Mid-Cretaceous Stratigraphy and Micropalaeontology of the Coastal Basins of Tanzania

Amina Karega Mweneinda

A thesis presented for the degree of Doctor of Philosophy

Cardiff University, 2014

School of Earth and Ocean Sciences

Cardiff University

Main Building, Park Place

Cardiff CF10 3AT

United Kingdom

TABLE OF CONTENTS

Chapter 2 Materials and Methods 41

Abstract

The aim of this study was to develop a stratigraphic framework for the 'mid-Cretaceous' (Aptian-Cenomanian) strata of the Tanzanian coastal basins and, in particular, attempt to identify and recover the Aptian/Albian boundary (the interval of 'Oceanic Anoxic Event' 1b) for detailed investigation. Six pre-existing industry boreholes were selected for detailed micropalaeontological study (planktonic and benthic foraminifera) using modern taxonomic and biostratigraphic concepts. These sites are arranged approximately along strike from one another, and their stratigraphy and palaeoenvironmental histories are established. Information from these boreholes and many additional surface outcrop samples was used to select a location for two new boreholes which were expected to penetrate through the Aptian/Albian boundary (Tanzania Drilling Project [TDP] Holes 40A and 40B).

In total, twelve planktonic foraminiferal biozones and two subzones of the upper Aptian - upper Cenomanian from the coastal basin of Tanzania are illustrated and described for the first time. Intra- and inter-basinal correlations are achieved using a combination of lithostratigraphy, biostratigraphy and carbon isotope stratigraphy. The planktonic and benthic foraminiferal assemblages are found to be similar to those reported from the Atlantic and Europe, and hence can be correlated to global records. An assessment of relative sea level change is achieved through benthic foraminiferal biofacies and planktonic: benthic ratios.

Biostratigraphy of TDP Holes 40A and 40B was developed from the foraminiferal assemblages. A tentative correlation of the carbon isotope stratigraphy is made to the isotope records from Ocean Drilling Program Site 1049 in the subtropical Western North Atlantic and Vocontian Basin, southeast France. These investigations show that lowermost part of the Albian is missing in TDP Holes 40A and 40B which may explain why no organic carbon-rich shales relating to Oceanic Anoxic Event 1b were encountered. More expanded and organic rich successions may exist in the northern part of Tanzania and offshore where the succession thickens.

Aknowledgements

I would like to express my sincere gratitude to my principal supervisor Prof. Paul Pearson and the co-supervisor Dr. Helen Coxall for their tireless and endless time they took to support me during my Fieldwork, Laboratory work and during the writing process of this work. I sincerely thank you for your advice, fruitful discussions sound remarks and thoughtful suggestions that made my work to have the present form. You were so supportive and your advice is highly appreciated.

I would like to thank the Director of Earth Postgraduate Studies, Prof. Ian Hall, who agreed to extend my writing period by six months and provided scientific and administrative assistance for me to complete this research.

I would like to thank the Cardiff University Technical Personnel for their helpful laboratory assistance. Special thanks are due to Mr. Pete Fisher who taught me how to use the SEM and make good SEM images of my foraminifera specimens. I would also like to thank Mr. Alun Rogers for graphics advice and to Mr. Andrew Wiltshire whose door was always open to help whenever I had problem with my PC especially in terms of software installation.

I am grateful to Dr. Stuart Robinson who had taught me how to process and analyze samples for geochemical and isotope data using University College London Chemistry laboratory facilities and for making my analysis easy and manageable throughout my period in London.

I am sincerely grateful to my employer; The Tanzania Petroleum Development Corporation for the financial support throughout the four years of my studies. My thanks are due to the TPDC Management especially the Managing Director (Mr. Yona Killagane) and the Director of Exploration and Technical Services (Mr. Halfani R. Halfani). I am also grateful to TPDC Chief Accountant and Accounts Section Staff who always make sure that I received my stipend on time. My thanks also go to TPDC drivers for their support. They were there for me whenever I needed to move from one place to another. Your support is highly recognized.

I would also like to thank TPDC staff who contributed in one way or another in my research. I am grateful to Dr. J. M. Singano, Mr. Elias Kilembe, Dr. Meshack Kagya, Dr. Wellington Hudson and Dr. Emma Msaky for their moral support throughout the period of my studies.

I am grateful to my family who morally supported me and missed my company for the whole period of my studies especially my Late mother, Bi Kijoli Pazi Katundu (May her soul rest in peace, Amen), my two beautiful daughters, Latifa and Nasra, and my husband, Mr. Abdallah Bakari. They were always there for me whenever I needed their assistance. I would also like to thank all the Tanzania Drilling Project Team members for organizing the fieldwork and helping in drilling the boreholes for my research. In particular, I wish to thank Dr. Alvaro Jiménez Berrocoso who was very helpful in the field and who taught me how to use the Psicat program/software.

Preface

I am employed as a Biostratigrapher by the Tanzanian Petroleum Development Corporation (TPDC), the sponsor of the present project. My PhD research is the result of working with a team of scientific researchers from Cardiff University, Trinity College, Ireland, Smithsonian Museum, USA, and University College London in my home Country (Tanzania), within the Tanzanian Drilling Project (TDP). The TPDC are the Tanzanian-based collaborators within this project. The aim of the TDP was to drill and recover hemiplegic sediment samples containing high quality microfossils for use in geochemical proxy reconstructions of Cretaceous and early Cenozoic climates. I joined the TDP in 1999 and my role was initially to help with core and biostratigraphy analysis but later I direct drilling at one site. In order to gain more knowledge in my field, the TPDC decided to fund this PhD project with the aim of expanding our understanding of the Tanzanian mid-Cretaceous stratigraphy and hydrocarbon potential. As part of the TDP and this project, I participated in two drilling seasons i.e. 2008 and 2009, during TDP Site 40 which provides much of the materials used in this research. I am so privileged to have working with two supervisors at Cardiff University (Prof. Paul Pearson and Dr. Helen Coxall) during my field work.

During that time, my role was to select and supervise all the drilling for TDP Site 40 that involved overseeing the core description, sampling, collection of core data from daily drilling reports and logging cores using stratigraphic software. The activities were planned by the TDP team for the purpose of broaden my knowledge and expand my research topic that include stable isotope and chemostratigraphy using the TDP Site 40 material. The scouting survey was done in July 2009 in Kilwa area close to Mkondaji village and selected the location for the TDP Site 40 (see fig. 1.4). The drilling of TDP Site 40 was due in August, 2009 and went well with almost 90% recovery; thirty-three cores were recovered in TDP Site 40A, and twenty-six in TDP Site 40B. TDP Site 40 (A and B Holes) materials are part of this thesis.

Thesis overview

This thesis is divided into six chapters, that comprises the main text body and appendices (I-III) attached at the last page cover of this thesis.

Chapter 1: In the introduction chapter the following were discussed: The placement of the global stratotype Aptian /Albian stage boundary in various sections of the world (e.g. Italy, Germany) using ammonites, ostracods, foraminifera, nannofossils, and carbon, oxygen and strontium isotopes. Ammonite species are commonly used to demarcate Cretaceous stage boundaries but because they are not globally distributed it was not possible to place this boundary using ammonite species. It was suggested that the boundary can be located properly by using calcareous nannofossil *Prediscosphaera columnata* its first occurrence (FO) in the early Albian (Nannofossil zone NC8A) to the first occurrence (FO) of *Ticinella primula* (Nannofossil zone NC8B) and *Paraticinella eubejaouaensis* its highest occurrence (HO) in the uppermost Aptian (Herrle and others, 2004; Huber and Leckie, 2011) together with Carbon isotope ($\delta^{13}C$) values.

Stratigraphy, previous biostratigraphy of the coastal basin of Tanzania is also discussed in detail including basin geology, paleogeography and the evolution of Tanzanian coastal basin. This covered part of the Ruvu, Mandawa and Rufiji and Dar es Salaam basins (see fig. 1.4b (Kidston and others, 1997). Early to mid-Cretaceous climate studies undertaken in the region; a brief discussion on the palaeoclimate data obtained in part of the Oceanic Anoxic Event 2 (OAE2; Jimenez Berrocoso and others, 2010) and Eocene /Oligocene (Lear and others, 2008). Paleogeography of the early to mid-Cretaceous of Tanzania is discussed including a paleogeography map of 112 Ma (fig. 1.1c), mid-Cretaceous climates, a general discussion on the origin, occurrence and importance Oceanic Anoxic events (OAEs; fig. 1.1 and fig. 1.3) and evolution of planktonic and benthic foraminifera.

Chapter 2: The chapter presents the Materials and Methods used in acquiring data for this research, including location maps and co-ordinates for these boreholes and outcrops. (see figs. 2.1-2.2). Standard micropalaentological procedures for sample preparation for the foraminifera, 713 samples were prepared and investigated for early and mid-Cretaceous planktonic and benthic foraminifera. Also procedures on the coating, SEM photographic and plates preparation are discussed in this part. Ninety two (92) samples were also processed and bulk isotope data were acquired. All the procedures for logging samples and the scientific presentation form of data and logs are also shown including the procedures for acquiring isotope data.

Chapter 3: In this chapter systematic description of stratigraphically important planktonic and few benthic foraminifera are discussed in detail especially index planktonic foraminifera for the Aptian-Cenomanian interval. The taxonomy of planktonic foraminifera based on the following published literatures including Postuma (1971), Caron (1985), Loeblich and Tappan (1987), Robasyznski and Caron (1995), BouDagher-Fadel and others (1997), Coxall and others (2000), Premoli Silva and Sliter (2002), Premoli Silva and Verga (2004), Caron and Spezzaferri (2006), Petrizzo and Huber (2006), Caron and Premoli Silva (2007), Gonzalez-Donoso and others (2007), Lipson-Benitah (2008), Premoli Silva and others (2009), Georgescue and Huber (2009), Huber and Leckie (2011), Petrizzo and others (2012).

Plates of foraminifera species encountered during the project are described and illustrated in plate 3.1 to plate 3.25. Samples, residues and microfossils slides are housed at the Tanzania Petroleum Development Corporation's Core Storage in Dar es Salaam, Tanzania. Benthic foraminifera taxonomy was described based on Scheibnerova (1972; 1978), Haynes (1981), Jenkins and Murray (1981), Loeblich and Tappan (1987), Bolli and others (1994), Holborn and Kaminski (1995; 1997), Kaminski, and others (1992) and Macmillan(2003).

Chapter 4: This chapter presents outcrop and boreholes lithostratigraphy, and biostratigraphy and discussed on the Aptian-Cenomanian studied section. Using planktonic foraminifera index marker species age and biostratigraphic Biozones are identified and discussed thoroughly. Planktonic and benthic foraminifera are illustrated in tables (range charts 4.1-5.2 and P/B ratio curves) including discussion on the abundance, correlation and preservations and sea level change using planktonic: benthic ratios.

Chapter 5: This chapter was intended to present a study on the Aptian /Albian boundary interval at TDP Site 40B and the OAE1b compared to world wide data of the similar interval. Unfortunately, the boundary could not be demarcated in the two boreholes and neither the presence of the OAE1b. Discussions on the presence of the *Paraticinella eubejaouaensis* zone and correlated to the Carbon Isotopic stage is done including foraminifera assemblages and illustrated in plates. Also, results of % TOC, % CaCO3 data, $\delta^{13}C$ data and TOC/TN versus $\delta^{13}C$, TIC/TN versus $\delta^{13}C$ data obtained from the TDP40 site B. The findings are discussed in detail in the same chapter.

Chapter 6: This chapter presents the summary and concluding remarks of the research findings References are listed in the last chapter of this thesis.

Appendix I, present the PSICAT TDP40 user guide for logging core information, and lithology and creating stratigraphic logs of the TDP40 Holes A and B. Appendix II; SEM analysis and micropalaentological plate preparations while Appendix III contains Geochemical analysis, instruments as well as method.

Chapter 1 Introduction

1.1 Background

Outcrops of Cretaceous and Palaeogene marine sediments are exposed along the Tanzanian coastal region south of Dar-es-Salaam (Haughton (Ed.) 1938); Kent and others (1971), Pearson and others (2001; 2004), Jimenez Berrocoso and others (2010). They comprise of clays and claystones, intercalated with siliciclastic turbidites. In some areas, thick sand bodies and reefal limestone occur, particularly in the early Cretaceous and Palaeogene sequences (see Kent and others, 1971). The Tanzanian coastal region came into the global picture in 1950's and 60's after the publications of Blow and Banner (1962) of the detailed Micropaleontological and biostratigraphy work in the region. It was during this time when British Petroleum's (BP) was exploring for the hydrocarbon potential in Tanzania. Blow (1979) demonstrated well preserved planktonic foraminifera recovered in Lindi area and the planktonic foraminifera specimens were deposited in the Micropaleontological collections of the British Museum, London. Prof. Paul Pearson, at Bristol University, found this material in the mid 1990's and was impressed by the exquisite preservation and thought that the specimens could be useful for studies on palaeoclimatic and geochemical records. He organized the Tanzania Drilling Project (TDP) with several British and American institutions, as well as the Tanzania Petroleum Development Corporation (TPDC) (the funders of this research) to drill shallow boreholes in the region using land-based drilling rig. The TDP drilled a total of 40 sites between 2002-2009 penetrating the Palaeogene and Cretaceous succession in Tanzania. These have provided crucial geochemical and biotic records of climate change from the early Cenozoic and late Cretaceous time (e.g., Lear and others, 2008).

The sedimentary record in Tanzania also has great potential for producing new information about climate change in the 'mid-Cretaceous' (a term used informally here for the interval from about 120 Ma to 90 Ma, comprising the Barremian through Turonian stage). New sedimentary records have been recovered by the TDP, which currently includes partners in Cardiff University, the US National Museum, and the TPDC. Many of these sediments also contain extremely well-preserved microfossils and organic biomarkers that are useful for geochemical proxy climate reconstructions. The aim of this project is to improve the stratigraphic framework of the mid-Cretaceous using planktonic and benthic foraminiferal biostratigraphy and to generate palaeoclimate and environmental records using geochemical approaches. Study materials include cores obtained by the TDP in addition to previously available well and outcrop material from the industry. An improved stratigraphic framework will also benefit hydrocarbon exploration and the identification of possible source and reservoir rocks in the Cretaceous of Tanzania thereby contributing to wealth creation in Tanzania.

1.1.1 Mid-Cretaceous Oceans and Climate

The mid-Cretaceous period spanning~120 to 90 Ma (Gradstein and others, 1995) was categorized to possess high atmospheric carbon dioxide, absence of polar ice caps, high sea level (Haq and others, 1988), low latitudinal temperature gradients (Huber and others, 1995) and higher global temperatures (Barron and others, 1995) than the present day (see figures 1.1 and 1.1b). There were considerable changes in the plate tectonic rearrangement and paleoceanographic settings such as a change in paleogeographic position of the continents and circulation pattern of the oceans (Barron and others, 1995) see figure 1.1c. During this time two large continents namely Eurasia (northern hemisphere) and Gondwana (southern hemisphere) existed. The two continents were separated by the large Tethys Ocean which includes the modern Indian Ocean that was connected to a large Pacific Ocean. Rifting began in the late Jurassic, splitting Gondwana during the early Cretaceous into African and South American components. The result was the formation of Atlantic basin and continued widening even today, creating north-south system of basins (Kennedy & Cooper, 1975) fig. 1.1c. In the early Cretaceous (Aptian /Albian boundary interval) sea level were lower than the late Albian and reached its peak in the early Turonian (Haq and others, 1987; 1988). During the Cretaceous period transgression took place and overflowing shelf areas (Haq and others, 1988). The transgression was experienced in the early Cretaceous and a break in the mid Aptian and earliest Albian sea level fall and from the late Albian sea level rise and overflowing shelf area. The harsh climatic and oceanic conditions activated the formation of the regional to global black shales (Schlanger & others (1976), Arthur & Premoli Silva (1982).

It was reported that marine fossil and geochemical proxy data reveals the Cretaceous “greenhouse” climates were not very similar but have some differences throughout the

Cretaceous period (e.g. Huber and others, 2002; Herrle and others, 2003b; Tiraboschi and others, 2009). From the Aptian, increased ocean crust production, and volcanic activity contributing to high atmospheric CO_2 is thought to have caused greenhouse global warming that emaciated in the early Turonian but continued through the early Campanian (Leckie and others, 2002) (see figs. 1.1 and 1.1b).

This research provides new biotic and geochemical records obtained from part of the East African continental margin, on the western margin of the southern Tethys Ocean, providing a view of climatic biotic responses through the mid Cretaceous, with particular focus on the part of the late Aptian to early Albian which is represented in the sequences studied here.

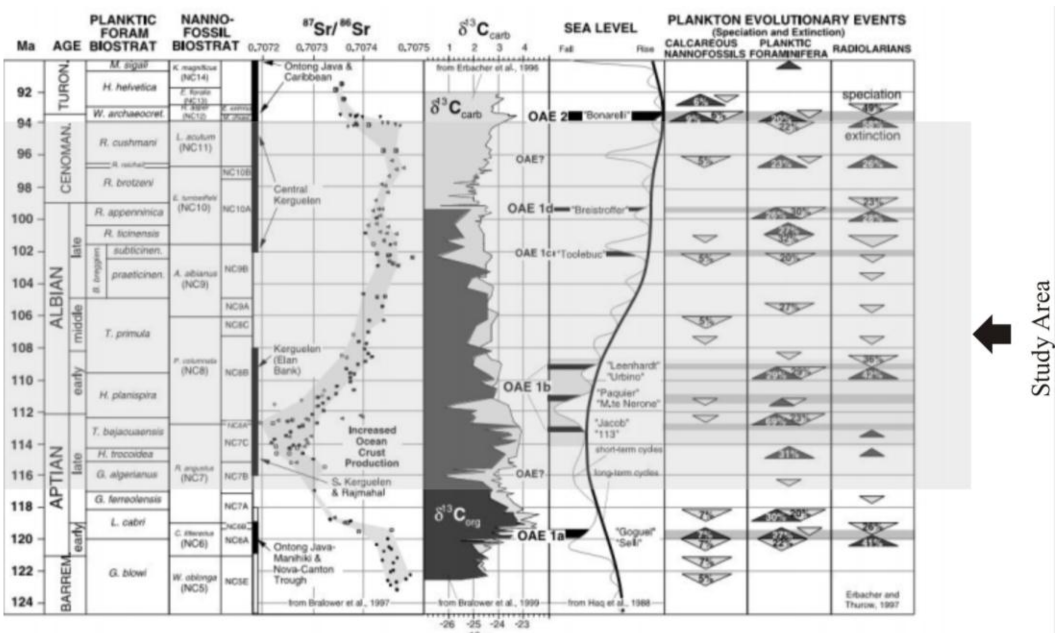


Figure 1.1: Mid-Cretaceous climates, major geochemical and tectonics (Bralower and others, 1997; 1999), sea level change (Haq and others, 1988 and oceanic anoxic events; modified after Leckie and others, 2002) and plankton evolutionary turnover events and percentages of species (speciation; first appearance) and extinction (Erbacher and Thurow, 1997).

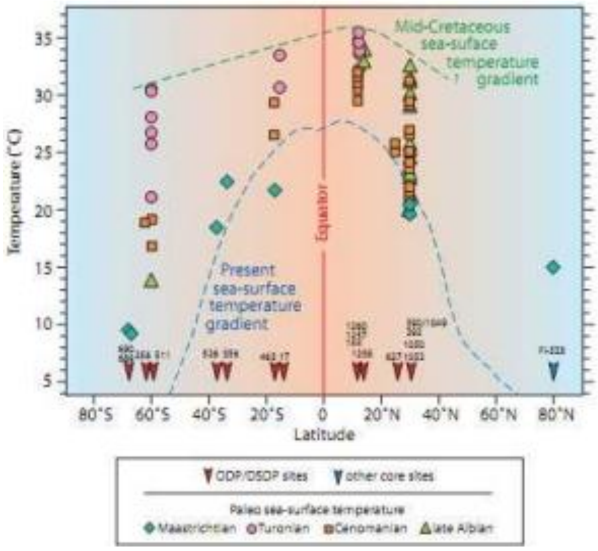


Figure 1.1b: Diagram showing latitudinal variations of surface ocean paleotemperatures derived from oxygen isotopes of planktonic foraminifera and TEX_{86} (after Takashima and others, 2006 and reference therein).

1.1.2 The latest Aptian to early Albian

The latest Aptian to early Albian is important because it is associated with a period of sea level fall (Haq and others, 1988), and major reorganization of marine planktonic organism and deposition of several organic carbon rich black shales beds of Oceanic Anoxic Event1b (OAE1b) (see Leckie and others, 2002). The black shale consists of a positive excursion in carbon inorganic (C_{inorg}) and organic carbon (C_{org}) stable isotopes ($\delta^{13}C$; Arthur and others, 1985; Leckie and others, 2002; fig. 1.1). The uppermost Aptian 'Jacob' event was a result of excessive land derived organic matter (detritus FED OAE or "DOAE") Erbacher and others (1998) whereas the lower Albian OAE 1b; 'Paquier' and 'Leenhardt' events were derived from high marine organic matter during sea level rise ("POAEs", or "thin black shales beds" (Leckie and others, 2002). The organic matter and its nutrients were deposited due to reduced dissolved oxygen concentrations of warm deep waters. This may probably lead to positive shift in $\delta^{13}C$ (Arthur and others, 1985).

The upper Aptian event is also associated with a pronounced negative $\delta^{13}C$ excursion due to the introduction of isotopically light carbon into the ocean atmosphere system from the dissociation of gas hydrates (Jahren and others, 2001; Luciani and others, 2004).

The carbon-isotope excursions, both positive and negative, are found in deep marine, platform and non-marine facies, they allowed correlation of sediments deposited in the oceans and on the continents (Scholle & Arthur, 1980; Stoll & Schrag, 2000; Nederbragt and others, 2001; Herrle and others, 2003). Therefore, an integration of palaeoclimatic data of the continental shelves and deep sea can produce a global view of climate change during critical events (e.g. Oceanic Anoxic Events; OAEs) in the Earth history (Leckie and others, 2002).

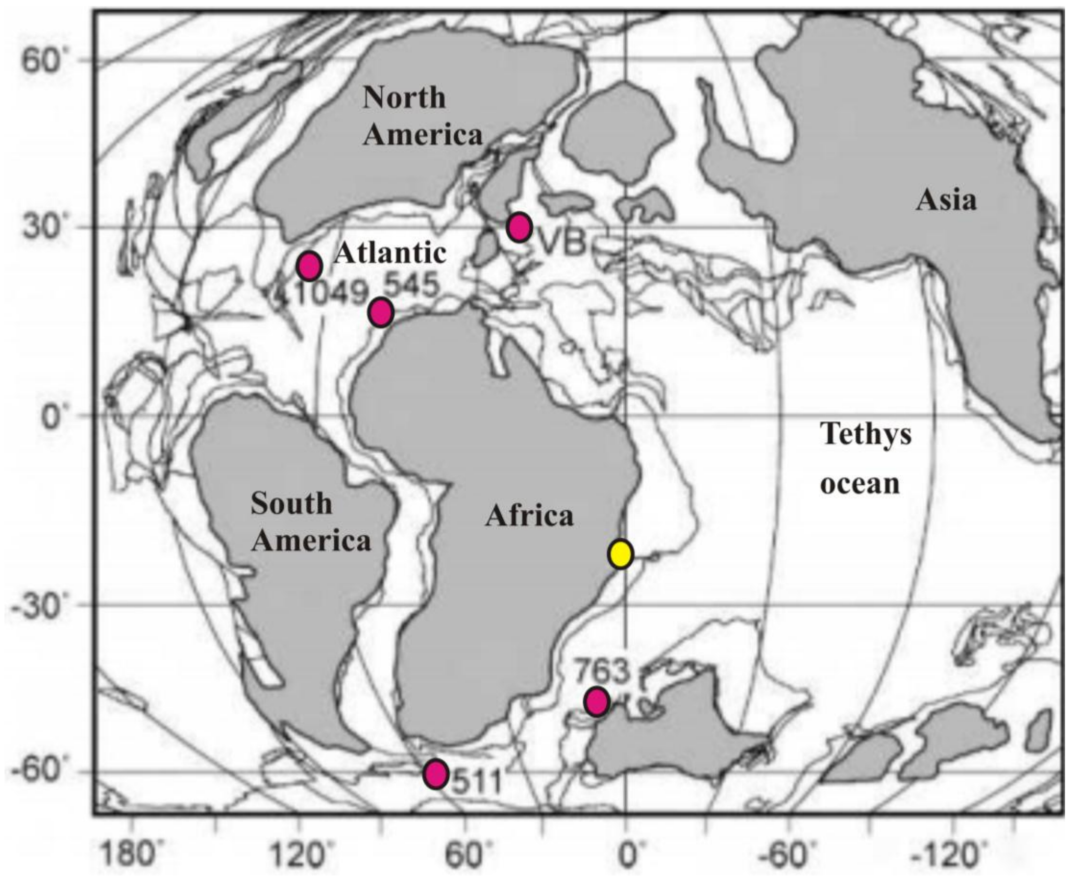


Figure 1.1c: Paleogeographic map of position of continents during 112 Ma showing location of important Global Stratotype Section points for the Aptian/Albian Boundary in Ocean Drilling Program (ODP) Site 1049 and DSDP Site 545 and Vocontian Basin (VB) Pre-Guittard section and Tanzania. Yellow circle indicate study area, and pink circles represent ODP and DSDP Sites. (Paleogeographic map reconstructed from the ODSN website: http://www.odsn.de/odsn/services/palaeomap/palaeomap.html).

1.2 Plankton Evolution

Planktonic foraminifera existed since the middle Jurassic (Bajocian) with initial stage half benthic and later stage as total planktonic (meroplanktonic mode of life; BouDagher-Fadel and others, 1997). The changes in the ocean climate system were linked to the changes in marine plankton evolution, especially planktonic foraminifera. The evolution of planktonic foraminifera in the mid-Cretaceous period is divided into three phases (Premoli Silva and Sliter, 1999; see fig. 1.2).

The first diversification took place in the early Valanginian to late Aptian covering some 22 m.y. The above radiation did not interrupt planktonic forms close to the Livello Selli (OAE 1a (Premoli Silva & Sliter, 1999). The low diversity and abundance of planktonic species was experienced at the Aptian/ Albian boundary interval, signifying a period of stasis and/ or carbonate dissolution (Premoli Silva & Sliter, 1999). However, near the Aptian /Albian boundary planktonic foraminifera abundance and diversity is high (Premoli Silva & Sliter, 1999). The Cretaceous second phase of radiation extended from the early Albian to late Albian, planktonic species abundances, and diversity increase but in half of the time and lasted for 12 m.y (Premoli Silva & Sliter, 1999; see fig. 1.2). The third phase continued up to the end of the Cretaceous period and was different from the first two phases. It was characterized by alternation of shorter periods of fast diversification and longer periods of stasis (Premoli-Silva & Sliter, 1999) (see fig. 1.2).

The short life time and fast evolution of planktonic foraminifera make them useful time marker control tool in the Cretaceous period. Periods of high diversity and abundance such as upper Albian, a wide range of biostratigraphical events can be differentiated, permitting correlation of strata and zones. However, problems do arise during the stasis period in the Aptian /Albian intervals characterized by low diversity of planktonic foraminifera and severe dissolution with no foraminifera present resulting in difficulties to robustly identify the Aptian /Albian boundary using planktonic foraminifera (Premoli-Silva &Sliter, 1999) (fig. 1.2).

There was an increase in planktonic foraminifera species richness, abundance, diversity and changes in morphologies in the Cretaceous. During the Jurassic to Albian planktonic, foraminifera were primitive, small and globular forms (morphotypes) shape (r-selected; Caron & Homewood, 1983) most probably living in the surface waters (Hart & Bailey, 1979; Hart, 1999; Premoli Silva & Sliter, 1999). The complicated morphotypes appeared in the late Albian (k-selected) with complex umbilical structures and the development of keel (Wonders, 1980; Caron & Homewood, 1983) living in deeper water (Hart & Bailey, 1979; Leckie, 1987; Hart, 1999).

Huber and Leckie (2011) investigated on the exquisite preserved late Aptian - early Albian foraminifera from subtropical North Atlantic (ODP Site 1049) and South Atlantic (DSDP Site 511). Their data provide indication for an ~80% extinction of planktonic foraminifera at exactly where the major shifts in oxygen, carbon, and strontium isotopic ratios are observed. The total extinction of the heavily ornamented large species of hedbergellids and ticinellids that dominated during the late Aptian. The two species that survived the extinction is *Microhedbergella rischi* and *Microhedbergella miniglobularis*, both were small and weakly calcified. These species gave rise to numerous Albian species which slowly increased in shell size and complex ornamentation.(Huber and Leckie, 2011). The exquisite preservation of microfossil at Site 1049 permit highly consistent and detailed oxygen and carbon isotopic records spanning from about 3 m.y. below and 2 m.y. above the Aptian/ Albian boundary level (Huber & Leckie, 2011). Therefore, the foraminiferal species turnover and geochemical shifts were suggested to be considered as marker events for defining the Global Stratotype Section Point (GSSP) at the base of the Albian stage (Herrle and others, 2004).

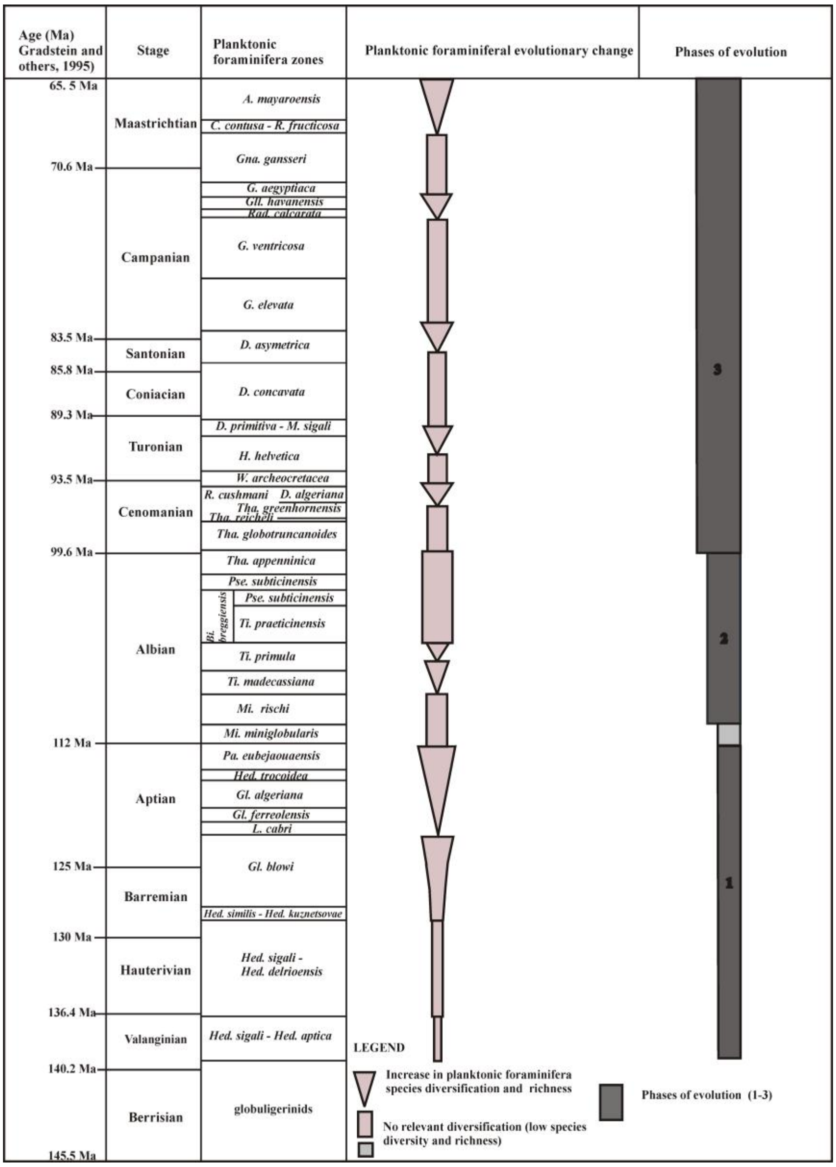


Figure 1.2: Schematic diagram showing the major evolutionary changes through the Cretaceous plotted against planktonic foraminiferal zonal scheme and major stratigraphic events for the studied interval (after Premoli Silver and Sliter, 1999 and reference therein). The purple shaded arrows and bars show a detailed planktonic foraminiferal evolutionary change. The three grey shaded bars (1, 2 and 3) show the three phases of the evolutionary patterns of planktonic foraminifera in the Cretaceous. The light grey shaded area at the Aptian /Albian boundary marks an interval of low species diversity and richness.

Note: A.= Abathomphilus, Bi.=Biticinella, C.=Contusotruncana, D.=Dicarinella, G.=Globotruncana, Gl.=Globigerinelloides, Gll. =Globotruncanella, Gn.=Gansserina, Hed=Hedbergella, M.=Marginotruncana, Pa.=Paraticinella, Pse. =Pseudothalmanninella, R.=Rotalipora, Ra.= Radotruncana, Ti.= Ticinella, Tha.= Thalmanninella, W.=Whiteinella.

1.2.1 Placement of the Aptian/Albian boundary

1.2.1.1 Biostratigraphy

Stratigraphic placement of the Aptian /Albian boundary has a controversial history and is an issue of ongoing debate. Traditional schemes grew from Tethyan studies used ammonite biostratigraphy to define Cretaceous stage boundaries (Birkelund and others, 1984; Mutterlose and others, 2003). This turned out to be problematic because the ammonite species were not globally distributed (Herrle and others, 2004). Planktonic foraminifera in contrast, together with calcareous nannofossils, which were abundant and diverse from the Cretaceous time, turned out to be excellent tools for biostratigraphy (e.g. Caron, 1985; Sliter, 1989; 1992; Robasyznski & Caron, 1995; Mutterlose and others, 2003).

Using ammonites, Kemper (1971) used the first occurrence (FO) *Leymeriella (P) schrammeni anterior* to define the base of the Albian (placed at 0.65 m) beneath the tuff of the Vöhrum classic Aptian /Albian section in northwest Germany. The FO of *L. (P.) schrammeni schrammeni* about 9 m above the tuff horizon provides an additional bracketing control in the northwest Germany sequence (Mutterlose and others, 2003). The relation between this marker and the tuff has been disputed (Kemper & Zimmerle, 1978; Owen, 1979; 1984a, Mutterlose and others, 2003), although the most recent assessment supports Kemper's original view. Planktonic foraminifera are either absent or extremely rare in this section. Benthic foraminifera do occur, although these are only useful for providing paleoenvironmental constraints (Kemper, 1975b; Bertram & Kemper, 1982; Mutterlose and others, 2003). Elsewhere, calcareous nannofossils and planktonic foraminifera are common and are useful for biostratigraphy. Herrle and Muttarlose (2003) made detailed correlations between Aptian - early Albian nannofossil records in the Vocontian Basin, southeast France, that have been cross-calibrated against the Tethyan ammonite and planktonic foraminiferal biostratigraphy (Herrle and others, 2004).

From the TDP Site 40 results the latest Aptian of the studied interval was earmarked by the occurrence of *Paraticinella eubejaouaensis*, while the Aptian /Albian boundary was missing and poor fauna and randomly distribution of the earliest Albian species which are rare in abundance e.g.; *Microhedbergella miniglobularis* possibly reworked and this inferred to a stratigraphic hiatus /unconformity at the earliest part of the Albian and hence TDP40 Hole A and B is missing and did not have a complete section of the Aptian/Albian boundary. This is supported by low values of δ13C and none deposition of the organic carbon rich black shales in the earliest section of Albian in the studied interval. The only biostratigraphical interval of the Paraticinella eubejaouaensis correlates and fit into the isotope carbon stratigraphy. Therefore, only partial correlation of the biostratigraphic events to isotope carbon stratigraphy was possible, i.e. *Paraticinella eubejaouaensis* biozone correlated to carbon isotope stage Ap12-Ap15 Zone (see figure 1.2b).

1.2.1.2 Isotopic Proxy Data

The comparison of the $\delta^{13}C$ based stratigraphy of the Atlantic and Tethys oceans has shown several of these datums appear to be diachronous by up to 1.6 m.y. (Herrle and others, 2004). This suggests that the local and regional paleoenvironmental conditions controlled distribution of planktonic foraminifera (Herrle and others, 2004), and $\delta^{13}C$ excursions must be globally synchronous). The Aptian /Albian boundary has been documented as the break point between the end of a positive $\delta^{13}C$ excursion in the latest Aptian and the beginning of a pronounced negative shift of $\delta^{13}C$ in early Albian (Herrle and others, 2004) (see figure1.2b). The $\delta^{13}C$ excursions are not unique to the Aptian /Albian interval; however, the combination of both the biostratigraphic and geochemical information is necessary to determine the boundary with certainty. Moreover, with this approach it is possible identify gaps in different sedimentary succession (Arthur and others, 1987; Jenkyns and Wilson, 1999, Coccioni and others, 2006).

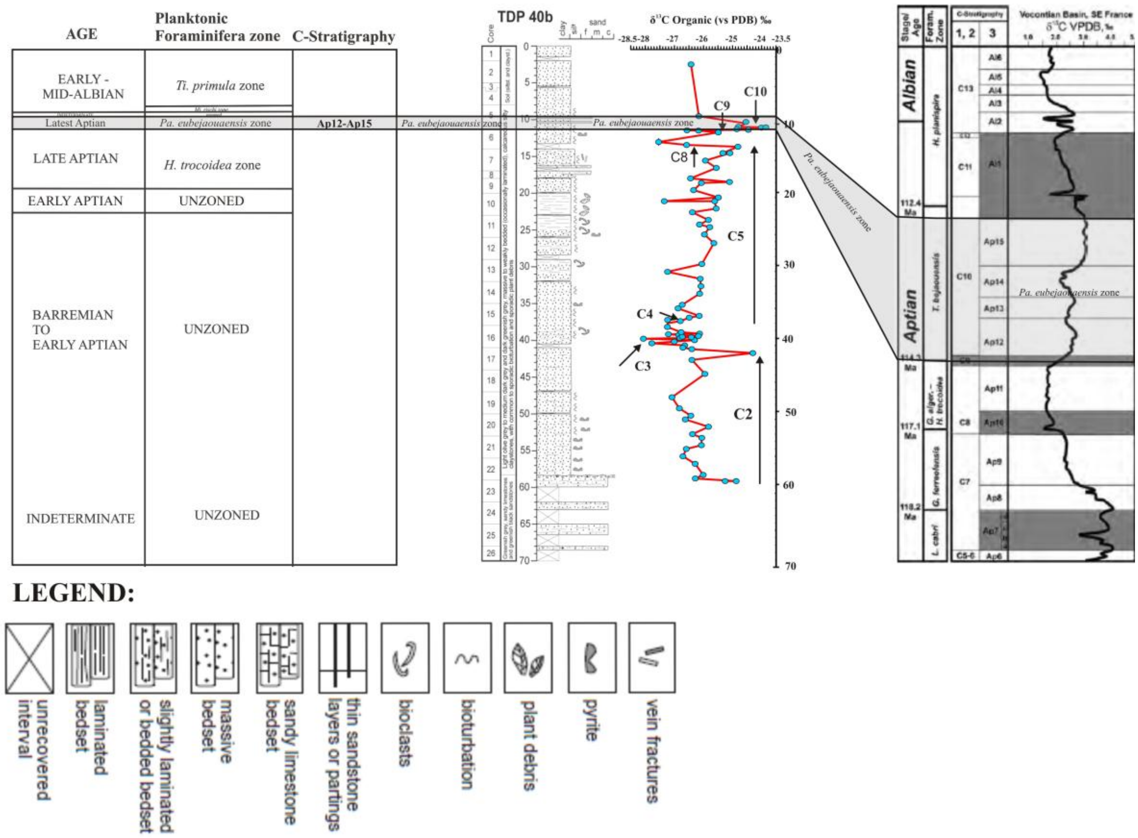


Figure 1.2b: Diagram showing the correlation of upper Aptian interval (*Paraticinella eubejaouaensis* zone; equivalent to Ap12-Ap15) of TDP Site 40B to Carbon Isotope Stratigraphic Curve (ICS) of the Global Stratotype Section Point of Vocontian Basin and ODP Site 1049 (Showing a shift trend in the carbon $\delta^{13}C$ at the Aptian / Albian boundary in the Vocontian Basin a sharp change of positive excursion in the upper Aptian to the negative $\delta^{13}C$ excursion (after Herrle and others, 2004).

A further stratigraphic constraint is provided by Sr-isotope stratigraphy (Bralower and others, 1997). $^{87}Sr/^{86}Sr$ measured on foraminifera and inoceramid bivalves from multiple mid-Cretaceous DSDP and ODP sites shows that the Aptian-Albian interval occurs in a 'trough' of markedly lower $^{87}Sr/^{86}Sr$ values (Bralower and others, 1997; see fig. 1.1b). This interval coincides with increased spreading rates at oceanic ridges and a pulse of mid-plate volcanic activity that produced the Ontong Java, Manikihi, and Kerguelen flood basalt igneous provinces, and suggests that the sea water $^{87}Sr/^{86}Sr$ signatures has a volcanic origin (Bralower and others, 1997). This association suggests that the global planktonic extinctions and $\delta^{13}C$ shifts were environmental consequences of these Cretaceous tectonics changes

(Rükheim and others, 2006). There is some support for this from analyses of bulk carbonate as well as single benthic and planktonic species that indicate higher vertical $\delta^{13}C$ stable isotope gradients, higher surface water temperatures ($\delta^{18}O$) and stronger thermal stratification associated with the early Albian OAE 1b black shale (Leckie and others, 2002). Atlantic calcareous nannofossil (Rükheim and others, 2006) show high abundance of cool water-taxa in Aptian and earliest Albian Atlantic sites with evidence for influx of either dysaerobic or mesotrophic surface water that may be related to changing circulation patterns associated with the Atlantic opening (Huber and Leckei, 2011).. High abundances of arenaceous benthic foraminifera suggest a deepening of the North Sea basin towards the Aptian-Albian boundary interval, which may have been responsible for the low oxygen conditions in the basin, and widespread loss of calcareous foraminifera which is a feature of the Aptian-Albian boundary interval (Huber and Leckie, 2011). Increasing abundances of benthic species *Crucibiscutum* spp. and *Rhagodiscus parvidentatum* indicate a cooling across the Aptian-Albian interval (Rükheim and others, 2006). This suggests that the global planktonic extinctions and geochemical shifts may have been related to water mass changes associated with the opening of the South Atlantic and the environmental consequences of Cretaceous tectonism (e. g., increased outgassing, and carbonate chemistry change (Jenkyns, 2010; Herrle and others, 2004).

Like most Cretaceous OAE studies, existing information for the Aptian-Albian interval is heavily biased towards the Atlantic and North West Tethys region (Jenkyns, 1980). This is largely because so much of the Tethyan and Pacific crust has been destroyed through subduction. There are some records from the Pacific (Bralower and others, 1993; Robinson and others, 2004; 2008) and Australian Ocean margins), however global coverage is lacking and the global extent of OAE1b is poorly understood (Fig. 1.1). The occurrence of mid-Cretaceous sediments on the East African margin is therefore extremely important, providing information about the scale of OAE1b in the Tethys Ocean when it extend over the modern Indian Ocean region.

1.3 Origin of the Oceanic Anoxic Events (OAEs)

Oceanic Anoxic events were short lived and last for a half million years and were formed when global oceans are depleted in oxygen (Jenkyns, 1980). During warm Cretaceous (greenhouse) period they were associated with higher levels of carbon-dioxide and mean surface temperatures of more than 25°C (77° F) (Huber and others, 1995; Oliver and others, 2008). These large volumes of carbon-dioxide (CO_2) were probably the source of huge quantities of outgassing natural gas (Methane). Scientific studies suggested that the huge release of natural gas is a major cause of climate change in the ocean system. Oceanic Anoxic Events (OAEs) were recognized in the Cretaceous and Jurassic periods and several OAEs have been documented (Gronstal, 2008) but they were reported to arise in the Triassic, Permian, Devonian, Ordovician and Cambrian (Pearce and others, 2008).

The Oceanic Anoxic Events (OAEs) was an idea proposed by Seymour Schlanger (1927-1990) and Hugh Jenkyns due to discoveries made in the Deep Sea Drilling Project (DSDP) in the Pacific Ocean (Schlanger and others, 1976). They were searching for the black carbon rich shales in the Cretaceous successions deposited in the Submarine Volcanic Plateaus (Shatsky Rise, Manihiki plateau). These sediments were similar to the ones reported from the Atlantic Ocean and outcrops in Europe particularly in the limestone succession of Italy. These were found to be widely distributed intervals in the low oxygen environments in the global oceans during numerous distinct geologic periods (Schlanger and others, 1976).

Scientific studies has proven that the organic carbon rich sediments consisting of fine laminations which are not disturbed by bottom-dwelling organisms suggesting anoxic conditions on the sea floor correspond to the low lying poisonous layers of hydrogen sulphide (H_2S), (Kump and others, 2005). Geochemical studies has confirmed the presence of molecules (biomarkers) originating from purple and green sulfur bacteria which use light and free hydrogen sulfide (H_2S). This indicates that the anoxic conditions have extended into the well-lit upper water column (Kump and others, 2005).

During the greenhouse period sea levels were as high as 200 meters in some areas and continental plates were apart and mountains which exist presently are the future tectonic events. The lands were lower and even during the supergreenhouse climates would have been periods of accelerated water erosion (Page and others, 2007) transporting enormous amounts of nutrients into the global oceans which increased population of microorganisms into the oxygenated upper layers (Leckie and others, 2002).

Detailed stratigraphic studies of Cretaceous black shales from many parts of the world have indicated that the two oceanic anoxic events which were significant in terms of their impact on the chemistry of the oceans, is an early Aptian, named Selli Event (or OAE 1a; see figure 1.3) after the Italian geologist, Raimondo Selli (1916-1983), and the Cenomanian-Turonian boundary named Bonarelli Event (or OAE2) after the Italian geologist, Guido Bonarelli (1871-1951).

Cretaceous Oceanic Anoxic Events (OAEs; see figure 1.3) are represented by type localities; that are outcrops of laminated black shales with variety of colours claystones, and pink and white coloured limestone in Gubbio, in the Italian Apennines which are the best candidate for 'Global Stratotype Section Point' (GSSP) (Herrle and others, 2004). Also the 1-meter black shales crops at the Cenomanian-Turonian boundary close to Gubbio are termed as the Livello Bonarelli after the man who first described it in 1891.

1.3.1 Mechanism

The warm temperatures which have persisted in the Jurassic and Cretaceous periods were favorable for the development of anoxia conditions. Appropriate explanation is required for the short life span (half a million year or less) of the oceanic Anoxic Events (OAEs). In this study, two Hypotheses were adopted.

The first Hypothesis: According to Meyer and Kump (2008).

This hypothesis is based on the organic carbon rich black shales formed under poor oxygen environment being a function of a specific geometry of the ocean basin, but is applicable to young narrow Cretaceous Atlantic (applied to Black Sea which is poorly connected to the Global Oceans). This hypothesis fails to explain the existence of black shale in open-ocean Pacific Plateaus and Shelf Sea around the world.

The second hypothesis:

Oceanic Anoxic Events (OAEs) are liable for a major change in the fertility of the oceans which led to an increase in organic-wall plankton (including bacteria) (Kump &Arthur, 2005). This hypothesis is based on increasing dissolved nutrients of phosphate, nitrates and iron to the phytoplankton in the photic layer of the oceans. In order to obtain such an increase it will require a high influx of land derived nutrients with vigorous outpouring and a climate change on a global scale (Oliver and others, 2008).

Studies on oxygen isotope ratios of carbonates and fossils data confirmed that OAEs were linked with thermal maxima, generating global weathering rates, and nutrients flux into the oceans which increased during this period. The solubility of oxygen decreased as a result of phosphate discharging into the ocean and accelerated productivity. Therefore, high oxygen was needed to support the event through a positive feedback (Meyer & Kump, 2008).

Oceanic Anoxic Events can be explained as follows:

Assuming that the earths is expelling a large amount of Carbon-dioxide (CO_2) due to volcanism which will rise the global temperatures due to greenhouse influence, this will result into the increase of global weathering rates, fluvial nutrient and organic productivity and increase in the deposition of organic carbon black shales in the oceans (OAE begin). Carbon dioxide ($CO_{2)}$ is drained in reverse of greenhouse and hence, global temperature fall, and the ocean-atmosphere system returns to equilibrium (OAE ends; Meyer & Kump, 2008).

Oceanic Anoxic Events can be considered as a result of extra carbon-dioxide added into the atmosphere and hydrosphere. Taking into accounts the huge amounts of Igneous Provinces (LIPs), the expulsion will be rapid outpouring of large quantities of volcanic gases such as carbon-dioxide. However, the age of the three LIPs (Karoo-Ferrar Flood Basalt, Caribbean Large Igneous Province, and Ontong Java Plateau) correlates well with the major Jurassic (early Toarcian) and Cretaceous (early Aptian and Cenomanian - Turonian) Oceanic Anoxic Events, which are possibly linked to each other (Jones and Jenkyns, 2001). Nevertheless, the mechanism for the formation of the OAEs is still unknown although a lot of explanation has been given by different scientists which are however, inadequate.

1.3.2 Significance of OAE1b

Oceanic Anoxic Event 1 b (OAE1b; see figure 1.3) is one of the most important Oceanic Anoxic Event which replicates the characters of the mid-Cretaceous climate, tectonics, sea level, lithofacies and marine plankton. It is comprised of several black shale beds that straddle the Aptian /Albian boundary (Arthur and Premoli Silva, 1982; Bréhéret and others, 1986; Bréhéret and Dalamette, 1987; 1989; Bréhéret, 1988; 1994; 1997). The uppermost Aptian black shales known as the 'Jacob' event is documented in the Vocontian basin, Central Italy. The lower Albian black shales ('Paquier' and 'Leenhardt' events have been documented in the Vocontian basin and "Monte Nerome' and Urbino events in the Apennines, Central Italy (see figure 1.3) (Erbacher and others, 1998).

The OAE1b black shales of (upper *Paraticinella eubejaouaensis* & *Muricohedbergella planispira* Biozones) studies were conducted in Mexico (eastern Tethys, North Atlantic basin (western Tethys) and Mediterranean (eastern Tethys) regions (Leckie and others, 2002). The black shale sequences of OAE 1b is linked to the cooling and sea level fall in the latest Aptian and later sea level rise during the early Albian (Leckie and others, 2002). 'Jacob' event in the uppermost Aptian (Vocontian basin) was interpreted as DOAE which is formed by land derived organic matter and the lower Albian 'Paquier' and 'Leenhardt' events as POAE formed by marine organic matter and controlled by rising sea level (namely; condensed black shale) (see Leckie and others, 2002).

Isotopic values of the OAE1b varies considerably with a decrease in the values of $\delta^{13}C$ in the middle-late Aptian (*Globigerinelloides algerianus* Biozone), then increased in the late Aptian (*Hedbergella trocidea* and lower *Paraticinella eubejaouaensis* Biozones), and a decrease in the latest Aptian (upper *Paraticinella eubejaouaensis* Biozone) and increased again in the early Albian (*Muricohedbergella planispira* Zone) (Leckie and others, 2002). OAE1b attributed to the negative carbon excursions and to the global cooling, ice sheet growth, and see level fall in the late Aptian and near the Aptian-Albian boundary as a positive feedback to the extended periods of C_{org} burial in the *Leupoldina Cabri* - *Globigerinelloides ferreolensis* Biozones and again in the *Hedbergella trocoidea* - *Paraticinella eubejaouaensis* Biozones.

The occurrence of ice-rafted debris and cool temperatures during the Aptian and Aptian /Albian transition in Australia support an interpretation of high latitude glaciation (s) (Frakes & Francis, 1988; Ferguson and others, 1999, Frakes and others, 1992).

The low planktic: benthic ratio (percent planktics) across the Aptian /Albian boundary may be partly related to increased carbonate dissolution, although preservation of the tiny planktonic and benthic species is moderately good with minimum test damage and etching of the calcareous tests. However, correlative strata from the Apennines of Central Italy show pronounced dissolution in the basal Albian (Premoli Silva and others, 1999; Tornaghi and others; 1989; Erba, 1992).

Erbacher and others (2001) reported stable isotopic data of planktic and benthic foraminiferal of the lower Albian correlated to the Paquier level at ODP Site 1049 in the Western tropical North Atlantic (Blake Nose). There is a sharp increase in planktic-benthic $\delta^{18}O$ gradients across the black event. The findings show that the increased stratification of the water column by surface water warmer and /or increased runoff suggest that this black shale was formed as megasapropel analogy to Plio-Pleistocene sapropel accumulation in the Mediterranean (Erbacher and others; 2001; Kuypers and others; 2001) concluded that severe oxygen depletion affected the water column during this event. On the basis of the document fraction of organic matter derived from chemoautotrophic Crenarchaeota bacteria in this black shale.

However, the basal Albian Paquier and lower Albian Leenhardt events in the Vocontian basin of SE France have been attributed to elevated primary productivity (Breheret, 1994; Erbacher and others, 1998), rather than increased thermocline stratification (Erbacher and others, 1996) show rockeval analyses for the interval around OAE 1b to have type II (marine) kerogen, and one has type III (terrestrial). These findings suggest that multiple black shales deposition was triggered by productivity, sea level, or climatic driven organic carbon burial events which characterized the broad interval of OAE1b (Leckie and others, 2002).

1.3.3 Importance of Oceanic Anoxic Events (OAEs)

Oceanic Anoxic Events were important for the generation of petroleum and gas source rocks globally in many environmental settings. In the Cretaceous period, the deposition of the source rocks was greater due to warmer greenhouse conditions which were conducive for the deposition of organic carbon rich black shales. It was pointed out that 70% of oil source rocks are of Mesozoic and 15% percent from warm Palaeogene (Klemme and Ulmisheck, 1991).

The decrease in oxygen level in the water column during the OAEs caused an adaptations of some planktonic foraminifera from shallow to deeper environments and some could not with stand the situation and therefore, major extinction events occurred in the mid-Cretaceous (Aptian/Albian and Cenomanian/Turonian) (Raup and Sepkoski, 1986). The extinction events and anoxic events are biostratigrahically time markers. OAEs have been responsible for mass extinctions of marine organisms both in the Palaezoic and Mesozoic (Raup and Sepkoski, 1986, Leckie and others, 2002).

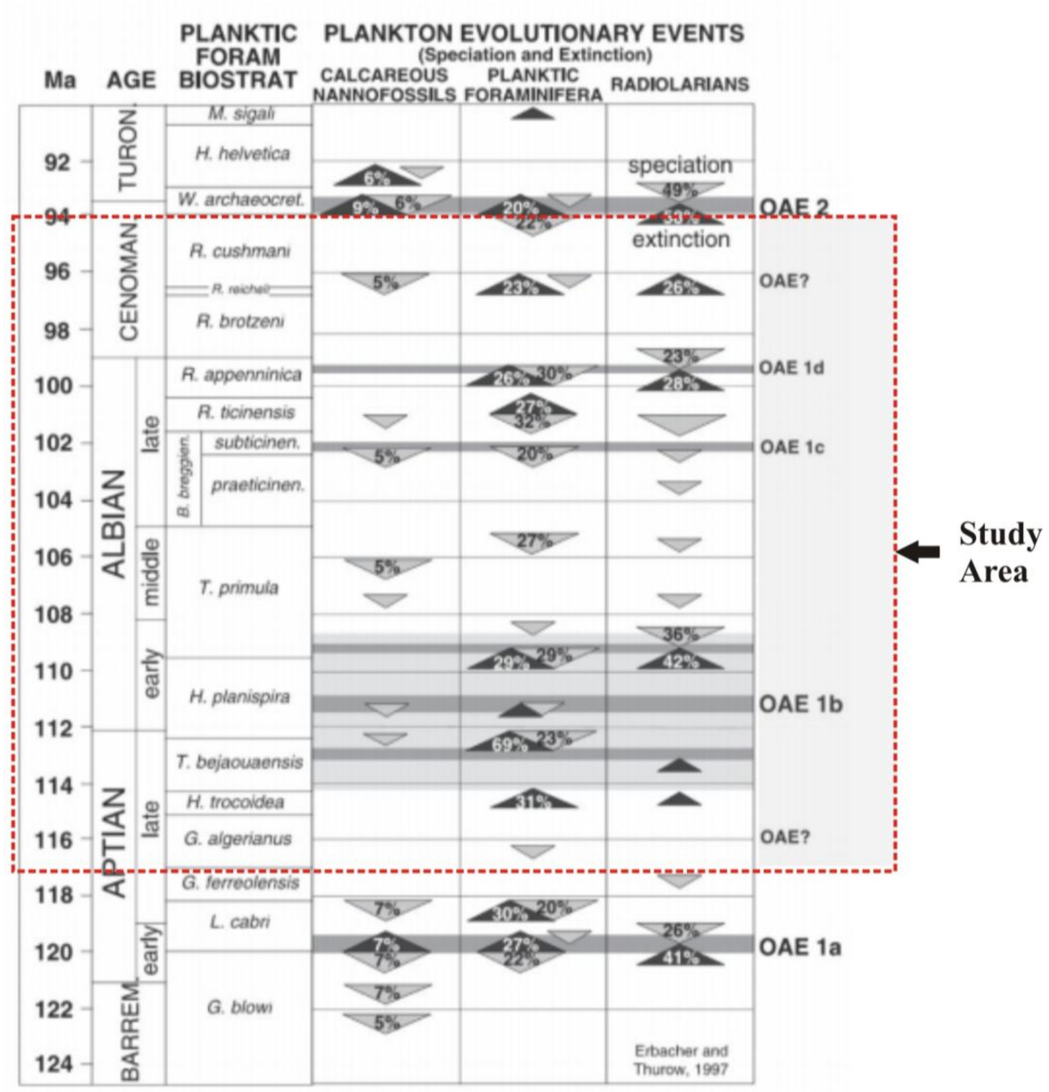


Figure 1.3: Mid-Cretaceous plankton evolutionary trends showing percentages of species first appearances (speciation) or disappearances (extinction) modified after Leckei and others (2002); Dotted square area is the area covered by the present study.

Ocean crust production in the mid Cretaceous was high (Stanley and Hardie, 1998; Stanley 1999). Mid Cretaceous greenhouse climate accelerate the formation of oceanic plateaus due submarine volcanism. Also temperature varies from high (greenhouse climate) to low (ice house period) (Stanley, 1999).

1.4 *Cretaceous Geology of Tanzania and development of the coastal basins*

A generalized surface geology shows the distribution of (Mesoproterozoic) older Mozambican belt basement rocks to younger (Quaternary) rocks from west to east in Tanzania (see fig. 1.4). Major river valleys (Ruvu, Rufiji and Ruvuma) are covered by Quaternary alluvium deposits. The outcrops are generally obscure and weathered as would be expected in a tropical environment (Barnard and Futyan, 1984). Knowledge of the early to mid-Cretaceous sedimentary sections in the coastal basin of Tanzania derives from geological surveys and from boreholes and deep wells drilled for hydrocarbon exploration (TPDC/Fairway, 1992; (see fig. 1.4b). In all the basins apart from Selous and the flank of Ruvu, where it is absent, the early Cretaceous is dominated by thick, sand facies of the Kipatimu formation comprising continental, deltaic and marginal marine deposits continuing the overall regressive regime established in the mid-Oxfordian (Terris & Stonely, 1955; Kent and others, 1971; Kidston and others, 1997; Ford, 1995; ECL, 1979). On the flank of the Rufiji Trough, however, thick Tithonian and early Cretaceous continental sands lie directly on the middle Jurassic limestone (Msindai, 1986, TPDC/Fairway, 1992). The Kipatimu formation forms the lower part of the reservoir in the Songo Songo field where it consists of sands and the unit may exceed 1,192m in thickness (TPDC / Fairway, 1992; Martin, 1957).

On the flanks of the Ruvu Basin, the Aptian consists of deltaic and shallow marine facies that appear to pass south westwards into deltaic sands and fluvial red-beds (Makonde sandstones) (Kent and others, 1971). Aptian-Albian fluvial sands with good reservoir characteristics cover the western part of the Mandawa basin, much of the Ruvuma basin and probably extend into Rufiji Trough (Barnard and Futyan, 1984). Platform carbonates were deposited in shallow area following the Albian water depths that increased rapidly over much of the area due to lithosphere cooling and subsidence of the Indian Ocean crust (Kidston and others, 1997; TPDC/Fairway, 1992). Throughout the Middle Cretaceous and early Palaeogene hemipelagic clays and shales were deposited in an outer shelf to bathyal environment (TPDC/Fairway, 1992; Kent and others, 1971). These have been shown to contain well preserved planktonic foraminifera that are the subject of this research (Kidston and others, 1997; TPDC/Fairway, 1992; Kajato, 1986).

1.4.1 Development of the coastal basin

The Tanzania coastal sedimentary basin went through one or two phase of rifting during the Karoo and or late Tertiary. The rifting began in the late Carboniferous and tillites were deposited. The development of grabens and regional uplift began in the Permian and the deposition of continental sediments of about 1000-3000 m thickness of lacustrine, fluvial, to deltaic environments (Mbede, 1991). Rifting continued into the early Jurassic and causing movement along bounding faults. The variations of sediments in Karoo sequence was a result of the difference in the rate of subsidence and sedimentation in the grabens (Mbede, 1991). During the late Jurassic / early Cretaceous, Madagascar move southwards relative to Africa (Mbede, 1991). This movement results into development of the oceanic crust and formed the floor of the proto Indian Ocean. From this period and thereafter, the coastal basin developed as a passive continental margin and with a series of transgression and regression developing eastwards into the open marine basins of the developing ndian Ocean. From the Palaeogene and onwards tectonic reactivation continued into the Neogene (Mbede, 1991).

1.4.2 The Tanzanian coastal basins

The Tanzania coastal basin stretches from the Kenyan border in the north to Mozambique border in the south. Mandawa, Rufiji, Dar es Salaam platform and Ruvu sub-basins are part of the coastal basin (see figures 1.4 and 1.4 b). The oldest rocks are Karoo and are present in Tanga, Ngerengere, Ruvu and Mandawa. The Karoo rocks in west are overlain the basement and east by middle Jurassic rocks.

The first record of the development of fully marine conditions in the basin took place in this period and the middle Jurassic sediments overlain the late Jurassic marls marking a transgressive phase which continued into early Cretaceous (TPDC/Fairway report, 1992). This transgression was followed by a series of transgression and regression phases which characterised the middle part of Cretaceous before it was followed by another transgression towards the end of Cretaceous continuing into early Tertiary.

Mid-Tertiary regression, marked by the absence of Oligocene were seen in some of the wells, followed by late Oligocene/Miocene transgression accompanied with intensive tectonic activities related to the rifting activities inland at time (Mbede, 1991; TPDC/Fairway report, 1992). This was followed by a regressive phase (which and) where the present coastlines are formed. Being a passive continental margin, subsidence was controlled by isostatic subsidence during the rifting stage, and by the thermal subsidence as a result of cooling of the newly generated oceanic crust (Mbede, 1991; TPDC/Fairway report, 1992).

Borehole and outcrop samples recovered from the Ruvu basin (Kiwangwa-1 and Makarawe-1 wells), Rufiji Trough (Songo Songo-4 well and Luhoi-1 borehole), Dar es Salaam Platform (Kisarawe-1) and Mandawa Basin (Kizimbani-1 well, TDP40A and TDP40B) were employed in this research (see fig. 1.4b).

1.4.3 Mandawa Basin

The Mandawa Basin lies along the southeast coast, south of Songo Songo and north of the Mbemkuru River (see fig. 1.4b). It covers an area of 16,000 square km, which is half onshore, and bounded to the south by the Ruvuma Basement Saddle, to the west by the Masasi Basement Spur, and to the north by the Rufiji Trough (TPDC/Fairway report, 1992). A total of five wells have been drilled in this region and one of them is used for this research i.e. Kizimbani-1. The mid-Cretaceous section was investigated for this research only. The Mandawa basin sedimentary sequence comprises: (1) deltaic sands in the Oligocene and Miocene (2) carbonate platform, clastics and reefal limestones in the Palaeogene, (3) the mid-Cretaceous claystones (4) the early Cretaceous sands and silts, minor limestone (5) Middle to late Jurassic contains clastics, carbonates during salt tectonics (6) Triassic to early Jurassic constitute of fluvial sands, marine shales and evaporites (TPDC/Fairway report, 1992 (see figure 1.4b).

1.4.4 Rufiji Trough

The Rufiji Trough is a major east-west trending basin that bisects the coastal zone of Tanzania stretching southwards about 70-80 km from Rufiji Rivers. It covers an area of about 21,000 square km, extending from the Ulanga basement Spur in the west to the Rufiji River delta and east of Mafia Island (TPDC/Fairway report, 1992). The Songo Songo gas field is included in this area. The generalized Rufiji basin sequences comprises: (1) Middle to late Cretaceous black, deep water shales within deltaic and turbiditic sand sequences (2) the early Cretaceous deltaic, fluvial sands (3) middle Jurassic marine shales and thick carbonates (up to 800 m) (4) the early Jurassic black carbonaceous mudstones and (5) the Permian to Triassic fluvial continental sediments make up the basal lithology (TPDC/Fairway report, 1992) see figures 1.4 & 1.4b.

1.4.5 Dar es Salaam Platform

The Dar es Salaam Platform lies onshore between the Ruvu River and Wami River in the north, to the Rufiji River in the south, and covers an area of about 20,000 square km. Six wells have been drilled in this basin (TPDC/Fairway report, 1992) and materials from Kisarawe-1 have been used in this present research.

1.4.6 Ruvu Basin

The Basin is about 15,000 square km, with three wells; the basin covers the onshore region from the western Dar es Salaam Platform to the Kenyan border (see figure 1.4). To the southeast, the basin is bound by the Kisangire and Pugu highs of the Dar es Salaam Platform. The eastern limit of the Ruvu Basin coincides with the present day coastline. Three wells have been drilled in this basin (see fig. 1.4) (TPDC Fairway report, 1992).

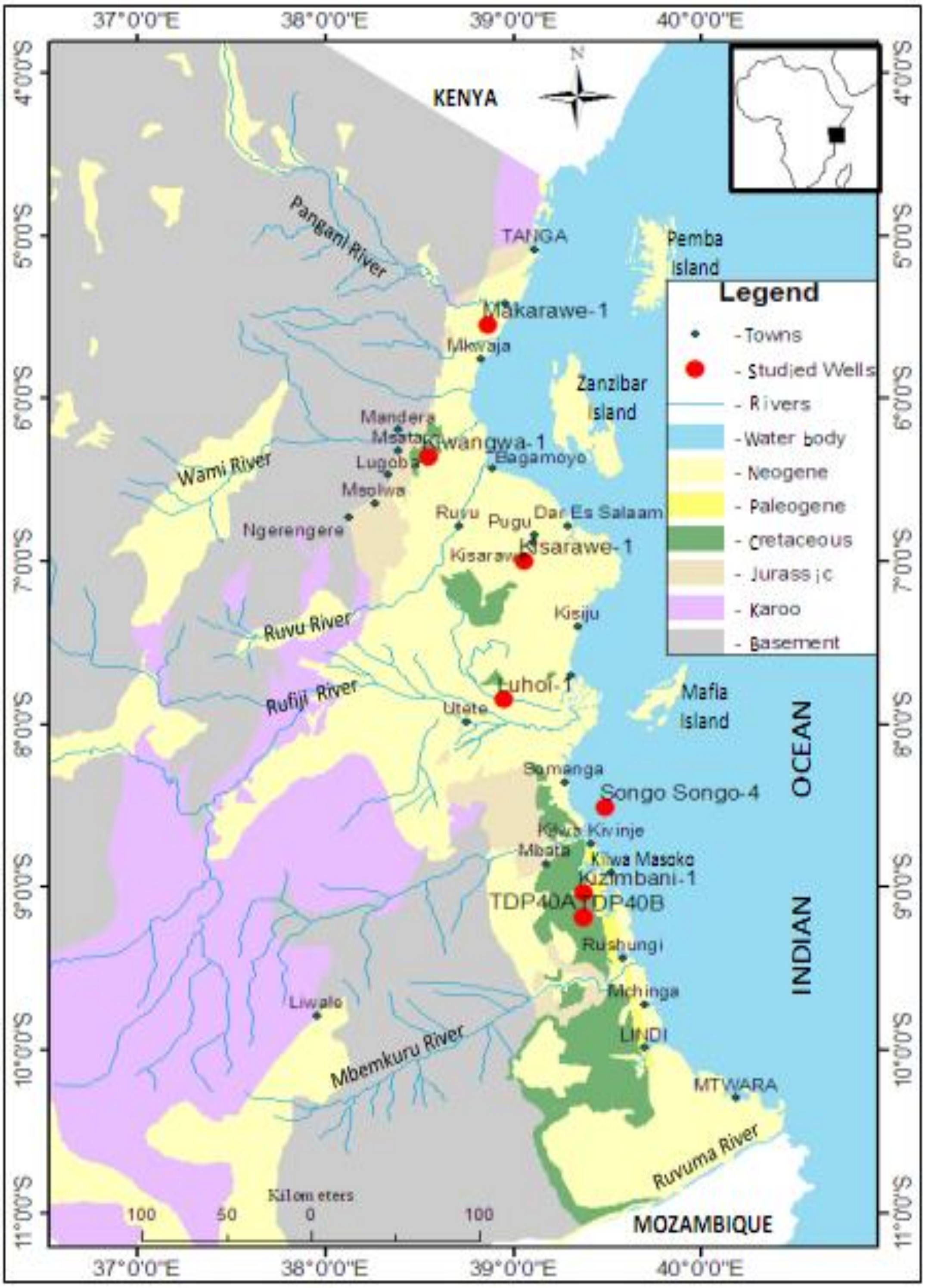


Figure 1.4: Map showing the surface geology of the coastal basin, Tanzania; (Modified after Barnard and Futyan, 1984).

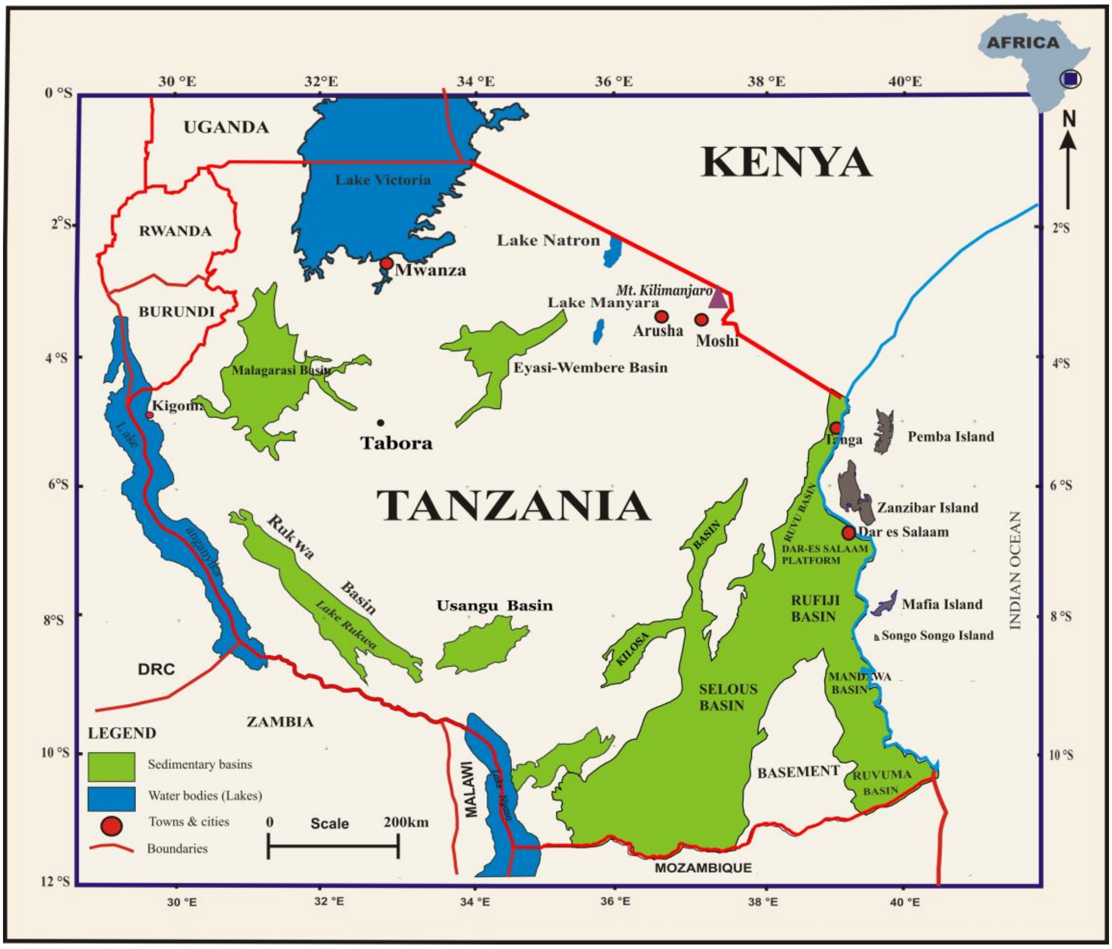


Figure 1.4b: Map showing inland and coastal sedimentary basin of Tanzania.

Materials from Makarawe-1 and Kiwangwa-1 well are used here. In this research, Mid-Cretaceous sections of the two boreholes were investigated. The sedimentary fill consists of Permo-Triassic to Neogene sediments. The basin contains: (1) Eocene shales, sands and limestones, and Cretaceous (2) Palaeocene turbidites, (3) early Cretaceous near shore shelf sands and (4) Permo-Triassic continental fluvial clastics (TPDC/Fairway report, 1992) see figure (1.4b).

1.4.7 The Cretaceous evolution of the Tanzania coastal basin

The beginning of the Cretaceous was a period of sea-floor spreading in the Somali and Mozambique basins and marine transgression extended to the southern end of the African block. Rifting structures and buildup of thick sedimentary sequences continued, accompanied by a partial regression. In the southern eastern margin of Africa, the development of the mid-Cretaceous and new transgression went through the African continent, and was probably related to the break-up of Western Gondwana, separation of South America and opening of South Atlantic in 130 Ma (Salman and Abdula, 1995). At the end of the early Cretaceous, Madagascar had nearly stopped drifting with respect to Africa and formation of the main structures of the East African continental margin had been completed (Mbede, 1991; Salman and Abdula, 1995; Nicholas and others, 2006).

Salman and Abdula (1995) state that the stabilization of the East African Continental margin took place during 118 Ma and 35 Ma and a widespread transgression developed during the late Cretaceous in the eastern Africa and argillaceous sediments were deposited in the continental margin prograding onto the continental slope they further show that the volcanic activities taking place in the southern part of Madagascar /Indian block, Mozambique Channel and Mascarene basins, results into the deposition of thick volcanogenic sedimentary sequences. This is associated with the beginning of the sea-floor spreading within the Mascarene Basin in the second half of the late Cretaceous and the separation of India and Seychelles from Madagascar (Magnetic anomaly 34, 84 Ma).

The stabilization of the east African continental margin was completed in the Palaeocene and Eocene and this was accompanied with widespread, shallow water shelf carbonate sediments with reefal facies along the outer edge of the shelf. A phase of new rifting commenced from ~35 Ma to the present and is closely connected with the commencement and development of the east African rift system (Salman and Abdula, 1995).

1.4.8 Importance of the area in hydrocarbon exploration

The occurrence of hydrocarbons in Tanzania is known from oil and gas wells, oil seeps and bitumen outcrops at localities across the region. Most well known are the significant gas discoveries made at Songo Songo and Mnazi Bay in the south of the country between 1954 and 1997. So far only gas fields have been developed on a commercial scale, the Songo Songo reserves are estimated to be 0.028 trillion cubic metres (1 trillion cubic feet) which occur in lower Cretaceous sands, offshore coastal basin (TPDC/Fairway report, 1992). The gas tested up to 0.651 million cubic metres (23 million cubic feet) per day including minor volumes of oil with 33°-47° API gravity (American Petroleum Institute gravity (API). API is a measure of how heavy or light petroleum liquid is compared to water. (API is graded in degrees on a hydrometer instrument; (en.wikipedia.org/wiki/API_gravity). Mnazi Bay-1: estimated gas reserves of about 0.028 trillion cubic metre (1 trillion cubic feet) (www.metric-conversions.org/volume/cubic-feet-to-cubic-meters.htm) have been discovered in Mnazi bay well tested gas at rates of up to 0.3964 million cubic meter (14 million cubic feet) per day from the Oligocene sands. Gas shows have been encountered in most of the deep wells in offshore and onshore coastal basin. Biogenic gas has also been reported in some shallow boreholes in the Msimbati area, Ruvuma Basin (TPDC/Fairway, 1992). Both oil and gas are important source of power generation in the country and therefore, renewed efforts are required to discover the source, seal and reservoirs by identifying the organic carbon rich sediments in the sedimentary basins of Tanzania through more research works on the Cretaceous period.

Exploration for Hydrocarbons in the Tanzanian inland and coastal basins has been sporadic over the past 50 years but more than 40 exploration wells have been drilled. Recent gas discoveries have been made in the Dar es Salaam Platform, Ruvuma and Mandawa basin and offshore. The prospective area covers 150,000 sq km and includes a sedimentary column up to 10 km thick (TPDC/Fairway, 1992). This is equated to an exploration success ratio of 1:10 and well density of about 1 well/7,000 sq km. Although the country has few wells there are more than 40,000 km of seismic data, and much geological survey data that could be made better use of (TPDC/Fairway, 1992). Oil shows have been reported in several wells. Significant oil shows were observed in a couple of formations encountered in Mita Gamma-1 and Mbate-1 wells in Mandawa basin. Apart from that, other formations such as Songo Songo wells, Mafia-1, Makarawe-1, Mnazi Bay-1, Mandawa-7 and Pemba-5 were also identified. Bitumen staining is reported in the early Cretaceous (Kipatimu beds) from Wingayongo-1 borehole, Bathonian limestone cores in Kisangire-1 and Miocene sands in Mtwara-1 borehole in the Ruvuma Basin are thought to be related to residue oil. Hydrocarbon source rocks have been encountered in exploration wells, shotholes and outcrops at different stratigraphic levels (Barnard and Futyan 1984). Proven live oil seeps occur at Luhoi river in Wingayongo area on the flanks of the Rufiji Trough at Tundaua on the west coast of Pemba Island and in Kilwa Masoko Jetty

(Nicholas and others, 2006). Oil seeps and a sublacustrine flow of asphalt have been reported elsewhere in Lake Tanganyika.

In Nyuni Island, an oil seep is apparently present in a sink hole in the middle of exposed reefal carbonates in the centre of the Island and tar balls occur along the south-eastern side coast. Thermogenic gas seeps occur in Msimbati Peninsula at various localities such as Nyuruko, Liangalikulu and Makukwa. Methane is a dominant component with high C1/ (C2 +C3) ratio in association with strong sulphur odour (Barnard and Futyan, 1984).

The source rocks comprise sediments rich in terrestrial and marine organic matter near shore, becoming increasingly enriched in marine organic matter offshore (Kidston and others, 1997; TPDC/Fairway report, 1992). Apart from the documented good source rock potentials for gas and oil in the Karoo, Triassic, early Jurassic and mid-Jurassic, early Cretaceous, late Cretaceous and Tertiary sequences, nothing has been investigated for the middle Cretaceous (Barnard and Futyan, 1984; Kidston and others, 1997). The late Albian to middle Turonian successions are said to have limited potential as an oil source, e.g. in Songo Songo-1 well (TPDC/Fairway, 1992). However, elsewhere in Tanzania the mid-Cretaceous lithology and stratigraphy is poorly known. Improved understanding of the hydrocarbon potential of the coastal sedimentary basin of Tanzania requires detailed studies of the stratigraphy, sedimentary history, palaeoclimate proxies, and palaeontology. No detailed work has been done for the Tanzanian coastal basins in terms of finding hydrocarbons by geophysical, geological and geochemical at a lower percentage. Therefore, there is a need of understanding the sedimentary history of these basins using modern parameters such as palaeoclimate proxies including chemostratigraphy, geochemical, paleontological and other proper methods to make oil discoveries in Tanzania. Also lesser understanding of the basins depositional histories, sea level change which control the accumulation of sedimentary sequences and the production of the hydrocarbons leads to the drilling of more dry wells or drilling off structures or few stratigraphic wells. Whereas more understanding of sedimentary history, sea level change and identification of sediments which are organic carbon rich using palaeoclimate proxies such as palaeontology chemostratigraphy and other geochemical analysis will be appropriate methods of discovering more gas and oil in the region.

Correlation of sequences using microfossils and carbon isotope stratigraphy is important in defining stratigraphic boundaries and events which are associated with (OAEs) the accumulation of the organic carbon rich sediments in Tanzanian coastal basin. These will help to correlate sequences within the Tanzanian basins and to global with similar stratigraphic intervals. Palaeoclimates parameters using carbon isotope stratigraphy in the early to mid-Cretaceous marine succession of Tanzania will help to demarcate proper areas in which to search for hydrocarbons particularly in defining OAEs (OAE1a, OAE1b and OAE1c OAEd, OAE2) which represent rich deposits of organic carbon. In addition, by studying the distribution patterns of fossil assemblages it will be possible to determine the sedimentary history of a basin including relative changes in sea levels which has a major influence on depositional patterns, and therefore, implications for the generation and distribution of hydrocarbons within a basin (van Wagoner and others, 1990).

1.5 Previous work on the Cretaceous stratigraphy and biostratigraphy of Tanzanian coastal basin

Much of the previous information on the Cretaceous of Tanzania comes from the sporadic Hydrocarbon exploration work over the last 50 years. Most of the multinational petroleum companies have been represented in the area at one time or another. Biostratigraphic data from 40 wells drilled in the coastal basins of Tanzania have been already compiled from a variety of sources including operator well reports and specialist biostratigraphic reports of such areas and samples are available (Aitken, 1961; Balduzzi, 1956; 1957; 1974; 1979; Balduzzi and others, 1992; Bate and Bayliss, 1969; 1973; 1984; Dilley, 1955, 1956; Dilley and Seymour, 1956; Eames, 1964; ECL, 1979; Ford, 1995; Haynes and others, 1987; Hermans, 1983; Jimenez Berrocoso and others, 2010; Kajato, 1982; 1986; Kamen-Kaye, 1974; 1978; Kapilima, 1984; Karega, 1992; 1995; Karega and Msaky, 1993; Karega and Singano, 2003, Kent, 1954; Kent and others, 1971; Kent and Perry, 1973; Kidston and others, 1997; Mpanda, 1997, Martin, 1957; Mbede, 1991; Msindai, 1993; Nicholas and others, 2006; Pearson and others, 2001; 2004; Lear and others, 2008, Singano & Karega, 2000; Schijfsma, 1956; Terris and Stonely, 1955; Tykoezinski, 1982; TPDC/Fairway, 1992; Weier, 1987). Moreover, there are reports on fieldwork samples, (including microfossil range charts) collected in different basins and these are available in the TPDC‘s Archive. The data include information on foraminifera, nannoplankton, ostracods and palynomorphs. These reports are of two sources, some done by TPDC specialists and others by ECL, AGIP, Robertson Research, International Stratigraphic Services (SSI) and many others.

In the Kilwa Administrative District in the south of Tanzania, Cretaceous outcrops occur along the Kilwa - Lindi Road and other outcrops along Somanga - Kipatimu road. A number of field surveys have been made by exploration companies in Mandawa, Rufiji Trough and Dar es Salaam Platform. Shallow boreholes have been drilled in Kilwa and Lindi and field surveys have been done by the Tanzania Drilling Project team (TDP) that involved the collection of 500 outcrop samples and drilled 40 shallow boreholes. Reports have been published covering the late Cretaceous to Palaeogene sequences (Pearson and others; 2001; 2004; 2006; 2007; 2008; Nicholas and others, 2006; Lear and others, 2008; Jimenez Berrocoso and others, 2010). Fieldwork and seismic surveys in Kilwa area have been conducted by Dominion Petroleum in Mandawa basin between years 2006-2008. These data have been used to produce updated geologic maps of the Mandawa basin. Upper Albian to Maastrichtian foraminifera of Tanzania has been studied in some detail (Karega, 1995, Singano & Karega, 2000; Jimenez Berrocoso and others, 2010). The mid-Cretaceous assemblages are poorly known. An important part of this research is to assess the composition of the mid-Cretaceous assemblages and classify the species present using the taxonomic classification schemes used by the international stratigraphic community as have been used by other scholars such as BouDagher-Fadel and others (1997), Caron (1985), Gonzalez-Donoso and others (2007), Georgescu and Huber (2009), Huber and Leckie (2011), Loeblich and Tappan (1987), Petrizzo and Huber (2006), Petrizzo and others (2012), Postuma (1971), Premoli Silva and Sliter (2002), Premoli Silva and Verga, (2004), Premoli Silva and others (2009), This will permit the use of global biozonation schemes and correlation of the Tanzanian sections globally.

1.6 Foraminifera

The microfossil group used in this research is foraminifera. Foraminifera are unicellular (Protists) organisms that build their shell and inhabit varied range of marine environment extending from shallow to the deep ocean. Their shell remains make a substantial amount of sedimentary rock

(Haynes, 1981). The foraminifera mineralized shell remains preserve records of ocean chemistry, ocean climate system, as well as evolutionary history (see Chapter 3).

Foraminifera shell range in size from 0.1 to 1.0 mm in size and present in global oceans and are extensively studied group of microfossils (shell or test; BouDagher-Fadel and others, 1997). Foraminifera shells are of various shapes and based on their living behavior there are divided into two groups; (i) benthic foraminifera records date to more than 550 million years (Langer, 1997) and live at the sea floor in a wide range of substrates at all depths in the marine region. They are also found in brackish, estuarine and salt marshes (Loeblich &Tappan, 1987). According to Haynes (1981) and Loeblich and Tappan (1987) benthic foraminifera tests may be agglutinated (quartz or other inorganic materials being glued together by calcite or organic cements) or mainly secreted; these latter may be calcite or aragonite. (ii) Planktonic foraminifera species range to approximately 190 million years (Langer and others, 1997). They first appeared in the mid-Jurassic (Bajocian or Bathonian) and inhabit the open ocean and float easily in the upper part of the water column. Planktonic foraminifera have tests made only of secreted calcite or aragonite (BouDagher-Fadel and others, 1997). Planktonic foraminifera are glassy-like; hyaline, perforate and lamellar shells consisting mostly of low-magnesium calcite, which is radially structured (e.g., Towe & Cifelli, 1967; Hansen, 1968). Only the Jurassic and early Cretaceous Favusellaceae had an aragonite test (Sen Gupta, 1999).

The increase in understanding and their widespread geologic record, abundance, and their importance in global oceanic systems has made them 'the most widely used fossil organisms for biostratigraphy, age dating and correlation of sediments, and paleoenvironmental interpretation, both as organisms whose living representative provide ecological data and as mineralized shells that are a geochemical record of palaeotemperatures, extent of glaciations, and other paleogeographic features (Langer and others, 1997). The planktonic foraminifera (the Globigerinina) are always multilocular; there are no single-chambered planktonic foraminifera. The secreted calcite or aragonite tests are always perforated (BouDagher-Fadel and others, 1997).

These scholars pointed out that foraminifera build their shells by adding a separate chamber each time, and each new chamber covering a former aperture to allow cytoplasm continuity through the test and contact with the external environment. The resulting tests may have uniserial, biserial, or triserial arrangement of chambers, planispiral, trochospiral, or streptospiral coiling, isolated or enveloping chambers. All combinations of these are repeated in time and space, although differences appear in the wall composition and structure and various internal and external morphologic details. The great abundance of planktonic foraminifera in marine sediments and short life span of many of its species makes them more important than benthic foraminifera as index fossils. Planktonic foraminifera are globally distributed in the world oceans making them important for correlation of strata of the same age in different regions (BouDagher-Fadel and others, 1997).

They clearly stated that Foraminifera are useful for biostratigraphy and paleoenvironmental analysis due to their small size, rapid evolution and abundance in close stratigraphic sequence through marine sediments (BouDagher-Fadel and others, 1997). Their test structures and taxonomic diversity have been providing continuous evidence of evolutionary changes (BouDagher-Fadel and others, 1997). These changes have been found useful for both microfossils researchers and for the hydrocarbon industry for the correlation in sedimentary sequences (BouDagher-Fadel and others, 1997). The petroleum exploration industry in particular, has been using planktonic foraminifera because they are easy to recover from drilling and also it is easy to prepare techniques from both outcrops and subsurface samples and allowed biostratigraphic dating to be done at the wellsite directly (BouDagher-Fadel and others, 1997).

Planktonic foraminifera are frequently used for biostratigraphic subdivision of Cretaceous strata (Premoli & Sliter, 1999; Caron, 1985) and the composition of benthic foraminifera assemblages can be used to interpret deposition environment of marine sediments (Sliter & Baker, 1972; Koutsoukos & Hart, 1990, Sikora & Olsson, 1991). The living representative species offer ecologic data and fossil remains provide geochemical record of past temperatures, period of glaciations, and other paleogeographic features (BouDagher-Fadel and others, 1997).

Planktonic foraminifera are thought to have originated in the Middle Jurassic (BouDagher-Fadel and others, 1997; Premoli Silva & Sliter, 1999), and began to diversify in the early Cretaceous. Current studies have shown that Cretaceous low trochospiral hedbergellids first evolved in the early Valanginian (Leckie and others, 2002). According to Premoli Silva and Sliter (1999) the earlier major diversification of planktonic foraminifera occurred in the Aptian ~120 Ma. Prior to the Aptian, assemblages consist of at least 15 isolated morphotypes or species belonging to three widely-accepted genera, *Hedbergella*, *Globigerinelloides* and *Leupoldina* (Premoli Silva & Sliter, 1999). During the Aptian, the planktonic foraminiferal diversity first gradually increases then extinct at the end of upper Aptian stage (Premoli Silva & Sliter, 1999). Few trochospiral forms were present in the assemblages at the end of the stage.

The decrease and increase in diversity in the Aptian involved the genera *Hedbergella* and *Globigerinelloides*, and the genus *Leupoldina* fast diversifies up to the mid Aptian where it extinct. The early planktonic foraminifera have microperforate walls and are thought to have originated from heterohelicid ancestor (s) (BouDagher-Fadel and others, 1997). The pattern of evolution in this first interval is characterised by increasing diversity, size, and complex morphology (Premoli Silva &Sliter, 1999).

