Cenomanian – Turonian Foraminifera and Palynomorphs from the Calabar Flank, South Eastern Nigeria: Implications for Age and Depositional Environment

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One of the most spectacular signatures of global “Oceanic Anoxic Events” (OAEs) of the Cretaceous was deposited at the Cenomanian–Turonian Boundary. This global oceanic anoxic event is also referred to as Cenomanian–Turonian Boundary Event (CTBE). This event is marked by the deposition of finely laminated organic carbon rich sediments deposited under oxygen depleted conditions. The main goal of the present research is to get a better understanding of the marine biota characterizing the oceanic anoxic event in the Calabar Flank. Core samples obtained from two (2) study wells in the Calabar Flank, southeastern Nigeria were utilized for this study and standard biostratigraphic sample preparation/separation and analytical approaches were applied in the course of the study. The Cenomanian – Turonian age was assigned based on age diagnostic foraminifera (Hedbergella crassa, Heterohelix moremani, Heterohelix planata, Heterohelix reussi, Hedbergella delrioensis, Hedbergella planispira) and age diagnostic palynomorphs (Steevesipollenites binodosus, Ephedripites sp, Leiotriletes sp, Classopollis sp, Classopollis classoides, Classopollis annulatus, Ephedripites jansonii, Cretacaeiporites mulleri, Cretacaeiporites polygonalis, Galeacornea clavis and Triorites aficaensis). The sediments of the study wells were deposited in a range of environments from non-marine to mid neritic and the recovered foraminifera are characterized by the presence of abundant but dwarfed planktic forms and low diversity of dwarfed arenaceous forms at some intervals which strongly support deposition in an oxygen depleted environment.

Keywords: Cenomanian, Turonian, Calabar Flank, Oceanic Anoxia Event.

INTRODUCTION

The earliest study on Oceanic Anoxic Events (OAEs) was carried out by Schlanger & Jenkyns (1976) and was defined as a global-scale transient period of marine anoxia followed by periods of widespread deposition of organic carbon-rich sediments at the Aptian-Albian and Cenomanian-Turonian boundaries. The Oceanic Anoxia Event (OAE 2) also referred to as Cenomanian–Turonian Boundary Event (CTBE) is characterized by finely laminated organic carbon-rich sediments deposited under oxygen depleted conditions. This boundary/transition is one of the most studied boundaries in the Cretaceous and it is dated 93.3Ma by International Commission on Stratigraphy drafted by Cohen et al., (2015). It is widespread and prominent and occurred during the warmest interval of the Cretaceous greenhouse when the bottom-water temperatures were far higher than today; up to 25°C (Huber et al.,1999, 2002; Friedrich et al., 2008). Intensive research has been carried out on the Cenomanian - Turonian boundary interval of the Calabar Flank in order to understand the Oceanic Anoxic Event and their associated marine biota (Nyang and Ramanathan,1985; Petters,1980; Petters and Ekwoezor, 1982; Ukpong and Ekhalialu, 2015; Akpan, 1985, 1992, 1996). It is typically represented by the worldwide deposition of organic-rich deposits such as the Ekenkpon Shale in the Calabar Flank. The Cenomanian – Turonian

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age according to the International Commission on Stratigraphy drafted by Cohen et al. (2015) range from 100.5 Ma – 89.8 ± 0.3 Ma. This interval of time in the Calabar Flank is characterized by periods of remarkable low oxygen levels based on foraminiferal studies by Nyong and Ramanathan (1985), Petters (1980), Petters and Ekweozor (1982), Ukpong and Ekhalialu (2015) while ichnological analyses and macrofaunal evidence by Akpan (1985, 1992, 1996) support periods of changing oxygen levels (long anaerobic and short aerobic periods). The wells (4N/2W and O/2W) under investigation were drilled at Mbarakpa, Calabar Flank (Figure 1) for limestone exploration and the samples were obtained in order to study the foraminifera and palynomorphs assemblages from the dark grey fissile shale of the Cenomanian – Turonian boundary interval in the Calabar Flank.

