

Early Eocene Thermal Stages in the Senegalo-Mauritanian Sedimentary Basin (Western Africa)

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Abstract: Eocene epoch is characterized by several warming stages which most important are the Eocene Thermal maxima ETM2, ETM3 and the Early Eocene Climate Optimum EECO defined using geochemical process. In addition to these methods, the thermal stages have been defined in oceanic areas mainly with planktonic foraminifera belonging to the genera *Morozovella* and *Acarinina*. Species belonging to these genera show a large extension during the Paleogene in the Senegalo-Mauritanian Basin. The studies of these assemblages in Eocene sediments deposits shows that the thermal maximum stages are marked by a decrease in the genera *Morozovella* and a simultaneous increase in the genera *Acarinina*. The disappearance of *Morozovellavelascoensis* and the diversification of *Acarininasoldadoensis* characterized the ETM2 stage, which occurs during the Ypresian. The EECO warming phase in the basal Lutetian was defined in the basin by the peak of *Acarininapentacamerata* and the abrupt disappearance of *Morozovellagracilis*. A similar distribution of *Acarinina* and *Morozovella* is observed in the Togolese coastal basin.

Keywords: *Morozovella*, *Acarinina*, Eocene thermal stages, Early Eocene climate optimum, Senegalo-Mauritanian Basin

1. Introduction

The Paleocene-Eocene transition has been the subject of several palaeo environmental studies based on isotope analyses and microfossils assemblages, in particular foraminifera (Tjalsma and Lohmann, 1983; Thomas, 1998, Thomas *et al.*, 2006). Based on palaeo climatic results, this transition is still characterised by a global warming in deep ocean waters in order of 4 to 8°C called Late Paleocene Thermal Maximum (LPTM) or Paleocene Eocene Thermal Maximum (PETM) or Initial Eocene Thermal Maximum (IETM) (Kennett and Scott, 1991; Zachos *et al.*, 2008; Röhl *et al.*, 2005). It is marked by a significant negative Carbon Isotopic Excursion (CIE) of $\delta^{13}\text{C}$ of the order of 2.5-3‰ in continental and oceanic domain. These high carbon dioxide levels known from the Late Paleocene (LPTM) increase further in the Early Eocene (Early Eocene Climate Optimum: EECO) (Pearson and Palmer, 2000; Fletcher *et al.*, 2008; Lowenstein and Demicco, 2006; Smith *et al.*, 2010; Hyland and Sheldon, 2013). Studies of carbonate sequences by Slotnick *et al.*, (2012, 2015) place the base of EECO at the J event (Cramer *et al.*, 2003) and negative incursions are thought to be between the hyperthermal H (or *Eocene Thermal Maximum 2*, ETM2) and K (or *Eocene Thermal Maximum 3*, ETM3) (Fig 1). The J event is associated with a rapid change from *Morozovella*-dominated planktonic foraminiferal assemblages to *Acarinina*-dominated assemblages (Frontalini *et al.*, 2016; Luciani *et al.*, 2016, 2017). Thus, these two genera have particular interest in climatic reconstruction because of their abundance in

tropical and subtropical assemblages but also because of their great taxonomic diversity in early Eocene (Lu and Keller, 1995; Lu *et al.*, 1998; Pearson *et al.*, 2006; Azeet *et al.*, 2011). However, the major of works on Eocene thermal maxima has been carried out on ocean cores and mainly in the Pacific. However, the numerous studies conducted in sedimentary formations of Paleocene to Eocene deposits of the Senegal-Mauritanian Basin (Ly, 1985; Thiam, 2014; Thiam and Sarr, 2014; Thiam, 2020; Thiam, 2021) reveal important associations of planktonic foraminifera. These studies show a high diversity and a large vertical extension of species belonging to the genera *Morozovella* and *Acarinina*. The main objective of the present work is to use these *Morozovella* and *Acarinina* assemblages to characterise the Eocene thermal maxima (ETM2, ETM3 and EECO) in the Senegalese-Mauritanian basin. Admittedly, the sampling effort is not similar to that of previous authors; but the high diversity of these two genera could provide substantial information on the thermal stage record in West African coastal basins.