Planktonic foraminifera start to evolve again in the early Albian although the new stock has macroperforate walls. It is still not known if there is a relationship between the Aptian microperforate survivors and the new Albian macroperforate-bearing planktonic foraminifera (Premoli Silva & Sliter, 1999). The first appearance of new genera and species within the trochospiral and planispiral groups and of the first Heterohelicidae (*Heterohelix*) was documented by Premoli Silva and Sliter (1999). These scholars showed that the form of evolution in this second interval is the same as the first one and characterized by increasing diversity, size and morphologic complexity. The group continued to survive and prolonged into the late Cretaceous reaching the highest diversity (> 60 species) in the late Campanian to the early Maastrichtian time-interval (see figure 1.3). However, the trochospiral taxa increase and diversify. This third interval involved short period of rapid diversification and turnover separated by longer periods of stasis. The overall increase in diversity is interrupted by episodes of reduced diversity (never less than 18 species) in the early Cenomanian and the latest Cenomanian-earliest Turonian. Diversity decreases gradually from the Late Maastrichtian before the sudden extinction of Cretaceous planktonic foraminifera species, all but three taxa, at the Cretaceous/Palaeocene boundary (Premoli Silva & Sliter, 1999). The evolution within Cretaceous planktonic foraminifera occurred rapidly in a geological sense. The first series of the major distinct changes in planktonic foraminifera test morphology allows the construction of a valuable biozonation scheme that is biostratigraphically applicable at least to low to middle latitude assemblages worldwide (Premoli Silva & Sliter, 1999).

1.6.1 Evolution of planktonic foraminifera

The origin of planktonic foraminifera is still unknown but Fuchs (1967) suggested that there are originating from benthic ancestor through a partially planktonic (meroplanktonic) stage into a totally planktonic (holoplankton) form of life. He described a group of 'Trias. Globigerinen was the first group with a planktonic form of life. According to Fuchs (1975) the Trissic genus *Oberhauserella* was the ancestor of the Jurassic planktonic genera *Conoglobigerina* and *Praegubkinella* and gave rise to the evolution and diversification of the planktonic foraminifera (Fuchs, 1975). When they reexamined the poorly preserved Triassic specimens of oberhauserellids they concluded that they are trochospiral benthic taxa with calcareous-hyaline tests. Simmons and others (1997) postulated the meroplanktic conoglobigerinids of Bajocian age are the oldest known planktonic species, known from Eastern Europe (central and northern Tethys). These species have an aragonitic, microperforate and pseudomuricate test with an umbilical aperture and subglobular chambers (Simmons and others, 1997). Then it was agreed that the planktonic foraminifera species originate from their ancestors which are benthic species with subglobular aragonitic chambers, undergone through series of morphologic changes in the pre-Bajocian age (Hart, 1980; Caron and Homewood, 1983).

According to Hemleben and others (1989) sea surface temperature is vital for controlling evolutionary trends., In cold periods, diversity of species reduced significantly tests shapes change into simple trochospiral forms while in warm periods associated with species radiation, empty niches were occupied by newly surfacing species (Hemleben and others (1989). During the Mesozoic, the evolution and diversification of planktonic foraminifera correspond with the recurring expansion of anoxic water masses in the world oceans and a following sea-level rise. Hart and others (2003) suggested the Early Toarcian OAE (Oceanic Anoxic Event) accompanied by high sea-level forces foraminifera to change their form of life from a benthic to planktonic mode of life. In the early Toarcian abrupt dissociations of sub-sea gas hydrates led to an oceanic perturbation (Hesselbo and others, 2000) and opened up new niches. The outcome of this was the foraminifera change into a meroplanktic form of life (Hart and others, 2003). Therefore, the increase of sea level during the Bajocian period gives way to the evolution and distribution of the early planktonic foraminifera (Haq and others, 1988; see chapter 3, figure 3.2).

1.6.2 Preservation of planktonic foraminifera

The preservation of the planktonic foraminifera in the studied succession varies from poor to moderate and few from moderate to good. Most of the specimens are filled with secondary calcite or filled with pyrite (see figure 2.6).

1.6.3 Importance of planktonic foraminifera

Planktonic foraminifera are important for biostratigraphical usage and paleoenvironmental interpretation (Hemleben and others, 1989, Hart, 1999). Due to their small size and short geologic age ranges, great abundance and widely distributed in marine sediments and good fossil records there are excellent stratigraphic tool for the Mesozoic and Cenozoic marine sediments (Bolli and others, 1985).

Most of the zonation schemes are based on planktonic foraminifera developed for the Tethyan Realm (Sigal, 1977; Premoli Silva & Sliter, 1995). Thus, in the Tanzanian coastal basin only the upper Cretaceous succession was researched and zones were established but the mid-Cretaceous as not done and therefore, the current study explores a suitable zonation scheme to fit with the Tanzanian assemblage and create Biozones for this part of the mid-Cretaceous of Tanzania.

The distribution of planktonic foraminifera is controlled by factors such as temperature, salinity, nutrient supply and oxygen (Hemleben and others, 1989). The distribution is affected by biological factors such as productivity, food supply or symbiosis (Be', 1977). Studies on palaeobiogeographical distribution patterns show a distinctive depth stratification of planktonic foraminifera (Hart & Bailey, 1979; Hart, 1999; Price & Hart, 2002). Globular forms, such as the genus *Hedbergella* seem to have inhabited near-surface waters, while flattened; keeled morphotypes represent deeper habitats (Caron & Homewood, 1983). According to Leckie

(1987) depth stratification of planktonic foraminifera seems to be partially a function of water density, especially in low latitudes.

The ratio of keeled specimens within a planktonic assemblage can be regarded as a proxy for water depth with increasing ratios indicating deeper waters (Leckie, 1987). Moreover, the ratio of planktonic to benthic specimens of a foraminiferal assemblage (P/B ratio) gives an indication of open-oceanic versus near-shore conditions (Murray, 1976), with enhanced planktonic ratios pointing to a more marine environment. This proxy can therefore, be used for paleoceanographic reconstruction (Gräfe, 1999).

Planktonic and benthic foraminifera tests are useful for analysis of stable isotopes and trace elements for reconstructing and understanding of the paleoceanography. The ratio of the stable oxygen isotope $^{18}O/^{16}O$ is used for estimation of water temperature (Anderson & Arthur, 1983). Variations of $\delta^{13}C$ isotopes are useful tool for the reconstruction of water mass movement and paleoproductivity (e.g., Shackelton, 1977). Ca/Mg ratio can be used to reconstruct fluctuations in sea surface temperatures (Hastings and others, 1998). The Sr/Ca ratio serves as a proxy for the estimation of sea-level fluctuations (Grahan and others, 1982). Planktonic foraminifera are major contributors of pelagic carbonates of about 32% - 80% of the total deep marine $CaCO_3$ budget in the world oceans since their radiation in the early Cretaceous (Schiebel, 2002).

1.6.4 Evolution and Taxonomy of Cretaceous benthic foraminifera

1.6.5 Agglutinated foraminifera

The agglutinated foraminifera were present since Cambrian time, and are the largest group and vary in morphology. They build their shell using varieties of materials obtained from the sea floor e.g. species such as *Hyperammina* and *Rhabdammina*. The globular and hemispherical form the Astrorhizidae; one–third are tubular, and coiled and others about one-fifth are irregular (Loeblich & Tappan, 1987 and reference therein; Haynes, 1981 and references therein). The chamber forms and arrangements are used to differentiate the group; the hemispherical to globular forms Ammodiscacea and Saccamminidae, Astrorhizidae are tubular, and branched, and the Ammodiscidae are enrolled and irregular unwounded form. Astrorhizidae and Ammodiscidae apertures are formed as open end of the tube and can be more than one if the tube is branched and open at both ends. The *Saccammina* has short neck while *Lagenammina* are much longer considerably extended including the genus *Pelosina*. *Rhizammina* are not selective and build shells using any particles available (Haynes, 1981). *Bathysiphon* build shells using sponge spicules glued by cement and *Rhabdamina* build using quartz grains and glued by cement. *Hyperammina* have two or more layers and particles are of different size and arrangements ((Loeblich & Tappan, 1987 and reference therein; Haynes, 1981 and references therein). In the fossil record, Ammodiscacea is the first group of foraminifera and appeared in the Cambrian bearing a hard shell. Astrorhizidae and Saccamminidae were very abundant in the Ordovician and the appearance of *Hyperammina, Rhabdammina*. Enrolled tubular genera appear in the Silurian, and all groups of families were present at the end of the early Palaeozoic and contain *Glomospira* and *Ammodiscus* (Loeblich & Tappan, 1987 and reference therein). The primitive globular saccamminids arisen from allogromiids and in turn, by extension of the apertural neck into a tube gave rise to the straight and enrolled tubular forms. The Lituolacea originate from the *Ammodiscus* and well represented in the carboniferous and gave rise to *Haplophragmoides* (Loeblich & Tappan, 1987 and reference therein). The uniserial form the *Reophax* descent from Ammodiscacea via *Hyperammina* and are said to be polyphyletic i.e. they have many different lines of lineage due to its uncoiling nature of their shell also originate from *Ammobaculites* present in the Carboniferous.

In the Carboniferous Trochamminidae appeared the group is represented by *Trochammina* with simple basal aperture (Loeblich and Tappan, 1987 and reference therein). Verneuilinidae and the Ataxophragmiidae were dominant trochospiral forms in the Cretaceous, high trochospiral Ataxophragmiacea in the Mesozoic and were present from the Triassic. *Verneuilina* gave rise to *Gaudryina* in the late Triassic and to *Dorothia* and its close relative *Marsonella* in the early Cretaceous. *Gaudryina* possibly gave rise to *Spiroplectinata,* in the Albian and *Verneuilina* to *Tritaxia* (Haynes, 1981 and references therein). The agglutinated foraminifera are long ranging species and have continuous evolutionary history since the Cambrian and new genera evolved in the Silurian and late Palaeozoic, the late Mesozoic and early Tertiary. The first appearance of these species is stratigraphical important (Loeblich and Tappan, 1987 and references therein).

The largest group of foraminifera are Miliolida which appeared in the upper Palaeozoic and have long evolutionary history from upper Palaeozoic and their distribution changes through time. There are important as rock builders from Jurassic onwards and reefal communities from the Triassic onwards and range to Recent (Loeblich and Tappan, 1987 and reference therein). Miliolida are thought to descent from *Spirillina* or *Ammodiscus* (Loeblich and Tappan, 1987 and reference therein).

1.6.6 Calcareous benthic foraminifera

The Nodosariida first appeared in the Permian and became rare all the way through to early Triassic and attain maximum numbers in late Triassic and Jurassic. They can be differentiated by its planispiral, uncoiled and uniserial or polymorphine chamber arrangements. Their wall texture is glassy, radial hyaline heavily perforated with fine pores. Aperture is mostly terminal in many genera with radiating slits or grooves. Majority of this group are uniserial ornamented with ribs or costae, umbilical bosses, septal nodes and peripheral keels (Loeblich &Tappan, 1987; Haynes, 1981).

The genus *Lenticulina* is planispiral compressed involute, uncoiled in the adult stage and is grouped as *Astacolus*, if semi-compressed; as Planularia, if very compressed; as *Marginulinopsis*, if subrounded to rounded; as *Saracenaria* if triangular. Apertural form and position is important to these forms with gradational features (Loeblich & Tappan, 1987; Haynes, 1981).

The Nodosariids evolved from the microgranular, uniserial *Nodosinella*, and *Lenticulina* descent from Endothyridae such as *Robuloides*. The Lingulinidae range from the Permian to the Recent. *Lingulina* arisen from the primitive Permian *Lenticulina* stock, with robuline apertural slit (Haynes, 1981 and the references therein). Also *Nodosaria* with round chambers may arise from *Lingulonodosaria*. Plectofrondiculariidae are polyphyletic group that may have arisen from different members of the Nodosariidae at different times. *Eoguttulina* appeared in the Triassic and are ancestral of the Polymorphinacea. *Globulina* gave rise to *Pyrulina* and *Guttulina* in the Jurassic and later to *Polymorphina* (Haynes, 1981 and references therein).

The Nodosariida are long ranging especially the families and genera but some short ranging species are useful for dating Jurassic and early Cretaceous and in a lesser extent to the middle to late Cretaceous. The Nodosariida, in particular the Nodosariidae, are commonly the dominant element in these faunas, sometimes to the almost complete exclusion of other groups. The Polymorphinacea occur rarely. The main genera of the Nodosariidae occur throughout but *Citharina* does not appear before the upper Lias. *Lingulina* is prominent in the late Triassic and Lias and *Lenticulina* in the middle and late Jurassic. In the current research there are intervals where planktonic foraminifera are absent and the species of Nodosariidae has helped in dating the sections due to some short range calcareous benthic taxa present (Haynes, 1981 and the references therein).

1.7 Research objectives

The Aptian/Albian boundary represents a time of pronounced biotic and climatic change but the records of the global scale are few and concentrated in the Atlantic, Pacific and possibly few areas in the Indian Ocean none in the east African continental shelf. The purpose of this research is to produce a detailed stratigraphy of the Aptian /Albian sequence if is present in the coastal Tanzania and document the southwest Tethys biotic and sedimentary response to major ocean climate changes associated with this time interval. The approach taken is to generate and synthesize stratigraphic, micropalaentological and geochemical information from new and existing sedimentary core material collected from coastal Tanzania by industry and through scientific research. As part of this I have selected a site for drilling a new borehole that recovered lower part of the Aptian /Albian boundary to middle Albian marine succession previously unsampled in Tanzania. The overarching objectives are to:

- Identify the Aptian/Albian boundary if present in the coastal Tanzania marine succession and attempt to correlate lithologically, biostratigraphically and correlate this section to carbon isotope stratigraphy (see figure 1.2b).
- Document the climatic / sea level response to Aptian-Albian changes on the Tanzanian margin.
- Document the associated pattern of planktonic and benthic foraminifera biotic turnover.

- Discover whether the late Aptian - early Albian margin in Tanzania contains organic carbon rich sediments associated with the OAE1b, as found in the Atlantic and North West Tethys.

- Assess the implications of the lithology for offshore hydrocarbon prospects.

In order to meet these objectives this study presents:

1. New foraminiferal biostratigraphy and age interpretation for the mid-Cretaceous (Aptian -Cenomanian) hemipelagic sections from coastal Tanzania, comprising biozone assessments and correlation of the Tanzanian material to global Cretaceous standard zonation schemes (Caron, 1985; González-Donoso & others, 2007; Huber & Leckie, 2011; Postuma, 1971; Premoli Silva & Sliter, 1999).

2. The first detailed stratigraphic range charts, taxonomic lists and illustrations of Tanzanian Aptian-Albian foraminifera.

3. Planktonic and benthic foraminifera abundance patterns and assessments of test preservation state.

4. Carbon isotope stratigraphy for the late Aptian to early Albian interval.

5. Assessment of the sediment organic carbon content during the Aptian/Albian.

The results show the Aptian /Albian boundary sequence is missing and probably have been eroded. Therefore, there is a stratigraphic gap of the boundary section. The improved stratigraphic framework will also benefit hydrocarbon exploration and the identification of possible source and reservoir rocks in the Cretaceous of Tanzania as well as establishing the stratigraphic gaps within the studied mid-Cretaceous sequences.

Chapter 2 Materials and Methods

2.1 Introduction

This research on the mid-Cretaceous Stratigraphy and Micropalaeontology of the Coastal Basin of Tanzania is based on foraminiferal data and bulk rock samples recovered in deep exploration wells, shallow boreholes and field outcrops from the north, central and southern coastal basins of Tanzania (see figures 2.1-2.1l; tables 2.1, 2.1b - 2.1m and Appendix I; Tables 2.2 - 2.6, 2.8 - 2.11). Much of the material was derived from industrial activities over the past 40 years. The samples, which include core, subsurface and ditch cutting material, were made available for this project by the Tanzania Petroleum Development Corporation (TPDC). Outcrop samples were from Msanga, Msata, Chalinze, Lugoba, Tarawanda and Mandawa areas, and were collected during fieldwork conducted in July 2009 (see tables 2.1k - 2.1l). Core and subsurface samples were studied in preference to ditch cuttings since they are less prone to down-hole contamination (see Appendix I; tables 2.2 - 2.4 and 2.11). However, core samples were unavailable for a number of deep exploration wells (e.g. Kizimbani-1, Kiwangwa-1, Kisarawe-1 and Makarawe-1; see Appendix-I; tables 2.5 - 2.6 & 2.8 - 2.9.) and it was necessary to examine the ditch-cuttings samples. Ditch cuttings were collected at an average interval of 3 m and 6 m. The project also benefited from the drilling and recovery of two new shallow boreholes, TDP Holes 40A and 40B. This provided the opportunity for more continuous sampling for studying the detailed sequence of events associated with the mid-Cretaceous climate events and environmental changes (Chapter 5). The site selection and drilling of this hole is described in section 2.1 below.

A total of seven hundred and thirteen samples were analyzed. Samples for foraminiferal analysis were selected from the clay intervals (see Appendix I, tables 2.2-2.11). Ditch cuttings, cores and outcrop samples were used for foraminifera biostratigraphy. Ninety-two bulk rock samples from TDP40B were processed for isotopes, total carbon and organic carbon (table 2.1b - 2.1e).

Table 2.1: Samples used for this research

Well/Borehole	No. of Samples	Cuttings	Cores	Basins
Kiwangwa-1 well	71 samples	cuttings	no cores	Ruvu Basin
Makarawe-1well	44 samples	cuttings	cuttings	Ruvu Basin
Songo Songo-4	79 cores	29 cuttings	cores	Rufiji Trough
Luhoi-1 borehole	80-samples	no cuttings	cores only	Rufiji Trough
Kisarawe-1well	63 samples	cuttings	cuttings	DSM Platform
Kizimbani-1 well	59-samples	cuttings	no cores	Mandawa Basin
TDP40A borehole	63 samples	no cuttings	cores	
TDP40B borehole	65 samples	no cuttings	cores	
TDP40B borehole	92 bulk rock samples	no cuttings	cores	
Bagamoyo-Msata, Chalinze and Msanga outcrops	51 samples	outcrops	no cores	Ruvu and DSM Platform

Table 2.1b: TDP40B bulk rock samples used for this research

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
1	2	0	3	4	1.0
2	1	2	0	1	2.0
2	2	2	0	1	3.0
2	3	2	0	1	4.0
2	3	2	99	100	5.0
3	1	5	1	25	5.1

Table 2.1c: TDP40B bulk rock samples used for this research

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
3	1	5	1	25	5.1
4	1	5.6	14	15	5.8
4	1	5.6	14	15	5.8
4	1	5.6	50	51	6.1
4	2	5.6	0	1	6.6
4	2	5.6	50	51	7.1
4	3	5.6	0	1	7.6
4	3	5.6	39	40	8.0
5	1	8	0	1	8.0
5	2	8	0	1	9.0
5	2	8	50	51	9.5
5	2	8	98	99	10.0
5	3	8	20	21	10.2
5	3	8	35	36	10.4
5	3	8	45	46	10.5
5	3	8	50	51	10.5
5	3	8	55	56	10.6
5	3	8	60	61	10.6
5	3	8	75	76	10.8
5	3	8	80	81	10.8
5	3	8	85	86	10.9
5	3	8	90	91	10.9

Table 2.1d: TDP40B bulk rock samples used for this research

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
5	3	8	99	100	11.0
6	2	11	50	51	12.5
6	3	11	13	14	13.1
7	1	14	0	1	14.0
7	2	14	0	1	15.0
7	3	14	0	1	16.0
8	1	17	41	42	17.4
8	1	17	89	90	17.9
9	1	18	2	3	18.0
9	2	18	0	1	19.0
9	2	18	50	51	19.5
10	1	20	0	1	20.0
10	1	20	50	51	20.5
10	2	20	50	51	21.5
10	3	20	0	1	22.0
11	1	23	64	67	23.7
11	2	23	0	1	24.0
11	3	23	0	1	25.0
12	1	26	16	17	26.2
13	1	29	0	1	29.0
13	2	29	50	51	30.5

Table 2.1e: TDP40B bulk rock samples

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
13	3	29	0	1	31.0
14	1	32	0	1	32.0
14	2	32	0	1	33.0
14	3	32	50	51	34.5
15	1	35	0	1	35.0
15	1	35	75	76	35.8
15	2	35	0	1	36.0
15	2	35	25	26	36.3
15	2	35	71	72	36.7
15	3	35	0	1	37.0
15	3	35	50	51	37.5
16	1	38	20	21	38.2
16	1	38	40	41	38.4
16	1	38	50	51	38.5
16	1	38	60	61	38.6
16	1	38	70	71	38.7
16	1	38	90	91	38.9
16	2	38	0	1	39.0
16	2	38	10	11	39.1
16	2	38	30	31	39.3
16	2	38	50	51	39.5

Table 2.1f: TDP40A cores

Core	Top core drilled	Bottom core drilled	Cored Interval	Recovery	Not Recovered	Bottom of cored interval (m)
1	0.00	2.00	2.00	1.43	0.57	1.4
2	2.00	4.60	2.60	2.37	0.23	4.4
3	4.60	5.00	0.40	0.40	0.00	5.0
4	5.00	8.00	2.90	2.90	0.10	8.0
5	8.00	11.00	2.90	2.90	0.10	11.0
6	11.00	14.00	3.00	3.00	0.00	14.0
7	14.00	15.00	1.00	0.80	0.20	14.8
8	15.00	17.00	2.00	1.30	0.70	16.3
9	17.00	20.00	3.00	1.80	1.20	19.0
10	20.00	23.00	3.12	3.12	0.00	23.0
11	23.12	26.12	3.12	2.52	0.60	25.5
12	26.12	29.12	3.12	2.92	0.20	29.0
13	29.12	32.37	3.25	3.25	0.00	32.4
14	32.37	35.37	3.00	2.94	0.06	35.3
15	35.37	38.37	3.00	2.90	0.10	38.3
16	38.37	41.37	3.00	2.85	0.15	41.2
17	41.37	44.37	3.00	2.87	0.13	44.2
18	44.37	47.37	3.00	2.95	0.05	47.3
19	47.37	50.45	3.08	3.08	0.00	50.5
22	56.45	59.45	3.00	2.84	0.16	59.3
23	59.45	62.45	3.00	1.37	1.63	61.0

Table 2.1g: TDP40B cores

Core	Top core drilled	Bottom core drilled	Cored Interval	Recovery	Not Recovered	Bottom of cored interval (m)
22	56.45	59.45	3.00	2.84	0.16	59.3
23	59.45	62.45	3.00	1.37	1.63	61.0
24	62.45	65.45	3.00	0.22	2.78	63.0
25	65.45	68.45	3.00	1.70	1.30	67.2
26	68.45	71.45	3.00	2.04	0.96	70.5
27	71.45	74.45	3.00	2.91	0.09	74.3
28	74.45	77.45	3.00	2.89	0.11	77.3
29	77.45	79.15	1.70	1.50	0.20	79.0
30	79.15	80.45	1.30	0.98	0.32	80.1
31	80.45	83.45	3.00	2.20	0.80	83.0
32	83.45	86.45	3.00	2.82	0.18	86.3
33	86.45	88.45	2.00	0.65	1.35	87.1

Table 2.1h: TDP40B cores

Core	Top core drilled	Bottom core drilled	Cored Interval	Recovery	Not Recovered	Bottom of cored interval (m)
1	0.00	2.00	2.00	1.45	0.55	1.5
2	2.00	5.00	3.00	3.00	0.00	5.0
3	5.00	5.60	0.60	0.45	0.15	5.5
4	5.60	8.00	2.40	2.40	0.00	8.0
5	8.00	11.00	3.00	3.00	0.00	11.0
6	11.00	14.00	3.00	2.30	0.70	13.3

Table 2.1i: TDP40B cores

Core	Top core drilled	Bottom core drilled	Cored Interval	Recovery	Not Recovered	Bottom of cored interval (m)
7	14.00	17.00	3.00	2.60	0.40	16.6
8	17.00	18.00	1.00	0.90	0.10	18.0
9	18.00	20.00	2.00	1.82	0.18	20.0
10	20.00	23.00	3.00	2.9	0.10	23.0
11	23.00	26.00	3.00	2.82	0.18	26.0
12	26.00	29.00	3.00	2.45	0.55	28.5
12	26.00	29.00	3.00	2.45	0.55	28.5
13	29.00	32.00	3.00	2.94	0.06	32.0
14	32.00	35.00	3.00	3.00	0.00	35.0
15	35.00	38.00	3.00	3.00	0.00	38.0
16	38.00	41.00	3.00	2.65	0.35	41.0
17	41.00	44.00	3.00	3.00	0.00	44.0
18	44.00	47.00	3.00	2.83	0.17	47.0
19	47.00	50.00	3.00	2.80	0.20	50.0
20	50.00	53.00	3.00	3.00	0.00	53.0
21	53.00	56.00	3.00	3.00	0.00	56.0
22	56.00	59.00	3.00	3.00	0.00	59.0
23	59.00	62.00	3.00	0.96	2.04	60.0
24	62.00	65.00	3.00	1.00	2.00	63.0
25	65.00	68.00	3.00	1.46	1.54	66.5
26	68.00	70.00	2.00	0.50	1.50	68.5

Table 2.1j: Geographical locations of wells and boreholes

Well	Latitude	Longitude	Basin
Kiwangwa-1 well	06° 21' 43"	38° 32' 56"	Ruvu basin
Makarawe-1 well	05° 33' 10"	38° 52' 11"	Ruvu basin
Songo Songo-4 well	08° 31' 01.43"	39° 29' 30.25"	Rufiji Trough
Kizimbani-1 well	09° 02' 25"	39° 22' 30"	Mandawa basin
Luhoi-1 borehole	07° 51' 00"	38° 57' 00"	Rufiji Trough
TDP40A borehole	09° 11' 15.42"	39° 22'19.68"	Mandawa basin
TDP40B borehole	09° 22'. 257	39° 22'.328	
Kisarawe-1 well	07° 00' 19"	39 °03' 32"	DSM Platform

Table 2.1k: Geographical locations of outcrop samples

LOCALITIES	WGS 84	Lat/Lon hddd°mm.mmm'			
Date	Locality	Sample	Latitude	Longitude	Altitude
22/07/2009 06:23	Stop 1	AK 22-1	S7 16.474	E38 45.183	398 m
22/07/2009 06:36	Stop 2	AK 22-2	S7 16.513	E38 45.176	372 m
22/07/2009 07:02	Stop 3	AK 22-3	S7 16.507	E38 45.124	407 m
22/07/2009 07:04	Stop 4	AK 22-4	S7 16.516	E38 45.114	407 m
22/07/2009 09:11	Stop 5	AK 22-5	S7 17.671	E38 43.681	283 m
22/07/2009 09:23	Stop 6	AK 22-6	S7 17.664	E38 43.688	285 m
22/07/2009 09:26	Stop 7	AK 22-7	S7 17.653	E38 43.700	287 m
22/07/2009 09:37	Stop 8	AK 22-8	S7 17.633	E38 43.722	290 m

Table 2.1l: Geographical locations of outcrop samples

LOCALITIES	WGS 84	Lat/Lon hddd°mm.mmm'			
Date	Locality	Sample	Latitude	Longitude	Altitude
22/07/2009 09:50	Stop 9	AK 22-9	S7 17.617	E38 43.738	291 m
22/07/2009 09:52	Stop 10	AK 22-10	S7 17.605	E38 43.751	294 m
22/07/2009 10:02	Stop 11	AK 22-11	S7 17.592	E38 43.766	296 m
22/07/2009 10:09	Stop 12	AK 22-12	S7 17.584	E38 43.772	297 m
22/07/2009 10:14	Stop 12	AK 22-13	S7 17.577	E38 43.778	298 m
22/07/2009 10:23	Stop 12	AK 22-14	S7 17.566	E38 43.785	298 m
23/07/2009 06:10	Stop1	AK 23-1	S6 38.761	E38 24.903	167 m
23/07/2009 06:10	Stop1	AK 23-2	S6 38.761	E38 24.903	167 m
23/07/2009 06:29	Stop1	AK 23-3	S6 38.750	E38 24.926	165 m
23/07/2009 07:47	Stop 2	AK 23-4	S6 37.366	E38 20.789	184 m
23/07/2009 08:08	Stop 2	AK 23-5	S6 37.378	E38 20.794	189 m
23/07/2009 08:23	Stop 3	AK 23-6	S6 36.125	E38 20.218	173 m
23/07/2009 08:31	Stop 3	AK 23-7	S6 36.032	E38 20.206	177 m
23/07/2009 09:34	Stop 4	AK 23-8	S6 30.432	E38 27.191	205 m
23/07/2009 09:54	Stop 4	AK 23-9	S6 30.420	E38 27.212	202 m
23/07/2009 14:29	Stop5	AK 23-10	S6 29.144	E38 26.596	159 m
23/07/2009 14:36	Stop5	AK 23-11	S6 29.144	E38 26.581	161 m
23/07/2009 14:57	Stop 6	AK 23-12	S6 28.657	E38 25.558	168 m
23/07/2009 15:19	Stop7	AK 23-13	S6 28.213	E38 24.358	188 m
23/07/2009 15:28	Stop7	AK 23-14	S6 28.193	E38 24.323	191 m
23/07/2009 16:27	Stop 8	AK 23-15	S6 21.372	E38 28.616	202 m
23/07/2009 16:44	Stop 9	AK 23-16	S6 21.711	E38 31.006	207 m

Table 2.1m: Geographical locations of outcrop samples

LOCALITIES	WGS 84	Lat/Lon hddd°mm.mmm'			
Date	Locality	Sample	Latitude	Longitude	Altitude
23/07/2009 17:05	Stop 9	AK 23-17	S6 21.723	E38 31.045	213 m
23/07/2009 17:12	Stop 9	AK 23-18	S6 21.725	E38 31.056	215 m
23/07/2009 17:28	Stop10	AK 23-19	S6 22.043	E38 32.302	219 m
23/07/2009 17:35	Stop10	AK 23-20	S6 22.055	E38 32.320	221 m
23/07/2009 17:42	Stop10	AK 23-21	S6 22.075	E38 32.354	224 m
23/07/2009 17:52	Stop11	AK 23-22	S6 22.322	E38 32.941	207 m
23/07/2009 17:59	Stop11	AK 23-23	S6 22.318	E38 32.936	206 m
23/07/2009 18:10	Stop11	AK 23-24	S6 22.330	E38 32.954	208 m
23/07/2009 08:57	Junction to Tarawanda		S6 27.426	E38 19.829	268 m
23/07/2009 16:02	Msata junction to Bagamoyo		S6 20.016	E38 23.419	273 m
23/07/2009 18:21	Kiwangwa		S6 22.410	E38 35.290	231 m
23/07/2009 09:23	Tarawanda		S6 29.861	E38 28.002	171 m

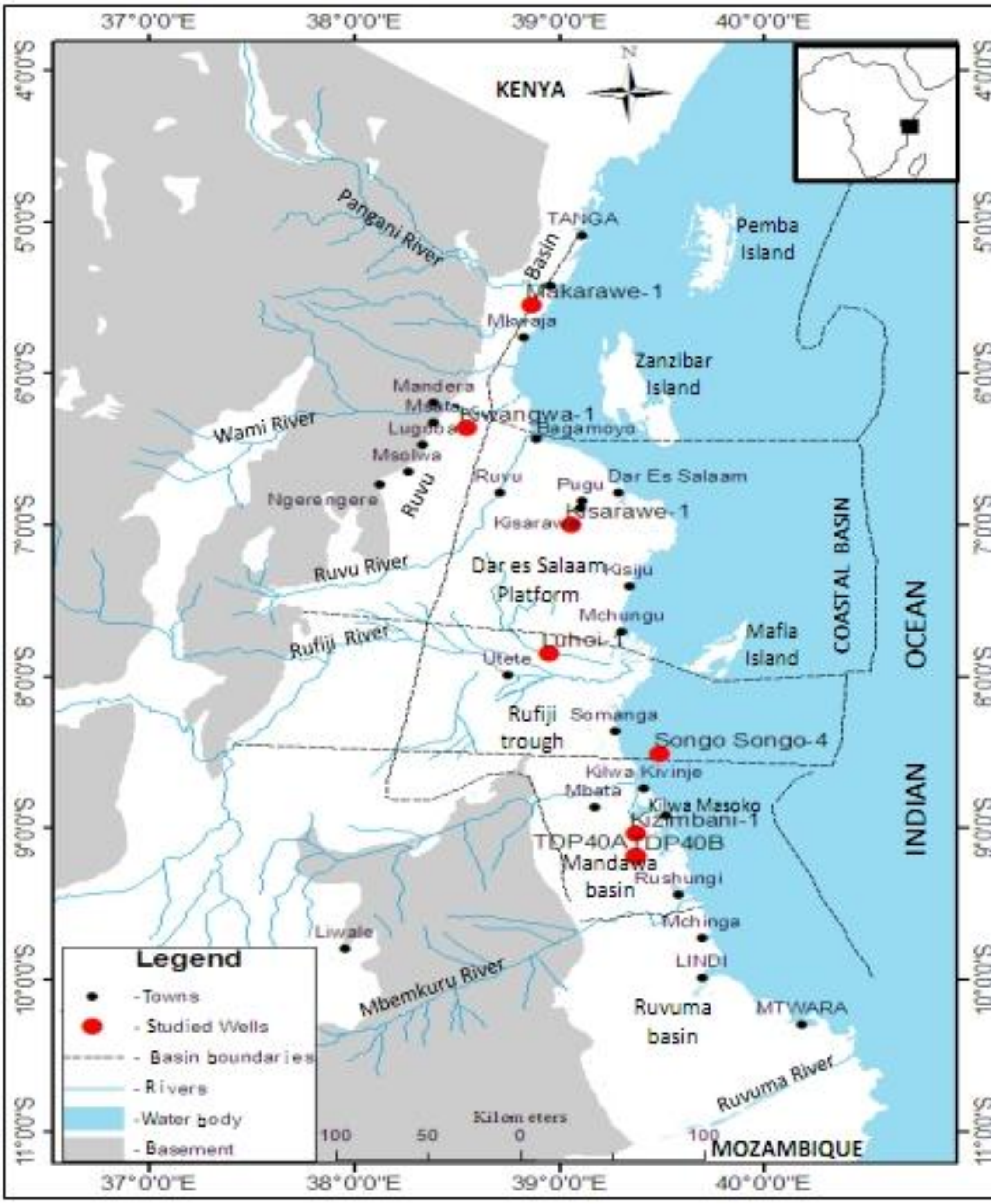


Figure 2.1: Map showing location of wells and boreholes drilled in the coastal basins, Tanzania, for this research.

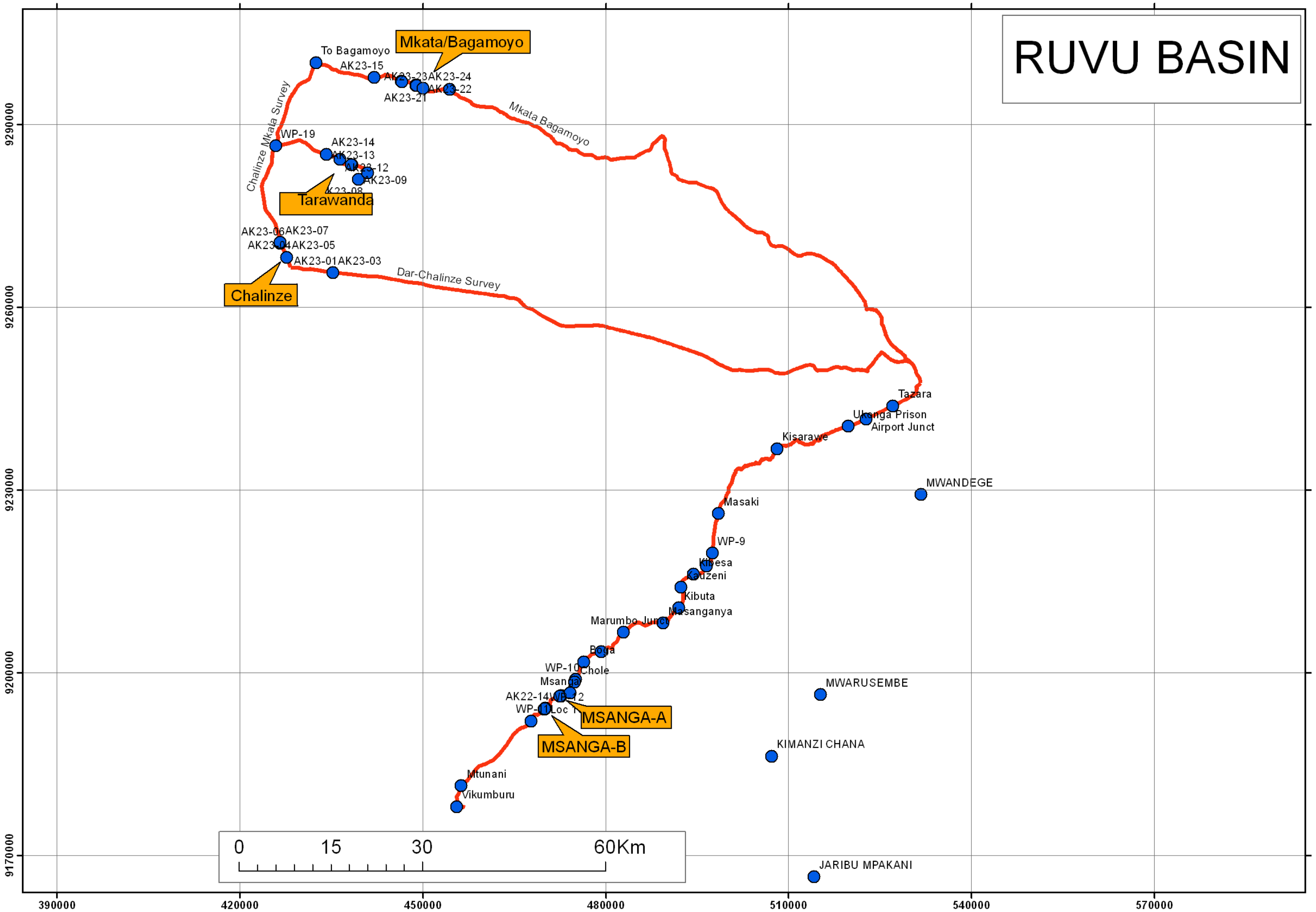


Figure 2.1b: Map showing an outline of the 2009 fieldwork conducted in the Ruvu basin with their corresponding outcrop samples location.

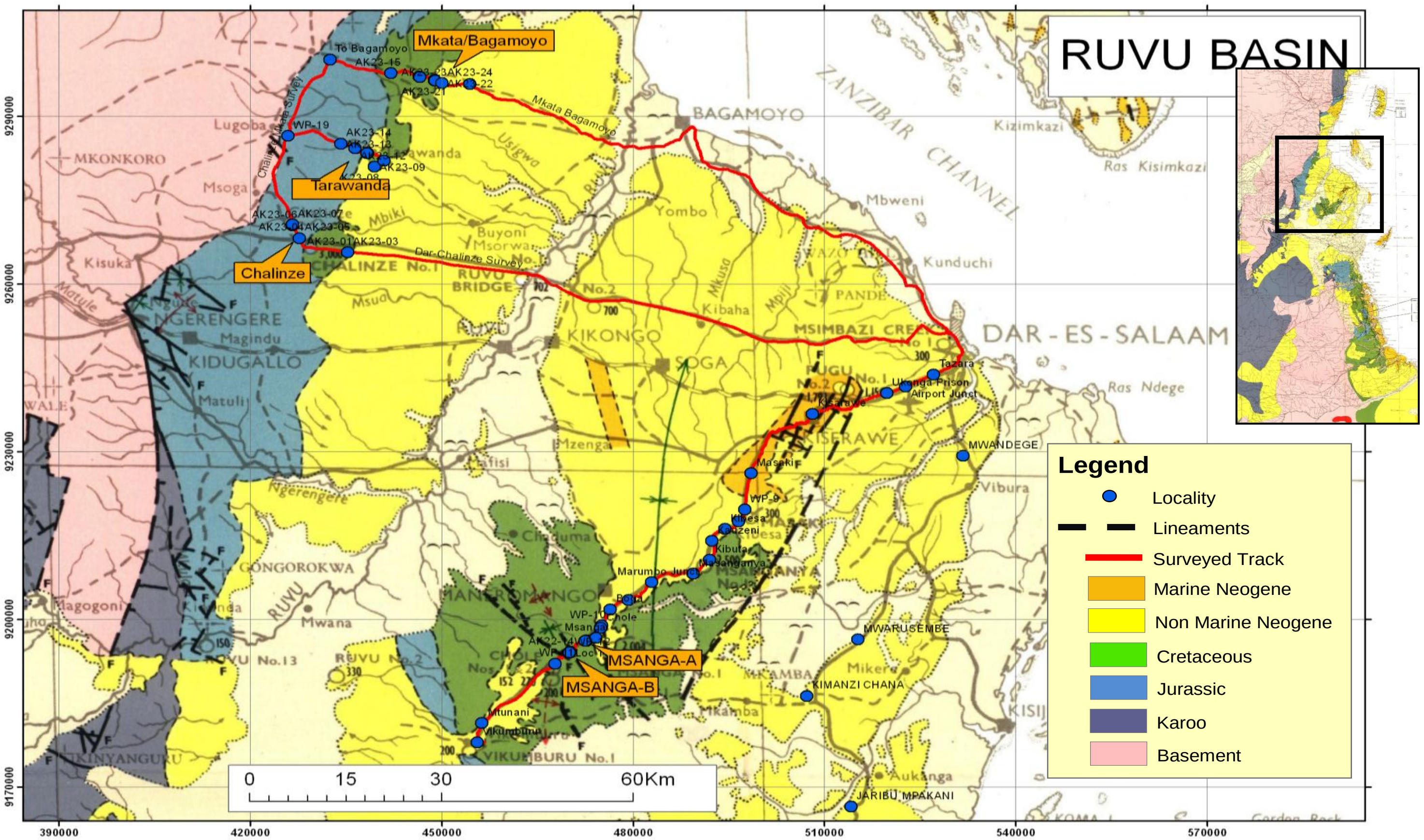


Figure 2.1c: Map showing location of outcrop samples collected during 2009 fieldwork in Ruvu basin (The area is divided into 5-sections; Msanga-A and Msanga-B, Tarawanda, Chalinze, and Mkata - Bagamoyo (Modified after Kent and others, 1971).

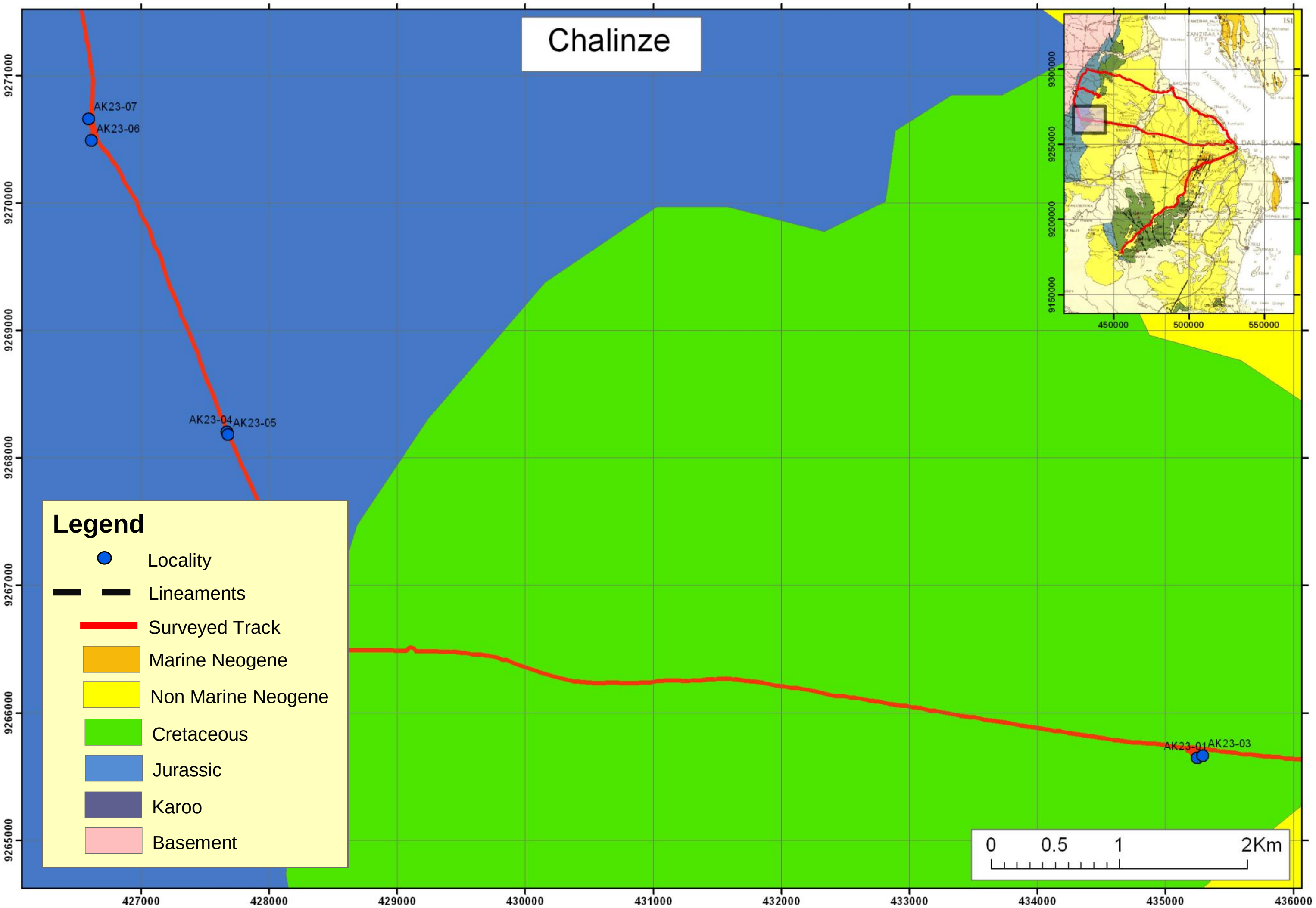


Figure 2.1d: Map showing location of outcrop samples (AK23-08 to AK23-14); Chalinze area, Ruvu basin (Modified after Kent and others, 1971).

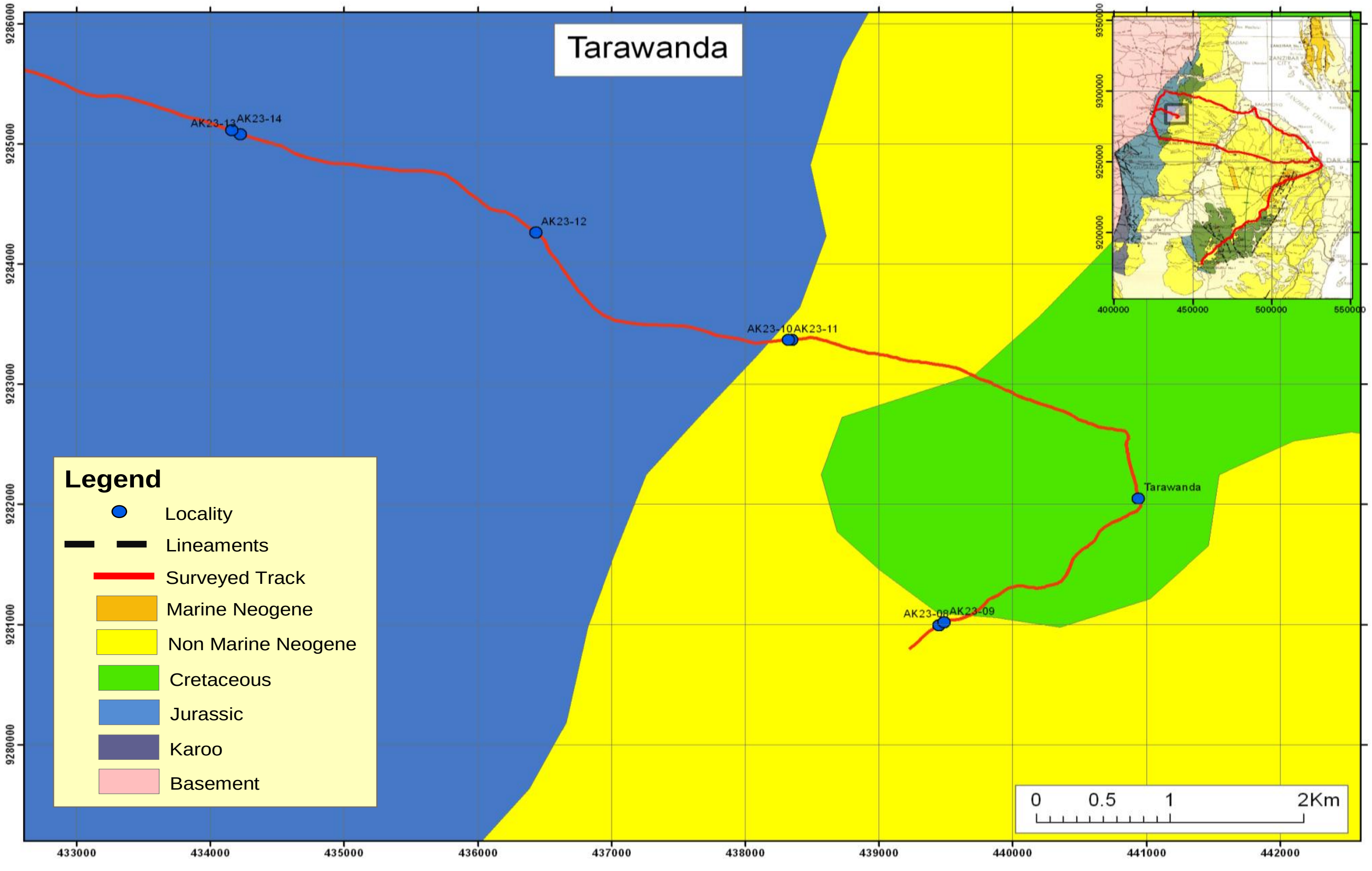


Figure 2.1e: Map showing location of outcrop samples (AK23-08 - AK 23-14); Tarawanda area, Ruvu basin (Modified after Kent and others, 1971).

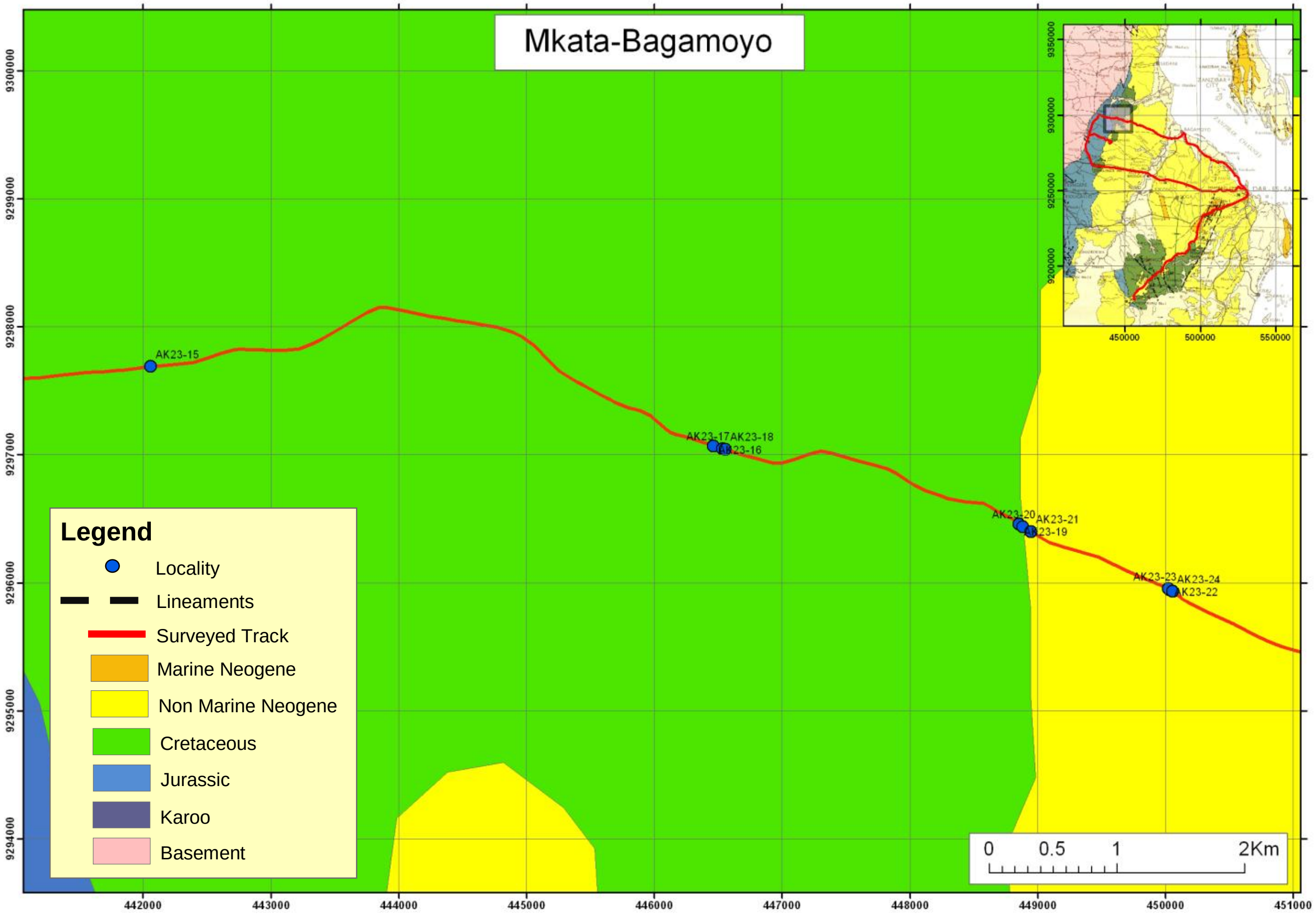


Figure 2.1f: Map showing location of outcrop samples (AK22-15 - AK23-24); Mkata-Bagamoyo area, Ruvu basin (Modified after Kent and others, 1971).

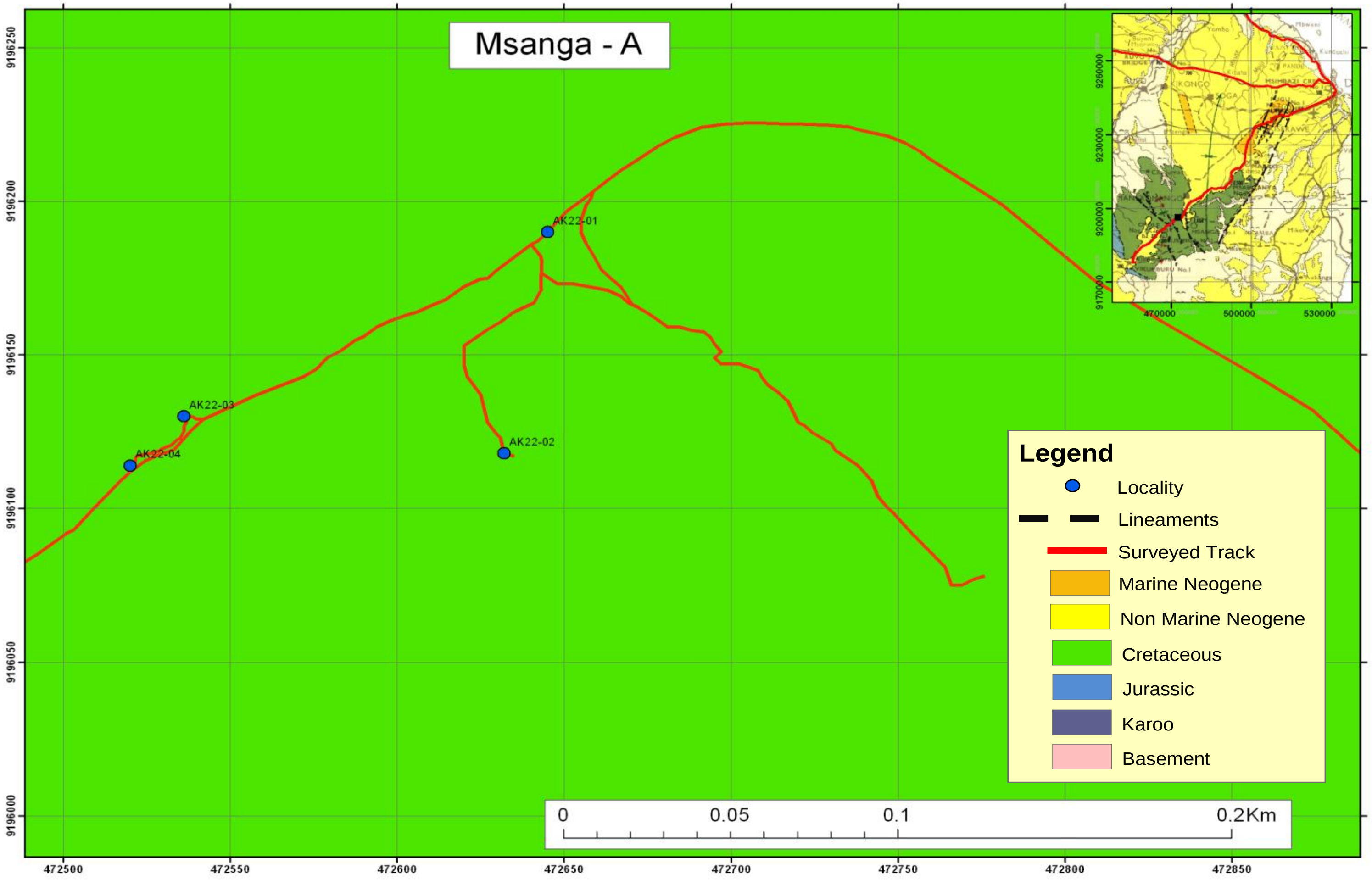


Figure 2.1g: Map showing location of outcrop samples (AK22-01 - AK22-04); Msanga- A area, Ruvu basin, (Modified after Kent and others, 1971).

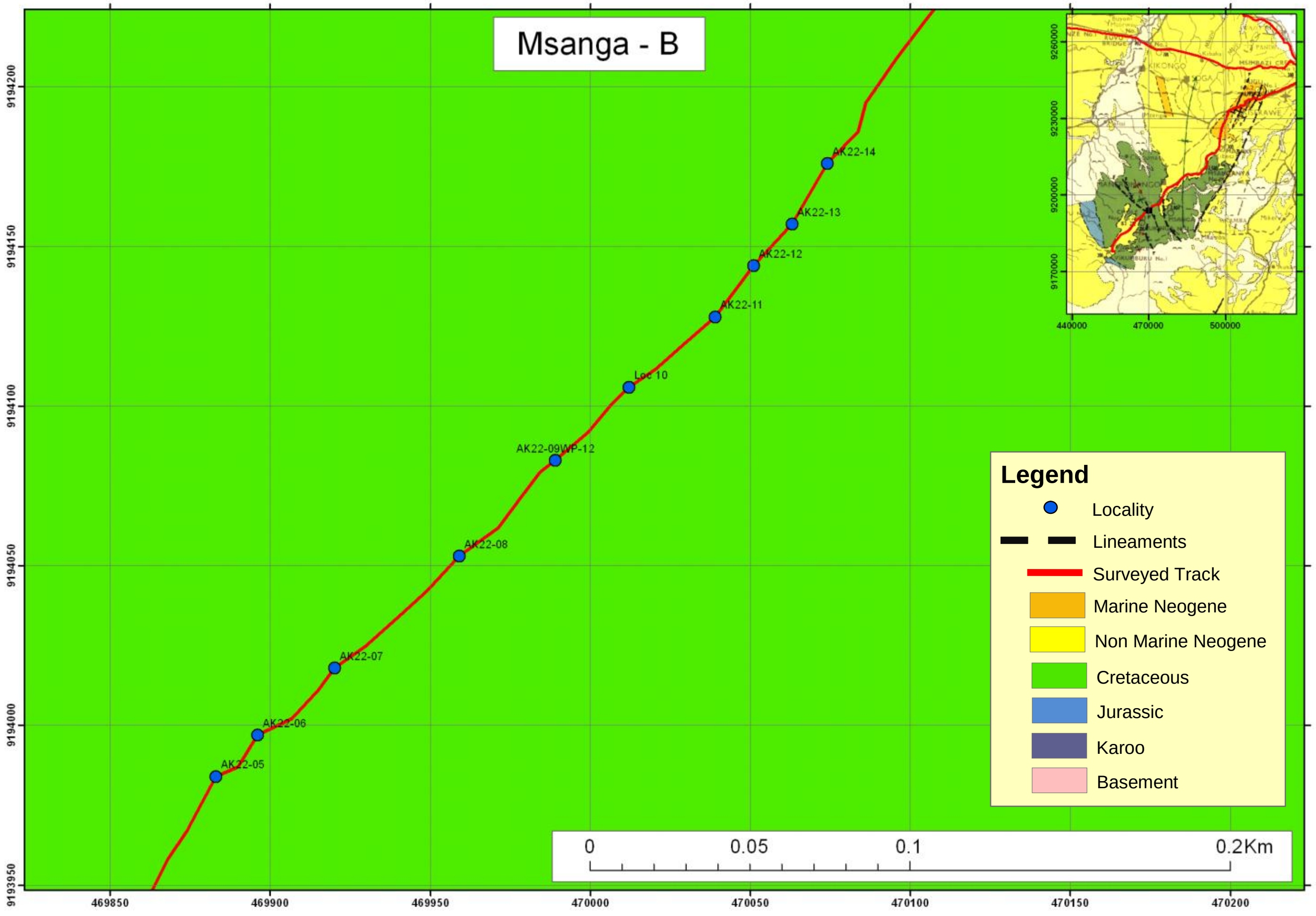


Figure 2.1h: Map showing location of outcrop samples (AK22-05 – AK22-14); Msanga-B area, Ruvu basin (Modified after Kent and others, 1971).

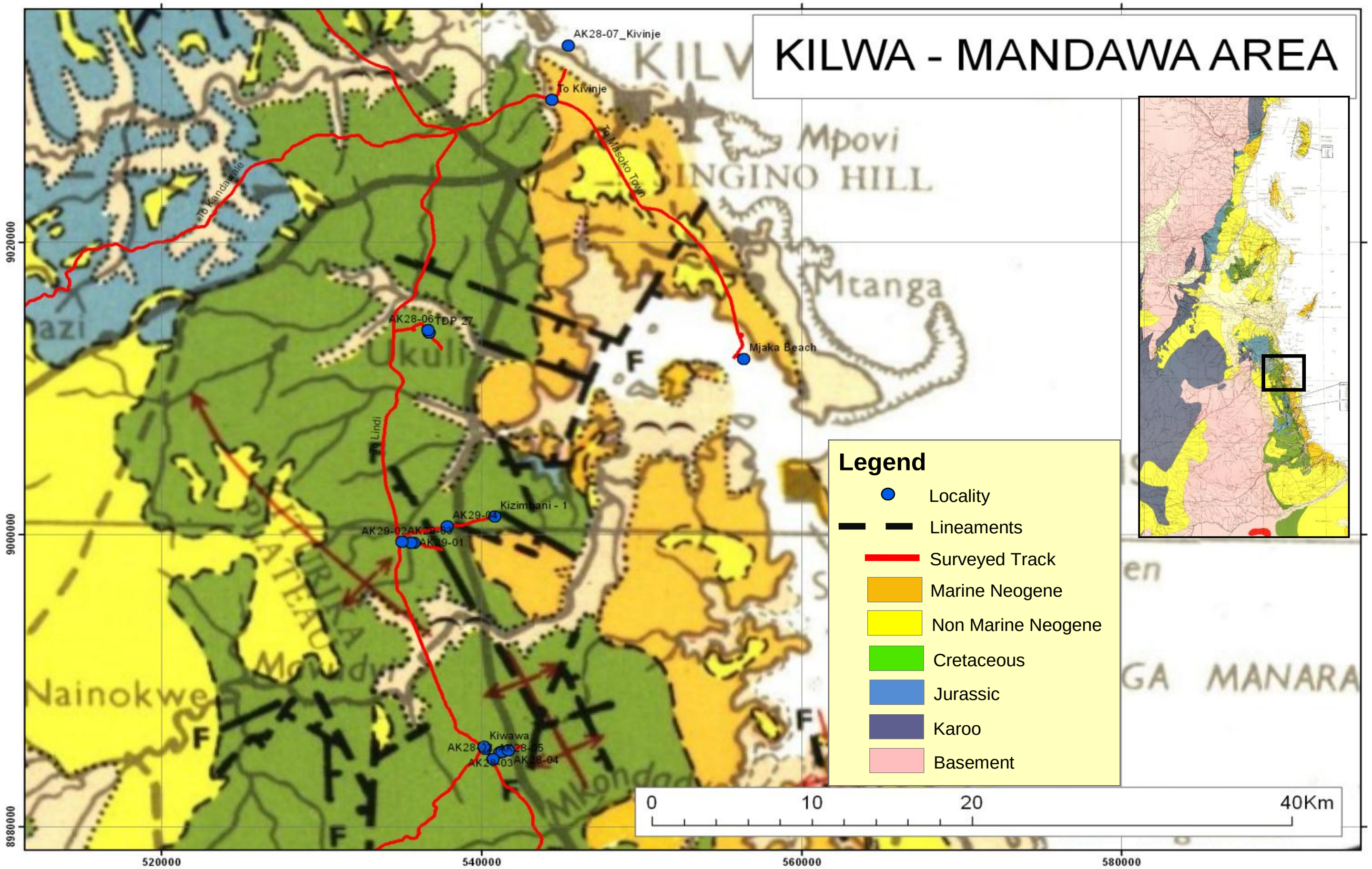


Figure 2.1i: Map showing location of outcrop samples (AK28-01-AK28-06 and AK29-01-AK29-04); Kilwa-Mandawa area (The area is divided into 3-sections; Masoko - Kivinje, Kiwawa and Kimamba, Mandawa basin (Modified after Kent, 1971). **Note:** Location of samples is shown clearly on large scale maps; Figures 2.1j - 2.1l below

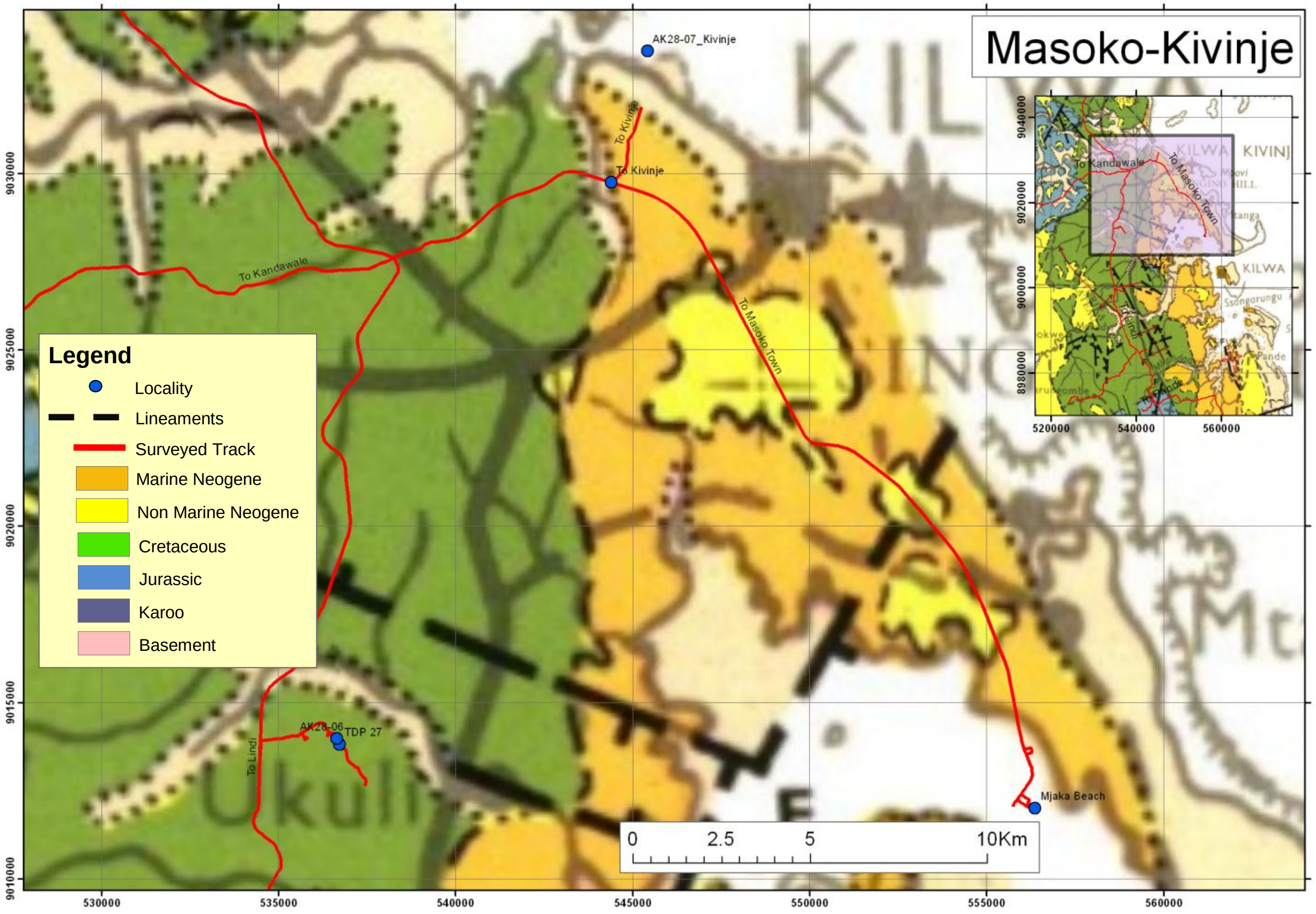


Figure 2.1j: Map showing location of outcrop samples (AK28-06 and AK28-07); Masoko-Kivinje area, Mandawa basin (Modified after Kent and others, 1971).

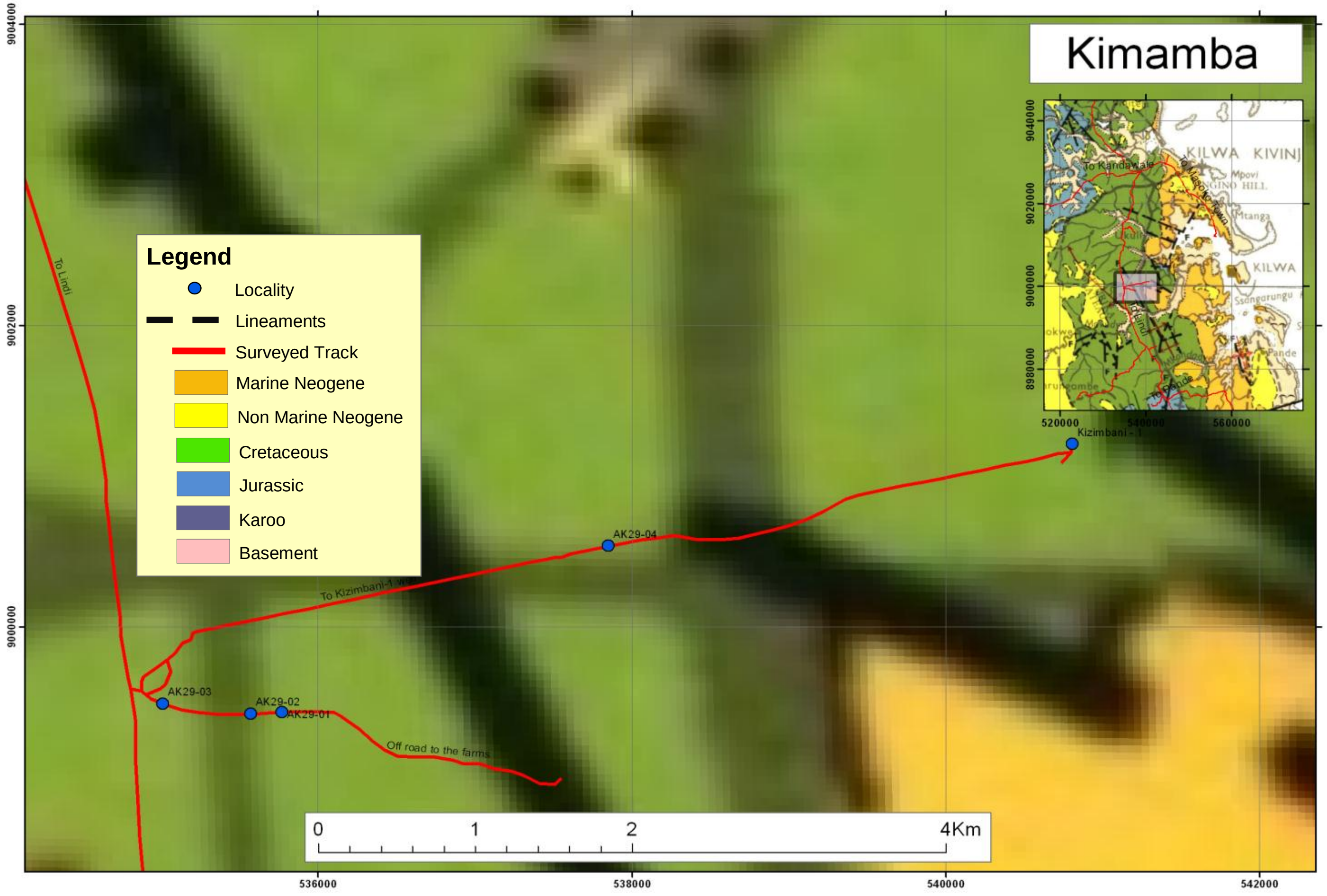


Figure 2.1k: Map showing location of outcrop samples (AK29-01 to AK29-04); Kimamba area, Mandawa basin, (Modified after Kent and others, 1971).

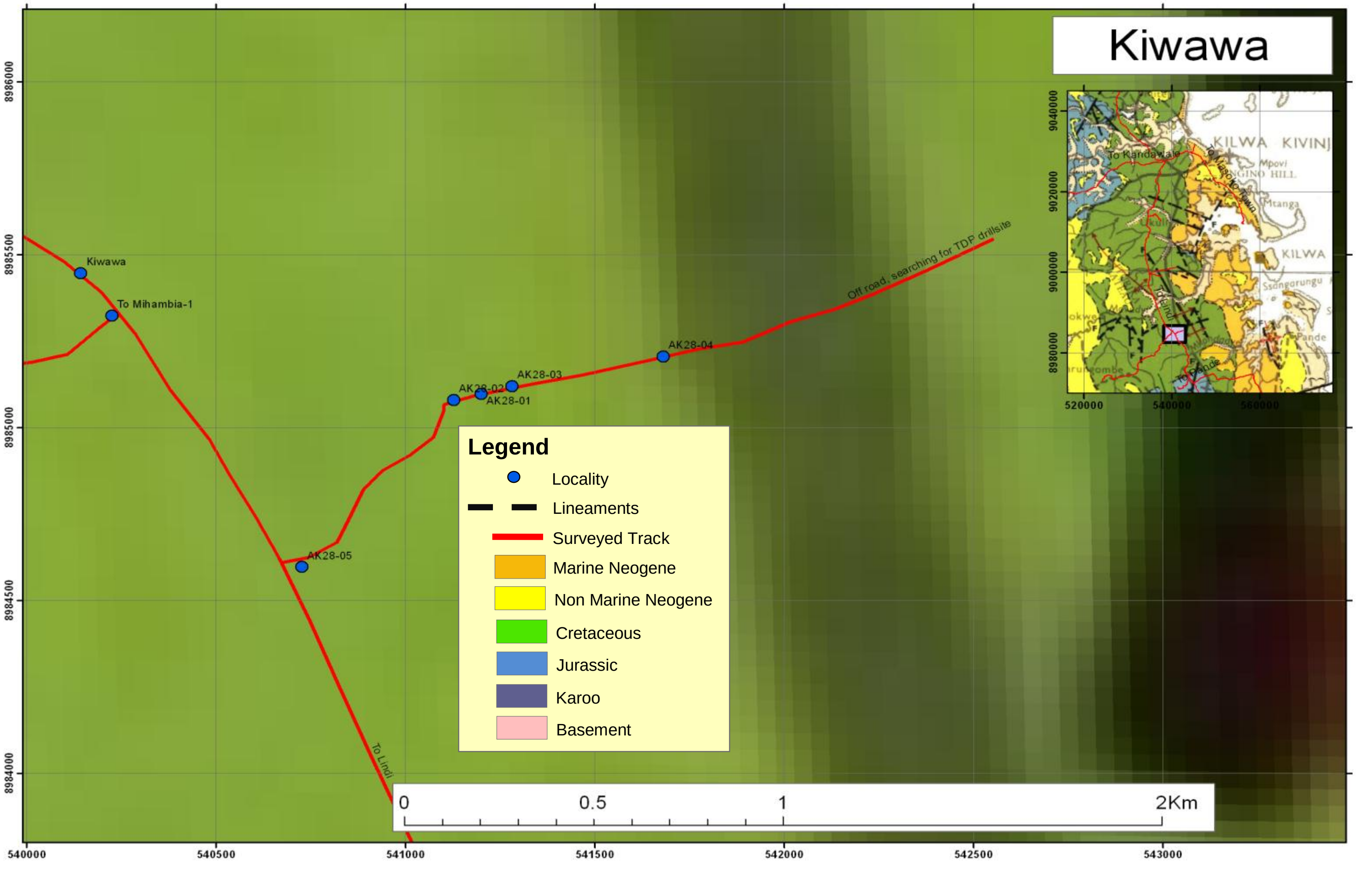


Figure 2.1l: Map showing location of outcrop samples (AK28-01 - AK28-05); Kiwawa area, Mandawa basin (Modified after Kent and others, 1971).

2.2 TDP Site 40

2.2.1 Site Selection

The combination of geological fieldwork and drilling of the shallow boreholes over the past ten years i.e 1998-2009, has put in place the first comprehensive stratigraphy of the upper Cretaceous to Palaeogene of the south-east coast of Tanzania (Nicholas and others, 2006). These records show that the Tanzanian coastal sedimentary succession is one of the most complete sections in the world containing well preserved microfossils (Pearson and others, 2001). Shallow borehole drilling and field surveys have been carried out in Kilwa and Lindi by the Tanzania Drilling Project team (TDP) and this work resulted in a collection of five hundred outcrop samples and the drilling of forty shallow boreholes, eight of which penetrated Albian-Turonian and two Aptian to Albian successions. Biostratigraphic and geochemical reports have been published covering the upper Cretaceous to Palaeogene sequences (Pearson and others, 2001; 2004; Nicholas and others, 2006). Geochemical palaeoclimates proxy records have also been produced using TDP core samples of Palaeogene age (Lear and others, 2008), with excellently preserved foraminifera providing the warmest tropical paleotemperatures for the periods investigated, and thus, a more realistic picture of past latitudinal thermal gradients. Better recovery of excellently preserved Cretaceous foraminifera in cores was needed in order to produce similar palaeoclimates analysis during the early and mid-Cretaceous times. TDP Site 40A and TDP Site 40B are shown in Appendix I; Figure 2.2 - 2.2b and Figure 2.2c- 2.2d respectively.

Figure 2.2: Showing a Long Year 38 model rig at TDP Site 40A

Figure 2.2b: A tent set-up for the geoscientist working area at the TDP Site 40A

Figure 2.2c: Drillers are setting the rig for drilling Hole TDP 40B; Mkondaji, Kilwa, Tanzania.

Figure 2.2d: Geoscientists working area at the TDP Site 40B

The purpose of drilling at TDP Site 40 was to recover continuous cores for this PhD research because cores have less down hole contamination than cuttings. The goal was to obtain core samples across the Aptian/Albian boundary that could be used to produce the first detailed biostratigraphy and palaeoclimates reconstructions of this event in Tanzania. It was my responsibility to select a location for drilling, after reconnaissance field sampling in the Kilwa area in July 2009, based on the micropalaeontology of sieved outcrop samples, the location for TDP Site 40 boreholes were selected close to Mkondaji village. TDP40A was drilled in August, 2009 with almost 99% core recovery; thirty-three cores were recovered in TDP 40A, and twenty-six cores in TDP 40B. On-site supervision of the drilling of the TDP 40B Hole was my responsibility for core description, core sampling, and collection of core data from daily drilling reports and core-logging using the stratigraphy program 'PSICAT'. These were an additional knowledge to my Micropaleontology background and also enable to expand my research topic, and include stable isotope and chemostratigraphy using the TDP Site 40B material. Assessments of stratigraphy completeness of the two Holes (TDP40A and TDP40B) are reflected in the biostratigraphy section in chapter 5. Assessment of the percentage of core recovery for both holes was done by a Stamico drilling Engineer and stratigraphic completeness was done for both Holes in this research. Further details are presented in Chapter 5.

2.2.2 Drilling, logging and sampling of TDP40

The State Mining Corporation (STAMICO) of Tanzania was contracted by the TDP group leader Dr. Brian Huber (Smithsonian Institution) to drill 500 m core in 2009 covering Cretaceous and Tertiary section missed during the earlier drilling season in Tanzania. These include upper Aptian/early Albian, upper Cenomanian/early Turonian and upper Cretaceous/early Palaeocene. A 'Long-Year-38' drilling rig (see figure 2.2) was used to retrieve cores from the two holes (TDP Site 40 boreholes). Core logging and descriptions were done at the drilling site, using PSICAT, which was downloaded from the 'Chronos' website (http://portal.chronos.org/psicat-site/). Core samples were regularly sieved and examined on site for foraminifera content to provide biostratigraphic control while drilling.

The diamond core drilling method was used to recover cores in TDP Site 40 boreholes. This kind of drilling is mainly used in the mining industry for mineral and in the oil industry for oil exploration. A diamond drilling system comprises three parts; the rotary drill which provides the power, the drill pipe 3 m long, (fig. 2.2e.) and core barrel that contains the recovered rock or sediment core once drilled (fig. 2.2f). A diamond bit is a circular tool that has an open middle area and clears entry into the ground (see fig. 2.2g). Rotary action is used to provide power to force the drill bit into the ground. As the drill bit penetrates the formation and the drill pipe slides in, a core is forced through the hole in the middle of the drill bit. The core then continues sliding into the drill pipe. Inside each drill pipe is a wire-line mechanism. This is used to contain and recover the core sample inside. When one drill pipe is completely in the ground, another is screwed to the top allowing deeper penetration. This process is repeated until the target depth is reached, where after all cores and pipe is retrieved from the ground. Recovered cores are removed from the core barrel and placed on an Aluminium sheet (Fig. 2.2h.). The drillers record the core length, percent recovery, top and base depths. The aluminium sheet containing the cores is lifted carefully to the geoscientists working bench for description and sampling (Fig. 2.2h). Core sizes abbreviated as HQ with core diameter of 63.5 mm and hole diameter 96 mm was used in the first few meters and NQ: core diameter is 47.6 mm and hole diameter 75.5 mm for the remaining bottom part of the hole.

Figure 2.2e: Photograph showing drilling rods used for drilling TDP Site 40 Holes A and B.

Figure 2.7f: Photograph showing core barrels and inner tubes used to recover cores.

Fig. 2.2g: Diamond core drill bits

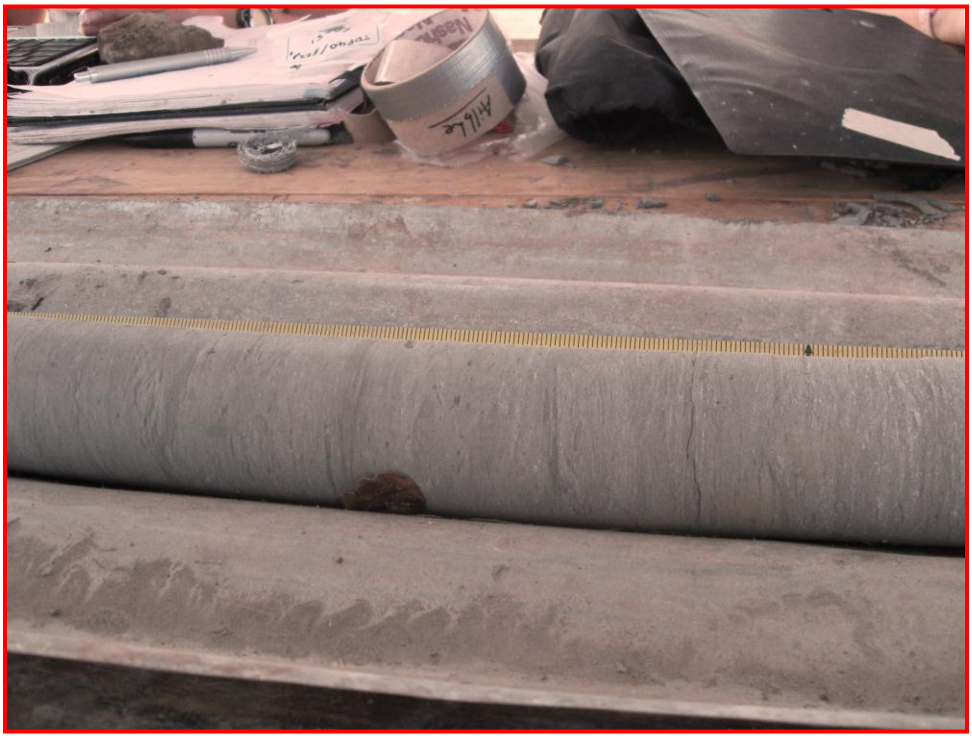


Fig. 2.2h: A core has been placed in a working bench for describing and sampling after being photographed.

2.3 TDP Site 40 Holes

Each core is measured using a three metre wooden rule. The core is cleaned using water and any adhering drilling mud is removed using a potato peeler or knife. The core is then photographed and returned to the working bench for sampling.

For the purposes of sampling and logging each core was divided into three 1m long sections, or part thereof. Foraminiferal samples were taken every 10 or 25 cm depending on the lithology and core recovery. Higher resolution sampling 1 cm for calcareous nannofossil and bulk samples while foraminifera 10-25 cm was done close to the Aptian/Albian boundary. Additional samples were collected at the same time for nannofossil palaeontology, organic, bulk sediment and geological analysis to be used by different laboratories. The remaining core was wrapped in plastic, labelled, and then packed into a core box for transportation back to Dar es Salaam and storage at the TPDC core repository.

2.3.1 Cores and sediment sampling

Accurate measuring and labelling of cores is crucial for producing realistic interpretations of the stratigraphy. Most importantly, the position of the top and bottom of the core must be indicated as the cores are recovered.

Figure 2.2i: Showing Cores are properly packed and ready for transport to Dar es Salaam. After sampling the remaining core material is wrapped in plastic and placed in wooden core boxes for storage and future use.

The core number is indicated by the drillers in the field using numbered wooden blocks that are placed next to each new core on the aluminium sheet. The top of the core is shown by an arrow facing away from the top and the word ‘Top’. Once prepared in this way the core is taken, photographed in natural overhead light. After photographing the core is taken to the geoscientists work bench for sampling. Each core if recovered in full length is of 3.0 m. When sampling the core it's normally divided into three sections and each section is 1.0 m in length. When sampling at an interval of 0-10 cm of the first section, then the sample labeled as follows; first the name of borehole, then the core number, core section and depth in centimetre for the top and bottom interval. e. g., TDP40B/1/1, 0-10 cm = TDP40B (well name), core 1, section 1, with a 10 cm long sample taken between 0 cm and 10 cm in section 1. After sampling the remaining core is wrapped in plastic rolls and labeled (see figure 2.3) The first section of the core is labeled as follows; e.g. by the well name, core number, core section and depth by showing an arrow and written the word 'Top" at the top of the core. Wooden cores boxes were made to store a three meter core and were divided into three compartments each occupied one section of a core and therefore there was no way of mixing up samples.

2.3.2 Logging at TDP Site 40

Core lithology is described on site and the data were recorded using the stratigraphic logging program PSICAT (Reeds, 2007). This is a free programme downloaded from Chronos website. This program helps to draw stratigraphic column diagrams automatically. The core description diagram is drawn at the drilling site and can observe the changes in lithology and grain size etc, (Reed, 2007). In the PSICAT diagram (see figure 2.3) you can fill all the necessary information; like geologic age, stratigraphic unit, core breaks, drilling disturbances, intervals and beds, facies, depositional environment, bioturbation, symbols, fossils, sedimentary structure, biostratigraphic zones, and core number. Also you can log into the diagram all the samples you have taken in each interval, lithologic descriptions and all relevant information of the cores (Reed, 2007).

A detailed user guide that describes the steps required to set up a new logging file in PSICAT can be found in Appendix I.

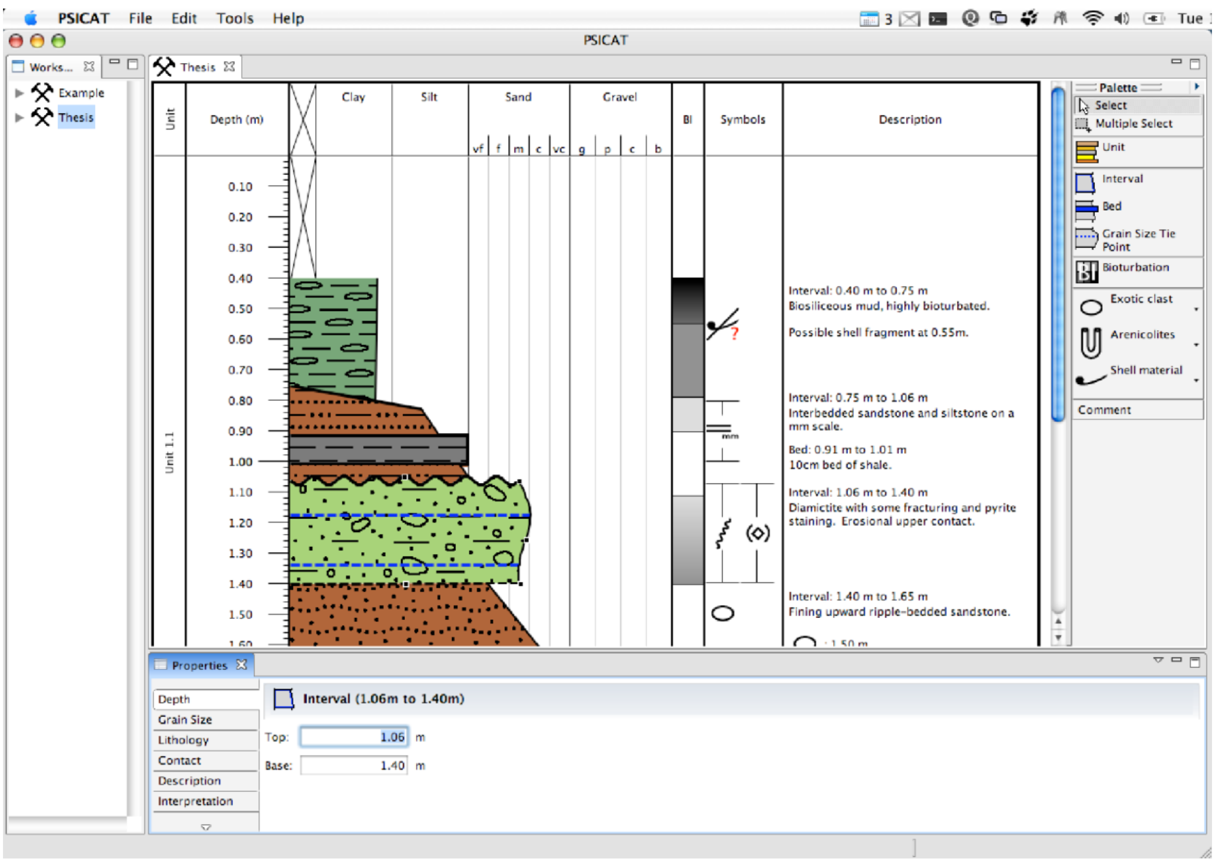


Figure 2.3: An example of core description window illustration of PSICAT's features (after Reed, 2007).