Geologic setting and stratigraphy

The Calabar Flank (Murat, 1972) is an epeirogenic basin situated in the easternmost part of the sedimentary basins in Southern Nigeria (Nyong and Ramanathan, 1985). It is bounded by the Cameroon volcanic trend to the east, the Ikpe platform to the west, the Oban Massif and Calabar hinge line to the north and south respectively (fig 2). It was thought to be the south – eastern extension of the Benue Trough trending in a Northwest – Southeast (NW-SE) and lying between latitudes 4° 50’ - 5° 50’N and longitudes 7° 50’ - 8° 50’E (Petters, 1982). The origin of the Calabar Flank is closely associated with the Rift System that formed the Benue Trough during the final opening of the South Atlantic from Africa (Petters, 1982, Petters et al, 1995). Sedimentation in the Calabar Flank started with the deposition of Fluvio-deltaic shale, mudstone and arkosic sandstone of the Awi Formation dated to be of the Aptian age (Adelanye and Fayose, 1978). Ekhalialu et al., (2016) carried out detailed description of the Awi Formation. The Awi Formation unconformably overlies the Precambrian Oban Massif (it consists of weathered granite, schists, migmatite and gniesses). Carbonate platform of the Mfamosing Limestone directly overlies the Awi Formation (Petters, 1982) believed to be deposited during the marine transgression in the Gulf of Guinea in the Mid-Albian times (Akpan, 1992). The Mfamosing Limestone is overlain by thick sequence of black to grey shale unit, the Ekenkpon Formation (Petters and Reijers, 1987). The formation is characterized by minor intercalation of marls; calcereous mudstone and oysters beds (Akpan, 1996). This shale unit was deposited during the Late Cenomanian-Turonian times. The Ekenkpon Shale is overlain by a thick marl unit; the New Netim Marl (Petters et al., 1995). This unit is nodular and shaly at the base and is interbedded with thin layer of shales in the upper section. Foraminifera age suggest Early Coniacian age for this marl unit (Nyong and Ramanathan, 1985). The New Netim Marl is unconformably overlain by carbonaceous dark grey shale, the Nkporo Formation which was deposited during the late
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Figure 2: The map of Niger Delta showing structural elements of the Calabar Flank in relation to other sedimentary basins in Nigeria (Nyang and Ramanathan, 1985).

Campanian-Maastrichtian times (Petters et al., 1995). The Nkporo Shale caps the Cretaceous sequence in the Calabar Flank. The Nkporo Shale sequence is overlain by a pebbly sandstone unit of the Tertiary Benin Formation (Reijers and Petters, 1997).

METHODOLOGY

Sample collection

A total of twelve (12) and eleven (11) core samples were collected from two wells (O/2W and 4N/2W) drilled to a depth of sixty-five (65) and seventy (70) metres respectively. Both wells were drilled at Mbarakpa, Calabar Flank and the samples were collected at 5m interval. The samples and were later composited at ten (10) metres interval resulting in six (6) samples each for the two (2) study wells

Lithologic description

Lithologic description was carried out on the samples based on their physical characteristics such as colour, texture, hardness, fissility and rock type. Chemical tests were also carried out to determine the presence of calcareous materials using 10% dilute Hydrochloric acid (HCl).

Biostatigraphic sample preparation

Foraminifera

Each sample was subjected to foraminifera sample preparation as outlined by Brasier (1980) and Armstrong and Brasier (2005). The identification of the foraminifera was done by comparing picked forms with previously published forms using a binocular microscope. Quantitative analysis was done using the number of species count per sample to establish abundance and diversity of foraminifera species.

Palynology

The core samples obtained from the study wells were also analyzed for palynomorphs. Samples preparation was done by acid maceration techniques used by Doher (1980) and Traverse (1988) for acid insoluble microfossils. The steps include dissolution of carbonates and silicate, acid neutralization and dissolution of humic matter. Concentration of palynomorphs was achieved by sieving using 200 and 400 mesh nylon screens and pipetting the organic residue from a watch glass. Slides of temporary strew mounts using glycerin jelly was made for each of the samples. Transmitted light microscope was used for studying the palynomorphs. The palynomorphs were counted and recorded. Analysis was done by comparison with published work to identify the various forms of palynomorphs.
RESULTS AND DISCUSSION

Lithostratigraphy

Two (2) distinct lithologic units were recognized in both wells (O/2W and 4N/2W). The topmost layers could be classified as overburden consisting of dark brownish silty materials. This layer is five metres (5m) thick in well O/2W and fifteen metres (15m) thick in well 4N/2W respectively. The first lithologic unit at the top consists of 50m and 20m of dark grey fossil shales in wells O/2W and 4N/2W respectively and belongs to the Ekenkpon Shale. The second lithologic unit at the basal section of the study wells consists of 10m and 20m of light grey fine-grained limestone in wells O/2W and 4N/2W respectively and belongs to the Mfamosing Limestone.