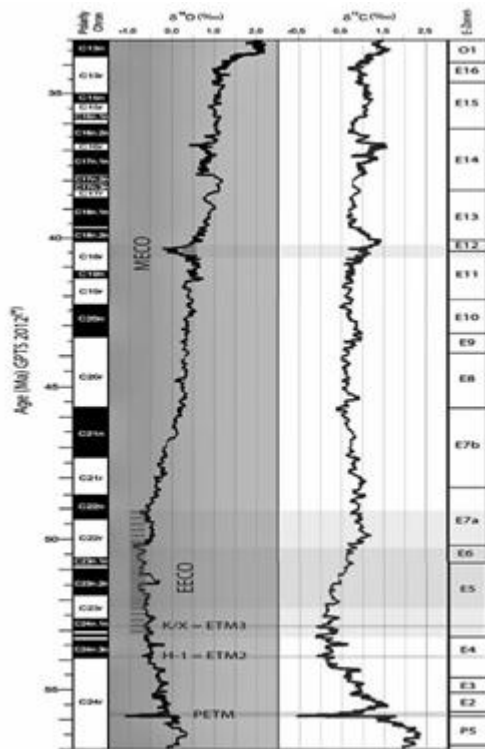


Figure 1: Evolution of the mid-Paleogene carbon and oxygen climate cycle based on geomagnetic polarity (GPTS 2012). Oxygen and carbon values are from compilations of Zachos *et al* (2008) and Cramer *et al*, (2009). Calibration based on planktonic foraminiferal biozones from Wade *et al*, (2011) with modifications.

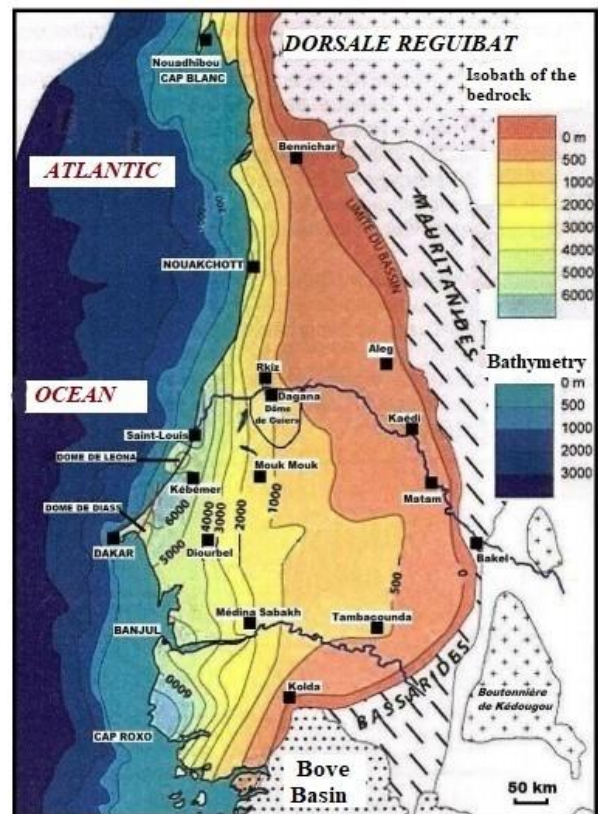


Figure 2: The Senegalo-Mauritania sedimentary basin in its regional context (Liger, 1979; Ly, 1985; Roger *et al*, 2009).

2. Stratigraphy and Micropaleontology

2.1 Stratigraphical framework

The Casamance sub-basin occupies the southern part of the vast Senegalese-Mauritanian basin, which covers an area of 350,000 km² (Fig 2). Meso-Cenozoic sediments from Upper Jurassic to Lower Miocene (Flicoteaux and Medus, 1974; Liger 1979; Le Priol, 1983; Carbonnel, 1986; Castelain, 1965; Bellion and Guiraud, 1984) compose it. Lithological and micropalaeontological studies carried out in the Cenozoic of Casamance highlight a complete sedimentary series ranging from the Paleocene to the Miocene (Castelain, 1965; Ly, 1985; Sarr, 1995; Thiam, 2014). The results obtained have made it possible to define two lithological sets: a lower set characterised by chemical deposits (limestone and marl) and an upper set made up of detrital deposits formed essentially of sands, clayey sands and clays (Thiam, 2014; Thiam and Sarr 2014; Thiam and Sarr, 2018).

