PALEOENVIRONMENTAL SETTINGS AND ASSEMBLAGE CHANGES OF FORAMINIFERA AND PALYNOMORPHS ACROSS THE EOCENE-OLIGOCENE BOUNDARY OF SOUTHERN TANZANIA

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ABSTRACT

A quantitative micropaleontological analysis was performed on outcrop and core samples across a shallow borehole drilled in the southern coastal basin of Tanzania with the aim of characterizing foraminifera and palynomorphs assemblage changes aiming at reconstructing paleoenvironmental settings across the Eocene-Oligocene transition (EOT). The data reveal high diversity and abundance of calcareous benthic foraminifera assemblages in the Late Eocene succession and a decline of their abundance and diversity across the EOT to Early Oligocene. Planktonic foraminifera assemblages were low in abundance and diversity in the Late Eocene succession and decreased through the EOT when most planktonic foraminifera species from Hantkeniide family and Turborotaloiide groups went extinct. Additionally, marine palynomorphs/dinoflagellate dominated the oldest sedimentary succession (Late Eocene). Their abundance and diversity declined towards the EOT to the Early Oligocene while terrestrial palynomorphs (spores and pollens) dominated the youngest succession. The palynomorphs assemblage changes responded rapidly to environmental variations across the Eocene-Oligocene boundary which was associated with a global cooling event. Both foraminifera (i.e. calcareous benthic foraminifera) and palynomorphs assemblages as well as planktonic/benthic ratios indicate that the EOT paleoenvironment settings were compatible with shallow marine of inner to outer shelf environments.

Keywords: Eocene-Oligocene, foraminifera, palynomorphs, paleoenvironment, Tanzania

INTRODUCTION

The southern coastal basins of Tanzania formed during the breakup of Gondwana and after the drifting of Madagascar away from Africa by the end of Mesozoic (Stankiewicz and de Wit 2000,Berrocoso et al. 2010, Kasanzu 2014). This rifting and spreading event was accompanied by major marine transgression into passive continental margins of both west and east Gondwana blocks (Geiger et al. 2004). In Tanzania, this resulted into thick Late Jurassic to Neogene sedimentation in a series of marginal basins, which include the Mandawa and Ruvuma basins of southern Tanzania (Fig. 1, Pearson et al. 2004). Thus, these basins reflect important accretionary tectonic events along the Panthalassan margin of Gondwana during when regional sedimentary megasequences were deposited in NNW-SSE oriented rift depocentres (Veevers and Powell 1994, Wopfner 2009). These sedimentary deposits represent important geological archives for studies of ancient tectonics, uplift histories, paleo-ambient conditions and environmental settings.

Micropaleontological investigations of ancient basins are generally vital in constraining foraminifera and palynomorphs assemblages which are key to the understanding of paleo-ambient depositional conditions and paleo-climatic changes (e.g. Stewart et al. 2004, Pearson et al. 2008; 2006, Lear et al. 2008, Berrocoso et al. 2015). For instance, Pearson et al. (2008), amongst others, contend that the EOT marks a period of change in global climatic conditions and the end to a comprehensive period of predominantly "greenhouse" conditions on Earth that stretches back into the Mesozoic. It was also a period of high extinction rates in planktonic organism as well as land fauna. Planktonic foraminifera that experienced a large effect on the extinction event include the five species in the families of Hantkeninidae, *Turborotaliacerroazulensis* group and the reduction in size of the Pseudohastigerina lineage (e.g. Coxall and Pearson 2006, Wade and Pearson 2008). However, benthic foraminifera experienced a gradual turnover, manifested by an overall decline in diversity, mostly due to the decline in abundance of biserial, triserial and other cylindrical taxa with a complex aperture (Thomas 1992). The Shannon diversity index for planktonic foraminifera displays moderate assemblages up to ca. 34 Ma whereby diversity declined towards the Eocene-Oligocene boundary at 33.7 Ma (Thomas 1992).

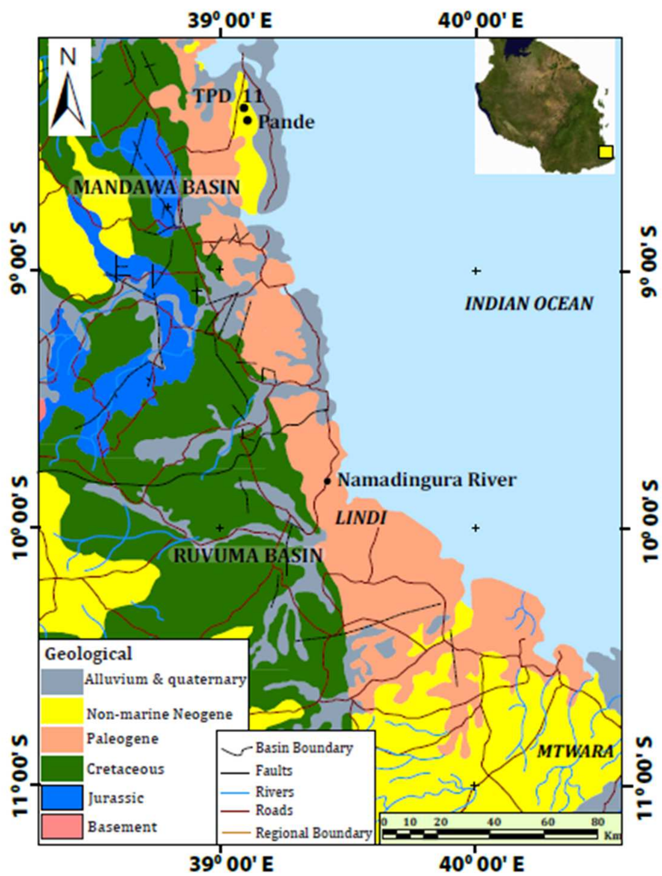

Figure 1: A simplified geological map of the southern coastal basin showing the geological setting of the studied area (modified after Mweneinda 2014).

Unpublished or limited number of studies has been conducted in Tanzania to characterize such fauna assemblages and their paleo-ecodynamics (Pearson et al. 2008; 2006). In this article, we present foraminifera and palynological data as a contribution towards understanding the assemblage changes across the EOT and paleoenvironmental settings of the area. This contribution will broaden the micropaleontological dataset for the Tanzania coastal basin which is currently under exploration for oil and gas.