Biostratigraphic analysis

The core samples from the two (2) wells yielded some foraminifera and palynomorph that are paleontological useful for age determination.

Figure 3 and 4 show biostratigraphic charts for well 02/W and 4N/2W respectively.
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**Figure 4.** The biostratigraphic range chart of foraminiferal species and palynomorphs species, depth of occurrence and their counts for well 2N/2W

<table>
<thead>
<tr>
<th>Age</th>
<th>Biostratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenomanian – Turonian</td>
<td>Classaporilla classapora</td>
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<tr>
<td></td>
<td>Classaporilla sp.</td>
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<tr>
<td></td>
<td>Ephedrinites multistatus</td>
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<tr>
<td></td>
<td>Ephedrinites sp.</td>
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<tr>
<td></td>
<td>Gaakiaecea elongata</td>
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<td></td>
<td>Glichntidites senonicus</td>
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<td></td>
<td>Loevigolitesporites sp.</td>
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<td></td>
<td>Leiochristes sp.</td>
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<td></td>
<td>Polypodiumites sp.</td>
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<td></td>
<td>Psalidcolporites sp.</td>
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<tr>
<td></td>
<td>Syncolporites sp.</td>
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<tr>
<td></td>
<td>Triticites aequoraeos</td>
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<tr>
<td></td>
<td>Triticites sp.</td>
</tr>
<tr>
<td></td>
<td>Classaporilla annulata</td>
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<tr>
<td></td>
<td>Cretaceoerotes mutleri</td>
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<tr>
<td></td>
<td>Cretaceoerotes polygona</td>
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<tr>
<td></td>
<td>Ephedrinites pannoni</td>
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<td></td>
<td>Latochristes adnanti</td>
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<td></td>
<td>Striatoerotes parvulus</td>
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<td></td>
<td>Tricopites sp.</td>
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<td></td>
<td>Zibionites brevispinus</td>
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<tr>
<td></td>
<td>Classaporilla jardinei</td>
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<tr>
<td></td>
<td>Deltoidospore sp.</td>
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<td></td>
<td>Retricolporites sp.</td>
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<tr>
<td></td>
<td>Stevesnepitrites binodosus</td>
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<tr>
<td></td>
<td>Deltoidospore minor</td>
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<tr>
<td></td>
<td>Lycopodiumsporites sp.</td>
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<tr>
<td></td>
<td>Lycopodiumsporites aequoraeos</td>
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<td></td>
<td>Lico. indet. sp.</td>
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<td></td>
<td>Leiosphaeridites sp.</td>
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<td></td>
<td>Spiniferites sp.</td>
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<td></td>
<td>Cirrospirellidites sp.</td>
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<tr>
<td></td>
<td>Selencopospher sp.</td>
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</tbody>
</table>

**FORAMMINERAL DISTRIBUTION**

<table>
<thead>
<tr>
<th>Sample</th>
<th>FOP</th>
<th>FOBA</th>
<th>MM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hedbergella crossa</td>
<td>Haplophragmoides sp.</td>
<td>Shell fragments</td>
</tr>
<tr>
<td></td>
<td>Heterohelix moremani</td>
<td>Hedbergella plantiapra</td>
<td>Ostracod sp.</td>
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<tr>
<td></td>
<td>Heterohelix planulis</td>
<td>Hedbergella deilia</td>
<td></td>
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<td></td>
<td>Heterohelix russel</td>
<td>Hedbergella deltoidea</td>
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<tr>
<td></td>
<td>Hedbergella sigal</td>
<td>Haplophragmoides sp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hedbergella plantiapra</td>
<td>Ammonia cf. nikalagum</td>
<td></td>
</tr>
</tbody>
</table>

**BIOSTRATIGRAPHIC CHART OF 2N/2W WELL**

**PALYNOFLORAL DISTRIBUTION**

**Spores And Pollen**

**Dinoflagellate Cysts**
Foraminifera biostratigraphic analysis

Foraminiferal analysis of wells O/2W and 4N/2W is characterized by diverse assemblages of planktic and agglutinated foraminifera with the planktic exhibiting higher diversity and abundance than the agglutinated forms. Only a species of calcereous benthic form with one (1) count is present in well 4N/2W while no count of calcereous benthic foraminifera was recorded in well 2N/2W. The upper and middle sections of the study well yielded abundance and diverse foraminiferal species with the lower section in both wells being barren. The foraminifera and palynologic biostratigraphic chart shows the depth distribution of the recovered foraminifera and palynomorphs.