2.2. Micropaleontology

The studied species allowed the determination of E₁ to E₁₆ planktonic foraminiferal biozones (*in* Thiam, 2014). The Lowerst Occurrence (LO) of *Pseudohastigerinawilcoxensis* Cushman & Ponton, 1932 and the Highest Occurrence (HO) of *Morozovellavelascoensis* Cushman, 1957 correspond to Berggren's biozones E₁ and E₂. The existence of biozone E₃ is explained by the LO of *Morozovellaformosa* Bolli, 1957 and the Partial Range Zone (PRZ) of *Morozovellamarginodonta* Subbotina, 1953. The biozone E₅ is defined with much more certainty and corresponds to the Concurrent Range Zone (CRZ) of *Morozovellasubbotinae* Morozova, 1929. The HO of *Morozovellasubbotinae*, *Morozovellaaequa* Cushman & Renz, 1942 and *Morozovellagracilis* Bolli, 1957 mark the top of E₅. The LO of *Acarininacuneicamerata* Blow, 1979 associated with the PRZ of *Acarininapentacamerata* Subbotina, 1947 corresponds to the extension of E₆. The LO of *Subbotinaeocaena* Gümbel, 1870; *S. yeguaensis* Weinzierl & Applin, 1929 *S. hagni* Gohrbandt, 1967 fix the base of biozone E₇. However, the top was defined by the HO of *Acarininasoldadoensis* Brönnimann, 1952 and the LO of *Acarininapraetopilensis* Subbotina, 1953. In addition, the HO of *Igorinabroedermanni* Cushman & Bermudez, 1942 and the HO of *Acarininacuneicamerata* fix the base of biozone E₉.

3. Materials and Methods

We collected samples from Paleocene to Eocene referenced borehole PXI located at Bounkiling (Fig 3) in Casamance

sub basin. Drilling boreholes were performed in the southern region of the Senegal-Mauritania basin, which is the more oceanic of the west Atlantic coastal sedimentary basins. For micropaleontologic analysis, we underwent the usual extraction procedures performed on 50g of sediment. Each sample was disaggregated in 10% hydrogen peroxide and then washed through a column of 250, 100 and 63µm sieves. The final residue was oven-dried at 50°C and sorted under a binocular magnifying microscope. The biostratigraphic zonation presented here are those proposed by the author in previous studies (Thiam, 2014) using planktonic foraminifera assemblages. In each sample, we calculated the percentage of species belonging to two characteristic genera *Morozovella* and *Acarinina* in relation to the totality of planktonic foraminifera (*Morozovella*, *Acarinina*, *Subbotina* and *Parasubbotina*). For each group (*Morozovella*, *Acarinina*) and in all samples, we determined the specific diversity, which allows us to appreciate the contribution of each species in the diversity of the group to which it belongs. Finally, for each group we identified the 10 most representative species (Table 1).

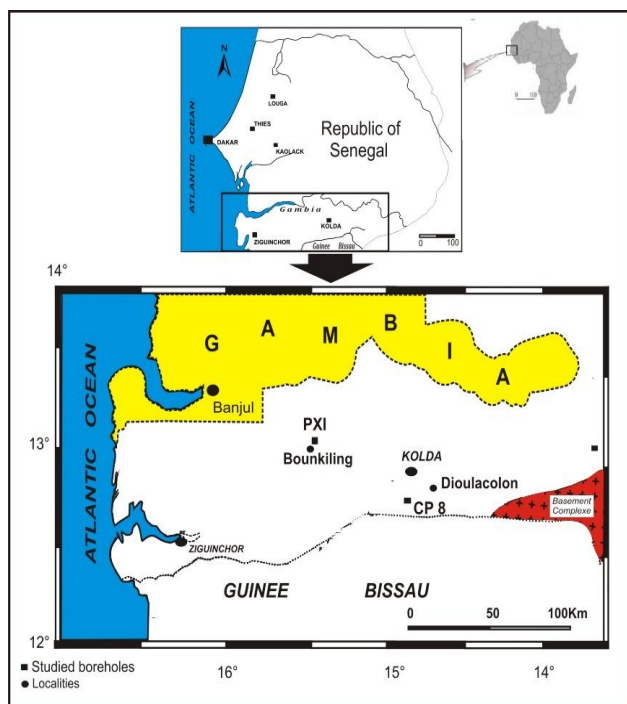


Figure 3: Location of the studied area

Table 1: List of morozovellids and acarininids studied species.