2.4 *Sampling of non TDP material*

Cores from Songo Songo-4 and Luhoi-1 were sampled at the TPDC core repository using the same methods as for TDP40 (figure 2.4, and tables 2.7 - 2.7i). Ditch cuttings from Makarawe-1, Kizimbani-1, Kiwangwa-1 and Kisarawe-1 and few samples from Songo Songo-4 wells were sampled (see tables 2.2 - 2.11). The cuttings samples are collected from the shale shaker using micropalaeontology sieves by a wellsite geologist every 20 or 30 m of drilling. The samples are rinsed with water to remove mud and dried in an oven using aluminium containers and packed in polythene sample bags, well labeled by name of the borehole, depth, date and drilling companies' name and transported in cardboard boxes to TPDC, Dar es Salaam for analysis or storage (see figure 2.4e). Ditch cuttings were sampled after every 3 or 6 m and were labelled accordingly. Outcrop sampling, done by removing overlying sediments by digging and removing away sampled unweathered sediments. Approximately 500 grams were taken from each locality in the field (see figure 2.4b - 2.4d). At each sampling locality the geographical position was recorded with reference to local features and local lithology. Coordinates were also recorded using a handheld GPS.

Figure 2.4: Photograph showing examples of labeled core samples; plastic bags showing well named core section, interval taken in cm and depth in the borehole in metres.

Figure 2.4b: Showing outcrop exposure in Msanga area, Ruvu basin sampled for this research.

Figure 2.4c: showing mid-Cretaceous outcrop in Kilwa area; Mandawa basin.

Figure 2.4d: showing mid-Cretaceous outcrop at Chalinze sampled for this research; Ruvu basin.

Figure 2.4e: Showing Kisarawe-1 well ditch cutting type of samples used for this research.

2.5 Sample preparation for foraminifera studies

The objective of processing techniques is to separate microfossils, foraminifera from the sediment grains that surround them. Only then can microfossils be adequately observed and studied. Unconsolidated sediments and soft rocks will break down after soaking in water for a few hours, whereas harder rocks may first require crushing, boiling or soaking using reagents (Haynes, 1981, Glaessner, 1945).

Samples were prepared using standard micropalaentological techniques (Glaessner, 1945, Haynes, 1981) either using water alone for washing or with a hydrogen peroxide soaking step for harder lithologies. Processing samples in the laboratory required a source of running water, a sieve, containers and chemicals to help disaggregate the sediments.

2.5.1 Soaking in water without adding any reagent

Clay samples from outcrops and newly drilled boreholes were soaked in a Pyrex beaker of 1000 ml and water was added to cover the sample. If the clays were very soft, the samples were washed directly but if slightly harder they were soaked for two to three hours (see figure 2.5). Once softened the samples were washed through a 63 µm mesh sieve size, under a stream of water. The sample was washed until the water passing through the sieve was clear. After every use, the sieve was dipped in a dilute solution of methyl blue dye to identify contaminants from previous samples. The clean residues were carefully transferred to an aluminium drying containers using a jet of water. After settling, the excess water is carefully poured away and the residue was left to dry under the sun (~30°C; see figure 2.5b). The majority of sample preparation was carried out in the TPDC sediment laboratory in Dar es Salaam. In the field the water for washing was obtained from the hotel supply and the washing was conducted using a gardeners' pressurized spray vessel. Samples were prepared at Cardiff University and they were dried in an oven at 50°C. Once dried the residues were placed in labelled glass vials, and sieved into three size fractions (300 µm, 250 µm and 125µm). Species identification for planktonic foraminifera were made on the 125 µm and >125 µm fraction (mid-Cretaceous) were examined for identification and abundance estimates.

2.5.2 Hydrogen Peroxide (H_20_2) Method

Some of the samples from the old drilled exploration wells were resistant to breakdown using water alone and therefore an additional treatment was required to break up the samples. This was done by soaking dry sample in water with 10% H_2O_2 added. The mixture was then stirred and left for 12 hours to disintegrate in 1000 ml Pyrex beaker. Following these steps the mixture was washed over a 63 µm sieve and dried as described above (Haynes, 1981).

Figure 2.5a: Showing preparation of samples for foraminiferal analysis (Clay samples soaked with water and hard shales soaked with water and 10% Hydrogen peroxide to break down.

Figure 2.5b: Drying samples under the sun after washing.

2.6 Foraminifera analysis

Planktonic foraminifera were examined using a Carl Zeiss binocular microscope at 12.5X, 40X, 50X magnification. Separated size fractions were then spread lightly across a black-backed brass picking tray with a grid of rectangular subdivisions, all of equal size. Planktonic foraminifera were most abundant in the 125 μm sieve mesh size fraction. The 250-300 μm mesh size sieve fraction yielded the highest abundance of calcareous and agglutinated benthic species. Individual foraminifera specimens encountered were isolated using the wetted tip of a paint brush (size 000, sable) and placed in 4-hole cavity slide for identification. Wetting of the specimens helps define details of the shell wall and aperture(s). Foraminifera residues were selectively picked for foraminifera and specimens were kept in slides.

The overall moderate preservation of the tests allows the use of most recent taxonomic classification (BouDagher–Fadel and others, 1997; Caron, 1985; González-Donoso, and others, 2007; Loeblich & Tappan, 1987; Petrizzo and Huber, 2006; Postuma, 1971) which is based on wall structure, apertural form and position, and chamber arrangement. Also the most recent classification of Huber and Leckie (2011) was used which is based on pore size and shell ornamentation. Species identification was done by careful comparison with published figures and description in general Cretaceous foraminifera literature (BouDagher-Fadel, 1996; BouDagher-Fadel and others, 1996; 1997; Bolli and others, 1994; Caron, 1985; Caron and Spezzaferri, 2006; Caron and Premoli Silva, 2007; González-Donoso and others, 2007; Jenkins and Murray, 1981, Kaminski and others, 1992; Loeblich and Tappan, 1987; Leckie and others, 2002; MacMillan, 2003; Moullade and others, 2002; 2005; 2008; Petrizzo and Huber, 2006; Petrizzo and others, 2012; Postuma, 1971; Premoli Silva & Sliter, 2002; Premoli Silva and Verga, 2004; Sikora and Olsson, 1991; Premoli Silva and others, 2009; and Schiebnerova, 1972; 1978) as well as more specific works that considered local south and east African micropalaeontology (Singano and Karega, 2000; Karega, 1995; Kent and others, 1973, Kapilima, 1984).

Species counts were made to quantify (i) planktonic/benthic ratios (P/B) (ii) planktonic foraminifera assemblage composition. Down hole P/B records counts were made on samples from deep wells and boreholes that contained the most abundant and best preserved foraminifera. This was performed by counting the numbers of benthic (calcareous and agglutinated) and planktonic species in representative samples of three hundred foraminifera specimens from the 125 μm sieve mesh size fraction. Semi-quantitative estimates of the abundance of individual planktonic foraminifera species were made by visual examination. Abundance was recorded as: Abundant (A); ≥21/300 specimens; Common (C); 11-20/300 specimens, Few (F), 6-10/300 specimens; or Rare (R) 2-5/300 specimens. Microfossil preservation was recorded Moderate to Good as (M-G), Poor-Moderate (P-M) and Poor (P) depending on the level of recrystallisation, infilling and/or dissolution. Moderate-Good preservation; primary morphological character slightly altered, little evidence of dissolution and/recrystallisation and species identification to species level. Moderate -poor preservation; recrystallisation, dissolution, primary morphological characteristics somehow altered and species identifiable to species level, Poor preservation; substantial overgrowth, dissolution, species identification to generic level (see figure 2.6). Data were recorded in a spread sheet together with details of the occurrence of the species in the sections and sample under investigations. Also species distribution charts were drawn for each well (see tables 4.1 to 5.2 in chapter 4 and 5).

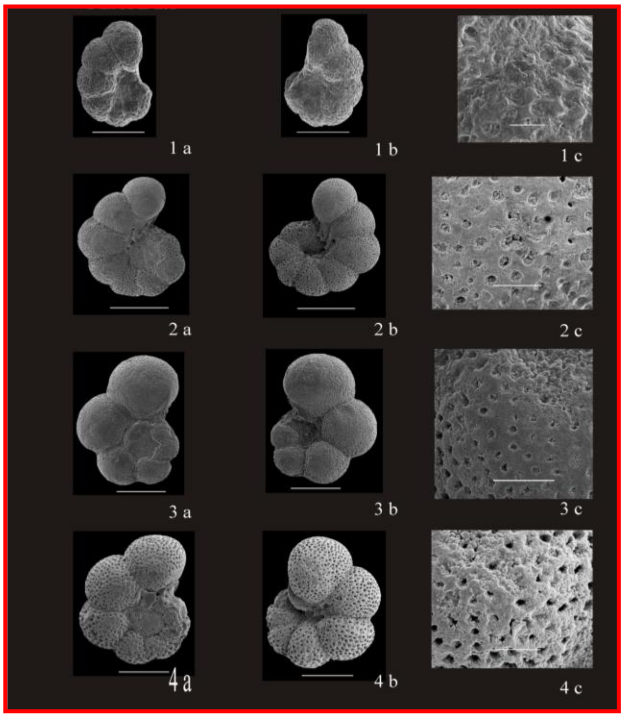


Figure 2.6: Showing categories of preservation of planktonic foraminifera; 1a – c: Poor; 2 a - c: Poor to Moderate, 3 a – c and 4 a – c; Moderate to good.

2.6.1 SEM- imaging and plate preparation

Better preserved and representative individuals of planktonic foraminifera, species, as well as some benthic taxa, were imaged using a Scanning Electron Microscope (XL30 ESEM FEG; see figure 2.6b) in order to aid taxonomic identification and document, the dominant and biostratigraphical important morphologies present in the Tanzania assemblages. Specimens were selected and mounted on a sticky carbon tab on a steel stub. They were then gold coated using a BIO-RAD Sputter Coater 500. Specimens were coated for 3½ minutes at 20-30 mǺ then removed, the STUB reoriented at a 45° angle and coated again for a further 3½ minutes. This approach achieves a better coverage of gold across subspherical surfaces; reducing electron charging and optimizing image quality (see Appendix II for detailed user guide). Three views of each specimen were obtained which were; spiral, umbilical and axial.

Plates were prepared using Adobe Photoshop 6 to edit SEM images and CorelDraw Graphics Suite X3 for final compilation. Further details of the SEM and plate preparation procedures are presented in the Appendix to this chapter.

Figure 2.6b: Scanning Electron Microscope (XL30 ESEM FEG) machine used for photographing foraminifera images.

2.7 *Geochemical analysis*

Ninety-two (92) bulk samples were selected from TDP Site 40B for geochemical and isotope analyses (see table 2.7-2.7c). Preliminary preparations were carried out in Cardiff. Bulk sediment core samples were cleaned using a sharp knife or scalpel to remove surface contamination. The samples were then rinsed in de-ionised water and oven dried for twenty-four hours at 50°C. The dried samples were grounded into powder using a porcelain mortar and pestle. The mortar and pestle were cleaned thoroughly between samples to avoid contamination using Kimtech wipes wetted with 99.9% acetone. The homogenized powdered samples were transferred to 250 ml glass jars for storage and transported to the Department of Earth Sciences, University College London (UCL), where the analysis was carried out. The sample preparation and analytical methods are summarized below. Further details for each specific method are presented in Appendix I-III.

Table 2.7: TDP40B bulk rock samples used for $\delta^{13}C$ isotope analysis

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
1	2	0	3	4	1.0
2	1	2	0	1	2.0
2	2	2	0	1	3.0
2	3	2	0	1	4.0
2	3	2	99	100	5.0
3	1	5	1	25	5.1
4	1	5.6	14	15	5.8
4	1	5.6	50	51	6.1
4	2	5.6	0	1	6.6
4	2	5.6	50	51	7.1
4	3	5.6	0	1	7.6
4	3	5.6	39	40	8.0
5	1	8	0	1	8.0
5	2	8	0	1	9.0
5	2	8	50	51	9.5
5	2	8	98	99	10.0
5	3	8	20	21	10.2
5	3	8	35	36	10.4
5	3	8	45	46	10.5
5	3	8	50	51	10.5

Table 2.7b: TDP40B bulk rock samples used for $\delta^{13}C$ isotope analysis

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
5	3	8	55	56	10.6
5	3	8	60	61	10.6
5	3	8	75	76	10.8
5	3	8	80	81	10.8
5	3	8	85	86	10.9
5	3	8	90	91	10.9
5	3	8	99	100	11.0
6	1	11	20	21	11.2
6	2	11	50	51	12.5
6	3	11	13	14	13.1
7	1	14	0	1	14.0
7	2	14	0	1	15.0
7	3	14	0	1	16.0
8	1	17	41	42	17.4
8	1	17	89	90	17.9
9	1	18	2	3	18.0
9	2	18	0	1	19.0
9	2	18	50	51	19.5
10	1	20	0	1	20.0
10	1	20	50	51	20.5
10	2	20	50	51	21.5
10	3	20	0	1	22.0

Table 2.7c: TDP40B bulk rock samples used for $\delta^{13}C$ isotope analysis

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
11	1	23	64	67	23.7
11	2	23	0	1	24.0
11	3	23	0	1	25.0
12	1	26	16	17	26.2
13	1	29	0	1	29.0
13	2	29	50	51	30.5
13	3	29	0	1	31.0
14	1	32	0	1	32.0
14	2	32	0	1	33.0
14	3	32	50	51	34.5
15	1	35	0	1	35.0
15	1	35	75	76	35.8
15	2	35	0	1	36.0
15	2	35	25	26	36.3
15	2	35	71	72	36.7
15	3	35	0	1	37.0
15	3	35	50	51	37.5
16	1	38	20	21	38.2
16	1	38	40	41	38.4
16	1	38	50	51	38.5

Table 2.7d: TDP40B bulk rock samples used for $\delta^{13}C$ isotope analysis

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
16	1	38	60	61	38.6
16	1	38	70	71	38.7
16	1	38	90	91	38.9
16	2	38	0	1	39.0
16	2	38	10	11	39.1
16	2	38	30	31	39.3
16	2	38	50	51	39.5
16	2	38	70	71	39.7
16	2	38	90	91	39.9
16	3	38	0	1	40.0
16	3	38	30	31	40.3
16	3	38	50	51	40.5
17	1	41	4	5	41.0
17	1	41	92	100	42.0
17	3	41	84	87	44.0
19	1	47	0	1	47.0
19	2	47	50	52	48.5
19	3	47	51	52	49.5
20	1	50	0	1	50.0
20	2	50	0	1	51.0

Table 2.7e: TDP40B bulk rock samples used for $\delta^{13}C$ isotope analysis

core number	core section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)
20	3	50	0	1	52.0
20	3	50	50	51	52.5
21	1	53	50	51	53.5
21	2	53	0	1	54.0
21	3	53	0	1	55.0
22	1	56	0	1	56.0
22	2	56	50	51	57.5
22	3	56	0	1	58.0

2.7.1 Total Carbon analysis

Carbon in the natural environment occurs in its inorganic and organic forms. Although organic carbon may be determined through different methods, it is most efficiently and accurately done through High Temperature Catalytic Combustion analysis coupled with an efficient decarbonatation method. For Total Carbon (TC) analysis 50-80 mg of powdered sample was used. Following standard procedures (Robinson and others, 2006), the dry, untreated samples were transferred onto individual tin cups, (10 x 10 mm in size; see figure 2.7f) and weighed precisely using a microbalance. The corners of the cups were folded to form a small capsule. The capsules were loaded into the autosampler. Analysis was carried out using a Thermo Finnegan Flash Elemental Analyzer Reproducibility of an internal standard was better than ±0.1 wt% (see figure 2.7g).

2.7.2: Total Organic Carbon analysis

Total organic carbon (TOC) analysis involved an acidification step to remove all $CaCO_3$ leaving only organic carbon in the sample. 100-120 mg of the powdered raw sample where weighed into silver cups, and dried in an oven at 60°C for 24 hours to make sure that all the powder is completely dry (see figure 2.7f). The samples were acidified individually using 10% 3M hydrochloric acid. Acid was added gradually 2-3 drops at a time until all the carbonate was removed (reaction stops, it takes a day or two days depending on the type of the sample. The samples were then returned to the oven and dried at 60°C for 24 hours before loading the cups into the autosampler. TOC analysis was carried out using the Flash Elemental Analyser (EA) and the same standards were used for the TC analysis (see figure 2.7j and table 2.7k).

Figure 2.7e: Naming and weighing samples for the TOC and TC analysis.

Figure 2.7f: Tin capsules for filling dried samples for weighing, acidifying and for run TC, TOC in the FlashEA 1112 Series Analyzer.

Figure 2.7g: A FlashEA 1112 Series Analyzer for TC and TOC runs, showing the two furnaces: 680˚C and 900˚C and Gas chromatogram.

Figure 2.7h: Acidified bulk samples dried at 60° C.

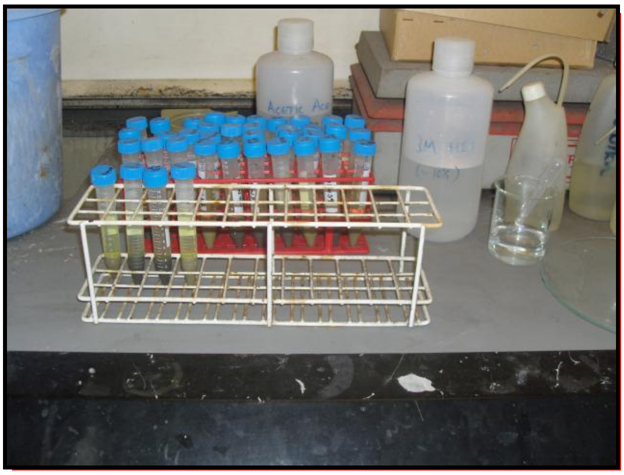


Figure 2.7i: Decarbonatation of samples for isotope analysis.

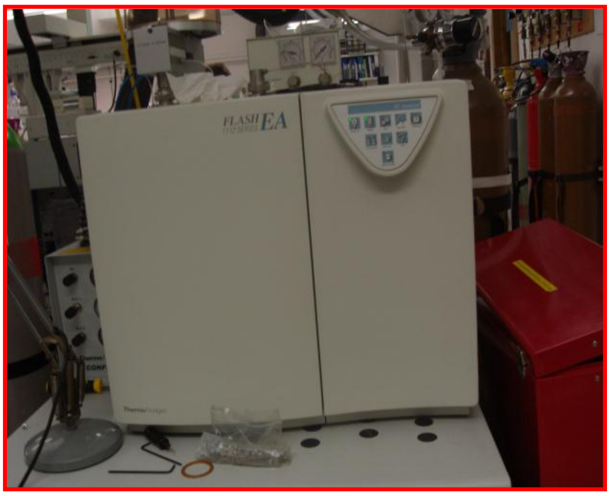


Figure 2.7j: Mass spectrometer coupled with–line to Thermo Finnegan Flash Elemental Analyser (EA) 1112 for isotope analysis.

Figure 2.7k: Standards used for isotope runs.

2.7.3 Inorganic carbon concentration (%CaCO3)

Total inorganic carbon (TIC) was calculated by subtracting TOC from TC {TIC (%) = TC (%) - TOC (%). To express TIC as a percent calcium carbonate (CaCO3), the following equation was used: CaCO3 (%) = (TIC - TOC) x 8.33. Reproducibility of an internal standard was better than ±0.1%.

2.7.4 Organic carbon stable isotope analysis

Stable carbon isotopes have proven to be effective tracers for documenting variations in the carbon cycle in natural environments. Organic carbon (C-org) isotopic composition is determined using a universal triple collector gas source mass spectrometer coupled with-line to an elemental analyzer for automated CO_2 preparation from carbonate samples for analysis. A thorough decarbonatation method must be used prior to analysis and data must be corrected using known house reference material interspersed in every analytical sequence (Werner, 2001). Adjusted to the Pee Dee Belemnite standards (PDB) for carbon and 0.02 for oxygen, adjusted to the Pee Dee Belemnite standards (PDB).

A total of ninety-two (92); see table 2.7- 2.7d) bulk rock samples from the TDP40B were taken in a sampling distance of 1.0 cm. The samples are freshly cut core pieces and homogenised in an agate mortar and pestle, decarbonated for C-org stable isotope analysis. Dried powdered bulk sediment samples each of about 0.5 - 1.0 gm were poured into 15 ml test-tubes to 1 ml mark, and 3M (10%) HCL was added to 4 ml mark using a pipette (see figure 2.7i). The tubes were shaken to aid reaction. Further acid was added up to the 7 ml then 8 ml marks and shaken in between. Acidified samples were left for an hour then shaken again to homogenize the liquid residue. After an hour, sediment remaining at the bottom of the test tubes was stirred to optimize digestion and centrifuged (16 test tubes at a time) for 5 minutes at 2000 RPM using a Bard Tat lock Auto Bach Centrifuge Mark IV. The yellow liquid was poured off as waste without disturbing the remaining solids. The samples were acidified again by adding more 3M HCL up to the 10 ml mark. Test tubes were then left over night, with the lids loosely closed to allow CO_2 to escape (see fig. 2.7i). The next day the samples were centrifuged again and the yellow liquid decanted. De-ionized water was added up to the 14 ml, centrifuged then decanted to rinse off acid (see fig. 2.7i). This step was repeated until the liquid pH was neutral (usually about 6-7), as measured using universal indicator paper. Finally samples were dried in an oven for 2-3 days at 50°C. (see figure 2.7h) After drying, samples were re-powdered and weighed into tin cups for isotopic analysis. Samples were analyzed using a Flash EA connected to a Thermo Finnegan Delta V isotope ratio mass spectrometer (see figure 2.7j). Carbon-isotope ratios are reported in the standard delta notation and were normalised to Vienna Pee Dee Belemnite (VPDB) using external international reference materials (see figure 2.7k). The Carbon ratio is expressed on a per mil (‰) relative to the Pee Dee Belemnite standard (VPDB). Analytical precision was better than 2%.

The C-org isotopic composition is expressed as $\delta^{13}C$ which is defined as:

$$\delta^{13}C = \frac{[(^{13}C/^{12}C)\ \text{sample} - (^{13}C/^{12}C)\ \text{VPDB}]}{(^{13}C/^{12}C)\text{VPDB}} \times 1000$$

$\delta^{13}C$ (‰) represents the parts per thousand difference (per mil) between the sample ratio and that of the international VPDB standard carbonate.

Chapter 3 Taxonomy and Biozonation

3.1 Introduction

The well recognized planktonic foraminiferal zonation of the Tethys e.g., Premoli Silva and Sliter (1995; 1999) placing the upper Aptian-upper Cenomanian interval in the G*lobigerinelloides algerianus* Zone that corresponds to the upper Aptian (Huber and Leckie, 2011) and the *Rotalipora cushmani* corresponds to the middle-upper Cenomanian (González-Donoso and others, 2007) (see figure 3.2-3.4).

A new planktonic foraminiferal biozonation scheme, based on the established Tethyan biozonation schemes, is suggested. Twelve zones and two subzones have been identified from upper Aptian to upper Cenomanian intervals (see figure 3.2). This period can now be compared with the early to mid-Cretaceous succession of Tethyan realm. Furthermore, a stratigraphic framework of upper Aptian to upper Cenomanian sediments of the Tanzanian coastal basin has been established.

The study area of this thesis is a proven hydrocarbon province where the early to mid-Cretaceous strata remain largely under-explored (Kidston and others, 1997). Understanding the history of Cretaceous deposition is very important for the Tanzanian petroleum industry because it is necessary to compare the stratigraphic and geographic distribution of both planktonic and benthic foraminifera in boreholes and compare the assemblages with others that are reported worldwide.

3.2 Evolutionary trends in mid-Cretaceous planktonic foraminifera

The mid-Cretaceous was a period of increased abundance and diversity of calcareous nannofossils, planktonic foraminifera and radiolarian (e. g. Lipps, 1970; Tappan and Loeblich, 1973; Erbacher and Thurow, 1997; Larson and Erba, 1999; Leckie and others, 2002). New niches were created as a result of changed oceanic water mass movements that allowed livelihood and division of new habitats (Leckie and others, 2002). Calcareous nannofossils and planktonic foraminifera were affected at a certain degree by the Oceanic Anoxic Events (OAEs) (e. g. Leckie, 1987; Bralower and others, 1988; Erba, 1994; Hart, 1999; Premoli Silva and others, 1999; Leckie and others, 2002). Leckie and others, (2002) described that mid-Cretaceous planktonic foraminiferal evolution was characterized by periods of high and low rates of turnover. The highest rates of turnover occurred in the early to mid Aptian, across the Aptian/Albian boundary, in the latest Albian, the mid-Cenomanian, and at the Cenomanian /Turonian boundary (Leckie and others, 2002) (see figure 3.1). Three peaks were identified in turnover through latest Aptian - early Albian interval, with the maximum turnover of planktonic foraminifera of the entire mid-Cretaceous occurring near the Aptian/Albian boundary e.g., 69% of the late Aptian species became extinct during the 112-113 Ma interval while the 23% speciation rate for a total of 92% species turnover (Leckie and others, 2002). There had been an increase in species richness in the late Barremian and peaked in the early Aptian, decreased in the mid Aptian, and remains steady throughout much of the late Aptian (see figure 3.1). An increase in diversity occurred between the early and late Albian while the total species richness remaining constant through the mid-Turonian although there were periods of high turnover. Foraminiferal and radiolarians evolutionary patterns show that the highest rates of speciation and /or extinction occur at or near the Oceanic Anoxic Events (OAEs). The major OAEs additional perturbations in the ocean-climate system may have occurred during the mid-Aptian, late Albian, and the mid-Cenomanian on the basis of increased evolutionary activity in both the planktonic foraminifera and the calcareous nannoplankton (Leckie and others, 2002).

Leckie and others, (2002) reported that the size of planktonic foraminiferal varies during the mid-Cretaceous. During the Barremian all species were <250 µm with an average size of 165 µm. Size increased towards the late Aptian corresponding with increasing diversity and variety and complexity (Leckie and others, 2002). The average size of planktonic foraminifera reached 330 µm by the late Aptian with the largest taxon (*Globigerinelloides algerianus*) attaining maximum diameters of 700 µm.

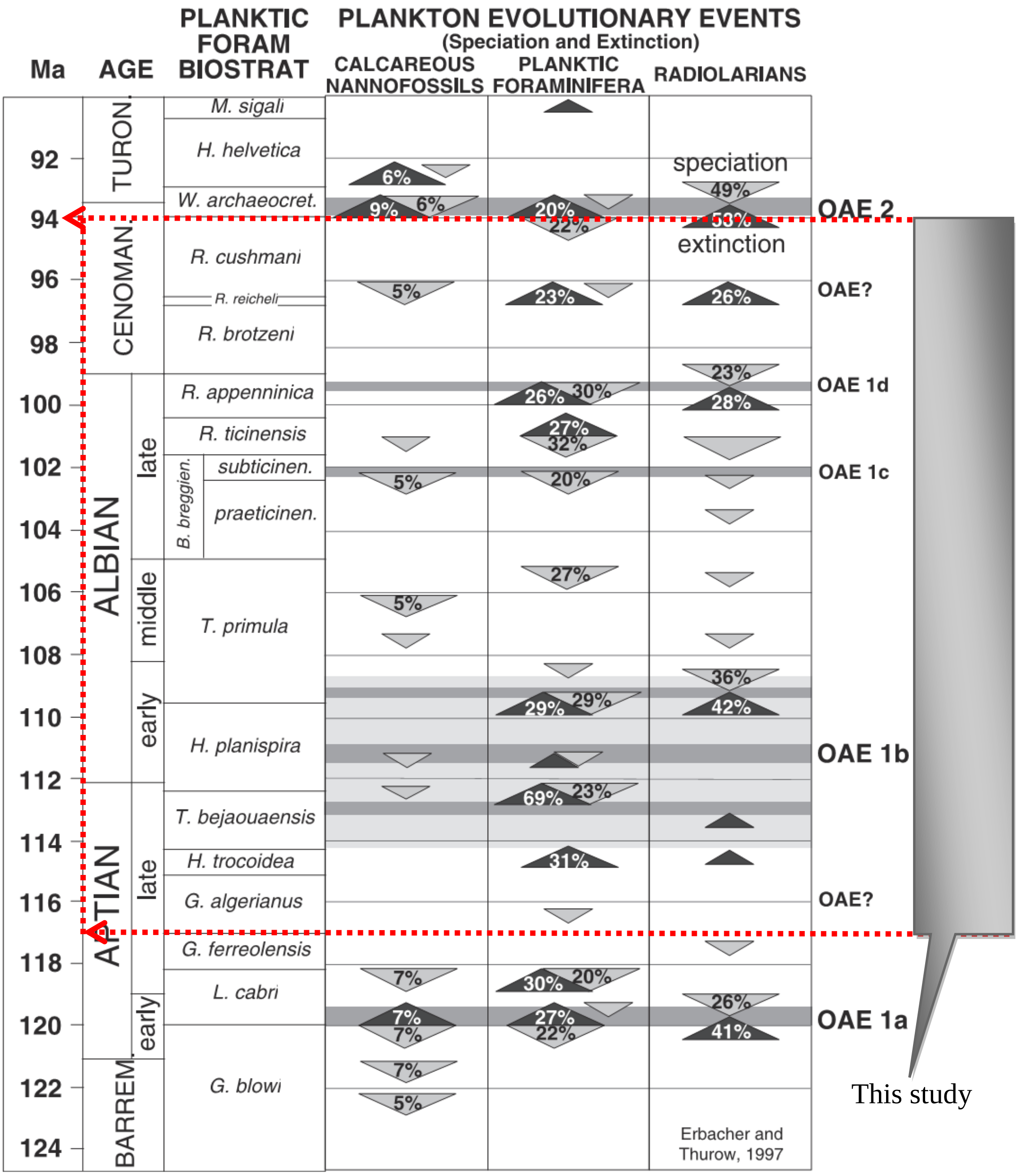


Figure 3.1: Showing mid-Cretaceous plankton evolutionary events (speciation and extinction) of foraminiferal and radiolarians with highest rates of speciation and /or extinction at or near the Oceanic Anoxic Events (OAEs), while calcareous nannofossil with the highest rates of turnover at the OAEs 1a (early Aptian) and OAE2 at the Cenomanian/Turonian boundary (after, Leckie and others, 2002). Grey shaded area and red arrows time interval of the present study.

Planktonic foraminifera size and diversity decreased across the Aptian /Albian boundary; at this time the average size reduced to 230 µm. Test size increased to 400 µm by the end of Albian together with the trend in diversity. The Cenomanian and Turonian planktonic foraminifera are similar to late Albian taxa in their range of size (Leckie and others, 2002).

Planktonic foraminifera are known from the middle Jurassic, and increased in diversity in the middle Cretaceous (Leckie and others, 2002). Before the Aptian, diversity was low; for instance during the Barremian only 15 specimens of *Hedbergella*, *Globigerinelloides* and *Leupoldina* existed (Coccioni and Premoli Silva, 1994). In the Aptian, planktonic foraminiferal numbers increased and the variety of test morphologies diversified until, and at the end of the stage they extincted (see figures 3.2-3.4). This extinction was mainly within the genera *Hedbergella*, and *Globigerinelloides*. These species wall surface structures are fine pores (microperforate) and it has been suggested that they originated from a serial form, an ancestral heterohelicid (Premoli Silva and Sliter, 1999).

An interval of relative evolutionary stasis was experienced in the early Albian until marked diversification resumed with appearance of new genera of trochospiral and planispiral forms and the first appearance of the Family Heterohelicacea. In the middle to late Albian, assemblage tended to increase in size, and there was another great increase in the variety of test morphologies and species richness (see figures 3.1-3.3 and figure 3.4) which is plotted against the current modified after biostratigraphic zonation scheme of Huber and Leckie, 2011, and Premoli Silva and Sliter, 1995).

The upper Albian is characterized by high abundance and diversity of planktonic foraminifera due to development of a strong thermocline and deep water niches and the development of oceanic conditions which results into the appearance of the genera *Biticinella*, *Rotalipora*, *Planomalina* and *Praeglobotruncana* (Petrizzo and Huber, 2006). The local abundance and diversity in the Cretaceous time interval was reduced repeatedly during the oceanic anoxic events including several affected horizons that are notably found in the upper Aptian-lower Albian: Paquier event; OAE1b and uppermost Cenomanian-lowermost Turonian: Bonarelli event; OAE 2. During these events there were typically low species abundance and several horizons within the affected intervals with no planktonic foraminifera. These OAEs correspond to global extinction of species e.g. at the Aptian Albian boundary interval species of hedbergellids while at the Cenomanian /Turonian boundary interval species of rotaliporids extinct (Premoli Silva and Sliter, 1999). Because of their evolutionary history, planktonic foraminifera in particular are important for subdivisions and correlation of Cretaceous sedimentary successions globally, especially in marine environment. In the hydrocarbon industry, accurate biostratigraphical subdivision is important for the identification and correlation of major reservoirs, seals and source rocks are of Cretaceous age. Benthic foraminifera are also of useful in correlating sedimentary sequences, in restricted marine facies where planktonic foraminifera are rare or absent (BouDagher-Fadel and others, 1997).

The planktonic foraminifera encountered in the studied Aptian to Cenomanian interval are described in detail in this chapter. The broad classification of foraminifera used in this study is based on BouDagher-Fadel and others, (1997), Caron (1985), González-Donoso and others (2007), Loeblich and Tappan (1987), Petrizzo and Huber (2006), Postuma (1971), Premoli Silva and Sliter (1995; 1999), Premoli Silva and others (2009), and specific characters of key species were described by Huber and Leckie (2011). These were used for identifying the genera and species. Species descriptions are taken from the original publications and are cited accordingly, with remarks on the Tanzanian occurrences where appropriate.

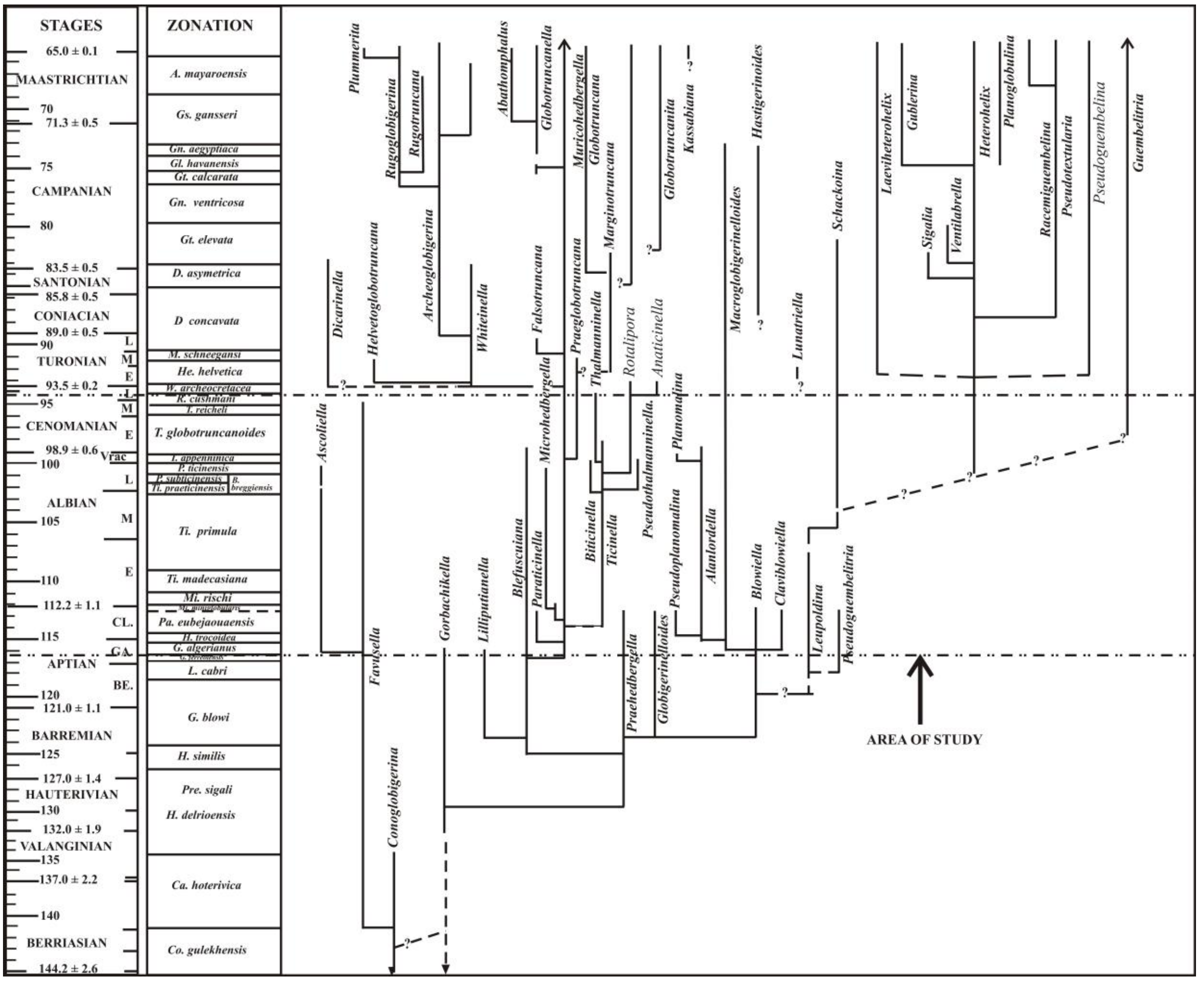


Figure 3.2: Showing evolutionary trend of the Cretaceous planktonic foraminifera from the Valanginian to end of the Cretaceous (modified after Hart, 1999), plotted against the biostratigraphical zonation scheme of Sliter (1989) and Premoli Silva and Sliter (1999). The area covered by the present study is shown in dotted lines.

Note: *A.= Abathomphalus, Ca.= Caucasella , Co.= Conoglobigerina, D.= Dicarinella, G.= Globigerina, Gl.= Globotruncanella, Gn.= Globotruncana, Gt.= Globotruncanita, Gs.= Gansserina, H.= Hedbergella, He.= Helvetoglobotruncana, L.= Leupoldina, M.= Marginotruncana, Mi.= Microhedbergella, Pa.= Paraticinella, Pre.= Praehedbergella, P.= Pseudothalmanninella, R.= Rotalipora, Ti.= Ticinella, T.= Thalmanninella.*

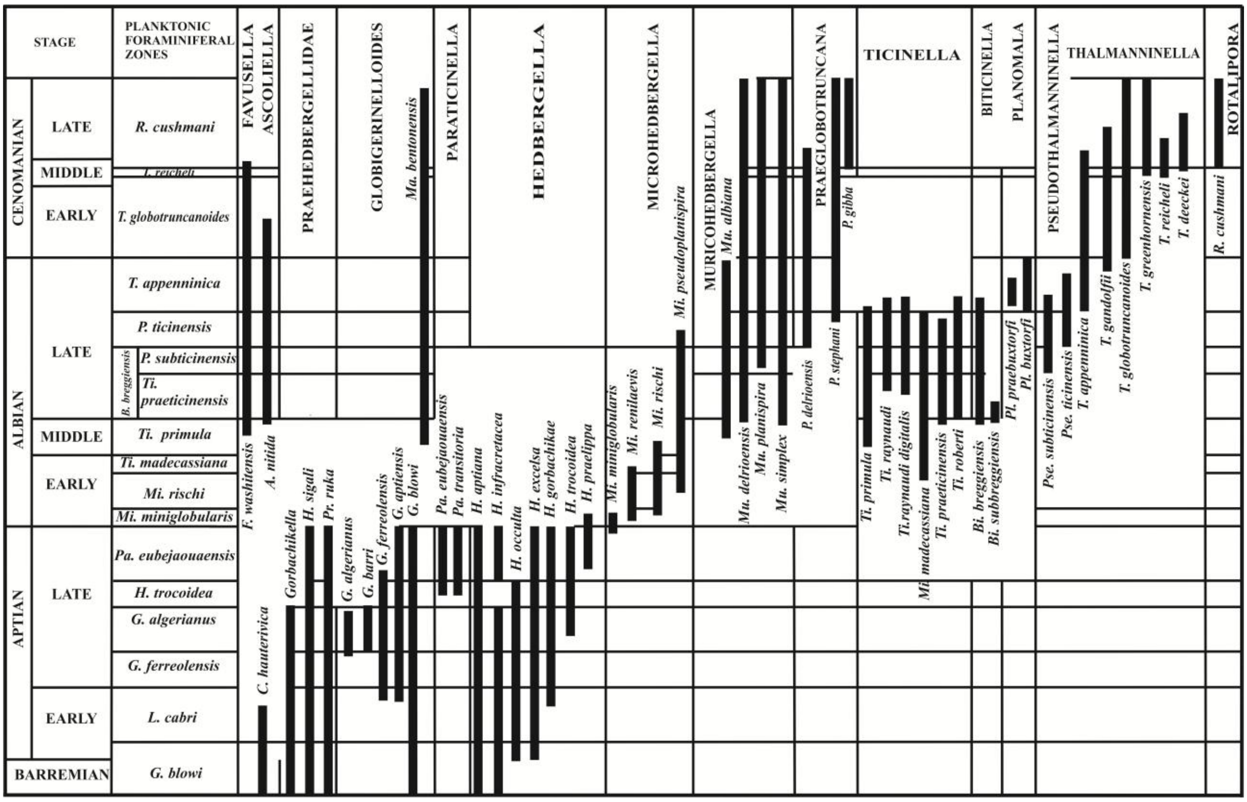


Figure 3.3: Showing the mid-Cretaceous planktonic foraminifera identified from the upper Aptian to Cenomanian of Tanzania coastal basin (modified after Leckie and others (2002) and plotted against biostratigraphic zonation scheme that is modified after Huber & Leckie (2011) and González-Donoso and others (2007)) and their stratigraphic range.

Note: *A = Ascoliella, B.= Biticinella, Ca.= Caucasella, F.= Favusella, G.= Globigerinelloides, H.= Hedbergella, L.= Leupoldina, Ma.= Macroglobigerinelloides, Mi.= Microhedbergella, Mu.= Muricohedbergella, Pa.= Paraticinella, Pl.= Planomalina, Pre.= Praehedbergella, Praeg.= Praeglobotruncana, P.= Pseudothalmanninella, R.= Rotalipora, Ti.= Ticinella.= Thalmanninella.*

3.3 Planktonic Foraminiferal Biozonation

The Tethyan planktonic foraminiferal zonation scheme for the mid-Cretaceous has been developed recently in a series of important studies notably by BouDagher-Fadel and others (1997), Caron (1985), González-Donoso and others (2007), Huber and Leckie (2011), Petrizzo and Huber, (2006), Petrizzo and others (2012), Postuma (1971), Premoli Silva and Sliter (1995; 1999), Premoli Silva and Verga, (2002; 2004), Premoli Silva and others (2009), Robaszynski and Caron (1995) and many others. The well recognized planktonic foraminiferal zonation of the Tethys (e.g., Huber and Leckie (2011), González-Donoso and others (2007) Premoli Silva and Sliter, (1995; 1999) places the upper Aptian to Cenomanian interval in the *Globigerinelloides algerianus* Zone corresponds to the late Aptian (Huber and Leckie, 2011) through *Rotalipora cushmani* corresponds to the mid-late Cenomanian (González-Donoso and others, 2007).

The global Tethyan scheme was found to be broadly applicable in this study. The precise zonation used here is a combination of zonal schemes for the late Albian to Cenomanian by González-Donoso and others (2007) and late Aptian to middle Albian as explained by Huber and Leckie (2011) as shown in figure 3.3 and fig. 3.4. The zonal schemes are essentially based on initial appearances, total ranges and partial ranges of the key stratigraphic planktonic foraminifera species. The zonal scheme presented here was found to be more applicable in Tanzania. The following twelve biostratigraphic zones and two subzones were identified from the studied material of Tanzania.

The late Aptian index species present belong to three planktonic foraminiferal zones and these are *Globigerinelloides algerianus*, *Hedbergella trocoidea* and *Paraticinella eubejaouaensis* Zones. *Globigerinelloides algerianus* Zone corresponds to the total range of G*lobigerinelloides algerianus* in the late Aptian (Moullade, 1966); top marked by Sigal (1977). The overlying *Hedbergella trocoidea* Zone corresponds to the late Aptian, base was marked by Sigal (1977) and top by Moullade (1966). The base corresponds to the highest occurrence (HO) of *Globigerinelloides algerianus* and top by the lowest occurrence (LO) of *Paraticinella eubejaouaensis*. The overlying Zone of *Paraticinella eubejaouaensis* Zone is a total range of the taxon (latest Aptian) and its base was marked by (Moullade, 1966) and top by (Moullade 1974).

The Albian and Cenomanian intervals are divided into early, middle and late. The early Albian is divided into three zones and these are *Microhedbergella miniglobularis* Zone, *Microhedbergella rischi* Zone and *Ticinella madecassiana* Zone. The base of *Microhedbergella miniglobularis* Zone (earliest Albian) was marked by Huber and Leckie (2011) and top by Moullade (1974). Its base corresponds to the highest occurrence (HO) of *Paraticinella eubejaouaensis* and top by the lowest occurrence (LO) of *Microhedbergella rischi*. Overlying this zone is the *Microhedbergella rischi* Zone (Moullade (1974) early-middle Albian; its base corresponds to the lowest occurrence (LO) of *Microhedbergella rischi* (formally *Hedbergella rischi*) and top by the lowest occurrence (LO) of *Ticinella madecassiana*.

Ticinella madecassiana Zone (Longoria and Gamper, 1974) in the uppermost early Albian to middle Albian its base corresponds to the lowest occurrence (LO) of *Ticinella madecassiana* and top by the lowest occurrence of (LO) of *Ticinella primula*; this zone was difficult to identify in Tanzanian materials due to its randomly distribution and perhaps contamination through washing and it was difficult to have a control of this zonal marker. The middle Albian has only one zone of *Ticinella primula* (Longoria and Gamper, 1974) its base corresponds to the lowest occurrence (LO) of *Ticinella primula* and top to the lowest occurrence (LO) of *Biticinella breggiensis*.

The late Albian is divided into three zones and two subzones and these are *Ticinella praeticinensis* (Sigal (1966) Subzone in the late Albian base marked by the lowest occurrence (LO) of *Biticinella breggiensis* and top by the (LO) *Pseudothalmanninella subticinensis*. *Biticinella breggiensis* Zone Postuma (1971); its base corresponds to the lowest occurrence (LO) of *Biticinella breggiensis* and top by the lowest occurrence (LO) of *Pseudothalmanninella ticinensis.*

In the late Albian *Pseudothalmanninella subticinensis* Subzone Postuma (1971) base marked by the lowest occurrence (LO) of *Pseudothalmanninella subticinensis* and top by the lowest occurrence (LO) occurrence of *Pseudothalmanninella ticinensis*. *Pseudothalmanninella ticinensis* is not present in the studied Tanzanian materials; therefore the zone of *Pseudothalmanninella ticinensis* is absent. The latest Albian zone of *Thalmanninella appenninica* Brönnimann (1952) in the late Albian is underlain by the subzone of *Pseudothalmanninella subticinensis*. The base of *Thalmanninella appenninica* was marked by the lowest occurrence (LO) of *Thalmanninella appenninica* and top by the lowest occurrence (LO) of *Thalmanninella globotruncanoides*.The Cenomanian Interval is divided into three zones and these are *Thalmanninella globotruncanoides* Zone (Lehmann (1966), *Thalmanninella reicheli* and *Rotalipora cushmani* Zone.

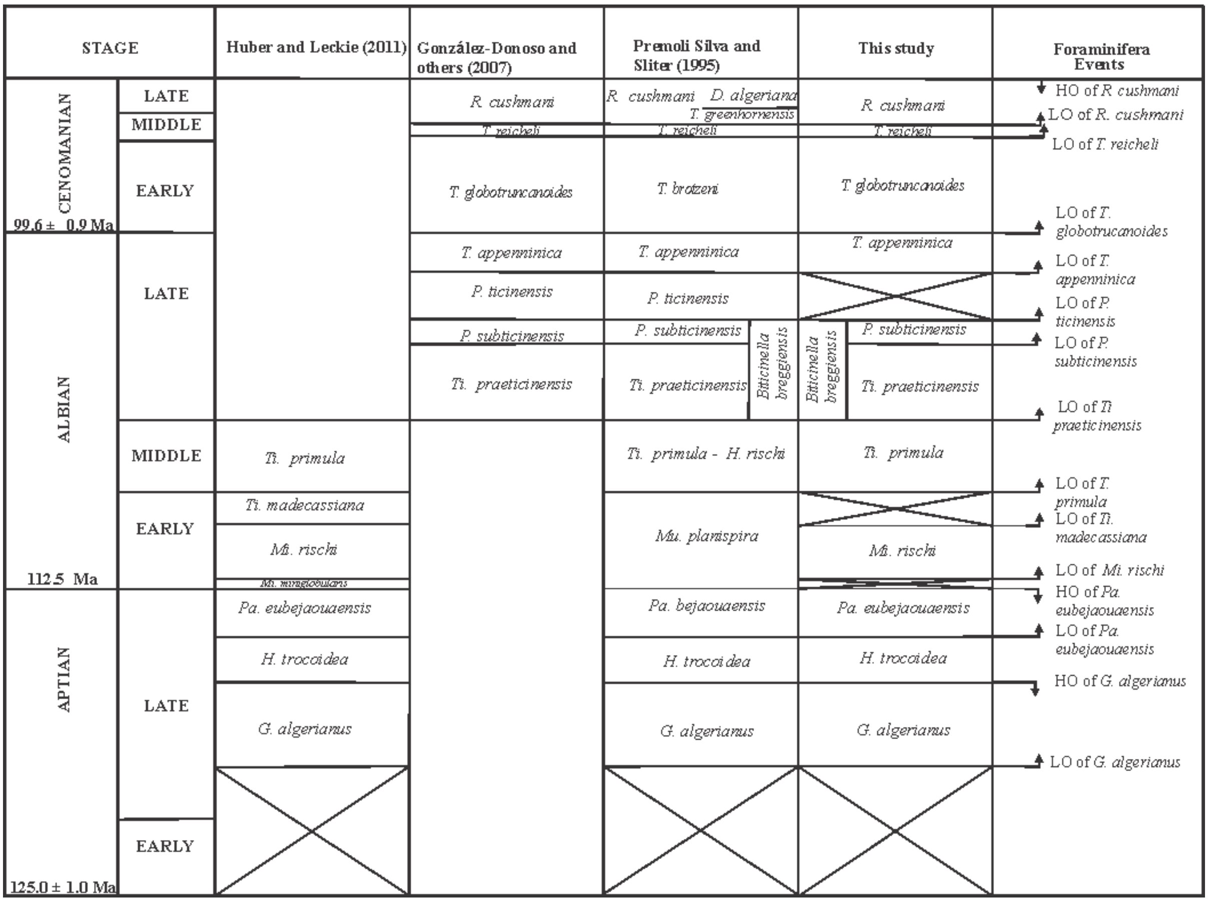


Figure 3.4: Showing planktonic foraminifera Biozones of the present study adopted from the zonal schemes of Huber & Leckie (2011), Gonzalez-Donoso and others (2007) and Premoli Silva and Sliter (1995).

Note: *D.= Dicarinella, G.= Globigerinelloides, H.= Hedbergella, Mi.= Microhedbergella, Mu.= Muricohedbergella, Pa.= Paraticinella, P.= Pseudothalmanninella, R.= Rotalipora, T.= Thalmanninella, Ti.= Ticinella, B.= Biticinella,* LO= Lowest occurrence, HO = Highest occurrence.

The base of the *Thalmanninella globotruncanoides* Zone corresponds to the lowest occurrence of *Thalmanninella globotruncanoides* and top by the lowest occurrence of *Thalmanninella reicheli*. *Thalmanninella reicheli* Zone Bolli (1966) in the early to middle Cenomanian corresponds to the total range of *Thalmanninella reicheli*. *Rotalipora cushmani Borsetti* (1962) in the middle to late Cenomanian corresponds to the total range of *Rotalipora cushmani (*see figure 3.4).

Detailed description of Zones (Zones are illustrated in figure 3.4)

3.3.1 Globigerinelloides algerianus Total range Zone

Stage: Late Aptian.

Author: Moullade (1966) and top by Sigal (1977).

Definition: Biostratigraphic interval of the total range of *Globigerinelloides algerianus*.

Remarks: Species present in this zone include *Hedbergella trocoidea*, *Globigerinelloides barri*, *Globigerinelloides aptiensis; Hedbergella infracretacea*, *Hedbergella gorbachikae*, and *Hedbergella trocoidea* (see figure 3.4).

3.3.2 Hedbergella trocoidea Partial range Zone

Stage: Late Aptian.

Author: Base by Sigal (1977), top by Moullade (1966).

Definition: This is a partial range zone of the nominal taxon from the highest occurrence (HO) of *Globigerinelloides algerianus* and the lowest occurrence (LO) of *Paraticinella eubejaouaensis* (see figure 3.4).

Remarks: Species encountered in this zone include *Globigerinelloides ferreolensis*, *Globigerinelloides aptiensis*, *Hedbergella trocoidea*, *Hedbergella gorbachikae*, and *Hedbergella infracretacea*.

3.3.3 Paraticinella eubejaouaensis Taxon range Zone

Stage: Latest Aptian.

Authors: Base by Moullade (1966); top by Moullade (1974).

Definition: Biostratigraphic interval of the total range of *Paraticinella eubejaouaensis*.

Remarks: Huber and Leckie (2011); suggested using *Paraticinella transitoria* in the absence of *Paraticinella eubejaouaensis* to identify the same biostratigraphic interval (Latest Aptian). In Tanzania large robust specimens of *Paraticinella eubejaouaensis* are frequent to common especially in the samples recovered from boreholes drilled in

Ruvu basin. Large and robust specimens with perforation cones on the surface texture are present in high abundance including *Hedbergella trocoidea, Hedbergella infracretacea, Hedbergella excelsa, Hedbergella gorbachikae, Globigerinelloides aptiensis*, and rare specimens of *Pseudoguembelitria* and *Hedbergella praelippa* in the upper section of this zone.

3.3.4 Microhedbergella miniglobularis Interval Zone

Stage: Earliest Albian.
Author: Base by Huber and Leckie (2011); top by Moullade (1974)
Definition: Biostratigraphic interval from the highest occurrence (HO) of *Paraticinella eubejaouaensis* to the lowest occurrence (LO) of *Microhedbergella rischi*.

Remarks: This zone partially replaces the former ***Hedbergella** planispira* Zone. The base of this zone corresponds to the extinction of *Paraticinella eubejaouaensis* or *Paraticinella transitoria* and other Aptian species such as *Hedbergella gorbachikae, Hedbergella excelsa*, and *Globigerinelloides aptiensis*. Transitional forms from *Hedbergella praelippa* to *Microhedbergella miniglobularis* and then to *Microhedbergella renilaevis* occur at the level of the uppermost *Paraticinella eubejaouaensis* Zone and through the *Microhedbergella miniglobularis* Zone (Huber and Leckie, 2011). This zone is recognized by the presence of *Microhedbergella miniglobularis* including other small microperforate hedbergellids (Huber and Leckie, 2011).

3.3.5 Microhedbergella rischi Partial range Zone

Stage: Early - Middle Albian. Author: Moullade (1974).
Definition: Biostratigraphic interval from the lowest occurrence (LO) of *Microhedbergella rischi* (formally *Hedbergella rischi*) to the lowest occurrence (LO) of *Ticinella madecassiana*.

Remarks: *Microhedbergella rischi* is rare in this interval in Tanzanian succession. At the base of the zone *Microhedbergella miniglobularis* decreased in number and extinct while *Microhedbergella renilaevis* are few and above the zone *Microhedbergella pseudoplanispira* are present. The highest occurrence (HO) of *Microhedbergella renilaevis* and *Microhedbergella pseudoplanispira* occurred in the upper part of this zone (see figure 3.4).

3.3.6 Ticinella primula Partial range Zone

Stage: Middle Albian.

Author: Longoria and Gamper (1974).

Definition: Interval zone from the lowest occurrence (LO) of *Ticinella primula* to the lowest occurrence (LO) of *Biticinella breggiensis.*

Remarks: This zone is characterized by the first occurrence of larger sized planktonic foraminifera and a high abundance of specimens. The last appearance of *Microhedbergella rischi,* and the first occurrence of *Muricohedbergella simplex*, occurs in this zone and near the upper boundary the species *Biticinella subbreggiensis, Ticinella roberti, Ticinella praeticinensis* and *Ticinella raynaudi* are present.

3.3.7 Biticinella breggiensis Interval Zone

Stage: Late Albian.

Author: Postuma (1971).

Definition: Interval Zone from the lowest occurrence (LO) of the nominal taxon to the lowest occurrence (LO) of *Pseudothalmanninella ticinensis* (refer to figure 3.4).

Remarks: Specimens abundance and diversity is much higher in this zone than in lower horizons and the zone corresponds to the lowest occurrence (LO) of single-keeled forms. Two species common in this zone are *Pseudothalmanninella subticinensis* and *Ticinella praeticinensis*. These species are used to subdivide this zone into two subzones.

3.3.8 Ticinella praeticinensis Subzone

Stage: Late Albian.

Author: Sigal (1966).

Definition: Partial range of the nominate taxon from the lowest occurrence (LO) of *Biticinella breggiensis* to the lowest occurrence (LO) of *Pseudothalmanninella subticinensis.*

Remarks: This subzone contains *Biticinella breggiensis*, *Ticinella raynaudi*, and *Ticinella roberti* and has the lowest occurrence (LO) of *Macroglobigerinelloides ultramicrus* near the top.

3.3.9 Pseudothalmanninella subticinensis Subzone

Stage: Late Albian.
Author: Postuma (1971).
Definition: Biostratigraphic interval from the lowest occurrence (LO) of *Pseudothalmanninella subticinensis* to the lowest occurrence (LO) of *Pseudothalmanninella ticinensis*.

Remarks: In Tanzania, similar assemblages are found in the *Ticinella praeticinensis* Subzone to the underlying subzone.

3.3.10 Thalmanninella appenninica Interval Zone

Stage: Latest Albian.
Author: Brönnimann (1952).
Definition: Biostratigraphic interval from the lowest occurrence of *Thalmanninella appenninica* to the lowest occurrence of *Thalmanninella globotruncanoides*.

Remarks: The lower part of the zone contains species such as *Praeglobotruncana stephani*, *Schackoina* sp., and *Planomalina buxtorfi*. Abundant specimens of *Heterohelix* and *Thalmanninella* and at the top of this zone *Thalmanninella gandolfi* first appeared (González-Donoso and others, 2007). The extinction of *Biticinella breggiensis* is in the middle part of this zone and all *Ticinella* except *Ticinella madecassiana* become extinct at the top of this zone.

3.3.11 Thalmanninella globotruncanoides Interval Zone

Stage: Early Cenomanian.
Author: Lehmann (1966).
Definition: Biostratigraphic interval from the lowest occurrence (LO) of *Thalmanninella globotruncanoides* to the lowest occurrence (LO) of *Thalmanninella reicheli*.

Remarks: This zone includes the extinction level of *Thalmanninella gandolfi* and the lowest occurrence (LO) of *Rotalipora montsalvensis* and some specimens of *Schackoina*.

3.3.12 Thalmanninella reicheli Total range Zone

Stage: Early to Middle Cenomanian. Author: Bolli (1966).
Definition: Biostratigraphic interval corresponding to the total range of *Thalmanninella reicheli*.

Remarks: The index taxon is very rare in the Tanzanian boreholes with just fragments occurring and only one or two specimen per borehole. The other species present are similar to the zone below.

3.3.13 Rotalipora cushmani Total range Zone

Stage: Middle-Late Cenomanian.
Author: Borsetti (1962).
Definition: Biostratigraphic interval corresponding to the total range of *Rotalipora cushmani*.

Remarks: older forms of *Rotalipora* became extinct.

3.4 Planktonic foraminifera Taxonomy

Species diversity is high in the late Aptian and late Albian. In the early Albian foraminifera are rare or absent in some intervals. Planktonic foraminifera in the Cenomanian are less diverse. The selected stratigraphically important planktonic foraminifera species discussed in this chapter are illustrated in plates 3.1-3.15, and species ranges are shown in range charts (see tables 4.1-5.2 and figures 3.1-3.4). Plates are organized by Biozone including the key index species and a few significant additional species in each Biozone (see figures 3.3-3.4).

In total, fifty-six (56) specimens of planktonic foraminifera were identified, and the following 20 genera: *Ascoliella, Biticinella, Caucasella, Clavihedbergella, Favusella, Gorbachikella, Globigerinelloides, Hedbergella, Loeblichella, Microhedbergella, Muricohedbergella, Paraticinella, Planomalina, Praeglobotruncana, Praehedbergella, Pseudoguembelitria, Pseudothalmanninella, Rotalipora, Ticinella* and *Thalmanninella* and have been described.

The criteria for classification were based on the criteria used by BouDagher-Fadel and others (1997), Caron (1985), Gonzales-Donoso and others (2007), Huber and Leckie (2011), Loeblich and Tappan (1987). Additional criteria were based on ongoing work by the Cretaceous planktonic Foraminifera Group (B. T. Huber, pers. Comm., 2009-2011 and M-R. Petrizzo, pers. comm., 2009-2011), Caron and Premoli Silva, (2007) and Premoli Silva and others (2009). The rotaliporids having a polyphyletic origin their differentiation was also based on their evolutional lineage rather than the morphologic differences (Gonzales-Donoso and others, 2007). The following characters were used for identifying genera and specimens of hedbergellids present in the upper Aptian to upper Cenomanian of Tanzania including other characters mentioned in the text.

- *Shape of the test;* whether the test is planoconvex, biconvex, concave, etc.
- *Height of spire:* low, medium, high.
- *Sutures:* observations on both sides of test; sutures can be depressed, raised, straight, radial, curved, etc.
- *Keels*: whether the specimen has a single keel or none.
- *Coiling mode*: trochospiral, planispiral, triserial etc.
- *Chamber shape*: For non-elongate chambers; spherical, globular, triangular, petaloid, crescentic, and digitate; if elongate: round, pointed, pyriform, digit form, etc.
- *Number of outer chambers* = (Number of chambers in the final whorl).
- *Growth rate of the chambers*: slow, medium or rapidly.
- *Aperture*: Position of primary aperture; umbilical, umbilical-extraumbilical, equatorial.
- *Peripheral outline*; subrounded, keel, symmetrical etc.
- *Shape of the primary aperture*; low arch, high arch etc.
- Presence of any structure covering the aperture whether covered by a lip; flap, and whether are thick or thin lips, portici etc.
- Additional apertures like; supplementary apertures, relict apertures, accessory apertures were also investigated.
- *Wall structure*: e.g. smooth, perforate, with perforation cones, reticulate, faveolate, pustulose, muricate etc.

- *Umbilicus*: Width and depth of the umbilical area; large, small shallow, deep.

3.4.1 SYSTEMATIC TAXONOMY

Phylum: SARCODINA Loeblich and Tappan 1964

Class: RHIZOPODA Loeblich and Tappan 1964

Supergroup RHIZARIA Cavalier-Smith, 2003

Order FORAMINIFERIDA Eichwald 1830

Suborder GLOBIGERININA Delage and Hérouard, 1896

3.4.2 Family FAVUSELLIDAE Longoria, 1974

Subfamily FAVUSALLINAE Loeblich and Tappan,
Genus *Ascoliella* Banner and Desai 1988

***Ascoliella* aff. *nitida* (Michael)**

Plate 3.1, figs. 1a-d

Type reference: *Favusella nitida* Michael, 1973, p. 214, pl. 3, figs. 10-12.
Ascoliella nitida Michael-BouDagher-Fadel and others, 1997: 73, 77 pl. 4.5, fig. 1-9; 4.7, fig. 1-3; fig.: 4.1.
Type species: Ascoliella scotiensis Banner and Desai-Banner and Desai: p. 150 pl. 2; fig. 3-4.

Description: The specimen of *Ascoliella* identified is moderate in size, biconvex; the spiral side is more convex than the umbilical side, with six subglobular chambers in the last whorl, increasing slowly in size as added; the umbilicus is small and deep and the primary aperture is clearly seen extending from the umbilical region to outside of the umbilical area. The surface of the test is covered by medium size reticulations which form ridges like structures.

Remarks: Specimens of *Ascoliella* and *Favusella* varies in abundance from rare to frequent in the studied interval. Varieties of test morphologies of *Ascoliella* and *Favusella* specimens were encountered in the studied sequence show the presence of few horizons with moderate to good preserved specimens but the rest are poor to moderate.

World Stratigraphic range: *Ascoliella nitida* ranges from middle Albian (upper *Ticinella primula* Zone) through early Cenomanian *Thalmanninella globotruncanoides* Zone. *Ascoliella nitida* is stratigraphically the oldest known specimens of *Ascoliella* (BouDagher-Fadel and others, 1997). Originally this species was recorded from the late Albian Duck Creek, Fort Worth and Denton Formations, north central Texas, USA.

Tanzania Range: Sample TDP40 Hole B; Core 3/1, 1-25 cm, (5.1 m).

Subfamily TICINELLINAE Longoria, 1974
Genus *Biticinella* Sigal, 1956

Biticinella breggiensis (Gandolfi)

Plate 3.1, figs. 2a-d, figs. 3a-d & figs. 4a-d

Type reference: *Anomalina breggiensis* Gandolfi, 1942, p. 102, pl. 3, figs. 6a-c.
***Type species*:** *Anomalina breggiensis* Gandolfi 1942.

Description: The specimens of *Biticinella breggiensis* encountered in the Tanzanian materials vary from moderate size to large pseudoplanispirally coiled and biumbilicate; wall surface is coarsely perforate. Chambers are higher than broad and there is no keel, with a round peripheral outlines. Relict apertures are seen on the umbilical sides and supplementary apertures on the spiral sides. They range from seven to twelve subglobular to reniform chambers in the final whorls; sutures are radial and depressed, primary apertures are equatorial extending on both sides to umbilical area. *Biticinella breggiensis* (sp. 2) see figures 3a-d with seven and figures 4a-d (sp. 3) eight chambers in the last whorl moderately increasing in size as added. Sutures on both sides are slightly curved to radial and depressed; umbilical area is small in size and moderately deep; wall perforate.

Remarks: *Biticinella breggiensis* can be distinguished from *Planomalina* in the absence of a keel. *Biticinella breggiensis* from this studied area some of them are small and others are robust specimens (Caron, 1985). There are various test morphologies of *Biticinella breggiensis* in the studied late Albian intervals of boreholes and outcrops. This specimen varies from rare to abundant in the studied upper Albian interval and preservations vary from poor to moderate and in few intervals in Luhoi vary from moderate to good.

World Stratigraphic range: *Biticinella breggiensis* ranges from the late Albian (*Ticinella praeticinensis* Zone) through latest Albian (*Thalmanninella appenninica* Zone). This specimen has been recorded from the uppermost Albian interval, in the *Thalmanninella appenninica* zone, of Switzerland (Caron, 1985) and in DSDP Leg 79 (Atlantic offshore Morocco, Leckie, 1984).

Note: Specimen of figs. 3a-d; *Biticinella breggiensis* (sp. 2); Sample Kisarawe-1; 1920.2 m., and specimen in figs. 4a-d; *Biticinella breggiensis* (sp. 3); Songo Songo-4 Hole, (1731.3 m) reworked specimen into higher level, ditch cuttings.

Tanzania Range: Sample Kizimbani-1 Hole, (46 m).

Subfamily TICINELLINAE Longoria, 1974
Genus *Biticinella* Sigal, 1956

Biticinella subbreggiensis (Sigal)

Plate 3.2, figs. 1a-d, figs. 2a-d & figs. 3a-d

Type reference: *Biticinella subbreggiensis* Sigal, 1966, p. 59, figs. 193.
Type species: *Anomalina breggiensis* Gandolfi 1942.

Description: The specimen of *Biticinella subbreggiensis* identified from this study is planispirally coiled and biumbilicate, one has nine (figs. 1a-d; sp. 1) and in figs. 2a-d (sp. 2) with 6-chambers in their final whorls which are spherical to oval shape; increasing in size rapidly as added in the final whorls. Test surface is coarsely perforate, relict apertures present on one side and supplementary apertures on the second side. The final chamber is slightly higher and broader in length; sutures on the umbilical side are radial and depressed. Primary apertures are low equatorial arch and asymmetrical.

Remarks: *Biticinella subbreggiensis* in the present study differs from *Biticinella breggiensis* by less number of chambers (6-9 in the last whorl) instead of 8-12 and primary aperture positions. Specimens of *Biticinella subbreggiensis* are rare in the studied Albian interval with poor to moderate preservation, and their tests are infilled with calcite and pyrite. Few specimens from outcrops and Kizimbani-1 Hole are moderate to good preserved.

World Stratigraphic range: *Biticinella subbreggiensis* stratigraphically ranges from the middle Albian (upper *Ticinella primula* Zone) through late Albian (*Ticinella praeticinensis* Zone).

Tanzania Range: Sample Songo Songo-4 Hole; (reworked specimens reported from ditch cuttings at 1670.3 m; figs. 1a-d (sp. 1), outcrop sample AK22-10; figs. 2a-d (sp. 2) and figs. 3a-d (sp. 3), sample Kizimbani-1, (67.1m).

Subfamily FAVUSALLINAE Loeblich and Tappan, 1982
Genus *Caucasella* Longoria 1974

***Caucasella hoterivica* (Subbotina)**

Plate 3.2, figs. 4a-d

Type reference: *Globigerina hoterivica* Subbotina, 1953, p. 50, pl. 1, figs. 1-4.

Favusella hoterivica (Subbotina), Wernli and others, 1995, pp. 379-390, pl. 1, figs. 1-7; pl. 2, figs. 1-6; pl. 3, figs. 1-15.

Type species: Globigerina hoterivica Subbotina 1953.

Description: This specimen is trochospiral coiled with four globular chambers increasing rapidly in size as added; wall is reticulate and primary aperture is infilled, and not visible due to poor preservation.

Remarks: *Caucasella hoterivica* differs from *Favusella washitensis* by its finely reticulate sculpture while *Favusella washitensis* the reticulation are broad. Specimens of *Caucasella hoterivica* are extremely rare in the studied interval and preservation varies from poor to moderate. BouDagher-Fadel and others, (1997) 'described *Favusella hoterivica* as an oldest

Favusella evolved in the Hauterivian from *Conoglobigerina* (Banner and Desai, 1988)'.

World Stratigraphic range: This species ranges from Berriasian to early Aptian. *Caucasella hoterivica* was originally described from the Hauterivian interval of northern Caucasus, Russia (Subbotina, 1953).

Tanzania Range: Sample TDP 40 Hole B; Core 10/3, 1-25 cm, (22.1 m).

Subfamily FAVUSALLINAE Loeblich and Tappan, 1982
Genus *Favusella* Michael, 1973

***Favusella washitensis* (Carsey)**

Plate 3.3, figs. 1a-d

Type reference: *Globigerina washitensis* Carsey, 1926, p. 44, pl. 7, fig. 10, pl. 8, fig. 2).
Type species: *Globigerina washitensis* Carsey 1926.

Description: *Favusella washitensis* identified in the present study is trochospirally coiled with four chambers in the last whorl, chambers increasing irregularly in size as added, wall coarsely reticulates; chambers are globular in shape, sutures are radial and depressed. Primary aperture is interiomarginal, nearly umbilical in position but shows slightly extra-umbilical bordered by a narrow lip.

Remarks: A variety of specimens of *Favusella* have been seen in the studied intervals of the Albian to Cenomanian of Tanzania but not in great abundance and varies from rare to frequent and preservation varies from poor to good in few intervals especially in TDP40 Holes, and Kizimbani-1 Hole otherwise in other holes varies from poor to moderate. It differs from *Globigerina* in its sculpture; reticulate ornamentation and position of the primary aperture.

World Stratigraphic range: This species has been originally described by Carsey (1926) from the early Cenomanian, intervals in Austin, Texas, USA. Stratigraphically ranges from the middle Albian (*Ticinella primula* Zone) through late Cenomanian (*Rotalipora cushmani* Zone).

Tanzania Range: Sample TDP40 Hole B; Core 4/2, 1-25 cm (6.7 m).

3.4.3 Family PRAEHEDBERGELLIDAE Banner and Desai, 1988

Subfamily PRAEHEDBERGELLINAE Banner and Desai, 1988

Genus *Gorbachikella* Banner and Desai, 1988

Gorbachikella sp. aff. _kugleri_ (Bolli)

Plate 3.3, figs. 2a-d

Type reference: *Gorbachikella Banner* and Desai, 1988.

Type species: *Globigerina kugleri Bolli*, 1959.

Description: *Gorbachikella* sp., in the current study is biconvex, spiral side is more convex than umbilical side; finely perforate to smooth, with four subspherical to spherical chambers in the last whorl; chambers increasing slowly in size as added in the last whorl; primary aperture not distinct obscured due to poor preservation, the aperture is covered by a thick lip, umbilicus is filled and it is not possible to determine its depth. Such forms have been named as *Gorbachikella* by Banner and Desai, (1988). This species closely resembles to *Gorbachikella kugleri*.

Remarks: *Gorbachikella* is thought to be either a direct or intermediate ancestor of Mesozoic *Globigerinacea (*BouDagher-Fadel and others, 1997). This species is rare in the studied interval and preservation of the specimens varies from poor to moderate.

World Stratigraphic range: This species stratigraphically ranges from the Late Valanginian to late Aptian.

Tanzania Range: Sample TDP 40 Hole B; Core 10/1, 1-25 cm (20.1 m).

3.4.4 Family GLOBIGERINELLOIDIDAE Longoria, 1974

Subfamily GLOBIGERINELLOIDINAE Loeblich and Tappan, 1982

Genus *Globigerinelloides* Cushman and Ten Dam, 1948

Globigerinelloides cf. *algerianus* (Cushman and Ten Dam)

Plate 3.3, figs. 3a-d

Type reference: *Globigerinelloides algerianus* Cushman and Ten Dam, 1948, fig. 8.9-8.12, fig. 9.1-9.13.
Type species: *Globigerinelloides algeriana* Cushman and Ten Dam, 1948.

Description: *Globigerinelloides algerianus* is compressed, planispiral with rounded test outline about 10- radial and reniform shaped chambers in the last whorl; increases slowly in size as added. The primary aperture is equatorial extending on both sides to the umbilical area with an additional thin narrow lip. Relict apertures present in the umbilical area, equatorial periphery is subrounded and sutures are radial to slightly curved and depressed while umbilicus is shallow and wide. The Tanzanian illustrated specimen of *Globigerinelloides algerianus* part of its last chamber is broken. Preservation varies from poor to moderate and moderate to good in few section of the Kizimbani-1 Hole.

Remarks: There are different morphological varieties of *Globigerinelloides algerianus* displayed in the Tanzanian material from outcrops to boreholes. In terms of abundance generally varies from rare to common in the studied late Aptian interval. *Globigerinelloides algerianus* differs from *Globigerinelloides ferreolensis* in its 10-12 numbers of chambers in the last whorl, compressed test shape, radial and reniform chambers of the last whorl. Chambers of the Tanzanian specimen of *Globigerinolloides algerianus* are too inflated and the umbilical area is too small and not as a perfect *Globigerinelloides algerianus* therefore is named as *Globigerinelloides* cf. *algerianus*.

World Stratigraphic range: Late Aptian (*Globigerinelloides algerianus* Total Range Zone)

Tanzania Range: Sample Kisarawe-1 Hole, (2268 m).

Subfamily GLOBIGERINELLOIDINAE Loeblich and Tappan, 1982
Genus *Globigerinelloides* Cushman and ten Dam, 1948

Globigerinelloides aptiensis (Longoria)

Plate 3.3, figs. 4a-d

Type reference: *Globigerinelloides aptiensis* Longoria, 1974, pl. 4, figs. 9-10, pl. 8, figs., 4-6, 17-18.
Type species: *Globigerinelloides algeriana* Cushman and ten Dam, 1948.

Description: *Globigerinelloides aptiensis* identified in the present study is biumbilicate with six spherical chambers in the last whorl; chambers increasing moderately in size as added. Peripheral outline is subrounded; primary aperture is equatorial extending on both sides to the umbilical area. Relict apertures are present in the umbilical area, and the umbilicus is wide and shallow. The last chamber is higher and broader than the rest.

Remarks: *Globigerinelloides aptiensis* differs from *Globigerinelloides algerianus* in the globular shape of its chambers and in the less number of chambers in the final whorl. Specimens varies from rare to abundant and preservation in most of the boreholes studied is poor to moderate except few specimens with moderate to good from Kizimbani-1 Hole.

World Stratigraphic range: This species stratigraphically ranges from the Barremian/Aptian boundary (*Leupoldina cabri* Zone) through late Aptian (*Paraticinella eubejaouaensis* Zone).

Tanzania Range: Samples TDP40 Hole B; Core 5/3, 70-80 cm, (10.8 m).

Subfamily GLOBIGERINELLOIDINAE Loeblich and Tappan, 1982
Genus *Globigerinelloides* Cushman and Ten Dam, 1948

Globigerinelloides barri (Bolli, Loeblich and Tappan)

Plate 3.4, figs. 1a-d

Type reference: *Biglobigerinella barri* Bolli, Loeblich and Tappan, 1957, p. 25, pl. 1 figs. 13-8b.

Description: *Globigerinelloides barri* identified in the current study is moderate in size, planispirally coiled; chambers are broader and high, eight chambers in the final whorl; Test medium size planispiral, chambers increasing slightly rapidly in size as added, globular to subglobular and a paired final chamber, equatorial periphery subrounded; sutures are straight to slightly radially curved, and depressed; umbilicus small, shallow and depressed; primary and relict apertures are not distinct due to the poor nature of preservation.

Remarks: The genus *Biglobigerinella* is no longer used and the original name of *Globigerinelloides barri* is retain for specimens of *Biglobigerinella barri* whether with one or two twin chambers in the final chamber of the last whorl (Verga and Premoli Silva, 2003). Preservation varies from poor to moderate except few specimen from Kizimbani-1 Hole with moderate to good preservation (see table 4.6). Specimens of *Globigerinelloides barri* identified from the Tanzanian material, Most *Globigerinelloides barri* from the studied interval have twin chambers in the last whorl but the umbilicus is not showing much, obscured due to poor preservation and *Globigerinelloides barri* of Kizimbani-1 well are more less moderately preserved and shows most of the features including in the umbilical region. In terms of abundance it is mostly very rare (one or two specimens per samples per hole). *Globigerinelloides barri* differs from *Globigerinelloides algerianus* in the less number of chambers (8-10) instead of (10-12), and slightly rapidly growth rate, and chamber shape and outline of the peripheral margin (Verga and Premoli Silva, 2003).

World Stratigraphic range: *Globigerinelloides barri* ranges throughout the *Globigerinelloides algerianus* Zone (late Aptian) and extinct at the top of *Globigerinelloides algerianus* Zone.

Tanzania Range: Kizimbani-1 Hole; (216.4 m).

Subfamily GLOBIGERINELLOIDINAE Loeblich and Tappan, 1982
Genus *Globigerinelloides* Cushman and Ten Dam, 1948

Globigerinelloides blowi (Bolli)

Plate 3.4 figs. 2a-d

Type reference: *Planomalina blowi* Bolli, 1959, p. 260, pl. 20, figs. 2a-b.
Type species: *Globigerinelloides algeriana* Cushman and ten Dam, 1948.

Description: *Globigerinelloides blowi* identified in the present study is small and the test is coiled planispirally with both sides with similar *Globigerinelloides* form features i.e. biumbilicate, five subspherical chambers in the final whorl; increasing moderately in size as added. Primary aperture is equatorial, at the base of the final chamber and extending to both sides of the umbical area, surrounded by a lip; relict apertures not visible in both umbilical areas.

Remarks: *Globigerinelloides blowi* identified in the present study resembles to G*lobigerinelloides blowi* described by Caron, (1985). Specimens of *Globigerinelloides blowi* are rare and preservation varies from poor to moderate but few specimens with moderate to good (see tables 5.1 and 5.2).

World Stratigraphic range: This species was originally reported from *Schackoina cabri* Zone, middle Aptian, in Trinidad (Bolli, 1959). *Globigerinelloides blowi* ranges from Barremian to late Aptian.

Tanzania Range: Sample TDP40B Hole; Core 5/3, 80-90 (10.9 m).

Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961
Genus *Hedbergella* Bronnimann and Brown, 1958

***Hedbergella aptiana* (Bartenstein)**

Plate 3.4, figs. 3a-d

Type reference: *Hedbergella aptiana* (Bartenstein), Sigal, 1979, p. 318, pl. 2, figs. 24, 25.
Blefuscuiana aptiana (Bartenstein) s. s., BouDagher-Fadel and others, 1996, p. 252, Fig. 4 (1-5).
Type species: *Anomalina lorneiana* d'Orbigny var. trocoidea Gandolfi, 1942.

Description: *Hedbergella aptiana* from the current study is trochospiral coiled; spiral side is almost flat and convex on the umbilical side. Two whorls are visible on the spiral side and six chambers in the final whorl, chambers are subspherical to spherical in the final whorl, chambers increasing rapidly in size as added. Periphery margin is subrounded, umbilical area is small and shallow; the primary aperture is extraumbilical-umbilical and bordered by a moderate size lip. The last chamber of the final whorl is higher than the rest of the chambers in the final whorl.

Remarks: *Hedbergella aptiana* recognized from the present study differs from *Hedbergella infracretacea* in its smoother wall surface and a rapidly chambers growth rate. Preservation varies from poor to moderate and few specimens from Kizimbani-1 Hole are moderate to good (see table 4.6). Specimens abundance varies from rare to abundant. *Hedbergella aptiana* differs from *Hedbergella occulta* by its faster chambers growth rate, and lacking deeply sunk umbilical sutures, and an apertural lip.

World Stratigraphic range: *Hedbergella aptiana* stratigraphically ranges from Barremian (*Hedbergella similis* Zone) through latest Aptian (*Paraticinella eubejaouaensis* Zone). Banner and others (1993) reported similar type of specimens in the *Hedbergella similis* Zone, Barremian through latest Aptian (*Paraticinella eubejaouaensis* Zone). At DSDP 511 Site, *Hedbergella aptiana* ranges within 0.67 m below the Aptian /Albian boundary (within the extinction level of *Paraticinella eubejaouaensis* (Huber and Leckei, 2011).

Tanzania Range: Sample TDP40 Hole B; Core 5/3, 30-40 cm (10.4 m).

Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961
Genus *Hedbergella* Brönnimann & Brown 1958

Hedbergella excelsa (Longoria)

Plate 3.4, figs. 4a-d

Type reference: *Hedbergella excelsa* Longoria, 1974, p. 55-6, pl. 18, figs. 6-8, 9-11, 14-16.
Type species: *Anomalina lorneiana* d'Orbigny var. trocoidea Gandolfi, 1942.

Description: Test small calcareous, finely perforate, chamber surfaces are covered by few scattered perforation cones, especially in the umbilical area and along sutural areas on the spiral side. 5-subglobular chambers in the last whorl; spiral side is highly convex with a small umbilicus.

Two whorls are visible on the spiral side; chambers in the last whorl increasing rapidly in size as added, equatorial peripheral moderately elongate, sutures depressed radially to slightly curved on both sides of the test. The primary aperture is umbilical- extraumbilical low arch with a lip.

Remarks: *Hedbergella excelsa* differs from *Hedbergella infracretacea* in its higher trochospire and more weakly developed perforation cones. *Praehedbergella ruka* is similar to *Hedbergella excelsa* in height but has a narrower umbilicus with 4- chambers in the final whorl. This species is rare in the upper Aptian interval of Tanzania and specimen preservation is poor to moderate.

World Stratigraphic range: *Hedbergella excelsa* ranges from the early Aptian that is from *Globigerinelloides blowi* Zone to late Aptian (*Paraticinella eubejaouaensis* Zone).

Tanzania Range: Sample TDP 40 Hole B; Core 5/3, 50-60 cm, (10.6 m).

Subfamily HEDBERGELLINAE and Tappan, 1961
Genus *Hedbergella* Brönnimann & Brown 1958

Hedbergella gorbachikae (Longoria)

Plate 3.5, figs. 1a-d

Type reference: *Hedbergella gorbachikae* Longoria, 1974, p. 56-58, pl. 15 figs. 11-13 [Upper Aptian, La Boca Canyon, Monterrey, Mexico].

Type species: *Anomalina lorneiana* d'Orbigny var. trocoidea Gandolfi, 1942.

Description: Test low trochospiral; wall finely perforate, perforation cones are scattered along the spiral and umbilical sutural areas of the last whorl and few; faintly seen on the surface of the chambers of the last whorl. Test is small, coiled in 2 whorls, visible on the spiral side; spiral side is almost flat and a high convex umbilical side. Chambers are globular to subglobular slightly compressed and increase moderately in size as added. Five chambers in the last whorl, three last chambers of the final whorl are becoming subtriangular on the umbilical side and rounded on the spiral side. The last chamber bends and covered three - quarter area of the umbilicus; sutures depressed, radial to straight on both sides and umbilical area is small and slightly deep, aperture obscures and not visible due to the poor preservation.

Remarks: *Hedbergella gorbachikae* observed in the studied interval shows variation in the shape and breadth of the final chamber and also length of protrusion towards the umbilicus; some covered the whole umbilicus and some covered about three - quarter of the umbilicus and varying in the length and width of last chamber of the final whorl. Specimens of *Hedbergella gorbachikae* in the studied interval varies in abundance from rare to frequent with poor to moderate but few horizons in Kizimbani-1 Hole there are some few specimens with moderate to good preservation (see table 4.6).

World Stratigraphic range: *Hedbergella gorbachikae* stratigraphically ranges from the early Aptian (*Globigerinelloides blowi* Zone) through late Aptian (upper *Paraticinella eubejaouaensis* Zone).

Tanzania Range: Sample TDP40 Hole B; Core 5/3, 30-40 cm, (10.4 m).

Genus *Hedbergella* Brönnimann and Brown, 1958

***Hedbergella infracretacea* (Glaessner)**

Plate 3.5, figs. 2a-d

Type reference: *Globigerina infracretacea* Glaessner, 1937, p. 28, fig. 1 [Albian Northwest Caucasus Mountains].

Description: *Hedbergella infracretacea* identified in the present study has a low trochospiral test with a convex umbilical and spiral side. Chambers are subspherical to spherical in shape with five chambers in the final whorl; two whorls are visible on the spiral side. Equatorial periphery is subrounded, sutures depressed, radial to straight, umbilical area is narrow, aperture obscured due poor preservation; pustules are randomly distributed and less dense in some part of the test, and concentrated in the inner chambers and along umbilical and spiral sutures.

Remarks: This specimen is rare to abundant in the studied interval.

World Stratigraphic range: This species is confined to the upper Aptian. It became extinct at the uppermost Aptian in the *Paraticinella eubejaouaensis* Zone.

Tanzania Range: Sample TDP40 HoleA, Core 5/3, 65-90 cm, (11 m).

Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961

Genus *Hedbergella* Brönnimann and Brown, 1958

***Hedbergella* sp.**

Plate 3.5, figs 3a-d

Type reference: *Hedbergella* Brönnimann and Brown, 1958.

Description: Specimen of *Hedbergella* sp., identified in the present study has a low trochospiral test with a high convex umbilical side and almost flat spiral side. Chambers are subspherical to spherical in shape with five chambers in the final whorl; two whorls are visible on the spiral side. Equatorial periphery is subrounded, sutures depressed, radial to straight, umbilical area is narrow, aperture obscured due nature of preservation; the pustules are randomly distributed and less dense in some part of the test, and concentrated in the inner chambers and along umbilical and spiral sutures and lacking on the two chambers of the last whorl both in the spiral and umbilical side.

Remarks: This specimen is very rare in the studied interval and preservation varies from poor to moderate.

World Stratigraphic range: This species ranges from the early Aptian to late Aptian

Tanzania Range: Sample TDP 40 Hole B; Core 5/3, 50-60 cm (10.6 m).

Subfamily HEDBERGELINAE Loeblich and Tappan, 1961

Genus *Hedbergella* Brönnimann and Brown, 1958

***Hedbergella occulta* Longoria**

Plate 3.5, figs. 4a-d

Type reference: *Hedbergella occulta* Longoria, 1974, p. 63, 64, pl. 11, figs. 1-3, 7, 8, Pl. 20, figs. 5-7, 8, 9, 17, 18 [early Aptian, Sierra Madre, northern Mexico].

Description: *Hedbergella occulta* is trochospirally coiled with the spiral side slightly convex to flat while the umbilical side is more convex; six spherical chambers in the final whorl, two whorls are visible on the spiral side. Equatorial periphery subspherical to oval and chambers in the last whorl increasing rapidly in size as added; umbilicus is small and moderately deep, the last chambers, is subtriangular on the umbilical side, test smooth, to finely perforate. Sutures depressed, and curved radially, primary aperture is a medium arch which stretches from the umbilical area to extraumbilical surrounded by a narrow lip.

Remarks: *Hedbergella occulta* differs from *Hedbergella trocoidea* in the smaller number of chambers in the final whorl and from *Hedbergella infracretacea*, *Hedbergella aptiana* and *Hedbergella excelsa* by the presence of an apertural lip and greater number of chambers. These species are rare in the studied interval and preservation varies from poor to moderate (specimens with calcite infill).