The Kilwa District of southern Tanzania (Fig. 2) comprises thick successions of claystones of outer shelf to shallow marine sediments ranging in age from Bartonian to Oligocene (Nicholas et al. 2006). A large proportion of this succession has been recovered in a series of shallow drill cores by the Tanzania Drilling Project Team (TDP) during the years 2002-2009. On the other hand, Paleogene sequences that are also found in the basin have been the focus of recent research on the paleontological and paleo-climates history of the area (Nicholas et al. 2006, Pearson et al. 2004, 2006; Bown et al. 2008, Berrocoso et al. 2010, 2012, 2015, Lear et al. 2008, Stewart et al. 2004). This study focuses on core samples of the Pande Formation in Kilwa recovered from TDP 11 borehole and outcrop samples collected in Lindi (Fig. 1). The Pande Formation is uniformly composed of dark greenish grey claystones.

GEOLOGICAL SETTING

A thick sequence of marine sedimentary strata of the Middle Cretaceous–Neogene crops-out in the coastal region of southern Tanzania, striking parallel to the shoreline and shallowly dipping towards the Indian ocean (Nicholas et al. 2007). The Kilwa Group comprises a circa. 1088 meters thick succession of dark claystone, siltstone, limestone and sandstone (Nicholas et al. 2006; see also Kasanzu 2014). The stratigraphy of the Group comprises the Lower Cretaceous Kingongo marls overlain through a disconformity by the Upper Cretaceous Nangurukuru Formation. The Nangurukuru rocks are overlain, in a younglings order, by the Lower Eocene Kivinje Formation, Middle Eocene Masoko Formation and Lower Oligocene Pande Formation. Miocene clays characterise the youngest formation overlying the Kilwa Group. Our foraminifera and palynomorph data were collected from the Pande Formation (Nicholas et al. 2007).

The EOT boundary in the study area is sporadically exposed on a hillside near the coastal village of Pande in Kilwa (Fig. 2). At this boundary there are three core samples that were recovered from drilling by TDP within the basin to a depth of circa 3 km at boreholes TDP11, 12 and 17 (Fig. 3). A hiatus unconformity characterizes the lower part of the Oligocene deposit at the two sites (TDP 17 and 11) which results into thickness reduction by ~12 m and 3 m, respectively. The southerly site (TDP 12) has a complete section across the E-O boundary, occurring in repetitive mudstone facies (Pearson et al. 2008).

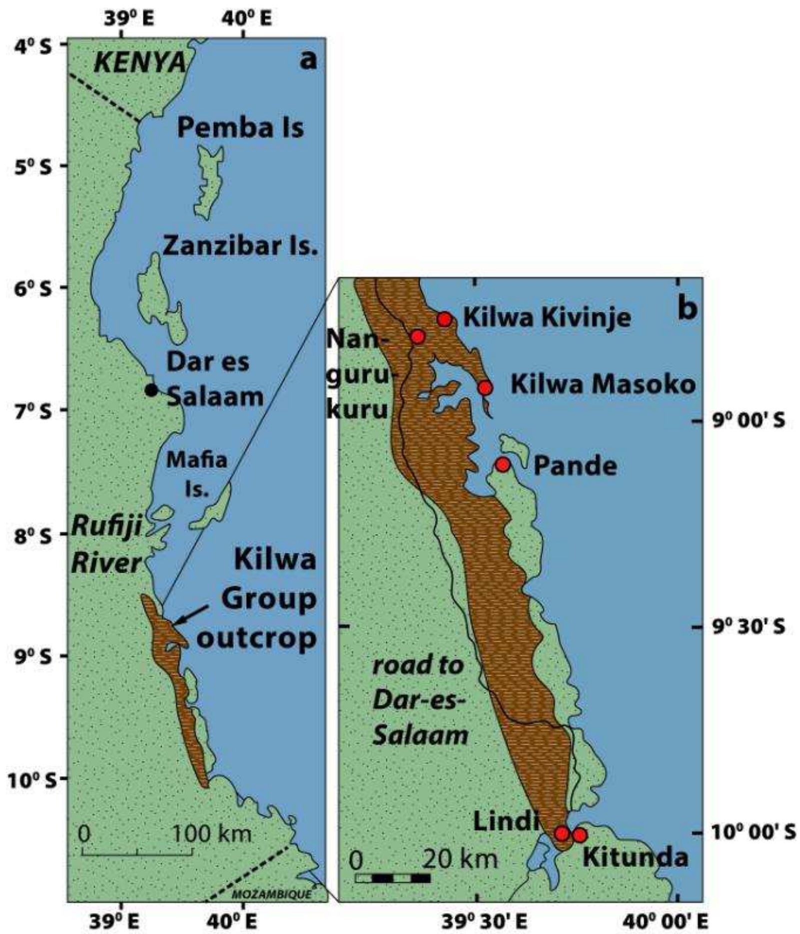

Figure 2: Geological setting of Kilwa Group showing the lateral extent of the outcrop in the southern coastal Tanzania (modified from Nicholas et al. 2006).

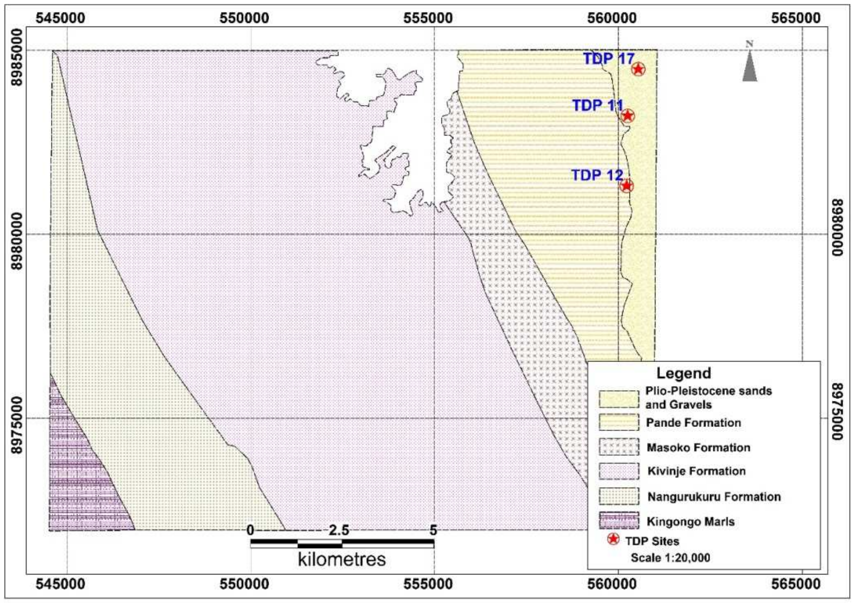

Figure 3: A map showing the geology of the area leading to the Pande Peninsula and location of the three TDP sites (11, 12 and 17) that were drilled and intersected the Eocene-Oligocene boundary (Map modified from Nicholas et al. 2006).