Genus	Species	Genus	Species
<i>Morozovella</i>	<i>M. subbotinae</i>	<i>Acarinina</i>	<i>A. wilcoxensis</i>
	<i>M. aequa</i>		<i>A. angulosa</i>
	<i>M. angulata</i>		<i>A. bulbrookii</i>
	<i>M. gracilis</i>		<i>A. cuneicamerata</i>
	<i>M. preangulata</i>		<i>A. pentacamerata</i>
	<i>M. formosaformosa</i>		<i>A. pseudotopilensis</i>
	<i>M. lensiformis</i>		<i>A. soldadoensis</i>
	<i>M. velascoensis</i>		<i>A. strabocella</i>
	<i>M. marginodentata</i>		<i>A. nitida</i>
	<i>M. conicotruncata</i>		<i>A. raetopilensis</i>

4. Results and Discussion

Based on planktonic foraminiferal distribution, we would show that the *Morozovella* are present only in the Ypresian, in contrast to *Acarinina*, which have a large vertical extension into the basal Lutetian (Fig 4). The percentage of acarininids increases to 75% to 80% at the base of the Lutetian. In biozone E₄, the decrease in morozovellids percentages (40% to 28%) is an indicator of the ETM2 stage. A rapid increase (76%) followed this decrease immediately. In biozone E₅, the morozovellids decline again from 70 to 30% before disappearing in biozone E₆ where the EECO is identified. The percentage of *Acarinina* increases between E₄ (35%) and E₅ (45%) to reach a maximum (76%) in biozone E₆. These results show that *Morozovella* decrease during the ETM2 and ETM3 stages while *Acarinina* increase during the same period. This suggests that *Morozovella* are more sensitive to warming, unlike *Acarinina*. Thus, the disappearance of *Morozovella* simultaneously with a rapid increase in *Acarinina* is correlatable with the EECO observed between biozones E₅ to E₆. However, the distribution of these genera does not provide precise information on the beginning or the end of the warming period observed during the Lower Eocene.

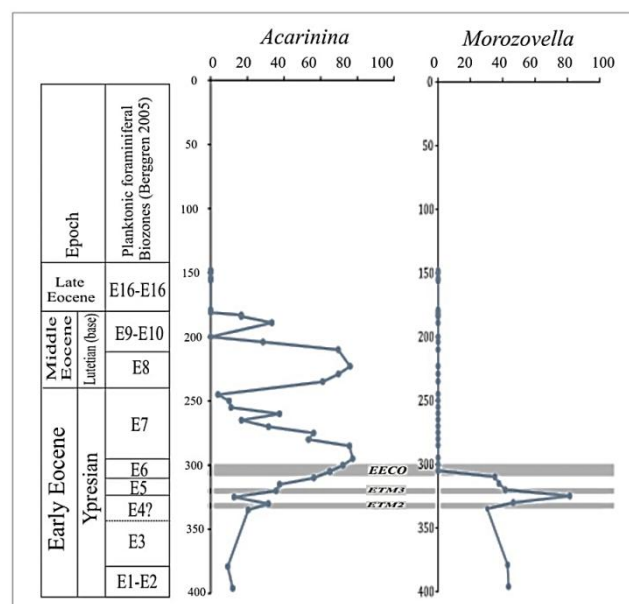


Figure 4: Relative abundance of *Acarinina* and *Morozovella* genera.