World Stratigraphic range: This species stratigraphically ranges from *Globigerinelloides blowi* Zone (early Aptian) through *Hedbergella trocoidea* Zone (late Aptian).

Tanzania Range: Sample TDP Site 40A Hole; Core 5/3, 50-60 cm, (10.6 m).

Subfamily HEDBERGELINAE Loeblich and Tappan, 1961
Genus *Hedbergella* Brönnimann and Brown, 1958

Hedbergella cf. _praelippa_ (Huber and Leckie n. sp.)

Plate 3.6, figs. 1a-d

Type reference: *Hedbergella praelippa* Huber and Leckie n sp., 2011, figs 12.1-12.5.

Description: Species of *Hedbergella praelippa* identified in the present study have a small test size, spherical to subspherical chambers of which are only four in the final whorl, chambers of the last whorl increasing rapidly in size as added. A flat to slightly convex spiral side and a more convex umbilical side; two whorls visible on the spiral side; the final chamber in the last whorl is broader and higher than the rest and facing towards the peripheral margin; sutures are depressed slightly curved to straight with small umbilical region which is slightly deep; primary aperture an arch extending from umbilical region to outside of the umbilical area. Test surface is rough or composed of perforation cones.

Remarks: *Hedbergella praelippa* is similar to *Hedbergella sigali* (Moullade, 1966), but differs in its last chamber which faces towards the peripheral margin and the test surface consists of perforation cones which *Hedbergella sigali* is lacking. This species is thought to evolve from *Hedbergella excelsa* or *Praehedbergella ruka* but more studies need to be done before drawing conclusions (Huber and Leckie, 2011). Specimen preservation varies from poor to moderate.

World Stratigraphic range: This species ranges from the late Aptian - earliest Albian (i.e. below the base of *Paraticinella eubejaouaensis* Zone to above the *Microhedbergella miniglobularis* Zone). It is rare in the studied Aptian to Albian interval of the coastal basin of Tanzania. This species has been also reported from ODP Site 1049 and ODP Site 763 (Huber and Leckie, 2011).

Tanzania Range: Sample from TDP Site 40B; Core 5/1, 1 - 25 cm, (8.1 m).

Subfamily HEDBERGELINAE Loeblich and Tappan, 1961
Genus *Hedbergella* Bronnimann and Brown, 1958

Hedbergella sigali (Moullade)

Plate 3.6, figs. 2 a-d

Type reference: *Hedbergella (Hedbergella) sigali* Moullade, 1966, P. 87, Pl. 7, figs. 24-25.

Description: *Hedbergella sigali* is trochospirally coiled with four spherical chambers in the last whorl, chambers increasing slowly in size as added. The primary aperture is not very well distinct but clearly shows its extension from the umbilicus and beyond with a thin and narrow lip. The peripheral margin is subrounded.

Remarks: *Hedbergella sigali* differs from *Muricohedbergella delrioensis* in having four instead of 5-6 globular chambers of last whorl. This species is rare in most of the boreholes studied except in the Kisarawe-1 Hole varies from rare to abundant and preservation varies from poor to moderate.

World Stratigraphic range: *Hedbergella sigali* stratigraphically ranges from Valanginian to latest Aptian.

Tanzania Range: Sample TDP40B Hole; Core 5/3, 80-90 cm, (10.9 m).

Subfamily HEDBERGELINAE Loeblich and Tappan, 1961
Genus *Hedbergella* Brönnimann and Brown, 1958

Hedbergella similis Longoria

Plate 3.6, figs. 3a-d

Type reference: *Hedbergella similis* Longoria, 1974, pl. 16, figs. 10-21, pl. 18, figs.12-13, pl.23, figs. 14-16.
Type species: *Anomalina lorneiana* d'Orbigny var. *trocoidea* Gandolfi, 1942.

Description: *Hedbergella similis* has a flat spiral side and convex umbilical side trochospirally coiled with six chambers in the final whorl and two whorls are visible on the spiral side. Chambers of the final whorl are oval in shape and the last one is more elongate (club like) and higher than the rest. Chambers of the last whorl increase in size rapidly as added; primary aperture stretches from outside and to the inside of the umbilical region, relict apertures not distinct. Periphery margin is rounded and somehow lobate. Chambers vary in shape from globular to subglobular.

Remarks: *Hedbergella similis* are of morphological varieties present in the Tanzanian materials. It differs from other *Hedbergella* species by its higher and broader final chamber than the rest of the chambers. Few moderate to good preserved specimens present in the Kizimbani-1 Hole and outcrops but are rare.

World Stratigraphic range: *Hedbergella similis* ranges from Barremian to early Aptian

Tanzania Range: Sample AK28-02.

Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961

Genus *Hedbergella* Bronnimann and Brown 1958

Hedbergella trocoidea (Gandolfi)

Plate 3.6, figs. 4a-d

Type reference: *Anomalina lorneiana* var. *trocoidea* Gandolfi, 1942, p. 134, pl. 2, fig. 1 a- c, pl. 4, figs. 2-3, pl. 13, figs. 2, 5, [Aptian, top of Biancone Limestone, southeastern Switzerland].

Type species: *Anomalina lorneiana* d'Orbigny var. *trocoidea* Gandolfi 1942.

Description: *Hedbergella trocoidea* identified in the present study has a medium size trochospire test, with eight chambers in the final whorl, and two whorls are visible on the spiral side; equitorial outline is spherical, and on the spiral side is very low convex to slightly flat, chambers in the final whorl increasing moderately in size as added; chamber shape subtriangular to triangular on the umbilical side, while on the spiral side, subspherical sutures depressed, radial to slightly curved; umbilical area is small and deep; wall finely perforate to smooth, aperture extraumbilical to umbilical with a thin lip.

Remarks: This species differs from *Hedbergella praetrocoidea* BouDagher-Fadel and others (1997) in the greater number of chambers in the outer whorl (6.5-8 instead of 5.5-6.5) and its smaller and deeper umbilicus. It was suggested that *Paraticinella eubejaouaensis* evolved from *Hedbergella trocoidea* by developing umbilical supplementary apertures (Premoli Silva and others, 2009). Specimens of *Hedbergella trocoidea* varies from rare to frequent in abundance and poor to moderate with few moderate to good preserved specimens from Kizimbani-1 Hole.

World Stratigraphic range: *Hedbergella trocoidea* stratigraphically ranges from the late Aptian (*Globigerinelloides algerianus* Zone) through latest Aptian *Paraticinella eubejaouaensis* Zone. It is a Zonal marker species of *Hedbergella trocoidea* Zone.

Tanzania Range: Sample TDP 40 Hole B; Core 5/3, 90-100 cm, (11 m).

3.4.5 Genera of Uncertain Status (Loeblich and Tappan, 1988)

Genus *Loeblichella* Pessagno 1967

Loeblichella sp.

Plate 3.7, figs. 1a-d

Type reference: *Loeblichella* Pessagno 1967.
Type species: *Praeglobotruncana hessi hessi* Pessagno 1962.

Description: Specimens of *Loeblichella* are coiled in a globorotaliform spire, test is compressed; wall surface is muricae, peripheral margin subrounded; primary aperture extending from the umbilicus to the spiral with five chambers in the last whorl, two whorls are visible in the spiral view; chambers are subspherical in both sides; chambers increasing slowly in size as added, umbilical region is narrow and shallow; sutures are depressed radial to straight.

Remarks: This species is morphologically slightly similar to *Loeblichella hessi* illustrated in Verga and Premoli Silva (2004) but differs slightly in chamber arrangements. Specimen of *Loeblichella* is extremely rare in the Tanzanian materials and preservation is poor to moderate.

World Stratigraphic range: Specimens of *Loeblichella* ranges from the middle Albian (*Ticinella primula* Zone) through middle Turonian (*Helvetoglobotruncana helvetica Zone*) with a questionable occurrences in the middle Turonian to Maastrichtian.

Tanzania Range: Sample Makarawe-1 Hole; (360 m).

Subfamily GLOBIGERINELLOIDINAE Loeblich and Tappan, 1982
Genus *Macroglobigerinelloides* Verga and Premoli Silva, 2004

***Macroglobigerinelloides bentonensis* (Morrow)**

Plate 3.7, figs. 2a-f

Type reference: *Anomalina bentonensis* Morrow, 1934, p. 201, pl. 30, figs. 4 a-b.
Type species: *Anomalina bentonensis* Morrow, 1934.

Description: *Macroglobigerinelloides bentonensis* in the studied section varies in the number of chambers in the last whorl from five and half to nine which are tightly coiled and inflated; chambers in the last whorl increase in size rapidly as added; chamber shapes are spherical and the peripheral outline is round. The test is totally planispiral, biumbilicate and their last chambers in the final whorls are longer than the rests. Primary aperture is equatorial extending from both sides to the umbilical area; wall is smooth; sutures are depressed curved backwards on both sides.

Remarks: Specimens of *Macroglobigerinelloides bentonensis* in the Tanzanian materials are of many varieties, and chambers of the final whorls vary from five and half to nine (see figures 2a-b and fig. 2d-e). *Globigerinelloides bentonensis* is currently renamed to *Macroglobigerinelloides bentonensis* (Premoli Silva and Verga, 2004). Recently the Cretaceous Working Group has revised some of the specimens of *Hedbergella* and *Globigerinelloides* and classified them using criteria like those applied to classify Cenozoic planktonic foraminifera such as size of perforations and wall texture (Steineck and Fleisher, 1978; Olsson and others, 1999; Pearson and others, 2006). Morphological varieties of *Macroglobigerinelloides bentonensis* have been encountered in the Albian to Cenomanian intervals of the studied interval, but are rare to abundant and preservation varies from poor to moderate and in Kizimbani-1 Hole, Luhoi-1 Hole, and TDP 40 Holes A & B where few with moderate to good (see tables 4.4, 4.6 and 5.1-5.2).

World Stratigraphic range: *Macroglobigerinelloides bentonensis* stratigraphically ranges from the middle Albian (*Ticinella primula* Zone) through Cenomanian *(Rotalipora cushmani* Zone). It has been reported from the early Albian interval of Angola basin (Caron, 1978).

Tanzania Range: Sample Luhoi-1 Hole; Core 53/2, 70-80 cm, (274 m, figs. 2a-c), sample Kizimbani-1 Hole, (70.1 m, figs. 2d-f).

Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961
Genus *Microhedbergella* Huber and Leckie, n genera, 2011

***Microhedbergella miniglobularis* (Huber and Leckie)**

Plate 3.7, figs. 3a-d

Type reference: *Microhedbergella miniglobularis* Huber and Leckie, 2011, figs. 12.6-12.8, 15.1-15.2, p. 75.
"*Hedbergella* sp., 3 chambers", Caron in Kennedy and others, 2000, fig. 22c.
Type species: *Microhedbergella renilaevis* Huber and Leckie, n sp., 2011.

Description: *Microhedbergella miniglobularis* is a small trochospirally coiled form with a slightly convex to flat spiral side and highly convex umbilical side. Surface of the test varies from smooth to few pustules concentrated in the sutural area on the spiral side and on the umbilical area; equatorial periphery is angular and elongate. Chambers are globular to subglobular in shape with four chambers in the final whorl; chambers increasing rapidly in size as added; umbilicus is shallow and the primary aperture is extraumbilical low arch just near the peripheral margin and slightly close to the umbilicus with a thin narrow lip.

Remarks: *Microhedbergella miniglobularis* closely resembles *Hedbergella praelippa n*. sp. (Huber and Leckie, 2011), but differs on its inflated chambers, a more lobate equatorial periphery and a more rapid increase in chamber size; presence of a lip which is bordering the aperture, and lacks perforation cones. It differs from *Microhedbergella renilaevis by* its narrow umbilicus and distinct globular chambers. This species are very rare in the studied area with poor to moderate preservation (with calcite infill).

World Stratigraphic range: Stratigraphically it ranges from near the top of the *Paraticinella eubejaouaensis* Zone (latest Aptian) through lowermost *Microhedbergella rischi* Zone (early Albian). It has been identified at DSDP Site 511 (southern Atlantic), ODP Site 1049 (western subtropical North Atlantic), ODP Site 763 (southeast Indian Ocean) and the Pre'Guittard Section in the Vocontian Basin of southeastern France (Huber and Leckie, 2011).

Tanzania Range: Sample from TDP 40 Hole B; 5/1, 1-25 cm, (8.1 m).

Subfamily HEDBERGELINAE Loeblich and Tappan, 1961
Genus *Microhedbergella* Huber and Leckie, n gen., 2011

***Microhedbergella pseudoplanispira* Huber and Leckie n sp.**

Plate 3.7, figs. 4a-d

Type reference: *Hedbergella planispira* Tappan, Gradstein, 1978, pl. 11, figs. 14, 15 [Middle Albian, *Ticinella primula* Zone, DSDP Hole 392A, Blake Plateau, western North Atlantic]. *Microhedbergella pseudoplanispira* Huber and Leckie, n. sp., Huber and Leckie, 2011, figs. 17.1-17.4, p. 77-79.

Description: *Microhedbergella pseudoplanispira* consists of a small trochospiral test with a flat to slightly convex spiral side and convex umbilical side with a spherical to slightly elongate and lobate equatorial outline. Chambers are subglobular to globular increasing moderately in size as added, coiled into two whorls with six chambers in the final whorl; sutures are depressed and curved radial on both sides; umbilicus is shallow, aperture an extraumbilical low arch that extends from near the equatorial peripheral margin and close to the umbilicus bordered by a narrow lip. Relict apertures not well defined due to the poor nature of preservation.

Remarks: The *Microhedbergella pseudoplanispira* found in this study is different from the one described by Huber and Leckie (2011), some of its features are somehow similar to the one described by Huber and Leckie (2011) with the difference in the number of chambers in the last whorl. The Tanzanian *Microhedbergella pseudoplanispira* specimen has six chambers in the final whorl; it is very rare in the studied sequence and preservation varies from poor to moderate and few horizons with moderate to good (see tables 5.1-5.2).

World Stratigraphic range: *Microhedbergella pseudoplanispira* stratigraphically ranges from *Microhedbergella rischi* Zone (early Albian) through *Pseudothalmanninella ticinensis* Zone (late Albian).

Tanzanian Range: Sample TDP 40B Hole Core 2/2, 1-25 cm (3.1 m).

Subfamily HEDBERGELINAE Loeblich and Tappan, 1961
Genus *Microhedbergella* Huber and Leckie, n gen., 2011

Microhedbergella renilaevis (Huber and Leckie n sp.)

Plate 3.8, figs. 1a-d & figs. 2a-d

Type reference: *Microhedbergella renilaevis* n. sp., Huber and Leckie, 2011, p. 25a, figs. 16-17.

Description: *Microhedbergella renilaevis* from the current study is low trochospiral with four chambers in the last whorl and chambers increasing rapidly in size as added; two whorls are visible on the spiral side. Smooth to finely perforate, the primary aperture is arch shape and at the base of the final chamber and extends into and out of umbilical region, covered by a lip or flap which also extends to umbilical region.

Remarks: Specimens of *Microhedbergella renilaevis* are present in only four boreholes i. e.; Kiwangwa-1, Makarawe-1 TDP Site 40 Hole A and TDP Site 40 Hole B and are very rare in the studied interval. This species is distinguished from other species of *Microhedbergella* by having a more compressed test, a wider umbilicus, chambers that are more reniform or lobate in equatorial view and common presence of an apertural flap and portici and preservation varies from poor to moderate (specimens with calcite and pyrite infill).

World Stratigraphic range: *Microhedbergella renilaevis* ranges from the early Albian (*Microhedbergella rischi* Zone) through middle Albian (*Ticinella madecassiana* Zone).

Tanzania Range: Makarawe-1 Hole; (620 m) and figs 1a-d, *Microhedbergella renilaevis* (sp. 1); sample TDP 40B Hole; Core 5/1, 1-25 cm, (8.1 m), figs. 2a- d (sp.2).

Subfamily HEDBERGELINAE Loeblich and Tappan, 1961
Genus *Microhedbergella* Huber and Leckie, n gen., 2011

Microhedbergella rischi (Moullade)

Plate 3.8, figs. 3a-d

Type reference: *Hedbergella* (*Hedbergella*) sp. aff. *infracretacea* (Glaessner), Moullade, 1966, p. 89, 90, pl. 8, figs. 6-16.
Hedbergella rischi Moullade, 1974, p. 1816.

Description: *Microhedbergella rischi* identified in the present study consists of a small test, trochospirally coiled with a flat to slightly convex spiral side and more convex umbilical side. Surface of the test is smooth with few finely scattered pores, equatorial periphery is elongate; subspherical to spherical chamber shape which increasing slightly as added; five chambers in the last whorl; two whorls which are visible in the spiral view, sutures on the umbilical side are radial while on the spiral side are radial to slightly curved and depressed. The umbilical region is small and moderately deep. The primary aperture is at the base of the final chamber and extends slightly near the equatorial periphery and slightly close to the umbilicus and is arch in shape. A lip which broadens into the final chamber and relict apertural lips are seen around the umbilicus.

Remarks: *Microhedbergella rischi* is thought to be an intermediate form between *Ticinella primula* and *Ticinella madecassiana* (Moullade and others; 2002). It differs from *Microhedbergella praeplanispira* on wall surface texture, subspherical chambers and a narrow umbilicus, plus relict apertures which are not well developed, and a higher than broader primary aperture. It was suggested by Huber and Leckie, (2011), that there is a high possibility *Microhedbergella rischi* was an ancestral to *Ticinella madecassiana.* It differs from *Hedbergella excelsa* by the absence of perforation cones on the test surface presence of an apertural lip and a more compact coiling and its flat trochospire test. Specimens are rare and preservation is poor to moderate (specimens with calcite infill).

World Stratigraphic range: *Microhedbergella rischi* is a zonal marker of the *Microhedbergella rischi* Zone, and stratigraphically ranges from the *Mi. rischi* Zone (early Albian) through *Ticinella primula* Zone (late Albian).

Tanzania Range: Sample from TDP40B Hole, Core 5/1, 1-25 cm (8.1 m).

Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961
Genus *Muricohedbergella* Huber and Leckie, n. gen., 2011

Muricohedbergella albiana (BouDagher-Fadel and others)

Plate 3.8, figs. 4a-d

Type reference: *Hedbergella infracretacea* (Glaessner), Gorbachik and Kretchmar, 1969, pp. 50, 51, pl. 1, figs 5a-c (non *Globigerina infracretacea* Glaessner, 1937).
Blefuscuiana albiana BouDagher-Fadel and others, 1996, p. 253, figs. 4, (6-9).
Type species: *Globigerina planispira* Tappan, 1940.

Description: The test of *Muricohedbergella albiana* is low trochospiral with spiral side slightly convex to flatter than the umbilical side; two whorls of the final chambers are visible on the spiral side, five subglobular chambers in the last whorl; increasing rapidly in size as added, umbilicus is small and deep. The aperture is extraumbilical-umbilical, bordered by a thin lip; wall is perforate and muricate much along the sutural areas on the umbilical side and spiral side.

Remarks: This species varies from rare to abundant in the studied interval and few intervals with moderate to good preservations in Kizimbani-1 Hole (table 4.4) and TDP Site 40 Holes (see table 5.1 and 5.2). This species is placed in *Muricohedbergella* based on wall textures and size of pores (perforations); Huber and Leckie, 2011).

World Stratigraphic range: This species was first described from the late Albian of the Speeton Cliffs, Filey Bay North Yorkshire, England (Banner and others, 1988). Stratigraphically it ranges from the middle Albian (*Ticinella primula* Zone) through latest Albian (*Thalmanninella appenninica* Zone).

Tanzania Range: Sample Luhoi-1 Hole; Core 53/1, 80-90 cm, (273 m).

Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961
Genus *Muricohedbergella* Verga and Premoli Silva, 2004

Muricohedbergella delrioensis (Carsey)

Plate 3.9, figs. 1a-d

Type reference: *Globigerina cretacea* d'Orbigny var. *delrioensis* Carsey, 1926, p. 43, type-figure not given).
Type species: *Globigerina planispira*, Tappan, 1940.

Description: Species of *Muricohedbergella delrioensis* identified in the studied interval, has small test coiled trochospirally with 5-globular chambers, increasing moderately in size as added; wall with perforation cones or muricae except lacking in the last chamber of the final whorl, primary aperture is an arch, at the base of final chamber and stretches from outside the umbilicus to umbilical, sutures are raised radially curved to straight and depressed on both sides.

Remarks: *Muricohedbergella delrioensis* present in the upper Albian to Cenomanian interval of the studied section (see table 4.1-5.2). *Muricohedbergella* differs from *Microhedbergella* by having a thicker, and finely perforate shell wall (pore 1-2.5 µm) and having a moderately to coarsely muricae wall, rather than a smooth, surface texture. Specimens varies in abundance from rare to abundant with poor to moderate preservation and few with moderate to good from Kizimbani-1 Hole (see table 4.6).

World Stratigraphic range: This species ranges from the late Albian to Maastrichtian.

Tanzania Range: Sample Songo Songo-4 Hole; (1670.3 m).

Remarks: *Microhedbergella* differs from *Hedbergella* by its smaller test size and thinner shell wall (< 3 µm vs. 4-6µm); microperforate with smooth surface and presence of an apertural lip or flap. *Microhedbergella* resembles *Praehedbergella* because of its small test size, thin wall texture, and considered as distantly related homeomorphic lineages because of their stratigraphic gap that separates species included within each of the genera. The new genus included *Microhedbergella miniglobularis n.* sp., *Microhedbergella praeplanispira, Microhedbergella pseudoplanispira n.* sp., *Microhedbergella pseudodelrioensis, Microhedbergella renilaevis n*. sp., and *Microhedbergella rischi* (Moullade).

The prefix micro - is added to the pre-existing genus name *Hedbergella in* reference to the microperforate wall microstructure (Huber and Leckie, 2011).

Subfamily HEDBERGELLINAE Loeblich and Tappan, 1961
Genus *Muricohedbergella* Huber and Leckie, n. gen., 2011

Muricohedbergella simplex (Morrow)

Plate 3.9, figs. 2a-d (sp. 1) and figs. 3a-d (sp. 2)

Type reference: *Hastigerinella simplex* Morrow, 1934, p. 198, pl. 30, fig. 6.

Type species: *Globigerina planispira* Tappan, 1940.

Description: *Muricohedbergella simplex* identified in the current study is trochospiral, with five subglobular chambers, and the two last chambers of the final whorl are broader and elongate with club like at the terminal ends, and increasing rapidly in size as added. Two whorls are visible on the spiral sides of the two specimens. Both have a coarsely perforated wall and perforation of different sizes are scattered throughout the test while *Muricohedbergella simplex* sp. 2 with muricae like structures distributed throughout the test. Both periphery outlines are subrounded; umbilical areas are narrow and deep; primary aperture; extraumbilical to umbilical bordered by a thick lip; sutures are radial and depressed. The two specimens of *Muricohedbergella simplex* have wall textures which qualifies to the species described by Premoli Silva and Verga, (2004), referred to *Muricohedbergella simplex*. Hence these two specimens (figs, 1a-d and figs 2a-d are currently named as *Muricohedbergella simplex* (Premoli Silva and Verga, 2004).

Remarks: Varieties of specimens of *Muricohedbergella simplex* were seen in the studied late Albian to Cenomanian interval. It differs from *Hedbergella flandrini*, in the stronger and more distinct elongation of the last chamber. *Muricohedbergella simplex* varies in abundance from rare to abundant. Specimens with moderate to good preservations are present in few intervals of Kizimbani-1 Hole (see table 4.6).

World Stratigraphic range: The original specimen of *Muricohedbergella simplex* (previous name *Hedbergella simplex*) was reported from the late Cenomanian, interval of Greenhorn Formation, Kansas, and USA. *Muricohedbergella simplex* stratigraphically ranges from the middle Albian through the Coniacian.

Tanzania Range: Sample Kisarawe-1 Hole; (1811 m, sp. 1) and sample Kisarawe-1 Hole; (1780 m, sp. 2) respectively.

Subfamily PARATICINELLINAE Huber and Leckie, n. subfamily 2011
Genus *Paraticinella* Premoli Silva, Caron, Leckie, Petrizzo, Soldan and Verga, 2009

***Paraticinella eubejaouaensis* Randrianasolo and Anglada, Premoli Silva, Caron, Leckie, Petrizzo, Soldan and Verga**

Plate 3.9, figs. 4a-d (sp. 1) and Plate 3.10, figs. 1a-d (sp. 2)

Type reference: Holotype = Paratype of *Ticinella bejaouaensis* Sigal, 1966 pl. V, figs. 8-9, microslides F6 0887, case 12, MNHN
Paraticinella eubejaouaensis Randrianasolo and Anglada, Premoli Silva and others, 2009, p. 131-135, text-figs. 3.3-3.6, pl. 2, figs. 1-6 [upper Aptian, DSDP Site 545, Mazagan Plateau, eastern North Atlantic].
Type species: *Ticinella roberti* var. *bejaouaensis* Sigal 1966.

Description: *Paraticinella eubejaouaensis* identified in the present study are trochospirally coiled with a flat spiral sides and convex umbilical side. The peripheral margin is spherical with number of chambers varying from 8-10 in the final whorl; chambers are spherical to reniform, sutures slightly radially curved and depressed on both sides. Test surface is finely perforate to smooth, but can have volcano-like perforation cones covering the inner whorl and earlier chambers in the last whorl in both sides; while four chambers of the last whorl are smooth on both sides of the test. Both umbilical regions of the two illustrated specimens are moderate in size and shallow in the second specimen the umbilical region is partially covered by flaps from the two last chambers of the final whorl which converge to form a cover plate.

The primary aperture is not very well defined in the first specimen but in the second specimen it is at the base of the final chamber and stretches from the umbilicus towards the periphery.

Remarks: *Paraticinella eubejaouaensis* differs from *Hedbergella trocoidea* by its larger test size and greater number of chambers (8-10) while *Hedbergella trocoidea* has (6.5-7.5). *Hedbergella trocoidea* possess a large final chamber which stretches into the umbilicus and a shallow and wide umbilicus and an aperture which is bordered by a lip. Specimens of *Paraticinella eubejaouaensis* identified in the present study closely resemble the one described by Premoli Silva and others (2009). *Paraticinella eubejaouaensis* in the studied material varies from rare to abundant and preservation varies from poor to moderate and few specimens in few levels of the uppermost Aptian in Kizimbani-1 Hole with moderate to good.

World Stratigraphic range: *Paraticinella eubejaouaensis* is a Zonal marker species for the latest Aptian (*Paraticinella eubejaouaensis* Zone). Its last occurrence is used to demarcate the Aptian /Albian boundary. Similar kind of specimens was reported from the uppermost Aptian interval of Site 545 (DSDP Leg 79, off Morocco (1969) and Vocontian Basin SE France.

Tanzania Range: Sample Kizimbani-1 Hole; (137.2 m; sp. 1 and sample Kiwangwa-1, (345 m; sp. 2).

Subfamily PARATICINELLINAE Huber and Leckie, n. subfamily 2011
Genus *Paraticinella* Premoli Silva, Caron, Leckie, Petrizzo, Soldan and Verga, 2009

Paraticinella transitoria (Longoria)

Plate 3.10, figs. 2a-d

Type reference: *Ticinella bejaouaensis* Sigal *transitoria* Longoria, 1974, p. 94, 95, pl. 21, figs. 9-11, 14-16 [uppermost Aptian, Vocontian Basin, Drome region, southeast France].

Description: *Paraticinella transitoria* is trochospirally coiled, with six chambers in the final whorl; two whorls are visible on the spiral side. The test is very rough (rugose) on the umbilical side but the roughness (rugosity) is less in the spiral side in the last whorl. While on the spiral side the roughness (rugosity) seen on the suture area of the earlier chambers and faintly seen in the last chambers of the final whorl. The primary aperture is not visible and umbilicus is shallow and small, and no lip or a cover plate in the umbilicus; supplementary apertures are not visible in the umbilicus. Identification is based on the test shape and chamber arrangement including test ornamentation. Comparison was made with published specimens of *Paraticinella transitoria* (Huber and Leckie, 2011).

Remarks: *Paraticinella transitoria* is distinguished from *Paraticinella eubejaouaensis* by having a medium to higher axis of coiling, less number of chambers (5.5-7 instead of 8-10) in the final whorl; smaller and shallow umbilicus lacking apertural flap and an umbilical cover plate. It differs from *Hedbergella trocoidea* in absence of a cover plate and rugosities which are arranged parallel to the equatorial outline on the early chambers in the final whorl. It has been suggested that *Paraticinella transitoria* is a transitional species between *Hedbergella trocoidea* and *Paraticinella eubejaouaensis* (Huber and Leckie, 2011). Specimens of *Paraticinella transitoria* are rare in the studied upper Aptian interval. Specimen preservation varies from poor to moderate.

World Stratigraphic range: *Paraticinella transitoria* stratigraphically is a late Aptian species and ranges from the middle through top of the *Paraticinella eubejaouaensis* Zone (Huber and Leckie, 2011).

Tanzania Range: Sample Kiwangwa-1 Hole; (370 m).

3.4.5 Family PLANOMALINIDAE Bolli, Loeblich and Tappan, 1957

The late Albian is characterized by the appearance of new genera such as *Biticinella, Rotalipora*, *Planomalina* and *Praeglobotruncana* (Petrizzo and Huber, 2006). Among these genera the planispiral and keeled genus *Planomalina* is confined to the uppermost Albian sediments (Petrizzo and Huber, 2006).

Petrizzo and Huber, (2006) studies confirmed that the macroperforate trochospiral form, *Hedbergella wondersi*, gave rise to *Planomalina*. The *Hedbergella wondersi-Planomalina buxtorfi* lineage spans the upper Albian interval from *Pseudothalmanninella ticinensis* Zone to the top of the *Thalmanninella appenninica* Zone. It was recorded in the central Atlantic Ocean

(Blake Nose, ODP Sites 1050 and 1052, and Moroccan DSDP Sites 547) and in northern Madagascar (Petrizzo and Huber, 2006).

The evolution from *Planomalina praebuxtorfi* to *Planomalina buxtorfi* in the lower part of the *Thalmanninella appenninica* Zone is characterized by the development of a peripheral keel in all the chambers of the final whorl and raised sutures which are curved backwards. Intermediate forms between *Planomalina praebuxtorfi* and *Planomalina buxtorfi* are lacking in peripheral keel and have depressed sutures on the last chambers (Petrizzo and Huber, 2006).

Subfamily PLANOMALININAE Bolli, Loeblich and Tappan, 1957
Genus *Planomalina* Loeblich and Tappan, 1946

Planomalina buxtorfi (Gandolfi)

Plate 3.10, figs. 3a-d

Type reference: *Planomalina buxtorfi* Gandolfi, 1942, p. 103, pl. 3, figs. 7a-c., pl. 5, figs. 3-6, pl. 6, figs. 1-3, pl. 8, fig. 8, pl. 9, fig. 2, pl. 12, fig. 2, pl. 13, fig. 13, 15.
Type species: *Planomalina apsidostroba* Loeblich and Tappan 1946 = *Planomalina buxtorfi* Gandolfi 1942

Description: *Planomalina buxtorfi* identified in the present study is planispiral, smooth, biumbilicate and with a primary aperture which extends from the equatorial margin to umbilical on both sides bordered by a narrow lip. It has a macroperforate wall and nine chambers which are visible in both sides of the test in the last whorl. A single peripheral keel is present, sutures are strongly raised and curved backwards and chambers are compressed.

Remarks: Specimens of *Planomalina buxtorfi* vary from rare to frequent in the studied uppermost Albian intervals of the boreholes and preservation is poor to moderate. Petrizzo and Huber (2006) ‘described the genus *Planomalina* as the end member of the lineage and was thought to originate during late Albian. It was also suggested that the trochospiral species of *Hedbergella wondersi* is the ancestral species of *Planomalina* (Petrizzo and Huber, 2006 and references therein).

World Stratigraphic range: *Planomalina buxtorfi* is an uppermost Albian species and its range does not extend further. The original specimen was reported from the latest Albian interval of Breggia river, Switzerland (Robaszynski and Caron; 1979a).

Tanzania Range: Sample Songo Songo-4 Hole; Core 2/2, 67-73 cm, (1839.3 m).

Subfamily PLANOMALININAE Bolli, Loeblich and Tappan, 1957
Genus *Planomalina* Loeblich and Tappan, 1946

***Planomalina praebuxtorfi* (Wonders-Wonders) transition to *Planomalina buxtorfi* (Gandolfi)**

Plate 3.10, figs. 4a-d

Type reference: *Planomalina praebuxtorfi* Wonders 1975; p. 90-91, pl. 1; fig. 1a-c, 2a-c; text-figure 4; 2a-b.

Description: Test is planispiral, globular to triangular compressed chambers, with randomly distributed and fused muricae in the earlier chambers of the last whorl, and becoming smoother on the last three chambers of the final whorl. Nine chambers in the final whorl increasing gradually in size as added, peripheral margin subacute to acute; sutures are depressed on the last chambers. Aperture is equatorial extending on both sides to the umbilical area. Umbilicus is wide and shallow and absence of a peripheral keel.

Remarks: This species is rare in the studied uppermost part of the Albian interval and preservation of this specimen is poor to moderate, specimen with calcite infill.

World Stratigraphic range: *Planomalina praebuxtorfi transition* to *Planomalina buxtorfi* is a latest Albian species and confined to the lower part of the *Thalmanninella appenninica* Zone.

Tanzania Range: Kiwangwa-1; 365 m, reworked specimens; Also similar specimen was encountered in sample Songo Songo-4 Hole; Core 4/2, 0-10 cm, (1871.6 m); it's also a reworked specimen through washing.

Subfamily PRAEGLOBOTRUNCANINAE Loeblich and Tappan, 1982

Genus *Praeglobotruncana* Bermudez, 1952

***Praeglobotruncana delrioensis* (Plummer)**

Plate 3.10, figs., 5a-d

Type reference: *Globorotalia delrioensis* Plummer, 1931, pl. 13, fig. 2, 199-200 p.
Type species: *Globorotalia delrioensis* Plummer 1931

Description: *Praeglobotruncana delrioensis* identified in the present study is characterized by a low trochospiral test, biconvex, with five chambers in the last whorl, and shows a less convex spiral side than umbilical side; two whorls are visible on the spiral side; umbilical sutures are depressed and radially curved on the umbilical and spiral side; pustule-like structures seen on the early chambers of the final whorls of both specimens. The primary aperture is interiomarginal extraumbilical to umbilical region, bearing a lip or a flap; and a single peripheral keel.

Remarks: *Praeglobotruncana delrioensis* differs from *Praeglobotruncana stephani* in its less convex spiral side. Specimens of *Praeglobotruncana delrioensis* vary from rare to abundant in the studied interval and preservation varies from poor to moderate.

World Stratigraphic range: *Praeglobotruncana delrioensis* ranges from the latest Albian (*Thalmanninella appenninica* Zone) through late Cenomanian (*Rotalipora cushmani* Zone). The original specimen was reported from the *Thalmanninella appenninica* Zone, latest Albian, in the Del Rio Formation, Austin, Texas, USA.

Tanzania Range: Sample Songo Songo-4 Hole, (1670.3 m).

Subfamily PRAEGLOBOTRUNCANINAE Loeblich and Tappan, 1982
Genus *Praeglobotruncana* Bermudez, 1952

Praeglobotruncana gibba (Klaus)

Plate 3.11, figs. 1a-d

Type reference: *Praeglobotruncana stephani* Gandolfi var. *gibba* Klaus, 1960, pp. 304-305. Holotype designated in Reichel, 1950, pl. 16, fig. 6, pl. 17, fig. 6.

Description: *Praeglobotruncana gibba* identified in the current study is trochospiral with a highly convex spiral side while the umbilical side is less convex; three whorls on the spiral side; test outline is subrounded; keel is well defined in the earlier chambers of the last whorl on the spiral and umbilical side; pustules surrounding the umbilical and spiral areas in the earlier chambers of the last whorl, smooth in the last two chambers, visible on the spiral side. The primary aperture is at the base of the final chamber extending towards the periphery margin to the umbilicus with a moderate flap/lip. On the spiral side chambers are petal-like in shape, umbilical chambers not fully triangular; six chambers on the final whorl. The umbilical area is wide and deep.

Remarks: This species differs from *Praeglobotruncana stephani* in its higher convex spiral side and in the presence of thin flap in a deep umbilicus. Structures on the umbilical side are obscured due to the nature of poor to moderate preservation. Specimen of *Praeglobotruncana gibba* varies in abundance from rare to abundant in the studied interval.

World Stratigraphic range: This species ranges from the late Cenomanian (*Rotalipora cushmani* Zone) through middle Turonian (*Helvetoglobotruncana helvetica* Zone). The Original specimen of *Praeglobotruncana gibba* was reported from Breggia River, Switzerland in the *Thalmanninella reicheli* Zone. It has also been described from the middle Cenomanian of Tunisia (Robaszynski and Caron, 1979).

Tanzania Range: Sample Kisarawe-1 Hole, (1762 m).

Subfamily PRAEGLOBOTRUNCANINAE Loeblich and Tappan, 1982
Genus *Praeglobotruncana* Bermudez, 1952

***Praeglobotruncana stephani* (Gandolfi)**

Plate 3.11, figs. 2a-d (sp. 1), figs. 3a-d (sp. 2) and figs. 4a-d (sp. 3)

Type reference: *Globotruncana stephani* Gandolfi, 1942; p. 130, pl. 3, figs. 4a-c.

Description: *Praeglobotruncana stephani* is coiled in a trochospiral, biconvex, with seven (figs. 2a-d, figs. 4a-d) and five (figs 3a-d) chambers in the last whorls and a nodose keel and visible in the early chambers of the final whorl. Sutures in the spiral are curved while on the umbilical side they are depressed and radial; umbilicus narrow and; slightly deep, primary aperture interiomarginal extraumbilical to umbilical, with a distinct bordering lip.

Remarks: *Praeglobotruncana stephani* is regarded as an intermediate form between *Praeglobotruncana delrioensis* and *Praeglobotruncana gibba* based on the height of the trochospire and the thickness of the pustulose peripheral band (Caron, 1985). It can be distinguished from *Praeglobotruncana gibba* in its moderate convex spiral side. Specimens of *Praeglobotruncana stephani* vary in abundance from rare to frequent and preservation varies from poor to moderate.

World Stratigraphic range: *Praeglobotruncana stephani* ranges from early Cenomanian (*Thalmanninella globotruncanoides* Zone) through middle Turonian (*Helvetoglobotruncana helvetica* Zone).

Tanzania Range: Sample Kisarawe-1 Hole, (1780 m.; sp. 1), sample Songo Songo-4, (1744 m.; sp. 2), and sample Kisarawe-1, (1823 m, sp. 3) respectively.

Subfamily PRAEHEDBERGELLINAE Banner and Desai, 1988
Genus *Praehedbergella* Gorbachik and Moullade, 1973

***Praehedbergella ruka* Banner, Copestake and White**

Plate 3.12, fig. 1 a-b

Type reference: *Praehedbergella ruka* Banner, Copestake and White, 1993, p. 6, pl. 1, figs. 2a-c.

Description: The test is moderately size and trochospirally coiled biconvex; spiral side is more convex than the umbilical side, with globular chambers, four in the final whorl increasing rapidly in size as added, two whorls are visible on the spiral side, equatorial outline is round, sutures depressed, radial to slightly straight; umbilical area is narrow and deep; primary aperture extends from umbilical to extraumbilical. The wall extends from smooth to finely perforate; while few pustules that are observed in the final chamber are seen on the umbilical side.

Remarks: The current *Praehedbergella ruka* identified from the Tanzanian Aptian interval closely resembles *Hedbergella ruka* described by Huber and Leckie (2011). Specimens of *Praehedbergella ruka* are rare in the studied interval and preservation varies from poor to moderate.

World Stratigraphic range: *Hedbergella ruka* stratigraphically ranges from the early Aptian through late Aptian. Similar type of species has been reported from the same level in North Sea region (Banner and others, 1993).

Tanzania Range: Sample TDP 40B Hole; Core 5/3, 30-40 cm, (10.4 m).

3.4.6 Family GUEMBELITRIIDAE Montanaro Gallitelli, 1957

Subfamily GUEMBELITRIINAE Montanaro Gallitelli, 1957
Genus *Pseudoguembelitria* Huber and Leckie, n gen., 2011

***Pseudoguembelitria* sp.**

Plate 3.12, figs. 2a-d

Type reference: *Pseudoguembelitria Huber and Leckie n. gen*., 2011, p., 62, figs. 5.1-5.2, 5.4.
Type species: *Pseudoguembelitria* Huber and Leckie, n. gen., 2011.

Description: *Pseudoguembelitria* species identified in the present study consists of a test which is triserial with globular chambers, 4-chambers in the last whorl, increasing in size slowly as added, primary aperture a simple arch at the base of the last chamber. Test perforate, sutures depressed radial to nearly straight.

Remarks: *Pseudoguembelitria* species differs from other Cretaceous planktonic foraminifera by its fewer chambers per whorl. This specimen identified here is different from other species described in the literatures and probably a juvenile form.

Preservation is poor to moderate; specimen with calcite infill.

World Stratigraphic range: *Pseudoguembelitria* is a late Aptian species.

Tanzania Range: Sample TDP 40A Hole; Core 5/3, 65-90 cm, (10.8 m).

3.4.7 Family ROTALIPORIDAE Sigal, 1958

The family Rotaliporidae Sigal (1958) is stratigraphically important for the Aptian to Cenomanian time interval. It is divided into two subfamilies Rotaliporinae Sigal (1974) with peripheral keel and Ticinellinae Longoria (1974) without keel. They are six genera in this subfamily which are *Rotalipora* Brotzen, 1942; *Thalmanninella* Sigal, 1948; *Anaticinella* Eicher, 1973; *Pseudoticinella* Longoria, 1973a; *Pseudothalmanninella* Wonders, 1978; and *Pseudorotalipora*, Ion, 1983 (González-Donoso and others, 2007). The taxonomic revision of Rotaliporinae was suggested during 2005 by the Mesozoic Planktonic Foraminifera Working Group of CHRONOS in Fribourg, Switzerland. Only three genera are described here and these are *Pseudothalmanninella*, *Thalmanninella* and *Rotalipora* based on evolutional lineage. The subfamily 'rotaliporids' is used for the polyphyletic group (González-Donoso and others, 2007).

Gonzalez-Donoso and others (2007) revised and redescribed the genera *Pseudothalmanninella, Thalmanninella* and *Rotalipora* based on a combination of new and old criteria (Gonzalez-Donoso and others (2007). *Globotruncana (Rotalipora) montsalvensis* was assigned to the genus *Rotalipora* and the genus *Rotalipora* and *Globotruncana (Rotalipora) reicheli* was assigned to the genus *Thalmanninella*. This new classification is based on lineage affinities more than on morphological differences (Caron and Spezzaferri, 2006). Species belonging to the genus *Thalmanninella* described in this thesis are *Thalmanninella appenninica*, *Thalmanninella gandolfi*, *Thalmanninella globotruncanoides*, *Thalmanninella greenhornensis*, *Thalmanninella reicheli*, and *Thalmanninella deeckei* (González-Donoso and others, 2007).

The genus *Pseudothalmanninella*, as emended, derives from *Ticinella praeticinensis* and possesses a trochospiral test, with intraumbical supplementary apertures. The *Pseudothalmanninella* range from the late Albian to earliest Cenomanian (González-Donoso and others, 2007). The genus *Thalmanninella* as emended, derives from *Ticinella raynaudi*, and possesses a trochospiral test with intraumbilical and sutural supplementary apertures. Species of *Thalmanninella* ranging from the late Albian to the Cenomanian. The genus *Rotalipora*, as amended, characterizes the Cenomanian only and has an uncertain origin possibly from *Praeglobotruncana* (González-Donoso and others, 2007). The morphological variability (e.g., the shape of the test and its lateral view, the number of chambers in the last whorl and the whorl expansion rate) is very high in all the species of the rotaliporids (González-Donoso and others, 2007). *Pseudothalmanninella*, became extinct during the earliest Cenomanian, species belonging to the *Pseudothalmanninella* described in the text are *Pseudothalmanninella ticinensis* and *Pseudothalmanninella subticinensis* (González-Donoso and others, 2007).

Subfamily ROTALIPORID Sigal, 1958
Genus *Pseudothalmanninella* Wonders, 1978, emended

Pseudothalmanninella subticinensis (Gandolfi)

Plate 3.12, figs. 3a-d

Selected figures: Gandolfi, 1942, pl. 2, fig. 4, under the name "*Globotruncana ticinensis* var. a;" Robaszynski, Caron and the EWGPF, 1979, pl. 19, figs. 1a-c, 2a-d.
Type species: Globotruncana ticinensis forma tipica Gandolfi, 1942.

Description: *Pseudothalmanninella subticinensis* identified in the Tanzanian material is trochospirally coiled with a more convex spiral side, than umbilical side, and a single peripheral keel in the early chambers, while the last whorl are not keeled and its spiral intercameral sutures are depressed. Tthe earlier chambers possess a single keel and raised spiral intercameral sutures with depressed umbilical sutures. Seven chambers in the last whorl, chambers increasing slowly in size as added. The primary aperture is extraumbilical-umbilical bordered by a lip, and supplementary apertures are not visible due to poor preservation. An umbilicus is shallow and narrow and peripheral margin is ovoid.

Remarks: *Pseudothalmanninella subticinensis* differs from *Pseudothalmanninella ticinensis* by lack of a keel on the last chambers of the final whorl and ovoid peripheral margin. The specimens of *Pseudothalmanninella subticinensis* are rare in most of the interval of late Albian of the boreholes except in Kisarawe-1 well with common abundance.

World Stratigraphic range: This species stratigraphically ranges from late Albian (*Pseudothalmanninella subticinensis* Zone) through latest Albian (*Thalmanninella appenninica* Zone).

Tanzania Range: Sample Makarawe-1, (570 m).

Subfamily ROTALIPORIDS (González-Donoso and others, 2007)
Genus *Rotalipora* Brotzen, 1942, emended

***Rotalipora* cf. *cushmani* (Morrow)**

Plate 3.12, figs. 4a-d

No Holotype designated, original specimen refigured by Brönnimann and Brown, 1956, pl. 20, figs. 10-12; Robaszynski, Caron and the EWGPF, 1979, Pl. 7, fig. 1 a-c; pl. 8, fig. 1a-c; González-Donoso and Linares, 1993, pl. 21,fig.1.
Type species: *Rotalipora turonica* Brotzen, 1942, junior synonym of *Rotalipora cushmani* (Morrow, 1934).

Description: *Rotalipora* cf. *cushmani* has a low trochospiral biconvex test; a lobulate equatorial periphery with a weakly beaded narrow keel, smooth in the last chambers; spiral side is more convex than the umbilical side; wall perforate, surface slightly rugose on both sides and a three sided thickened ridge present on top of the last chambers on the umbilical sides. Chambers of the last whorl increasing rapidly in size as added; sutures on spiral side curved, raised and weakly beaded in the last whorl, depressed in the initial whorls; on umbilical side radial, depressed; umbilicus fairly wide and deep. Primary aperture is a high, interio-marginal, extraumbilical-umbilical arch, bordered above by a distinct lip, visible in the last chamber. A single elongated, well developed sutural secondary aperture bordered by a lip is present on the umbilical shoulder of each chamber, two whorls are visible on the spiral side; chambers on the umbilical side are triangular in shape and on the spiral side are rhomboid. Ornamentation of beads diverges from the central part of each chamber, forming a triradial arrangement on the spiral and umbilical side.

Remarks: Specimens of *Rotalipora cushmani* were recognized in Songo Songo-4 and Kisarawe-1 material; Preservation of specimens varies from poor to moderate. Specimens of *Rotalipora cushmani* are present throughout the late Cenomanian interval and range in abundance from rare to frequent. However the specimen *Rotalipora cushmani* illustrated in Plate 3.12 figure 4a-d, does not have a typical shape of *R. cushmani* especially the spiral side therefore named as *Rotalipora* cf. *cushmani*.

World Stratigraphic range: *Rotalipora cushmani* stratigraphically range from the middle to late Cenomanian (ranges throughout the *Rotalipora cushmani Zone*). Specimens of *Rotalipora cushmani* have been recorded earlier from the *Rotalipora cushmani* Zone in the late Cenomanian of Hartland shale, Greenhorn Formation, Kansas, USA.

Tanzania Range: Sample Kisarawe-1 Hole; (1737.4 m).

Subfamily TICINELLINAE Longoria, 1974
Genus *Ticinell*a Reichel 1950

Ticinella sp., aff. _madecassiana_ (Huber and Leckie)

Plate 3.13, figs. 1a-d

Type reference: *Ticinella* sp., aff. *madecassiana* Huber and Leckie, 2011, figs. 16.1-6.7.
Type species: *Anomalina roberti* Gandolfi 1952

Description: *Ticinella* sp. aff. *madecassiana* is low, trochospirally coiled form, with almost flat spiral side, equatorial periphery slightly elongate and chambers are subglobular increasing moderately in size as added in the final whorl. Sutures slightly depressed and curved radially onboth sides; umbilicus is small and deep, primary aperture an extraumbilical-umbilical, with a low arch extends from the near the equatorial peripheral margin nearly to the umbilicus, bordered by a narrow lip which broadens to apertural flap extending towards the umbilicus, relict apertural flaps are visible surrounding the umbilicus.

Remarks: Specimens of *Ticinella madecassiana* are present in the Albian interval of the boreholes studied but their distribution was difficult to locate the zone with certainty. This species is rare within the studied sequence and specimen preservation varies from poor to moderate (specimens with calcite and pyrite infill). *Ticinella madecassiana* differs from *Ticinella primula* in a less lobate equatorial outline, a less-broadly rounded peripheral margin, a more circular peripheral outline, fewer chambers in the final whorl, and a rapid rate of chamber size increase and a narrow umbilicus.

World Stratigraphic range: *Ticinella madecassiana* stratigraphically ranges from the upper early Albian (*Ticinella madecassiana* Zone) through latest Albian (*Planomalina buxtorfi* Subzone).

Tanzania Range: Sample TDP40 Hole B; Core 2/1, 1-25 cm, (2.1 m).

Subfamily TICINELLINAE Longoria, 1974
Genus *Ticinella* Reichel, 1950

Ticinella madecassiana Sigal

Plate 3.13, figs. 2a-d

Type reference: *Ticinella madecassiana* Sigal, 1966, p. 197, pl. 3, figs. 7a–b.

Description: *Ticinella madecassiana* consists of a trochospiral test which is more convex on the umbilical side and less convex on the spiral side. It has six chambers in the final whorl, increasing rapidly in size as added; two whorls are visible in spiral view. Chambers are spherical and the peripheral margin is subrounded; primary aperture extends from umbilical to extraumbilical; supplementary apertures are present inside umbilical region; umbilical area is moderate and slightly deep.

Remarks: Specimens of *Ticinella madecassiana* are present in most of the boreholes drilled through the Albian. It differs from *Ticinella primula* in a less lobate equatorial outline; a less broadly rounded peripheral margin; and a more circular peripheral outline, less size increase, and a narrow umbilicus. Specimens of *Ticinella madecassiana* are rare in the late early Albian to mid Albian of Tanzania coastal basin and preservation is poor to moderate.

World Stratigraphic range: *Ticinella madecassiana* ranges from late early Albian (*Ticinella madecassiana* Zone) to the latest Albian (*Planomalina buxtorfi* Subzone).

Tanzania Range: TDP40B Hole; Core 2/1, 1-25 cm, (2.1 m).

Subfamily TICINELLINAE Longoria, 1974
Genus *Ticinella* Reichel 1950

Ticinella praeticinensis (Sigal)

Plate 3.13, figs. 3a-d

Type reference: *Ticinella praeticinensis* Sigal, 1966, pp.195- 6, pl. 2, figs. 3-5.

Description: *Ticinella praeticinensis* encountered in the present study is trochospirally coiled, biconvex, with seven subspherical chambers in the last whorl increasing slowly in size as added. Two whorls are visible on the spiral side, and the primary aperture is umbilical to extraumbilical. Sutures are radially curved to straight in both sides; and few supplementary apertures are seen inside the umbilicus. The umbilical region is shallow and wide; with subrounded peripheral margin and no keel; wall surface is coarsely perforate.

Remarks: *Ticinella praeticinensis* differs from *Ticinella roberti* by its subrounded periphery and pustules present in the early chambers of the last whorl, and absent in the last chamber. *Rotalipora subticinensis* evolved from *Ticinella praeticinensis* by growing a pseudo-keel (Caron, 1985). Specimens of *Ticinella praeticinensis* are rare in the studied upper Albian interval and specimens vary in preservation from poor to few moderate.

World Stratigraphic range: *Ticinella praeticinensis* stratigraphically is a late Albian species and ranges from the uppermost part of *Ticinella primula* Zone through *Pseudothalmanninella ticinensis* Zone.

Tanzania Range: Kizimbani-1 Hole; (46 m).

Subfamily TICINELLINAE Longoria, 1974

Genus *Ticinella* Reichel, 1950

Ticinella primula (Luterbacher)

Plate 3.13, figs. 4a-d

Type reference: *Ticinella primula* Luterbacher, in Renz and others, 1963, p. 1085, text-figs. 4 [Upper Albian, western Switzerland].

Description: *Ticinella primula* described from the present study composed of a test with a slightly convex to flat spiral side and a convex umbilical side; trochospirally coiled with a moderate test size; seven chambers in the last whorl, increasing gradually in size as added, spherical to subspherical in shape; while the last chamber is broader and higher. Test surface varies from finely perforate to macroperforate wall with nearly smooth surface; primary aperture is umbilical-extraumbilical covered by a thick imperforate lip or flap which also extends towards the umbilicus. Subrounded to oval and somehow lobate equatorial outline, round in edge view; close to the umbilicus two supplementary sutural apertures are present.

Remarks: Specimens of *Ticinella primula* are rare in the middle Albian interval of the studied succession of Tanzania and preservation of specimens vary from poor to moderate and few horizons in TDP 40 Sites A & B Holes and Kizimbani-1 Hole where varies from moderate to good (see tables 4.6 and tables 5.1-5.2).

World Stratigraphic range: Middle Albian (*Ticinella. primula* Zone) through latest Albian (*Planomalina buxtorfi* Subzone).

Tanzania Range: Sample TDP40B Hole; Core 4/2, 1-25 cm, (6.7 m)

Subfamily TICINELLINAE Longoria, 1974

Genus *Ticinella* Reichel 1950

Species *Ticinella raynaudi* Sigal 1966

Subspecies *Ticinella raynaudi aperta* Sigal 1966

Ticinella raynaudi aperta (Sigal.-Sigal)

Plate 3.13, figs. 5a-d

Type reference: *Ticinella raynaudi* var aperta Sigal-Sigal 1966: p. 202, pl. 11a, b-13a, b. *Ticinella raynaudi aperta* Sigal, Pflaumann and Krasheninnikov, 1977: p. 561, pl. 5, fig. 1, 2. *Type species*: *Anomalina roberti* Gandolfi 1952.

Description: *Ticinella raynaudi aperta* identified in the present study is low trochospirally coiled, with a slightly flat spiral side and convex umbilical side; moderate in test size, smooth to finely perforate, few pustules present along the sutural area of the test on the umbilical side; equatorial outline spherical and elongate, periphery margin rounded; chambers globular to subglobular, increasing rapidly in size as added, 6-chambers in the last whorl; umbilicus is small and slightly deep; sutures radially curved and depressed on both sides; primary aperture is umbilical to extraumbilical, bordered by a thick narrow lip.

Remarks: This specimen its chambers are quite different from other *Ticinella raynaudi* species chambers are globular to subglobular while *Ticinella raynaudi digitalis* has pointed ends. This species is very rare and preservation is poor to moderate in the studied sequence of the upper Albian.

World Stratigraphic range: *Ticinella raynaudi aperta* is a late Albian species.

Tanzania Range: Sample Makarawe-1 Hole; (540 m).

Subfamily TICINELLINAE Longoria, 1974
Genus *Ticinella* Reichel, 1950

Ticinella raynaudi digitalis (Sigal)

Plate 3.14, figs. 1a-d

Type reference: *Ticinella raynaudi* digitalis Sigal, 1966, pp. 202, pl. 6, figs. 6-8.

Type species: *Anomalina roberti* Gandolfi 1952

Description: *Ticinella raynaudi digitalis* has a thin and small test; radial elongate chambers and digitate; planispirally coiled flat on both sides with six chambers in the final whorl, chambers are higher and broader and increasing rapidly in size as added. The outline of the shell is lobate; the umbilical area is small and shallow. The primary aperture is extraumbilical- umbilical, chamber of the last whorl, with a lip and two whorls are visible on the spiral side; supplementary a pertures on the umbilical side.

Remarks: *Ticinella raynaudi digitalis* specimens are rare in the studies succession of the Albian of Tanzania. This species differs from *Ticinella raynaudi* due to its elongate and pointed ends of their last chambers of the final whorl and its preservation varies from poor to moderate.

World Stratigraphic range: *Ticinella raynaudi digitalis* stratigraphically ranges from the late Albian (*Ticinella praeticinensis* Zone) through *Thalmanninella appenninica* Zone (latest Albian).

Tanzania Range: Sample TDP 40B Hole; Core 2/1, 1-25 cm, (2.1 m).

Subfamily TICINELLINAE Longoria, 1974
Genus *Ticinella* Reichel 1950

Ticinella roberti (Gandolfi)

Plate 3.14, figs. 2a-d

Type reference: *Anomalina roberti* Gandolfi, 1942, pp. 100-1, pl. 2, figs 2a-c.
Type species: *Anomalina roberti* Gandolfi 1952

Description: *Ticinella roberti* identified from this study has a trochospirally coiled test; low convex spiral and umbilical side, chambers of the final whorl are slowly increasing in size as added. Primary aperture extraumbilical- umbilical with eight chambers in the final whorl; chambers are globular in shape and supplementary apertures are inside of umbilical area.

Remarks: *Ticinella roberti* differs from *Ticinella primula* in a higher trochospire and a rough surface on the chambers; from *Hedbergella trocoidea* by the presence of umbilical supplementary apertures. *Ticinella roberti* in the studied Tanzanian materials varies in abundance from rare to frequent and preservations varies from poor to moderate and in few intervals in Luhoi-1 Hole and Kizimbani-1 few intervals with moderate to good preservation.

World Stratigraphic range: *Ticinella roberti* stratigraphically ranges from the late Albian (*Ticinella praeticinensis* Zone) through latest Albian (*Thalmanninella appenninica* Zone). The original specimen of *Ticinella roberti* was first described from the late Albian of Breggia River, Canton Tessin, Switzerland (Caron, 1985).

Tanzania Range: Sample Luhoi-1 Hole; Core 53/1, 20-30 cm, (272.3 m).

Subfamily TICINELLINAE Longoria, 1974
Genus *Ticinella* Reichel, 1950

***Ticinella* sp.**

Plate 3.14, figs. 3a-d

Type reference: *Ticinella* Reichel, 1950

Description: Specimen of *Ticinella* is trochospirally coiled with a slightly convex to flat spiral side and inner chambers are depressed on the spiral side, while convex on the umbilical side. The final chamber in the last whorl is much broader and higher than the rest. Wall surface is smooth to small pores which are scattered randomly and few pustulose seen in the umbilical areas of the earlier chambers of the final whorl and sutural regions of the spiral side. Elongate to lobate equatorial outline, chambers are spherical and increasing rapidly in size as added; six chambers in the final whorl and two whorls are visible on the spiral side. Sutures are radially curved on both sides and depressed; slightly deep; primary aperture low arch stretching close to equitorial periphery margin nearly to the umbilicus, which is surrounded by a narrow lip which extends and broaden to an imperforate apertural flap towards the umbilicus, and relict apertural flaps surrounding the umbilicus.

Remarks: *Ticinella* species in the studied succession of the early Cretaceous of Tanzania are rare especially in TDP Site 40 Holes A and Hole B and preservation varies from poor to moderate.

World Stratigraphic range: Species of *Ticinella* stratigraphically ranges from the early to latest Albian.

Tanzania Range: Sample from TDP 40B Hole; Core 2/1, 1-25cm, (2.1 m).

Subfamily ROTALIPORID Sigal, 1958
Genus *Thalmanninella* Sigal, 1948, emended

***Thalmanninella appenninica* (Renz)**

Plate 3.14, figs. 4a-d

Selected figures: Renz, 1936, p. 14, fig. 2; Luterbacher and Premoli Silva, 1962, pl. 19, fig. 1; Robaszynski, Caron and the EWGPF, 1979, pl. 4, fig. 1a-c; Gonzalez-Donoso and Linares, 1993, pl. 17, fig. 4.

Description: Test trochospiral, biconvex, with a slightly convex spiral side, and a very distinct broader and higher final chamber of the last whorl; there is a presence of a single peripheral keel. The primary aperture is extraumbilical-umbilical; chambers increase rapidly in size as added; umbilicus become small, slightly deep, supplementary aperture not distinct, infilled, and obscured due to poor-moderate preservation. Varieties of species of *Thalmanninella appenninica* have been encountered in the upper Albian interval of Tanzania.

Remarks: Specimens of *Thalmanninella appenninica* display a variety of morphology and are abundant in the upper Albian succession of Tanzania. This species differs from T*halmanninella balernaensis* in having perumbilical ridges.

World Stratigraphic range: This species has been described from the late Albian of Bottacione, NE Gubbio, Italy; Gandolfi (1942) described from the latest Albian *Thalmanninella appenninica* Zone of Breggia River, Switzerland. According to Gonzalez-Donoso and others (2007) the Tanzanian specimen of *Thalmanninella appenninica* is biconvex and spiral side more convex to range from the latest Albian (*Thalmanninella appenninica* Zone) through middle Cenomanian (*Thalmanninella reicheli* Zone).

Tanzania Range: Sample Kisarawe-1 Hole, (1902 m).

Subfamily ROTALIPORIDS González-Donoso and others, 2007

Genus *Thalmanninella* Sigal, 1948, emended

Thalmanninella deeckei (Franke)

Plate 3.15, figs. 1a-d

Type reference: Selected figures. Dalbiez, 1957, text-figs. 1-4; Robaszynski, Caron and the EWGPF, 1979, pl. 9, figs. 1a-c, 2a-c; Gonzalez-Donoso and Linares, 1993, pl.19, fig. 6.

Description: *Thalmanninella* identified in the present study is trochospirally coiled in a globorotaliform coil, moderate in size, umbilical side is more convex and spiral side is slightly convex, with the last chamber of the final whorl is higher than the rest; the umbilicus is moderate in size and slightly deep. Sutures are curved on both sides. Primary aperture is extraumbilical - umbilical, 6- chambers in the last whorl, increasing slowly in size as added, chambers on the umbilical side are triangular while on the spiral side are trapezoidal; presence of sutural supplementary apertures along the shoulders of each umbilical chambers. A single periphery keel is seen.

Remarks: *Thalmanninella deekei* reported from few levels in the Cenomanian strata of Kisarawe-1 and Songo Songo-4 well are very rare and only one specimen of *Thalmanninella deeckei* in each of the two studied boreholes and specimens with pyrite and calcite infill.

World Stratigraphic range: *Thalmanninella deekei* stratigraphically ranges from the middle Cenomanian (*Thalmanninella reicheli* Zone) through late Cenomanian (*Rotalipora cushmani* Zone).

Tanzania Range: Sample from Kisarawe-1; (1750 m).

Subfamily ROTALIPORIDS (González-Donoso and others, 2007).
Genus *Thalmanninella* Sigal, 1948, emended

Thalmanninella globotruncanoides (Sigal)

Plate 3.15, figs. 2a-d

Selected figures: Brönnimann and Brown, 1956, pl. 20, figs. 7-9; Eicher, 1973, pl. 1, fig. 3a -b, 6 a-b; González-Donoso and Linares, 1993, pl. 19, fig.7; Ando, written communication, 2005.

Type species: *Thalmanninella brotzeni* Sigal, 1948, junior synonym of *Rotalipora globotruncanoides* Sigal, 1948

Description: The specimen of *Thalmanninella globotruncanoides* of Tanzania characterized by low trochospiral, umbilical-convex; spiral side somehow flat with inner spire slightly raised, peripheral margin acute in edge view keeled on all chambers of the last whorl. On spiral side 2 1/2 or 3 whorls; seven chambers in the last whorl, are initially slightly crescentic then petaloid, increasing rapidly in size; surface of the last two chambers slightly depressed on the central part adding to the trochospire point towards flat; peripheral outline lobate; intercameral sutures curved shown by a beaded keel, somewhat raised in the first chambers of the last whorl becoming smoother and flush with test surface in the last two; spiral suture of the first whorls, keeled; umbilical side chambers are subtrapezoidal; intercameral sutures initially radial and oblique with respect to equatorial margin, the last two sutures curved and strongly depressed; sutural beaded keels visible, each extending to form a periumbilical ridge,absent in the last chamber; primary aperture umbilical-extraumbilical as a medium high arch at the base of a vertical aperture face; umbilicus rather large and shallow; supplementary apertures not visible obscured (infilled with sediments) due to poor or moderate nature of preservation.

Remarks: *Thalmanninella globotruncanoides* differs from *Thalmanninella brotzeni* for having larger size in average, a more petaloid chambers and faster growth rate, folded surface in the last two inflated and petaloid chambers, a larger and shallower umbilicus, a higher arched primary aperture, and supplementary apertures migrating along the sutures and out of the umbilical area through ontogeny (Ando and Huber, 2007). *Thalmanninella greenhornensis* is well differentiated by its numerous elongated chambers in the last whorl which curved backward both in spiral and umbilical sides and a symmetrical biconvex profile as discussed by Ando and Huber (2007).

World Stratigraphic Range: From the Albian/Cenomanian boundary to lower Upper Cenomanian.

Tanzanian Range: Sample Songo Songo-4 Hole; (Core 1/3, 21-40 cm, (1830 m).

Subfamily ROTALIPORIDS (González-Donoso and others, 2007).
Genus *Thalmanninella* Sigal, 1948, emended

***Thalmanninella greenhornensis* (Morrow)**

Plate 3.15, figs. 3a-d

Selected figures: Sigal 1948, pl. 1, fig. 4; Robaszynski, Caron and the EWGPF, 1979, pl. 12, figs. 1-2, pl. 13, figs. 1-2 under the name "*Rotalipora greenhornensis*" Idem, pl. 6, fig. 2a-c, under the name ***Rotalipora*** *brotzeni*," González-Donoso and Linares, 1993, pl. 19, fig. 5; Eicher, 1973, pl. 1, fig. 4a-b under the name "*Rotalipora greenhornensis*".

Description: Specimen of *Thalmanninella greenhornensis* illustrated here is trochospiral coiled with two whorls visible on the spiral side, a more convex umbilical side than spiral side; six chambers in the last whorl; the primary aperture is obscured due to the poor nature of preservation. Chambers increase rapidly in size as added arranged in two whorls visible on the spiral side. Chambers on the spiral side are crescentic while on the umbilical side are roughly triangular; sutures on the spiral side are strongly curved and raised while two in the final chambers are almost radial, while partially raised and depressed on umbilical side. Final chamber is larger, higher and broader than the rest of the chambers. The beaded keel is less defined on the last whorl; umbilical area is slightly deep and wide; supplementary apertures are umbilical in position, two are seen clearly, surrounded by a continuous series of periumbilical ridges; chambers in the spiral and umbilical side are smooth with a semi- circular peripheral outline.

Remarks: This species differs from *Thalmanninella globotruncanoides* by its symmetrical biconvex profile (Ando and Huber, 2007). Also the sutures of *Thalmanninella greenhornensis* are curved, as in *Thalmanninella globotruncanoides*, allowing the differentiation of this species from primitive *Thalmanninella praebalernaensis* (González-Donoso and others, 2007).

Thalmanninella greenhornensis is rare to abundant in the studied interval and preservation varies from poor to moderate. *Thalmanninella greenhornensis* is distinguished from *Thalmanninella gandolfi* by having strong oblique sutures on the spiral side, a tendency towards a more pronounced asymmetrical test, raised umbilical sutures and well developed umbilical supplementary apetures. *Thalmanninella greenhornensis* differs from *Thalmanninella globotruncanoides* by a higher number of chambers (8-10) in the last whorl, chambers in the last whorl are elongated and crescentic shape in spiral side and sutures are strongly curved and raised on both spiral and umbilical side.

World Stratigraphic range: González-Donoso and others (2007) placed the biconvex and spiral convex specimen of *Thalmanninella greenhornensis* similar in character to the Tanzanian form which stratigraphically ranges from the early Cenomanian (*Thalmanninella globotruncanoides* Zone) through late Cenomanian (*Rotalipora cushmani* Zone).

Tanzania Range: Sample Songo Songo-4 Hole; (1670.3 m).

Subfamily ROTALIPORIDS (González-Donoso and others, 2007).
Genus *Thalmanninella* Sigal, 1948, emended

Thalmanninella reicheli (Mornod)

Plate 3.15, figs. 4a-d

Selected figures: Caron 1976, text-fig. 2a- c, pl. 2, figs. 1-5; Robaszynski, Caron and the EWGPF, 1979, pl. 16, fig. 1, pl. 17, fig. 1, pl. 18, fig. 1.

Description: *Thalmanninella reicheli* identified in the present study is characterized by a trochospirally coiled test which is highly convex in the umbilical while the spiral side is almost flat to concave; chambers of the last whorl increase slowly as added with six chambers in the final whorl; the primary aperture is usually obscured to due poor preservation; the spiral side is almost flat, umbilical area is shallow and wider; supplementary apertures present on the umbilical side are along sutures with well developed, single keel present. Chambers are triangular on the umbilical side and crescentic on the spiral side, suture on spiral side are oblique curved, raised and beaded, on the umbilical slightly curved to radial, raised in the early portion of the last whorl; and depressed in the later portion. The chambers of the last whorl display a peripheral ridge surrounding the umbilical area; umbilicus is shallow and wide, and a symmetrical peripheral outline.

Remarks: Specimens of *Thalmanninella reicheli* are extremely rare in the studied interval; only one or two specimens for each borehole studied which penetrated the middle Cenomanian interval. *Thalmanninella reicheli* differs from *Thalmanninella caroni* in its cylindrical nature in lateral view (González-Donoso and others, 2007) and specimens preservation varies from poor to moderate.

World Stratigraphic range: *Thalmanninella reicheli* is a Zonal marker species of the middle Cenomanian. This species has been reported in the middle Cenomanian; *Thalmanninella reicheli* Zone in several areas to include Ruisseau des Covayes, Montsalvens, Canton of Fribourg, Switzerland and the Montmorin section, SE France (Robaszynski & Caron, 1979). The specimen of *Thalmanninella reicheli* identified from the Tanzanian material is cylindrical and umbilico-convex and according to Gonzalez-Donoso and others (2007) placed to a total range of the *Thalmanninella reicheli* Zone in the middle Cenomanian.

Tanzania Range: Sample Songo Songo-4, (1774 m).

Subfamily ROTALIPORIDS González-Donoso and others, 2007
Genus *Thalmanninella* Sigal, 1948, emended

Thalmanninella sp.

Plate 3.15, figs. 5a-d

Selected figures: Luterbacher and Premoli Silva, 1962, pl. 19, fig. 3; Caron and Luterbacher 1969, pl. 9, fig. 9. González-Donoso and Linares, 1993, pl. 19, fig. 1.

Description: The specimen of *Thalmanninella* identified in the current study is trochospirally coiled; biconvex, spiral side is more convex with angular peripheral outline. There are seven chambers in the last whorl and chambers increase rapidly in size as added. Primary aperture is extraumbilical- umbilical with a thin lip. There are sutural supplementary apertures in the umbilical shoulders of the last whorl in each chamber and a single peripheral keel somehow resembles to characters of *Thalmanninella caroni*.

Remarks: This Specimen is rare in the studied interval. It is difficult to give its species name with certainty but morphologically is somehow slightly close to *Thalmanninella caroni* and preservation varies from poor to moderate.

World Stratigraphic range: Species of *Thalmanninella* stratigraphically ranges from late Albian through late Cenomanian.

Tanzanian Range: Outcrop sample AK22-02.

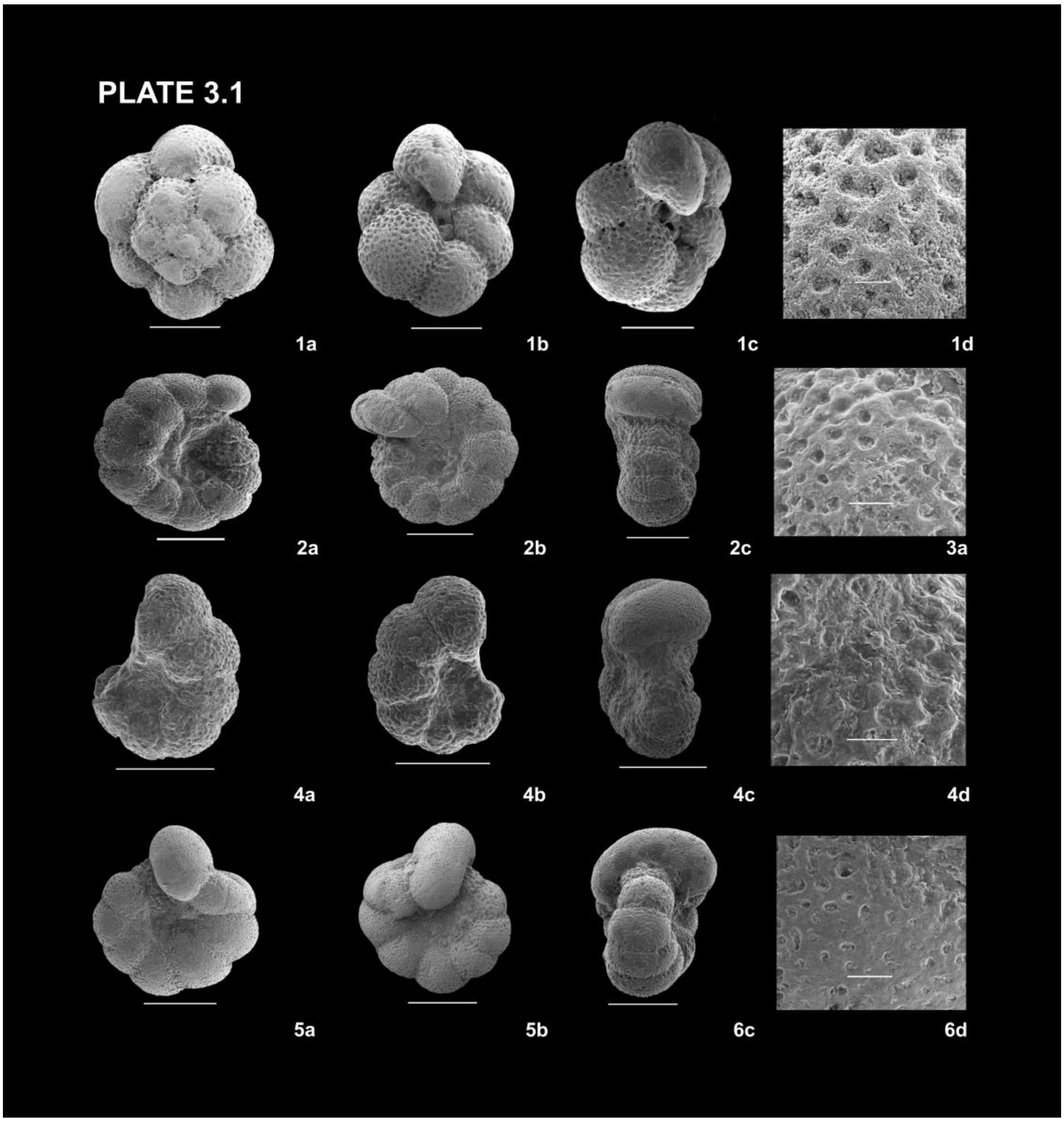


Plate 3.1: Late Albian Zonal Marker species and Late Albian-early Cenomanian accompanying taxa

Figures 1a-d: *Ascoliella* sp. aff. *nitida*; Sample TDP40 Hole B, Core 3/1, 1-25 cm, (5.1 m).
Figures 2ad: *Biticinella breggiensis* sp. 1; Sample Kizimbani-1 Hole, (46 m).
Figures 3a-d: *Biticinella breggiensis* (sp. 2); Sample Kisarawe-1 Hole, (1920.2 m).
Figures 4a-d: *Biticinella breggiensis* (sp. 3); Sample Songo Songo-4 Hole, (1731.3 m), reworked specimen into higher level, ditch cuttings.

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up.
Scale bars views: a-c = 200 µm, view d = 20 µm.

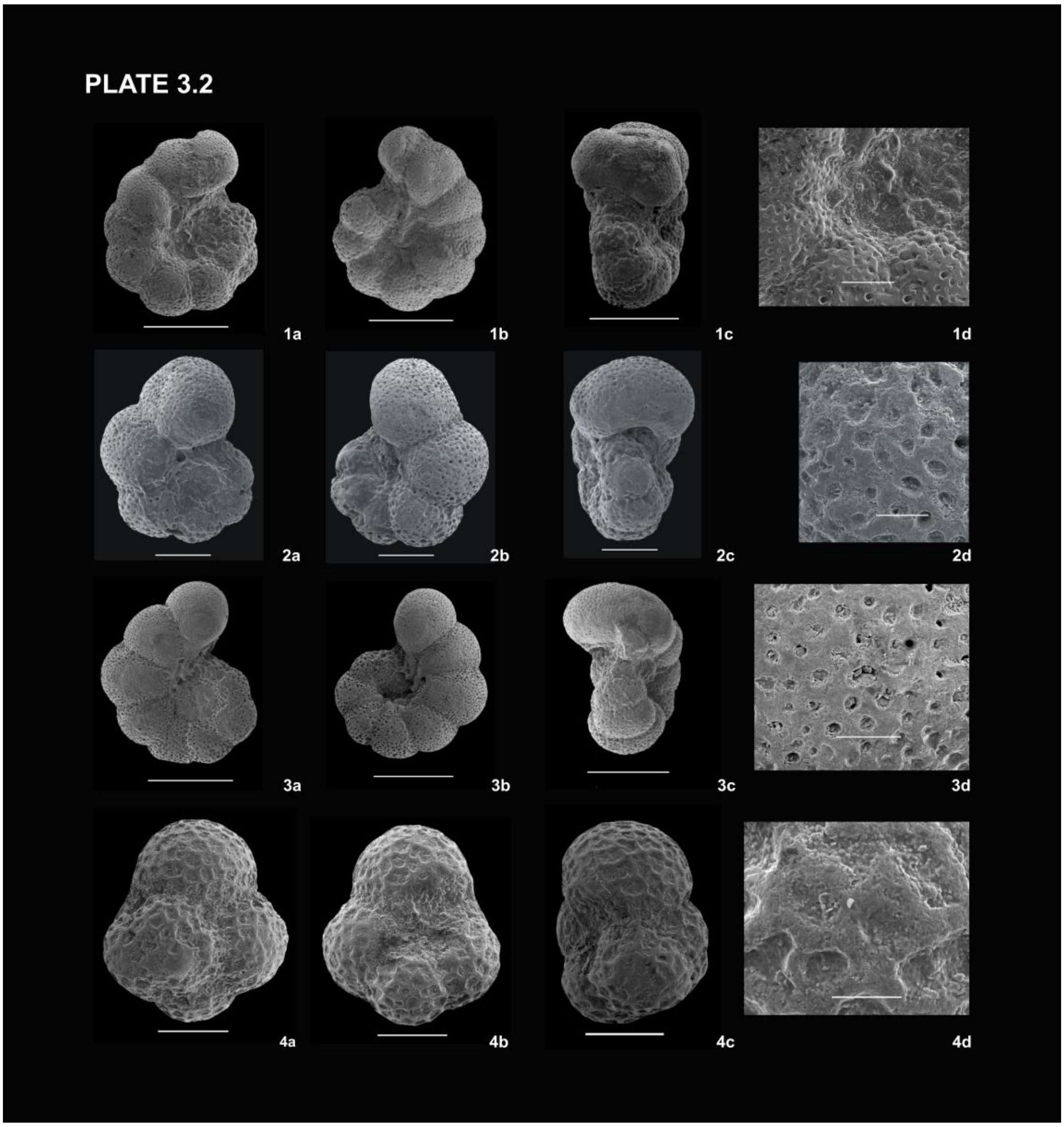


Plate 3.2: EarlyAptian zonal marker and late Albian taxa

Figures 1a-d: *Biticinella subreggiensis* (sp.1); Sample Songo Songo-4 Hole, (reworked specimens at 1670.3 m, ditch cuttings).
Figures 2a-d: *Biticinella subbreggiensis* (sp.2); Field sample AK22-10.
Figures 3a-d: *Biticinella subbreggiensis* (sp. 3); Sample Kizimbani-1 Hole, (67.1 m).
Figures 4a-d: *Caucasella hoterivica*; Sample TDP40 Hole B, Core 10/3, 1-25 cm, (22.1 m).

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up.
Scale bars views: a-c = 200 µm; figs.1 & 3, view a-c =100 µm; figs. 2 & 4 and view d = 20 µm.

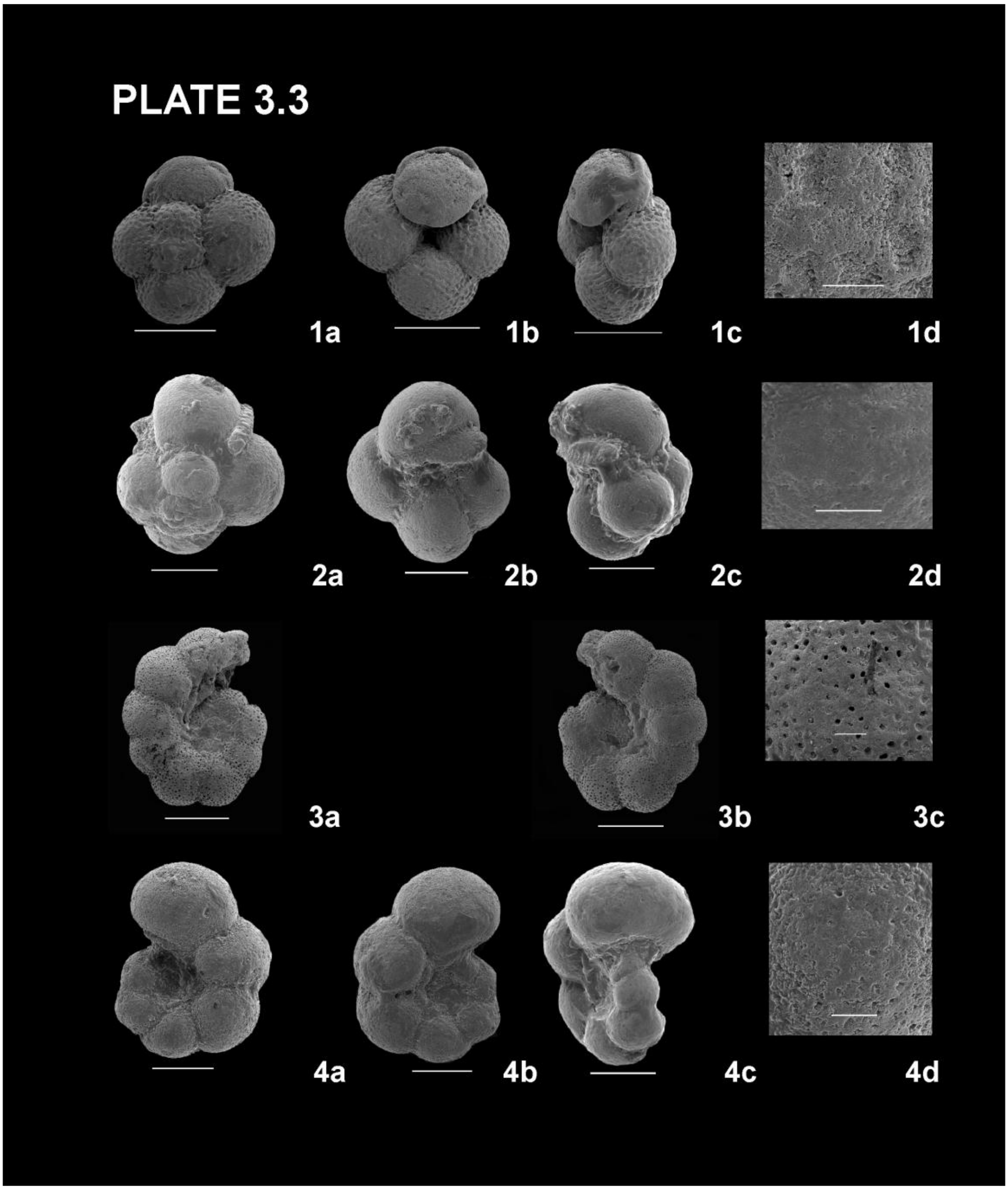


Plate 3.3: Late Aptian zonal marker, Aptian and Late Albian-Cenomanian accompanying taxa

Figures 1a-d: *Favusella washitensis*; Sample TDP40 Hole B, Core 4/2, 1-25 cm (6.7 m).
Figures 2a-d: *Gorbachikella* sp. aff. *kugleri*; Sample TDP40, Hole B, Core 10/1, 1-25 cm, (20.1 m).
Figures 3a-d: *Globigerinelloides* cf. *algerianus;* Sample Kisarawe-1 Hole, (2268 m).
Figures 4a-d: *Globigerinelloides aptiensis*; Sample TDP40 Hole B, Core 5/3, 70-80 cm, (10.8 m).

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up
Scale bars views: view: a-c= 200 µm; figs. 1 & 3, view a-c=100 µm; figs. 2 & 4 and view d = 20 µm

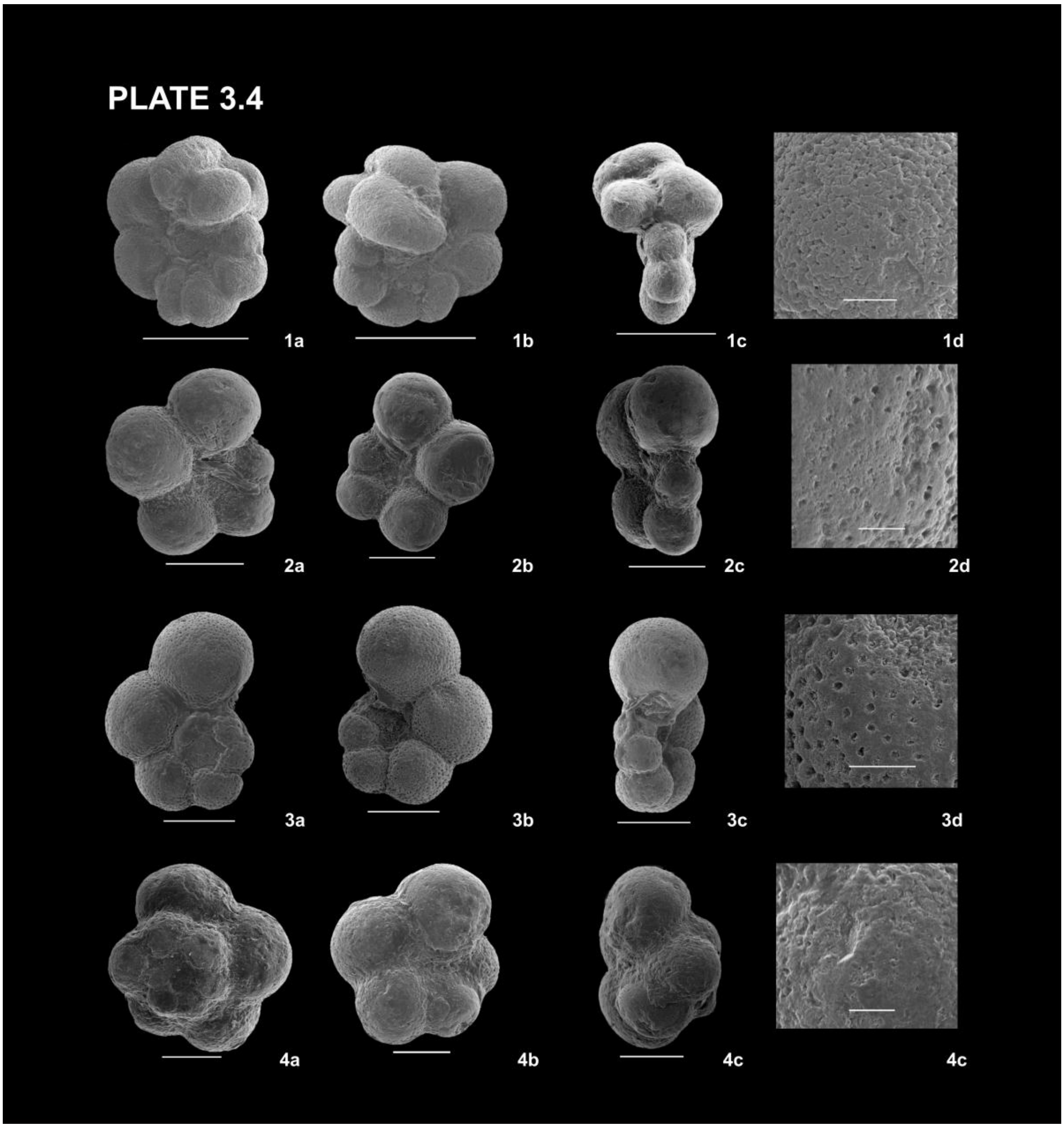


Plate 3.4: Aptian Zonal markers and accompanying taxa

Figures 1a-d*: Globigerinelloides barri*; Sample Kizimbani-1 Hole, (216.4 m).
Figures 2a-d: *Globigerinelloides blowi*; Sample TDP40 Hole B, Core 5/3, 80-90 cm, (10.9 m).
Figures 3a-d: *Hedbergella aptiana*; Sample TDP40 Hole B, Core 5/3, 30-40 cm, (10.4 m).
Figures 4a-d: *Hedbergella excelsa*; Sample TDP40 Hole B, Core 5/3, 50-60 cm, (10.6 m).

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up.
Scale bars views: a-c= 200 µm; figs. 1, view a-c = 100 µm; figs. 2-4 and view d = 20 µm.