MATERIALS AND METHODS

This study utilized core samples from TDP 11 provided by Tanzania Petroleum Development Corporation (TPDC) and outcrop samples collected from Kilwa (Pande) and Lindi (Namadingura River) (Fig. 1). Core lengths for the samples are shown in Table 1. For the purpose of studying foraminifera, samples were prepared using standard micropaleontological techniques as in Hess et al. (2014). The samples were washed through a 63 µm size mesh sieve, under running tap water until the passing water was clear. The clean residual materials were then dried in an oven at 50 ºC and 1/3 portion of the dried residual was analysed for foraminifera under a reflected light microscope. This 1/3 portion of the samples was sieved into 500 µm, 250 µm and 125µm size sieves. The individual foraminifera specimens were hand-picked from a picking tray and arranged according to morphological similarities on the micropaleontological slides to enable identification. For quantification of planktonic/benthic ratios as well as planktonic and benthic foraminifera assemblage, each species were counted from 125 µm mesh-size fraction.

TDP 11 core samples were also analysed for palynomorphs (dinoflagellate, spores and pollens). Samples were prepared by using palynological standard technique and for quantitative palynological analysis according to Vega (1992). Samples were soaked and placed in a fume chamber ready for treatment with acids, in order to remove the carbonate and silica materials, dilute (10%) HCl and HF acids were used respectively. Organic residual was then taken into a vial follow up with the additional of polyvinyl alcohol as a dispersant for the purpose of making the samples distribute evenly on the slide. The eye dropper was then used to spread the residual materials on the coverslip glass placed on a warm hotplate. When sample residue on the coverslip dried, permanent slide was made by using epoxy resin as a mountant. Each slide underwent palynological analyses by using transmitted light microscope for identification. Counting of structured organic materials (palynomorphs) was done in each single slide of the sample and images were captured for representative specimen. The palynological analysis involved identification of palynomorphs to species and/or genus level.

RESULTS

Core samplesforaminifera assemblages

On the overall, the analysed sample intervals showed recovery of foraminifera in the range of 38 – 261 specimens/g (see Table 1; shown as percentages). Most of the sample intervals showed recovery of foraminifera between 100 – 220 specimens/g and while a few samples showed moderately recovery which ranged between 90 -100 specimens/g. (Table 1). TDP 11 borehole yielded good recovery of calcareous benthic foraminifera that were found to dominate all sample intervals, their abundance proportion ranged between 50 - 90%. Agglutinated benthic foraminifera were found to be in relatively low abundances in most sample intervals. Additionally planktonic foraminifera abundances were relatively lower compared to benthic foraminifera (combined both calcareous and agglutinated benthic) but reached high peak (42.5% by proportion) at 82.32 m depth (TDP11/27/2, 22-25 cm). The bar charts in figures 4 and 7 show the variation of foraminifera abundances in terms of P:B ratios which were obtained for each sampled interval.

$$\frac{P}{P+B} * 100$$

Where P and B stand for planktonic and benthic foraminifera, respectively.

Table 1: Absolute abundance of foraminifera computed from each core sample interval.

SAMPLE ID	%FOP	%FOBC	%FOBA	% S &P	% DINO
TDP 11/27/1, 0-3 cm	25	71.67	3.33	75	25
TDP 11/27/1, 25-28cm	21	79	0	50	50
TDP 11/27/1, 50-53cm	15.6	84.4	0	53	47
TDP 11/27/1, 75-78cm	38.7	61.3	0	73	27
TDP 11/27/1, 97-100cm	18.3	81.7	0	67	33
TDP 11/27/2, 22-25cm	42.5	55.2	2.3	40	60
TDP 11/27/2, 50-53cm	21.2	78.8	0	28.6	71.4
TDP 11/27/2, 75-78cm	22.8	68.34	8.86	33	67
TDP 11/27/3, 0-3cm	24.8	60.32	14.87	25	75
TDP 11/27/3, 28-31cm	15.8	81.94	2.26	33	67
TDP 11/27/3, 53-56cm	22.15	76.06	1.79	16	84
TDP 11/27/3, 75-78cm	24.23	75.77	0	35.3	64.7
TDP 11/27/3,100-103cm	18.94	81.06	0	18.5	81.5
TDP 11/28/1, 0-3cm	11.11	88.89	0	50	50
TDP 11/28/1, 27-30cm	19.48	78.79	1.73	30	70
TDP 11/28/1, 49-52cm	28.1	67.77	4.13	28.6	71.4

FOP = Planktonic Foraminifera; FOBC = Calcareous Benthic Foraminifera; FOBA = Agglutinated Benthic Foraminifera.

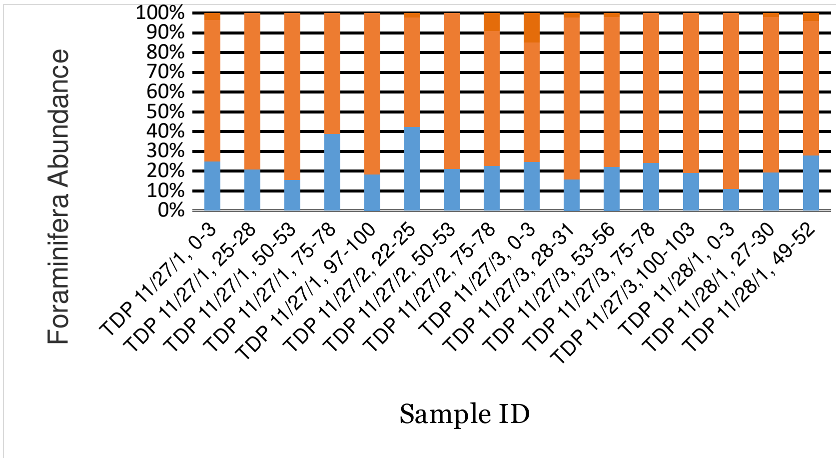

Figure 4: A bar chart showing the foraminifera abundance variation in terms of P:B ratios; green=Agglutinated benthic foraminifera; orange=Calcareous benthic foraminifera; blue=Planktonic foraminifera.