4.1 Evolution of the morozovellids

Morozovellids diversify from the base of the Eocene and represent nearly 50% of the planktonic foraminiferal assemblages. This percentage decreases during the thermal stages ETM2 and ETM3 located respectively in biozones E₄ and E₅ (Fig 4 and 5). However, the species diversify during the cooling periods between ETM2 and ETM3 with a maximum of 90%. Species belonging to the genus *Morozovella* disappear completely during or just after the EECO. Beyond this limit, no species of this group remain during the Lutetian. Furthermore, the analysis of intraspecific variation shows that:

- The ETM2 mainly affects the species *Morozovella aequa*, *M. velascoensis* and *M. marginodentata* (Fig 5), which

had representative percentages before this stage. We didn't observed this rapid disappearance in other species.

- ETM3 acts differently on the species. Indeed, *M. formosaformosa*, *M. lensiformis* and *M. velascoensis* seem to be more sensitive to warming, unlike the others, which manage to renew themselves during the cooling phase that comes just after ETM3.
- Only the species *M. subbotinae* (20%), *M. aequa* (6%) and *M. gracilis* (15%) are affected by the EECO warming. However, all morozovellids disappear at the end of the Early Eocene thermal maximum, which is located at the top of the E₆biozone.

These results show that themorozovellids do not have the same responses to warming during the ETM2 and ETM3 stages. However, the species *M. aequa*, *M. velascoensis* and *M. marginodentata* were able to renew themselves after the warming. Moreover, the disappearance of *M. velascoensis* is more characteristic of the ETM2 stage. Therefore, I could be considered as characteristic of ETM2 in the Ypresian. The EECO stage is mainly marked by the rapid decline of *M. gracilis* and *M. subbotinae*. Thus, the disappearance of *M. velascoensis* is more characteristic of the ETM2 stage even though the disappearance of *M. marginodentata* and *M. conicotruncata* during this period does not seem to define correctly the ETM2 stage. Otherwise, the disappearance of *M. gracilis* seems to mark the EECO stage.