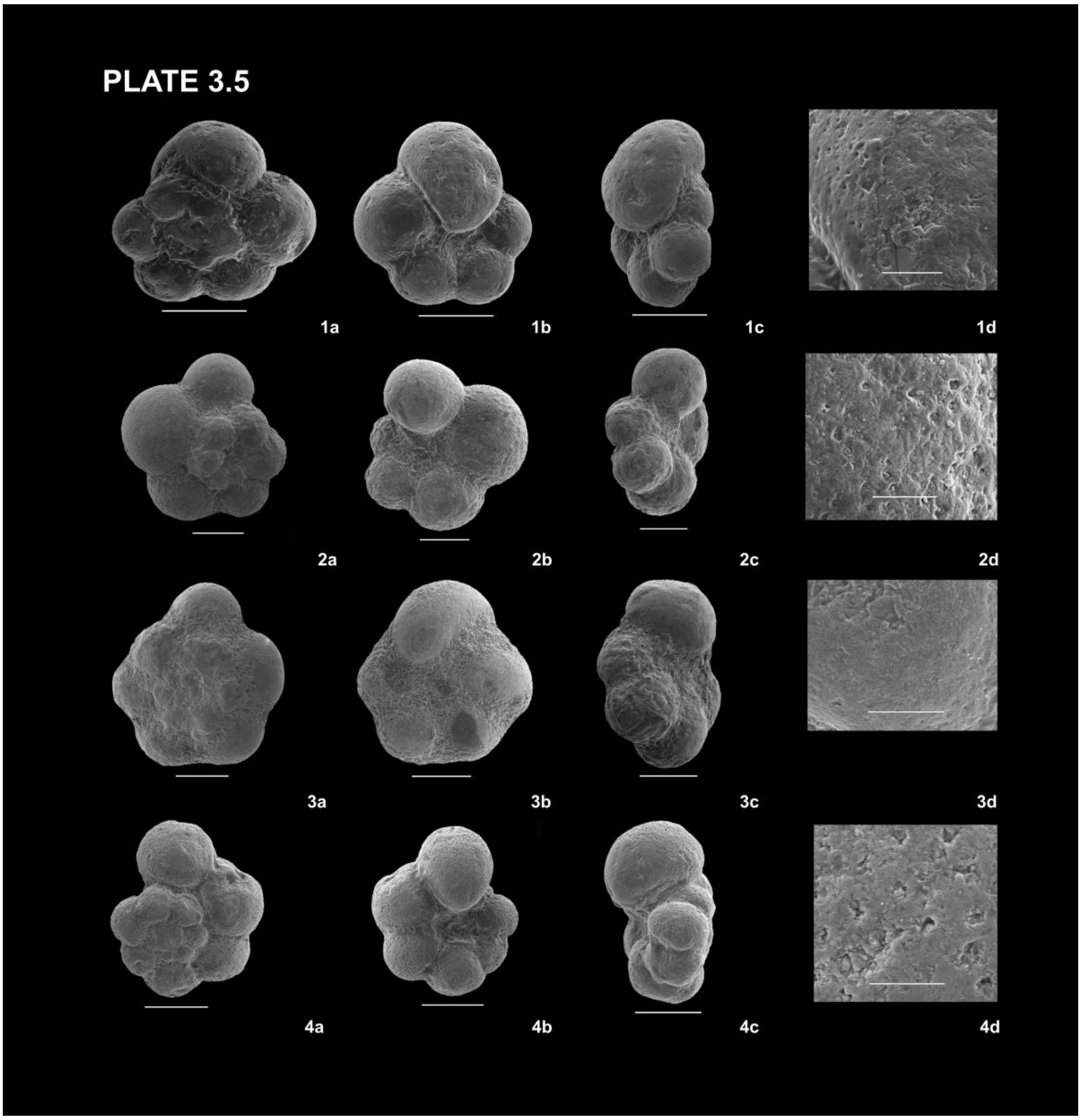


Plate 3.5: Late Aptian secondary zonal marker and accompanying taxa

Figures 1a-d: *Hedbergella gorbachikae*; Sample TDP40 Hole B, Core 5/3, 30-40 cm, (10.4 m).
Figures 2a-d: *Hedbergella infracretacea*; Sample TDP40 Hole A, Core 5/3, 65-90 cm, (10.8 m).
Figures 3a-d: *Hedbergella* sp.; Sample TDP 40 Hole B; Core 5/3, 50-60 cm, (10.6 m).
Figures 4a-d: *Hedbergella occluta*; Sample TDP40 Hole B; Core 5/3, 50-60 cm, (10.6 m).

Each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up
Scale bars views: a-c = 100 µm and view d = 20 µm.

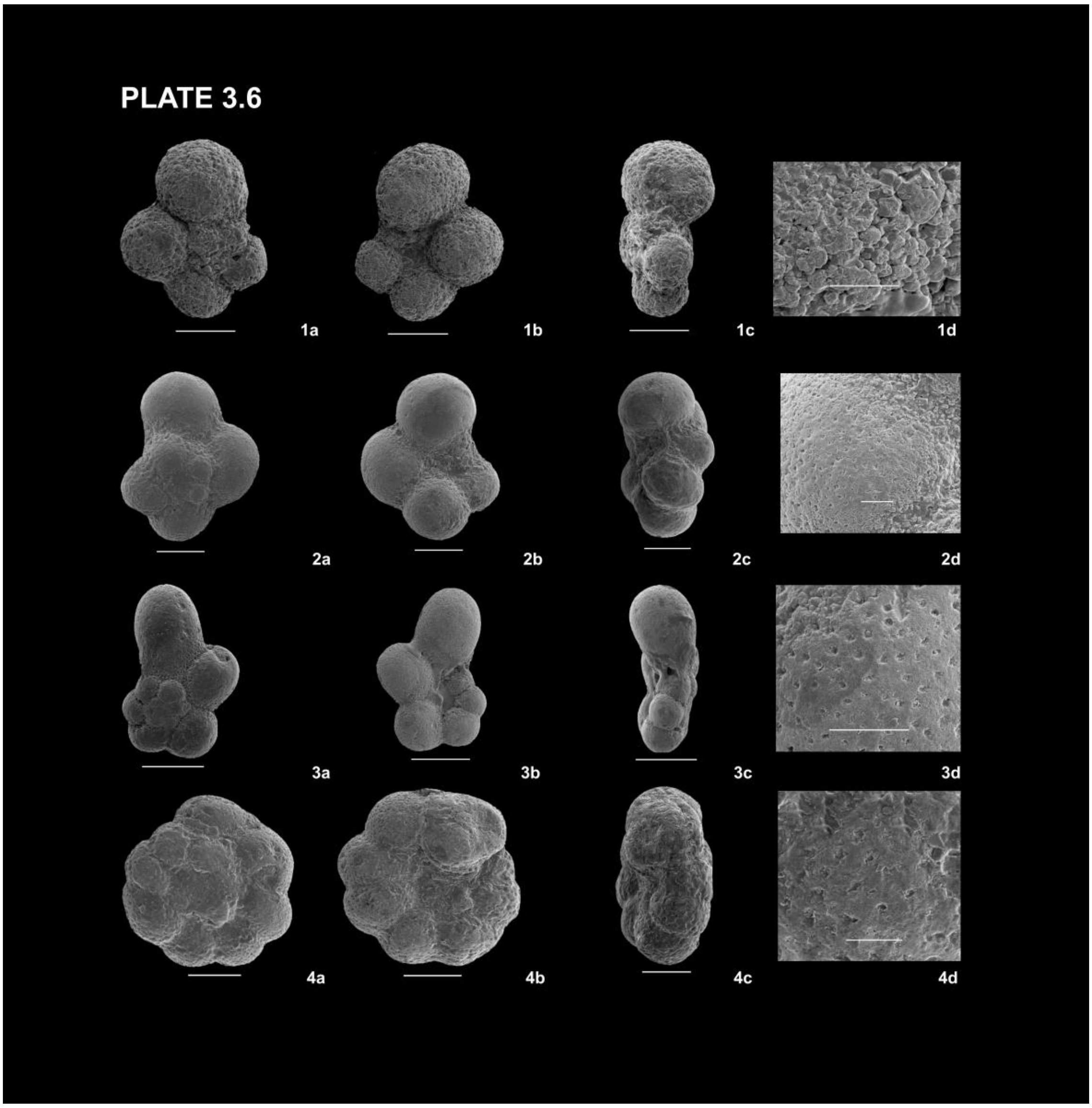


Plate 3.6: Late Aptian zonal Marker and Accompanying taxa

Figures 1a-d: *Hedbergella praelippa*; Sample TDP40B Hole, Core 5/1, 1-25 cm, (8.1 m).
Figures 2a-d: *Hedbergella sigali*; Sample TDP40B Hole, Core 5/3, 80-90 cm, (10.9 m).
Figures 3a-d: *Hedbergella similis;* Sample AK28-02.
Figures 4a-d: *Hedbergella trocoidea*; Sample TDP 40B Hole, Core 5/3, 90-100 cm, (11 m).

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up.
Scale bars views: a-c = 100 µm and view d = 20 µm.

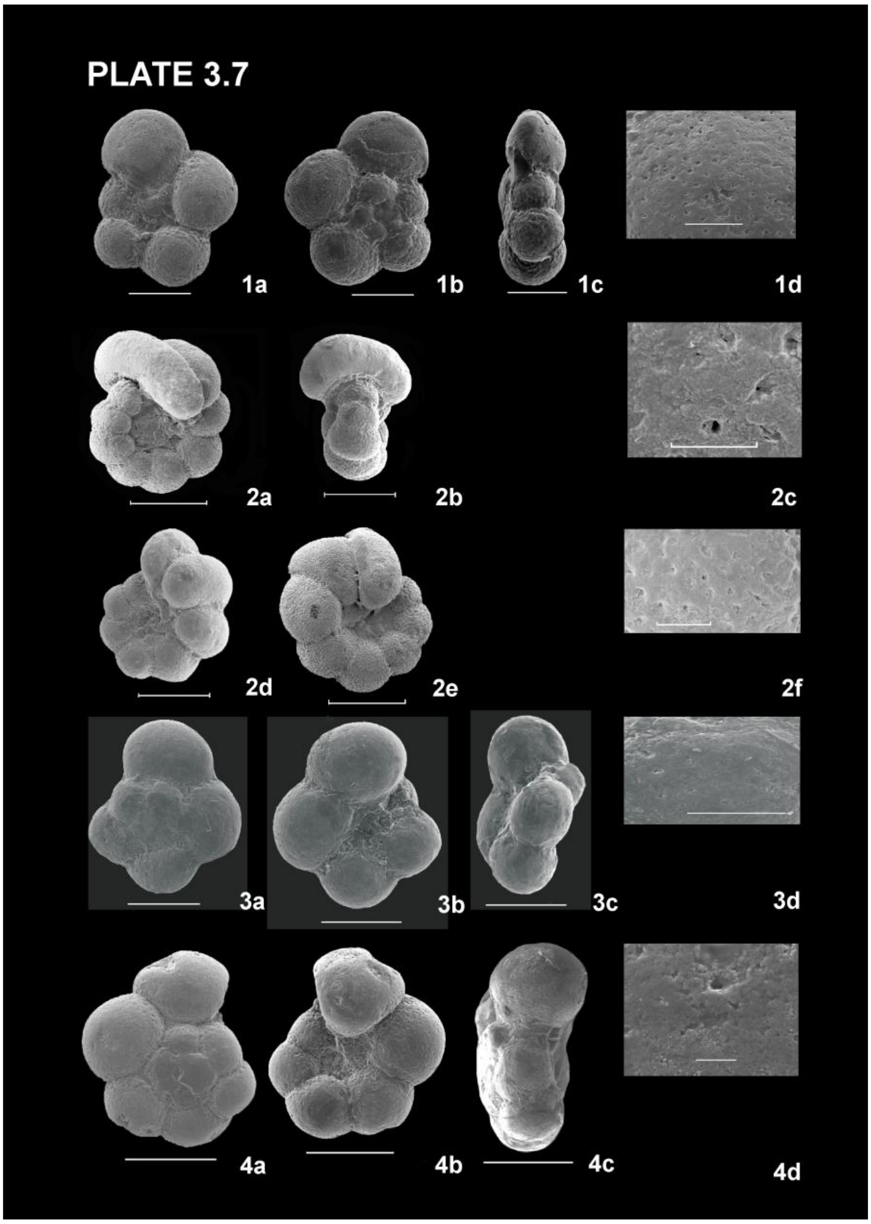


Plate 3.7: Early Albian Marker and latest Albian- early Cenomanian accompanying taxa

Figures 1a-d: *Loeblichella* sp.; Sample Sample Makarawe-1 Hole, (360 m).
Figures 2a-f: *Macroglobigerinelloides bentonensis*; Sample Luhoi-1 Hole, Core 53/2, 70-80 cm (274 m; figs. 2a-c ;), Sample Kizimbani-1 Hole, (70.1 m; figs. 2d-f).
Figures 3a-d*: Microhedbergella miniglobularis*; Sample TDP40 Hole B, Core 5/1, 1-25 cm, (8.1 m).
Figures 4a-d: *Microhedbergella pseudoplanispira*; Sample TDP40 Hole B, Core 2/2, 1-25 cm, (3.1 m).
In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up
Scale bars views: a-c = 100 µm; figs. 1& 4, view a-c = 200 µm; figs. 2, view a-c = 50 µm figs. 3, d view = 20 µm.

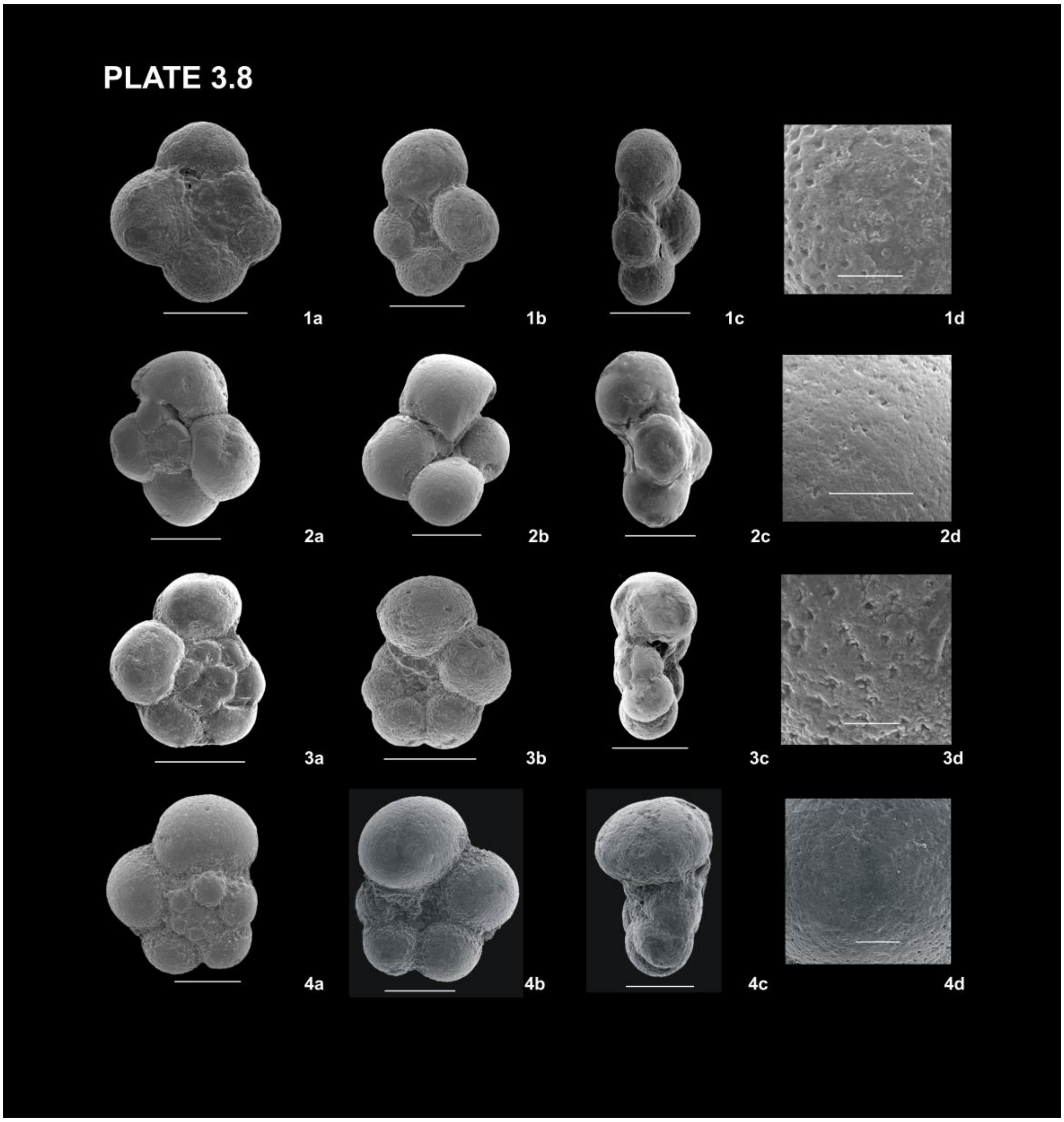


Plate 3.8: Early Albian zonal markers and late Albian taxa

Figures 1a-d: *Microhebergella renilaevis* (sp.1); Sample Makarawe-1 Hole, (620 m).
Figures 2 a-d: *Microhedbergella renilaevis* (sp. 2); Sample TDP40 Hole B, Core 5/1, 1-25 cm, (8.1 m).
Figures 3a-d: *Microhedbergella rischi;* Sample TDP40 Hole B, Core 5/1, 1-25 cm, (8.1 m).
Figures 4a-d: *Muricohedbergella albiana;* Sample Luhoi-1 Hole, Core 53/1, 80-90 cm, (273 m).

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up
Scale bars views: a-c = 100 µm, d view = 20 µm.

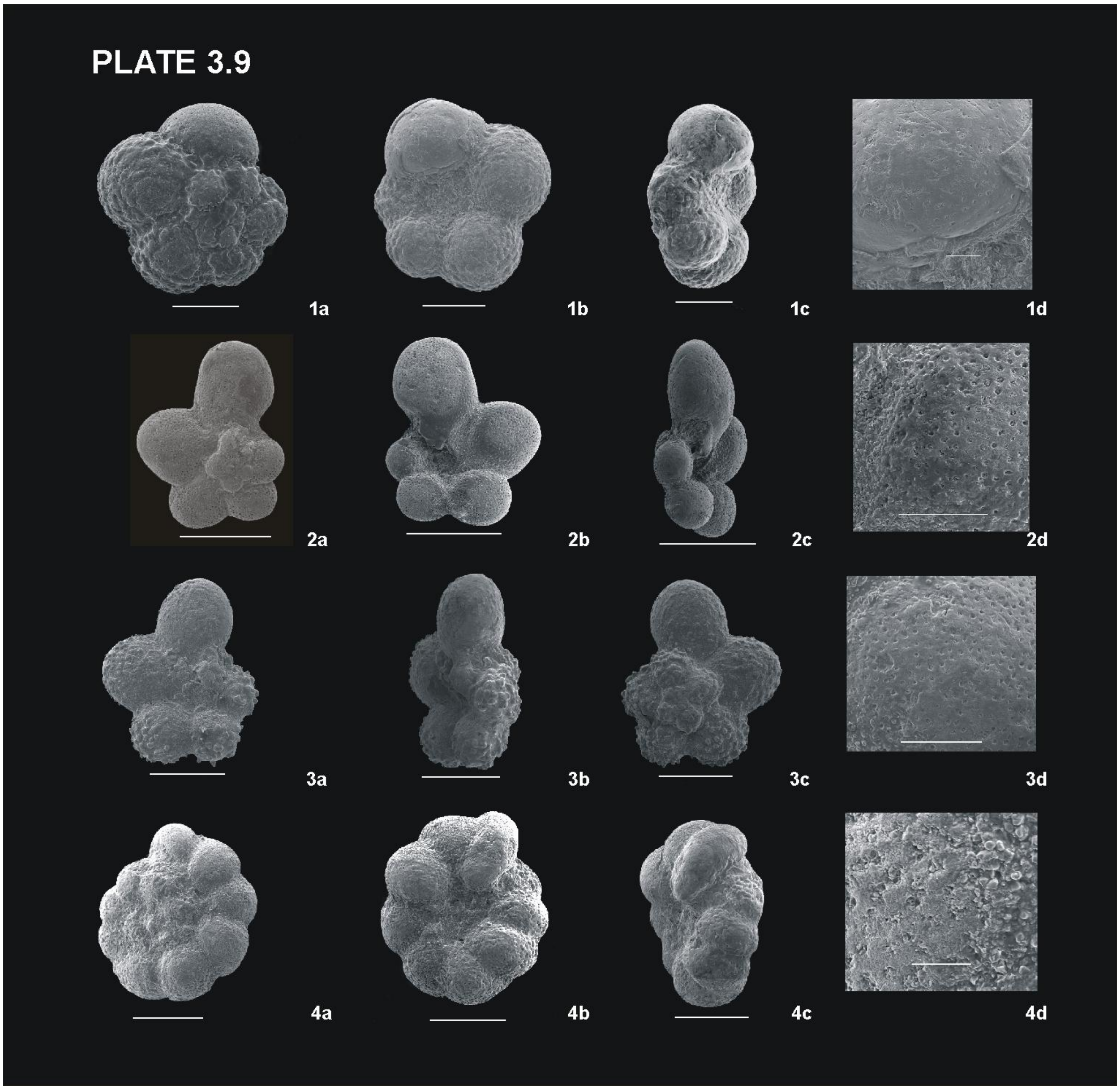


Plate 3.9: Late Aptian Zonal Marker and late Albian accompanying taxa

Figures 1a-d: *Muricohedbergella delrioensis;* Sample Songo Songo-4 Hole, (1670.3 m).
Figures 2a-d: *Muricohedbergella simplex* (sp.1); Sample Kisarawe-1 Hole, (1811 m).
Figures 3a-d: *Muricohedbergella simplex* (sp.2); Sample Kisarawe-1 Hole, (1780 m).
Figures 4a-d: *Paraticinella eubejaouaensis* (sp.1); Sample Kizimbani-1 well Hole, (137.2 m).

In each view: a = spiral, b = umbilical c = apertural, d = wall close-up.
Scale bars views: a-c = 100 µm; figs. 1-3 and view a-c = 200 µm; figs. 4 and view d = 20 µm.

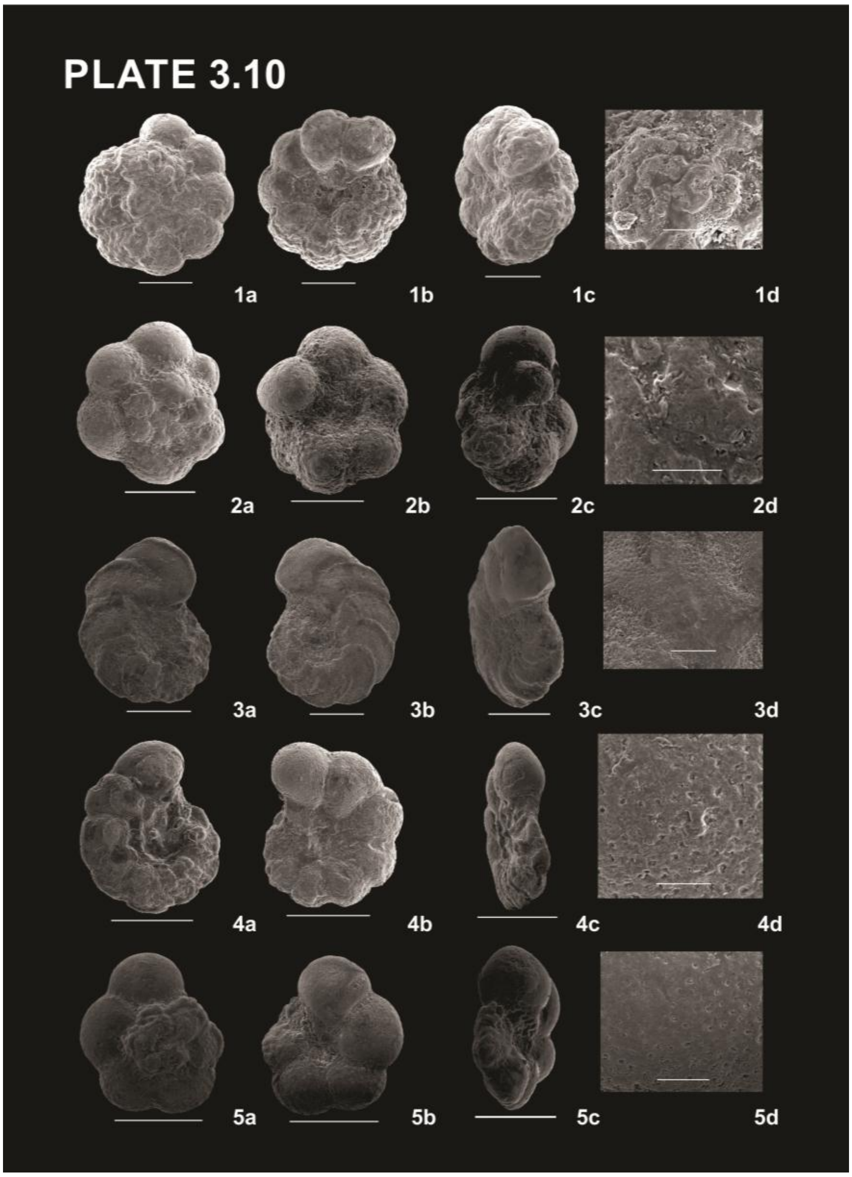


Plate 3.10 Late Aptian and late Albian zonal markers and accompanying taxa

Figures 1a-d: *Paraticinella eubejaouaensis* (sp.2); Sample Kiwangwa-1 Hole, (345 m).
Figures 2a-d: *Paraticinella transitoria;* Sample Kiwagwa-1 Hole, (370 m).
Figures 3a-d: *Planomalina buxtorfi;* Sample Songo Songo4 Hole, Core 2/2, 62-73 cm, (1839.3 m).
Figures 4a-d: *Planomalina praebuxtorfi* transition to *Planomalina buxtorfi*; Sample Kiwangwa-1 Hole, (reworked specimen at 365 m).
Figures 5a-d: *Praeglobotruncana delrioensis;* Sample Songo Songo-4 Hole, (1670.3 m).

In each view: a = spiral, b = umbilical c = apertural, d= wall close-up
Scale bars views: a-c = 200 µm; figs. 2-5, view a-c = 100 µm; figs.1 and view d = 20 µm.

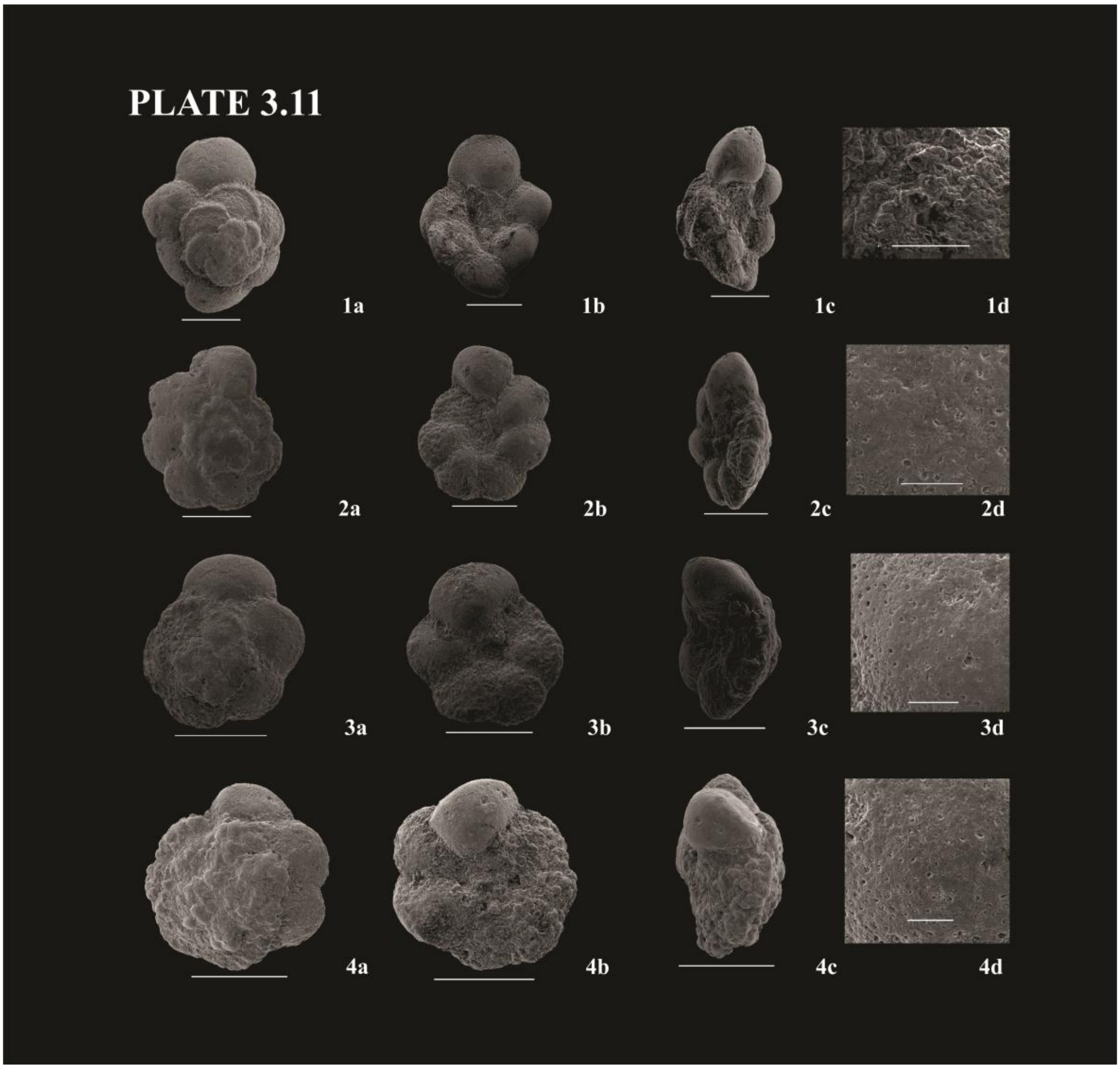


Plate 3.11: Late Albian–Cenomanian taxa

Figures 1a-d: *Praeglobotruncana gibba*; Sample Kisarawe-1 Hole, (1762).
Figures 2a-d: *Praeglobotruncana stephani* (sp.1); Sample Kisarawe-1 Hole, (1780 m).
Figures 3a-d: *Praeglobotruncana stephani* (sp.2); Sample Songo Songo-4 Hole, (1744 m).
Figures 4a-d: *Praeglobotruncana stephani* (sp. 3); Sample Kisarawe-1 Hole, (1823 m).

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up
Scale bars views: a-c = 200 µm and view d = 20 µm.

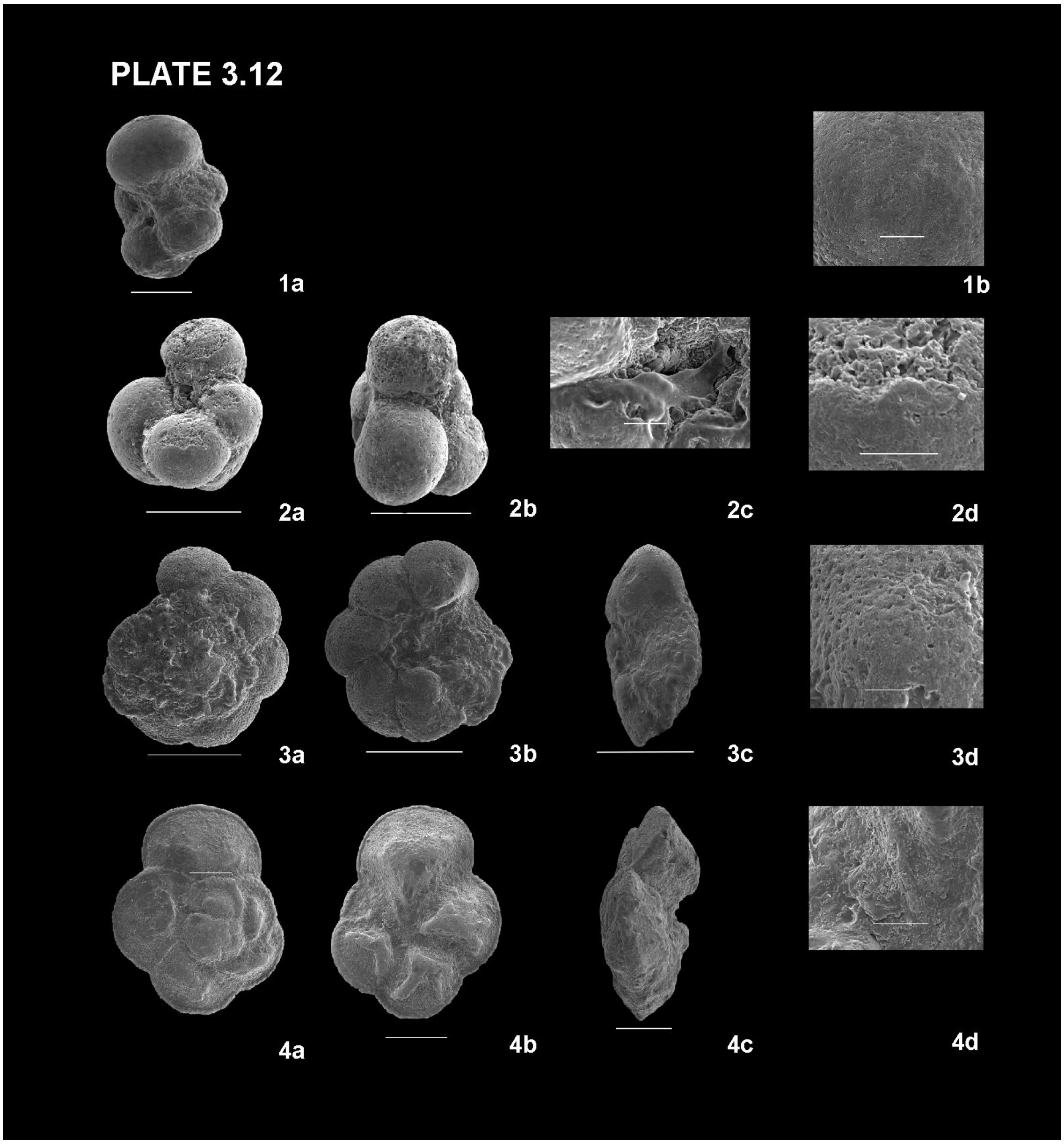


Plate 3.12: Late Aptian accompanying taxa and late Albian-late Cenomanian zonal markers

Figures 1a-b: *Praehedbergella ruka;* Sample TDP40 Hole B, Core 5/3, 30-40 cm, (10.4 m).
Figures 2a-d: *Pseudoguembelitria* sp.; Sample TDP40 Hole A; Core 5/3, 65-90 cm, (10.8 m).
Figures 3a-d: *Pseudothalmanninella subticinensis*; Sample Makarawe-1 Hole; (570 m).
Figures 4a-d: *Rotalipora* cf. *cushmani;* Sample Kisarawe-1 Hole, (1737.4 m).

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up.
Scale bars views: 1a & 2a-b =100 µm, Figs. 3-4; views a-c = 200 µm and views 1b, 2c-d & 3-4d = 20 µm.

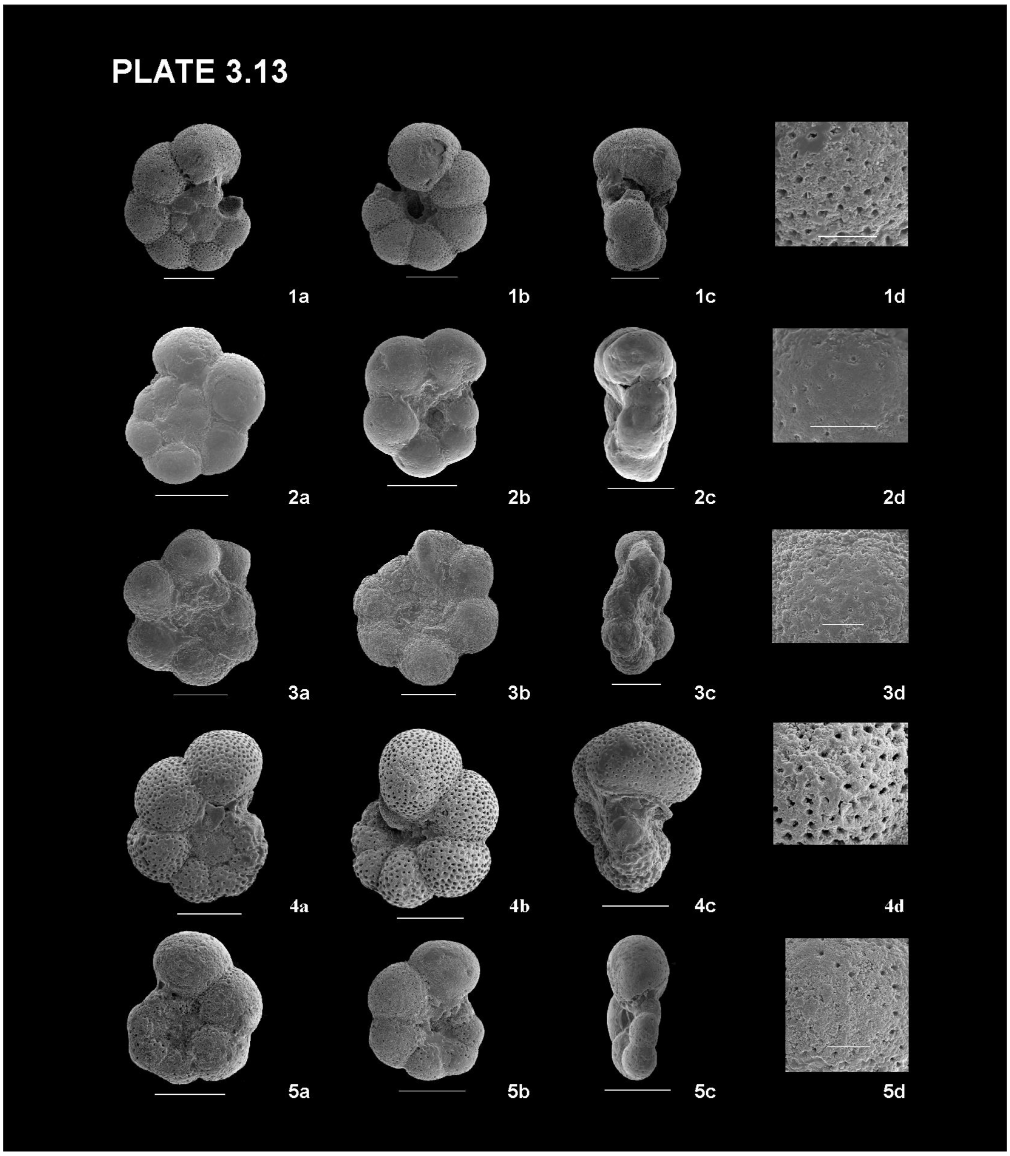


Plate 3.13: Mid Albian Zonal marker and accompanying late Albian taxa

Figures 1a-d: *Ticinella sp.* aff *madecassiana* Sample TDP40 Hole B, Core 2/1, 1-25 cm, (2.1 m).
Figures 2a-d: *Ticinella madeccassiana;* Sample TDP40 Hole B, Core 2/1, 1-25 cm, (2.1 m).
Figures 3a-d: *Ticinella praeticinensis;* Sample Kizimbani-1 Hole, (46 m).
Figures 4a-d: *Ticinella primula*; Sample TDP40 Hole B, Core 4/2, 1-25 cm, (6.7 m).
Figures 5a-d: *Ticinella raynaudi aperta;* Sample Makarawe-1 Hole, (540 m).

In each view: a = Spiral b = umbilical, c = apertural, d = wall close-up
Scale bars views: a-c = 100 µm, view d = 20 µm.

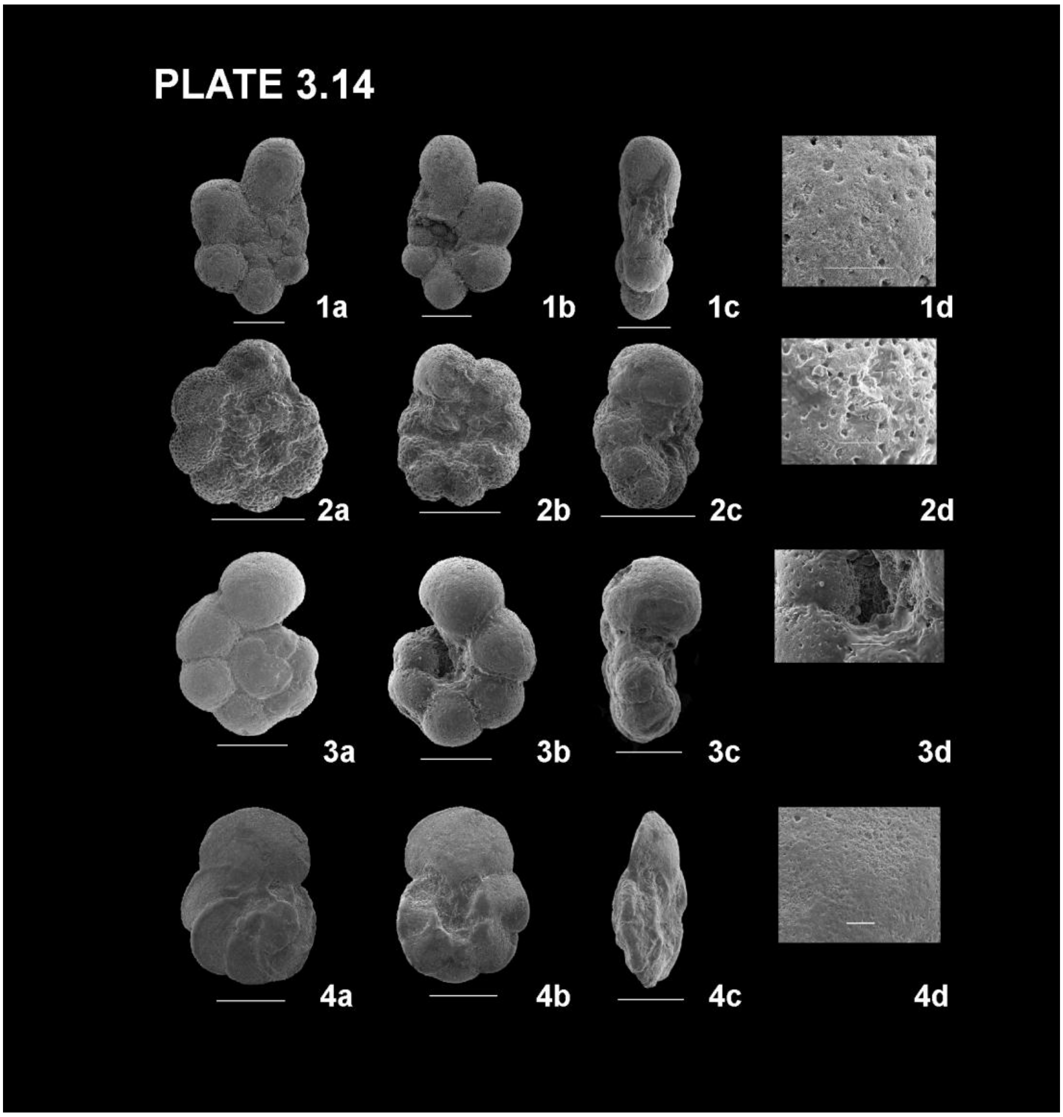


Plate 3.14: Mid-late Albian and Cenomanian taxa

Figures 1a-d: *Ticinella raynaudi digitalis*: Sample TDP4 Hole B, Core 2/1, 1-25 cm, (2.1 m).
Figures 2a-d: *Ticinella roberti;* Sample Luhoi-1 Hole, Core 53/1, 20-30 cm, (272.3 m).
Figures 3a-d: *Ticinella* sp.; Sample TDP40 Hole B, Core 2/1, 1-25 cm, (2.1 m)
Figures 4a-d: *Thalmanninella appenninica*; Sample Kisarawe-1 Hole, (1902 m).

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up.
Scale bars views: a-c = 100 µm; figs. 1 & 3, view a-c = 200 µm; figs. 2 & 4 and view d = 20 µm.

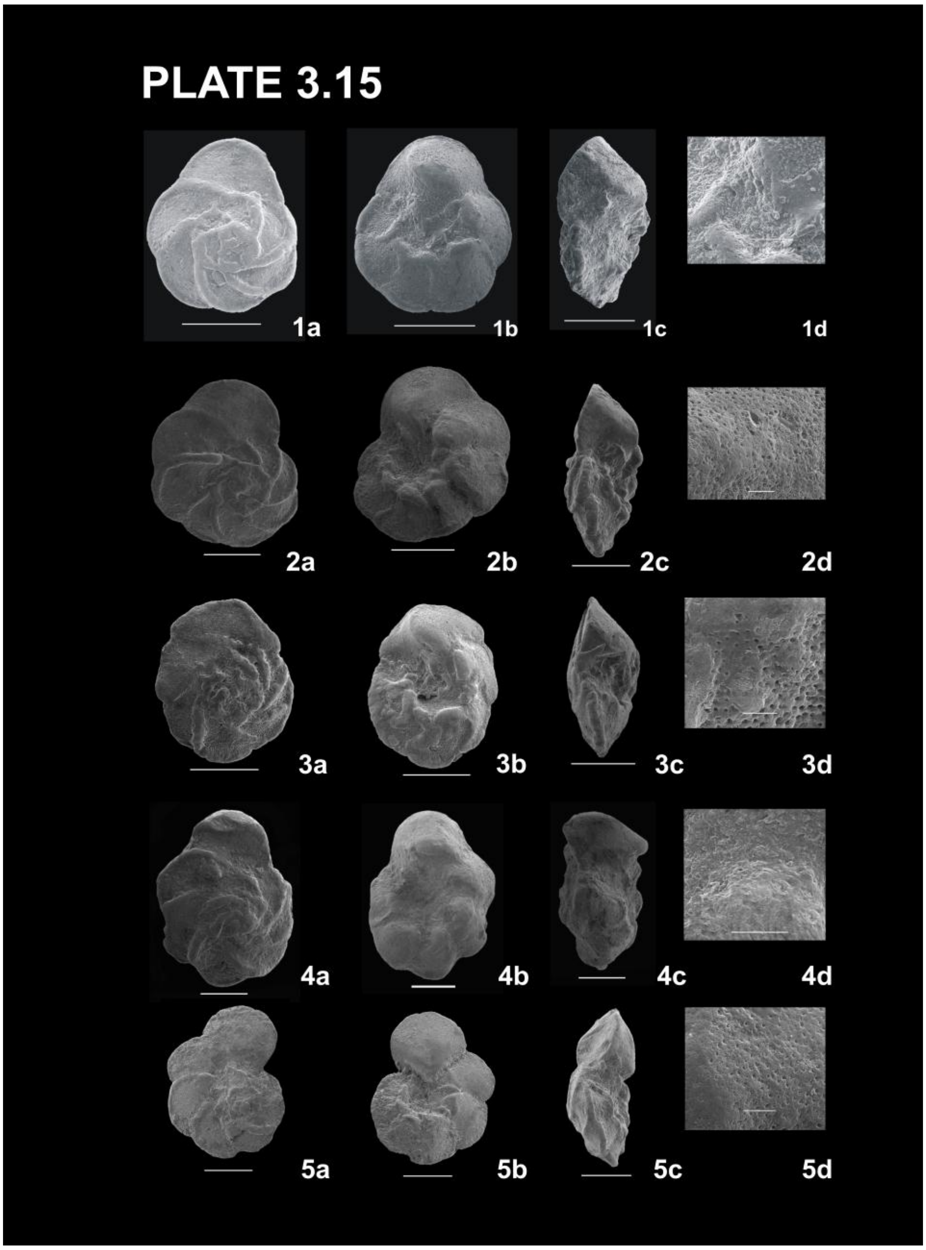


Plate 3.15: Cenomanian zonal markers and accompanying species

Figures 1a-d: *Thalmanninella deckeei*; Sample from Kisarawe-1; (1750 m).
Figures 2a-d: *Thalmanninella globotruncanoides;* Sample Songo Songo-4 Hole, Core 1/3, 21-40 cm, (1830 m).
Figures 3a-d: *Thalmanninella greenhornensis;* Sample Songo Songo-4 Hole, (1670.3 m).
Figures 4a-d: *Thalmanninella reicheli;* Sample Kisarawe-1 Hole; (1774 m).
Figures 5a-d: *Thalmanninella* sp.; Outcrop sample AK22-02.

In each view: a = Spiral, b = umbilical, c = apertural, d = wall close-up
Scale bars views: views a-c= 200 µm, view d = 20 µm.

List of planktonic foraminifera species cited in the text and the figures arranged in alphabetic order.

Ascoliella aff. *nitida* (Michael, 1973)	Plate 3.1, figs. 1a-d
Biticinella breggiensis (sp. 1) Gandolfi, 1942	Plate 3.1, figs. 2a-d
Biticinella breggiensis (sp. 2) Gandolfi, 1942	Plate 3.1, figs. 3a-d
Biticinella breggiensis (sp. 3) Gandolfi, 1942	Plate 3.1, figs. 4a-d
Biticinella subbreggiensis (sp. 1) (Sigal, 1966)	Plate 3.2, figs. 1a-d
Biticinella subbreggiensis (sp. 2) (Sigal, 1966)	Plate 3.2, figs. 2a-d
Biticinella subbreggiensis (sp. 3) (Sigal, 1966)	Plate 3.2, figs. 3a-d
Caucasella hoterivica (Subbotina, 1953)	Plate 3.2, figs.4a-d
Favusella washitensis (Carsey, 1926)	Plate 3.3, figs. 1a-d
Gorbachikella sp. aff. *kugleri* (Bolli 1959)	Plate 3.3, figs. 2a-d
Globigerinelloides cf. *algerianus* (Cushman and Ten Dam, 1948)	Plate 3.3, figs. 3a-d
Globigerinelloides aptiensis (Longoria, 1974)	Plate 3.3, figs. 4a-d
Globigerinelloides barri Bolli, Loeblich and Tappan, 1957	Plate 3.4, figs. 1a-d
Globigerinelloides blowi (Bolli, 1959)	Plate 3.4, figs. 2a-d
Hedbergella aptiana (Bartenstein, 1965)	Plate 3.4, figs. 3a-d
Hedbergella excelsa (Longoria, 1974)	Plate 3.4, figs. 4a-d
Hedbergella gorbachikae (Longoria, 1974)	Plate 3.5, figs. 1a-d
Hedbergella infracretacea (Glaessner)	Plate 3.5, figs. 2a-d
Hedbergella Borneman	Plate 3.5, figs. 3a-d
Hedbergella occluta (Longoria, 1974)	Plate 3.5, figs. 4a-d
Hedbergella praelippa (Huber and Leckie, 2011)	Plate 3.6, figs. 1a-d
Hedbergella sigali (Moullade, 1966)	Plate 3.6, figs. 2a-d
Hedbergella similis (Longoria, 1974)	Plate 3.6, figs. 3a-d
Hedbergella trocoidea (Gandolfi, 1942)	Plate 3.6, figs. 4a-d
Loeblichella Pessagno, 1967	Plate 3.7, figs. 1a-d
Macroglobigerinelloides bentonensis (Morrow, 1934)	Plate 3.7, figs. 2a-f
Microhedbergella miniglobularis (Huber and Leckie, 2011)	Plate 3.7, figs. 3a-d
Microhedbergella pseudoplanispira (Huber and Leckie, 2011)	Plate 3.7, figs. 4a-d
Microhedbergella renilaevis (sp. 1) (Huber and Leckie, 2011)	Plate 3.8, figs. 1a-d
Microhedbergella renilaevis (sp. 2) (Huber and Leckie, 2011)	Plate 3.8, figs. 2a-d
Microhedbergella rischi (Moullade, 1966)	Plate 3.8, figs. 3a-d
Muricohedbergella albiana (BouDagher–Fadel and others, 1996)	Plate 3.8, figs. 4a-d
Muricohedbergella delrioensis (Carsey, 1926)	Plate 3.9, figs. 1a-d
Muricohedbergella simplex (sp. 1) (Morrow, 1934)	Plate 3.9, figs. 2a-d
Muricohedbergella simplex (sp. 2) (Morrow, 1934)	Plate 3.9, figs. 3a-d
Paraticinella eubejaouaensis (sp. 1) Randrianasolo and Aglanda, 2009	Plate 3.9, figs. 4a-d
Paraticinella eubejaouaensis (sp. 2) (Randrianasolo and Anglanda 2009	Plate 3.10, figs. 1a-d
Paraticinella transitoria (Longoria, 1974)	Plate 3.10, figs. 2a-d

Planomalina buxtorfi (Gandolfi, 1942)	Plate 3.10, figs. 3a-d
Planomalina praebuxtorfi (Wonders, 1975) transition-*Planomalina buxtorfi* (Gandolfi, 1942)	Plate 3.10, figs. 4a-d
Praeglobotruncana delrioensis (Plummer, 1931)	Plate 3.10, figs., 5a-d
Praeglobotruncana gibba (Klaus, 1960)	Plate 3.11, figs. 1a-d
Praeglobotruncana stephani (sp. 1) (Gandolfi, 1942)	Plate 3.11, figs. 2a-d
Praeglobotruncana stephani (sp. 2) (Gandolfi, 1942)	Plate 3.11, figs. 3a-d
Praeglobotruncana stephani (sp. 3) (Gandolfi, 1942)	Plate 3.11, figs. 4a-d
Praehedbergella ruka (Banner, Copestake and White, 1993)	Plate 3.12, figs. 1a-b
Pseudoguembelitria sp. (Huber and Leickie n. gen., 2011)	Plate 3.12, figs. 2a-d
Pseudothalmanninella subticinensis (Gandolfi, 1942)	Plate 3.12, figs. 3a-d
Rotalipora cushmani (Morrow, 1934)	Plate 3.12, figs. 4a-d
Ticinella sp. aff. *madecassiana* (Sigal, 1966)	Plate 3.13, figs. 1a-d
Ticinella madecassiana (Sigal, 1966)	Plate 3.13, figs. 2a-d
Ticinella praeticinensis (Sigal, 1966)	Plate 3.13, figs. 3a-d
Ticinella primula (Luterbacher, 1963)	Plate 3.13, figs. 4a-d
Ticinella raynaudi aperta Sigal.-Sigal (1966)	Plate 3.13, figs. 5a-d
Ticinella raynaudi digitalis (Sigal, 1966)	Plate 3.14, figs. 1a-d
Ticinella roberti (Gandolfi, 1942)	Plate 3.14, figs. 2a-d
Ticinella Reichel, 1950	Plate 3.14, figs. 3a-d
Thalmanninella apenninica (Renz, 1936)	Plate 3.14, figs. 3a-d
Thalmanninella deeckei (Franke, 1925)	Plate 3.15, figs. 3a-d
Thalmanninella globotruncanoides (Sigal,1948)	Plate 3.15, figs. 3a-d
Thalmanninella greenhornensis (Morrow, 1934)	Plate 3.15, figs. 3a-d
Thalmanninella reicheli (Mornord, 1949-1950)	Plate 3.15, figs. 3a-d

3.5 Taxonomy and Systematic description of benthic Foraminifera

Calcareous and agglutinated foraminifera from the Aptian to Cenomanian of the studied interval are presented, described and illustrated in Plate 3.16-3.25 and their stratigraphic Tanzania ranges are shown in Tanzania range charts (see tables 4.1-5.2). Published literatures for identifying benthic forms are very few and other species were difficult to identify even to generic level. Therefore only forms which were identified to genus and few to species level are described here and illustrated in plates. Taxonomic classification of Loeblich and Tappan (1987) was used to classify Aptian-Albian benthic foraminifera. Published literatures were used to compare and identify some of the species; this to include Abu Zeid (2007), Bolli and others (1994), Haynes (1981), Holbourn and Kaminski (1995; 1997), Jenkins and Murray (1981), Kaminski (1992), Macmillan (2003) and

Scheibnerova (1972; 1978) and Sikora and Olsson, (1991).

Criteria used to identify benthic foraminifera are as follows:

1. Shape of the test; is necessary to identify if the fossil foraminifera has a single or is made up of many chambers.
2. Chamber shape; if are globular, conical, or whether compressed, if high or low trochospiral whether one side is more convex, or planoconvex or concave or flat than the other side.
3. Periphery outline whether is round, angular, or keeled.
4. Coiling mode of whorls; whether coiled in a single plane; planispiral, or trochospiral, uniserial, biserial, triserial, or streptospiral.
5. Shape of the chambers, is important to estimate the rate of increase in size of the chambers per whorl also chambers can be of various shapes such as globular, lenticular, triangular.
6. Sutures; are also important to know whether they are curved, radial, limbate, or curved at high angle or straight.
7. Aperture form and position, this is very important for the identification of genera and species, umbilical, dorsally, or periphery margin and etc., and apertural form whether an arch, slit etc.
8. Other features covering the apertural area are also important to investigate when identifying foraminifera such as lips and flaps and their thickness.
9. Wall, whether calcareous, or agglutinated.
10. Test surface sculpture, whether is smooth or ribbed and etc.

A total of forty-three (43) genera of calcareous and agglutinated benthic foraminifera were identified and this includes 20- agglutinated and 23 calcareous benthic forms.

3.6 Agglutinated foraminifera

A total of sixteen families of agglutinated benthic foraminifera were identified in the studied succession. These are Ammodiscidae, Bathysiphonidae, Cyclamminidae Eggerellidae, Hyperamminidae, Hormosinidae. Lituolidae, Psammosphaeridae, Pseudogaudryinidae, Rhabdamminidae, Rzehakinidae, Saccamminidae, Spiroplectamminidae, Tritaxidae, Trochamminidae, and Verneuilinidae.

The following genera were identified; *Ammobaculites*, *Ammodiscus*, *Bathysiphon*, *Cyclammina*, *Gaudryina*, *Glomospira*, *Glomospirella*, *Hormosina*, *Hyperammina*, *Lagenammina*, *Marssonella* *Psammosphaera*, *Pseudogaudryinella*, *Reophax*, *Rhizammina*, *Rzehakina*, *Saccammina*, *Spiroplectammina*, *Tritaxia* and *Trochammina*

3.7 Calcareous benthic foraminifera

Fourteen families of calcareous benthic foraminifera were identified within the studied interval and these are; Anomalinidae, Epistominidae, Gavelinellidae, Globorotalidae, Lagenidae, Lingulinidae, Lingulogavelinellidae, Nodosariidae, Osangulariidae, Patellinidae, Polymorphinidae , Pleurostomellidae, Sphogenerinoididae and Vaginulinidae.

The genera identified are as follows *Astacolus*, *Conorotalites*, *Epistomina*, *Gavelinella*, *Globulina*, *Globorotalites*, *Gyroidinoides*, *Laevidentalina*, *Lenticulina*, *Lingulina*, *Lingulogavelinella*, *Nodosaria*, *Orithostella*, *Orthokarstenia*, *Osangularia*, *Palmula*, *Patellina*, *Pleurostomella*, *Pseudonodosaria*, *Psilocitharella*, , *Saracenaria*, *Ramulina* and *Tristix*.

3.8 Systematic Description

Order FORAMINIFERIDA Eichwald, 1830

3.8.1 Family LITUOLIDAE de Blainville, 1825

Genus *Ammobaculites* Cushman, 1910

***Ammobaculites subcretacea* (Cushman and Alexander) Plate 3.16, figs. 1a-b**

Type reference: *Ammobaculites subcretaceus* Cushman and Alexander 1930, *Contribution Cushman Laboratory Foraminifera. Res.*, 6, p. 6, pl. 2, figs. 9, 10.

Description: Initial coiling is planispiral to uniserial in the three final chambers. Test is coarsely agglutinated, the uniserial chamber is broader and test in general is medium in size; chambers increasing slowly in size as added; aperture is terminal produced at the end of the final chamber.

Remarks: *Ammobaculites* species from the present study closely resembles *Ammobaculites subcretacea* described by Bolli and other (1994). This species is rare in the present studied interval and preservation varies from poor to moderate.

World Stratigraphic Range: This species has been reported from the late Aptian to early Albian Trinidad (Bolli, 1994). Worldwide it has been recorded from the Albian–early Cenomanian (*Rotalipora ticinensis* Zone to *Rotalipora appenninica* Zone).

Tanzania Range: Sample TDP40B Hole; Core 4 / 3, 1-25 cm (7.7 m).

***Ammobaculites* sp. 1**

Plate 3.16, figs. 2a-c

Type reference: *Ammobaculites* Cushman 1910, *Bulletin of the United States National museum* 71, 1, p. 1-134.

Descriptions: Test shape is elongate and conical with triserial to biserial in the final chamber arranged overlapping; wall agglutinated, aperture is round and terminal at the end of the final chamber, Chambers increasing slowly in size as added.

Remarks: Specimens of *Ammobaculites* varies in abundance from rare to abundant but identifying to species level is difficult. This species is rare in the studied interval and its preservation varies from poor to moderate.

World Stratigraphic Range: The genus *Ammobaculites* stratigraphically ranges from the early Carboniferous to Holocene.

Tanzania Range: Sample TDP40B Hole; Core 13/1, 1-25 cm, (29.1 m).

Genus *Ammobaculites* Cushman 1910

Ammobaculites sp. 2

Plate 3.16, fig. 3

Type reference: *Ammobaculites* Cushman 1910, *Bulletin of the United States National Museum* 71 (1), p. 1-134.

Descriptions: Test; small, planispiral with enrolled spherical chamber on the initial part of the test; the final chambers are straight uniserially arranged with three chambers in the last portion; chambers are separated by depressed horizontal sutures; arenaceous agglutinated materials are fine and glued tightly. An aperture is small, round terminal and produced in a slightly short neck, chambers are broader increasing irregularly in size as added, and globular.

Remarks: This specimen is rare in the studied interval and preservation varies from poor to good. In general the specimens of *Ammobaculites* vary in abundance from rare to abundant but identification to species level is difficult due to limited literatures on benthic foraminifera.

World Stratigraphic Range: Valanginian - Late Cretaceous.

Tanzania Range: Sample TDP40B Hole; Core 13/1, 1-25 cm, (29.1 m).

3.8.2 Family AMMODICIDAE Reuss, 1862

Genus *Ammodiscus* Reuss, 1862

***Ammodiscus cretacea* (Reuss)**

Plate 3.16, figs. 4a-b

Type reference: *Ammodiscus cretacea* Reuss, Riegraf and Luterbacher, 1987a, p. 1087, pl.1, fig. 7.

Description: The proloculus is globular followed by six coiled tubular chambers; second chamber show constrictions, wall agglutinated; aperture at the open end of the tube. This species is rare present in most of the boreholes studied.

Remarks: Specimens of *Ammodiscus* in the studied interval varies from rare to abundant and preservations varies from poor to moderate and in few specimens are moderate to good (see tables 4.1-5.2).

World Stratigraphic Range: Cretaceous.

Tanzania Range: Sample Luhoi-1 Hole; Core 53/2, 35-45 cm (273.5 m).

***Ammodiscus* sp.**

Plate 3.16, fig. 5a-b

Type reference: *Ammodiscus* Reuss 1862, *Sitzungsberichte der Kaiserlichen akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Classe* 44; 1, p. 365.

Description: Test is elongate, ovate in outline and slender in shape, tubular, compressed five whorls are visible in one side; tightly coiled in one plane and agglutinated; aperture is at the end of the tube.

Remarks: This species is rare in the studied interval and preservation is poor.

World Stratigraphic Range: Silurian-Holocene.

Tanzania Range: Sample Songo Songo-4 Hole; Core 3/3, 80-90 cm (1865.2 m).

3.8.3 Family VAGINULINIDAE Reuss 1863

Genus *Astacolus* Montfort 1808

***Astacolus* aff. *gratus* (Reuss)**

Plate 3.16, figs. 6a-c

Type reference: *Cristellaria* (*Cristellaria*) *grata* (Reuss) 1863, p. 70, pl. 7, fig. 14.

Description: The specimen of *Astacolus* are smooth, calcareous test, elongate and chambers are compressed, not visible; earlier chambers are broader and coiled planispiral while the later chambers are rectilinear arranged with a terminal aperture at an angle on one side, periphery, test outline is angular.

Remarks: This specimen is similar to *Astacolus gratus* described by Bolli and others, (1994). This specimen is rare in the Tanzanian materials and preservation is poor to moderate.

World Stratigraphic Range: pecies of *Astacolus gratus* has been reported from the late Aptian to early Albian of Trinidad (Bolli and others, 1994) and possibly have similar stratigraphic range to the Tanzanian specimen.

Tanzania Range: Sample TDP40 Hole A; Core 10/1, 30-58 cm (0.4 m).

3.8.4 Family BATHYSIPHONIDAE Avnimelech, 1952

Genus *Bathysiphon* M. Sars, 1872

***Bathysiphon* sp.**

Plate 3.16, fig. 7

Type reference: *Bathysiphon* M. Sars, in G. O. Sars, 1872, p. 46-255.

Description: Test is elongate, with openings at both ends of the tube; and test wall is agglutinated and an aperture situated at one end of the tube, not well defined it has been infilled with materials.

Remarks: Fragments of *Bathysiphon* specimens present in the studied samples are rare to abundant and preservations varies from poor to moderate and few samples in TDP 40 Holes, A and B, Songo Songo-4 Hole and Kizimbani-1 Hole where preservation varies from moderate to good (see Tables 4.5, 4.6, and 5.1-5.2).

World Stratigraphic Range: The genus *Bathysiphon* stratigraphically ranges from late Triassic to Recent.

Tanzania Range: Sample Kizimbani-1 Hole; (213.4 m).

3.8.5 Family GLOBOROTALIDAE Cushman, 1927

Genus *Conorotalites* Kaever, 1958

***Conorotalites bartensteini aptiensis* (Bettenstaedt)**

Plate 3.16, figs 8a-b and Plate 3.17 figs. 1a-b

Type reference: *Conorotalites bartensteini aptiensis* (Bettenstaedt) 1952, p.278, 282, pl. 3, fig. 32.

Description: small, trochospiral, biconvex, umbilical side is highly convex and conical, and spiral side is almost flat, chambers on both sides are not visible. Aperture is an arch below the final chamber, wall calcareous, finely perforate, and smooth.

Remarks: Specimens of *Conorotalites* are rare to abundant and preservation is poor to moderate in the studied interval. This specimen closely resembles to *Conorotalites bartensteini aptiensis* described by Bolli and others (1994).

World Stratigraphic Range: Late Aptian - earliest A lbian.

Tanzanian Range: Sample TDP40 Hole A; Core 5/2, 8-33 cm (9.2 m).

3.8.6 Family CYCLAMMINIDAE Marie, 1941

Genus *Cyclammina* Brady, 1879

Cyclammina sp. 1

Plate 3.17, figs. 2a-c (sp. 1)

Type reference: *Cyclammina* Brady, 1879, new ser. 19, p. 62, Part 1, On new or little known arenaceous types, *Quarterly Journal of Microscopical Science.*

Description: *Cyclammina* that is identified in the present study is coiled planispiral, flat, and chambers are triangular to trapezoidal in shape, increasing rapidly in height as added, and are broader and the last chamber is much broader and higher than the rest. Sutures are curved radially on both sides, periphery margin is broad and rounded; aperture is interiomarginal equatorial and slit in shape at the base of the last chamber and is equatorial; a series of pores seen above the aperture face.

Remarks: This species is rare in the studied interval.

World Stratigraphic Range: Normally it is a Tertiary form but found in the mid-Cretaceous of Tanzania (reworked specimens).

Tanzania Range: Sample Songo Songo-4 Hole; Core 3/3, 80-90 cm, (1865. 2 m).

Cyclammina sp. 2

3.17 figs. 3a-c

Type reference: Type reference: *Cyclammina* Brady, 1879, new ser. 19, p. 62, Part 1, On new or little known arenaceous types, *Quarterly Journal of Microscopical Science.*

Description: *Cyclammina is unknown* unknown but probably it belongs to *Cyclammina* group. Test; coiled streptospiral to planispiral, flat, and chambers globular increasing rapidly in size as added, and are broader. Periphery margin is rounded.

Remarks: This species is rare in the studied interval (reworked specimen).

World Stratigraphic Range: Normally it is a Tertiary form but found in the mid-Cretaceous of Tanzania (reworked specimen).

Tanzania Range: Sample Songo Songo-4 Hole Core; 3/1, 40-50 cm, (1861 m).

3.8.7 Family EPISTOMINIDAE Wedekind, 1937

Genus *Epistomina* Terquem, 1883

Epistomina aff. _hetchi_ (Bartenstein, Bettenstaedt and Bolli)

Plate 3.17, figs. 4a-c

Type reference: *Epistomina* (*Brotzenia*) *hetchi* Bartenstein, Bettenstaedt and Bolli, 1957, pl. 7, Figs 170a-c, p. 46.

Description: This species is low trochospiral, biconvex, but the spiral side is slightly convex; chambers increasing in size rapidly as added; periphery outline is angular and a slit aperture which runs parallel to the periphery margin. Sutures on the spiral side are curved obliquely and in the ventral side curved to slightly radial. Test surface is smooth on the umbilical side while rough on the spiral side. on the ventral side; sutural ribs are slightly thick converge at the centre to form a ring like structure, while in the dorsal side the intercameral sutures curved obliquely and reaching and touching lateral marginal openings.

Remarks: Specimens of *Epistomina hetchi* identified in the present study is similar to specimen described by Sikora and others, (1991). Specimens of *Epistomina hetchi* are rare to abundant in the studied interval with poor to moderate preservation (see tables 4.3 & 4.6).

World Stratigraphic Range: Barremian-Late Albian.

Tanzania Range: Sample Kizimbani-1 Hole; (82.3 m).

3.8.8 Family GAVELLINELLIDAE Hofker, 1956

Genus *Gavelinella* Brotzen, 1942

Gavelinella barremiana Bettenstaedt

Plate 3.17, figs. 5a-c

Type reference: *Gavelinella barremiana* Bettenstaedt 1952, p. 275, pl. 2, fig. 27 (Holotype), pl. 2, figs. 26, 28, 29 (Paratype).

Description: Test low trochospiral, slightly biconvex to flat, with 9-chambers in the last whorl; increasing rapidly in size as added; two whorls are visible in the dorsal side. The umbilical region consists of subtriangular flap covering part of the umbilicus and is originating from each chamber and extending to the umbilicus. An aperture is a slit opening which stretches near the periphery margin to the umbilical area and is surrounded by a thin lip.

Remarks: Specimens of *Gavelinella barremiana* from Tanzanian materials are similar to the one described in Bolli and others, (1994). These specimens vary in abundance from rare to abundant with poor to moderate preservation and few specimens with moderate to good (see tables 4.3, 4.6 and tables 5.1- 5.2).

World Stratigraphic Range: Middle Barremian - Aptian.

Tanzania Range: Sample TDP40 Hole B; Core 18/3, 25-50 cm (46.4 m).

Gavelinella intermedia (Berthelin)

Plate 3.17, figs. 6a-c

Type reference: *Anomalina intermedia* Berthelin, 1880, p. 67, pl. 4, fig. 14.

Description: Test outline is rounded, trochospirally coiled, biconvex to slightly flat, calcareous, with a large umbilical boss at the centre of the dorsal side. Not all the chambers are visible on both sides of the test; about nine-chambers in the last whorl and chambers increases rapidly in size as added. Sutures are curved and slightly depressed those separating the four chambers of the last whorl. The umbilicus is partly covered by the apertural flap like structure which extends towards the umbilicus from each individual chamber, test wall is smooth, perforate, and aperture at the base of the final chamber and stretching from the peripheral margin to the umbilical region and join into the apertural flap with a well defined thick lip.

Remarks: The species of *Gavelinella intermedia* closely resemble the similar type of species described by Tyszka (2006). *Gavelinella intermedia* range from rare to abundant in the studied Albian interval of all boreholes. Preservation of specimens in Kizimbani-1Hole there are few specimens with moderate to good while the rest are poor to moderate.

World Stratigraphic Range: Albian - Cenomanian.

Tanzania Range: TDP40 Hole B, Core 3/1, 1-25 cm (5.1 m).

Genus *Gavelinella* Brotzen, 1942

***Gavelinella* sp. 1**

Plate 3.17, figs. 7a-c

Type reference: *Gavelinella* Brotzen, F., 1942, Die Foraminiferengattung *Gavelinella* nov. gen. und die Systematik der Rotaliformes, *Årsbok Sveriges Geologiska Undersökning* 36 (8), p. 1-60.

Description: Test outline is subrounded to angular, low trochospirally coiled, slightly biconvex to flat; calcareous, presence of umbilical depression on the ventral side and depressed early whorl. 8- chambers in the final whorl increasing moderately in size as added. Not all the chambers are visible on both sides of the test; about 9-chambers in the last whorl and chambers increases rapidly in size as added. Sutures are slightly curved radially in the ventral side. Sutures on the ventral side are thick and converging at the umbilical area. Aperture is interiomarginal stretching from the periphery margin to halfway down near to the umbilicus with a thin apertural lip.

Remarks: This species is rare to abundant in the studied interval with poor to moderate preservation except in Kizimbani-1 Hole where few specimens are moderate to poor.

World Stratigraphic Range: Barremian - late Cretaceous

Tanzania Range: Sample Kisarawe-1 Hole; (1823 m).

***Gavelinella* sp. 2 and *Gavelinella* sp. 3**

Plate 3.18, figs. 1a-c and figs. 2a-c

Type reference: *Gavelinella* Brotzen, F., 1942, Die Foraminiferengattung *Gavelinella* nov. gen. und die Systematik der Rotaliformes, *Årsbok Sveriges Geologiska Undersökning* 36 (8), p. 1-60.

Description: *Gavelinella* sp. 2: Test is biconvex, compressed, trochospiral, dorsal side is slightly more convex than the ventral side, test flatten, sutures are depressed chambers are higher than broader and sutures are curved, and ends up into a large and depressed umbilical boss. Periphery margin is circular; chambers are visible on both sides and a total of 12 in the last whorl. One whorl is visible on the spiral side. Aperture is an interiomarginal arch extending from the periphery on the ventral side to the umbilicus below the umbilical chamber flap. *Gavelinella* sp. 3: test compressed, biconvex, trochospiral, few chambers are visible on both sides of the test, aperture is a wide slit opening running beyond the periphery margin to dorsal with a central plug below the final chamber flap, test calcareous, finely perforate.

Remarks: Both specimens are rare in the studied interval and preservations vary from poor to moderate.

World Stratigraphic Range: Barremian - Paleocene.

Tanzania Range: Sample TDP40B Hole, Core 5/1, 1-25 cm, and sample TDP40 B Core 5/3, 70-80 cm, (8.1; sp. 2 and 10.8 m; sp. 3) respectively.

Genus *Globorotalites* Bolli, 1957

***Globorotalites* sp.**

Plate 3.18 figs. 3a-b

Type reference: *Globorotalites* Bolli, 1957, p. 117.

Description: Test low trochospiral biconvex, high conical on the umbilical side, aperture is an arch below the final chamber, wall calcareous, finely perforate, and smooth.

Remarks: It differs from *Conorotalites* by its large size and the high convex and raised umbilical side. This species is rare in the studied interval and preservation varies from poor to moderate.

World stratigraphic range: Early - mid Cretaceous.

Tanzania Range: TDP40A Hole; Core 5/2, 8-33 cm, (9.2 m).

3.8.9 Family POLYMORPHINIDAE d'Orbigny, 1839

Genus *Globulina* d'Orbigny, 1839

Globulina sp. aff. _lacrima lacrima_ (Reuss)

Plate 3.18, figs. 4a-c

Type reference: *Polymorphina (Globulina) lacrima* Reuss, 1845, p. 40, pl. 12, fig. 6, pl. 13, fig. 84.

Description: Test ovoid, to subspherical, single chamber, other chambers are not visible at all possibly due to the nature of preservation; aperture partly terminal and partly slit. Test surface is calcareous and smooth.

Remarks: Specimens of this species are rare in the studied interval and preservation is poor to moderate. It differs from *Lagena* species in the test morphology which is much broader and aperture. *Lagena* has an aperture which is round terminal and produced in a short neck. This species is slightly similar to the one described by Bolli and others (1994).

World Stratigraphic Range: Late Albian (*Pseudothalmanninella ticinensis* Zone) to late Paleocene (*Morozovella velascoensis* Zone).

Tanzania Range: Sample Makarawe-1 Hole; (325 m).

Globulina sp. aff. *prisca* (Reuss)

Plate 3.18, fig. 5

Type reference: *Polymorphina (Globulina) prisca* Reuss, 1863, p. 79, pl. 9 fig. 8.

Description: Test elongate, ovoid, single chamber, aperture round and terminal. Test surface is calcareous and smooth.

Remarks: Specimens of *Globulina* are rare in the studied interval and preservation is poor to moderate with few moderate to good (see table 4.6). This species is similar to the one illustrated in Bolli others (1994).

World Stratigraphic Range: Maastrichtian species reworked into this interval.

Tanzania Range: Sample Kizimbani-1 Hole; (161.5 m).

Genus: *Glomospira* Rzehak, 1885

Glomospira charoides (Berthelin)

Plate 3.18, figs. 6a-b

Type reference: *Trochammina squamata* var. *charoides* Jones and Parker, 1860, p. 306.

Description: Test is enrolled into four whorls in the outer layer of coils; a proloculus is followed by a tubular second chamber that is coiled streptospiral. These tubular chambers are not divided, coiled in the same plane. The aperture is at the end of the tubular chamber, test surface is finely agglutinated.

Remarks: Specimens of *Glomospira charoides* are rare to abundant in the studied interval and few moderate to good preserved specimens otherwise most samples analysed from boreholes were poor to moderately preserved (specimens with calcite and pyrite infill).

World Stratigraphic Range: early - middle Cretaceous.

Tanzania Range: Sample TDP 40B Hole, Core 6/3, 1-32 cm, (13.2 m).

Genus *Glomospirella* Plummer, 1945

Glomospirella aff. *gaultina*
(Berthelin) Plate 3.18, figs 7a-c

Type reference: *Ammodiscus gaultina* Berthelin, 1880, p. 19, pl. 1, fig. 13.

Description: Test initially is a proloculus and later a tubular undivided coil, streptospiral coiled of the second chamber and the remaining coiled planispiral and disc-like. Test surface is agglutinated with a smooth wall; aperture at the end of the tube.

Remarks: This specimen is similar to specimen described by Kaminski (1992). Specimens of *Glomospirella gaultina* are rare in the studied interval and preservation varies from moderate to good.

World Stratigraphic Range: Late Aptian - Early Albian.

Tanzania Range: Sample TDP40A Hole; Core 2/1, 33-62 cm (2.5 m).

Subfamily GYROIDINOIDINAE Saidova, 1981

Genus *Gyroidinoides* Brotzen, 1942

Gyroidinoides sp. 1
Plate 3.19, figs. 1a-c

Type reference: *Gyroidinoides* Brotzen, 1942, Die Foraminiferengattung *Gavelinella* nov. gen. und die Systematik der Rotaliformes, *Årsbok Sveriges Geologiska Undersökning* 36 (8), p. 1-60.

Description: Specimen of *Gyroidinoides* identified is a trochospirally coiled, spiral side is flat and umbilical side is convex, sutures and chamber partitioning are not visible, only outline of the two whorls are visible, you cannot tell even the number of chamber. Periphery outline is round; wall calcareous, smooth and a slit aperture which stretches from the periphery margin to the umbilical area. Other structures are not present like apertural flap possibly obscured due to the poor to moderate nature of preservation.

Remarks: Specimens of *Gyroidinoides* sp. 1 are rare to common in the studied mid-Cretaceous section of Tanzania but are present not continuous but in several intervals. Preservation of specimens varies from poor to moderate. Morphological and other characters of this species resembles to species of *Gyroidinoides* described in various publication such as Loeblich and Tappan (1988).

World Stratigraphic Range: Cenomanian to Holocene.

Tanzania Range: Sample Songo Songo-4; Core 1/1; 16-30 cm (1826 m).

Genus *Gyroidinoides* Brotzen, 1942

***Gyroidinoides* sp. 2**

Plate 3.19, figs. 2a-c

Type reference: *Gyroidinoides* Brotzen, 1942, Die Foraminiferengattung *Gavelinella* nov. gen. und die Systematik der Rotaliformes, *Årsbok Sveriges Geologiska Undersökning* 36 (8), p. 1-60.

Description: Test coiled trochospiral, plano-convex chambers and sutures are not visible but test outline is round and angular in equatorial view, smooth, calcareous finely perforate with two visible whorls. Umbilical side is more convex than the flat spiral side. Aperture is at the base of the final chamber and stretches near the periphery and near the umbilicus and is slit- to lens like shape and an aperture lip is well defined in the umbilical view.

Remarks: Specimens of *Gyroidinoides* are rare to frequent in the studied interval but of variety in morphology and preservations varies from poor to moderate.

World Stratigraphic Range: Cenomanian to Holocene.

Tanzania Range: Sample Songo Songo-4 Hole; Core 1 / 2, 30 - 44 cm, (1828 m).

Genus *Gyroidinoides* Brotzen, 1942

Gyroidinoides sp. 3

Plate 3.19, figs. 3a-c

Type reference: *Gyroidinoides* Brotzen, 1942, Die Foraminiferengattung *Gavelinella* nov. gen. und die Systematik der Rotaliformes, *Årsbok Sveriges Geologiska Undersökning* 36 (8), p. 1-60.

Description: Test; coiled trochospiral, plano-convex; sutures and chamber arrangements part are not visible on both sides of the test; test outline is round; smooth, calcareous finely perforate with one which is visible. An aperture is at the base of the final chamber and extends from the periphery margin to the umbilical area. The specimens are rare to abundant in the two Holes of TDP40 A and B, with poor to moderate preservation.

World Stratigraphic Range: Cenomanian to Holocene. (No clues if these specimens really belong to the intervals which were found or contamination or probably new species.

Tanzania Range: TDP40 Hole B; Core 1 /1, 40-49 cm, (0.5 m).

3.8.10 Family HYPERAMMINIDAE Eimer and Fickert, 1899

Genus *Hyperammina* Brady, 1878

Hyperammina sp. and _Hyperammina gaultina_

Plate 3.19, figs. 4a-b and figs. 5a-b

Type reference: *Hyperammina* Brady, 1878, *Annals and Magazine of Natural History*, ser. 51:425-440.

Description: Specimens of *Hyperammina* identified in the studied interval are elongate; straight, and tubular in shape with the early chamber that is spherical in shape (proloculus). Aperture is at the end of the tube, round in shape and test surface is fine to medium grain size. Plate 3.19 and figs. 4a-b are *Hyperammina* with just tubular chamber. (Plate 3.19 and figs. 5a-b) otherwise are not different and possibly different specimens of *Hyperammina* or the proloculus that is lost due to some reasons. *Hyperammina* specimen on figure 5a-b: closely resembles to *Hyperammina gaultina*.

Remarks: *Hyperammina* species are rare to abundant in the studied intervals and preservation is poor to moderate except in few specimens are moderate to good (see tables, 4.4 - 4.6).

World Stratigraphic Range: Early Cretaceous - Holocene.

Tanzania Range: Sample Songo Songo-4 Hole; Core 2/3, 20-30, (1843.6 m).

3.8.11 Family SACCAMMINIDAE Brady, 1884

Genus *Lagenammina* Rhumbler, 1911

Lagenammina aff. _alexanderi_ (Loeblich and Tappan)

Plate 3.20, figs. 1a-b

Type reference: *Proteonina alexanderi* Loeblich and Tappan 1950, pl. 1, figs. 1-2.

Lagenammina alexanderi (Loeblich and Tappan) - Haig 1980 pl. 1, figs. 14-17.

Descriptions: *Lagenammina* species identified from Tanzanian material; test unilocular, flaskshaped; pointed at the cemented together.

Remarks: Specimens of *Lagenammina* sp. aff. *alexanderi* identified in the present study is similar to the one described by Holbourn and Kaminski (1995). Specimens of *Lagenammina* are rare to abundant but *Lagenammina* sp. aff. *alexanderi* are rare to common in the studied interval and preservation is poor to moderate only in one horizon in the TDP40 Hole B where specimens are moderate to good (see table 5.1).

World Stratigraphic Range: Aptian - Cenomanian.

Tanzania Range: Sample TDP40B Hole, Core 2/2, 1-25 cm, (3.1 m)

3.8.12 Family NODOSARIIDAE Loeblich and Tappan, 1986

Genus *Laevidentalina* Loeblich and Tappan, 1986

***Laevidentalina communis* (d'Orbigny)**

Plate 3.20, figs. 2a-b

Type reference: *Nodosaria (Dentalina) communis* d'Orbigny 1826, p. 254.

Description: Test rectilinear, uniserial with 5- chambers and chambers are increasing moderately in size as added and irregularly especially in the early part of the test. Aperture is terminal and produced and the last two chambers are oval in shape and broader and higher than the rest. Sutures curved obliquely in the early chambers but are horizontal in the f *Laevidentalina* are rare to abundant in the current studied sections of the boreholes and preservation varies from poor to moderate and few samples with moderate to good (see table 4.6).

World Stratigraphic Range: Barremian-Early Eocene.

Tanzania Range: Sample TDP40B Hole; Core 22 / 2, 1-25 cm, (57.1 m).

***Lenticulina muensteri* (Roemer)**

Plate 3.20, figs. 3a-c (sp. 1)

Type reference: *Robulina müensteri (*Roemer) 1839, p. 48, pl. 20, fig. 29.

Description: Specimens of *Lenticulina* encountered in the present study have lenticular test outline, biconvex with terminal periphery aperture, chambers and sutures are flushed curved and are visible; sutures are not well defined and not visible. Test surface is smooth, calcareous and finely perforate. Varieties of specimens of *Lenticulina muensteri* were earmarked in the studied succession.

Remarks: Specimens of *Lenticulina muensteri* are rare to abundant in the late Aptian, and middle to late Albian intervals with poor to moderate preservation and few samples with moderate to good specimens (see tables 4.6, & 5.2). This species is similar to *Lenticulina* *muensteri* described by Bolli and others (1994). *Lenticulina muensteri* of plate 3.20, figs 3a-c are similar to species of *Lenticulina muensteri* described by MacMillan (2003).

World Stratigraphic Range: This species has been reported from Barremian-Early Aptian of Cuche Formation and late Aptian to early Albian Maridale Formation in Trinidad (Bolli, 1994). It has also been reported from the Aalenian - Albian of Europe (MacMillan, 2003).

Tanzania Range: Sample TDP40 Hole B; Core 18/2, 25-50 cm (45.4 m).

***Lenticulina muensteri (Roemer)* (sp. 2)**

Plate 3.20, figs. 4a-c

Type reference: *Robulina müensteri (*Roemer) 1839, p. 48, pl. 20, fig. 29.

Description: Specimens of *Lenticulina* encountered in the present study have lenticular test outline; biconvex with terminal periphery aperture; chambers and sutures are flushed curved few can be seen. Sutures are not well defined and not visible. Test surface is smooth, calcareous and finely perforate. Varieties of specimens of *Lenticulina muensteri* were seen in the studied succession.

Remarks: Specimens of *Lenticulina muensteri* are from frequent to common in the late Aptian, and middle to late Albian intervals and preservation varies from poor to moderate. This species resembles *Lenticulina muensteri* described in Bolli and others (1994) and in MacMillan (2003).

World Stratigraphic Range: This species has been reported from Barremian - early Aptian of Cuche Formation and late Aptian to early Albian Maridale Formation in Trinidad (Bolli, 1994). This species also has been reported from the Aalenian -Albian of Europe (MacMillan, 2003).

Tanzania Range: Sample TDP40 Hole A, Core 18/3, 29-57 cm (47 m).

Genus *Gavelinella* Brotzen, 1942

Lenticulina (Lenticulina) nodosa

(Reuss) Plate 3.20, figs. 5a-c

Type reference: *Robulina nodosa* (Reuss) 1863, p. 78, pl. 9, fig. 6, Neotype: Bartenstein 1974, *Eclog. Geol. Helv*., 67, p. 540, pl. 1, fig. 1.

Description: Test, broad and short, planispiral in the early chambers and uncoiled in the later few; round periphery outline, circular in equatorial view, with eleven chambers in the final whorl; chambers increase moderately in size as added, sutures extends to the peripheral margin to form node like structures and are thick curved and meet centrally to form a boss, wall is smooth, calcareous and perforate and terminal aperture at a periphery angle facing apertural face.

Remarks: This specimen is rare in the studied sequence and is similar to specimen illustrated by Bolli and others (1994). It differs from other forms by its thick sutural ribs which meet at the centre and form a boss on both sides.

World Stratigraphic Range: Barremian - Early Aptian

Tanzania Range: Sample TDP40 Hole A; Core 11/ 1, 1-25 cm, (23.3 m).

Lenticulina (Lenticulina) ouachensis ouachensis

(Sigal) Plate 3.20, figs. 6a-c

Type reference: *Cristellaria ouachensis* Sigal 1952, 19^{me}Congr. Géol. Int. Algers. Monogr. Rég. sér. no. 26, p. 16, text fig. 10.

Description: Test broad and short, planispiral in the early chambers and uncoiled in the later few; subcircular in equatorial view, carinate, with eight chambers in the final whorl; chambers increase rapidly in size as added, sutures are curved and meet to form a ring centrally, wall is smooth, calcareous and perforate.

Remarks: This specimen is rare to frequent and preservation varies from poor to moderate. This specimen is similar to the one described by Bolli and others (1994).

Remarks: It differs from other forms by its ring like form at the centre and a well developed carina.

World Stratigraphic Range: Middle Valanginian to Early Aptian.

Tanzania Range: Sample TDP40 Hole B; Core 11/2, 1-25 cm, (24.1 m).

***Lenticulina (Lenticulina) subgaultina* (Bartenstein)**

Plate 3.20, figs. 7a-b

Type reference: *Lenticulina (Lenticulina) subgaultina* Bartenstein, 1962, Senckenberg Lethaea, 43, p. 136, pl. 15, fig. 1.

Description: Test, elongate, biconvex, coiled planispiral in the early chambers and uncoiled in the later few chambers, lenticular, test is compressed and non carinate; chambers increase in size slowly as added, and broader, sutures are curved but not very well visible, wall; smooth, calcareous and perforate.

Remarks: This specimen is rare in the studied sequence and is similar to *Lenticulina (Lenticulina) subgaultina* described by Bolli and others, (1994).

World Stratigraphic Range: Aptian - Early middle Albian. In Trinidad it occurs in the late Aptian intervals.

Tanzania Range: Sample TDP40 Hole A; Core 19/3, 1-25 cm, (49.5 m).

Genus *Lenticulina* Lamarck, 1804

***Lenticulina* sp. A**

Plate 3.21, figs. 1a-c

Type reference: *Lenticulina* Lamarck, 1804, Suite des mémoires sur les fossils des environs de Paris, *Annales Muséum National d'Histoire Naturelle* 5, p. 153.