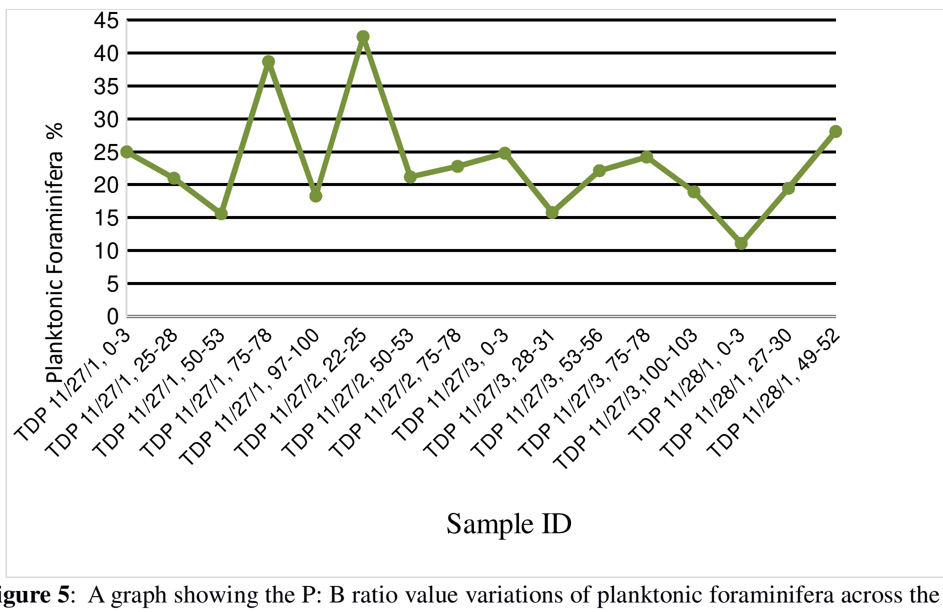

Figure 5: A graph showing the P: B ratio value variations of planktonic foraminifera across the TDP 11 borehole. Samples TDP11/27/1, 0-78 represent the Oligocene time interval while all other samples are Eocene.

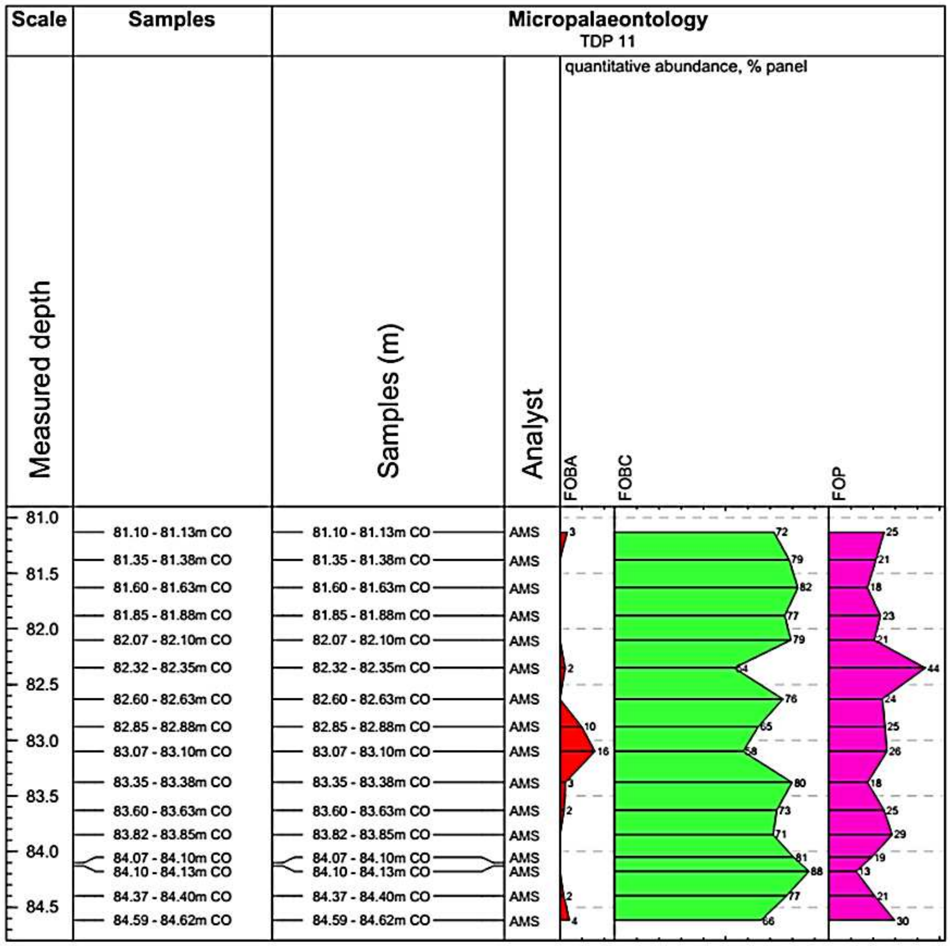

Figure 6: Foraminifera abundance distributions and paleo-depth of TDP 11 borehole.

Outcrop samplesforaminifera assemblages
Outcrop samples yielded about 131 and 172 specimens/g for PAN 01 and PAN 03, respectively, of foraminifera in the two outcrop points from Pande. Samples collected from Namadingura River yielded very low amount with maximum amount of 24 specimens/g from sample NAM 01.The outcrop samples showed high variation of foraminifera abundance, but generally calcareous benthic foraminifera (FOBC) appeared to dominate the sediments with percentage ranges between ca. 55- 80% (see Table 2 and Fig. 6). Agglutinated benthic foraminifera (FOBA) were very low with abundance ranging from 0 – 13% whereas most of their recovery are from Namadingura River samples. Planktonic foraminifera (FOP) also yielded low amount with abundance range between circa. 20-35% with high peak from NAM 05. On the overall, the identified foraminifera types include

Subbotinaangiporoides, *Subbotinaeocaena*, *Subbotinacrosiapertura*, *Subbotinajacksonensia*, *Globigerina officinalissubbotinaPseudohastigerinanaguewchiensis,Chiloguembelinatrinitatensis*, *Tenuitellainsolita*, *Tenuitellapraegemana* and *Pseudohastigerinanagguewichiensis.* Other types were*Turborotaliacerroazulensis*, *Hantekininaalabamensis*, *Cribohantkenina inflate*, *Turborotaliacerroazulensis* and *Globoturborotalita*groups.