The age determination of the sediments penetrated by the study wells were based on age diagnostic planktic assemblages identified and recorded in the samples. The planktic foraminifera species include Hedbergella crassa, Heterohelix moremani, Heterohelix planata, Heterohelix reussi, Hedbergella delrioensis, Hedbergella planispiral which confirms the Cenomanian - Turonian boundary interval. The study of Adegbie and Bassey (2007) and Ukpong and Ekhalialu (2015) used a similar assemblage of Hedbergellids and Heterohelicids to define this age interval.

Fayose (1979) used the occurrence of Heterohelix moremani and Heterohelix reussi to confirm similar age in the Ituk-2 well. Sediments of Cenomanian - Turonian age were also recognized on the basis of the occurrence of Heterohelix reussi, Heterohelix moremani, Heterohelix simplicissima and Globigerinelloides caseyi. (Petters, 1980). Petters (1982) also recognized these forms from road cut samples of the Eze-Aku Shale at km 24.8 on the Calabar-Ilu highway. The single occurrence of Ammotium nkalagum also points to Cenomanian - Turonian age.

Palynostratigraphy

Palynological analysis of the Well O2/W yielded forty-one (41) palynomorphs species. Large numbers of these assemblages were gotten from interval 15-45m with practically no palynomorphs recovered from 0-10m interval. Palynological analysis of well 4N/2W on the other hand yielded about thirty-eight (38) palynomorphs species and a few associated dinoflagellate cysts. Large numbers of these assemblages were gotten from interval of 20-50m with practically no palynomorphs recovered from 60-70m interval. The co-occurrences of age diagnostic palynomorphs such as: Stevesipollenites binodosus, Ephedrites sp, Leiotriletes sp, Classopollis sp, Classopollis classoides, Classopollis annulatus, Ephedrites jansonii, Cretaceaeiporites mulleri, Cretaceaeiporites polygonalis, Galeacornea clavis and Triorites africanais is indicative of a Cenomanian-Turonian age. Ukpong and Ekhalialu (2015), used a similar assemblage including Classopollis sp, Triorites africanais and Cretaceaeiporites mulleri to define this age interval.

Ephedritipites sp. was reported by Schrank and Ibrahim (1990) in Egypt and Abubakar et al (2011) in Nigeria. The occurrences of this palynomorphs gave credence to the Cenomanian-Turonian age. The Stevesipollenites binodosus assemblage zone (Cenomanian-Turonian) is correlated with the Yolde and Gongila Formations also dated Cenomanian-Turonian by Lawal and Moullade (1986). Essien and Ufot (2005) also used Classopollis sp. and Ephedrites sp. to assign Mid Albian – Early Cenomanian age for the Mfamosing Limestone in the Calabar Flank.

Paleoenvironmental interpretation

In the study well, the distribution of foraminiferal forms and palynomorphs taxa were used as a tool for the interpretation of the paleoenvironmental condition under which the sediments were deposited. Paleoenvironmental interpretations using the recovered foraminifera was based on modern foraminifera ecology which provides distinct criteria for the reconstruction of marine environment (Murray, 2006) using their environmental preferences. For paleoenvironmental interpretation using the recovered palynomorphs, the knowledge of palynomorphs production and dispersal, palynomorphs source and deposition as well as palynomorphs preservation and the relationship between preserved palynomorphs and plant communities were considered. It is pertinent to note that different palynomorphs possesses different production rates.

- **Non Marine Environment**

The lower interval (60-70m) of well 4N/2W and the upper section (0 – 5m) of the well 02/W shows a barren interval (no occurrence of forms), and this suggests a non-marine environment.

- **Shallow Inner Neritic Environment**

Depth interval 20-30m in well 4N/2W is characterized by shale and shell fragments. There is complete lack of planktic foraminifera and a presence of very low abundance of benthic foraminifera, Haplophragmoides sp. This genus is a probable infaunal detritivore that is commonly found in muddy to sandy substrate in environment ranging from marsh hyposaline lagoon and estuaries to bathyal (Murray, 1991; Bronnimann et al; 1992). There is also high abundance of terrestrial pollen and spores in this interval such as Classopollis sp, Ephedrites sp and Leiotriletes sp which further suggest deposition in the shallow inner neritic environment. The shallow inner neritic environment was not encountered in well 02/W.

