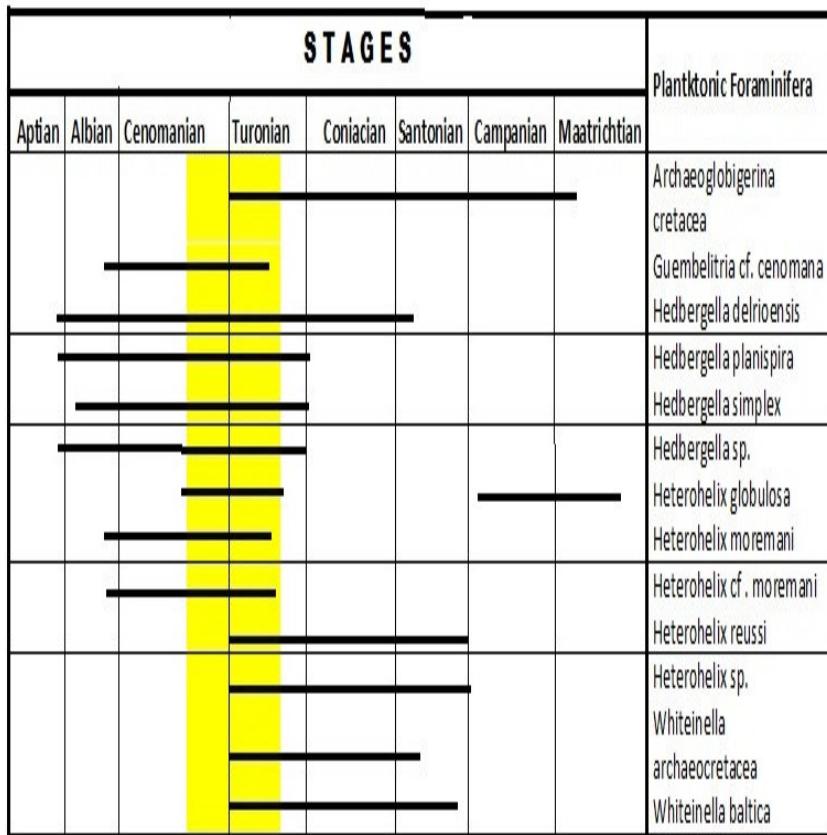


Figure 4: Stratigraphical distribution of Planktonic Foraminifera according to Caron (bold black lines) and the co-occurrence of the main species described in the Cenomanian-Turonian boundary according to the present study (yellow area).

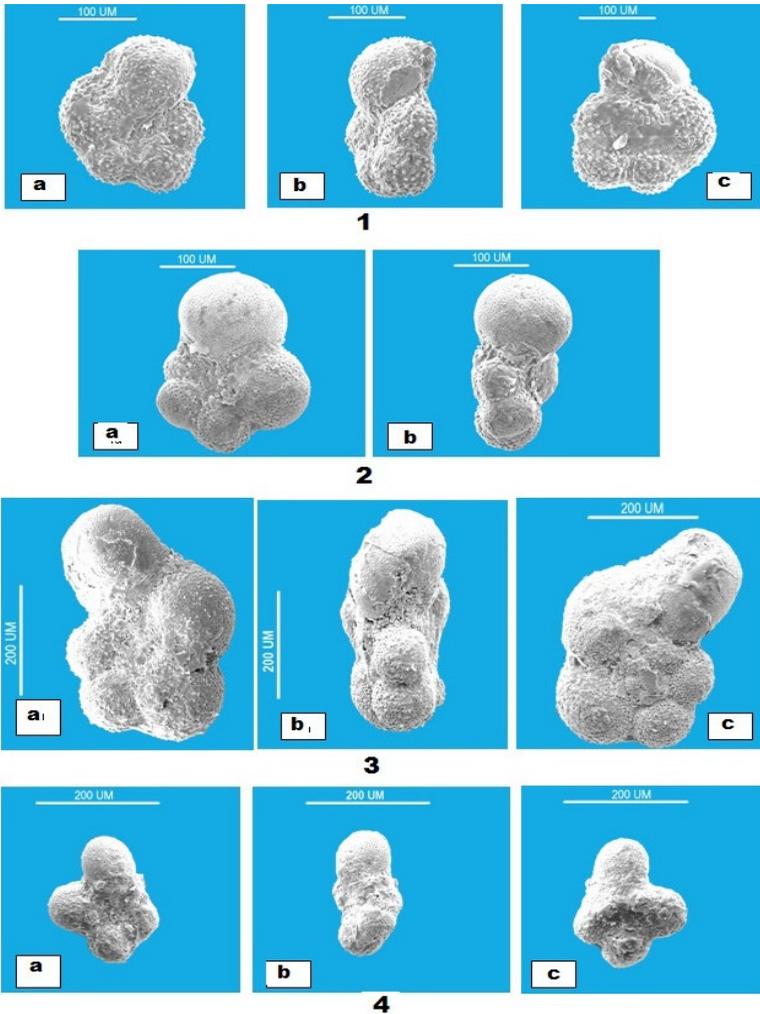


Plate 1: Figures 1 & 2. *Hedbergella delrioensis*, Tiémié 1, Sample (1580/1590 m). Figures 3 & 4. *Hedbergella Gr. simplex*, Tiémié 1, Sample (1560/1570m). For each figure: a) umbilical view; b) face lateral view, c) spiral view (except otherwise indicated).