Table 2: The absolute abundance of foraminifera computed in each outcrop samples.

SAMPLE ID	FOP	FOBC	FOBA	TOTAL	Specimens /gram	%FOP	%FOBC	%FOBA
PAN 01	36	138	0	174	131	20.7	79.3	0
PAN 02	12	43	0	55	41	21.8	78.2	0
PAN 03	56	166	2	224	172	25	74.1	0.9
NAM 01	6	14	0	20	24	30	70	0
NAM 05	10	18	4	32	15	31.25	56.25	12.5
NAM 09	5	14	1	20	15	25	70	5

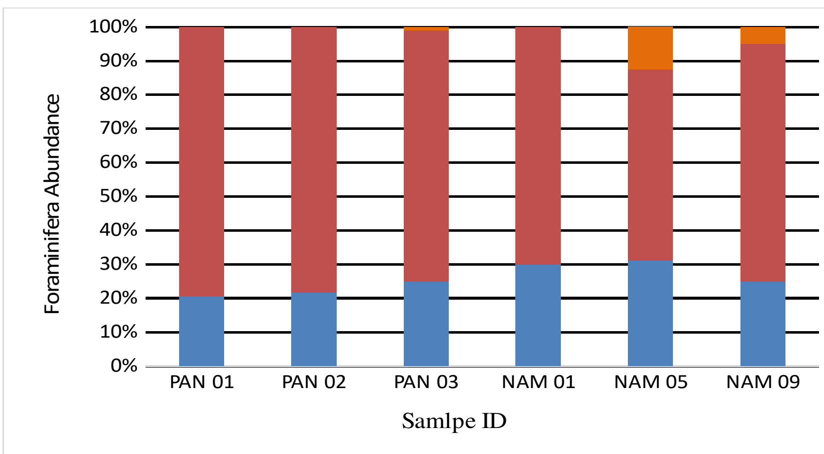

Figure 7: A bar chart showing the foraminifera abundance variation in terms of P:B ratio; green=Agglutinated benthic foraminifera; orange=Calcareous benthic foraminifera; blue=Planktonic foraminifera.

Palynomorph assemblages

Examples of the observed and identified palynomorphs taxa types are shown in Plate 1. The assembled palynological data showed fluctuations in abundance and distribution from sample to sample. Generally, the samples yielded low abundances of palynomorphs (terrestrial and marine) in each analysed single slide from each sample interval. The results showed the highest abundance of 35 specimens/slide at 82.6 m depth (TDP11/27/2, 50-53 cm) whereas the overall abundances ranged between 3-35 specimens per slide for most intervals. The total length of one meter from the top of TDP 11 borehole, which included samples from TDP11/27/1, 0-3 cm (81.1 m) up to TDP11/27/1, 97-100 cm (82.07 m), were found to be dominated by terrestrial palynomorphs (spores and pollens) with the abundance ≥ 50% of the palynomorphs recovered. However, the results showed great variation of terrestrial palynomorphsbetween samples, ranging from 16-75%. Marine palynomorphs (dinoflagellate) dominate approximately 2.5 m of the borehole which is from 82.32 m to 84.62m depth (TDP11/27/2, 22-25 cm - TDP11/28/1, 49-52 cm) with high peak of 84% at 83.6 m depth (TDP11/27/3, 53-56) and lowest abundance was 25 % at 81.1 m depth (TDP11/27/1, 0-3 cm).

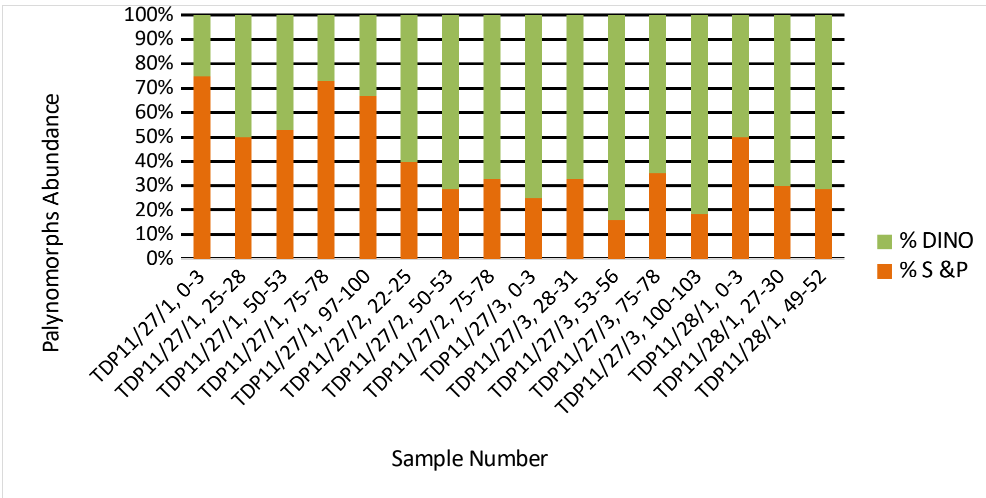

Figure 8: A bar chart showing abundance distribution of dinoflagellate cysts (DINO), spore and pollen (S & P) at different core sample intervals.