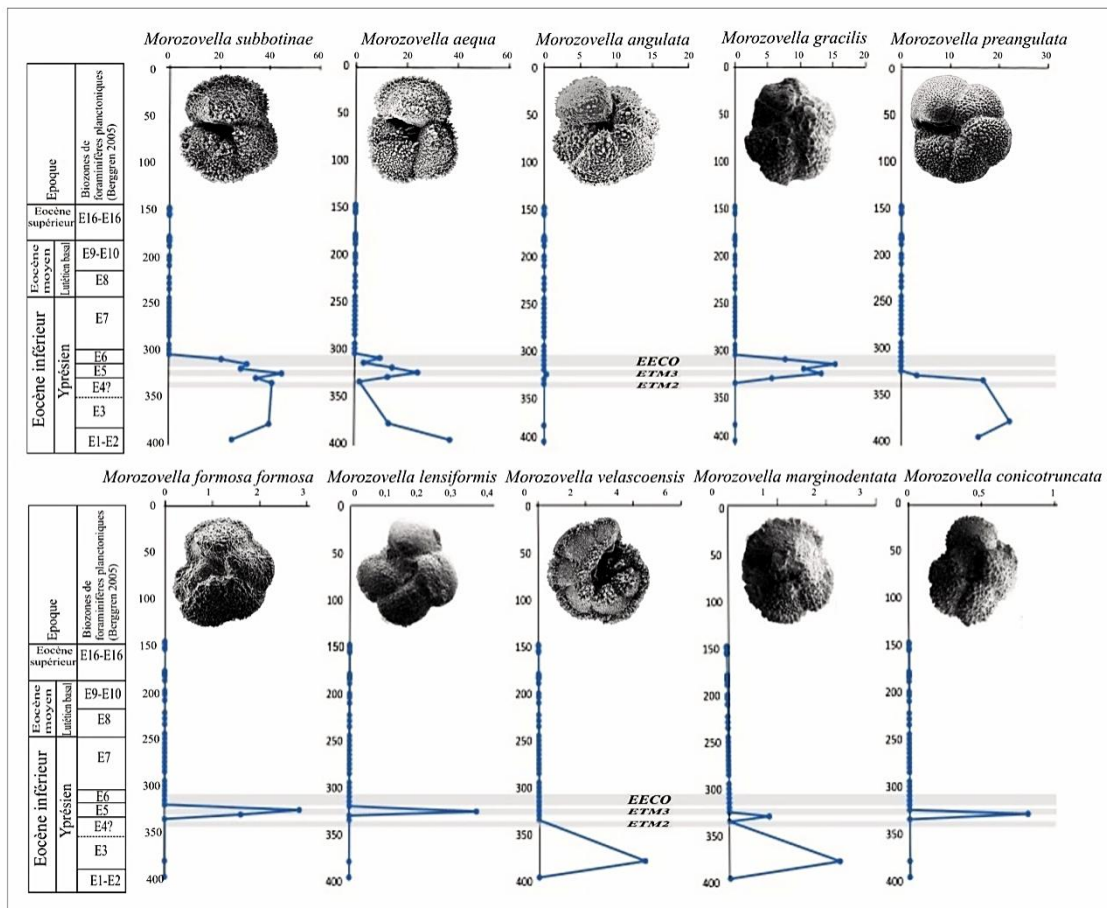


Figure 5: Relative abundance of representative species of the genus *Morozovella*

4.2 Evolution of acarininids

The density of acarininids is low (20%) in the Early Ypresian (E₁-E₃) compared to morozovellids (Fig 4 and 6). A first peak (30%) appears during the ETM2 stage followed by a second and more important peak (35%) during the ETM3 stage. However, it is mainly during the EECO that species belonging to the genus *Acarinina* proliferate and represent 65% of the assemblages. This high percentage of acarininids decreases at the end of the Ypresian (top of biozone E₇)

Thus, species of the genus *Acarinina* undergo two phases of diversification: the first occurs during or just after the EECO stage and the second during the Lutetian. (Fig 6).

- Of all the species inventoried, only *A. pseudotopilensis* (40%), *A. soldadoensis* (20%) and *A. strabocella* (0.9%) proliferate during the ETM2 thermal stage.
- The ETM3 stage is poorly characterised by Acarinidea; there is only a slight peak in *A. soldadoensis* (20%) and an increase in *A. wilcoxensis*.

The peaks of *A. pentacamerata* (70%) and *A. wilcoxensis* (30%) which are the most significant (Fig 6) mainly mark the EECO stage. However, the peak of *A. soldadoensis* (50%) remains late compared to the previous ones. This suggests that the maximum of *A. pseudotopilensis* biozone E₄ marks the ETM2 stage while the ETM3 stage remains poorly characterised. The period of maximum warming coinciding with the EECO and can be correlated with the high percentage of *A. pentacamerata* and *A. wilcoxensis*.