Description: Test is broader in the early part and coiled planispirally in the early chambers to uncoil or uniserial in the last. Chambers are not visible in both sides but an umbilical plug (boss) is centrally and flushed. Aperture is slit-like form at the periphery edge in the last chamber. Sutures are flushed and not visible in both sides and test surface is smooth, and calcareous.

Remarks: Specimen of *Lenticulina* sp. A is rare but preservation is moderate to good. This specimen was recovered from the lower - middle Albian of Tanzania.

World Stratigraphic Range: Early - middle Albian

Tanzania Range: Sample Kizimbani-1 Hole; (146.3 m).

3.8.13 Family LINGULOGAVELINELLIDAE Scheibnerova, 1972

Genus *Lingulogavelinella* Malapris, 1965

Lingulogavelinella sp.

Plate 3.21, figs. 2a-c

Type reference: *Lingulogavelinella* Malapris, M. 1965, *Revue de Micropaléontologie* 8, p. 139.

Description: Test, low trochospiral, with inflated chambers round less lobulate periphery both sides are involute, sutures on the ventral side are flushed and not visible. On the dorsal side sutures are curved, test surface is covered with scattered and randomly distributed pores, seven chambers in the last whorl, and an apertural flap (folia) present and covering the umbilicus. Aperture is arched like shape and interiomarginal.

Remarks: This species closely resembles to *Lingulogavelinella spinosa* illustrated by Sikora Olsson (1990). *Lingulogavelinella* differs from *Gavelinella* by the presence of umbilical flap (folia) covering the entire umbilicus. Specimens of *Lingulogavelinella* sp.1 are rare and preservation varies from poor to moderate.

World Stratigraphic Range: This species stratigraphically ranges from late Albian through late Cenomanian.

Tanzania Range: Sample Songo Songo-4 Hole; (1823).

***Lingulogavelinella* sp. 1**

Plate 3.21, figs. 3a-c

Type reference: *Lingulogavelinella* Malapris, 1965, *Revue de Micropaléontologie* 8, p. 139.

Description: Test is trochospiral, biconvex to flat, with seven chambers in the final whorl; sutures on the dorsal side are slightly curved to radial and ventral sutures are not visible umbilicus covered completely with a triangular apertural flap, extended from the chambers to the umbilicus and making a star-like shape in the umbilicus. Test outline is round, wall calcareous, aperture an arch at the base of the final chamber stretching from the periphery to the umbilical region covered by a very thin and narrow lip which broadens and just near the umbilicus.

Remarks: Specimens of *Lingulogavelinella* are rare and preservation varies from poor to moderate and few with moderate to good.

World Stratigraphic Range: Albian - Turonian.

Tanzania Range: Sample TDP40 Hole A; Core 2/3, 1-25 cm, (4.1 m).

Genus *Orithostella* Eicher and Worstell, 1970

***Lingulogavelinella* sp. 2.**

Plate 3.21, figs. 4a-c

Type reference: *Lingulogavelinella* Malapris, 1965, *Revue de Micropaléontologie* 8, p 39.

Description: Test is trochospiral, biconvex to flat, with seven chambers in the final whorl; sutures on the dorsal side are curved inward and ventral sutures are not visible are flushed but curved, umbilicus covered halfway with a triangular apertural flap, extended from the chambers to the umbilicus and making a star-like shape in the umbilicus. Test outline is lobate, wall calcareous, aperture an arch at the base of the final chamber stretching from the periphery to the umbilical region covered by a very thin and narrow lip which broadens at the end of the umbilicus and set a stallate flaps.

Remarks: Specimens of *Lingulogavelinella* in the present study are rare and specimen preservation is poor to moderate.

World Stratigraphic Range: Albian - Turonian.

Tanzania Range: Sample Makarawe-1 Hole; (360 m).

Marssonella oxycona (Reuss)

Plate 3.21, figs. 5a-c

Type reference: *Marssonella oxycona* Reuss, 1860, *Sitzungsberichte der K. akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche* Classe 40, 147-238.

Description: Test; conical, elongate, biserial in the later stage and trochospiral in the initial stage; spherical in cross section, chambers of the final part increase rapidly in diameter as added. And the last face is somehow flat to concave; aperture is an arch at the base of the final chamber and is not visible including other features; wall finely agglutinated with calcareous material with organic lining.

Remarks: It differs from specimens of *Dorothia* by its conical shape and a flattened to concave terminal face. *Marssonella oxycona* in the studied interval varies in abundance from rare to abundant and preservation varies from poor to moderate and few with moderate to good specimens from Kizimbani-1 Hole.

World Stratigraphic Range: Valanginian– Maastrichtian.

Tanzania Range: Sample Kisarawe-1 Hole; (1762 m).

Genus *Nodosaria* Lamarck 1812

Nodosaria sp.

Plate 3.21, figs. 6a-b

Type reference: *Nodosaria* Lamarck, 1812, *Extrait du cours de Zoologie du Muséum d'Histoire Naturelle sur les animaux invertébres*. Paris, d'Hautel, p. 121.

Description: This species has three chambers which vary in shape from oval shape in the initial chamber then spherical, medium chamber and oval shape of the last chamber. These chambers are separated by septal sutures which are horizontal and at the base of each chamber (2^{nd} and third chamber). Aperture is terminal and is at the end of the last chamber. Test surface is smooth, finely perforate and calcareous.

Remarks: Specimens of *Nodosaria* are of variety in the studied section but varies from rare to frequent and preservation varies from poor to moderate and few samples with moderate to good (see Tables 4.6 and 5.2).

World Stratigraphic Range: Early Jurassic - Holocene.

Tanzania Range: Sample TDP40B Hole; Core 6/2, 25-55 cm, (12.1 m).

3.8.14 Family OSANGULARIIDAE Loeblich and Tappan 1964

Genus *Osangularia* Brotzen 1940

Osangularia californica Dailey

Plate 3.21, figs. 7a-c

Type reference: *Osangularia californica* Dailey 1970, p. 108, pl. 13, figs. 3, p 4.

Description: Test shape of *Osangularia californica* is biconvex in both sides but the ventral side is more convex than the dorsal, test outline slightly rounded, chambers are visible on both sides; sutures are curved with two whorls visible on the spiral side; twelve chambers in the last whorl. Aperture is a combination of two slit-like form at the base of the last chamber extends towards the umbilicus where a v-shaped opening.

Remarks: Specimens of *Osangularia californica* are rare in the studied interval but closely resembles the one described by Bolli and others (1994). Specimens are rare with poor to moderate preservation.

World Stratigraphic Range: This species stratigraphically ranges from the late Albian-early Cenomanian.

Tanzania Range: Sample Songo Songo-4 Hole; (1865.4 m)

Genus *Osangularia* Brotzen 1940

Osangularia sp. aff. _schloebanchi_ Brotzen

Plate 3.22, figs. 1a-c

Type reference: *Osangularia* Brotzen, F. 1940, Flintrännans och trindelrännans *Geologi, Årsbok Sveriges Geologiska Undersökning* 34(5):1-33.

Description: Specimens of *Osangularia schloebanchi* identified are convex on the ventral side and slightly flat to concave dorsal side outline is angular and elongate. It has 12 or more chambers in the last whorl; only few chambers are visible in the ventral side while in spiral and part of the ventral chambers are not visible; on the spiral side; two whorls are visible in the spiral view. Sutures are curved and visible few in the ventral side; aperture is at the base of the final chamber; an arch-shape and a slit parallel to the final chamber. Wall is calcareous and smooth for all *Osangularia* species identified in the current study.

Remarks: Specimens of *Osangularia* varies from rare to abundant in the Aptian to Albian of Tanzania and preservation varies from poor to moderate.

World Stratigraphic Range: Stratigraphically *Osangularia schloebanchi* ranges from the late Aptian through late Albian.

Tanzania Range: Sample Kizimbani-1 Hole; (55 m).

***Osangularia* sp.**

Plate Plate 3.22, figs. 2a-c

Type reference: *Osangularia* Brotzen, F. 1940, Flintrännans och trindelrännans *Geologi*, *Årsbok Sveriges Geologiska Undersökning* 34(5):1-33.

Description: Test; biconvex, low trochospiral, slightly more convex in the ventral side; spherical in outline; 12-chambers in the final whorl are visible in the ventral side and dorsal side is slightly concave; sutures are curved at high angle in the last 4 chambers of the last whorl while less curved almost straight in the initial chambers of the last whorl, aperture is a slit shape covered by a lip at the base of the final chamber.

Remarks: Specimens of *Osangularia* are rare in the studied section and varies in preservation from poor to moderate.

World Stratigraphic Range: The genus *Osangularia* stratigraphically ranges from the early Cretaceous to Holocene.

Tanzania Range: Sample Songo Songo-4 Hole; Core 3 /2, 0-14 cm, (1868 m).

Genus *Osangularia* Brotzen 1940

***Osangularia*. aff. *utaturensis* Sastry and Sastri**

Plate 3.22, figs. 2a-c

Type reference: *Eponides utaturensis* Sastri and Sastry, 1966, p. 292, pl. 19, fig. 6a-c.

Description: Species of *Osangularia* identified in the present study are biconvex in both sides but the dorsal side is more convex, with a spherical outline. It has 12-chambers in the last whorl on the spiral side; 3-whorls are visible sutures are raised especially the few 4-in the last 4-chambers of the last whorl and curved. While in the early portion of the initial chambers of the last whorl are curved to low angle; aperture is a combination of two v-shaped opening and continued towards down in the umbilical region as slit-like form at the base of the last chamber.

Remarks: Specimens of *Osangularia utaturensis* described by Scheibernová, (1972), closely resembles the one identified from the present studied interval. Specimens of *Osangularia utaturensis* are rare in the studied interval and preservation is poor.

World Stratigraphic Range: Stratigraphically is of late Albian.

Tanzania Range: Sample Songo Songo-4 Hole; Core 3/3, 80-90 cm, (1865.2 m).

Genus *Orithostella* Eicher and Worstell, 1970

***Orithostella indica* Sastri and Sastry**

Plate 3.22, figs. 4a-c

Type reference: *Anomalina indica*, Sastri and Sastry 1966, pl. 5, fig 13 - 17; pl. 11, figs. 7a - c.

Description: Test is biconvex, asymmetrical, planispirally coiled, one side is more involute than the other, oval test outline; chambers are inflated on the umbilical side, calcareous, trochospiral, with 10-chambers in the final whorl, aperture is a narrow equatorial arch. An umbilical plug seen in specimen and umbilicus is filled with flaps.

Remarks: It differs from *Orithostella australis* by its many chambers in the last whorl and outline of oval rather than round shape. It differs from *Lingulogavelinella* by its imperforate apertural flap covering the dorsal part of the aperture. This specimen is rare in the studied interval and preservation varies from poor to moderate and few specimens are moderate to good.

World Stratigraphic Range: Late Albian.

Tanzania Range: Sample TDP40 Hole B; Core 2/2, 1-25 cm, (3.1 m).

***Orithostella* sp.**

Plate 3.22 figs. 5a-c

Type reference: *Orithostella* Eicher, and Worstell, 1970, *Micropalaeontology* 16, p. 295.

Description: Test is trochospiral, biconvex to flat, with 9- chambers in the final whorl; sutures on the dorsal side are radial and chambers are seen protruding along the narrow umbilicus which has a small boss, and the umbilicus is covered completely with an apertural flap, extended from the chambers to the umbilicus; test outline is subangular, wall calcareous, finely perforate, aperture a narrow equatorial arch.

Remarks: Specimens of *Orithostella* are rare in the present study. It differs from *Lingulogavelinella* by the presence of the umbilical boss in the umbilicus and protrusions of the chambers along the narrow umbilicus. *Lingulogavelinella* has a star-like shape in the umbilical region. This specimen is rare and preservation is poor to moderate.

World Stratigraphic Range: Albian - Turonian.

Tanzania Range: Sample TDP40 Hole B; Core 5/1, 1-25, (8.1 m).

3.8 15 Family SIPHOGENERINOIDIDAE Saidova, 1981

Genus *Orthokarstenia* Dietrich, 1935

***Orthokarstenia* aff. *shastaensis* Dailey**

Plate 3.22, figs. 6a-c

Type reference: *Orthokarstenia shastaensis* Dailey, 1970. *Contribution Cushman Foundation foramin. Res*., 21, p. 107, pl. 12, fig. 8.

Description: Test is elongate, triserial in the initial stage and later biserial; chambers are more or less cylindrical, inflated in the uniserial stage. Sutures are depressed and overlapping with a crown-like cap separating chambers, wall calcareous and perforate, and aperture terminal at the end of the short neck, chambers increasing moderately in size as added, wall calcareous perforate smooth to slightly rough.

Remarks: This specimen is rare in the studied interval and preservation varies from moderate to good (see Table 4.6). This specimen closely resembles to specimen described by Bolli and others (1994) although the Tanzanian form has few chambers thatare possibly a juvenile form.

World Stratigraphic Range: Barremian - Cenomanian.

Tanzania Range: Sample Kizimbani-1 Hole; (67.1 m).

Genus *Palmula* Lea, 1833

***Palmula* sp.**

Plate 3.22, figs. 7a-b

Type reference: *Palmula* Lea, 1833, *Contributions to geology*, p. 219.

Description: Specimens of *Palmula* identified in the present study; test is flat, elongate test, planispirally coiled in the early chambers and straight uniserially arranged with inverted v-shaped sutures and broader in the later chambers, parallel sides and test outline is rounded. Surface of the test is smooth, calcareous with a terminal aperture.

Remarks: This specimen is rare in the studied interval and preservation is poor.

World Stratigraphic Range: Tertiary to Neogene; hence it is unusual that it occurs in the mid-Cretaceous of Tanzania. It may be a contaminant.

Tanzania Range: Sample TDP40 Hole B; Core 13 / 1, 1-25 cm, (29.1).

3.8.16 Family PATELLINIDAE Rhumbler, 1906

Genus *Patellina* Williamson, 1858

***Patellina subcretacea* Cushman and Alexander**

Plate 3.23 figs. 1a-c

Type reference: *Patellina subcretacea* Cushman and Alexander 1930, *Contrib. Cushman*

Lab. Foraminifera Research, 6, p. 10, pl. 3, fig. 1.

Description: Test shape is conical, planoconvex, chambers are visible on the spiral side, only the final pair is visible on the umbilical side, The earlier chamber is followed by coiled a tubular chamber, one to three whorls per single growth, wall calcareous. Two to three chambers in the last whorl.

Remarks: This specimen is similar to specimen described by Bolli, and others, (1994) and is rare with poor to moderate preservation.

World Stratigraphic Range: Barremian - Early Cenomanian.

Tanzania Range: Sample TDP40 Hole B; Core 10/1, 1-25 cm, (20.1 m).

3.8.17 Family PLEUROSTOMELLIDAE Reuss, 1860

Genus *Pleurostomella* Reuss, 1860

***Pleurostomella* sp. 1**

Plate 3.23, fig. 3a-b

Type reference: *Pleurostomella Reuss*, A. E. 1860, Die Foraminiferen der Westphalischen *Kreideformation, Sitzungsberichte der K. Akademie derWissenschaften in Wien, Mathematisch - Naturwissenschaftliche Classe* 40, p. 147-238.

Description: Test is broad, elongate, with smooth, finely perforate calcareous, initial chambers arranged biserially but alternating in the two opposite sides and the later chamber is uniserial. Aperture is at the end of the uniserial chamber and is terminal and slit like shape and covered by teeth which are triangular in shape at two opposite sides. Sutures are curved obliquely while below the uniserial chamber is horizontal and flushed.

Remarks: Specimens of *Pleurostomella* are very rare in the studied interval and preservation varies from poor to moderate with few specimens who are moderate to good (see tables 4.6 and 4.1-5.2).

World Stratigraphic Range: Aptian - Holocene.

Tanzania Range: Sample Luhoi-1 Hole; Core 53/1, 60-70 cm, (273 m).

***Pleurostomella* aff. *obtusa* Berthelin**

Plate 3.23, figs. 2a-b

Type reference: *Pleurostomella obtusa* Berthelin, 1880, *Mémoire sur les Foraminiféres*, p. 9, pl. 1, fig. 9 a-b.

Description: Test; straight, elongate, with a smooth surface; chambers are broader, convex, and trapezoidal in shape and are five in total alternating in arrangements. Chambers increase rapidly in size as added and initial chamber is round, sutures are curved slight oblique, last chamber is slightly higher and pointed at the top than the rest. Aperture is terminal and infilled other structures like a bifid tooth which *Pleurostomella* usually has are not visible.

Remarks: It differs from *Pleurostomella reussi* by its convex chambers and it's slightly obliquely curved sutures. Specimen of this species is rare and preservation is poor to moderate.

World Stratigraphic Range: Late Albian - early Turonian.

Tanzania Range: Sample Songo Songo-4 Hole; (1707 m).

Genus: *Psilocitherella* Loeblich and Tappan, 1986

***Psilocitherella* aff. *arguta* Reuss**

Plate 3.23, figs. 4a-c

Type reference: *Vaginulina arguta* Reuss, 1860: 202, pl. 8 (fig. 4); 1863: 47, pl. 3 (fig. 13a-b).

Description: Test is flat, lenticular, rectangular in cross section, chambers are slightly broader and distinct proloculus, sutures are flushed, periphery ribs are seen on each side of the test, triangular in peripheral outline; aperture terminal, marginal above the last chamber.

Remarks: Specimen of *Psilocitherella* is rare in the studied interval and preservation varies from moderate to good. *Psilocitherella arguta* identified from Tanzania material is similar to species described by Macmillan (2003).

World Stratigraphic Range: It ranges from Valanginian-Cenomanian, but common in the Late Aptian-Cenomanian intervals (Macmillan, 2003).

Tanzania Range: Sample TDP40A Hole; Core 5/2, 65-90 cm, (10 m).

Genus *Psilocitherella* Loeblich and Tappan, 1986

***Psilocitherella* sp.**

Plate 3.23, figs. 5a-c

Type reference: *Psilocytherella* Loeblich, and Tappan, 1986, *Transactions of the American Microscopical Society* 105, p. 246.

Description: *Psilocitherella* species encountered in the present study; test is oval shape; flattened on both sides of the test with a globular earlier chamber (proloculus); followed by a single and broader chamber; no further partitioning of chambers was seen. Test is calcareous; smooth with no test ornamentation and aperture at an angle on the dorsal area near the periphery margin.

Remarks: Possibly a juvenile form of *Psilocitherella*; specimens can be differentiated from specimens of *Citharina* in their smooth test rather than striations or costate ornamentations. Specimens of *Psilocitherella* are rare in the studied interval and vary in preservation from poor to moderate and few with moderate to good (see tables (4.6 and 5.1).

World Stratigraphic Range: Plienbachian - Cenomanian.

Tanzania Range: Sample TDP40 Hole A; Core 5/2, 65-90 cm, (10 m).

3.8.18 Family PSAMMOSPHAERIDAE Haeckel, 1894

Genus *Psammosphaera* Schlutze, 1875

***Psammosphaera* sp.**

Plate 3.23, figs. 6a-b

Type reference: *Psammosphaera* Schlutze 1875, *Jahresberichte Kommission zur Untersuchung der Deutschen Meer in Kiel fur die Jahr* 1872, 1873, p. 13.

Description: Test is spherical, a single chamber is visible, wall with large quartz grain mixed with finer grains, not seen any kind of arrangement of chambers. Aperture not well defined but seen two pores.

Remarks: The specimens of *Psammosphaera* are rare to common in the studied interval with poor to moderate preservation (see table 4.5).

World Stratigraphic Range: ?Middle Ordovician - Recent.

Tanzania Range: Sample Songo Songo-4 Hole; Core 1 / 1, 16-30 cm (1826 m).

Genus *Pseudogaudryinella* Cushman, 1936

***Pseudogaudryinella* sp.**

Plate 3.23 fig. 7

Type reference: *Pseudogaudryinella* Cushman, 1936, Special *Publications Cushman Laboratory for Foraminiferal Research* 6, p. 23.

Description: *Pseudogaudryinella* species from the present study; slender and elongate, the initial chambers are triserial arranged, triangular in cross section followed by a single biserial chamber and later chamber is uniserial and spherical in cross section; aperture is at the last chamber and is round and terminal.

Remarks: Specimens of *Pseudogaudryinella* are rare to frequent in the studied interval and preservation is poor to moderate and moderate to good in few specimens (see table 4.6). *Pseudogaudryinella* differs from *Tritaxia* by having its biserial stage at the second level between triserial and uniserial and can be distinguished from *Gaudryina* due to its last stage as uniserial form.

World Stratigraphic Range: Normally are found in the upper Cretaceous but also have been reported in the Albian section of many areas worldwide (Bolli and others, 1994).

Tanzania Range: Sample TDP40 Hole B; Core 7/ 2, 1-25 cm, (15.1 m).

Pseudonodosaria* aff. *mutabilis (Reuss)

Plate 3.24, figs. 1a-c

Type reference: *Glandulina mutabilis* (Reuss), 1863, p. 58, pl. 5, figs. 7-11.

Description: Specimen of *pseudonodosaria mutabilis* identified in the present study is cylindrical in shape, chambers are uniserial, and a total of five chambers; the two earlier chambers are tightly appressed while the preceding chambers enlarge in size rapidly and are separated by septal sutures which runs horizontal to the base of each chamber. In general chambers are globular and aperture is round and terminal and surrounded with radiating slits.

Remarks: Specimen of *Pseudonodosaria* aff. *Mutabilis* is rare and preservation is poor to moderate and closely resembles to *Pseudonodosaria mutabilis* described by Bolli and others (1994).

World Stratigraphic Range: Barremian to Aptian.

Tanzania Range: Smple TDP40 Hole A; Core 10/3, 88-12 cm, (23 m).

Reophax sp. aff. _scorpiurus_ (Montfort)

Plate 3.24, figs. 2a-b and figs. 3a-b

Type reference: *Reophax scorpiurus* Montfort 1808, *Conchyliologie systématique et classification méthodique des coquilles,* Paris, F. Schoell, 1, p. 331, text-fig. on p. 330.

Description: Test is rectilinear; three chambers which are uniserial arranged and increase in size rapidly as added with tightly constricted sutural neck, chambers are pyriform in shape final chamber is broader and longer than the rest. Aperture is round, terminal and produced in a short neck at the end of the final chamber. The second specimen possesses only two chambers and probably other chambers are broken; chambers increases in size.

Remarks: These specimens closely resemble *R. scorpiurus* illustrated in Bolli and others, (1994). These specimens are rare and preservation is poor to moderate.

World Stratigraphic Range: Early Cretaceous - Recent.

Tanzania Range: Sample TDP40 Hole A; Core 5/3, 30-40 cm (10.4 m).

Genus *Reophax* Montfort, 1808

Reophax sp. 1

Plate 3.24, figs. 4a-c

Type reference: *Reophax* de Montfort, 1808. l, v. 1, p. 331, text-fig. on 33 p.

Description: Test is slightly elongate, rectilinear, with three uniserial arranged globular chambers; increasing irregularly in size as added, each chamber is connected to the next one through an apertural neck at the base of each chamber; wall coarsely agglutinated, aperture round terminal at the end of the last chamber; presence of constricted sutural neck at the base of each chambers.

Remarks: Varieties of specimens of *Reophax* are present within the studied interval, but identification to species level is difficult. The specimen is rare and poor preserved.

World Stratigraphic Range: Middle Ordovician–Holocene.

Tanzania Range: Sample TDP40 Hole B; Core 6/3, 1-32 cm, (13.2 m).

Reophax sp. 2

Plate 3.24, figs. 5a-c

Type reference: *Reophax* de Montfort, 1808. *Conchyliologie* v. 1, p. 331, text-fig. on p. 33.

Description: Test is rectilinear to slightly curved, with three uniserial arranged chambers, coarsely agglutinated, chamber shape is pyriform to globular increasing slowly as added, and aperture is terminal at the end of the last chamber. Suture below each chamber is slightly constricted.

Remarks: This species slightly resembles *Reophax deckeri* described by Zeid (2007). The specimens of *Reophax* sp. 2 vary in abundance from rare to common and preservation varies from poor to moderate.

World Stratigraphic Range: Barremian to late Aptian.

Tanzania Range: Sample TDP40 Hole B; Core 13/1, 1 - 25 cm (29.1 m).

Reophax sp. 3

Plate 3.24, figs. 6a-b

Type reference: *Reophax* de Montfort, 1808, v. 1, p. 331, text-fig. on p. 33.

Description: *Reophax* identified from the studied interval is uniserial, with only two chambers increasing rapidly in size as added; the last chamber shape is pyriform, and initial chamber is globular. Agglutinated materials are medium size grain and horizontal suture at the base of the final chamber is tightly constricted than the *Reophax duplex*.

Aperture is round and terminal on the final chamber close to periphery margin.

Remarks: This species morphologically close to similar species described by Kaminski and others, (1992). But it differs by the high and broader final chamber and an aperture which is not round and terminal as the *Reophax duplex* and as well the initial chamber is globular while *Reophax duplex* is pyriform, higher and broader. Specimens of *Reophax* sp. 3 varies in abundance from rare to frequent and preservation varies from poor to moderate and few specimens with moderate to good (see table 5.2).

World Stratigraphic Range: Barremian - Aptian.

Tanzania Range: Sample TDP40 Hole B; Core 11/2, 1-25 cm (23.3 m).

3.8.19 Family RZEHAKINIDAE Cushman, 1933

Genus *Rzehakina* Cushman, 1927

Rzehakina epigona Rzehak

Plate 3.24, fig. 7

Type reference: *Silica epigona Rzehak*, 1895, Annalen *Naturhistorisches Hofmuseum,* Wien 10, p. 214.

Description: *Rzehakina epigona* test is planispirally coiled similar to millioliids, with an oval outline and flat. Test is agglutinated with fine particles in organic base cement, with three chambers two elongate chambers extending and cover earlier whorl, the wall become thick at the centre. Chambers are added in different planes; aperture is at the terminal end of the last whorl in the periphery margin and is lacking a tooth.

Remarks: This species differs from milliolids by lacking a tooth and arrangements of chambers are different although both are added at different planes. Specimens are rare and preservation is poor to moderate.

World Stratigraphic Range: Cretaceous to Holocene.

Tanzania Range: Sample Luhoi-1 Hole, Core 53/3, 30-40 cm, (274.4 m).

Genus *Saccammina* Carpenter, 1869

Saccammina sp.

Plate 3.25 figs. 1a-b

Type reference: *Saccammina* Carpenter, 1869, *Proceedings of the Royal Society of London* 18, p. 61.

Description: Test; unilocular, single and globular in shape, agglutinated with quartz grains in organic cement, aperture is round terminal produced on a short neck.

Remarks: It differs from specimens of *Lagenammina* by its globular and smooth polished test surface. Specimens of *Saccammina* are rare to frequent and preservation varies from poor to moderate but few from Kizimbani are moderate to good specimens.

World Stratigraphic Range: Silurian - Holocene.

Tanzania Range: Sample Kizimbani-1 Hole; (73.2 m).

Saracenaria triangularis (d'Orbigny)

Plate 3.25, figs. 2a-c

Type reference: *Cristellaria triangularis* d'Orbigny 1840, p. 27, pl. 2, figs. 21, 22.

Description: This species is planispirally coiled in the early stage and rectilinear in the later stage, triangular in cross section, apertural face is broader, with carinate margins, sutures are curved, test surface is calcareous and perforate, aperture terminal radiate at the margin edge of the periphery margin at an angle to the dorsal side.

Remarks: This specimen is rare in the studied sequence but varieties of *Saracenaria* species are present and preservations vary from poor to moderate.

World Stratigraphic Range: Late Albian - Early Eocene.

Tanzania Range: TDP40 Hole A; Core 4/3, 26-50 cm, (7.4 m).

3.8.20 Family SPIROPLECTAMMINIDAE Cushman, 1927

Genus *Spiroplectammina* Cushman 1927

Spiroplectammina sp.

Plate 3.25, figs. 3a-b

Type reference: *Spiroplectammina* Cushman 1927.p.23 *Journal of Foraminiferal Research* 11, p. 98.

Description: Test; biserial, chambers alternating in and flaring in the two sides, with parallel sides, wall agglutinated with calcite material, a single chamber at the base, and an aperture is infilled and obscured due poor preservation.

Remarks: Specimens of *Spiroplectammina* are rare to frequent and preservation varies from poor to moderate few specimens from Kizimbani-1 Hole is moderate to good.

World Stratigraphic Range: Pliensbachian - Maastrichtian

Tanzania Range: Sample Makarawe-1 Hole, (300 m).

3.8.21 Family TRITAXIDAE Plotnikova, 1979

Genus *Tristix* Macfadyen, 1941.

Tristix excavata (Reuss)

Plate 3.25, figs. 4a-b

Type reference: *Rhabdogonium excavatum* Reuss 1863, p. 91, pl. 12, fig. 8.

Description: Test is elongate, uniserial, rectilinear, wall surface is calcareous, smooth, and perforate, aperture is terminal and radiate and produced in a short neck. Sutures are depressed and curved inwardly, chambers increasing moderately in size as added, triangular in cross section.

Remarks: This specimen is similar to the specimen described by Bolli and others, (1994). Specimens of *Tristix excavata* are rare and preservation is poor to moderate and few specimen are moderate to good (see tables 4.2 and 5.2).

World Stratigraphic Range: Late Albian - early Cenomanian (*Thalmanninella. appenninica-Thalmanninella globotruncanoides* Zone).

Tanzania Range: Sample Kizimbani-1 Hole; (46 m).

Genus *Tritaxia* Reuss, 1860

***Tritaxia pyramidata* (Reuss)**

Plate 3.25 figs. 5a-c, Figs. 6a-b and fig. 7

Type reference: *Tritaxia pyramidata* Reuss 1863, p. 32, pl. 1, fig. 9.

Description: Tests; elongate triserial, with a prominent carinates, no uniserial chamber seen in these specimens, wall agglutinated, and apertures are round terminal and centrally in the triserial stage and a slight depression. These species are elongate, triserial throughout, and triangular in cross sections, wall finely agglutinated, apertures are openings at the inner margins of their last chambers and are arch-like shape.

Remarks: Specimens of *Tritaxia pyramidata* are similar to Trinidad specimens described by Bolli and others, (1994). These specimens are rare and preservation varies from poor to moderate.

World Stratigraphic Range: Albian - Cenomanian

Tanzania Range: Samples Kisarawe-1 Hole; (Sp.1; 1823 m), sample TDP40 Hole B; Core 5 /2, 1-25 cm (sp.2; 9.1 m), and sample TDP40 Hole B, Core 2/2, 1-25 cm, (sp.3; 3.1 m) respectively.

3.8.22 Family TROCHAMMINIDAE Schwager, 1877

Genus *Trochammina* Parker & Jones, 1860

***Trochammina* sp.**

Plate 3.25, figs. 8a-b

Type reference: *Trochammina* Parker, and Jones 1860, *Quarterly Journal of the Geological Society of London* 16, p. 304.

Description: Test; trochospiral, chambers on the final whorl increasing fast in size as added, sutures are radial and periphery is round, wall smoothly agglutinated, aperture obscured due to the poor nature of preservation.

Remarks: Variety of specimens of *Trochammina* are rare to abundant but it was difficult to identify to species level and preservation varies from poor to moderate and few specimens from Kizimbani-1 Hole are moderate to good.

World Stratigraphic Range: Carboniferous - Holocene.

Tanzania Range: Luhoi-1 Hole, Core 56/1, 40 - 50 cm, (281.5 m).

3.8.23 Family VERNEUILINIDAE Cushman, 1911

Genus *Verneuilina* d'Orbigny, 1839

***Verneuilina* sp.**

Plate 3.25 figs. 9a-b

Type reference: *Verneuilina* d'Orbigny, 1839, p. 104, Foraminiféres, in Ramon de la Sagra, *Historie physique, politique et naturelle de li ile de Cuba*. Paris: Arthus Bertrand.

Description: This species has a medium elongate test, triserial in the early chambers and triangular in cross section and later biserial, with triangular to round in cross section, test surface is agglutinated, aperture an arch shaped in the inner margin of the last chamber.

Remarks: Specimens of *Verneuilina* are rare in the studied section and preservation vary from poor to moderate to few specimen with moderate to good (see Tables 4.6 and 5.2).

World Stratigraphic Range: Late Triassic - Holocene.

Tanzania Range: Sample Songo Songo-4 Hole; (1707 m).

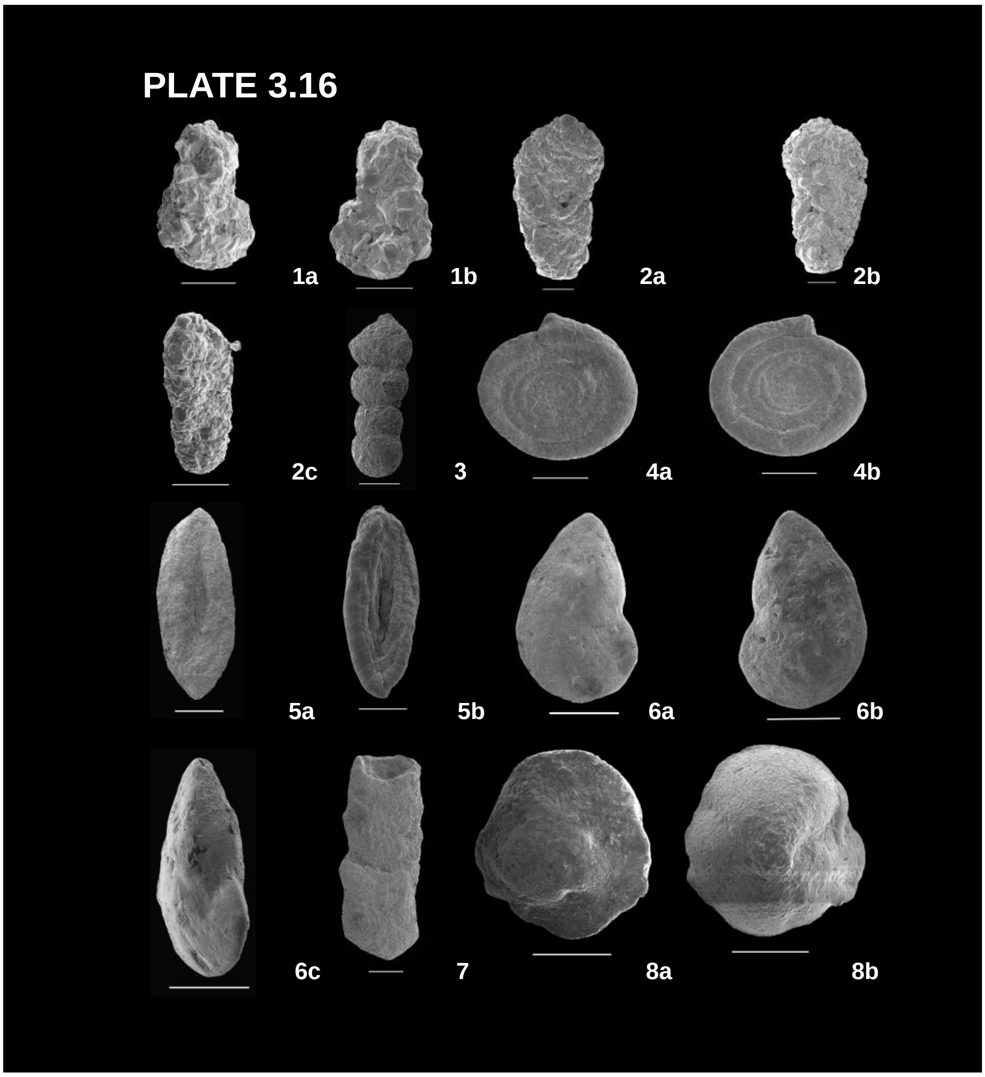


Plate 3.16

Figures 1a-b: *Ammobaculites subcretacea*; Sample TDP40 Hole B, Core 4/3, 1-25 cm, (7.7 m).
Figures 2a-c: *Ammobaculites* sp. 1; Sample TDP40 Hole B, Core 13/1, 1-25 cm, (29.1 m).
Figures 3: *Ammobaculites* sp. 2; Sample TDP40 Hole B, Core 13/1, 1-25 cm, (29.1 m).
Figures 4a-b: *Ammodiscus cretacea*: Sample Luhoi-1 Hole; Core 53/2, 35-45 cm, (273.5 m).
Figures 5a-b: *Ammodiscus* sp.; Sample Songo Songo-4 Hole, Core 3/3, 80-90 cm, (1865.2 m).
Figures 6a-c: *Astacolus* aff. *gratus*; Sample TDP40 Hole A, Core 1/1, 30-58 cm, (0.4 m).
Figure 7: *Bathysiphon* sp.; Sample Kizimbani-1 Hole (213.4 m).
Figures 8a-b: *Conorotalites bartensteini aptiensis*; Sample TDP40 Hole A, Core 5/2, 8-33 cm, (9.2 m).

In each view: a = dorsal, b = ventral, c = apertural. Scale bars views: views a-c or a-b = 200 µm; figs.1, 2, 4, 6 & figs. 8, views; a-b = 500 µm; figs. 3, 5 & fig. 7.

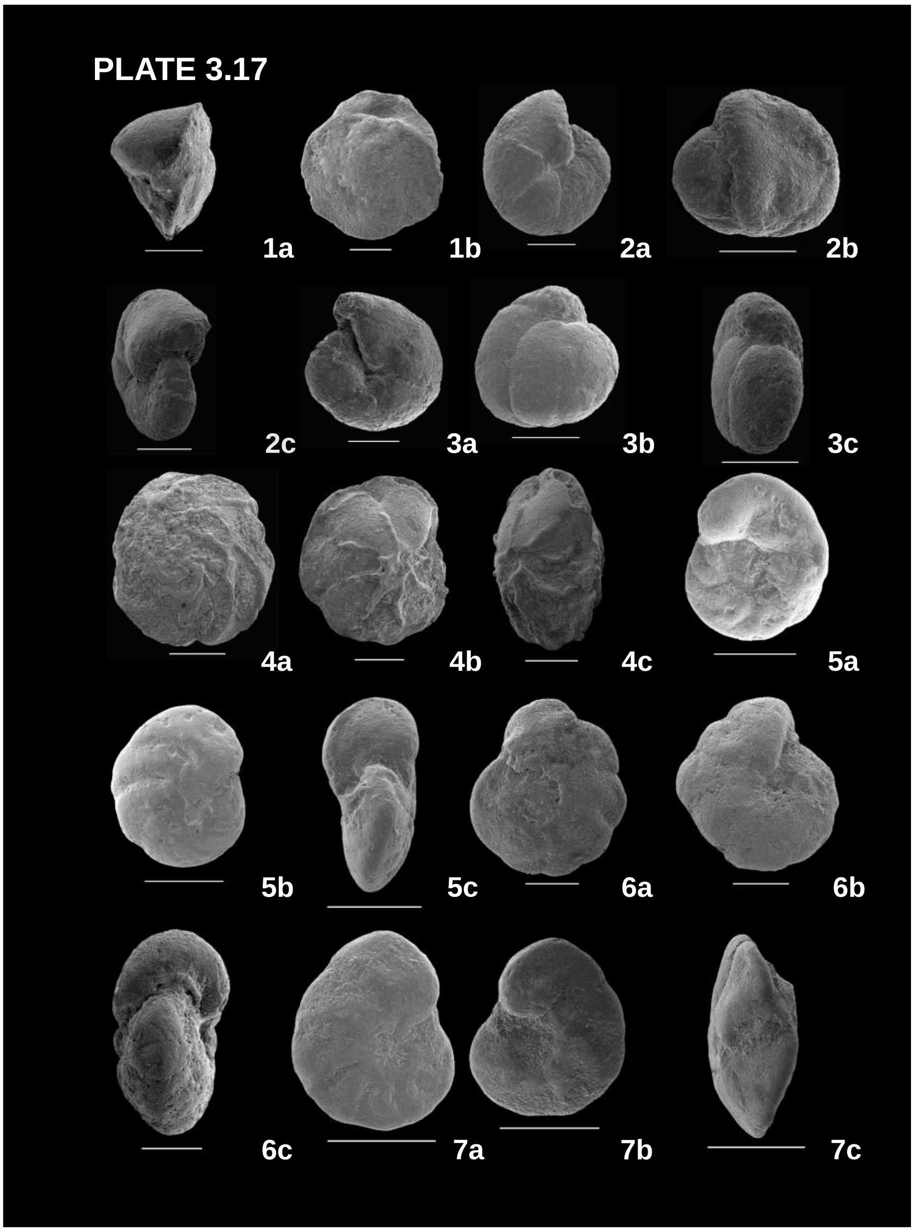


Plate 3.17

Figures 1a-b*: Conorotalites bartensteini aptiensis;* Sample TDP40 Hole A, Core 5/2, 8-33 cm, (9.2 m).
Figures 2a-c: *Cyclammina* sp. 1; Sample Songo Songo-4 Hole, Core 3/3, 80-90 cm, (1865.2 m).
Figures 3a-c: *Cyclammina* sp. 2; Sample Songo Songo -4 Hole, Core 3/1, 40-50 cm, (1861 m).
Figures 4a-c: *Epistomina* aff. *hetchi*; Sample Kizimbani-1 Hole, (82.3 m).
Figures 5a-b: *Gavelinella barremiana;* Sample TDP40 Hole B, Core 18 / 3, 25-50 cm (46.4 m)
Figures 6a-c: *Gavelinella intermedia;* TDP40 Hole B, Core 3/1, 1-25 cm, (5.1 m)
Figures 7a-c: *Gavelinella* sp. 1; Sample Kisarawe-1 Hole, (1823 m).

In each view: a = dorsal, b = ventral, c = apertural. Scale bars views: views a-c or a-b = 200 µm; figs. 1-3, & 7 and views; a-c = 100 µm; figs. 4-6.

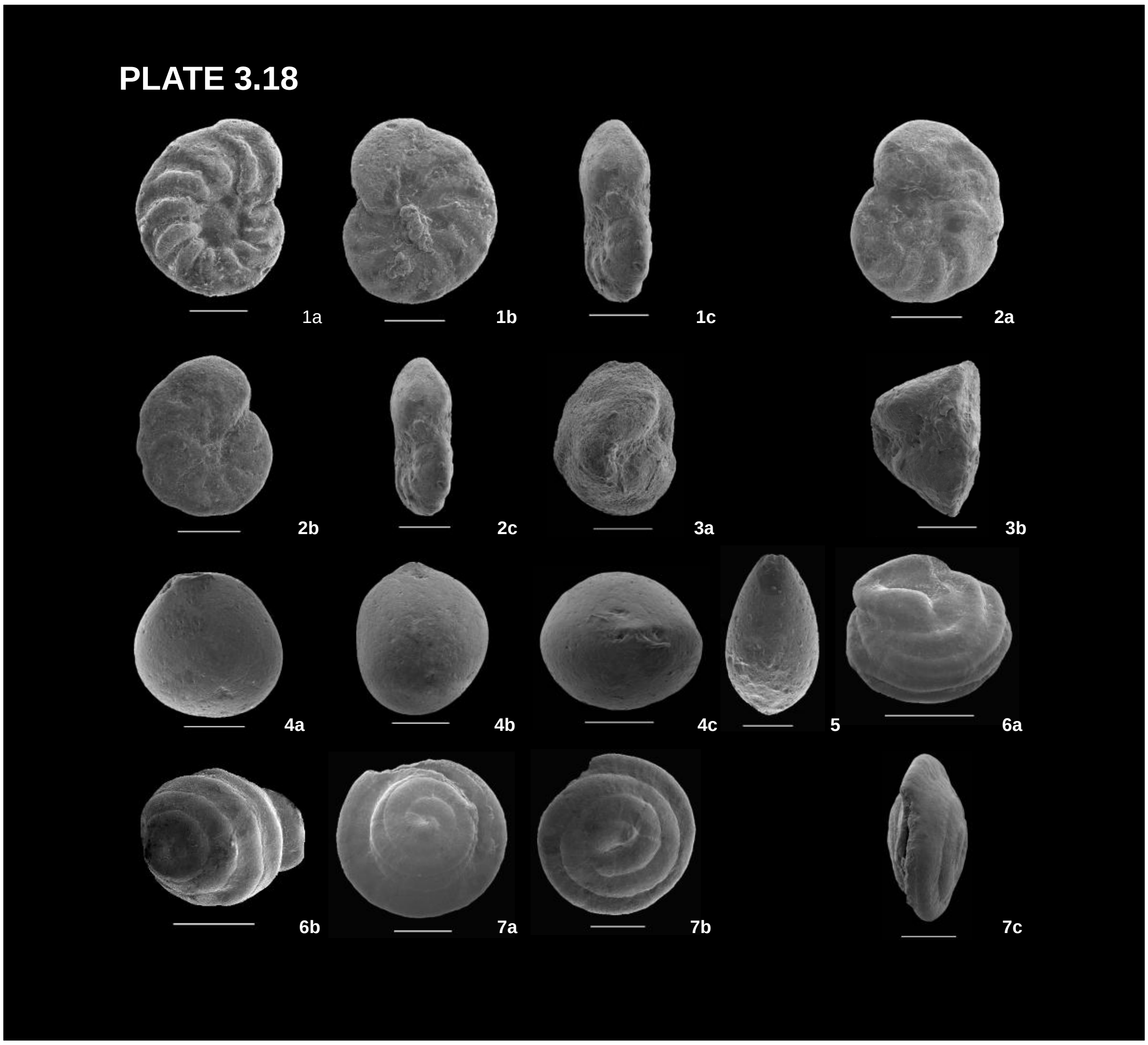


Plate 3.18

Figures 1a-c: *Gavelinella* sp. 2; TDP40 Hole B, Core 5/3, 70-80 cm (8.1m).
Figures 2a-c: *Gavelinella* sp. 3; Sample TDP40 Hole B, Core 5/1, 1-25 cm (10.8 m).
Figures 3a-b: *Globorotalites* sp. Sample TDP 40 Hole A, Core 5/2, 8-33 cm, (9.2 m).
Figures 4a-c: *Globulina* sp. aff. *lacrima lacrima*; Sample Makarawe-1 Hole, (325 m).
Figures 5: *Globulina* sp. aff. *prisca*; Sample Kizimbani-1 Hole, (161.5 m).
Figures 6a-b: *Glomospira charoides;* Sample TDP40 Hole B, Core 6/3, 1-32 cm, (13.2 m).
Figures 7a-c: *Glomospirella* aff. *gaultina*; Sample TDP40 Hole A, Core 2/1, 33-62 cm. (2.5 m).

In each view: a = Spiral, b = umbilical, c = apertural.

Scale bars views: views a-c or a-b = 200 µm; figs. 1-3, 5 & 7, figs. 4 views; a-c = 100 µm and figs. 6; views a-b = 500 µm.

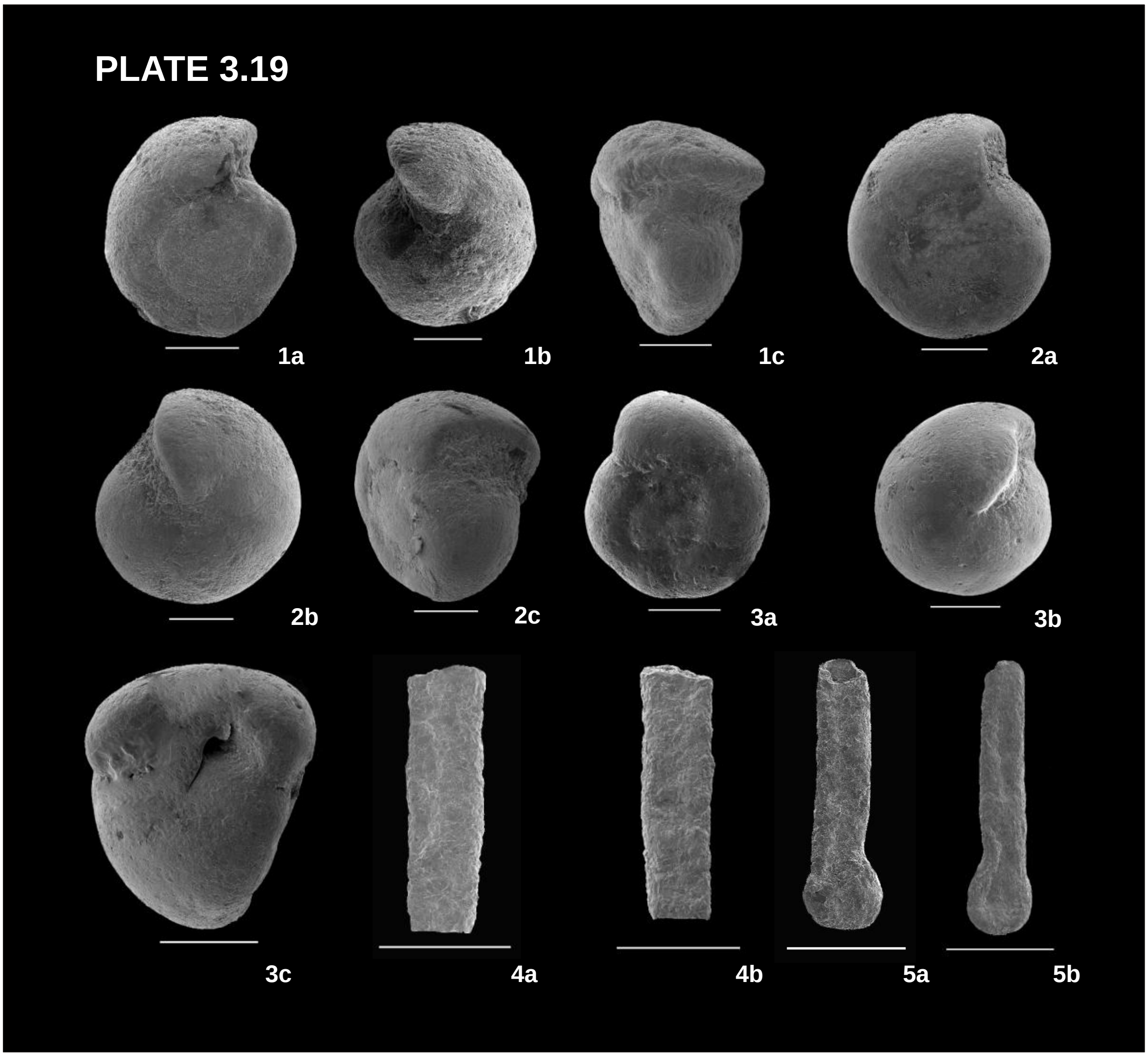


Plate 3.19

Figures 1a-c: *Gyroidinoides* sp. 1; Sample Songo Songo-4 Hole, Core 1/1, 16-30 cm (1826 m).
Figures 2a-c: *Gyroidinoide*s sp.2; Sample Songo Songo-4 Hole; Core 1/2, 30-44 cm (1828 m).
Figures 3a-c: *Gyroidinoides* sp. 3; sample TDP40B Hole; Core 1/1, 40-49 cm, (0.5 m).
Figures 4a-b: *Hyperammina* sp.; Sample Songo Songo-4 Hole, Core 2/3, 20-30 cm (1843.6 m).
Figures 5a-b: *Hyperammina* sp. aff. *gaultina*; Sample Songo Songo-4 Hole, Core 2/3, 20-30 cm (1843.6 m).

In each view: a = Spiral, b = umbilical, c = apertural.
Scale bars views: views a-c =100 µm; figs. 1-3 & figs. 4-5; views a-b = 500 µm.

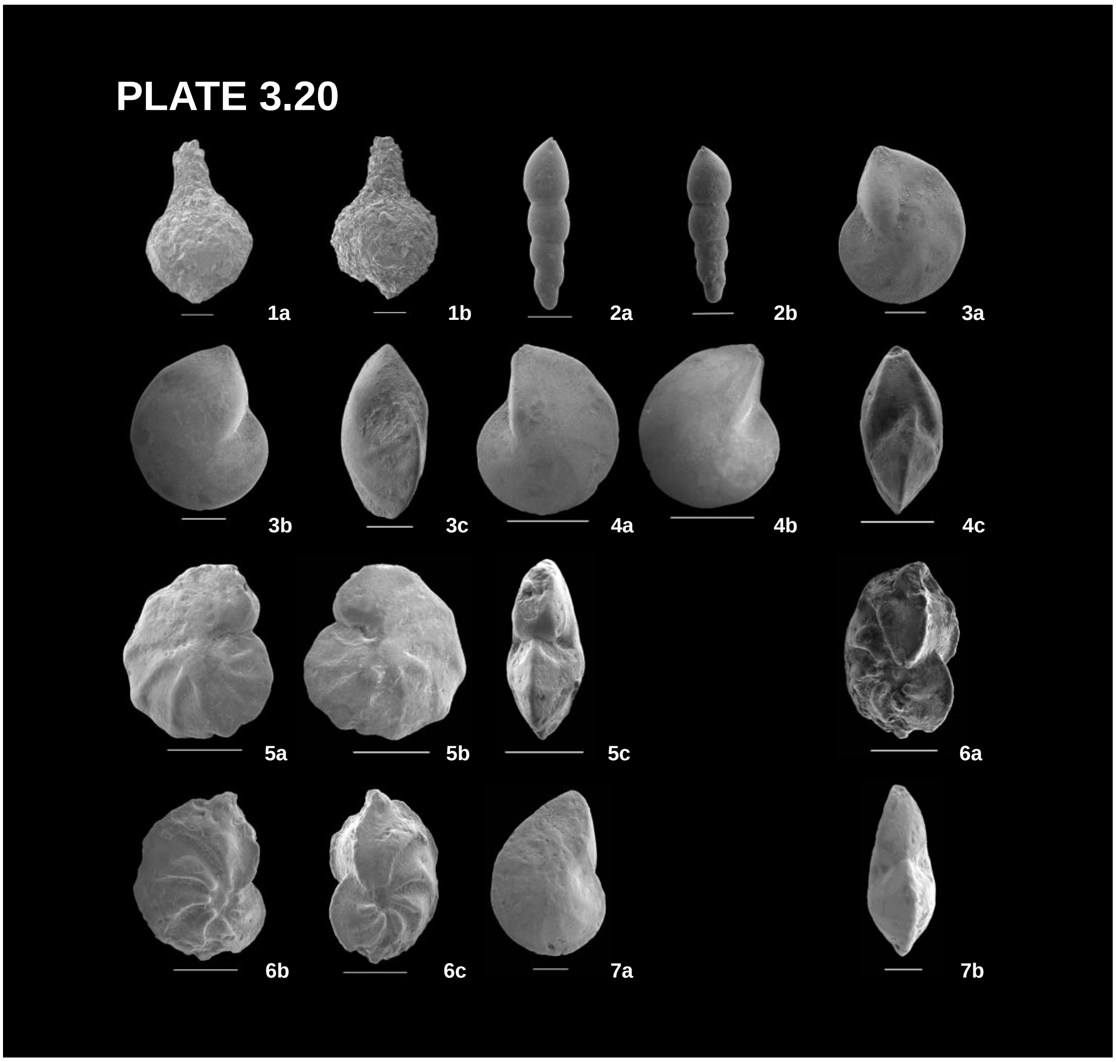


Plate 3.20

Figures 1a-b: *Lagenammina* sp. aff *alexandrei*; Sample TDP40 Hole B, Core 2/2, 1-25 cm, (3.1 m),

Figures 2a-b: *Laevidentalina communis*; Sample TDP40 Hole B, Core 22/2, 1-25 cm, (57.1 m).

Figures 3a-c: *Lenticulina muensteri* (sp. 1); Sample TDP40 Hole B, Core 18/2, 25-50 cm, (45.4 m).

Figures 4a-c: *Lenticulina muensteri* (sp. 2); Sample TDP40 Hole A, Core 18 /3, 29-57 cm, (46.8 m).

Figures 5a-c: *Lenticulina* (*Lenticulina*) *nodosa*; Sample TDP40 Hole A; Core 11/1, 1-25 cm, (23.3 m).

Figures 6a-c: *Lenticulina* (*Lenticulina*) *ouachensis*; Sample TDP40 Hole B, Core 11/2, 1-25 cm, (24.1 m).

Figures 7a-b: *Lenticulina* (*Lenticulina*) *subgaultina*; Sample TDP40 Hole A, Core 19/3, 1-25 cm, (49.5 m).

In each view: a = Spiral, b = umbilical, c = apertural.
Scale bars views: views a-c or a-b = 200 µm; figs.1,3-7 & views a-b = 500 µm; figs. 2.

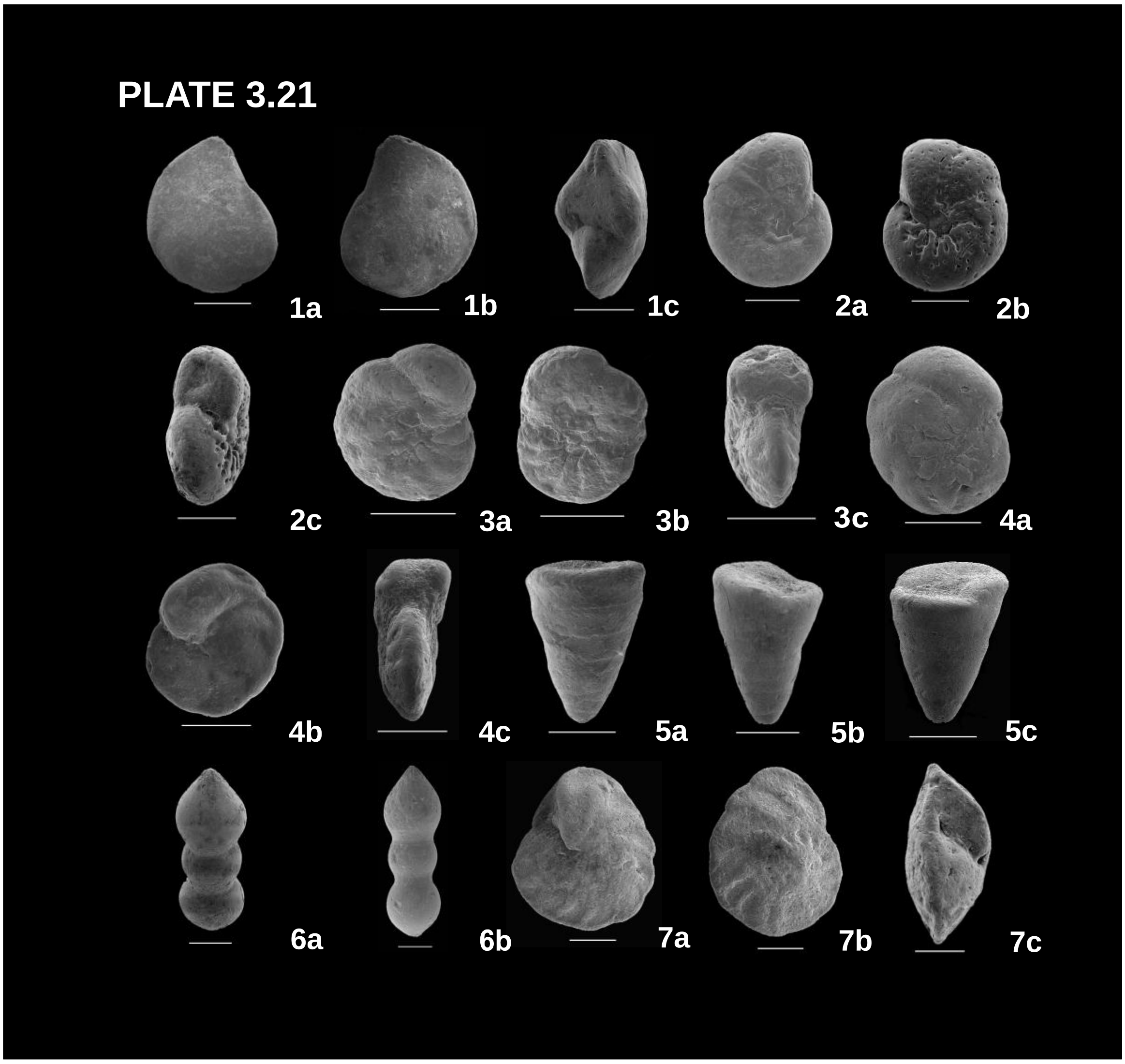


Plate 3.21

Figures 1a-c: *Lenticulina* sp. A; Sample Kizimbani-1 Hole, (146.3 m).
Figures 2a-c: *Lingulogavelinella* sp. aff. *spinosa*; Sample Songo Songo-4 Hole, (1823 m).
Figures 3a-c: *Lingulogavelinella* sp.1; Sample TDP40 Hole A, Core 2/3, 1-25 cm, (4.1 m).
Figures 4a-c: *Lingulogavelinella* sp. 2; Sample Makarawe-1 Hole, (360 m).
Figures 5a-c: *Marssonella oxycona*; Sample Kisarawe-1 Hole, (1762 m).
Figures 6a-b: *Nodosaria* sp.; Sample TDP40 Hole B, Core 6/2, 25-55 cm (12.1 m).
Figures 7a-c: *Osangularia californica*; Sample Songo Songo-4 Hole, (1865.4 m).

In each view: a = Spiral, b = umbilical, c = apertural.
Scale bars views: views a-c = 200 µm; figs. 1, 3-5, views a-b = 500 um; figs 6 and views a-c = 100 µm; figs. 2 & 7.

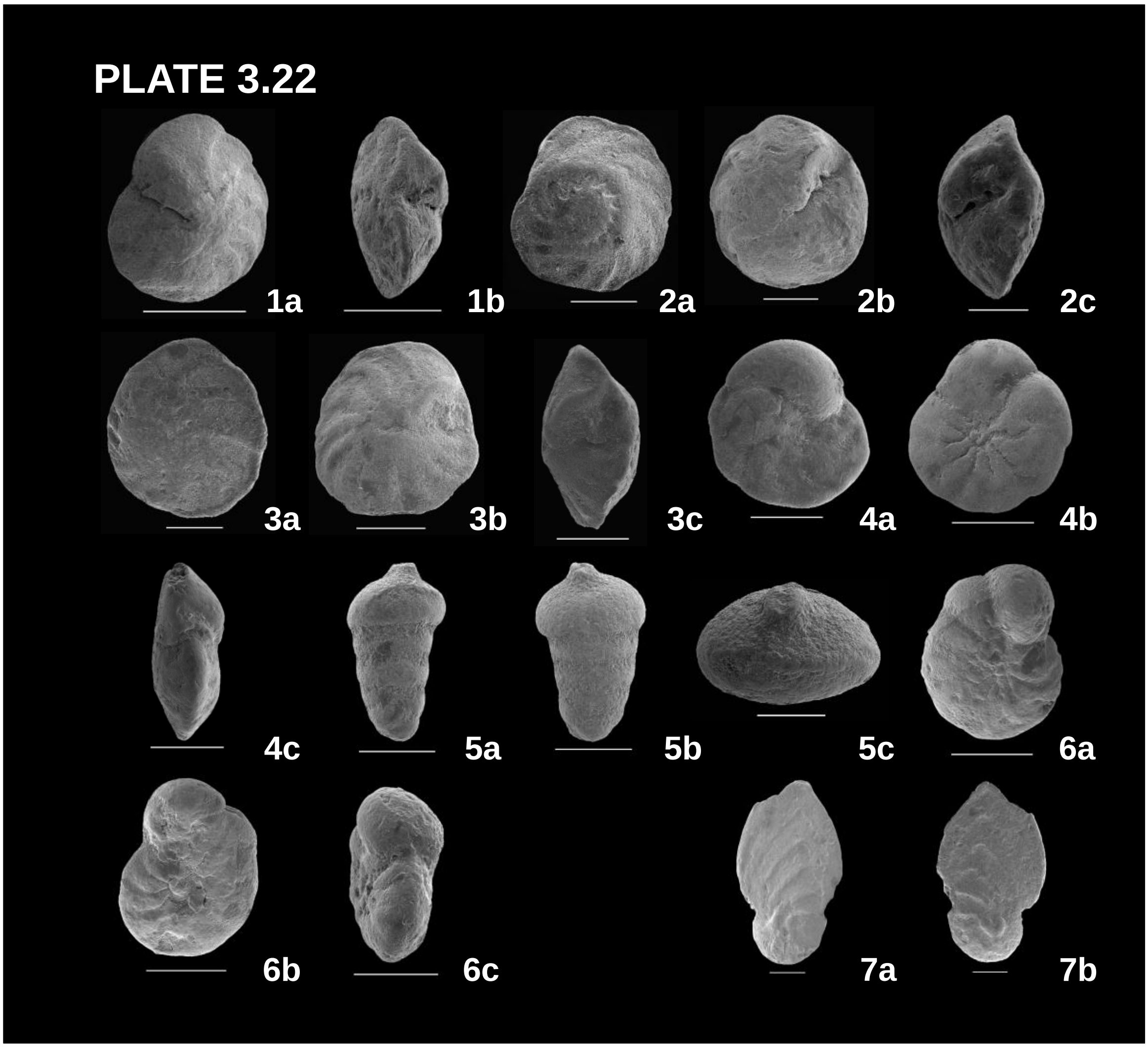


Plate 3.22

Figures 1a-b: *Osangularia* sp. aff. *schloebanchi*; Sample Kizimbani-1 Hole, (55 m).
Figures 2a-c: *Osangularia* sp.; Sample Songo Songo-4 Hole, Core 3/2, 0-14 cm, (1868 m).
Figures 3a-c: *Osangularia* sp. aff. *utaturensis*; Sample Songo Songo-4 Hole, Core 3/3, 80-90 cm, (1865.2 m).
Figures 4a-c: *Orithostella indica*; Sample TDP40 Hole B, Core 2/2, 1-25 cm, (3.1 m).
Figures 5a-c: *Orithostella* sp.; Sample TDP40 Hole B, Core 5/1, 1-25 cm, (8.1 m).
Figures 6a-c: *Orthokarstenia* sp. aff. *shastaensis*; Sample Kizimbani-1 Hole, (67.1 m)
Fgures 7a-b: *Palmula* sp.; SampleTDP40 Hole B, Core 13/1, 1-25 cm, (29.1 m).

In each view: a = Spiral, b = umbilical, c = apertural. Scale bars views: views a-b or a-c = 100 µm; figs. 1-5, and views a-c = 200 µm; figs. 6-7.

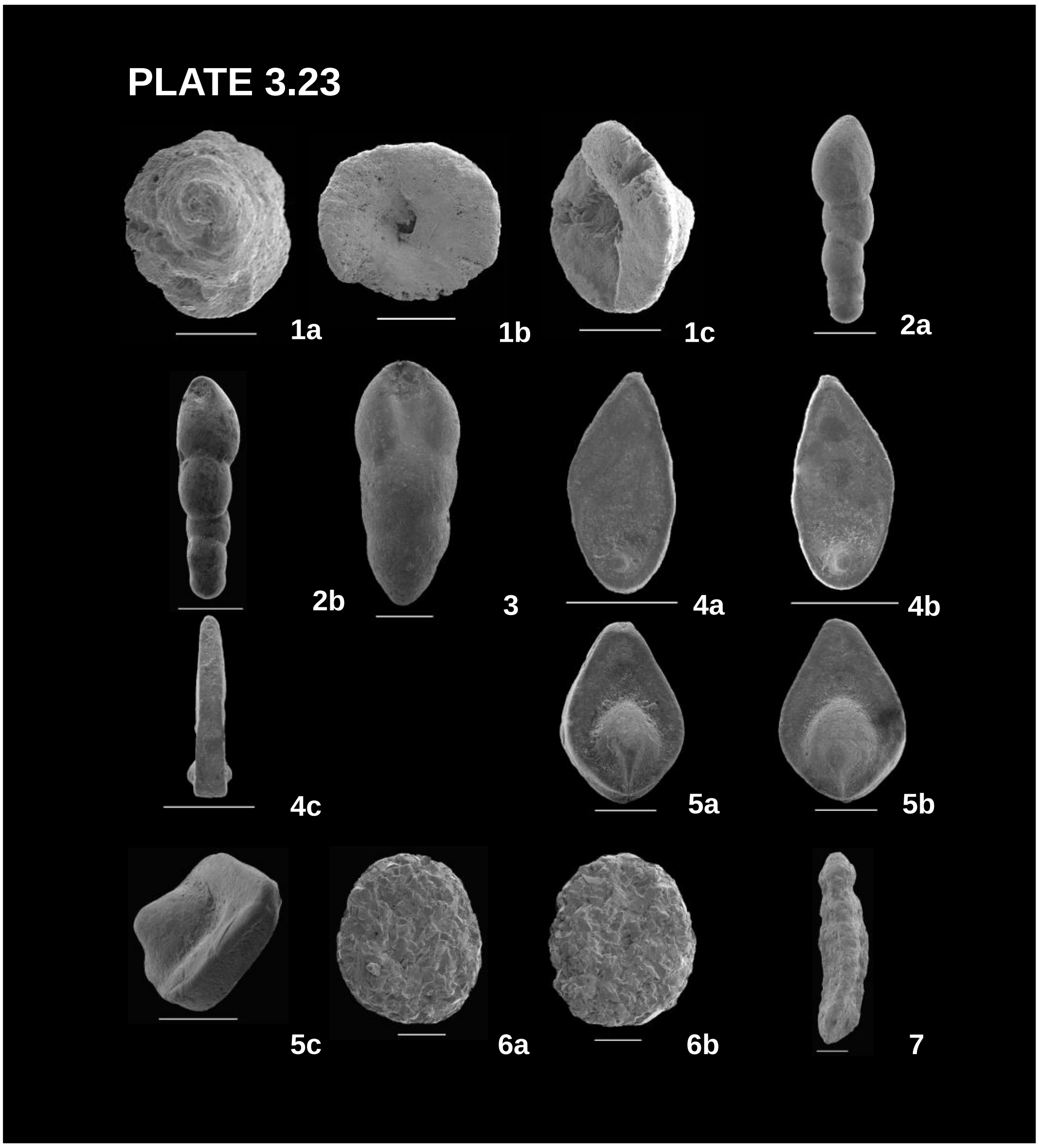


Plate 3.23

Figures 1a-c: *Pattelina* sp. aff. *subcretacea*; Sample TDP40 Hole B, Core 10/1, 1-25cm, (20.1 m).
Figures 2a–b: *Pleurostomella* sp. 1; Sample Luhoi-1 Hole, Core 53/1, 60-70 cm, (272.7 m).
Figures 3a-c: *Pleurostomella* sp. aff. *obtusa*; Sample Songo Songo-4 Hole, (1706.9 m).
Figures 4a-c: *Psilocitherella* sp. aff. *arguta;* Sample TDP40A Hole; Core 5/2, 65-90 cm, (10 m).
Figures 5a-c: *Psilocitherella* sp.; Sample TDP40 Hole A, Core 5/ 2, 65-90 cm, (10 m).
Figures 6a-b: *Psammospheara* sp.; Sample Songo Songo-4 Hole, Core 1/1, 16-30 cm (1826 m).
Figure 7: *Pseudogaudryinella* sp.; Sample TDP40 Hole B, Core 7/2, 1-25 cm, (15.1 m).

In each view: a = Spiral, b = umbilical, c = apertural. Scale bars views: views a-c or a-b = 200 µm; figs. 1, 3-4, views a-b= 500 um; figs. 2, 6 & 7, views a-c=100 um; figs. 5.

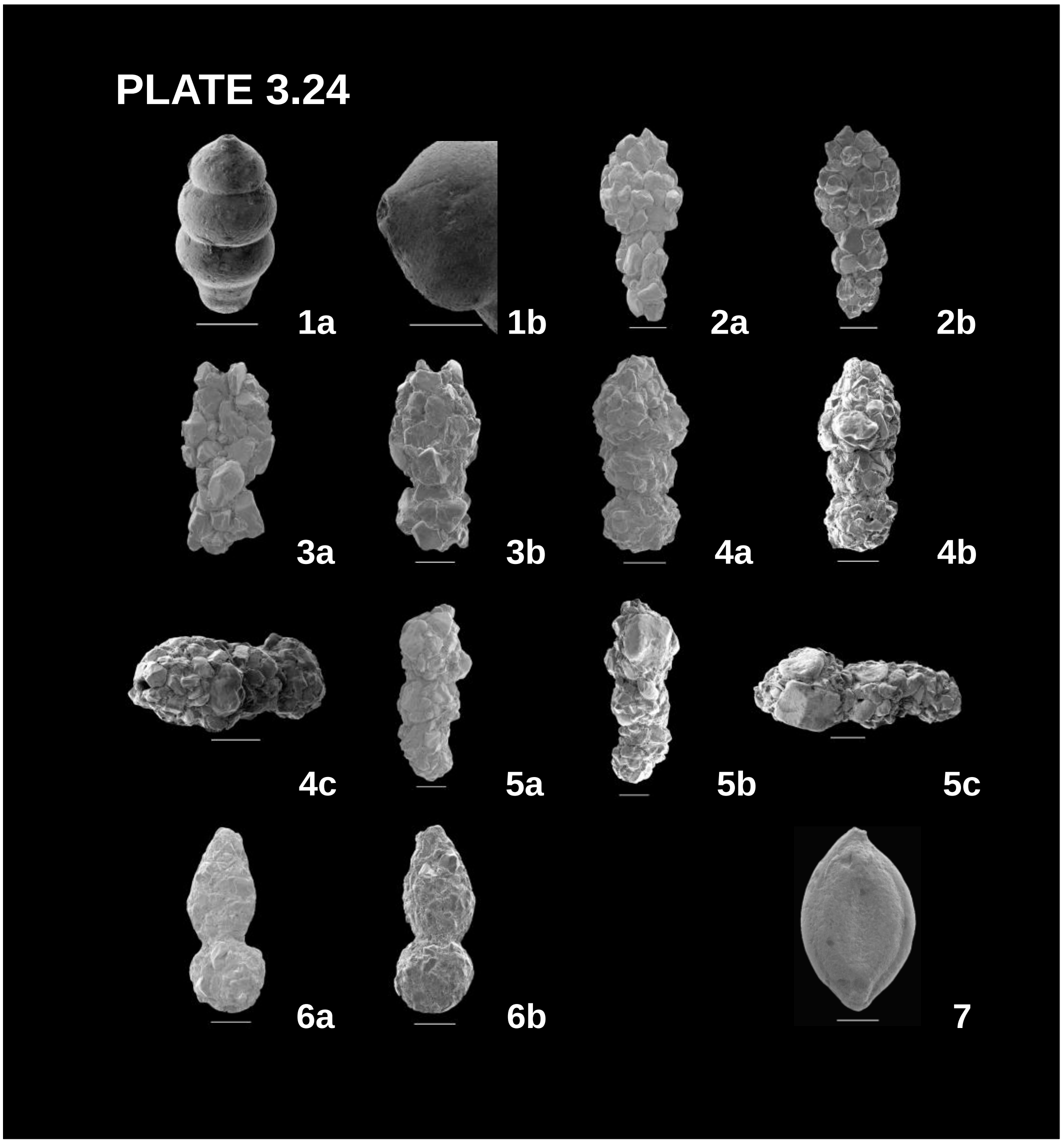


Plate 3.24

Figures 1a-b: *Pseudonodosaria* sp. aff. *mutabilis*; Sample TDP40A, Core 10/3, 88-11 cm (23m).
Figure 2a-b: *Reophax* sp aff *scorpirus*; Sample TDP40 Hole B; 5/3, 30-40 cm, (10.4 m).
Figure 3a-b: *Reophax scorpiurus*; Sample TDP40 Hole B; 5/3, 30-40 cm, (10.4 m).
Figures 4a-c: *Reophx* sp. 1; Sample TDP40 Hole B, Core 6/3, 1-32 cm, (13.2 m).
Figures 5a-c: *Reophax* sp. 2; Sample TDP40 Hole B, Core 13/1, 1-25 cm, (29.1 m).
Figures 6a-b: *Reophax* sp. 3; Sample TDP40 Hole A, Core 11/1, 1-25 cm, (23.3 m
Figure 7: *Rzehakina epigona*; Sample Luhoi-1 Hole, Core 53/3, 30-40 cm, (274.4 m).

In each view: a = Spiral, b = umbilical, c = apertural. Scale bars views: a-c = 100 µm; figs. 1, and views a-b or a-c = 200 µm; figs. 2-7.

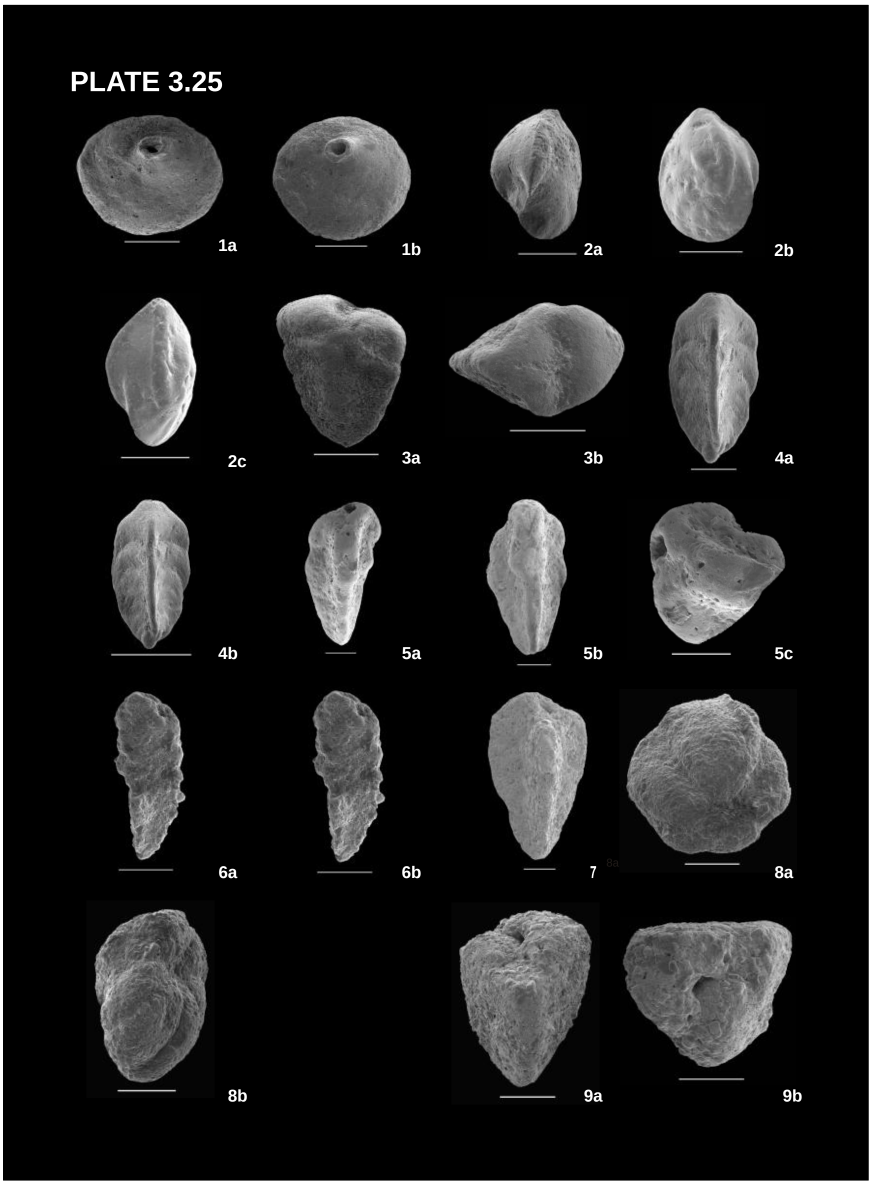


Plate 3.25

Figures 1a-b: *Saccammina* sp; Sample Kizimbani-1 Hole, (73.2 m).
Figures 2a-c: *Saracenaria triangularis*; Sample TDP40 Hole A; Core 4/3, 26-50 cm, (7.4 m).
Figures 3a-b: *Spiroplectammina* sp.; Sample Makarawe-1 Hole, (300 m).
Figures 4a-b: *Tristix excavata*; Sample Kizimbani-1 Hole, (46 m).
Figures 5a-c: *Tritaxia pyramidata* (sp.1); Sample Kisarawe-1 Hole, (1823 m).
Figures 6a-b: *Tritaxia pyramidata* (sp. 2); TDP 40 Hole B, Core 5/2, 1-25 cm, (9.1 m)
Figure 7: *Tritaxia pyramidata* (sp.3); TDP40 Hole B, Core 2/2, 1-25 cm, (3.1 m).
Figures 8a-b: *Trochammina* sp.; Sample Luhoi-1 Hole; Core 56/1, 40-50 cm, (281.5 m).
Figures 9a-b: *Verneulina* sp; Sample Songo Songo-4 Hole, (1706.9 m).

In each view: a = Spiral, b = umbilical, c = apertural.
Scale bars views: a-b or a-c= 200 µm, figs 1-8, and views a-b = 500 µm; figs. 9.

List of benthic foraminifera species cited in the text in alphabetic order.

Ammobaculites subcretacea (Cushman and Alexander, 1930)	Plate 3.16, figs. 1a-b
Ammobaculites sp. 1	Plate 3.16, figs. 2a-c
Ammobaculites sp. 2	Plate 3.16, fig. 3
Ammodiscus cretacea (Reuss, 1987a)	Plate 3.16, figs.4a-b
Ammodiscus Reuss, 1862	Plate 3.16, figs. 5a-b
Astacolus aff. *gratus* (Reuss, 1863)	Plate 3.16, figs. 6a-c
Bathysiphon M. Sars, 1872	Plate 3.16, fig. 7
Conorotalites bartensteini aptiensis (Bettenstaedt, 1952)	Plate 3.16, figs 8a-b
Conorotalites bartensteini aptiensis (Bettenstaedt, 1952*)*	Plate 3.17, figs 1a-b
Cyclammina sp. 1	Plate 3.17, figs. 2a-c
? Cyclammina sp. 2	Plate 3.17, figs. 3a-c
Epistomina aff. *hetchi* (Bartenstein, Bettenstaedt and Bolli, 1957)	Plate 3.17, figs. 4a-c
Gavelinella barremiana (Bettenstaedt, 1952)	Plate 3.17, figs. 5a-c
Gavelinella intermedia (sp. 2) (Berthelin, 1880)	Plate 3.17 figs. 6a-c
Gavelinella sp. 1	Plate 3.17, figs. 7a-c
Gavelinella sp. 2	Plate 3.18, figs. 1a-c
Gavelinella sp. 3	Plate 3.18, figs. 2a-c
Globorotalites sp.	Plate 3.18, figs. 3a-c
Globulina sp. aff. *lacrima lacrima* (Reuss, 1845)	Plate 3.18, figs. 4a-c
Globulina aff. *prisca* (Reuss, 1863)	Plate 3.18, figs. 5a-c
Glomospira charoides (Berthelin, 1880)	Plate 3.18, figs. 6a-c
Glomospirella sp. aff. *gaultina* (Berthelin, 1880)	Plate 3.18, figs. 7a-c
Gyroidinoides sp. 1	Plate 3.19, figs. 1a-c
Gyroidinoides sp. 2	Plate 3.19, figs. 2a-c
Gyroidinoides sp. 3	Plates 3.19, figs. 3a-c
Hyperammina Brady, 1878	Plate 3.19, figs. 4a-b
Hyperammina sp. aff. *gaultina* (Berthelin, 1880)	Plate 3.19, figs. 5a-b
Lagenammina aff. alexanderi (Loeblich and Tappan, 1950)	Plate 3.20, figs. 1a-b
Laevidentalina communis (d'Orbigny, 1826)	Plate 3.20, figs. 2a-b
Lenticulina muensteri (Roemer, 1839)	Plate 3.20, figs. 3a-c
Lenticulina muensteri (Roemer, 1839)	Plate 3.20, figs. 4a-c
Lenticulina (Lenticulina) nodosa (Reuss, 1863)	Plate 3.20 figs. 5a-c
Lenticulina (Lenticulina) ouachensis (Sigal, 1952)	Plate 3.20, figs. 6a-c
Lenticulina (Lenticulina) subgaultina (Bartenstein,	Plate 3.20 figs. 7a-c
Lenticulina sp. A	Plate 3.21, figs. 1a-c
Lingulogavelinella sp. aff. *spinosa* (sp. 1)	Plate 3.21, figs. 2a-c
Lingulogavelinella sp. 1	Plate 3.21, figs. 3a -c
Lingulogavelinella sp. 2	Plate 3.21, figs. 4a-c
Marssonella oxycona (Reuss, 1860)	Plate 3.21, figs. 5a-c

Nodosaria (Lamarck, 1812)	Plate 3.21, figs. 6a-c
Osangularia californica (Dailey, 1970)	Plate 3.21, figs. 7a-c
Osangularia aff. *schloebanchi* (Brotzen, 1940)	Plate 3.22, figs. 1a-c
Osangularia Brotzen, 1940	Plate 3.22, figs. 2a-c
Osangularia. aff. *utaturensis* (Sastry and Sastri, 1966)	Plate 3.22, figs. 3a-c
Orithostella indica (Sastri and Sastry, 1966)	Plate 3.22, figs. 4a-c
Orithostella sp. 2	Plate 3.22, figs. 5a-c
Orthokarstenia aff. *shastaensis* (Dailey, 1970)	Plate 3.22, figs. 6a-c
Palmula Lea, 1833	Plate 3.22, figs. 7a-b
Patellina subcretacea (Cushman and Alexander, 1930)	Plate 3.23 figs. 1a-c
Pleurostomella sp. 1	Plate 3.23 figs. 2a-b
Pleurostomella sp. aff. *obtusa* (Berthelin, 1880)	Plate 3.23 figs. 3a-c
Psilocitherella sp. aff. *arguta* (Reuss, 1860)	Plate 3.23 figs. 4a-c
Psilocitherella Loeblich and Tappan, 1986	Plate 3.23 figs. 5a-c
Psammosphaera Schlutze, 1875	Plate 3.23 figs. 6a-b
Pseudogaudryinella Cushman, 1936	Plate 3.23 figs. 7
Pseudonodosaria aff. *mutabilis* (Reuss, 1863)	Plate 3.24, figs. 1a-b
Reophax sp. aff. *scorpiurus* (Montfort, 1808)	Plate 3.24, figs. 2a-b
Reophax sp. aff. *scorpiurus* (Montfort, 1808)	Plate 3.24, figs. 3a-d
Reophax sp. 1	Plate 3.24, figs. 4a-c
Reophax sp. 2	Plate 3.24, figs. 5a-c
Reophax sp. 3	Plate 3.24, figs. 6a-c
Rzehakina epigona (Rzehak, 1895)	Plate 3.24, figs. 7
Saccammina Carpenter, 1869	Plate 3.25 figs. 1a-b
Saracenaria triangularis (d'Orbiny, 1840)	Plate 3.25 figs. 2a-b
Spiroplectammina Cushman, 1927	Plate 3.25 figs. 3a-c
Tristix excavata (Reuss, 1863)	Plate 3.25 figs. 4a-b
Tritaxia pyrammidata (Reuss, 1863)	Plate 3.25 figs. 5a-b
Tritaxia pyrammidata (Reuss, 1863)	Plate 3.25 figs. 6a-b & 7
Trochammina Parker and Joes, 1860	Plate 3.25 figs. 8a-b
Verneuilina d' Orbigny, 1839	Plate 3.25 figs. 9a-c

Chapter 4 Foraminiferal biostratigraphy and biofacies of the Tanzanian middle Cretaceous from industry boreholes and outcrop samples

4.1 Introduction

Much of the previous work on early to mid-Cretaceous foraminifera from Tanzania coastal basin consists of unpublished well reports by consultants from petroleum industry. This considerable amount of work is mostly confidential and often involves the use of different, sometimes individual, zonations, which have no published records of the biostratigraphical data that were used to construct them. Equally there is very little published data. The early to mid-Cretaceous foraminifera from Tanzania were previously reported by Moore and others (1963) from Msata-Bagamoyo road, Kiwangwa and Lugoba; and by Bate and Bayliss (1969; 1973) in Mandawa anticline, Lindi area and Wami river section. Also major sections have been dated by the micropalaeontological divisions of British Petroleum and others such as; Eames, 1964; Dilley, 1955; 1956; Balduzzi, 1956; 1957; 1974; 1979; Balduzzi and others, 1992; Barnard and Futyan, 1984; Singano & Karega, 2003; Karega , 1992; 1995; Karega and Singano; 2003, Van Morkhoven; 1986; Kapilima,1984. Some of these reports are unpublished and some are published. However, detailed biostratigraphic work has yet to be synthesized across the basins and there has been no special focus on the mid-Cretaceous.

The mid-Cretaceous is of a particular interest to the research groups involved in Tanzania Drilling Project (TDP) because the previous investigation that was done before 2009 focused on the younger part of the record (late Cretaceous and Palaeogene), which was designated for Kilwa Group (see Nicholas and others, 2006). Systematic investigation of the underlying strata became a priority as plans to extend the coring into older time intervals were developed.

For the first phase of this research project, a series of six industrial boreholes was selected for detailed study, each of which is known to have exceeded the required time interval. The boreholes (Makarawe-1, Kiwangwa-1, Kisarawe-1, Luhoi-1, Songo Songo-4 and

Kizimbani-1 (see fig. 2.1) lie in a roughly north-south line, that is, along the regional strike, and are separated by approximately 375 km (see figure 2.1). The first three boreholes are broadly within the Ruvu Basin, the fourth in the Rufiji trough, and the fifth and sixth are in Mandawa Basin. The outline litho and biostratigraphy of all these boreholes are documented in their respective completion reports, available from the Tanzania Petroleum Development Corporation (see table 4).

In this chapter, results of detailed foraminiferal biostratigraphy (both planktonic and benthic) are reported from six boreholes (Makarawe-1, Kiwangwa-1, Kisarawe-1, Luhoi-1, Songo Songo-4, and Kizimbani-1) and outcrops. The boreholes were drilled and outcrops sampled in the mid-cretaceous sequence which is the focus of this research. Only the late Aptian to Cenomanian of Kisarawe-1, Makarawe-1, Kiwangwa-1, Songo Songo-4, Kizimbani-1 and Luhoi-1 and outcrops are described here. The studied mid-cretaceous sequence consists of: marls, clays, clay stones, shale, calcareous sandstones, and lime-mudstones (see graphic logs: figures 4.2 to 4.7). In total, twelve zones and two subzones of planktonic foraminiferal biozones have been established in the studied interval (Figure 3.3). Range charts for all the boreholes have been plotted and are shown in tables 4.2- 4.7. Lithology and Biozones are also indicated on the stratigraphic logs of each borehole (see figures 4.2-4.7). Planktonic: benthic ratios (P/B ratio) are also plotted in their respective stratigraphic well logs (see figures 4.2-4.7). Samples analysed were mostly from well cuttings for all the boreholes studied except for the Songo Songo-4 where both cuttings and cores are availed and Luhoi-1 borehole which was cored. Preservation of foraminifera varies from poor to good. Reworking of older specimens into younger intervals and contamination is noticed throughout especially when the cutting samples are very high.