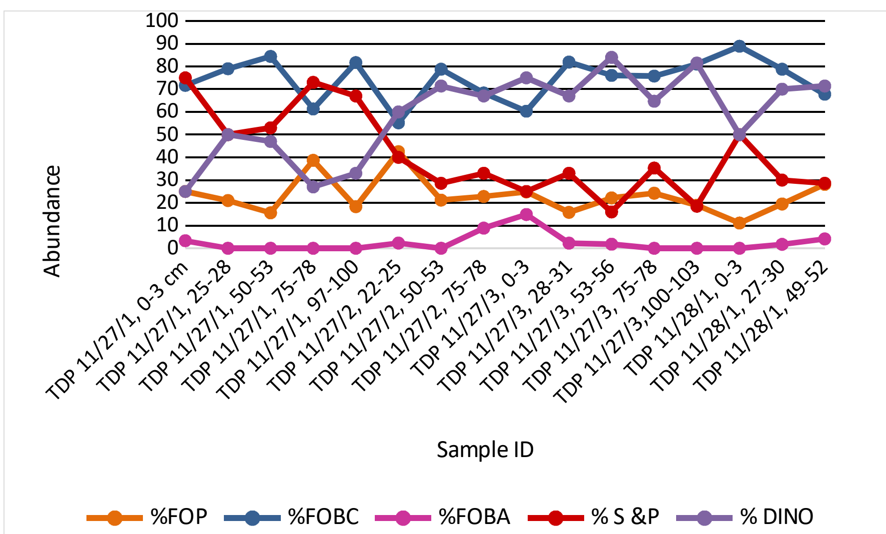

Figure 9: A bar chart showing the abundance distribution of foraminifera and palynomorphs across TDP 11 borehole. FOP-Planktonic foraminifera; FOBC-Calcareous benthic foraminifera; FOBA-Agglutinated benthic foraminifera; DINO-Dinoflagellate.

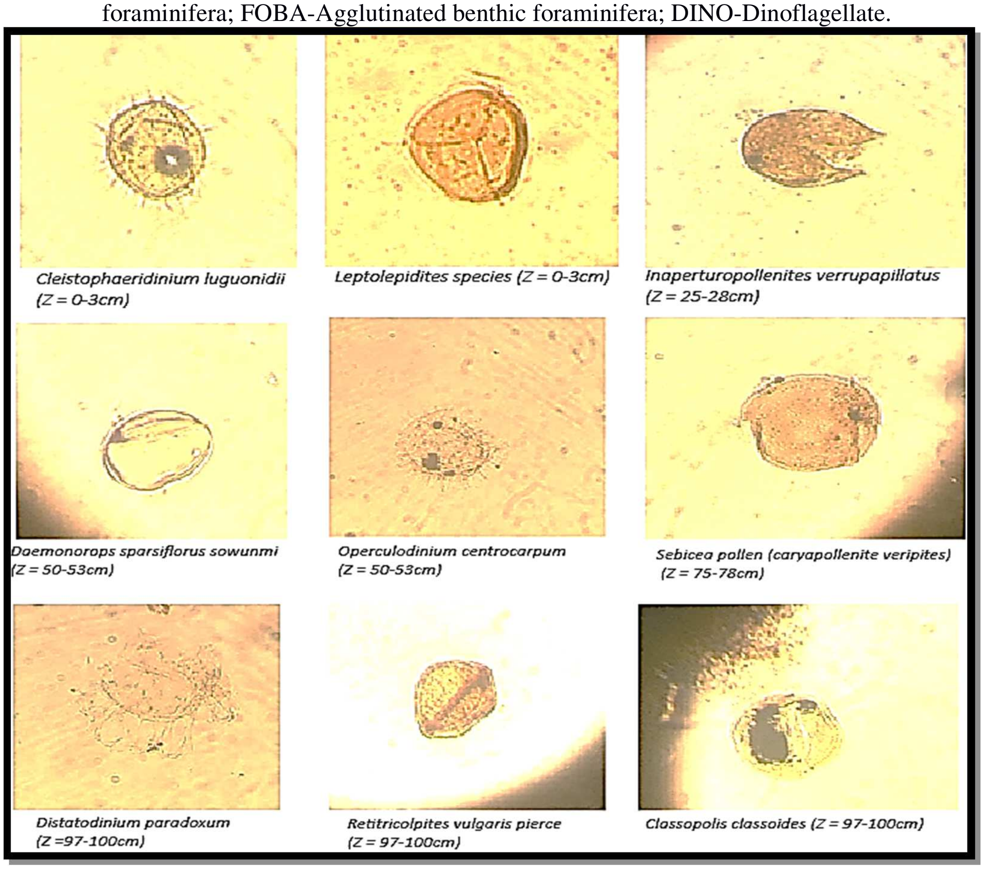

Plate 1: Examples of observed palynomorphs at different sample intervals across the TDP 11 borehole.