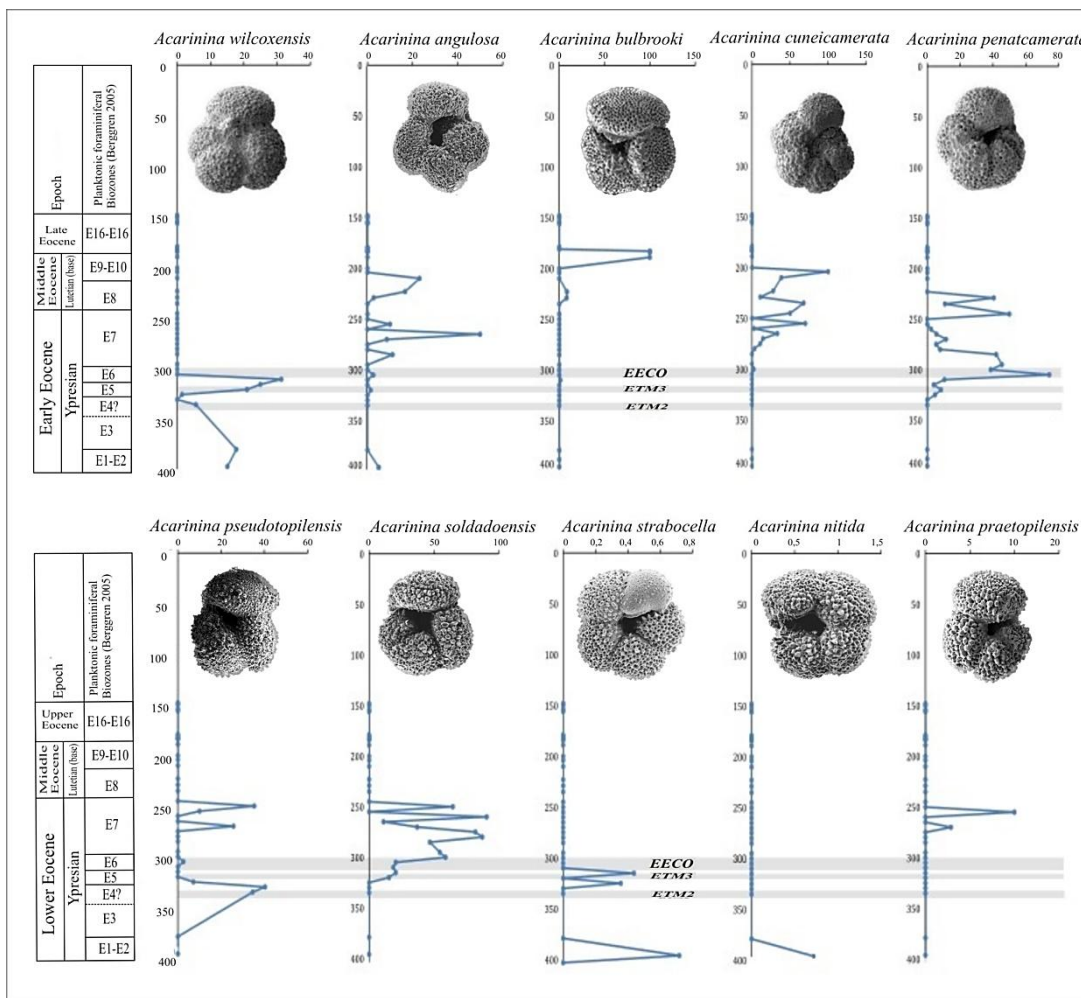


Figure 6: Relative abundance of representative species of the genus *Acarinina*

4.3 Biostratigraphic data (Paleocene, Eocene) of the Togo Coastal Basin

Other foraminiferal associations found in the MH and AM boreholes from the Togolese coastal basin show similar distributions (Da Costa, 2005). The middle to upper Paleocenemicrofauna of the AM borehole contains *Morozovellaangulata*, *Morozovellaconicotruncata*, *Morozovellaacuta*, *Morozovellavelascoensis*, *M. aequa*, *M. subbotinae*, *M. quetra*, *M. formosagracilis*, *M. occlusa* and *Morozovella sp.* (Fig 7). Furthermore, the Early Eocene recognised in borehole MH is composed by *Acarininawilcoxensis*, *A. pseudotopilensis*, *A. spinuloinflata*, *A. soldadoensis*, *A. pentacamerata*, *A. broedermanni* (Fig 8). In the AM borehole, the Paleocene-Eocene transition is characterised by an association consisting of *Morozovellaaequa*, *M. formosagracilis*, *Acarininasoldadoensis*, *A. pseudotopilensis* and *Acarininawilcoxensis* (Da Costa, 2005). The Lutetian planktonic foraminiferal associations of the MH borehole contain also the genera *Subbotina*, *Turborotalia*, *Globigerina* and *Acarinina*. The species *A. bulbrookii*, *A. densa*, *A. soldadoensis*, *A. spinuloinflata*, *A. pentacamerata* represented the acarininids.