The aims of this work are:

- ❖ To use modern taxonomic and biostratigraphic criteria (see Chapter 3) to create new distribution range charts and a refined biozonation.
- ❖ To study benthic foraminiferal biofacies and planktonic: benthic (P: B) ratios to determine environmental records for the six boreholes in order to identify episodes of transgression and regression that may have affected the whole area.

- To assess the preservation states of the foraminifera tests to identify intervals with potentially very well-preserved tests that may be suitable for geochemical analysis and palaeoclimatic study.

In addition to the work on the pre-existing boreholes, new field collecting was conducted in 2009 to investigate areas which were reported to have, or to be potential for, mid-Cretaceous outcrop. The following areas were visited: Msanga, Chalinze, Msata, and Mkondaji from which 54 surface samples were studied for foraminifera. These samples were found to belong to a variety of biozones and are of potential use in regional mapping. The results are reported here for completeness.

An additional goal of the work described in this chapter (borehole and outcrop studies) was to help determine a suitable place for a new attempt to drill the Aptian - Albian transition by the Tanzania Drilling Project with continuous core recovery. The results of the drilling (TDP Site 40) form the focus of the following chapter. Results from both the borehole and outcrop work, and the TDP 40 drilling are synthesized in chapter 6.

SEM photographs of stratigraphically important planktonic foraminifera from the various borehole and outcrop samples are illustrated in chapter 3, Plates 3.1 - 3.15. Selected benthic foraminifera are illustrated in chapter 3, Plates 3.16 - 3.25. Some of these species are stratigraphically useful especially in the intervals where there are no planktonic foraminifera. For the first time a consistent and well evidenced taxonomy and biostratigraphy is applied to all the available materials. In this chapter, the boreholes are described in turn (working north to south) and foraminiferal distribution charts are presented together with an updated biostratigraphic zonation. A brief palaeo-environmental interpretation is given. The outcrop samples are briefly included for completeness.

Table 4: Shows the six boreholes studied containing mid-Cretaceous sediments and additional relevant information including unpublished well completion reports available at TPDC office in Dar es Salaam, Tanzania.

Well / Borehole	Location		Samples		Total Sequence drilled	Drilled by/Objectives of drilling	Mid-Cretaceous interval	Date spudded	Date completed	Status	Reports available at TPDC Archive; Dar Es Salaam, Tanzania (Unpublished)
	Latitude	Longitude									
Makarawe-1	5° 33' 09.9" S	38° 52' 11.2" E	cuttings	no cores	Neogene-Triassic (TD 3821 m)	IEDC 1984 drilled to test pre-mid Jurassic Karoo sediments.	35-757 (722 m); Aptian-Cenomanian (marls).	07/08/1984	09/11/1984	Plugged & Abandoned with oil & shows.	Makarawe-1 well, Tanzania, SSI (UK) Ltd, 7 p.
Kiwangwa-1	6° 21' 43" S	38° 32' 56" E	cuttings	no cores	Cenomanian - Triassic(TD 3514 m)	1985/1986 Drilled to test mid-Jurassic and Karoo sequence	Cenomanian; marls, sandstone and shales).	04/09/1985	04/01/1986	Plugged and Abandoned with gas shows.	Haynes, R. C. 1987. Stratigraphy of the Kiwangwa-1 well, 37 p, 3 figs.
Kisarawe-1	7° 00' 19" S	39° 03' 32" E	cuttings	no cores	Quaternary -mid Jurassic (TD-4057 m)	Drilled to test the early Cretaceous and mid-Jurassic reservoirs.	1737-2286 m: (549 m); Late Aptian - Late Cenomanian; shale, limestone and sandstones.	16/03/1976	09/07/1976	Plugged and Abandoned.	SHELL, 1983. (Bio) Stratigraphic review of well Kisarawe-1 & Kisangire-1, SHELL, 5 p, 1. fig. AGIP, 1976. Kisarawe-1, Tanzania, Stratigraphic report, 4 p.
Luhoi-1	7° 51' S	38° 57' E	no cuttings	cores	Recent - Early Cretaceous (TD 296 m)	sedimentology of the subsurface; alsos to investigate the area extent of the Albian-Cenomanian shale encountered in three shallow boreholes east of Wingayongo Hill.	250-296 m (46 m): Late Aptian to Late Albian; sandstones and thin stringers of clays.	26/11/1992	08/02/1993	Plugged and Abandoned with gas shows.	Msindai, J. P. A. 1993. Luhoi-1 Preliminary report, 6 p, 2 text-figs. Karega, A., Msaki, E., 1993. Biostratigraphical report of Luhoi-1 well, Tanzania, 15 p., 2 figures, 1 table and I chart.
Songo Songo-4	8° 31' 01.30" S	39° 29' 30.25" E	cuttings	cores	Eocene - Early Cretacous (TD: 2011 m)	Drilled by TPDC, 1978 as an apprais	1621-1877 m: (256 m); Late Aptian to Turonian (marls and claystones).	03/05/1978	22/08/1978	Gas well	Stratigraphical/ Palaeontological final report of Songo Songo-4. Core Laboratories, UK Limited, 21 p.
Kizimbani-1	09° 02' 25" S	39° 22' 30" E	cuttings	no cores	Albian - Precambrian (TD: 2696 M)	Drilled by TPDC, 1976 to test the early Cretaceous and mid-Jurassic	Surface-244 m (244 m): Claystones and sandstones.	20/07/1979	30/09/1979	Plugged and Abandoned.	Balduzzi, 1979. Kizimbani-1 biostratigraphy report, 10 p.

4.2 Makarawe-1 borehole

The Makarawe-1 borehole (figure 4.2) is located at Latitude 5º 33' 09.9" S and Longitude 38º 52' 11.2" E. It was drilled in 1984 by International Energy Development Corporation (IEDC) to investigate pre-middle Jurassic and Karoo sandstone, and no interval was tested for hydrocarbons. The borehole drilled through a thin Neogene cover into mid-cretaceous and then to 3,821m of Total Depth (TD) in the early Triassic Karoo sandstone. The well was plugged and abandoned as a dry hole. High gas readings were associated with middle Jurassic clay stones with TOC values up to 4%, which is the most promising oil prone source rock encountered in the Ruvu Basin (TPDC/Fairway, 1992). Forty-four samples were re-analyzed from this borehole for foraminifera as part of this study.

4.2.1 Lithostratigraphy

The lithostratigraphy is summarized from IEDC, which is unpublished final drilling report compiled by Macmatry (1985). The following is a summary of the lithologic units from the top to base.

4.2.1.1 Sakura Formation (35-675 m)

35 - 515 m: Marl sequence, medium grey to bluish grey, soft, sticky, few pyrite cubes seen throughout this section. There is an unconformity above this interval, Cenomanian sediments are overlain by Neogene sediments. No samples were availed from 685-696 m. (see figure 4.2).

515-675 m: Marl is medium grey to bluish grey, soft, sticky, occasionally calcareous, few pyrite cubes throughout the interval.

4.2.1.2 Kipumpwe Formation: 675-685 m, 705-740 m

These are claystones that are greenish grey in colour, with minor siltstone and limestone. Claystones are moderately hard, platy and calcareous. Siltstones are grey, argillaceous, micaceous and calcareous.

4.2.2 Foraminiferal Biostratigraphy

A distribution chart for both planktonic and benthic foraminifera is shown in Table 4.2. Key biostratigraphic datum is identified from which four standard biozones are recognized. The zones and their typical assemblages are described in the following sections, working from the base to top.

4.2.2.1 Late Aptian (675-740 m): Paraticinella eubejaouaensis Taxon range Zone

The zone of *Paraticinella eubejaouaensis* is defined as the biostratigraphic interval of the total range of *Paraticinella eubejaouaensis* (Base by Moullade (1966) and top by Moullade (1974). The highest occurrence (HO) of *Paraticinella eubejaouaensis* at 675 m and lowest occurrence (LO) at 740 m is the total interval range of the *Paraticinella eubejaouaensis*, indicating the uppermost late Aptian age. Samples analyzed from this interval yield microfauna of the uppermost Aptian. Planktonic species diversity is moderate and abundance varies from rare to frequent and preservation varies from poor to moderate. Species present include the late Aptian *Globigerinelloides, Hedbergellids* and *Pseudoguembelitria* illustrated in table 4.2 and plates 3.3 - 3.6, 3.9 - 3.10 and plate 3.12.

The diversity of calcareous benthic foraminiferal species is moderate in this interval with variations from rare to abundant. Species present include *Conorotalites bartensteini aptiensis*, *Gavelinella barremiana, Gavelinella intermedia* and others (see table 4.2 & plates 3.16 - 3.17).

Agglutinated forms are moderately diverse in this interval with low abundance and a few species varies from common to abundant. Species present include *Ammodiscus cretacea, Glomospira charoides, Tristix excavata*, and others including rare ostracods and abundant pyrite cubes (see table 4.2 and plates 3.16, 3.18 and plate 3.25).

4.2.2.2 Indeterminate (585-665 m): (Unzoned)

The Planktonic foraminifera presnt in this interval include: *Microhedbergella miniglobularis, Microhedbergella renilaevis, Microhedbergella pseudoplanispira* and *Ticinella roberti.* Planktonic foraminifera are rare and scattered and mixed up the late

Albian with earliest Albian forms and are extremely rare in abundance; and therefore this interval cannot be placed in either of the earliest or late Albian biozones with certainty; and therefore this interval is unzoned and not possible to date (see table 4.2 and plates 3.7 - 3.8, and plate 3.14).

The calcareous benthic foraminifera are moderately diverse and vary from rare to abundant. Species of *Conorotalites bartensteini aptiensis, Gavelinella intermedia* and *Osangularia schloebanchi,* and pyrite cubes in few levels are present in rare amounts. Also some of the calcareous benthic forms range in age some from the late Aptian to earliest Albian (e.g. *Gavelinella barremiana*) and some late Aptian to early Cenomanian e.g. *Gavelinella intermedia* (see plates, 3.16 - 3.17, and plate 3.22).

Agglutinated benthic foraminiferal diversity is low and rare abundance with fewer frequent to common. Species present include *Ammodiscus cretacea, Glomospira charoides,* and others (see table 4.2 and plates 3.16 and plate 3.18).

4.2.2.3 Late Albian (570–580 m): Biticinella breggiensis Interval Zone

The zone of *Biticinella breggiensis* is defined as the Interval Zone from the lowest occurrence (LO) of the nominal taxon to the lowest occurrence (LO) of *Pseudothalmanninella ticinensis*. This interval contains rare to few planktonic foraminifera with low species diversity. The lowest occurrence (LO) of *Biticinella breggiensis* that is at 580 m indicates late Albian age. The presence of *Biticinella breggiensis* and its two subzone species of *Pseudothalmanninella subticinensis* and *Ticinella praeticinensis* confirms the above age. Species present include *Pseudothalmanninella subticinensis; Ticinella praeticinensis, Muricohedbergella* sp., and many others (see table 4.2 and plates 3.2, 3.9, and plates 3.12 - 3.13).

Calcareous benthic foraminifera present are few with abundance varying from rare to common. Species present include *Epistomina spinulifera, Gavelinella intermedia* and agglutinated forms include *Glomospira charoides, Pseudogaudryinella dividens* and many others (see table 4.2 and plates 3.17-3.18 and plate 3.23).

4.2.2.4 Indeterminate (535- 545 m): Unzoned

In this interval, the present planktonic and benthic foraminifera have low diversity and abundance. Species present include *Ticinella raynaudi sp., Ticinella raynaudi aperta,* and *Muricohedbergella albiana.* No zonal marker species present and this interval cannot be place into any appropriate biozones. Calcareous benthics are rare in abundance and include *Epistomina* sp., *Gavelinella intermedia,* and many others (see table 4.2 and plate 3.13 and plate 3.17).

4.2.2.5 Indeterminate (520-530): Unzoned

There are planktonic and benthic foraminifera with extremely low diversity and abundance varying from rare to frequent. Species present include *Ticinella raynaudi digitalis Muricohedbergella albiana* and others (see table 4.2 and plates 3.8 and 3.14). Benthic forms include *Gavelinella intermedia*, *Epistomina* sp., *Pseudogaudryinella* sp., and many others (see table 4.2 and plates 3.17 & 3.23). No index taxon to place this interval in any biozones and therefore is unzoned and not dated.

4.2.2.6 Late Albian: (230–515 m) Thalmanninella appenninica Interval zone

The zone of *Thalmanninella appenninica* is defined as the biostratigraphic interval from the lowest occurrence (LO) of *Thalmanninella appenninica* to the lowest occurrence of *Thalmanninella globotruncanoides.* At this interval the diversity of planktonic species is high and abundance varies from rare to common. The lowest occurrence (LO) of *Thalmanninella appenninica* at 515 m is the indicative of the base of the topmost late Albian interval of Makarawe-1 borehole. Species present include *Planomalina buxtorfi, Praeglobotruncanids* and others (see table 4.2 and plate 3.10, and plates 3.14 - 3.15). Species of *Thalmanninella globotruncanoides* are present in this interval and is probably due to contamination or reworked through washing etc., since these are cutting samples.

Calcareous benthics diversity is high and the variation is from rare to abundant. Species present include: *Gavelinella intermedia*, *Epistomina* sp., and many others (see table 4.2 and plate 3.17). Agglutinated forms vary from frequent to abundant for species such as:

Pseudogaudryinella sp., *Ammodiscus cretaceous* and others (see table 4.2 and plates 3.16 - 3.17 & 3.23).

4.2.2.7 Indeterminate (80-200): Unzoned

In this interval planktonic foraminifera species vary from rare to abundant and less diversified. Species present such as *Favusella washitensis, Muricohedbergella* sp., and *Thalmanninella globotruncanoides* (see table 4.2 and plates 3.3 and 3.15) as contaminant specimens. Therefore this interval cannot be either dated or placed in any planktonic foraminiferal biozone. The present Benthic foraminifera species include: *Marssonella oxycona, Gavelinella intermedia, Tristix excavata* any many others (see table 4.2, and plates 3.16, 3.21, 3.23 and 3.25).

4.2.2.8 Middle–Late Cenomanian (35 m); Rotalipora cushmani Interval zone

The zone of *Rotalipora cushmani* is defined as the biostratigraphic interval corresponding to the total range of *Rotalipora cushmani*. At 35 m., planktonic foraminiferal species abundance and diversity is extremely low and rare in abundance. The occurrence of *Rotalipora cushmani* at 35 m indicates Middle - late Cenomanian age of this sample. The present planktonic foraminifera include: *Favusella washitensis*, *Muricohedbergella* spp., *Praeglobotruncanids, Thalmanninella greenhornensis, Rotalipora cushmani* and others (see table 4.2 plates 3.3, 3.9 – 3.12). Calcareous benthic foraminifera abundance is rare to few and diversity is low.

4.2.3: Synthesis

Figure 4.2 shows the summary of the planktonic foraminiferal biostratigraphy of the mid-Cretaceous part of this borehole against the lithologic description and the planktonic : benthic ratio data from this study. For the most part of the borehole planktonic foraminifera species in the succession appears not to be complete due to absence of zonal marker species and some intervals with a mixture of zonal markers and was difficult to recognize the zones with certainty. At the same level (~580 m) either a large change in sedimentation rate or a substantial hiatus must be inferred (the latter is the preferred explanation).

The data are best explained by a hiatus extending from about 107 Ma-111 Ma. This corresponds to a subtle change in lithology within the Sakura Formation/Kingongo Formation. Planktonic: benthic ratios are variable in the lower part of the succession, reaching a low level just above the inferred hiatus. Ratios gradually increase, suggesting transgression, between about 550 m to 350 m and above, the ratios that are mostly high.

Table 4.2: Makarawe-1 borehole planktonic and benthic foraminifera range chart

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zone	*Hedbergella aptiana*	*Hedbergella sigali*	*Hedbergella infracretacea*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Hedbergella* sp.	*Paraticinella eubejaouensis*	*Pseudoguembelitria* sp.	*Favusella washitensis*	*Microhedbergella miniglobularis*	*Microhedbergella renilaevis* (sp. 2)	*Microhedbergella pseudoplanispra*	*Muricohedbergella delrioensis*	*Muricohedbergella simplex*	*Muricohedbergella albiana*	*Ticinella primula*	*Ticinella raynaudi*	*Ticinella roberti*	*Ticinella praeticinensis*	*Ticinella* sp.	*Ticinella raynaudi aperta*	*Biticinella breggiensis*	*Pseudothalmanninella subticinensis*	*Heterohelix moremani*	*Thalmanninella appenninica*	*Planomalina buxtorfi*	*Loblichella* sp.	*Praeglobotruncana delrioensis*	*Thalmanninella globotruncanoides*	*Praeglobotruncana stephani*	*Rotalipora cushmani*	*Thalmanninella greenhornensis*	*Praeglobotruncana gibba*	
Makarawe-1	35 m	P-M	Middle - Late Cenomanian	*R. cushmani* zone									R				R	R										R				R	R	R	R	R	R	LO of *R. cushmani*
Makarawe-1	80 m	P-M	INDETERMINATE	UNZONED									R				C	F	R					R									R					
Makarawe-1	200 m	P-M															C	R	A														R					
Makarawe-1	230 m	P-M	Late Albian	*T. appenninica* zone													C	R	F											R		F	R	F				
Makarawe-1	280 m	P-M											R				C	R	F					R						R			R					
Makarawe-1	290 m	P-M											R				F													R			R					
Makarawe-1	300 m	P-M															F	R	F					R								R	R					
Makarawe-1	315 m	P-M															F	R	F													R	R					
Makarawe-1	320 m	P-M															F	R	C					R									R					
Makarawe-1	325 m	P-M															C	R	C										R									
Makarawe-1	335 m	P															F	R	R										F	R		R						
Makarawe-1	360 m	P-M															C		C					R					F	R	R							
Makarawe-1	395 m	P-M											R				F	R				R							F			R						
Makarawe-1	415 m	P-M															F	R	C										R	R								
Makarawe-1	445 m	P-M															C	R	C					R					R	R								
Makarawe-1	450 m	P-M															F	R	F										R	R		R						
Makarawe-1	470 m	P-M											R				C	R	C										R	R								
Makarawe-1	480 m	P-M															C		R					R				R		R								
Makarawe-1	485 m	P-M															C							R					R	R								
Makarawe-1	495 m	P-M															F							R														
Makarawe-1	515 m	P-M															F		R					F					R	R								LO of *T. appenninica*
Makarawe-1	520 m	P-M	INDETERMINATE	UNZONED													R				R			R														
Makarawe-1	530 m	P-M															F		R					R														
Makarawe-1	535 m	P-M	INDETERMINATE	UNZONED																				R														
Makarawe-1	540 m	P-M															R							R	R													
Makarawe-1	545 m	P-M																	R																			

Table 4.2: Makarawe-1 borehole planktonic and benthic foraminifera range

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zone	*Hedbergella aptiana*	*Hedbergella sigali*	*Hedbergella infracretacea*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Hedbergella* sp.	*Paraticinella eubejaouensis*	*Pseudoguembelitria* sp.	*Favusella washitensis*	*Microhedbergella miniglobularis*	*Microhedbergella renilaevis*	*Microhedbergella pseudoplanispra*	*Muricohedbergella delrioensis*	*Muricohedbergella simplex*	*Muricoedbergella albiana*	*Ticinella primula*	*Ticinella raynaudi*	*Ticinella roberti*	*Ticinella praeticinensis*	*Ticinella* sp.	*Ticinella raynaudi aperta*	*Biticinella breggiensis*	*Pseudothalmanninella subticinensis*	*Heterohelix moremani*	*Thalmanninella appenninica*	*Planomalina buxtorfi*	*Loblichella* sp.	*Praeglobotruncana delrioensis*	*Thalmanninella globotruncanoides*	*Praeglobotruncana stephani*	*Rotalipora cushmani*	*Thalmanninella greenhornensis*	*Praeglobotruncana gibba*	
Makarawe-1	570 m	P-M	Late Albian	*B. breggiensis* zone												R	R		R	R	R	R	R	R		R	R											
Makarawe-1	580 m	P-M											R			R	R	R		R			R	R		R	R											LO of *B. breggiensis*
Makarawe-1	585 m	P-M	INDETERMINATE	UNZONED												R				R																		
Makarawe-1	590 m	P-M												R		R																						
Makarawe-1	605 m	P-M													R	R																						
Makarawe-1	615 m	P-M												R		R						R																
Makarawe-1	620 m	P-M													R	R																						
Makarawe-1	645 m	P-M														R																						
Makarawe-1	660 m	P-M												R		R																						
Makarawe-1	665 m	P-M												R		R																						
Makarawe-1	675 m	P-M	Late Aptian	*Pa. eubejaouensis* zone		R					R																											HO of *Pa. eubejaouaensis*
Makarawe-1	680 m	P-M										R																										
Makarawe-1	685 m	P-M					R	F																														
Makarawe-1	690 m	P-M						F	R																													
Makarawe-1	705 m	P-M						R	R		R																											
Makarawe-1	710 m	P-M			R		R	R	R	R	F																											
Makarawe-1	720 m	P-M							R	R	R																											
Makarawe-1	740 m	P-M			R						F																											LO of *Pa. eubejaouaensis*

Note: *B.* = *Biticinella*, *Pa*. = *Paraticinella*, *T*. = *Thalmaninella*, *Ti*. = *Ticinella*, *R.* = *Rotalipora*, R= rare; 2 - 5 specimens, F = Frequent; 6 - 10 specimens, C = Common, A = Abundant; ≥ 21

Table 4.2: Makarawe-1 borehole planktonic and benthic foraminifera

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zone	*Conorotalites bartensteini aptiensis*	*Gavelinella barremiana*	*Globulina* sp. aff. *lacrima lacrima*	*Lenticulina* sp.	*Marssonella kummi*	*Osangularia* sp.	*Gyroidinoides gracillima*	*Orthocastenia* sp.	*Marssonella oxycona*	*Gavelinella intermedia*	*Osangularia schloenbachi*	*Pseudonodosaria humilis*	*Gavelinella* sp.	*Lenticulina muensteri*	*Epistomina spinulifera*	*Pseudonodosaria obscura*	*Pleurostomella* sp.	*Gyroidinoides* sp. 1	*Lagena globosa*	*Psilocitharella* sp.	*Gyroidinoides* sp. 2	*Laevidentalina communis*	*Astacolus* sp.	*Lingulogavelinella* sp. 2	*Ramulina tetrahedralis*	*Ammobaculites* sp.	*Ammodiscus cretacea*	*Gaudryinopsis* sp.	*Glomospira charoides*	*Reophax* sp.	*Tristix excavata*	*Gaudryina* sp.	*Spiroplectammina* sp.	*Spiroplectinella* sp.	*Ramulina* sp.	*Bathysiphon* sp.	*Trochammina* sp.	*Pseudogaudryinella dividens*	*Quinqueloculina* sp.	*Hyperammina* sp.	*Lagenammina* sp.	*Quinqueloculina antiqua*	*Ammonites*	*Gastropods*	*Ostracods*	*Pyrite*
Makarawe-1	35 m		Mid - Late Cenomanian	*R. cushmani* zone									R	R			R																																
Makarawe-1	80 m	P-M	INDETERMINATE	UNZONED								R	R	F			F					R		R	R		R		R														F							C
Makarawe-1	200 m	P-M						R				R		F			R					F			R										R			R			A	R	F							F
Makarawe-1	230 m	P-M	Late Albian	*T. appenninica* zone				R				R		F			F	R				F			R	R					R							R			F	R	R			R	R			F
Makarawe-1	280 m	P-M						R					C	F			F		F			C		R	R				R		R										F	R				F	R		R	A
Makarawe-1	290 m	P-M						R					R	F																											F		R						R	F
Makarawe-1	300 m	P-M											R	F			R		R				R								R						R				R		F							F
Makarawe-1	315 m	P-M										R	F	C					F			C									R										A					F				F
Makarawe-1	320 m	P-M						R					R	C					C			C																R					C							C
Makarawe-1	325 m	P-M					R			R				A					R			A									R	R				R							R							F
Makarawe-1	335 m	P											C	F			R		F																															A
Makarawe-1	360 m	P-M						R				R	F	C			R		C			F						R							R			R										R		C
Makarawe-1	395 m	P-M						R		R			A						C																									R	R			R		A
Makarawe-1	415 m	P-M						R				R	A						F													R											F				R	R		A
Makarawe-1	445 m	P-M						R				R																															F					R		A
Makarawe-1	450 m	P-M											A						F																								F							A
Makarawe-1	470 m	P-M																	F																								C							C
Makarawe-1	480 m	P-M											C		R				C		R										R					R							A							
Makarawe-1	485 m	P-M					R							R		R																							R		R	F	A							
Makarawe-1	495 m	P-M					R	R				R			R																	F										R								
Makarawe-1	515 m	P-M					R	R						R					F													R									R	R	A					R		
Makarawe-1	520 m	P-M	INDETERMINATE	UNZONED				R											F													F									F								R	
Makarawe-1	530 m	P-M												R																		F										R								
Makarawe-1	535 m	P-M												R			R															R									R									
Makarawe-1	540 m	P-M						R						R			R		R													R																		
Makarawe-1	545 m	P-M											R	R		R				R																														

Table 4.2: Makarawe-1 borehole planktonic and benthic foraminifera range chart

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zone	*Conorotalites bartensteini aptiensis*	*Gavelinella barremiana*	*Globulina sp. aff. lacrima lacrima*	*Lenticulina sp.*	*Marssonella kummi*	*Osangularia sp.*	*Gyroidinoides gracillima*	*Orthokarstenia sp.*	*Marssonella oxycona*	*Gavelinella intermedia*	*Osangularia schloenbachi*	*Pseudonodosaria humilis*	*Gavelinella sp.*	*Lenticulina muensteri*	*Epistomina spinulifera*	*Pseudonodosaria obscura*	*Pleurostomella sp.*	*Gyroidinoides sp 1*	*Lagena globosa*	*Psilocitharella sp.*	*Gyroidinoidesp. 2*	*Laevidentalina communis*	*Astacolus sp.*	*Lingulogavelinella sp. 2*	*Ramulina tetrahedralis*	*Ammobaculites sp.*	*Ammodiscus cretacea*	*Gaudryinopsis sp.*	*Glomospira charoides*	*Reophax sp.*	*Tristix excavata*	*Gaudryina spp.*	*Spiroplectammina sp.*	*Spiroplectinella sp.*	*Ramulina sp.*	*Bathysiphon sp.*	*Trochammina sp.*	*Pseudogaudryinella dividens*	*Quinqueloculina sp.*	*Hyperammina sp.*	*Lagenammina sp.*	*Quinqueloculina antiqua*	*Ammonites*	*Gastropods*	*Ostracods*	*Pyrite*
Makarawe-1	570 m	P-M	Late Albian	*B. breggiensis* zone				R					R	C	C				R										R				R					R												
Makarawe-1	580 m	P-M											F	R			R		R													R								R										
Makarawe-1	585 m	P-M	INDETERMINATE	UNZONED				R										R																																
Makarawe-1	590 m	P-M					R							F																																				
Makarawe-1	605 m	P-M						F				R		R																																				
Makarawe-1	615 m	P-M										R		R																										R										
Makarawe-1	620 m	P-M					R	R		F		R																			R																			
Makarawe-1	645 m	P-M			R			F				R		R		R																						R	R										F	
Makarawe-1	660 m	P-M				R		F				R																												R										
Makarawe-1	665 m	P-M					R							R	R																		R						R										R	A
Makarawe-1	675 m	P-M	Late Aptian	*Pa. eubejaouaensis* zone		R																																												
Makarawe-1	680 m	P-M																														R																		
Makarawe-1	685 m	P-M												R																																				
Makarawe-1	690m	P-M				F		R				R																								R														
Makarawe-1	705 m	P-M			R	A		R	R	F	R	R	C																				R																R	A
Makarawe-1	710 m	P-M				A				A	R																			R	R	R	R	R	R															
Makarawe-1	720 m	P-M				F																																												
Makarawe-1	740 m	P-M			F	A	R	F	R	A																			R	R	R	R																		

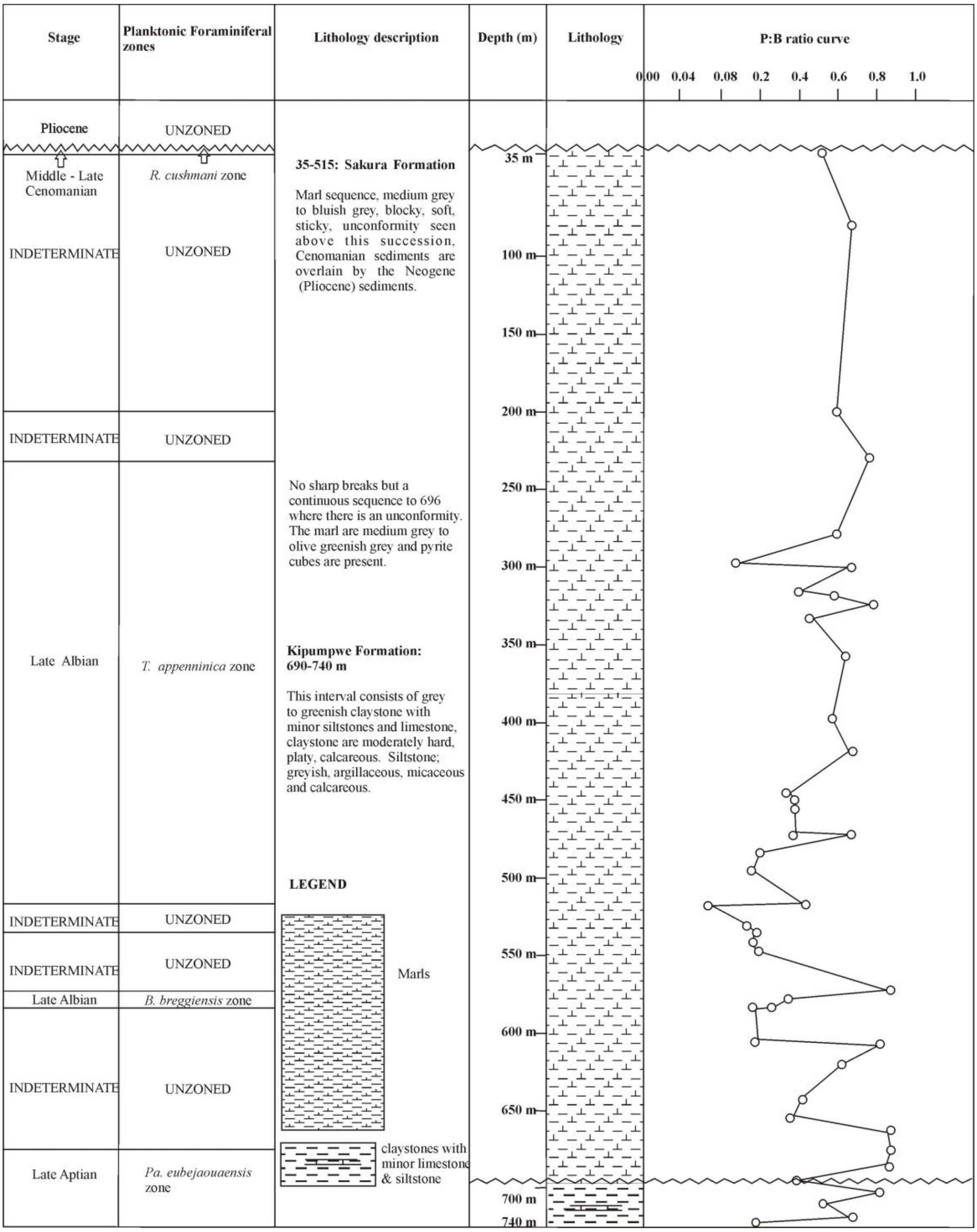


Figure 4.2: Summary biozonation and lithostratigraphy and P: B ratio curve for the Makarawe-1 borehole. Note inferred hiatus above 700 m and increasing P: B trend above the hiatus. N.B: *B. = Biticinella*, *Pa.= Paraticinella T.*, *= Thalmanninella*, *R. = Rotalipora.*

4.3 Kiwangwa-1 borehole

The Kiwangwa-1 borehole (figure 4.3) is located in Latitude 6º 21' 43.25" S and Longitude 38º 32' 55.77" E. It was drilled in 1985/86 by Kuwait Foreign Petroleum Company (KUFPEC, formerly known as IEDC) to test the Middle Jurassic and Karoo sequences in the central part of the Ruvu Basin about 85 km northwest of Dar-es-Salaam. The well was spud in the Cenomanian and drilled to a total depth of 3514.3 m in the Karoo sandstone. The well was plugged and abandoned as a dry hole. Seventy-one samples were analyzed from this borehole but sample gaps were large.

4.3.1 Lithostratigraphy

The lithostratigraphy of this core is summarized by IEDC Company (Unpublished Makarawe-1 well completion report, 1986). The following is a summary of the lithologic units encountered in this borehole described from the top to base.

4.3.1.1 Wami River Series (0-50 m)

Predominantly marl, calcareous, soft, sticky olive greenish grey to bluish grey in colour.

4.3.1.2 Sakura Formation / Kingongo Formation (50–250 m)

Predominantly marl, calcareous, soft, sticky olive greenish grey to bluish grey, with a thin sandstone bed below 80 m.

4.3.1.3 Sakura / Kingongo Formation (250-325 m)

Claystone and sandstone: Claystone greyish green, bioturbated, very silt with interbeds and stringers of sandstone, white to pale greyish, moderately hard, blocky, quartz grains, well sorted, very fine to fine grain, subrounded, cemented with calcite, occasionally glauconitic. Abundant mica and pyrite cubes.

4.3.1.4 Kipumpwe / Kihuluhulu Formation (325-460 m)

Claystone, silt, hard greenish grey, bioturbated, pyritic, micaceous, blocky alternating with mica, pyrite and plant remains seen, calcareous. sandstone; white to pinkish grey, quartz grains, fine to medium grain, subrounded, cemented with calcite, pyritic and glauconitic. Reddish brown and pale greenish claystones are seen.

4.3.1.5 Kipumpwe / Kihuluhulu Formation (460-475 m)

Claystone greenish grey, moderately hard, blocky, with mica and pyrite cubes, bioturbated, occasionally with sand and silt, glauconitic, micaceous and calcareous.

4.3.1.6 Kipumpwe/ Kihuluhulu Formation (475-540 m)

Alternation of sandstone and clay stone, moderately hard, micaceous, pyritic, occasionally bioturbated, rare coal fragments, reddish brown claystone are seen. Sandstone; white, hard, blocky, unconsolidated, poorly sorted, fine to very coarse grain subrounded, calcite cemented. Mica, pyrite rare coal fragments, trace of glauconite pale green and moderately reddish brown claystone noted, sandstone is associated with claystone.

4.3.1.7 Kipumpwe / Kihuluhulu Formation (540-650 m)

Claystone greenish grey, moderately hard, blocky, micaceous, bioturbated, plant remains and rare coal material. Pyritic in some of the section, calcareous throughout, often sand and /or silt. With minor sandstone; white, moderately hard, blocky quartz grains, fine to coarse grain poorly sorted. At 620-640 gastropods and ostracods are present.

4.3.1.8 Kipumpwe /Kipatimu Formation (650-865 m)

Claystone, greenish grey, moderately hard, blocky, micaceous, bioturbated with plant remains rare coal material, occasionally pyritic in some section of this interval, calcareous, often sand or silt with minor sandstone, white, moderately hard and blocky. From 700-790 m, 800, 825, 835; ostracods and gastropods are present. And at 835 m and 865 m bivalves and iron nodules seen. Sandstone; pale green, hard, blocky, fine to very fine grains, calcareous, pyritic, grading at the base to pinkish to medium grey, poorly sorted, with minor coal fragments (see fig. 4.3

Kiwangwa-1 stratigraphic log and table 4.3 planktonic and benthic foraminifera range chart).

4.3.2 Planktonic foraminiferal biostratigraphy

A distribution chart for both planktonic and benthic foraminifera is shown in table 4.3. Key biostratigraphic datum allows the succession to be divided into seven standard biozones which are described in the following sections from the base to the top.

4.3.2.1 Indeterminate (855 - 865 m): Unzoned

No planktonic foraminifera encountered in this interval and benthic foraminifera species vary in abundance from rare to abundant but diversity is extremely low. Species present include: *Lenticulina (Lenticulina) ouachensis ouachensis, Epistomina hetchi* and others. Barremian to late Aptian species are present in this interval, therefore this interval cannot be dated and assigned to any planktonic foraminiferal biozones because there is no planktonic foraminifera index species present (see table 4.3 and plates 3.17, & plate 3.20).

4.3.2.2 Late Aptian (810 - 845 m): Globigerinelloides algerianus Total range zone

The occurrence of *Globigerinelloides algerianus* at this interval indicates late Aptian age. The zone of *Globigerinelloides algerianus* is the total range of the nominal taxon (Moullade (1966) and top by Sigal (1977)). Planktonic species diversity is extremely low and abundance varies from rare to abundant. Planktonic foraminifera species that are present include: *Globigerinelloides barri, Globigerinelloides ferreolensis* and *Globigerinelloides algerianus*. Mixed assemblage of benthic of different stratigraphic levels means an element of reworked and contamination possibly through washing, hence older and younger specimens were observed. Species present include: *Lenticulina (Lenticulina) ouachensis ouachensis, Epistomina hetchi,* and many others (see table 4.3 and plates 3.3-3.4, plates 3.17 and , 3.20).

4.3.2.3 Indeterminate (545–800 m): Unzoned

In this interval only *Caucasella hoterivica* present at 730 m and *Hedbergella infracretacea* at 670 m and are very rare. Benthic foraminifera are moderately diverse and vary from rare to abundant. Many samples in this interval are barren at the following intervals: 545 m, 550 m, 570 m, 585 m, 610 m, 650 m, 690 m, 775 m and 790 m (see table 4.3). Benthic foraminifera are moderately diverse and vary from rare to abundant.

Species present include *Lenticulina (Lenticulina) ouachensis ouachensis, Lenticulina muensteri* and many others (see table 4.3 and plates 3.2, 3.5 & plate 3.20).

4.3.2.4 Indeterminate (470–540 m): Unzoned

No planktonic foraminifera species are present and therefore this interval is not dated and cannot be placed in any of the planktonic foraminiferal biozones. Some intervals are barren such as (e. g. 470 m-510 m). Benthic foraminifera are rare (see table 4.3).

4.3.2.5 Late Aptian (345–460 m): Paraticinella eubejaouaensis Taxon range zone

The highest occurrence (HO) of *Paraticinella eubejaouaensis* at 345 m and lowest occurrence (LO) at 460 m indicates the topmost late Aptian age. The occurrence of *Paraticinella eubejaouaensis* throughout this interval indicates late Aptian age of the sediments and this interval lies in the *Paraticinella eubejaouaensis* Taxon range zone. The diversity of Planktonic foraminiferal species is moderate to slightly high and abundance varies from rare to few. Preservation varies from poor to moderate. This interval contains planktonic foraminiferal species such as *Paraticinella eubejaouaensis*, species of hedbergellids and many others (see table 4.3, plates 3.4 - 3.5, and plates 3.9 - 3.10).

In this interval there is a high diversity of calcareous benthic foraminifera and vary in abundance from rare to abundant. Species present such as *Gavelinella barremiana, Lenticulina (Lenticulina) ouachensis ouachensis, Lenticulina (Lenticulina) nodosa, Saracenaria triangularis* and many others (see table 4.3 and plates 3.17, 3.20 and plate 3.25).

Agglutinated forms in this interval are highly diversified with rare abundance. Species present include: *Ammodiscus cretacea, Tristix excavata*; and many others (see table 4.3 and plates 3.16 and 3.25).

4.3.2.6 Early Albian (325–335 m) Microhedbergella miniglobularis Interval zone

Planktonic foraminifera present at 330 m and 335 m are *Microhedbergella miniglobularis* only, its occurrence indicates an earliest Albian age of this interval. The zone of *Microhedbergella* *miniglobularis* is defined as a biostratigraphic interval from the highest occurrence (HO) of *Paraticinella eubejaouaensis* to the lowest occurrence (LO) of *Microhedbergella rischi* (Base by Huber and Leckie (2011); top by Moullade (1974), see plate 3.7 - 3.8).

Benthic species diversified and abundance varies from rare to abundant. Species present include *Tritaxia pyramidata, Gavelinella intermedia*; *Conorotalites bartensteini aptiensis* and many others (see table 4.3 and plates 3.17 and 3.25).

4.3.2.7 Indeterminate (260 - 300 m): Unzoned

No planktonic foraminifera present in this interval only benthics. Benthic foraminifera diversified and vary in abundance from rare to abundant. Other samples taken at 280 m and 300 m are barren (see table 4.3).

4.3.2.8 Middle Albian (200 - 250 m): Ticinella primula Interval zone

The zone of *Ticinella primula* is an interval zone from the lowest occurrence (LO) of *Ticinella primula* to the lowest occurrence (LO) of *Biticinella breggiensis* (Longoria and Gamper (1974)). The lowest occurrence of *Ticinella primula* at 250 m indicates middle Albian age. Species present at this interval include: *Ticinella primula, Muricohedbergella* spp., and *Biticinella subreggiensis* and many others (see table 4.3 and plates 3.2, & 3.8, and 3.13). When the lowest occurrence (LO) of *Ticinella primula* is at 250 m that indicates middle Albian age. Calcareous benthic foraminifera are moderately diverse and vary in abundance from rare to frequent. Species present such as *Epistomina*

sp., *Gavelinella intermedia* (see table 4.3 and plate 3.17) and ostracods and pyrite cubes are rare in this interval. Planktonic foraminifera are low in abundance and diversity. Planktonic foraminifera are low in abundance and diversity.

4.3.2.9 Late Albian (100-200 m): Biticinella breggiensis Interval zone

Planktonic species diversity is high and abundance is rare for most of the species Postuma (1971). The zone of *Biticinella breggiensis* is an interval zone from the lowest occurrence (LO) of the nominal taxon to the lowest occurrence (LO) of *Pseudothalmanninella ticinensis.* The lowest occurrence (LO) of *Biticinella breggiensis* at 200 m indicates late Albian age confirmed by the presence of its two subzone marker species of *Pseudothalmanninella subticinensis* and *Ticinella praeticinensis*.

Preservation varies from poor to moderate and most of the specimens have calcite infill. Species present such as *Ticinella praeticinensis, Ticinella raynaudi digitalis, Pseudothalmanninella subticinensis,* and *Biticinella breggiensis* (see table 4.3 and plate 3.1, 3.12 - 3.14).

Calcareous Benthic foraminifera are diverse and their abundances vary from rare to common. Species of *Gavelinella intermedia,Osangularia schloebanchi, Saracenaria triangularis,* and others. Pyrite cubes, bivalves and ostracods are present in this interval (see table 4.3; plates 3.17, 3.20, 3.22, and plate 3.25). Agglutinated forms are low in diversity and abundance and species encountered in this interval are, *Marsonella oxycona, Lagenammina alexanderi* and many others.

4. 3.2.10 Late Albian (50–80 m): Thalmanninella appenninica Interval zone

The planktonic species diversity and abundance is very low in this interval. The zone of *Thalmanninella appenninica* is a biostratigraphic interval from the lowest occurrence (LO) of *Thalmanninella appenninica* to the lowest occurrence (LO) of *Thalmanninella globotruncanoides* (Brönnimann (1952)). The lowest occurrence (LO) of *Thalmanninella appenninica* at 80 m indicates that it dates from late Albian age. Species present include: *Muricohedbergella albiana, Thalmanninella appenninica; Planomalina buxtorfi* and others (see table 4.3 and plates 3.10, 3.14 - 3.15).

Calcareous benthic foraminiferal diversity is low with rare abundance. Species present include *Gavelinella intermedia, Lenticulina muensteri* and others (see table 4.3 and plates 3.17, 3.20). Agglutinated forms are low in diversity and abundance. Rare specimens of *Bathysiphon* sp., *Gaudryina* sp., and many others (see table 4.3; plate 3.16).

4.3.2.11 Early Cenomanian (0-50 m): Thalmanninella globotruncanoides Interval zone

The zone of *Thalmanninella globotruncanoides* is defined as a biostratigraphic interval from the lowest occurrence (LO) of *Thalmanninella globotruncanoides* to the lowest occurrence (LO) of *Thalmanninella reicheli* (Lehmann (1966)). The lowest occurrence (LO) of

Thalmanninella globotruncanoides at 50 m indicates early Cenomanian age. Planktonic species diversity and abundance is extremely low and preservation varies from poor to moderate. Planktonic foraminifera species that are present in include: *Favusella washitensis, Muricohedbergella* spp., Praeglobotruncanids, *Thalmanninella globotruncanoides* and others (see table 4.3 and plates 3.9, 3.11 and 3.15).

Calcareous benthic and agglutinated foraminiferal are low in diversity and abundance. Species that are present include: *Gavelinella intermedia, Patellina subcretacea* and others (see table 4.3 and plate 3.17, and plate 3.23).

4.2.3 Synthesis

Figure 4.3 shows the summary of the planktonic foraminiferal biostratigraphy of the mid-Cretaceous part of this borehole against the lithologic description and the Planktonic, based on Benthic ratio data. The stratigraphy in the upper part of the succession contains regular series of biozones from the early Cenomanian into the late Aptian and Albian in a condensed succession. At approximately 250 m (within the Sakura/Kingongo Formation) there is a succession of alternating marls and sandstones in which planktonic foraminifera are absent, below the unzoned interval.

Below this is a possible transition from lowermost Albian into uppermost Aptian, where planktonic foraminifera are once again abundant. A second substantial hiatus is inferred at 460 m between the topmost late Aptian *Paraticinella eubejaouaensis* zone and what is

probably the stratigraphic equivalent of the lower Aptian. Planktonic: benthic ratios are relatively low throughout the succession. The highest ratios and inferred deeper water interval is in the uppermost Aptian *Paraticinella eubejaouaensis* zone.

Table 4.3: Kiwangwa borehole-1 planktonic and benthic foraminifera range chart

Well name	Sample depth (m)	Stage	Planktonic foraminiferal zones	Preservation	*Caucasella hoterivica*	*Hedbergella infracretacea*	*Globigerinelloides ferreolensis*	*Hedbergella gorbachikae*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Hedbergella trocoidea*	*Paraticinella eubejaouaensis*	*Paraticinella eubejaouaensis (sp. 2)*	*Paraticinella transitoria*	*Pseudoguembelitria sp.*	*Favusella washitensis*	*Microhedbergella miniglobularis*	*Muricohebergella delrioensis*	*Muricohedbergella simplex*	*Muricohedbergella albiana*	*Ticinella primula*	*Ticinella raynaudi*	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Ticinella praeticinensis*	*Biticinella breggiensis*	*Pseudothalmanninella subticinensis*	*Planomalina praebuxtorfi transition to Planomalina buxtorfi*	*Planomalina praebuxtorfi*	*Thalmanninella appenninica*	*Thalmanninella globotruncanoides*	*Praeglobotruncana gibba*	
Kiwangwa-1	50	Early Cenomanian	*T. globotrunca-noides* zone	P-M												R		R	R	R											R	R	LO of *T. Globotruncanoides*
Kiwangwa-1	80	Latest Albian	*T. appenninica* zone	P-M												R		R	R	R									R	R			LO *T. appenninica*
Kiwangwa-1	100	Late Albian	*B. breggiensis* zone	P-M												R		R	R					R		R	R						
Kiwangwa-1	150-151			P-M												R		R		R		R	R	R	R	R	R						
Kiwangwa-1	200			P														R		R				R	R	R							LO of *B. breggiensis*
Kiwangwa-1	250	Middle Albian	*Ti. primula* zone	P-M														R		R	R												LO of *Ti. primula*
Kiwangwa-1	260	INDETERMINATE	UNZONED	P-M																													
Kiwangwa-1	270			P																													
Kiwangwa-1	280			Barren																													
Kiwangwa-1	290			P-M																													
Kiwangwa-1	300			Barren																													
Kiwangwa-1	325	Early Albian	*Mi. miniglobularis* zone	P-M																													
Kiwangwa-1	330			M-G													R																
Kiwangwa-1	335			P													R																HO of *Pa. eubejaouaensis*
Kiwangwa-1	345	Late Aptian	*Pa. eubejaouaensis* zone	M		R				R		F	R	R			R																
Kiwangwa-1	355			P-M		R					R	C		R																			
Kiwangwa-1	365			P-M							R	F		R														R					
	370			P-M		F		R			R	F		R																			
Kiwangwa-1	385			P-M								F																					
Kiwangwa-1	395			Barren																													
Kiwangwa-1	410			P-M							R	F			RR																		
Kiwangwa-1	415			Barren																													
Kiwangwa-1	425			P-M		R						F																					
Kiwangwa-1	440			P							R	F																					
Kiwangwa-1	450			Barren																													
Kiwangwa-1	460			P								R																					LO of *Pa. eubejaouaensis*

Table 4.3: Kiwangwa borehole-1 planktonic and benthic foraminifera range chart

Well name	Sample depth (m)	Age	Planktonic foraminiferal zones	Preservation	*Caucasella hoterivica*	*Hedbergella infracretacea*	*Globigerinelloides ferreolensis*	*Hedbergella gorbachikae*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Hedbergella trochoidea*	*Paraticinella eubejaouaensis*	*Paraticinella eubejaouaensis* (sp. 2)	*Paraticinella transitoria*	*Pseudoguembelitria* sp.	*Favusella washitensis*	*Microhedbergella miniglobularis*	*Muricohebergella delrioensis*	*Muricohedbergella simplex*	*Muricohedbergella albiana*	*Ticinella primula*	*Ticinella raynaudi*	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Ticinella praeticinensis*	*Biticinella breggiensis*	*Pseudothalmanninella subticinensis*	*planomalina praebuxtorfi* transition to *Planomalina buxtorfi*	*Planomalina praebuxtorfi*	*Thalmanninella appenninica*	*Thalmanninella globotruncanoides*	*Praeglobotruncana gibba*	
Kiwangwa-1	470	INDETERMINATE	UNZONED	Barren																													
Kiwangwa-1	480			Barren																													
Kiwangwa-1	490			Barren																													
Kiwangwa-1	495			Barren																													
Kiwangwa-1	500			Barren																													
Kiwangwa-1	510			Barren																													
Kiwangwa-1	520			P																													
Kiwangwa-1	530			P																													
Kiwangwa-1	540			P																													
Kiwangwa-1	545	INDETERMINATE	UNZONED	Barren																													
Kiwangwa-1	550			Barren																													
Kiwangwa-1	555			B																													
Kiwangwa-1	570			B																													
Kiwangwa-1	580			P																													
Kiwangwa-1	585			B																													
Kiwangwa-1	595			P																													
Kiwangwa-1	610			B																													
Kiwangwa-1	620			P																													
Kiwangwa-1	630			P																													
Kiwangwa-1	640			P																													
Kiwangwa-1	650			B																													
Kiwangwa-1	670			P-M		R																											
Kiwangwa-1	680			P																													
Kiwangwa-1	690			B																													
Kiwangwa-1	700			P																													
Kiwangwa-1	710			P																													
Kiwangwa-1	720			P																													
Kiwangwa-1	730			P	RR																												
Kiwangwa-1	735			P-M																													
Kiwangwa-1	740			P																													
Kiwangwa-1	750			P																													
Kiwangwa-1	760			P-M																													
Kiwangwa-1	770			P																													
Kiwangwa-1	775			B																													
Kiwangwa-1	780			P																													
Kiwangwa-1	790			B																													
Kiwangwa-1	795			P-M																													
Kiwangwa-1	800			P																													
Kiwangwa-1	810	Late Aptian	*G. algerianus* zone	P					R																								HO of *G. algerianus*
Kiwangwa-1	825			P			R		R	R																							
Kiwangwa-1	835			P																													
Kiwangwa-1	845			P					R																								LO of *G. algerianus*
Kiwangwa-1	855	INDERMINATE	UNZONED	P																													
Kiwangwa-1	860			P																													
Kiwangwa-1	865			P																													

Note: *B*. = *Biticinella* , G.= *Globigerinelloides* , Pa. = *Paraticinella* , *T* . = *Thalmanninella* , *Ti.* = *Ticinella* , B = Barren, P = Poor

P-M = Poor -Moderate, M-G = Moderate-Good, RR= Rare; 1 specimen, R =Rare; 2-5 specimens, f = frequent; 6-10 specimens, C = Common; 11-20 specimens, A = Abundant; ≥21

Table 4.3: Kiwangwa borehole-1 planktonic and benthic foraminifera range chart continued.

Well name	Sample depth (m)	Stage	Planktonic foraminiferal zones	Preservation	*Epistomina caracolla*	*Lenticulina (L.) ouachensis ouachensis*	*Epistomina chapmanni*	*Epistomina hetchi*	*Lenticulina muensteri*	*Epistomina reticulata*	*Astacolus* sp.	*Lenticulina ex.gr.muensteri*	*Glomospira charoides*	*Psammosphaera* sp.	*Ramulina* sp.	*Trochammina* sp.	*Osangularia schloenbachi*	*Gyroidinoides* sp.	*Ammobaculites* sp. 2	*Bathysiphon* sp.	*Gaudryina* sp.	*Laevidentalina communis*	*Marssonella oxycona*	*Ammodiscus cretacea*	*Spiroplectammina* sp.	*Epistomina carpenteri*	*Gavelinella barremiana*	*Gavellinella* sp.	*Lenticulina (Lenticulina) nodosa*	*Reophax* sp. 2	*Marssonell kummi*	*Orthocastenia* sp.	*Gavelinella intermedia*	*Hyperammina gaultina*	*Osangularia* sp.	*Hyperammina* sp.	*Lagenammina* sp.	*Rhabdammina* sp.	*Gaudryina gradata*	*Ammodiscus* sp.	*Tristix excavata*	*Tritaxia pyramidata*	*Quinqueloculina* sp.	*Ramulina tetrahedralis*	*Orbitolina* sp.	*Orithostella* sp.	*Pattelina subcretacea*	*Epistomina spinulifers*	*Pseudonodosaria humilis*	*Pseudogaudrinella dividens*	*Epistomina ornata*	*Pseudogaudryinella* sp.	*Bivalves*	*Gastropods*	*Ostracods*	*Pyrite cubes*
Kiwangwa-1	50	Early Cenomanian	*T. globotruncanoides* zone	P-M					R											R	R	R						R					R														R									
Kiwangwa-1	80	Late Albian	*T. appenninica* zone	P-M					R									R	R	R	R							C					F						F			R					R									
Kiwangwa-1	100	Late Albian	*Bi. breggiensis* zone	P-M					R									R															C						R			R		R								R				
Kiwangwa-1	150-151			P-M					R							R		R	R		F		R	R									A			R			R				R	R			R	R	R				R		R	R
Kiwangwa-1	200			P																																									A											
Kiwangwa-1	250	Middle Albian	*Ti. primula* zone	P-M			R	F										R		R	R							R			R	R	F				R									R				R	R				R	R
Kiwangwa-1	260	INDETERMINATE	UNZONED	P-M				R	R								F		R								F	C				R	A				R							R												
Kiwangwa-1	270			P																																																				
Kiwangwa-1	280			B																																																				
Kiwangwa-1	290			P-M				A	A		R			R		F	R										C	F				R	A				R										R	R								
Kiwangwa-1	300			B																																																			
Kiwangwa-1	325	Early Albian	*Mi. miniglobularis* zone	P-M													R	R	R	R	R		R	R	R		R	R					A									R	R		R												
Kiwangwa-1	330			M-G					R						R	R	C			F				R			R						A			F		R		R			R												R	
Kiwangwa-1	335			P														R									R	R																												
Kiwangwa-1	345	Late Aptian	*Pa. eubejaouaensis* zone	M		R		R								F		R			R			R			C	A					R	R	R		R																			
Kiwangwa-1	355			P-M				R	F		R	R				F					R						R	F					R																							
Kiwangwa-1	365			P-M					R		R	C				R					R						R																													
Kiwangwa-1	370			P-M					R		R	R	R							R	R			R			R	F			R	R	R																							
Kiwangwa-1	385			P-M		R			R									R									F	R																												
Kiwangwa-1	395			B																																																				
Kiwangwa-1	410			P-M		R			R		R	F						R									R																													
Kiwangwa-1	415			B																								R																											R	
Kiwangwa-1	425			P-M					R			F	R			R											C		R	R																										
Kiwangwa-1	440			P																							R		R																											
Kiwangwa-1	450			B																																																				
Kiwangwa-1	460			P																							R																												R	

Table 4.3: Kiwangwa borehole-1 planktonic and benthic foraminifera range chart

Well name	Sample depth (m)	Stage	Planktonic foraminiferal zones	Preservation	*Epistomina caracolla*	*Lenticulina (L.) ouachensis ouachensis*	*Epistomina chapmanni*	*Epistomina hetchi*	*Lenticulina muensteri*	*Epistomina reticulata*	*Astacolus* sp.	*Lenticulina* ex.gr.*muensteri*	*Glomospira charoides*	*Psammosphaera* sp.	*Ramulina* sp.	*Trochammina* sp.	*Osangularia schloebanchi*	*Gyroidinoides* sp.	*Ammobaculites* sp. 2	*Bathysiphon* sp.	*Gaudryina* sp.	*Laevidentalina communis*	*Marssonella oxycona*	*Ammodiscus cretacea*	*Spiroplectammina* sp.	*Epistomina carpenteri*	*Gavelinella barremiana*	*Gavellinella* sp.	*Lenticulina (Lenticulina) nodosa*	*Reophax* sp. 2	*Marssonell kummi*	*Orthocastenia* sp.	*Gavelinella intermedia*	*Hyperammina gaultina*	*Osangularia* sp.	*Hyperammina* sp.	*Lagenammina* sp.	*Rhabdammina* sp.	*Gaudryina gradata*	*Ammodiscus* sp.	*Tristix excavata*	*Tritaxia pyramidata*	*Quinqueloculina* sp.	*Ramulina tetrahedralis*	*Orbitolina* sp.	*Orithostella* sp.	*Pattelina subcretacea*	*Epistomina spinulifers*	*Pseudonodosaria humilis*	*Pseudogaudrinella dividens*	*Epistomina ornata*	*Pseudogaudryinella* sp.	*Bivalves*	*Gastropods*	*Ostracods*	*Pyrite cubes*
Kiwangwa-1	50	Early Cenomanian	*T. globotrunca-noides* zone	P-M					R											R	R	R						R					R														R									
Kiwangwa-1	80	Late Albian	*T. appenninica* zone	P-M					R									R	R	R	R							C					F						F			R					R									
Kiwangwa-1	100	Late Albian	*Bi. breggiensis* zone	P-M					R									R															C						R			R		R								R				
Kiwangwa-1	150-151			P-M					R							R		R	R		F		R	R									A			R			R				R	R			R	R	R				R		R	R
Kiwangwa-1	200			P																																									A											
Kiwangwa-1	250	Middle Albian	*Ti. primula* zone	P-M			R	F										R		R	R							R			R	R	F				R									R				R	R				R	R
Kiwangwa-1	260	INDETERMINATE	UNZONED	P-M				R	R								F		R								F	C				R	A				R							R												
Kiwangwa-1	270			P																																																				
Kiwangwa-1	280			B																																																				
Kiwangwa-1	290			P-M				A	A		R			R		F	R										C	F				R	A				R										R	R								
Kiwangwa-1	300			B																																																			
Kiwangwa-1	325	Early Albian	*Mi. miniglobularis* zone	P-M													R	R	R	R	R		R	R	R		R	R					A								R	R		R												
Kiwangwa-1	330			M-G					R						R	R	C			F				R			R						A			F		R		R			R												R	
Kiwangwa-1	335			P														R									R	R																												
Kiwangwa-1	345	Late Aptian	*Pa. eubejaouaensis* zone	M		R		R								F		R			R			R			C	A					R	R	R		R																			
Kiwangwa-1	355			P-M				R	F		R	R				F					R						R	F					R																							
Kiwangwa-1	365			P-M					R		R	C				R					R						R																													
Kiwangwa-1	370			P-M					R		R	R	R							R	R			R			R	F			R	R	R																							
Kiwangwa-1	385			P-M		R			R									R									F	R																												
Kiwangwa-1	395			B																																																				
Kiwangwa-1	410			P-M		R			R		R	F						R									R																													
Kiwangwa-1	415			B																								R																											R	
Kiwangwa-1	425			P-M					R			F	R			R											C		R	R																										
Kiwangwa-1	440			P																							R		R																											
Kiwangwa-1	450			B																																																				
Kiwangwa-1	460			P																							R																												R	

Table 4.3: Kiwangwa borehole-1 planktonic and benthic foraminifera range chart

Well name	Sample depth (m)	Age	Planktonic foraminiferal zones	Preservation	*Epistomina caracolla*	*Lenticulina (L.) ouachensis ouachensis*	*Epistomina chapmanni*	*Epistomina hetchi*	*Lenticulina muensteri*	*Epistomina reticulata*	*Astacolus* sp.	*Lenticulina ex.gr. muensteri*	*Glomospira charoides*	*Psammosphaera* sp.	*Ramulina* sp.	*Trochammina* sp.	*Osangularia schloebanchi*	*Gyroidinoides* sp.	*Ammobaculites* sp. 2	*Bathysiphon* sp.	*Gaudryina* sp.	*Laevidentalina communis*	*Marssonella oxycona*	*Ammodiscus cretacea*	*Spiroplectammina* sp.	*Epistomina carpenteri*	*Gavelinella barremiana*	*Gavellinella* sp.	*Lenticulina (Lenticulina) nodosa*	*Reophax* sp. 2	*Marssonell kummi*	*Orthocastenia* sp.	*Gavelinella intermedia*	*Hyperammina gaultina*	*Osangularia* sp.	*Hyperammina* sp.	*Lagenammina* sp.	*Rhabdammina* sp.	*Gaudryina gradata*	*Ammodiscus* sp.	*Tristix excavata*	*Tritaxia pyramidata*	*Quinqueloculina* sp.	*Ramulina tetrahedralis*	*Orbitolina* sp.	*Orithostella* sp.	*Pattelina* sp.	*Epistomina spinulifers*	*Pseudonodosaria humilis*	*Pseudogaudrinella dividens*	*Epistomina ornata*	*Pseudogaudryinella* sp.	Bivalves	Gastropods	Ostracods	Pyrite cubes
Kiwangwa-1	470	INDETERMINATE	UNZONED	B																																																				
Kiwangwa-1	480			B																																																				
Kiwangwa-1	490			B																																																				
Kiwangwa-1	495			B																																																				
Kiwangwa-1	500			B																																																				
Kiwangwa-1	510			B																																																				
Kiwangwa-1	520			P					R																																														
Kiwangwa-1	530			P					R																																														
Kiwangwa-1	540			P																								R																												
Kiwangwa-1	545	INDETERMINATE	UNZONED	B																																																				
Kiwangwa-1	550			B																																																				F
Kiwangwa-1	555			B																																																				F
Kiwangwa-1	570			B																																																				F
Kiwangwa-1	580			P																																																				F
Kiwangwa-1	585			B																																																				
Kiwangwa-1	595			P																																																				
Kiwangwa-1	610			B																																																				
Kiwangwa-1	620			P				R	R												R																																	R		
Kiwangwa-1	630			P																																																		RR		
Kiwangwa-1	640			P	A	R	A	F	R																	F																												R	R	
Kiwangwa-1	650			B																																																				
Kiwangwa-1	670			P-M					R						R			R					R	R	R																															
Kiwangwa-1	680			P	A	R	A	F	R																																														R	
Kiwangwa-1	690			B																																																				
Kiwangwa-1	700			P	R		R																																																R	
Kiwangwa-1	710			P	R		R																																																R	
Kiwangwa-1	720			P			C	C	R																																															
Kiwangwa-1	730			P			F	F		R	R																																													
Kiwangwa-1	735			P-M			A	F	R			R	R	R		C	R	R	R	R	C	R																																		
Kiwangwa-1	740			P						R																																														
Kiwangwa-1	750			P				R																																																
Kiwangwa-1	760			P-M			F	R	R			R																																												
Kiwangwa-1	770			P			A	C	F																																														R	
Kiwangwa-1	775			B																																																				
Kiwangwa-1	780			P																																																		R	R	
Kiwangwa-1	790			B																																																			RR	
Kiwangwa-1	795			P-M		R	A	F	C		R																																										R		R	
Kiwangwa-1	800			P		R	A	A	F	R																																												R		
Kiwangwa-1	810	Late Aptian	*G. algerianus* zone	P		R	A	A	R	R	R																																													
Kiwangwa-1	825			P		R	A	A	F	R																																													R	
Kiwangwa-1	835			P		R	C	F	R																																												R	R		
	845			P			F	R																																																
Kiwangwa-1	855	INDERMINATE	UNZONED	P	A		F	R																																																
Kiwangwa-1	860			P	A		A	C	F																																															
Kiwangwa-1	865			P	A	R	A	A																																												R	F	R	

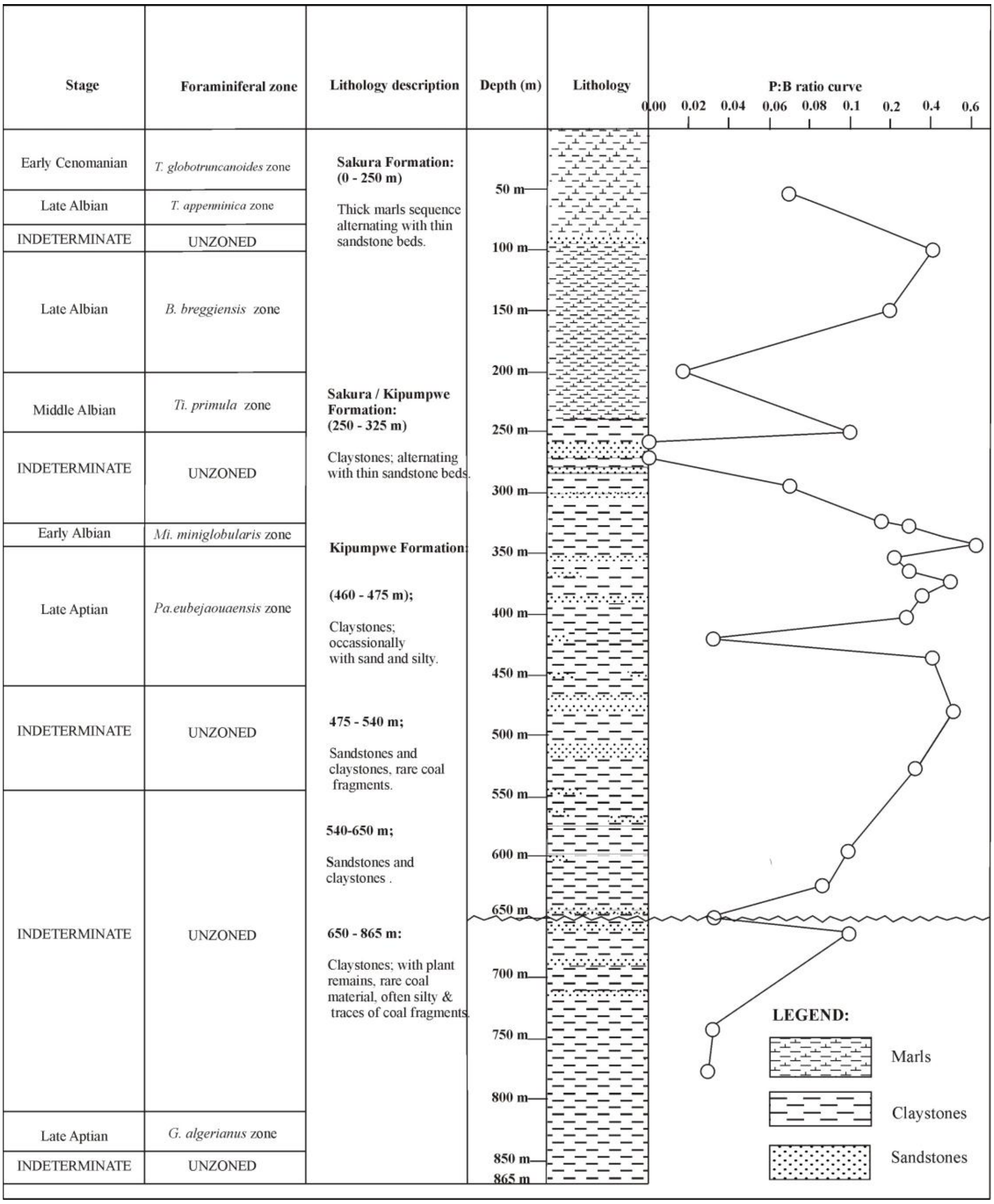


Figure 4.3: Summary biozonation, lithostratigraphy and P: B ratio curve for Kiwangwa-1 borehole.

Note: *G.=Globigerinelloides*, *Mi.=Microhedbergella*, *Pa.=Paraticinella*, , *Ti.= Ticinella*, *T.= Thalmanninella.*

4.4 Kisarawe-1 Borehole

The Kisarawe-1 borehole (see figure 4.3) is located at Latitude 7º 00' 18.60" S and Longitude 39º 03' 31.80" E, drilled in Dar-es-Salaam Platform or southern Ruvu Basin. This well was drilled by AGIP in 1976. It was spud on the Tertiary (Miocene) and drilled down to a total depth of 4057 m in the late Jurassic. The well was drilled to test early Cretaceous and middle Jurassic reservoirs. The well was plugged and abandoned as a dry hole and no hydrocarbon shows were encountered. This work covers the late Aptian to late Cenomanian of this borehole only. Sixty-three samples were studied and were only ditch cuttings. Reworked specimens were noticed throughout the borehole.

4.4.1 Lithostratigraphy:

The lithostratigraphy is summarized from the well completion report compiled by AGIP and is described below.

4.4.1.1 Wami River Series: (1737.4 - 1823 m)

The top part of the studied interval is predominantly clay, olive greenish grey in colour, sticky, and calcareous. From 1822.7 to 1862.3 m is a marl sequence, medium grey to bluish grey, soft, sticky, with pyrite cubes in small amounts seen throughout this interval. This interval is rich in planktonic foraminifera.

4.4.1.2 Sakura Formation / Kingongo Formation (1862.3–1927.3 m)

This is an interval of limestone underlain and overlain by marls sequence, medium grey to bluish grey, soft, sticky, pyrite cubes in small amounts seen throughout this interval.

4.4.1.3 Kipumpwe/Kihuluhu Formation (1975.1 m to 2006 m)

This interval is of claystone, dark greenish grey, silt, calcareous, blocky, pyritic and micaceous, siltstone, hard, calcareous, blocky pyritic, dark grey, micaceous, argillaceous.

4.4.1.4 Kipumpwe/Kihuluhu Formation (2006-2067 m)

This intervalcomprised of siltstone, hard, calcareous, blocky, pyritic, dark grey, micaceous, and argillaceous. From 2067-2103.1 m are dark greenish grey claystones that are silt calcareous, blocky, pyritic, and micaceous. From 2103.1-2201 m there is hard, calcareous, blocky, pyritic, dark grey, micaceous, argillaceous siltstones. From 2201-2268 m there are claystones that are dark greenish grey, blocky, pyritic, micaceous, and calcareous.

4.4.2 Foraminiferal biostratigraphy

The distribution chart for planktonic and benthic foraminifera is shown in Table 4.4. Eight biozones were identified based on key zonal markers as described in this section.

4.4.2.1 Late Aptian (2170.2-2268 m): Globigerinelloides algerianus Total range zone

Planktonic foraminiferal species are moderately diverse and abundance varies from rare to abundant. The lowest occurrence of (LO) *algerianus* at 2268 m indicates late Aptian. This zone contains *Globigerinelloides algerianus* and others including common late Aptian hedbergellids and *Globigerinelloides* (see table 4.4 and plates 3.3-3.5).

Calcareous benthic forms are moderately diverse with rare to common abundance and are similar to agglutinated forms. Benthic forms present include *Conorotalites bartensteini aptiensis, Gavelinella barremiana,* and many others (see table 4.4 and plates 3.16 - 3.17,). The present agglutinated forms ares such as *Ammodiscus cretacea, Glomospira charoides, Glomospirella* sp., (see table 4.4 and plates 3.17 and 3.18).

4.4.2.2 Late Aptian (1951 -2155m): Paraticinella eubejaouaensis Taxon range zone

The highest occurrence (HO) of *Paraticinella eubejaouaensis* at 1951 m and its lowest occurrence (LO) at 2155 m indicating the total interval range of the *Paraticinella eubejaouaensis* to be of late Aptian age. Planktonic foraminiferal species diversity and abundance is high and preservation varies from poor to moderate. Pyrite cubes and ostracods are also present. Species of *Paraticinella eubejaouaensis* are abundant in this interval and samples analyzed fall within the *Paraticinella eubejaouaensis* zone. Accompanied by late Aptian planktonic species of *Globigerinelloides* spp., *Pseudoguembelitria* sp., *hedbergellids* and others (see table 4.4 and plates 3.5 - 3.6, 3.9 - 3.10 and plate 3.12).

Benthic foraminifera are highly diversified with variation from rare to abundant. Species that are present include *Conorotalites bartensteini aptiensis, Gavelinella* spp., *Globorotalites* sp., *Marsonella oxycona, Glomospira charoides* and many others (see table 4.4 and plates 3.17 - 3.18, 3.21).

4.4.2.3 Middle Albian (1932.4-1945 m): Ticinella primula Partial range zone

The diversity of planktonic species is very low and abundance varies from frequent to common. The lowest occurrence (LO) of *Ticinella primula* at 1945 m indicates middle Albian age. Species present include *Ticinella primula, Muricohedbergella* spp., and others (see table 4.4 and plates 3.2, 3.9, and plate 3.13).

Calcareous nd agglutinated benthic foraminifera are moderately diverse and abundance varies from rare to few except *Gavelinella intermedia* which are abundant. Species encountered in this interval include: *Marsonella oxycona*, *Pseudogaudryinella* sp, and many others (see table 4.4 and plates 3.17, 3.21, 3.23).

4.4.2.4 Late Albian (1914-1920.2 m): Biticinella breggiensis Interval zone

The lowest occurrence (LO) of *Biticinella breggiensis* at 1920.2 m indicates late Albian age. Planktonic species diversity is low and their abundance varies from rare to few abundant. Planktonic foraminifera present include *Biticinella breggiensis, Ticinella praeticinensis, Pseudothalmanninella subticinensis* and others (see table 4.4 and plates 3.1 and 3.12).

Benthic forms are moderately diverse and abundance is from rare to few. Species present include *Gavelinella intermedia, Globorotalites sp.,* and others (see table 4.4 and plates 3.17-3.18). Agglutinated forms are moderately diverse in this interval with rare abundance with few pyrite cubes present. Species encountered are *Marsonella oxycona, Tristix excavata, Tritaxia pyramidata* and others (see table 4.4 and plates 3.21, 3.25).

4.4.2.4 Late Albian (1829-1908 m): *Thalmanninella appenninica* Interval zone

The lowest occurrence (LO) of *Thalmanninella appenninica* at 1908 m indicates topmost late Albian age. Planktonic species diversity is moderate to slightly high and abundance varies from rare to abundant but majority of the species are few to abundant.

Thalmanninella appenninica is present throughout this interval with joint occurrence of *Planomalina buxtorfi*, *Muricohedbergella* spp., and many others (see table 4.4 and plates 3.9 - 3.11 and 3.14). Preservation varies from poor to moderate and pyrite cubes are rare to few in abundance.

Calcareous benthic species that are diversified and abundant vary from rare to common. Species present include *Gavelinella intermedia*, *Osangularia californica*, and many others (see table 4.4 and plates 3.17 & plate 3.21). Agglutinated forms with the highest diversity and are rare in abundance except some with few to common in abundance. Species present include *Ammodiscus cretacea*, *Pseudogaudryinella* sp., and many others (see table 4.4 and plates 3.16 and plate 3.23). Ostracods seen at 1874.5 m; few are in abundance and at 1902 m are rare and few to common abundance in pyrite cubes.

4.4.2.5 Early Cenomanian (1786.1-1823 m): *Thalmanninella globotruncanoides* Interval zone

The lowest occurrence (LO) of *Thalmanninella globotruncanoides* at 1823 m indicates early Cenomanian age. Species' diversity is low and abundance varies from rare to abundant but there are few species with good abundance and the rest with rare to few. Preservations vary from poor to moderate. Planktonic foraminifera encountered in this interval include: *Thalmanninella globotruncanoides*, *Macroglobigerinelloides* sp., *Muricohedbergella* spp., *Praeglobotruncanids* and others (see table 4.4 and plates 3.9; 3.11 and plate, 3.15).

Calcareous benthic foraminifera diversified with majority with rare and few abundant. Species present include, *Pleurostomella sp.*, *Rzehakina epigona*, *Gavelinella intermedia*, *Neoflabellina* sp., and many others (see table 4.4 and plates 3.17, 3.19 and plates 3.23-3.24). Agglutinated forms are moderate in diversity and rare in abundance, species of *Marssonella oxycona*, *Spiroplectammina* sp., and others including pyrite cubes vary from rare to abundant (see table 4.4 and plate 3.2, and plate 3.25).

4.4.2.6 Early-Middle Cenomanian (1774-1780 m): Thalmanninella reicheli Total range zone

The zone of *Thalmanninella reicheli* is a biostratigraphic interval of the total range of *Thalmanninella reicheli* (Bolli (1966)). The index taxon *Thalmanninella reicheli* is present with its highest occurrence (HO) at 1764 m and lowest occurrence (LO) at 1780 m indicative of early to middle Cenomanian age of this interval. Preservation of microfauna is poor to moderate throughout the studied intervals. Planktonic foraminiferal diversity is low and abundance varies from rare to abundant. Most specimens have either calcite or pyrite infill. Planktonic foraminifera present at this interval are *Thalmanninella*, *Muricohedbergella*, *Praeglobotruncanids* and many others (see table 4.4 and plates 3.9, 3.11 and plates 3.15).

Calcareous benthic foraminifera are rare and preservations vary from poor to moderate. Species that are present include *Gyroidinoides* sp., *Gavelinella intermedia* and others (see table 4.4, plates 3.17, and 3.19). Agglutinated forms are rare in abundance and less diverse. Species that are present include *Ammodiscus cretacea*, *Spiroplectammina* sp., and others with rare in pyrite cubes (see table 4.4 and plates 3.16, and plate 3.25).

4.4.2.7 Middle-Late Cenomanian (1737.4-1762 m):Rotalipora cushmani Total range zone

The zone of *Rotalipora cushmani* is defined as a biostratigraphic interval corresponding to the total range of *Rotalipora cushmani* (Borsetti (1962)). The lowest occurrence (LO) of *Rotalipora cushmani* at 1762 m and highest occurrence (HO) at 1737.4 m is the total interval of the *Rotalipora cushmani* and indicates middle to late Cenomanian age. Species diversity is slightly moderate to low and abundance varies from rare to abundant and a few long ranging tax are abundant. Preservation varies from poor to moderate. Planktonic species present in this interval include *Muricohedbergella* spp., *Praeglobotruncana* spp., *Rotalipora cushmani*, *Thalmanninella* spp., and others (see table 4.4 and plates 3.9, 3.11 - 3.12).

Calcareous and agglutinated foraminifera are diverse and range from rare to common in abundance. Calcareous benthic forms include *Gavelinella* spp., *Gyroidinoides* sp., and others (see table 4.4 and plates 3.17, and 3.19). Agglutinated forms are *Ammodiscus cretacea*, *Glomospira charoides*, and others. Rare pyrite cubes present in this interval (see table 4.4, and plates 3.16 & 3.18).

4.4.3 Synthesis

Figure 4.4 shows the summarised stratigraphy of this borehole. The succession of zones is complete from the late Cenomanian to the middle Albian. A substantial hiatus is inferred at ~ 1950 m separating the middle Albian *Ticinella primula* zone from the uppermost Aptian *Paraticinella eubejaouaensis* zone. Below that the succession appears to be complete down into the *Globigerinelloides algerianus* zone.

Planktonic: benthic ratios are relatively high throughout indicating the presence of relatively deep water, even in the intervals of limestone which are interpreted as Hemipelagic chalks not shelf limestone.

Table 4.4: Kisarawe borehole-1 planktonic and benthic foraminifera range chart.

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zone	*Hedbergella aptiana*	*Hedbergella sigali*	*Hedbergella infracretacea*	*Globigerinelloides ferreolensis*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Hedbergella trocoidea*	*Pseudoguembelitria sp.*	*Paraticinella eubejaouensis*	*Paraticinella transtoria*	*Muricohedbergella delrioensis*	*Muricohedbergella albiana*	*Muricohedbergella planispira*	*Ticinella primula*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex* (sp. 1)	*Muricohedbergella simplex* (sp. 2)	*Biticinella breggiensis*	*Ticinella raynaudi*	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Pseudothalmanninella subticinensis*	*Heterohelix moremani*	*Thalmanninella appenninica*	*Planomalina buxtorfi*	*Praeglobotruncana delrioensis*	*Thalmanninella globotruncanoides*	*Praeglobotruncana stephani* (sp. 3)	*Praeglobotruncana stephani* (sp. 1)	*Thalmanninella reicheli*	*Thalmanninella deekei*	*Rotalipora cushmani*	*Thalmanninella greenhornensis*	*Praeglobotruncana gibba*	
Kisarawe-1	1737.4	P-M	Middle - Late Cenomanian	*R. cushmani* zone													R		R				F							F			F			R			R	A	F	HO of *R. Cushmani*
Kisarawe-1	1750	P-M															R		R				R							F			F			F		R	R	A	C	
Kisarawe-1	1756	P-M															F		R				R							R			F			R			R	A	C	LO of *R. cushmani*
Kisarawe-1	1762	P-M															C		R		R		F										C			F			F	A	A	
Kisarawe-1	1774	P-M	Early - Middle Cenomanian	*T. reicheli* zone													C		R				R							R			F	R		F	R		F	A		
Kisarawe-1	1780	P-M															A		R				F	R						R			C	F		C	R		F	A		LO of *T. reicheli*
Kisarawe-1	1786.1	P-M	Early Cenomanian	*T. globotruncanoides* zone													A		R				R							R			F	R		R						
Kisarawe-1	1792.2	P-M															F		R				F							R			F	R		F						
Kisarawe-1	1798.3	P-M															C		R				F										R	F		R						
Kisarawe-1	1804.4	P															F		R			C	R							R				C								
Kisarawe-1	1811	P															F		R			C	R							R				C								
Kisarawe-1	1817	P															F		R			F	F							R			R	R		R						
Kisarawe-1	1823	P-M															R	R	R			R	R							R				R	RR							LO of *T. globotruncanoides*
Kisarawe-1	1829	P	Late Albian	*T. appenninica* zone													R	F	R			R	R								F											
Kisarawe-1	1835	P-M															C	F	R			R	R								C	R										
Kisarawe-1	1841	P-M															R	R				C	R								C	R	R									
Kisarawe-1	1847.1	P-M															C	F				F	R								C	F	F									
Kisarawe-1	1853.2	P-M																			R										C	F	F									
Kisarawe-1	1859.3	P															R	R				F	R							R	F	F	C									
Kisarawe-1	1865.4	P																													F	R	R									
Kisarawe-1	1872	P-M															C	A	F								R	R			C		A									
Kisarawe-1	1875	P-M															A	C	F			A	R					R			A	R										
Kisarawe-1	1884	P-M															A	C	F			A	R			R				R	C	R										
Kisarawe-1	1890	P-M															C	R	R			A	R							R	C	F	R									
Kisarawe-1	1896	P-M															F	R				C	R							F	R	F	R									
Kisarawe-1	1902	P-M															F					A	R								R	F	R									
Kisarawe-1	1908	P-M															A	C	F			F	R			R					F											LO of *T. appenninica*
Kisarawe-1	1914	P-M	Late Albian	*B. breggiensis* zone													F		F				R		R				C													
Kisarawe-1	1920.2	P-M															A	C	A				F		R				C													LO of *B.breggiensis*
Kisarawe-1	1932.4	P-M	Middle Albian	*Ti. primula* zone													C		F	F			F																			
Kisarawe-1	1945	P-M															F		F	F																						LO of *T. primula*

Table 4.4: Kisarawe borehole-1 planktonic and benthic foraminifera range chart continued.

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zones	*Hedbergella aptiana*	*Hedbergella sigali*	*Hedbergella infracretacea*	*Globigerinelloides ferreolensis*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Hedbergella trocoidea*	*Pseudoguembelitria* sp.	*Paraticinella eubejaouensis*	*Paraticinella transtoria*	*Muricohedbergella delrioensis*	*Muricohedbergella albiana*	*Muricohedbergella planispira*	*Ticinella primula*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex*	*Muricohedbergella simplex* (sp. 2)	*Biticinella breggiensis*	*Ticinella raynaudi*	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Pseudothalmanninella subticinensis*	*Heterohelix moremani*	*Thalmanninella appenninica*	*Planomalina buxtorfi*	*Praeglobotruncana delrioensis*	*Thalmanninella globotruncanoides*	*Praeglobotruncana stephani* (sp. 3)	*Praeglobotruncana stephani* (sp. 1)	*Thalmanninella reicheli*	*Thalmanninella deekei*	*Rotalipora cushmani*	*Thalmanninella greenhornensis*	*Praeglobotruncana gibba*	
Kisarawe-1	1951	P-M	Late Aptian	*Pa. eubejaouensis* zone	F	R	F		R	R			R		F																											HO of *Pa. eubejaouensis*
Kisarawe-1	1957	P-M			F	R	R		R	R			R		C																											
Kisarawe-1	1963	P-M			F		R			R			R		F																											
Kisarawe-1	1975.1	P-M			F					R				R	A																											
Kisarawe-1	1981.2	P-M			F	R									F																											
Kisarawe-1	1993.4	P-M			A	F	R			R					F																											
Kisarawe-1	2000	P-M			C		F			F					C																											
Kisarawe-1	2006	P-M								R					R																											
Kisarawe-1	2012	P-M			C	R	F			F					R																											
Kisarawe-1	2067	P-M			C	F	F		R	F			R	R	R																											
Kisarawe-1	2073	P-M			C	F	F		R						F																											
Kisarawe-1	2085	P-M			F																																					
Kisarawe-1	2091	P-M			C	A	R		R	R					R																											
Kisarawe-1	2103.1	P-M			C		C								F																											
Kisarawe-1	2115.3	P-M			F										R	R																										
Kisarawe-1	2128	P-M				F	F						R		R																											
Kisarawe-1	2134	P-M			R		R								R																											
Kisarawe-1	2149	P-M			A										R																											LO of *Pa. eubejaouensis*
Kisarawe-1	2155	P-M			A		C		R				R		R																											
Kisarawe-1	2170.2	P-M	Late Aptian	*G. algerianus* zone	R	R		R			R		R																													
Kisarawe-1	2179.3	P-M			R			C																																		
Kisarawe-1	2189	P-M			A		F	F		F	R		F																													
Kisarawe-1	2195	P-M			A	F	C	F			R																															
Kisarawe-1	2207	P-M			F			F			R																															
Kisarawe-1	2219	P-M			R		R	R	R		R		R																													
Kisarawe-1	2225	P-M			F			F		F	C	RR																														
Kisarawe-1	2237	P-M			A			F		F	C																															
Kisarawe-1	2243.3	P-M			F		F	R	R	R	F																															
Kisarawe-1	2256	P-M			A	F	R	F		F	C																															LO of *G. algerianus*
Kisarawe-1	2268	P-M			A	C	C	R	R	F	C		R																													

Note: *B.* = *Biticinella*, *G.* = *Globigerinelloides*, *Pa.* = *Paraticinella*, *R.* = *Rotalipora*, *T.* = *Thalmanninella*, *Ti.* = *Ticinella*, LO = Lowest Occurrence, HO = Highest Occurrence moderate

P-M = Poor to Moderate, RR = Rare; 1 specimen, R = Rare; 2-5 specimens, F = Frequent; 6-10 specimens, C = Common; 11-20 specimens, A = Abundant ≥21 specimens

Table 4.4: Kisarawe borehole-1 planktonic and benthic foraminifera range chart continued.

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zone	*Gavelinella barremiana*	*Osangularia* sp.	*Pseudonodosaria* sp.	*Ammodiscus cretacea*	*Marssonella kummi*	*Glomospira charoides*	*Lenticulina muensteri*	*Lenticulina* sp.	*Laevidentalina communis*	*Psilocitherella* sp.	*Trochammina* sp.	*Bathysiphon* sp.	*Glomospirella* sp.	*Gavelinella* sp. 1	*Conorotalites bartensteini aptiensis*	*Gyroidinoides gracillima*	*Ramulina* sp.	*Gaudryina* sp.	*Rzehakina epigona*	*Ammobaculites* sp.	*Marssonella oxycona*	*Spiroplectammina* sp.	*Hormosina* sp.	*Neoflabellina* sp.	*Gavelinella intermedia*	*Pseudogaudryinella dividens*	*Quinqueloculina antiqua*	*Pleurostomella reussi*	*Tritaxia pyramidata*	*Tristix excavata*	*Hyperammina* sp.	*Ramulina tetrahedralis*	*Gaudryina gradata*	*Gyroidinoides* sp.	*Pleurostomella* sp.	*Osangularia californica*	*Saracenaria triangularis*	*Iron nodules*	*Pyrite*	*Ostracods*
Kisarawe-1	1737.4	P-M	Middle - Late Cenomanian	*R. cushmani* zone								R						R							R							R						C					R	
Kisarawe-1	1750	P-M						R		F		R			R			R							R													F	R				R	
Kisarawe-1	1756	P-M						R				R						R				R																R					R	
Kisarawe-1	1762	P-M										R						R				R			R	R				R								R					R	
Kisarawe-1	1774	P-M	Early - Middle Cenomanian	*T. reicheli* zone				R				R						R							R					R								R			R		R	
Kisarawe-1	1780	P-M						R																								RR											R	
Kisarawe-1	1786.1	P-M	Early Cenomanian	*T. globotruncanoides* zone				R																	R	R																	R	
Kisarawe-1	1792.2	P-M						R		R																													R				A	
Kisarawe-1	1798.3	P-M					R	R																	R								R					F					A	
Kisarawe-1	1804.4	P																R							R	R						RR					R	F					R	
Kisarawe-1	1811	P																R							R					R								R					F	
Kisarawe-1	1817	P						R				R			R			R					R		R			R	R									R		R			C	
Kisarawe-1	1823	P-M						R		R			R			R	R	R							R				F			RR	R					F					C	
Kisarawe-1	1829	P	Late Albian	*T. appenninica* zone																																							F	
Kisarawe-1	1835	P-M								R			R																R												R		F	
Kisarawe-1	1841	P-M																R							R				R											R			F	
Kisarawe-1	1847.1	P-M						R																	R				F														F	
Kisarawe-1	1853.2	P-M						R		R															R				R														F	
Kisarawe-1	1859.3	P						F										R					R		R	R			R		R		R											
Kisarawe-1	1865.4	P						R																	R				R		R												F	
Kisarawe-1	1872	P-M						R		R													R		R	R			R				R										F	F
Kisarawe-1	1875	P-M						R		R					R	R	R								R			R	A	R						R	R						F	
Kisarawe-1	1884	P-M					R	R										C							R	F			F														F	
Kisarawe-1	1890	P-M						R		R						R	R						R			C			C														F	
Kisarawe-1	1896	P-M														R										F			F							R							F	
Kisarawe-1	1902	P-M						R																					F														R	R
Kisarawe-1	1908	P-M						R																	R	R			R	R													F	
Kisarawe-1	1914	P-M	Late Albian	*B. breggiensis* zone								R	R		R	R							R		R				A	R			R	R	R								F	
Kisarawe-1	1920.2	P-M						R							R										R																			
Kisarawe-1	1932.4	P-M	Middle Albian	*Ti. primula* zone				R				R													R				R				R											
Kisarawe-1	1945	P-M						R		F		R	R		F														R	R														

Table 4.4: Kisarawe borehole-1 planktonic and benthic foraminifera range chart.