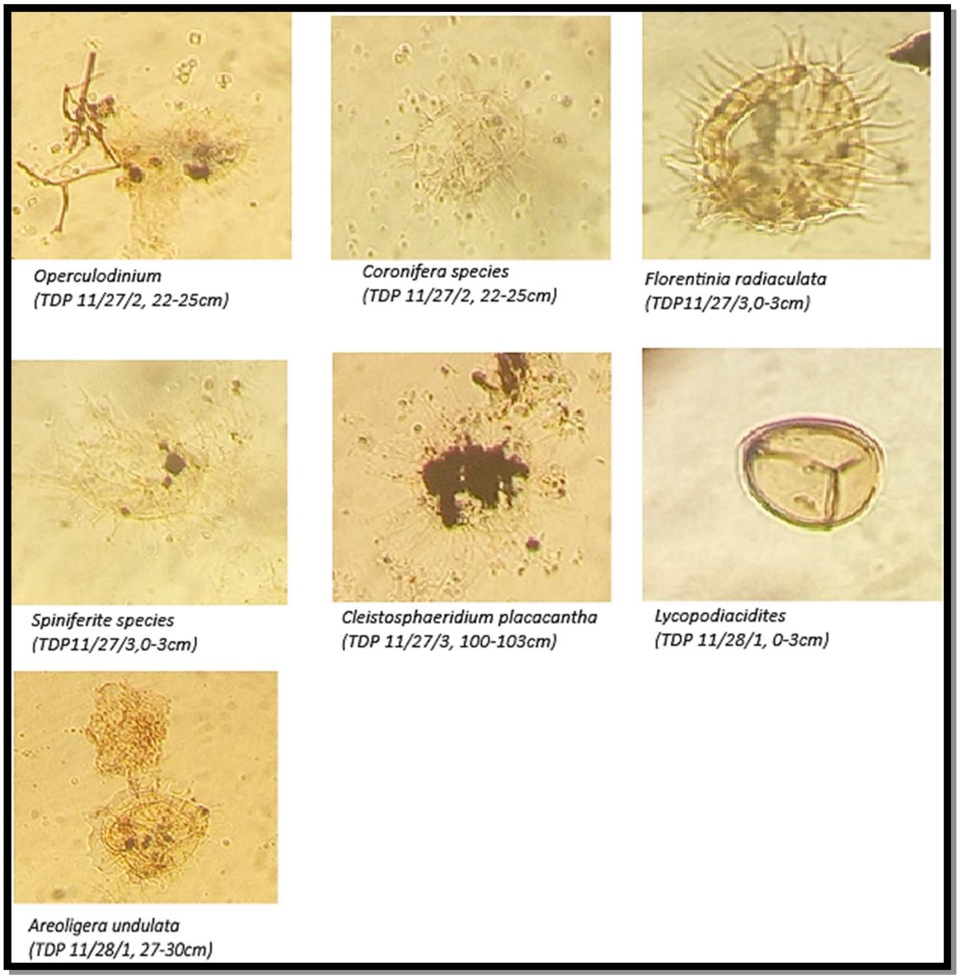

Plate 1(continuing): Examples of observed palynomorphs at different sample intervals across the TDP 11 borehole.

DISCUSSIONS

Foraminifera assemblages

Approaches using foraminifera assemblages have been used with success in elucidating depositional environments of ancient sedimentary basins (Ferrow et al. 2011, Crouch et al. 2003). The premise for such pursuit relies on the type of foraminifera (benthic versus planktonic) recovered from sediment samples. From the results obtained above, it is evident that the most common planktonic foraminifera assemblages in the current study include *Subbotina* species such as *Subbotinaangiporoides, Subbotinaeocaena, Subbotinacrosiapertura*, *Subbotinajacksonensia* and *Globigerina officinalissubbotina.* Marker foraminifera species for each geologic time intervals are those reported in Pearson and Wade (2015). Core samples suggest high diversity of planktonic foraminifera compared to outcrop samples whereas most of the species recovered from outcrop samples were of Oligocene age. Planktonic foraminifera assemblage associated with Early Oligocene Biozone; *Pseudohastigerinanaguewchiensis* - Highest Occurrence Zone (HOZ) or O1; (Berggren and Pearson 2005) such as *Chiloguembelinatrinitatensis, Tenuitellainsolita, Tenuitellapraegemana* and *Pseudohastigerinanagguewichiensis* were recovered from outcrop samples. However, most of planktonic foraminifera assemblages recovered from the borehole are of Late Eocene age and all fall within the global range. Studied sections in various parts show that *Hantkenina* and *Cribohantkenina* extinction was headed by the extinction of *Turborotaliacerroazulensis* group. The planktonic foraminifera assemblage of zone E16 (*Hantekininaalabamensis*, *Cribohantkeninainflata* and *Turborotaliacerroazulensis*) is rich and highly diversified which is different compared to recovered species in TDP 11 borehole which were found to be rare, this discrepancy may point to poor preservation. The last occurrence of *Hantkeninaalabanensis* species which was used to demarcate the Eocene – Oligocene transition boundary occur at 81.85m depth of the TDP 11 borehole. The fact that Early Oligocene marker species such as *Pseudohastigerinanagguewichiensis* were not recovered from our core samples may be attributed to the documented hiatus on the lower most Oligocene or due to poor preservation. The planktonic genera that record high percentages include *Globigerina officinalissubbotina, Globoturborotalita*species,and *Subbotina*species that straddle the age range Late Eocene – Early Oligocene.

On the other hand, benthic foraminifera assemblages dominate both core and outcrop samples; this observation suggests sediments deposition in shallow to relatively deeper water depths of between 25 to 350 meters. Benthic foraminifea taxa appear to be highly dominated by calcareous benthic foraminifera assemblages rather than agglutinated benthic foraminifera assemblage which are limited in the range of ~ 0 - 20%. The notable decrease in abundance and size of benthic foraminifera during Early Oligocene may indicate a decrease in their reproduction rate which could suggest limited food availability. However, the presence of relatively high abundance of triserialbuliminids is interpreted as an indication of high food availability (e.g. Jorissen et al. 2007; Gooday 2003). In general the foraminifera abundance and diversity of the assemblages started to drop in the Late Eocene and reached its lowest just below the Eocene - Oligocene boundary and gradually recovered. This decline of foraminifera diversity is largely associated with the decline in temperature at EOT which caused the extinction of most foraminifera (both planktonic and benthic) species (Bordiga et al. 2015).

Palynomorph assemblages

Inferences on ancient depositional environments can be obtained from studies of pollen and spores of terrestrial and aquatic vascular plants, preserved in corresponding sedimentary sequences (see Medeanic 2006). The palynological data obtained in our study indicate that the younger sedimentary successions were dominated by terrestrial palynomorphs assemblage. However, there was a small percent of dinocysts that were observed at these successions. The common terrestrial palynomorphs species observed include; *Classopolisclassoides*, *Inaperturopollenitesdubius* and *Daemonoropssparsiflorussowun*.Marine palynomorphs assemblage appears to be more common and diversified in the Late Eocene sedimentary succession than in Early Oligocene which occurs at deeper depth > 82.1 m interval of the borehole. Although few in proportions, the most common dinoflagellates species that were found in the older sedimentary succession were *Cleistosphaeridiumplacacantha, Cleistosphaeridiumaustrate, Operculodiniumf loridium*, *Spiniferite*, *Florentinia* spp. and *Impletosphaeridiuminsolitum*. The high percentage of marine palynomorphs in the older sedimentary succession samples indicate that sea levels were probably higher during the Late Eocene compared to Early Oligocene period.

Paleoenvironmental settings

Foraminifera inhabit different kinds of environments thus allowing micropaleontologists to reconstruct paleoenvironmental settings of ancient sediments (Culver 1987). Planktonic species float in the upper surface of the ocean waters while benthic species dwell on the sea bed or just below the sediment surface (BouDagher-Fade 2013). Various factors such as temperature, light intensity, prey or nutrient availability and others tend to control the distribution and abundance of foraminifera species, therefore this can be used as a proxy for the re-establishment of paleoenvironments(BouDagher-Fade 2013). However, benthic foraminifera assemblages are known to respond rapidly to environmental changes, also are widely distributed and more abundant on the sea floor and therefore they can be used for paleoenvironmental reconstruction (Li et al. 1999; Friedrich and Hemleben 2007; Sliter and Baker 1972). The planktonic/benthic ratios (P:B ratios) have been applied in a number of studies to infer depth of deposition whereby higher ratios of planktonic indicate deep marine environments and vice versa (see Murray 1991**).**

Most of benthic foraminifera recovered in both core and outcrop samples which occur in relatively high abundances are of inner to outer neritic marine environments. These taxa are *Quinqueloculina* spp. *Eponides* spp. *Lenticulina*spp. *Cibicidoides*spp.*Bovilina* spp. and triserialBuliminids. These species tend to inhabit different environments of deposition from inner to outer shelf environments.