- **Inner Neritic Environment**

The depth interval of 30-40m in well 4N/2W and 25-55m in well 02/W respectively was inferred to be an inner neritic
setting. The lithology of these interval was characterized by shale with intercalation of mudstone with significant counts of agglutinated benthic foraminifera taxa (Ammotium nkalagum, Haplophragmoides sp, Ammobaculites sp) and calcareous planktonic taxa mainly of the Heterolcids, Hedbergella moremani was also encountered. The diversity as well as the abundance of planktic and benthic foraminifera in this section of the well is low with the exception of the Ammotium nkalagum which is relatively very abundant. The high percentage of Ammotium nkalagum indicates brackish water (Murray, 1991). Olaleye (1983), suggested that the low diversity of the benthonic assemblage and the scarcity of the planktonic species in the Pindiga Formation reflects deposition in a shallow marine Epi-continental sea. Low diversity is also characteristics of modern brackish lagoons and estuaries (Murray, 1991).

- **Inner to Middle Neritic Environment**

The inner – middle neritic environment is assigned to the depth interval 40-50m of well 4N/2W and 10-25m of well 02/W. The criteria for this inference were based increase in the abundance and diversity of the planktics and benthic foraminifera within these intervals. A high planktic/benthic ratio was also observed in this interval. Increase in percentage of planktonic foraminifera relative to benthonics is a general index of increasing water depth (Phleger, 1960). There is also a general decrease in the pollen and spores assemblages towards this zone reflecting deeper water.

- **Anoxia conditions**

The oxygenation conditions in ancient environments can be determined based on the recovered foraminifera. Changes in dissolved oxygen concentration at the water column, sediment-water interface and in-sediment affects the foraminifera make up of sediments. The study of Miller et al (1992) determined that low Oxygen, low pH and more corrosive bottom waters favour the development of Agglutinating benthic foraminifera and complete absence of calcareous benthic foraminifera which suggests total oxygen-deficient bottom conditions during deposition. This means that the agglutinated foraminifera forms (Ammobaculites coprolithiformis, Ammotium cf nkalagum, Ammotium cf nwallium, Haplophragmoides sp etc.) found in the study wells suggest deposition in an oxygen-deficient environment as well as low salinities. The presence of abundant but dwarfed planktic foraminifera and the presence of low diversity of dwarfed agglutinated forms at some intervals further support this interpretation. This interpretation conforms to the study of Nyong and Ramanathan (1985), Petters (1980), Petters (1982), Petters and Ekwuozor (1982), Ukpong and Ekhalialu (2015). It is believed by several authors that the oceanic anoxia effects was triggered by enhanced volcanic activity that lead to the release of huge amounts of volcanogenic CO₂ and CH₄ in the ocean-atmosphere system that drove the known worldwide Cretaceous maximum warmth (Jenkyns et al., 1994; Huber et al., 1995, 2002; Clarke and Jenkyns, 1999 and Friedrich et al., 2012).

**SUMMARY AND CONCLUSION**

The study wells (02/W and 4N/2W) located in Mbarakpa, Calabar Flank, Nigeria were studied for its sedimentological and biostatigraphic (micropaleontological and palynological) content. The study wells penetrated a latertitic layer as well as limestone and shale lithologic units. These lithologic units belong to Mfamosing Limestone and the Ekenkpon Shale respectively of the Calabar Flank. Biostratigraphic results reveal a fairly high abundant and low diversity of foraminiferal species together with high abundant and diversity of Palyonomorph. The integration of these results enables the assignment of a Cenomanian to Early-Turonian age to the study wells. This was made possible by the presence of the following age diagnostic foraminifera such as Hedbergella crassa, Heterohelix moremani, Heterohelix planata, Heterohelix reussi, Hedbergella delrioensis, Hedbergella planispira, Hedbergella sigali and age diagnostic palynomorphs such as Steevespolenites binodosus, Ephedriites sp, Leiotriletes sp, Classopolis sp, Classopolis classoides, Classopolis annulatus, Ephedriites jansoni, Cretaceaeiporites mulleri, Cretaceaeiporites polygonalis, Galeacornea clavis and Priorites africana. The assigned age is known as one of the warmest periods in the past 300 m.y., with tropical sea-surface temperatures at well over 30 °C (Pucéat et al., 2007; Forster et al., 2007) and atmospheric CO₂ levels much higher than today.

**REFERENCES**


**Accepted 28 December 2017**


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