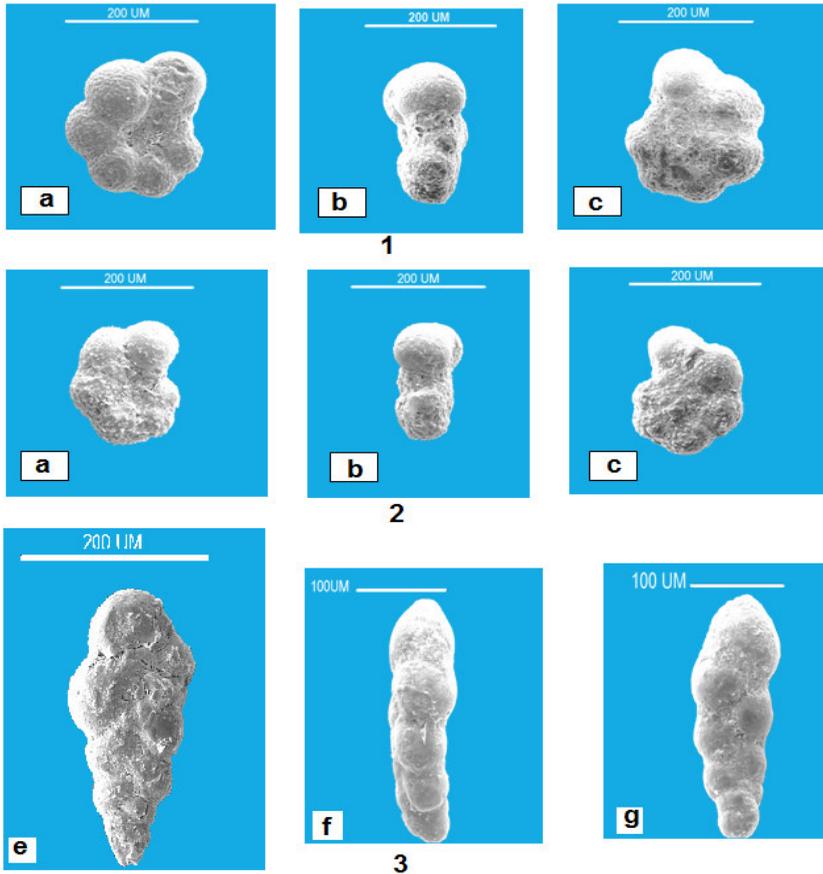


Plate 2: Figures 1 & 2. *Hedbergella planispira*, Tiémié 1, Sample (1560/1570 m). Figure 3e. *Heterohelix moremani*, Tiémié 1, Sample (1430/1440 m). Figure 3f & 3g. *Heterohelix* cf. *moremani*, Tiémié 1, Sample (1560/1570 m). For figures 1 & 2 : a) umbilical view; b) face lateral view, c) spiral view except otherwise indicated)

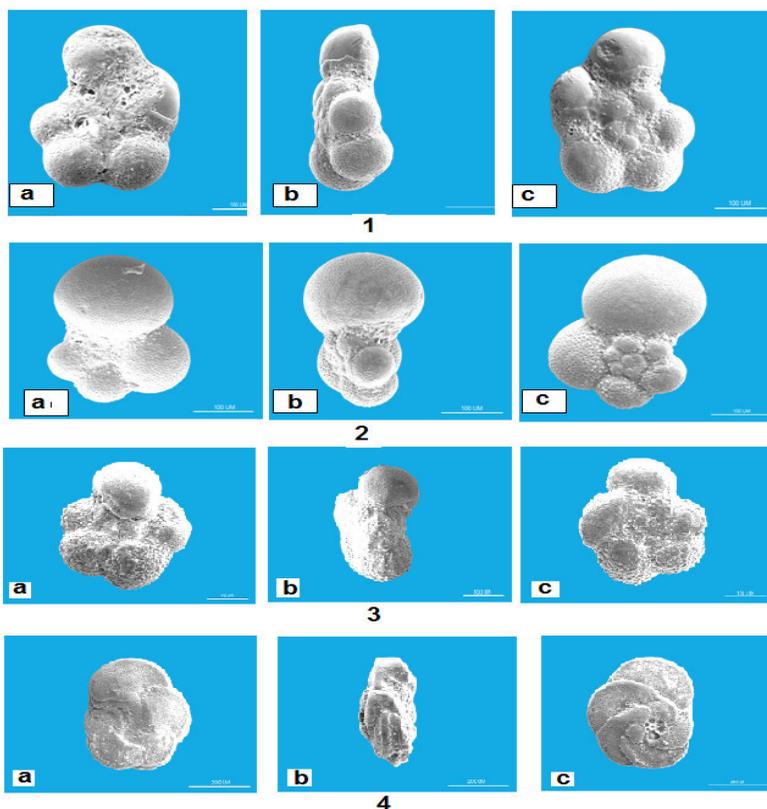


Plate 3: Figure 1. *Whiteinella archaeocretacea*, Tiémié 1, Sample (1400/1410m). Figure 2. *Whiteinella cf. baltica*, Tiémié 1, Sample (1520/1530 m). Figure 3. *Archaeoglobigerina cretacea*, Tiémié 1, Sample (1400/1410 m). Figure 4. *Marginotruncana* sp, Tiémié 1, Sample (1580/1590 m). For each figure : a) umbilical view; b) face lateral view, c) spiral view (except otherwise indicated)