The P:B ratio values of TDP 11 borehole fluctuate from sample to sample suggest sporadic sea level variations. These values range between 10 and 45% (in abundance proportions) while outcrop samples yielded a range between 20% and 35%. Murray (1991) and Pflum and Frerichs (1976) contend that P:B ratios of inner shelf environments are characterized by values of P<20% planktonic tests whereas those for middle shelf straddle between 20-50%. Thus, results obtained from TDP 11 samples suggest shallow marine environments (inner to middle shelf). This observation indicates that sea level during Late-Eocene- Early Oligocene time intervals was almost steady and thus the abundances of foraminifera were not highly impacted.

On the other hand, dinoflagellates live in various types of aquatic environments, including lakes, estuaries, epicontinental seas and oceans, from equatorial to polar settings (Taylor et al. 2008). However, most dinoflagellate species live in marine waters whereas only a few species are known to live in fresh waters. In marine environments, dinoflagellates show high species diversity together with high variability in morphology and adaptation to a wide range of environments (Smayda and Reynolds 2003). In the current study, the palynological data show high abundance of marine palynomorphs from bottom up to 82.1 m depth which covers the older sedimentary succession of TDP 11 borehole. High abundance of marine palynomorphs relatively to terrestrial may suggest that the sediments were deposited in distal environments away from land (see Fig. 10). However, marine palynomorphs (dinoflagellates) abundance drops to its minimum at E-O boundary were it reached 27% of the specimens recovered. Terrestrial palynomorphs abundance increase into the younger sedimentary succession which can indicate drop of sea level on earliest Oligocene and therefore increase the fluvial and/or land input into marginal marine environment. Sea level fluctuations across E-O transition in other studies have been reconstructed based on the change in composition of dinocyst assemblage (BouDagher-Fade 2013; Brinkhuis 1994). The palynological data show assemblage changes from marine palynomorphs to more terrestrial palynomorphs from oldest to youngest sedimentary successions, respectively. This change may imply disappearance of older marine taxa and reappearance of new taxa possibly due to the change of climatic conditions at the EOT that has been envisaged to be associated with a global cooling event which resulted from sea level fall (Gedl and Leszczyñski 2005). The TDP 11 core samples have high abundance of outer neritic taxa, an observation compatible with the deposition of the sediments during transgression process. Also the increase in abundance of terrestrial palynomorphs assemblages may indicate a regressive period. The presence of terrestrial influx together with deep marine palynomorphs suggests the existence of high energy water runoff and/ or wind, depositing these terrestrial palynomorphs into deep water environments. Also, it may suggest that the sediments were deposited in an area with a short shoreline where there is high level of water depth near shore (Biffi and Grignani 1983; Dupont and Wyputta 2003; de Vernal and Giroux 1991).

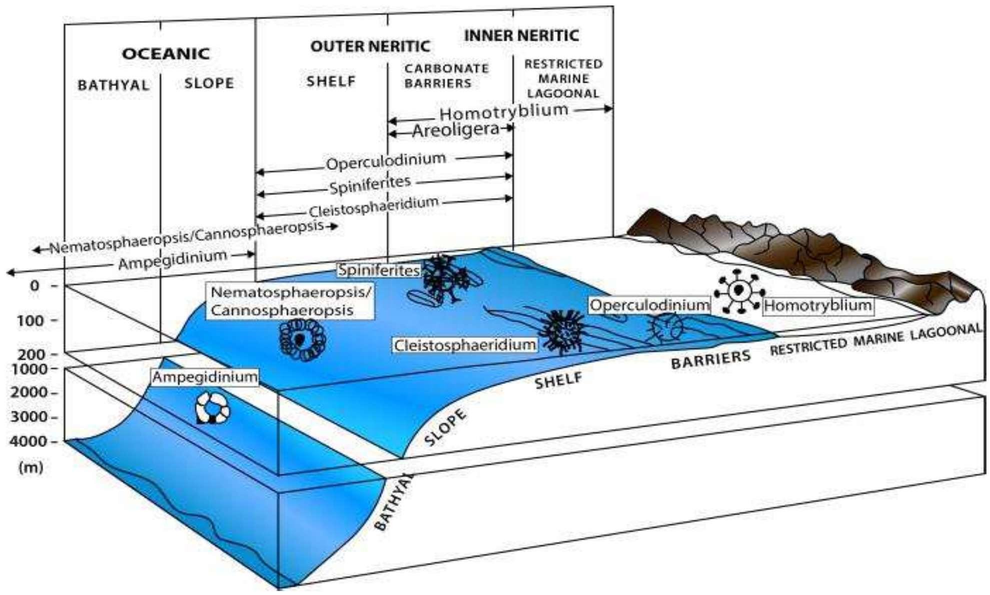

Figure 10: Trends in bathymetry and global palynomorphs content of sediments from the shelf to the abyssal plain. Palynomorph types obtained in our study are also indicated in the diagram (modified after Haq and Boersma 1998).

CONCLUSIONS

Micropaleontological results obtained from the current study reveal the followings:-

1. Planktonic foraminifera abundance and diversity appear to be low during the Late Eocene compared to benthic foraminifera and kept decreasing across the EOT to the Early Oligocene. This low diversity and abundance of planktonic foraminifera was associated with sea level decrease which is attributable to the regional global cooling event during the EOT.
2. Marine palynomorphs responded rapidly to environmental changes as their abundances and diversity dropped across the EOT and reached minima during the Early Oligocene.
3. The P:B ratio data together with the foraminifera and palynomorphs assemblages suggest that the Eocene – Oligocene boundary paleoenvironment settings was generally shallow marine of inner to outer shelf environment.

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