Thus, the Middle to Upper Paleocene association and the Paleocene-Eocene transition remains dominated by *Morozovellids* with few *Acarininids* and *Globigerinids*. During the Early Eocene, the diversity of *Morozovellids*

decrease to the benefit of acarininids with a high specific diversity. In addition, during the Middle Eocene, acarininids show a high specific diversity and are associated with other genera like *Turborotalia*, *Truncorotaloides*, *Globigerina*, *Subbotina* and *Cassigerinella* (Da Costa, 2005)

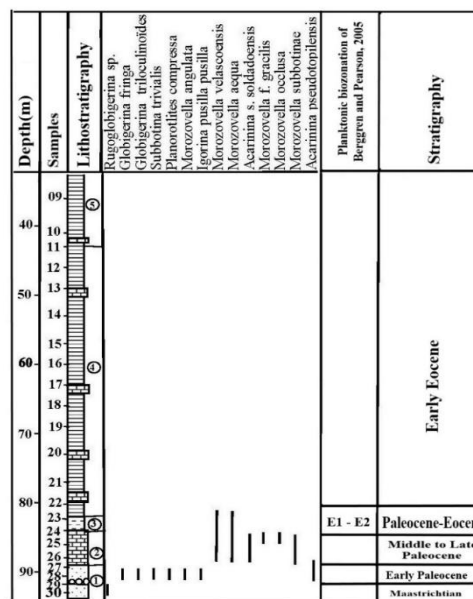
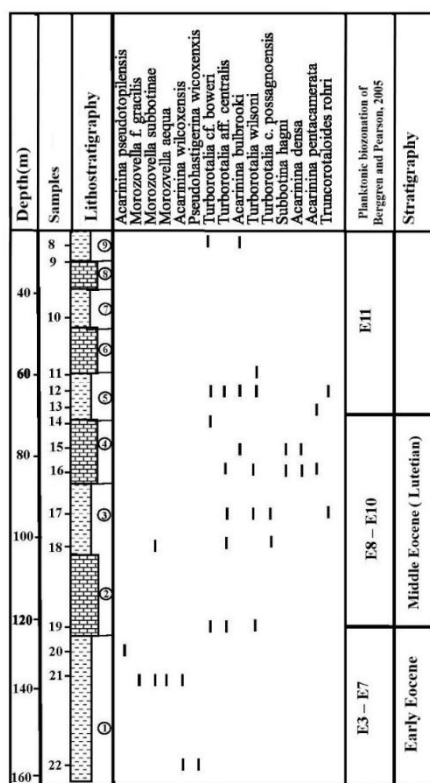


Figure 7: Stratigraphic range of planktonic foraminifera in AM borehole (Da Costa, 2005)



1. Black clay, 2. Carbonated mudstone, 3. Grey clay, 4. Clayey limestone, 5. Coarse sandy clay, 6. Phosphatic limestone, 7. Grey coarse clay, 8. Sandstone-limestone clay, 9. Sandstone clay.

Figure 8: Stratigraphic range of planktonic foraminifera in MH borehole (Da Costa, 2005)

5. Conclusion

Eocene climatic warming phases observed in several oceanic environments around the globe (Lowenstein and Demicco, 2006; Smith *et al*, 2010; Hyland and Sheldon, 2013; Luciani *et al*, 2016) have also been identified in sedimentary basins of the western Atlantic margin. In the Senegalo-Mauritanian Basin, the relative proportions of the genera *Morozovella* and *Acarinina* may characterise thermal stages. The disappearance of *Morozovella* coinciding with an increase in *Acarinina* typical of these stages is observable in this part of the basin. The disappearance of *Morozovella velascoensis* and the development of *Acarinina pentacamerata* defined mainly the ETM2 stage. On the other hand, the ETM3 stage is not well highlighted due to the reappearance of *M. formosaformosa*, *M. lensiformis* and *M. velascoensis* and a slight increase in *A. soldadoensis* and *A. wilcoxensis*. The EECO, which is the longest stage, is characterized by a significant increase in *Acarinina pentacamerata* and the rapid disappearance of *M. gracilis*. Beyond the characterisation of thermal stages, these results show that the diversification of acarininids during the Eocene indicates a warming phase unfavourable to the evolution of morozovellids. The composition and relative abundances of planktonic foraminifera documented at Site 577 (Lu, 1995; Lu and Keller, 1995) show similar results marked by a turnover between *Morozovella* and *Acarinina* during the early Eocene. However, the low resolution of the sampling and the poor preservation of the material may be limitations to the correct identification of thermal phases at the basin level. A correlation with the results obtained in other West African basins and those defined from foraminifera in the oceanic environment would allow a better understanding of the

impact of warming phases in the different domains (continental and oceanic).

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