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zones	*Gavelinella barremiana*	*Osangularia sp.*	*Pseudonodosaria sp.*	*Ammodiscus cretacea*	*Marssonella kummi*	*Glomospira charoides*	*Lenticulina muensteri*	*Lenticulina sp.*	*Laevidentalina communis*	*Psilocitharella sp.*	*Trochammina sp.*	*Bathysiphon sp.*	*Glomosperella sp.*	*Gavelinella sp.*	*Conorotalites aptiensis*	*Gavelinella gracillima*	*Ramulina sp.*	*Gaudryina spp.*	*Rhezakina epigona*	*Ammobaculites sp.*	*Marssonella oxycona*	*Spiroplectammina sp.*	*Hormosina sp.*	*Neoflabellina sp.*	*Gavelinella intermedia*	*Pseudogaudryinella dividens*	*Quinqueloculina antiqua*	*Pleurostomella reussi*	*Tritaxia pyramidata*	*Tristix excavata*	*Hyperammina sp.*	*Ramulina tetrahedralis*	*Praebulimina sp.*	*Gyroidinoides sp.*	*Pleurostomella sp.*	*Osangularia californica*	*Saracenaria triangularis*	Iron nodules	Pyrite	Ostracods
Kisarawe-1	1951	P-M	Late Aptian	*Pa. eubejaouaensis* zone	F			R		F		R					R																											
Kisarawe-1	1957	P-M			F	R		F		C		R	R		R	R	R	R	R																									
Kisarawe-1	1963	P-M			R							R							R																									
Kisarawe-1	1975.1	P-M			A			F		F					R		R										R																	
Kisarawe-1	1981.2	P-M																R								R																		
Kisarawe-1	1993.4	P-M						R		R													R																					
Kisarawe-1	2000	P-M																																										
Kisarawe-1	2006	P-M			C			R		R					R					R																								R
Kisarawe-1	2012	P-M			F			R		R														R																				R
Kisarawe-1	2067	P-M			R			R		R									R																									
Kisarawe-1	2073	P-M						R											R																									R
Kisarawe-1	2085	P-M			R																																							
Kisarawe-1	2091	P-M						R		R											R																							
Kisarawe-1	2103.1	P-M						R		R		R				R					R	F																						
Kisarawe-1	2115.3	P-M																		R																								
Kisarawe-1	2128	P-M			R																																							
Kisarawe-1	2134	P-M			R						R	R	R						R																									
Kisarawe-1	2149	P-M			R			R		R							R																											
Kisarawe-1	2155	P-M			R			R		R			R		R	R																												
Kisarawe-1	2170.2	P-M	Late Aptian	*G. algerianus* zone															R																									
Kisarawe-1	2179.3	P-M						R		R								R																										
Kisarawe-1	2189	P-M			F					R						R	R																											
Kisarawe-1	2195	P-M			F	R		R		R		R			R	R																												
Kisarawe-1	2207	P-M						R						RR																														
Kisarawe-1	2219	P-M			R					R																																		
Kisarawe-1	2225	P-M			R		R				R	R	R																															
Kisarawe-1	2237	P-M			C																																							
Kisarawe-1	2243.3	P-M																																										
Kisarawe-1	2256	P-M						R	R	R																																		
Kisarawe-1	2268	P-M			C	R	R	F																																				

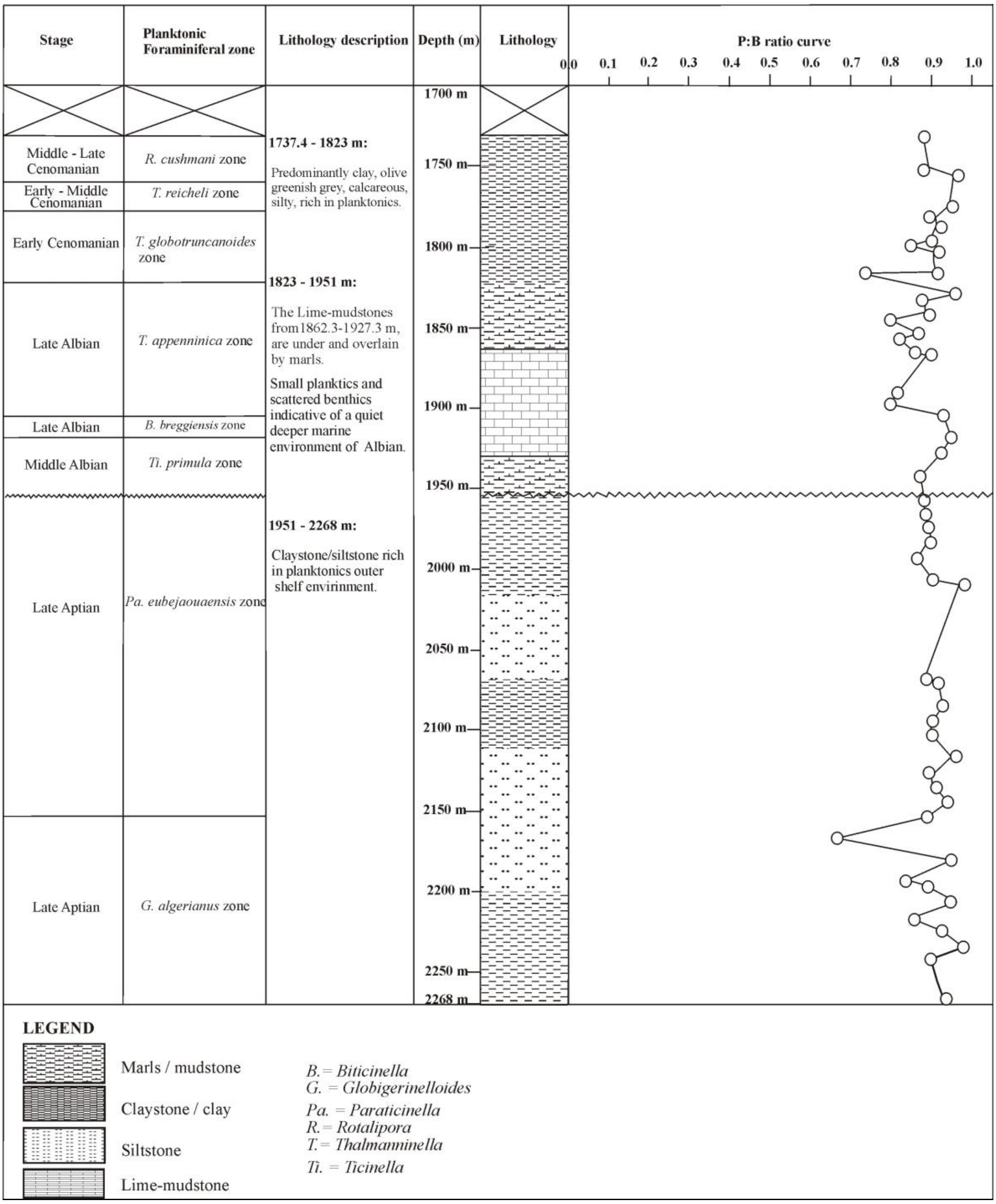


Figure 4.4: Summary biozonation and lithostratigraphy and P:B ratio curve for Kisarawe-1 borehole.

4.5 Luhoi-1 borehole

The Luhoi-1 borehole (7° 51' S, 38° 57' E) (Figure 4.4) was drilled in the central coastal basin (Rufiji Trough by the State Mining Corporation (STAMICO) under contract from the Tanzania Petroleum Development Corporation (TPDC) in 1992/3. The hole was plugged and abandoned due to technical problems after 296.0 m were drilled, with continuous coring. This borehole was drilled to investigate the areal extent of Albian-Cenomanian shales encountered in three shallow holes east of Wingayongo Hill and the extent of the bitumen impregnation found at Wingayongo and at the Luhoi hot springs. The borehole was spud on recent sediments and ended in the early Cretaceous. There were frequent occurrences of gas shows throughout the section.

4.5.1 Lithostratigraphy

Lithostratigraphy descriptions are summarized here from the borehole completion report (Msindai, 1993). The borehole penetrated recently to mid-cretaceous sediments. The core recovery in the cretaceous section was high (75%). Both early and late cretaceous sediments were drilled. The cretaceous unconformable underlies the Neogene with notable absence of the Paleogene and Maastrichtian. Within the Cretaceous, the Turonian and Cenomanian are not present, indicating an unconformity between the late and early Cretaceous.

The mid-Cretaceous succession below 251 m unconformable underlies the upper cretaceous. It consists of very calcareous and micaceous massive, indurated, bioturbated, greyish-green to olive greenish-grey claystones between 251 m and 287 m. Below 287 m, the mid-Cretaceous is dominated by fine grained moderately sorted, very calcareous, clayey, well consolidated buff to grey sandstones. The lower six meters were not cored (refer to fig. 4.5: Luhoi-1 Stratigraphic log).

Eighty samples were studied for this research from 272 m to 293 m. The lithostratigraphy units are summarized below.

4.5.1.1 Kingongo Formation (272.0-274 m)

This interval is claystone, calcareous, indurated and bioturbated, greyish green to olive greenish-grey, with mica flakes and pyrite cubes.

4.5.1.2 Kihuluhulu Formation (274-291.4 m)

274-281 m, claystone, massive dark greyish green to olive greenish grey, calcareous, seen pyrite cubes and mica flakes.

281.0 – 284.0 m: Claystone, calcareous, dark greenish grey to olive greenish grey, pyrite, and mica flakes, bioturbated, hard. Towards the bottom, sandstone bed with pink to light brown in colour, calcareous.

284.0 - 287.0 m: Claystone, very sandy, olive greenish grey to brownish, fine grain, well consolidated, buff to grey, clayey, calcareous.

287.0 - 289.59 m: Sandstone; fine grain, moderately sorted, very calcareous, clayey, well consolidated buff to grey.

289.59 - 291.40 m: Sandstone; fine grain, moderately sorted, very calcareous, clayey, well consolidated buff to grey.

291.40 - 293. No recovery.

4.5.2 Foraminiferal biostratigraphy

The early Cretaceous sedimentary sequence of a cored Luhoi-1 borehole (Rufiji Trough) has been examined. the sequence has been studied for benthic and planktonic foraminifera as reported in the distribution chart (see table 4.5). Planktonic foraminifera vary in preservation vary from poor to moderate; calcareous benthic ranges from moderate to good, while agglutinated forms are better preserved than the rest. The (272 - 296 m) interval of Luhoi-1 borehole is assigned to the age of late Aptian to late Albian, Luhoi-1 borehole samples reveal characteristic foraminiferal assemblages which can be divided into the following

4.5.2.1 Indeterminate (284.9 - 289.4 m): Unzoned

Samples that were analyzed from 284.9-285.2 m did not contain any planktonic foraminifera. Only benthic foraminifera with low diversity and abundance vary from rare to abundant and are poorly preserved. Species present include *Bathysiphon* sp., *Spiroplectammina* sp., and *Psilocitherella recta* (see table 4.5 and plates 3.16, 3.23 & plate 3.25). Also samples analyzed from 285.4-289.4 m did not contain any microfauna (Barren). Therefore this interval did not have any index taxon of planktonic foraminifera and was not dated and not placed in any of the planktonic foraminiferal biozones.

4.5.2.2 Late Aptian (283.4 m-284.6 m): Globigerinelloides algerianus Total range zone

The lowest occurrence (LO) of *Globigerinelloides algerianus* at 284.6 m, and its highest occurrence (HO) at 283.4 m indicate late Aptian age of this interval and is assigned to the *Globigerinelloides algerianus* total range zone. Species diversity and abundance is slightly less than the unit above and abundance varies from rare to frequent with few long ranging with good abundance. Planktonic species present include *Globigerinelloides algerianus, Globigerinelloides barri,* and common late Aptian hedbergellids (see table 4.5, and plates 3.3 - 3.5).

Calcareous benthic foraminifera are low in diversity and their abundance varies from rare to abundant. Species present include *Lenticulina* (*Lenticulina*) *nodosa, Conorotalites bartensteini aptiensis,* and others (see table 4.5 plates 3.17 & 3.20). Agglutinated forms such as *Ammodiscus cretacea*; *Bathysiphon* sp.*,* and others including ostracods and pyrite cubes are present in this interval (see table 4.5 and plates 3.16).

4.5.2.3 Indeterminate (Unzoned: 281.9-283 m)

The interval from 281.9-282.1 m is barren. The interval from 282.5-283 m there is no planktonic foraminifera encountered in this interval. Benthic foraminifera are few and some varies in abundance from rare to abundant. Species of *Ammodiscus cretacea,* *Conorotalites bartensteini aptiensis,* and others including ostracods and pyrite cubes are present (see table 4.5, and plates 3.16 and 3.17).

4.5.2.4 Latest Aptian (276.2 m - 281.7 m): Paraticinella eubejaouaensis Taxon range zone

A stratigraphic hiatus is noticed at 276.2 m. where the late Albian sediments are underlain by the uppermost Aptian sediments. This is proved by the highest occurrence (HO) of *Paraticinella eubejaouaensis* 276.2 m that are present throughout to 281.7 m (LO; lowest occurrence). This interval is assigned to the *Paraticinella eubejaouaensis* Taxon range zone. The variation of species' diversity is low and abundance varies from rare to abundant. Planktonic species present include *Paraticinella eubejaouaensis,* and common late Aptian hedbergellids and *Globigerinelloides* (see table 4.5 and plates, 3.3 – 3.6 and plates 3.9 - 3.10).

Calcareous benthic foraminifera are moderately diverse and abundance varies from rare to abundant. Benthic species present include: *Conorotalites bartensteini aptiensis, Gavelinella barremiana, Lenticulina (Lenticulina) nodosa,* and many others (see table 4.5 and plates 3.17, & 3.20).

Agglutinated forms are diverse with abundance rate from rare to frequent. Species encountered in this interval are *Ammodiscus cretacea, Bathysiphon* sp., and many others (see table 4.5 and plates 3.16).

4.5.2.5 Late Albian (272.1 m-275.9 m): Biticinella breggiensis Interval zone

The lowest occurrence (LO) of *Biticinella breggiensis* at 275.9 m and through to 275.9 m indicates the upper Albian stratigraphic level of this interval. Species' diversity is moderate and abundance varies from rare to abundant, and preservation varies from poor to moderate. Planktonic foraminifera that are present in this interval include: *Biticinella breggiensis, Pseudothalmanninella subticinensis, Ticinella* spp., *Muricohedbergella* spp., and many others (see table 4.5 and plates 3.1, 3.12, 3.17 and plate 3.20).

Calcareous benthic foraminifera diversity and abundance varies from rare to abundant, the majority are rare. Species present include *Gavelinella intermedia, Patellina* *subcretacea*, and others (see table 4.5 and plates 3.17, & 3.23).

Agglutinated forms vary in abundance from few to abundant. Species present include *Ammodiscus cretacea*, *Tritaxia pyramidata*, *Glomospira charoides* and others including ostracods and pyrite cubes are present throughout this interval (see table 4.5 and plates 3.16, 3.18, & plate 3.23, 3.25).

4.5.3 Synthesis

In the Luhoi-1 borehole a major hiatus exists at 276.2 m which cuts out most of the Albian, although there is no obvious change in sediment type at this level. P/B records show distinct variation from relatively shallow intervals with few planktonics to deeper intervals where they may be some high resolution cyclicity.

Table 4.5: Luhoi borehole-1 planktonic and benthic foraminifera range chart.

Well name	Top core depth (m)	Bottom core depths (m)	Core number	core section	Top sample interval (cm	Bottom sample interval (cm)	Depth below surface (m)	Preservation	Stage	Planktonic foraminiferal zones	*Hedbergella aptiana*	*Hedbergella infracretacea*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Globigerinelloides algerianus*	*Globigetinelloides barri*	*Hedbergella trocoidea*	*Paraticinella eubejaouaensis*	*Muricohedbergella delrioensis*	*Muricohedbergella albiana*	*Ticinella primula*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex*	*Ticinella praeticinensis*	*Biticinella breggiensis*	*Ticinella raynaudi*	*Ticinella roberti*	*Pseudothalmanninella subticinensis*	
Luhoi-1	272	273	53	1	0	10	272.1	P-M	Late Albian	*B. breggiensis* zone									A		R		F	F		A	R		R	
Luhoi-1	272	273	53	1	20	30	272.3	P-M											R	R			R	R		A		R		
Luhoi-1	272	273	53	1	40	50	272.5	P-M											R				F	F		A				
Luhoi-1	272	273	53	1	60	70	272.7	P-M											R		R		R	R		A		R		
Luhoi-1	272	273	53	1	80	90	272.9	P-M											R	R		R		R		A			R	
Luhoi-1	272	273	53	1	91	100	273	P-M											R	R			F	R		A		R		
Luhoi-1	273	274	53	2	0	10	273.1	P											R	R	R		F	F		C	R			
Luhoi-1	273	274	53	2	20	30	273.3	P											R	R				R		C				
Luhoi-1	273	274	53	2	35	45	273.5	P												R			F	R		A		R		
Luhoi-1	273	274	53	2	50	60	273.6	P											R	R	R		R	R	R	C	R			
Luhoi-1	273	274	53	2	70	80	273.8	P											R				F			C				
Luhoi-1	273	274	53	2	90	100	274	P															R			A				
Luhoi-1	274	275	53	3	0	10	274.1	P													R					F				
Luhoi-1	274	275	53	3	30	40.00	274.4	P															R			C				
Luhoi-1	274	275	53	3	50	60	274.6	P														R			R	A				
Luhoi-1	274	275	53	3	90	100.00	275	P															F			A				
Luhoi-1	275	276	54	1	0	30.00	275.3	M-G															F			A				
Luhoi-1	275	276	54	1	40	55	275.6	P-M													R		R			A				LO of *B. breggiensis*
Luhoi-1	275	276	54	1	60	70	275.7	P-M															R			A				
Luhoi-1	275	276	54	1	77	90	276	P-M															R		R	A				
Luhoi-1	276	277	54	2	13	24	276.2	P-M	Late Aptian	*Pa. eubejaouaensis* zone	F	R						R												
Luhoi-1	276	277	54	2	30	44	276.4	P-M			F							R												
Luhoi-1	276	277	54	2	50	60	276.6	P-M			F							R												HO of *Pa. eubejaouaensis*
Luhoi-1	276	277	54	2	70	80	276.8	P-M			F							R												
Luhoi-1	276	277	54	2	90	100	277	P			R	R						R												
Luhoi-1	277	278	54	3	0	20	277.2	P-M			F		R					R												
Luhoi-1	277	278	54	3	30	50	277.5	P-M			F		R					R												
Luhoi-1	277	278	54	3	55	65	277.7	P-M			F			R				R												
Luhoi-1	277	278	54	3	78	90	277.9	P-M			F							R												
Luhoi-1	277	278	54	3	92	100	278	P-M			R		R																	
Luhoi-1	278	279	55	1	0	10	278.1	P-M			R	R	R					R												
Luhoi-1	278	279	55	1	20	30	278.3	P-M			R																			
Luhoi-1	278	279	55	1	50	60	278.6	P			R							R												
Luhoi-1	278	279	55	1	70	80	278.8	P-M			R						R	R												
Luhoi-1	278	279	55	1	90	100	279	P-M			R	R					R	R												
Luhoi-1	279	280	55	2	0	10	279.1	P-M			F		R				R	R												
Luhoi-1	279	280	55	2	25	45	279.5	P			R						R	R												
Luhoi-1	279	280	55	2	55	65	279.7	P-M			R						R	R												
Luhoi-1	279	280	55	2	75	85	279.9	P-M			R	R					R	R												
Luhoi-1	279	280	55	2	90	100	280	P-M			R						R	R												
Luhoi-1	280	281	55	3	10	20	280.2	P-M			R			R			R	R												
Luhoi-1	280	281	55	3	34	50	280.5	P-M			R	R	R				R	R												
Luhoi-1	280	281	55	3	60	70	280.7	P-M			F						R	R												
Luhoi-1	280	281	55	3	80	90	280.9	P			R						R	R												
Luhoi-1	280	281	55	3	91	100	281	P-M			R	R					R	R												
Luhoi-1	281	282	56	1	40	50	281.5	P-M			R						R													LO of *Pa. eubejaouaensis*
Luhoi-1	281	282	56	1	60	70	281.7	P			R	R	R				R													
Luhoi-1	281	282	56	1	81	90	282	B	INDETERMINATE	UNZONED																				
Luhoi-1	282	283	56	2	0	10	282.1	B																						
Luhoi-1	282	283	56	2	41	50	282.5	P-M																						
Luhoi-1	282	283	56	2	51	60	282.6	P-M																						
Luhoi-1	282	283	56	2	61	70	282.7	P-M																						
Luhoi-1	282	283	56	2	80	90	282.9	P-M																						
Luhoi-1	282	283	56	2	91	100	283	P-M																						
Luhoi-1	283	284	56	3	19	35	283.4	P-M	Late Aptian	*G. algerianus* zone	F	F	R		F	R	R													HO of *G. algerianus*
Luhoi-1	283	284	56	3	40	55	283.6	P-M			F	F			F		R													
Luhoi-1	283	284	56	3	60	70	283.7	P-M			F	F	R		F		R													
Luhoi-1	283	284	56	3	75	95	284	P			F	F			F	R	R													
Luhoi-1	284	285	57	2	43	60	284.6	P			RR	R			R		R													
Luhoi-1	284	285	57	2	70	90	284.9	P	INDETERMINATE	UNZONED																				LO of *G. algerianus*
Luhoi-1	284	285	57	2	91	100	285	P																						
Luhoi-1	285	286	57	3	0	20	285.2	P																						
Luhoi-1	285	286	57	3	30	40	285.4	B																						
Luhoi-1	285	286	57	3	50	60	285.6	B																						

Table 4.5: Luhoi borehole-1 planktonic and benthic foraminifera range chart continued.

Well name	Top core depth (m)	Bottom core depths (m)	Core number	core section	Top sample interval (cm	Bottom sample interval (cm)	Depth below surface (m)	Preservation	Stage	Planktonic foraminiferal zones	*Psilocitharella recta*	*Bathysiphon* sp.	*Spiroplectammina* sp.	*Conorotalites barensteini aptiensis*	*Gavelinella intermedia*	*Nodosaria* sp.	*Lenticulina muensteri*	*Lenticulina (Lenticulina) nodosa*	*Astacolus* sp.	*Laevidentalina communis*	*Gavelinella* sp.	*Gavelinella barremiana*	*Trochammina* sp.	*Ammodiscus cretacea*	*Marssonella oxycona*	*Ammobaculites* sp.	*Gaudryina gradata*	*Reophax* sp.	*Rzehakina epigona*	*Gyroidinoides* sp.	*Patellina subcretacea*	*Glomospira charoides*	*Tritaxia pyramidata*	*Psilocitharella* sp.	*Pleurostomella* sp. 1	*Saccammina* sp.	*Glomospirella* sp.	Ostracods	Pyrite
Luhoi-1	272	273	53	1	0	10	272.1	P-M	Late Albian	*B. breggiensis* zone		C	R		R					RR				R	F	RR	R					RR					RR	R	R
Luhoi-1	272	273	53	1	20	30	272.3	P-M			RR	C	R		R										F		R			R						R		R	R
Luhoi-1	272	273	53	1	40	50	272.5	P-M				C	R		R	R								R	F		R			R		R	R					R	R
Luhoi-1	272	273	53	1	60	70	272.7	P-M				F	R		R										R		R			R	RR	RR			R	R	RR	R	R
Luhoi-1	272	273	53	1	80	90	272.9	P-M				F	R		R	R					F				R		R			R				R	R	R		R	R
Luhoi-1	272	273	53	1	91	100	273	P-M				R	R		R						F				F		R			R		RR	R	R	R	R		R	R
Luhoi-1	273	274	53	2	0	10	273.1	P				R			R	R				RR					F		R			R				R		R		R	R
Luhoi-1	273	274	53	2	20	30	273.3	P				R			R	R									F	RR	R			R				R				R	R
Luhoi-1	273	274	53	2	35	45	273.5	P				R			R	R					R			R	R		R			R			R	R	R	R		R	R
Luhoi-1	273	274	53	2	50	60	273.6	P				R			R	R									F	R	R			R			R		R	R		R	R
Luhoi-1	273	274	53	2	70	80	273.8	P				R			R						R				A		R			R		RR						R	R
Luhoi-1	273	274	53	2	90	100	274	P				R			R	R									F					R								R	R
Luhoi-1	274	275	53	3	0	10	274.1	P				R			R	R				RR					F		R			R	RR							R	R
Luhoi-1	274	275	53	3	30	40.00	274.4	P				R			R						R			R	F		R		R									R	R
Luhoi-1	274	275	53	3	50	60	274.6	P				R			R						R				F													R	R
Luhoi-1	274	275	53	3	90	100.00	275	P							R									R	A		R											R	R
Luhoi-1	275	276	54	1	0	30.00	275.3	M-G							R					RR				R	C													R	R
Luhoi-1	275	276	54	1	40	55	275.6	P-M							R									R	A													R	R
Luhoi-1	275	276	54	1	60	70	275.7	P-M							R	R				R	R				F	R												R	R
Luhoi-1	275	276	54	1	77	90	276	P-M							R	R				R	R				C													R	R
Luhoi-1	276	277	54	2	13	24	276.2	P-M	Late Aptian	*Pa. eubejaouaensis* zone		RR		R					R		R	R			F													R	R
Luhoi-1	276	277	54	2	30	44	276.4	P-M				R		R					R		R	R	RR		C													R	R
Luhoi-1	276	277	54	2	50	60	276.6	P-M				R		R					R		R	R			C													R	R
Luhoi-1	276	277	54	2	70	80	276.8	P-M				R									R			RR	A													R	R
Luhoi-1	276	277	54	2	90	100	277	P				R							R		R				A													R	R
Luhoi-1	277	278	54	3	0	20	277.2	P-M				R		R		F					R				F													R	R
Luhoi-1	277	278	54	3	30	50	277.5	P-M				R				F				R	R			RR	A													R	R
Luhoi-1	277	278	54	3	55	65	277.7	P-M								F			R		R				F													R	R
Luhoi-1	277	278	54	3	78	90	277.9	P-M				R		R		R					R																	R	R
Luhoi-1	277	278	54	3	92	100	278	P-M				R				R					R				R													R	R
Luhoi-1	278	279	55	1	0	10	278.1	P-M				R		R					R		R	R	RR		F													R	R
Luhoi-1	278	279	55	1	20	30	278.3	P-M				R									R	R			F													R	R
Luhoi-1	278	279	55	1	50	60	278.6	P				R				R					R	R		R														R	R
Luhoi-1	278	279	55	1	70	80	278.8	P-M			RR	R		R					R		R	R		R														R	R
Luhoi-1	278	279	55	1	90	100	279	P-M				R		R			R	R	R		R	R		RR														R	R
Luhoi-1	279	280	55	2	0	10	279.1	P-M				R		R		R	F	R	R			R		RR														R	R
Luhoi-1	279	280	55	2	25	45	279.45	P				R		R		R	F	R			R	R																	R
Luhoi-1	279	280	55	2	55	65	279.65	P-M				R		R		R	F	R				R																R	R
Luhoi-1	279	280	55	2	75	85	279.85	P-M				R		R			F	R				R																R	R
Luhoi-1	279	280	55	2	90	100	280	P-M				R		R			R	R				R																R	R
Luhoi-1	280	281	55	3	10	20	280.2	P-M				R		R		R	F	R	R			R																R	R
Luhoi-1	280	281	55	3	34	50	280.5	P-M				R		R		R	C	R	R		R	R																R	R
Luhoi-1	280	281	55	3	60	70	280.7	P-M				R		R			F	R	R	R	R	R																R	R
Luhoi-1	280	281	55	3	80	90	280.9	P				R	R	R		R	F	R	R	R	R	R																R	R
Luhoi-1	280	281	55	3	91	100	281	P-M				R		R			F	R			R	R																R	R
Luhoi-1	281	282	56	1	40	50	281.5	P-M						R			F	R	R		R	R	RR															R	R
Luhoi-1	281	282	56	1	60	70	281.7	P					R	R		R	F	R			R	R																R	R

Table 4.5: Luhoi borehole-1 planktonic and benthic foraminifera range chart.

Well name	Sample Depth (m)	Preservation	Stage	Planktonic foraminiferal zones	*Gavelinella barremiana*	*Osangularia sp.*	*Pseudonodosaria sp.*	*Ammodiscus cretacea*	*Marssonella kummi*	*Glomospira charoides*	*Lenticulina muensteri*	*Lenticulina sp.*	*Laevidentalina communis*	*Psilocitharella sp.*	*Trochammina sp.*	*Bathysiphon sp.*	*Glomosperella sp.*	*Gavelinella sp.*	*Conorotalites aptiensis*	*Gavelinella gracillima*	*Ramulina sp.*	*Gaudryina spp.*	*Rhezakina epigona*	*Ammobaculites sp.*	*Marssonella oxycona*	*Spiroplectammina sp.*	*Hormosina sp.*	*Neoflabellina sp.*	*Gavelinella intermedia*	*Pseudogaudryinella dividens*	*Quinqueloculina antiqua*	*Pleurostomella reussi*	*Tritaxia pyramidata*	*Tristix excavata*	*Hyperammina sp.*	*Ramulina tetrahedralis*	*Praebulimina sp.*	*Gyroidinoides sp.*	*Pleurostomella sp.*	*Osangularia californica*	*Saracenaria triangularis*	*Iron nodules*	*Pyrite*	*Ostracods*
Kisarawe-1	1951	P-M	Late Aptian	*Pa. eubejouaensis* zone	F			R		F		R					R																											
Kisarawe-1	1957	P-M			F	R		F		C		R	R		R	R	R	R	R																									
Kisarawe-1	1963	P-M			R							R							R																									
Kisarawe-1	1975.1	P-M			A			F		F					R		R										R																	
Kisarawe-1	1981.2	P-M																R								R																		
Kisarawe-1	1993.4	P-M						R		R													R																					
Kisarawe-1	2000	P-M																																										
Kisarawe-1	2006	P-M			C			R		R					R					R																								R
Kisarawe-1	2012	P-M			F			R		R														R																				R
Kisarawe-1	2067	P-M			R			R		R									R																									
Kisarawe-1	2073	P-M						R											R																									R
Kisarawe-1	2085	P-M			R																																							
Kisarawe-1	2091	P-M						R		R											R																							
Kisarawe-1	2103.1	P-M						R		R		R				R					R	F																						
Kisarawe-1	2115.3	P-M																		R																								
Kisarawe-1	2128	P-M			R																																							
Kisarawe-1	2134	P-M			R						R	R	R						R																									
Kisarawe-1	2149	P-M			R			R		R							R																											
Kisarawe-1	2155	P-M			R			R		R			R		R	R																												
Kisarawe-1	2170.2	P-M	Late Aptian	*G. algerianus* zone															R																									
Kisarawe-1	2179.3	P-M						R		R								R																										
Kisarawe-1	2189	P-M			F					R						R	R																											
Kisarawe-1	2195	P-M			F	R		R		R		R			R	R																												
Kisarawe-1	2207	P-M						R						RR																														
Kisarawe-1	2219	P-M			R					R																																		
Kisarawe-1	2225	P-M			R		R				R	R	R																															
Kisarawe-1	2237	P-M			C																																							
Kisarawe-1	2243.3	P-M																																										
Kisarawe-1	2256	P-M						R	R	R																																		
Kisarawe-1	2268	P-M			C	R	R	F																																				

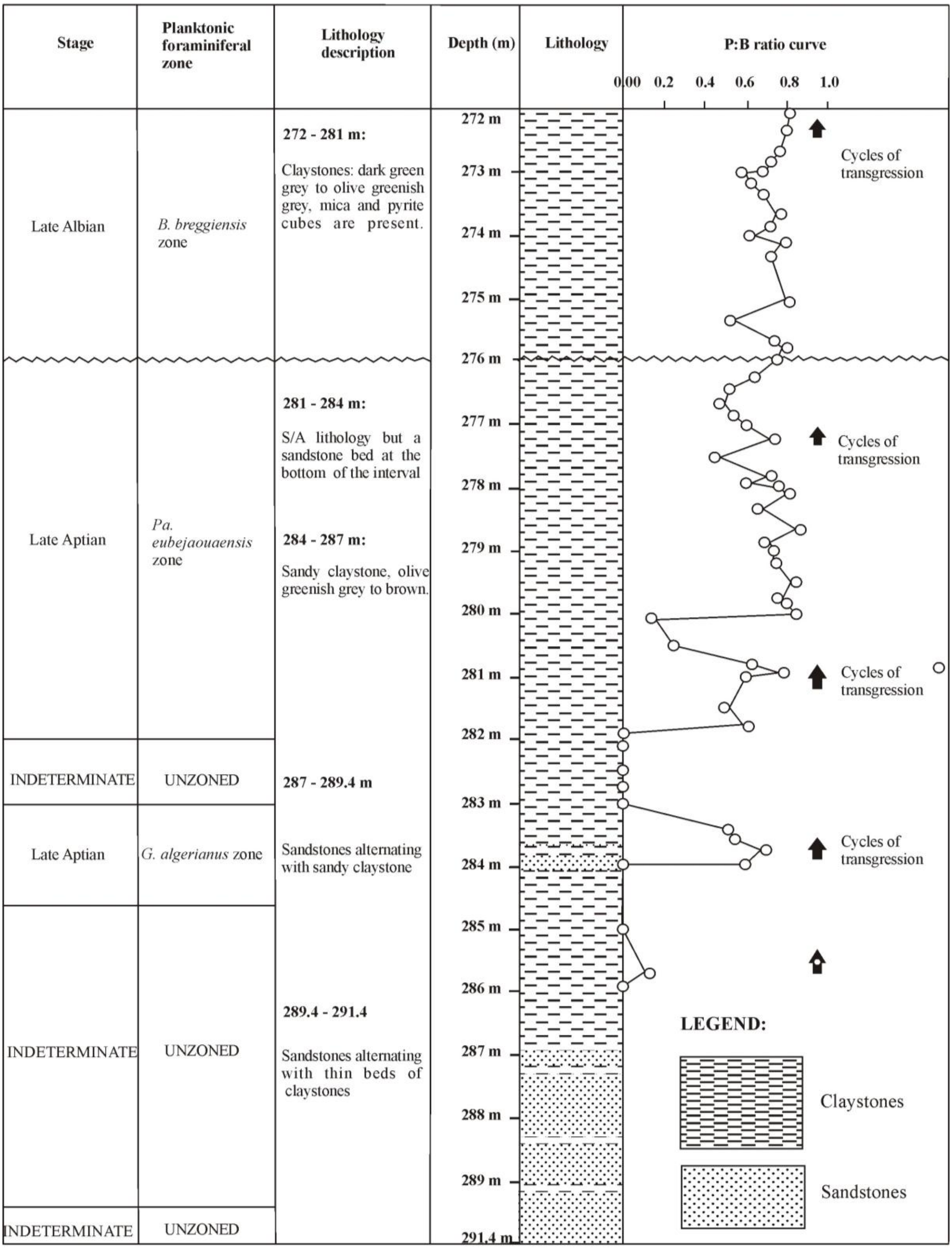


Figure 4.5: Summary biozonation and lithostratigraphy and P/B ratio curve for Luhoi-1 borehole.

Note; *B. =Biticinella, G. = Globigerinelloides, Pa. = Paraticinella*.

4.6 Songo Songo-4 borehole

Hydrocarbon exploration in the offshore coastal basin commence in 1952 when BP/Shell acquired an area covering the entire coastal strip of Tanzania. They drilled five boreholes before relinquishing the license in 1964 after drilling the Pemba-5 well which was found to be off structure. In 1974 AGIP drilled the Songo Songo-1 well as a first successful hydrocarbon test in Tanzania. This well tested gas from Albian and early Cretaceous sands around 1900 m on a fault block structure. AGIP and Amoco considered the Songo Songo gas field non-commercial and dropped the acreage in 1976. An independent evaluation on behalf of TPDC indicated commercial potential, and TPDC began an appraisal program in 1976. The first appraisal well, Songo Songo-2 was a shallow blow-out, but subsequent appraisal wells which are Songo Songo-3 and Songo Songo-4, confirmed the potential of the gas discovery. The Songo Songo-4 well was drilled in 1978 and is located on latitude 8º 31' 01.30" S and longitude 39º 29' 30.25"E. It was drilled from the Tertiary to the early Cretaceous and reached down to a total depth of 2011 m.

4.6.1 Lithostratigraphy

Lithostratigraphy descriptions (figure 4.6) are based on well completion report by Agip Oil Company, 1974 and are summarized below.

4.6.1.1 Wami River Series (1670.3-1831.2 m)

From 1670.3-1703.8 m; claystone, silt, dark greyish green in colour, blocky, calcareous, pyritic and micaceous. 1703.8-1810.5 m: Dark greyish green claystones, silt, friable, calcareous, blocky, pyritic, micaceous alternating with olive greyish green claystone. 1810.5-1831.2 m: Dark greenish grey, silt, friable, bioturbated, calcareous, massive, pyritic.

4.6.1.2 Kingongo Formation (1831.2-1870.6m)

These are claystones, silt, calcareous, moderately hard, pyritic, bioturbated, massive, and dark greenish grey.

4.6.1.3 Kihuluhulu Formation (1870.6–1928.2 m)

Claystones are similar throughout the succession. The claystones are silt, calcareous, moderately hard, pyritic, bioturbated, dark greenish grey.

4.6.2 Foraminiferal biostratigraphy

A distribution chart for planktonic and benthic foraminifera is presented in Table 4.6. A total of seven biostratigraphic zones were determined which are described as follows:

4.6.2.1 Late Aptian (1869.9-1875.5 m): Paraticinella eubejaouaensis Taxon range zone

The zone of *Paraticinella eubejaouaensis* is defined as a biostratigraphic interval of the total range of *Paraticinella eubejaouaensis* (Base by Moullade (1966); top by Moullade (1974)). The lowest occurrence (LO) of *Paraticinella eubejaouaensis* at 1873 m and highest occurrence (HO) at 1870 m indicates latest Aptian age of this interval. Planktonic species diversity is low and abundance varies from rare to common and preservation varies from poor to moderate. Planktonic species present include *Pseudoguembelitria* sp., *Paraticinella eubejaouaensis*, and common late Aptian hedbergellids (see table 4.6 and plates 3.5 - 3.6, 3.9 - 3.10 & plate 3.12).

Calcareous benthic foraminifera diversified with rare abundance of most of the species. Species encountered in this interval are *Gavelinella barremiana, Osangularia schloebanchi*, and others (see table 4.6 and plates 3.17 & 3.22). Agglutinated forms diversified with abundance varying from rare to abundant. Species present include *Ammodiscus cretacea, Glomospira charoides,* and many others (see table 4.6 and plate 3.16 & 3.18). No planktonic foraminifera were encountered at 1874 m.

4.6.2.2 Indeterminate (1868.3-1868.8 m): Unzoned Interval

No planktonic foraminifera present in this interval. Benthic species moderately diversified and abundance varies from rare to common. Species found at this interval include *Gavelinella* spp., *Lenticulina* spp., *Pleurostomella* spp., and others. Agglutinated forms are

Ammodiscus cretacea, *Bathysiphon* sp., and many others (see table 4.6 and plates 3.16-3.17, 3.20, 3.23). No planktonic index marker to date this interval and therefore is undated and cannot be placed into any planktonic foraminifera biozones.

4.6.2.3 ***Middle Albian (1866.7 - 1868 m): Ticinella primula Partial range zone***

The zone of *Ticinella primula* is defined as an interval zone from the lowest occurrence (LO) of *Ticinella primula* to the lowest occurrence (LO) of *Biticinella breggiensis* (Longoria and Gamper (1974)). This interval is extremely low in planktonic foraminifera and is also rare in abundance. The lowest occurrence of (LO) *Ticinella primula* at 1866.7 m indicates middle Albian age. This interval is rare in planktonic foraminifera and species present include *Biticinella subbreggiensis, Muricohedbergella* spp., *Ticinella primula* and others (see table 4.6 and plates 3.2, 3.8 - 3.9 & plates 3.12-3.13).

Calcareous benthic species diversity is slightly moderate and rare in abundance. Species present include: *Gavelinella intermedia*, *Osangularia schloebanchi*, and others (see table 4.6 and plates 3.17 and plate 3.22).

Agglutinated forms moderately diversify and their abundances vary from rare to abundant. Species that are present include: *Ammodiscus cretacea*, *Bathysiphon* sp., *Hyperammina* sp., and others (see table 4.6 and plates 3.16 & 3.19).

4.6.2.4 Indeterminate (1865.7-1866.4 m): Unzoned Interval

No planktonic foraminifera in this interval and benthic forms with low diversity and abundance vary from rare to abundant. Species present include *Ammodiscus cretacea*, *Bathysiphon* sp., *Hyperammina* sp., *Gavelinella intermedia,* and others (see table 4.6 and plates 3.16 – 3.17 and plate 3.19).

4.6.2.5 Late Albian (1845.2-1865.4 m): Biticinella breggiensis Interval zone

Planktonic species diversity is moderate and abundance varies from rare to frequent and few with common to abundant. The lowest occurrence (LO) of *Biticinella breggiensis* is at 1865.4 m indicates late Albian age. Species present include *Biticinella breggiensis; Ticinella roberti*, *Pseudothalmanninella subticinensis* and others (see table

4.6 and plates 3.12 – 3.14).

Calcareous benthic foraminifera diversified and abundance varies from rare to frequent and few common to abundant. Species present include *Gavelinella intermedia, Osangularia schloebanchi,* and others (see table 4.6 and plates 3.17 and 3.22). Agglutinated forms are diversified with abundance varying from rare to abundant and few vary from rare to frequent. Species present include *Ammodiscus cretacea, Bathysiphon* sp., *Psammosphaera* sp., and others (see table 4.6 and plates 3.16, & plate 3.23). Sample analyzed from 1861.4 m is barren.

4.6.2.6 Indeterminate (1843.-1845 m): Unzoned interval

Planktonic species diversity is low and abundance varies from rare to abundant. Species that are present include *Muricohedbergella* and others (see table 4.6 and plate 3.9). Calcareous benthic foraminiferal species are diversified with abundance rate varying from rare to abundant. Species that are present include *Osangularia* sp., and many others (see table 4.6 and plate 3.22). Agglutinated forms diversified and abundance varies from frequent to abundant and few rare. Species present include, *Hyperammina* sp., *Psammosphaera* sp., and others including pyrite cubes are abundant (see table 4.6 and plates 3.19 and 3.23).

4.6.2.7 Late Albian (1832.7-1843. 5 m): Thalmanninella appenninica Interval zone

The zone of *Thalmanninella appenninica* is a biostratigraphic interval from the lowest occurrence (LO) of *Thalmanninella appenninica* to the lowest occurrence (LO) of *Thalmanninella globotruncanoides* (Brönnimann (1952)). Planktonic foraminifera are diversified and most of them are rare and few are in abundance. The lowest occurrence (LO) of *Thalmanninella appenninica* at 1843.5 m, indicates latest Albian age. Species present include *Thalmanninella appenninica*, *Muricohedbergella* spp., *Planomalina buxtorfi; Praeglobotruncanids* and others (see table 4.6 and plates 3.9 - 3,11 and plates 3.14 - 3.15).Benthic foraminifera diversified with abundance vary from rare to abundant. Calcareous benthic species present such as *Gavelinella* sp., *Gyroidinoides* sp. 2, *Osangularia schloebanchi,* and others (see table 4.6 and plates 3.18-3.19 and plate 3.22). Agglutinated forms diversify and abundance varies from rare to abundant. Species that are present include: *Hyperammina* sp., *Pseudogaudryinella sp., Psammosphaera* sp., and others. This interval contains abundant and some varieties of agglutinated foraminifera (see table 4.6 and plate 3.19 and 3.23).

4.6.2.8 Early Cenomanian (1823-1831.5 m): Thalmanninella globotruncanoides Interval zone

The zone of *Thalmanninella globotruncanoides* ia a biostratigraphic interval from the lowest occurrence (LO) of *Thalmanninella globotruncanoides* to the lowest occurrence (LO) of *Thalmanninella reicheli* (Lehmann (1966)). Planktonic species are moderately diversified and abundance varies from rare to abundant. The lowest occurrence (LO) of *Thalmanninella globotruncanoides* at 1831. 3 m indicates an early Cenomanian age. Species present include: *Praeglobotruncana* spp., *Thalmanninella globotruncanoides* and others. This interval is assigned to *Thalmanninella globotruncanoides* zone (see table 4.6 and plates 3.11 & 3.15).

Benthic species are diversified and abundance varies from rare to abundant. Species that are present include *Gavelinella intermedia, Lenticulina sp.,* and others (see table 4.6 and Plates 3.17, 3.21). Agglutinated forms diversify and abundance varies from rare to abundant. The present species are such as *Bathysiphon* sp., *Hyperammina* sp., *Psammosphaera* and others including pyrite cubes that are abundant (See Table 4.6 and plates 3.16, 3.19 and 3.23).

4.6.2.9 Early Middle Cenomanian (176-1810.5 m): Thalmanninella reicheli Total range zone

The zone of *Thalmanninella reicheli* is a biostratigraphic interval of the total range of *Thalmanninella reicheli* Bolli (1966). The lowest occurrence (LO) of *Thalmanninella reicheli* at 1810.5 m and highest occurrence (HO) at 1762 m indicates the total range of the taxon and is of early to middle Cenomanian age. The diversity of Planktonic foraminiferal species is moderate and abundance varies from rare to abundant and preservation varies from poor to moderate. Species encountered on this interval include: *Muricohedbergella* spp., *Praeglobotruncana* spp., *Thalmanninella reicheli* and others (see table 4.6 and plates 3.9, 3.11, and-3.15).

Benthic species are diversified and their abundance varies from rare to abundant. Calcareous benthic forms present include: *Gavelinella* spp., *Gyroidinoides* spp., and others (see table 4.5 and plates 3.18 - 3.19).

Agglutinated species present include *Ammobaculites* spp., *Bathysiphon* sp., *Hyperammina* sp., *Trochammina* sp., and others. Pyrite cubes are abundant (see table 4.6 and plates 3.16, 3.19, & plate 3.25).

4.6.2.10 Middle - Late Cenomanian (1670.3 - 1750 m): Rotalipora cushmani Total range zone

The zone of *Rotalipora cushmani* is a biostratigraphic interval corresponding to the total range of *Rotalipora cushmani* (Borsetti (1962). The lowest occurrence (LO) of *Rotalipora cushmani* at 1750 m and highest occurrence (HO) at 1670.3 m is an indication of the total range zone of the nominal taxons. The occurrence of *Rotalipora cushmani* throughout this interval indicates that the age of this interval is of middle to late Cenomanian and assigned to the *Rotalipora cushmani* zone. The diversity of planktonic foraminiferal species is moderate and abundance varies from common to abundant for the majority of the species, and are from rare to frequent for some few. Preservation varies from poor to moderate. It contains planktonic species of *Muricohedbergella* spp., *Praeglobotruncana* spp., *Rotalipora cushmani*, and *Thalmanninella greenhornensis* (see table 4.6 and plates 3.9, 3.11-3.12).

Calcareous benthic foraminifera species are diversified and abundance varies from frequent to abundant and few are from rare to abundant. Benthic species that are present include: *Gavelinella intermedia*, *Gyroidinoides* spp., *Pleurostomella* sp., and others (see table 4.6 and plates 3.17, 3.19, 3.23). Agglutinated foraminifera species are moderate in diversity rare in abundance. Species present include: *Hyperammina* sp., *Trochammina* sp., *Ammobaculites* spp., and others (see table 4.6, plates 3.16, 3.19, & plate 3.25). Pyrite is abundant in this interval.

4.6.3 Synthesis

The summary stratigraphy of the mid-Cretaceous interval of the Songo-Songo-4 borehole is shown in Figure 4.5. The uppermost Albian to Cenomanian part of the succession is much expanded relative to other sections, possibly because of its more offshore distal setting. Two intervals of low planktonic abundance at ~ 1852 m and ~1865 m may indicate short hiatuses. The major regional hiatus between the middle Albian and uppermost Aptian occurs at 1868 m.

Planktonic: benthic ratios are variable through the Aptian to middle Albian part of the succession, possibly representing a succession of transgression / regression cycles associated with the development of unconformities. From the late Albian the evidence suggests a gradual deepening in two phases until eventually P:B ratios approaching 100% indicating deep water continental slope environment.

Table 4.6: Songo Songo borehole-4 planktonic and benthic foraminifera range

Well Name	Top core depth (m)	Bottom core depth (m)	Core number	Section	Top interval (cm)	Bottom interval (cm)	Depth (m)	Preservation	Age	Planktonic foraminiferal zone	*Hedbergella* sp.	*Hedbergella sigali*	*Paraticinella eubejaouaensis*	*Pseudoguembelitria* sp.	*Muricohedbergella delrioensis*	*Muricohedbergella planispira*	*Muricohedbergella albiana*	*Ticinella primula*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex*	*Biticinella subbreggiensis*	*Biticinella breggiensis*	*Ticinella roberti*	*Pseudothalmanninella subticinensis*	*Heterohelix moremani*	*Thalmanninella appenninica*	*Planomalina praebuxtorfi transition to Planomalina buxtorfi*	*Planomalina buxtorfi*	*Praeglobotruncana delrioensis*	*Thalmanninella globotruncanoides*	*Praeglobotruncana stephani*	*Praeglobotruncana stephani* (sp. 2)	*Thalmanninella reicheli*	*Rotalipora cushmani*	*Thalmanninella greenhornensis*	*Praeglobotruncana gibba*	
Songo Songo-4							1670.3	P-M	Middle - Late Cenomanian	*R. cushmani* zone					C						C	RR				A				A		A			R	R	A	
Songo Songo-4							1673.4	P-M							F						C					A				A		A			R	R	A	HO of *R. cushmani*
Songo Songo-4							1680	P-M							R						F					A				R		F					A	
Songo Songo-4							1683	P-M							F						F					A				A		A				R	A	
Songo Songo-4							1686	P-M							R						C					A				A		A			R	R	A	
Songo Songo-4							1692	P-M							C						A					A				A		A			R	R	A	
Songo Songo-4							1698	P-M							R						F					A				A		A			R	R	A	
Songo Songo-4							1704	P-M							F						F					A				A		A			R	R	A	
Songo Songo-4							1707	P-M							F						C					A				F		F				F	F	
Songo Songo-4							1719.1	P-M							C						A					A				F		R			R	F	C	
Songo Songo-4							1731.3	P-M							F					A	A		RR			A				A		A				R	A	
Songo Songo-4							1744	P-M							F					A	A					A				R		R	R		R	R	C	
Songo Songo-4							1750	P-M							C					A	C					A										R		
Songo Songo-4							1762	P-M	Early - Middle Cenomanian	*T. reicheli* zone					C					A	F					A								R				LO of *R. cushmani*
Songo Songo-4							1774	P-M												A	R									F		F		R				
Songo Songo-4							1780	P-M							A					A	A																	
Songo Songo-4							1792.2	P-M							A						A					A				R		R						
Songo Songo-4							1798.3	P-M							A					A	A					A				C								
Songo Songo-4							1810.5	P-M												A						A				F				R				LO of *T. reicheli*
Songo Songo-4							1823	P-M	Early Cenomanian	*T. globotruncanoides* zone					A					A	A					A					R							
Songo Songo-4	1825.75	1826.67	1	1	16	30	1826	P																						R								
Songo Songo-4	1825.75	1826.67	1	1	30	45	1826.1	P													R					R				R	R	R						
Songo Songo-4	1825.75	1826.67	1	1	70	80	1826.50	P-M							R															F		R						
Songo Songo-4	1826.67	1827.58	1	2	7	20	1827.80	P-M																						C	R							
Songo Songo-4	1826.67	1827.58	1	2	30	44	1828	P-M																						R								
Songo Songo-4	1826.67	1827.58	1	2	61	71	1828.3	P-M																														
Songo Songo-4							1829	P-M							A					A	A									C	R							
Songo Songo-4	1827.58	1828.5	1	3	21	40	1830	P-M							R				R	R						R					R							
Songo Songo-4	1827.58	1828.5	1	3	50	60	1830.1	P																						R		R						
Songo Songo-4	1827.58	1828.5	1	3	61	70	1830.2	P-M											R												R							
Songo Songo-4	1829.41	1830.32	1	2	21	40	1830.7	B																														
Songo Songo-4	1829.41	1830.32	1	2	50	70	1831	P							R															F	R							
Songo Songo-4							1831.2	B																														
Songo Songo-4	1829.41	1830.32	1	2	80	90	1831.3	P							R																R							LO of *T. globotruncanoides*

Table 4.6: Songo Songo-4 borehole planktonic and benthic foraminifera range chart continued.

Well Name	Top core depth (m)	Bottom core depth (m)	Core number	Section	Top interval (cm)	Bottom interval (cm)	Depth (m)	Preservation	Age	Planktonic foraminiferal zone	*Hebergella* sp.	*Hedbergella sigali*	*Paraticinella eubejaouaensis*	*Pseudoguembelitria* sp.	*Muricohedbergella delrioensis*	*Muricohedbergella planispira*	*Muricohedbergella albiana*	*Ticinella primula*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex*	*Biticinella subbreggiensis*	*Biticinella breggiensis*	*Ticinella roberti*	*Pseudothalmanninella subticinensis*	*Heterohelix moremani*	*Thalmanninella appenninica*	*Planomalina praebuxtorfi* transition to *Planomalina buxtorfi*	*Planomalina buxtorfi*	*Praeglobotruncana delrioensis*	*Thalmanninella globotruncanoides*	*Praeglobotruncana stephani*	*Praeglobotruncana stephani* (sp. 2)	*Thalmanninella reicheli*	*Rotalipora cushmani*	*Thalmanninella greenhornensis*	*Praeglobotruncana gibba*	
Songo Songo-4	1830.32	1831.24	1	3	25	45	1832.7	P-M	Late Albian	*T. appenninica* zone									R								R			F								
Songo Songo-4	1830.32	1831.24	1	3	57	70	1833	P-M											R					R						R								
Songo Songo-4	1830.32	1831.24	1	3	75	90	1833.2	P-M							R				R					R						F								
Songo Songo-4	1832.15	1833.98	1	2	0	20	1833.3	P-M							R					R				R			R			R								
Songo Songo-4	1832.15	1833.98	1	2	25	36	1833.4	B																														
Songo Songo-4	1832.15	1833.98	1	2	50	60	1833.70	P									R										R											
Songo Songo-4	1832.15	1833.98	1	2	75	92	1834	B																														
Songo Songo-4	1833.98	1834.9	1	1	40	60	1834.5	P-M																														
Songo Songo-4	1833.98	1834.9	1	1	70	90	1834.8	P-M							R												R			F								
Songo Songo-4	1834.9	1835.81	2	1	0	26	1835	B																														
Songo Songo-4	1834.9	1835.81	2	1	35	55	1835.4	B																														
Songo Songo-4	1834.9	1835.81	2	1	65	80	1835.6	B																														
Songo Songo-4	1834.9	1835.81	2	1	81	92	1836	P							R					R																		
Songo Songo-4							1836.7	B																														
Songo Songo-4	1835.81	1836.72	2	2	0	20	1837	P																			R											
Songo Songo-4	1835.81	1836.72	2	2	30	50	1837.2	P							R									R			R			R								
Songo Songo-4	1835.81	1836.72	2	2	60	86	1838	P																		R	R			R								
Songo Songo-4							1838.3	P																					R									
Songo Songo-4	1837.64	1838.55	2	2	10	20	1838.8	P																					R									
Songo Songo-4	1837.64	1838.55	2	2	35	41	1839	P																					R	R								
Songo Songo-4	1837.64	1838.55	2	2	62	73	1839.3	P							R												R		R	R								
Songo Songo-4	1838.55	1839.47	2	3	0	10	1840.60	P-M							R					R				R						R								
Songo Songo-4	1838.55	1839.47	2	3	30	40	1841.00	P-M							F		F			R	F						R			R								
Songo Songo-4	1838.55	1839.47	2	3	60	70	1841.20	P							R						R					R	R											
Songo Songo-4	1838.55	1839.47	2	3	80	92	1841.40	P																														
Songo Songo-4	1840.38	1841.3	2	2	22	35	1841.7	B																														
Songo Songo-4	1840.38	1841.3	2	2	35	41	1841.8	P-M							R																							
Songo Songo-4	1840.38	1841.3	2	2	50	60	1841.9	P-M									F			R						R	R											
Songo Songo-4	1840.38	1841.3	2	2	60	70	1842	P-M																			R											
Songo Songo-4							1842.2	P																														
Songo Songo-4	1840.38	1841.3	2	2	84	92	1842.3	P-M									R			R						R												
Songo Songo-4	1841.3	1842.21	2	3	10	20	1843.5	P							R									R			R	R		R								LO of *T. appenninica*

Table 4.6: Songo Songo-4 borehole planktonic and benthic foraminifera range chart.

Well Name	Top core depth (m)	Bottom core depth (m)	Core number	Section	Top interval (cm)	Bottom interval (cm)	Depth (m)	Preservation	Age	Planktonic foraminiferal zone	*Hedbergella sp.*	*Hedbergella sigali*	*Paraticinella eubejaouaensis*	*Pseudoguembelitria sp.*	*Muricohedbergella delrioensis*	*Muricohedbergella planispira*	*Muricohedbergella albiana*	*Ticinella primula*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex*	*Biticinella subbreggiensis*	*Biticinella breggiensis*	*Ticinella roberti*	*Pseudothalmanninella subticinensis*	*Heterohelix moremani*	*Thalmanninella appenninica*	*Planomalina praebuxtorfi transition to Planomalina buxtorfi*	*Planomalina buxtorfi*	*Praeglobotruncana delrioensis*	*Thalmanninella globotruncanoides*	*Praeglobotruncana stephani*	*Praeglobotruncana stephani (sp. 2)*	*Thalmanninella reicheli*	*Rotalipora cushmani*	*Thalmanninella greenhornensis*	*Praeglobotruncana gibba*	
Songo Songo-4	1841.3	1842.21	2	3	20	30	1843.6	P	Indeterminate	Unzoned						R	R																					
Songo Songo-4	1841.3	1842.21	2	3	46	50	1843.8	P							R		R																					
Songo Songo-4							1844	P-M							F		F			A	A																	
Songo Songo-4	1841.3	1842.21	2	3	73	80	1844.10	P							F						A																	
Songo Songo-4	1843.43	1844.04	2	2	31	50	1845	P							F	A					A																	
Songo Songo-4	1843.43	1844.04	2	2	60	88	1845.2	P	Late Albian	*B. breggiensis* zone						F							R															
Songo Songo-4							1853.2	P-M								R	F																					
Songo Songo-4							1859.3	P-M									F			A																		
Songo Songo-4	1860.5	1861.41	3	1	40	50	1861	P																														
Songo Songo-4	1860.5	1861.41	3	1	70	80	1861.3	P							R								R															
Songo Songo-4							1861.4	B																														
Songo Songo-4	1861.41	1862.33	3	2	40	50	1863	P							F		F								R													
Songo Songo-4	1861.41	1862.33	3	2	70	80	1863.2	P															R		R													
Songo Songo-4							1863.2	P																														
Songo Songo-4	1862.33	1863.24	3	3	40	50	1865	P							R	R								R	R													
Songo Songo-4							1865.1	P																														
Songo Songo-4	1862.33	1863.24	3	3	80	90	1865.2	P							R	R							R	F	R													
Songo Songo-4							1865.4	P-M							F	R	R			A			R															LO of *B. breggiensis*
Songo Songo-4	1864.16	1865.07	3	2	45	60	1865.7	P	INDETERMINATE	UNZONED																												
Songo Songo-4	1864.16	1865.07	3	2	70	90	1866	P																														
Songo Songo-4	1865.99	1866.9	3	1	0	20	1866.9	P																														
Songo Songo-4	1865.99	1866.9	3	1	33	43	1866.4	P																														
Songo Songo-4	1865.99	1866.9	3	1	64	75	1866.7	P	Middle Albian	*Ti. primula* zone								R			R	R																
Songo Songo-4	1865.99	1866.9	3	1	75	78	1867	P								R																						
Songo Songo-4	1865.07	1866	3	3	75	90	1867.90	P-M							R																							
Songo Songo-4	1866.9	1867.81	3	2	0	14	1868	P																														LO of *Ti. primula*
Songo Songo-4	1866.9	1867.81	3	2	30	40	1868.3	P	INDERMINATE	UNZONED																												
Songo Songo-4	1866.9	1867.81	3	2	62	71	1868.6	P																														
Songo Songo-4							1868.7	P																														
Songo Songo-4	1866.9	1867.81	3	2	80	90	1869	P-M																														HO of *Pa. eubejaouaensis*
Songo Songo-4	1867.81	1868.73	3	3	0	20	1870	P-M	Late Aptian	*Pa. eubejaouaensis* zone			R	R																								
Songo Songo-4	1867.81	1868.73	3	3	20	30	1870.1	P																														
Songo Songo-4	1867.81	1868.73	3	3	40	50	1870.3	P-M																														
Songo Songo-4	1867.81	1868.73	3	3	70	90	1870.6	P				R	F																									
Songo Songo-4	1870.56	1871.47	4	2	0	10	1871.6	P-M			R		R															R										
Songo Songo-4	1870.56	1871.47	4	2	29	39	1872	P					C																									
Songo Songo-4	1872.39	1873.3	4	1	30	40	1872.7	P-M					F																									
Songo Songo-4	1872.39	1873.3	4	1	50	60	1873	P-M					F																									
Songo Songo-4	1872.39	1873.3	4	1	80	90	1873.2	B																														
Songo Songo-4	1873.3	1873.91	4	2	0	20	1875	P																														
Songo Songo-4	1873.3	1873.91	4	2	50	60	1875.5	P																														LO of *Pa. eubejaouaensis*

Note: LO = Lowest occurrence, HO = Highest occurrence, *B.* = *Biticinella*, *Pa.* = *Paraticinella*, , *Ti.* = *Ticinella*, *R.* = *Rotalipora*, *T.* = *Thalmanninella* , RR = 1 specimen, R = rare; 2-5 specimens, F + frequent; 6-10 specimens, C = 11-20, specimens, ≥ 21 specimens

Table 4.6: Songo Songo borehole-4 planktonic and benthic foraminifera range chart continued.

Well Name	Top core depth (m)	Bottom core depth (m)	Core number	Section	Top interval (cm)	Bottom interval (cm)	Depth below surface (m)	Preservation	Age	Planktonic foraminiferal zone	*Trochammina* sp.	*Bathysiphon* sp.	*Gyroidinoides gracillima*	*Ramulina* sp. 1	*Ammodiscus cretacea*	*Hyperammina* sp.	*Quadrimorphina* sp.	*Laevidentalina communis*	*Glomospira charoides*	*Gavelinella* sp.	*Pleurostomella* sp.	*Reophax* sp. 1	*Osangularia* sp.	*Osangularia schloenbachi*	*Pleurostomella* aff. *obtusa*	*Pleurostomella reussi*	*Saracenaria* sp.	*Lenticulina (Saracenaria) spinosa*	*Rhabdammina* sp.	*Cyclammina* sp. 2	*Haplophragmoides* sp.	*Gavelinella intermedia*	*Osangularia* aff. *utaturiensis*	*Psammesphaera* sp.	*Laevidentalina* sp.	*Gyroidinoides* sp. 2	*Marssonella oxycona*	*Gyroidinoides* sp. 4	*Gyroidinoides* sp. 1	*Epistomina* sp.	*Hormosina* sp.	*Osangularia californica*	*Ramulina spandeli*	*Ammodiscus* sp.	*Cyclammina* sp. 1	*Lenticulina* sp.	*Ramulina tetrahedralis*	*Pseudogaudryinella dividens*	*Saccammina* sp.	*Lingulogavelinella* aff. *spinosa*	*Ammobaculites* sp. 3	*Tritaxia pyramidata*	*Pseudonodosaria* sp.	*Verneuillina* sp.	*Psilocitharella* sp.	*Lagenammina* sp.	*Rhezakina epigona*	*Ammonites*	*Belemnites*	*Bivalves*	*Gastropods*	*Iron nodules*	*Ostracods*	*Pyrite*
Songo Songo-4							1670.3	P-M	Middle - Late cenomanian	*R. cushmani* zone					R					R							R														R							R																A
Songo Songo-4							1673.4	P-M			R	R			R					R			R																														R											A
Songo Songo-4							1680	P-M				R								F															R				R												R													A
Songo Songo-4							1683	P-M				R								F																					R					R		R									R							A
Songo Songo-4							1686	P-M				R								R																	R				R																							A
Songo Songo-4							1692	P-M							R												R								R						R																							A
Songo Songo-4							1698	P-M			R				R				R	R																	R				R							R																A
Songo Songo-4							1704	P-M							R					A																	R									R																		A
Songo Songo-4							1707	P-M				R			R	R				F					R												R									R								R									A
Songo Songo-4							1719.1	P-M								R				F												F			R						R												R											A
Songo Songo-4							1731.3	P-M			R	R				R				A												F																																A
Songo Songo-4							1744	P-M				R				R				R																	R		R	R						R		R																A
Songo Songo-4							1750	P-M							R				R	C	R		R														R		C							R																		A
Songo Songo-4							1762	P-M	Early - Middle Cenomanian	*T. reicheli* zone		R				R	R			C																										R						R											A
Songo Songo-4							1774	P-M			R									C												A					R		F									R			R													A
Songo Songo-4							1780	P-M								R				C									R										F							R					R													A
Songo Songo-4							1792.2	P-M				R			R	R			R	C									R										F		R					R																		A
Songo Songo-4							1798.3	P-M				R								C									R										F							R		R																A
Songo Songo-4							1811	P-M							R	R				C									R										F							R																		A
Songo Songo-4							1823	P-M	Early Cenomanian	*T. globotruncanoides* zone	R								R	C																			F									R		R														A
Songo Songo-4	1825.75	1826.67	1	1	16	30	1826	P				R			R																			R		R		R	R										R															A
Songo Songo-4	1825.75	1826.67	1	1	30	45	1826.1	P			F	A			R	C																				R																												A
Songo Songo-4	1825.75	1826.67	1	1	70	80	1826.50	P-M			R	C			R	R													C						R						R																							A
Songo Songo-4	1826.67	1827.58	1	2	7	20	1827.80	P-M			F	R					R			R									R					R																														A
Songo Songo-4	1826.67	1827.58	1	2	30	44	1828	P-M												R									R							R																												A
Songo Songo-4	1826.67	1827.58	1	2	61	71	1828.3	P-M			R																		R																																			A
Songo Songo-4							1829	P-M			R					R				C									R			A					R				R							R																	A
Songo Songo-4	1827.58	1828.5	1	3	21	40	1830	P-M				F			R														F			R														R																		A
Songo Songo-4	1827.58	1828.5	1	3	50	60	1830.1	P																																																								A
Songo Songo-4	1827.58	1828.5	1	3	61	70	1830.2	P-M				R																																																				A
Songo Songo-4	1829.41	1830.32	1	2	21	40	1830.7	B																																																								A
Songo Songo-4	1829.41	1830.32	1	2	50	70	1831	P				R			R	R													F																																			A
Songo Songo-4							1831.2	B																																																								A
Songo Songo-4	1829.41	1830.32	1	2	80	90	1831.3	P				C																	F			R																																A

Table 4.6: Songo Songo borehole-4 planktonic and benthic foraminifera

Well Name	Top core depth (m)	Bottom core depth (m)	Core number	Section	Top interval (cm)	Bottom interval (cm)	Depth below surface (m)	Preservation	Age	Planktonic foraminiferal zone	*Trochammina* sp.	*Bathysiphon* sp.	*Gyroidinoides gracillima*	*Ramulina* sp. 1	*Ammodiscus cretacea*	*Hyperammina* sp.	*Quadrimorphina* sp.	*Laevidentalina communis*	*Glomospira charoides*	*Gavelinella* sp.	*Pleurostomella* sp.	*Reophax* sp.1	*Osangularia* sp.	*Osangularia schloenbachi*	*Pleurostomella* aff. *obtusa*	*Pleurostomella reussi*	*Saracenaria* sp.	*Lenticulina (Saracenaria) spinosa*	*Rhabdammina* sp.	*Cyclammina* sp. 2	*Haplophragmoides* sp.	*Gavelinella intermedia*	*Osangularia* aff. *utaturiensis*	*Psammespahaera* sp.	*Laevidentalina* sp.	*Gyroidinoides* sp. 2	*Marssonella oxycona*	*Gyroidinoides* sp. 4	*Gyroidinoides* sp. 1	*Epistomina* sp.	*Hormosina* sp.	*Osangularia californica*	*Ramulina spandeli*	*Ammodiscuss* sp.	*Cyclammina* sp. 1	*Lenticulina* sp.	*Ramulina tetrahedralis*	*Pseudogaudryinella dividens*	*Saccammina* sp.	*Lingulogavelinella* aff. *spinosa*	*Ammobaculites* sp. 3	*Tritaxia pyramidata*	*Pseudonodosaria* sp.	*Verneuillina* sp.	*Psilocitharella* sp.	*Lagenammina* sp.	*Rhezakina epigona*	*Ammonites*	*Belemnites*	*Bivalves*	*Gastropods*	*Iron nodules*	*Ostracods*	*Pyrite*
Songo Songo-4	1830.32	1831.24	1	3	25	45	1832.7	P-M			F	R			R														R					R																													A
Songo Songo-4	1830.32	1831.24	1	3	57	70	1833	P-M			F	R																																																				A
Songo Songo-4	1830.32	1831.24	1	3	75	90	1833.2	P-M			C	R																																																				A
Songo Songo-4	1832.15	1833.98	1	2	0	20	1833.3	P-M			F				R					R				R																																								A
Songo Songo-4	1832.15	1833.98	1	2	25	36	1833.4	B																																																								A
Songo Songo-4	1832.15	1833.98	1	2	50	60	1833.70	P			C	R																						C																														A
Songo Songo-4	1832.15	1833.98	1	2	75	92	1834	B				A																																																				A
Songo Songo-4	1833.98	1834.9	1	1	40	60	1834.5	P-M				C			R	R				R				R					R																							R													A
Songo Songo-4	1833.98	1834.9	1	1	70	90	1835	P-M			R	A			R	R				R	R								A																											R									A
Songo Songo-4	1834.9	1835.81	2	1	0	26	1835.03	B																																																							A
Songo Songo-4	1834.9	1835.81	2	1	35	55	1835.4	B																																																							A
Songo Songo-4	1834.9	1835.81	2	1	65	80	1835.6	B																																																							A
Songo Songo-4	1834.9	1835.81	2	1	81	92	1836	P			F	R			R				R					R			R					R														R																				A
Songo Songo-4							1836.7	B																																																							A
Songo Songo-4	1835.81	1836.72	2	2	0	20	1837	P				R																																																			A
Songo Songo-4	1835.81	1836.72	2	2	30	50	1837.2	P			F	A			R	R	R		R	R				R		R			A						R																													A
Songo Songo-4	1835.81	1836.72	2	2	60	86	1837.5	P			C	A			R	F	F												A						R											R																		A
Songo Songo-4							1838.3	P				R			R	R													R																																				A
Songo Songo-4	1837.64	1838.55	2	2	10	20	1838.8	P			R	R			R																																																A
Songo Songo-4	1837.64	1838.55	2	2	35	41	1839	P	Late Albian	*T. appenninica* zone	F	F			R		F			R									C																	R																			A
Songo Songo-4	1837.64	1838.55	2	2	62	73	1839.3	P			F	C			F		C						R																																									A
Songo Songo-4	1838.55	1839.47	2	3	0	10	1840.60	P-M			C	A			F		R																							R						R																			A
Songo Songo-4	1838.55	1839.47	2	3	30	40	1841.00	P-M			F	F			C	R	R												F																																			A
Songo Songo-4	1838.55	1839.47	2	3	60	70	1841.20	P			C	A			F	F	F			R									A						R		R									R							R											A
Songo Songo-4	1838.55	1839.47	2	3	80	92	1841.40	P			C	A			C	A	C												A			R		R																					R									A
Songo Songo-4	1840.38	1841.3	2	2	22	35	1841.7	B																																																							
Songo Songo-4	1840.38	1841.3	2	2	35	41	1841.8	P-M			F	A				A				R				R					A						R																													A
Songo Songo-4	1840.38	1841.3	2	2	50	60	1841.9	P-M			A	F			F	R	F			R									A			R			R											R																		A
Songo Songo-4	1840.38	1841.3	2	2	60	70	1842	P-M			F	A				C				R				R					A			R			R												R																	A
Songo Songo-4							1842.2	P				A				R													R																																			
Songo Songo-4	1840.38	1841.3	2	2	84	92	1842.3	P-M			F	A			F	A	F			R															R											R																		A
Songo Songo-4	1841.3	1842.21	2	3	10	20	1843.5	P			C	A			F	A			R	R									A																																			A

Table 4.6: Songo Songo borehole-4 planktonic and benthic foraminifera

Well Name	Top core depth (m)	Bottom core depth (m)	Core number	Section	Top interval (cm)	Bottom interval (cm)	Depth below surface (m)	Preservation	Age	Planktonic foraminiferal zone	*Trochammina* sp.	*Bathysiphon* sp.	*Gyroidinoides gracillima*	*Ramulina* sp. 1	*Ammodiscus cretacea*	*Hyperammina* sp.	*Quadrimorphina* sp.	*Laevidentalina communis*	*Glomospira charoides*	*Gavelinella* sp.	*Pleurostomella* sp.	*Reophax* sp.1	*Osangularia* sp.	*Osangularia schloenbachi*	*Pleurostomella* aff. *obtusa*	*Pleurostomella reussi*	*Saracenaria* sp.	*Lenticulina (Saracenaria) spinosa*	*Rhabdammina* sp.	*Cyclammina* sp. 2	*Haplophragmoides* sp.	*Gavelinella intermedia*	*Osangularia* aff. *utaturiensis*	*Psammespahaera* sp.	*Laevidentalina* sp.	*Gyroidinoides* sp. 2	*Marssonella oxycona*	*Gyroidinoides* sp. 4	*Gyroidinoides* sp. 1	*Epistomina* sp.	*Hormosina* sp.	*Osangularia californica*	*Ramulina tetrahedralis*	*Amodiscuss* sp.	*Cyclammina* sp. 1	*Lenticulina* sp.	*Ramulina tetrahedralis*	*Pseudogaudryinella dividens*	*Saccammina* sp.	*Lingulogavelinella* aff. *spinosa*	*Ammobaculites* sp. 3	*Tritaxia pyramidata*	*Pseudonodosaria* sp.	*Verneuillina* sp.	*Psilocitharella* sp.	*Lagenammina* sp.	*Rhezakina epigona*	*Ammonites*	*Belemnites*	*Bivalves*	*Gastropods*	*Iron nodules*	*Ostracods*	*Pyrite*
Songo Songo-4	1841.3	1842.21	2	3	20	30	1843.6	P	Indeterminate	Unzoned	F	A			R	C	R		A				R						A					R																														A
Songo Songo-4	1841.3	1842.21	2	3	46	50	1843.8	P			A	A			R	F		R											A					R									R																					A
Songo Songo-4							1844	P-M			R				R	R				R	R								R					R						R																									
Songo Songo-4	1841.3	1842.21	2	3	73	80	1844.10	P			C	A				A	R	R			R								C																																			A
Songo Songo-4	1843.43	1844.04	2	2	31	50	1845	P			R	F			R	R				R									C																																			
Songo Songo-4	1843.43	1844.04	2	2	60	88	1845.2	P	Late Albian	*B. breggiensis* zone	F	A			R	A	F			R	R								A																																			
Songo Songo-4							1853.2	P-M				R			R	R								R								A								R																								
Songo Songo-4							1859.3	P-M				R			R				R	C							R								R					R	R																							
Songo Songo-4	1860.5	1861.41	3	1	40	50	1861	P			R	F				R													R	R																																		
Songo Songo-4	1860.5	1861.41	3	1	70	80	1861.3	P			R	C				F													C																																			
Songo Songo-4							1861.4	B																																																							
Songo Songo-4	1861.41	1862.33	3	2	40	50	1863	P			R	A			F	C													R			F																															
Songo Songo-4	1861.41	1862.33	3	2	70	80	1863.2	P																																																							
Songo Songo-4							1863.2	P				C																																																			
Songo Songo-4	1862.33	1863.24	3	3	40	50	1865	P			F	R				F								R					F			R			R																												
Songo Songo-4							1865.1	P				F																																																			
Songo Songo-4	1862.33	1863.24	3	3	80	90	1865.2	P			F	A			R																		R										R	R	R																			
Songo Songo-4							1865.4	P-M				R			R												R					F								R	R	R																						
Songo Songo-4	1864.16	1865.07	3	2	45	60	1865.7	P	INDETERMINATE	UNZONED	R	A			R	R					R								A																																			
Songo Songo-4	1864.16	1865.07	3	2	70	90	1866	P			R	A			R	A					R			R					R			R																												R				
Songo Songo-4	1865.99	1866.9	3	1	0	20	1866.1	NP																																																							
Songo Songo-4	1865.99	1866.9	3	1	33	43	1866.4	P																																																							
Songo Songo-4	1865.99	1866.9	3	1	64	75	1867	P	Middle Albian	*Ti. primula* zone																																																						
Songo Songo-4	1865.07	1866	3	3	15	30	1867.30	P			R	F				A													R								R																											
Songo Songo-4	1865.07	1866	3	3	75	90	1867.90	P-M			F	F			R	A				R														F	R																											A
Songo Songo-4	1866.9	1867.81	3	2	0	14	1868	P			F	F				R							R						R																														R					C
Songo Songo-4	1866.9	1867.81	3	2	30	40	1868.3	P	INDERMINATE	UNZONED	R	R				F					R								R																																			
Songo Songo-4	1866.9	1867.81	3	2	62	71	1868.6	P			F	C				R													F			R																																
Songo Songo-4							1868.7	P				R					R																																															
Songo Songo-4	1866.9	1867.81	3	2	80	90	1869	P-M			F	C			R	F	R			R				R				R			R	R																																
Songo Songo-4	1867.81	1868.73	3	3	0	20	1870	P-M	Late Aptian	*Pa. eubejaouaensis* zone	R	R	R			R	R						R					R	R	R																																		
Songo Songo-4	1867.81	1868.73	3	3	20	30	1870.1	P			R	C				F	R												R																																			
Songo Songo-4	1867.81	1868.73	3	3	40	50	1870.3	P-M			R	A	R		F	A	R	R									R	R																																				
Songo Songo-4	1867.81	1868.73	3	3	70	90	1870.6	P			F	F	R			F	R			R				R		R																																						
Songo Songo-4	1870.56	1871.47	4	2	0	10	1871.6	P-M				F	R		R	R						R	R																																									
Songo Songo-4	1870.56	1871.47	4	2	29	39	1872	P				F	R							R	R																																											
Songo Songo-4	1872.39	1873.3	4	1	30	40	1872.7	P-M			F	R			R	R				R																																												
Songo Songo-4	1872.39	1873.3	4	1	50	60	1873	P-M			R	R	R		R	R	R	R	R																																												
Songo Songo-4	1872.39	1873.3	4	1	80	90	1873.2	B																																																								
Songo Songo-4	1873.3	1873.91	4	2	0	20	1875	P			R	R	R	R	R	R	R																																															
Songo Songo-4	1873.3	1873.91	4	2	50	60	1875.5	P			R	F																																																				

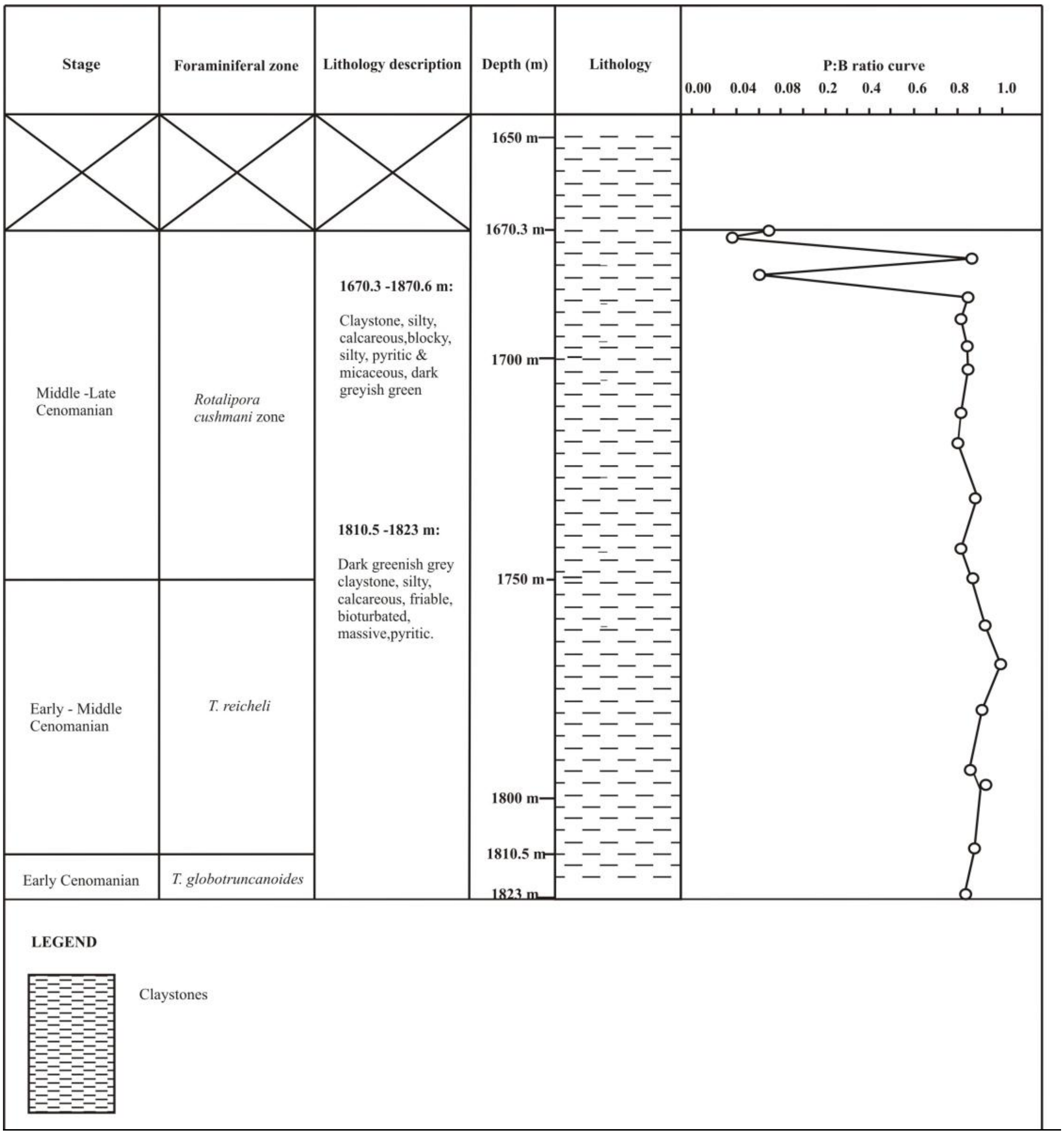


Figure 4.6: Summary of lithostratigraphy and P : B ratio curve for Songo Songo-4 borehole. Note: *T. = Thalmanninella,*

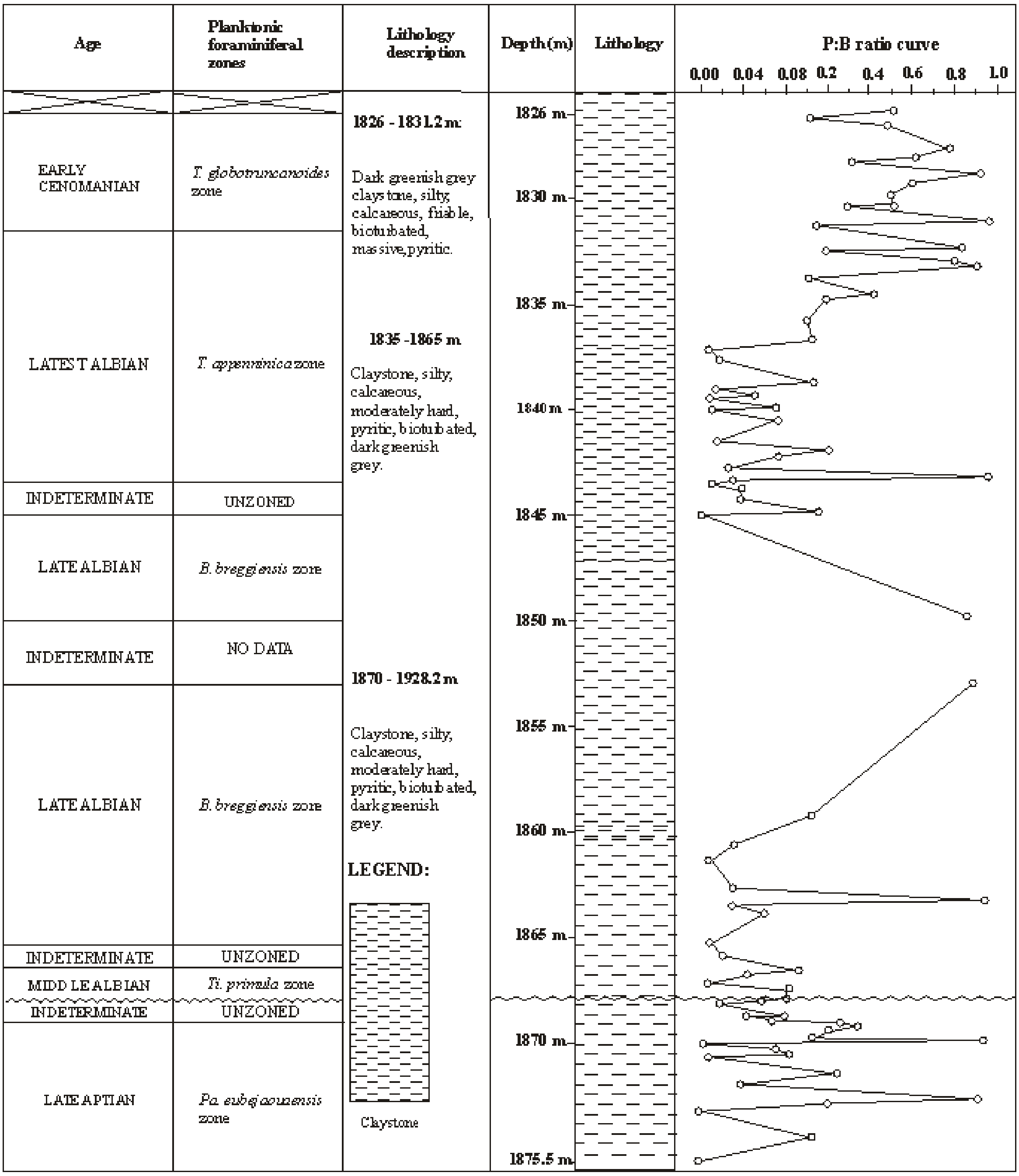


Figure 4.6: Summary of lithostratigraphy and P : B ratio curve for Songo Songo-4 borehole. Note*: B. = Biticinella, Pa. = Paraticinella, Ti. = Ticinella, T. = Thalmanninella.*

4.7 Kizimbani-1 borehole:

This borehole is located at latitude 9º 02' 25.00" S and longitude 39º 22' 30.00" E and was drilled in Mandawa Basin by AGIP in 1979 to test a large structure related to a basement high (figure 4.7). It was drilled to a total depth of 2,697 m but did not produce any hydrocarbons. The well was plugged and abandoned as a dry hole, but it was drilled through a sedimentary sequence ranging from early Cretaceous to Jurassic. The borehole was spud in the late Albian and drilled down to the basement. Since this research is mainly based on the middle Cretaceous section of the borehole then fifty-nine samples were analyzed for the present study.

4.7.1 Lithostratigraphy

The lithostratigraphy is based on the completion report of AGIP Oil Company. See the summary below that is described from the top to bottom.

4.7.1.1 Kingongo Formation (45.7-131.1 m)

This interval consists of shale, dark greenish grey alternating with thin beds of calcareous sandstones, white, fine grained. The shale is hard, platy, pyritic and calcareous. The lithology is uniform from 45.7 to 131.06 m.

4.7.1.2 Kihuluhulu Formation (131.1-243.8 m)

Dark greenish grey shale, platy, fissile, blocky, very hard, pyritic, calcareous and micaceous and in the upper section of this interval is a thick sandstone bed between 131.1 and 135 m, calcareous, fine grained and poorly sorted (refer to figure 4.7: Kizimbani-1 stratigraphic log).

4.7.2 Planktonic foraminiferal biostratigraphy

The borehole is divided into five biostratigraphic intervals. Planktonic and benthic foraminiferal data are shown in table 4.7 Planktonic assemblages are moderately diverse in the Albian and more diverse and abundant in the late Aptian. Preservation varies throughout the borehole, ranging from poor to moderate and few with good intervals and most shell of the foraminiferal tests are filled with calcite.

4.7.2.1 Late Aptian (204.2-244 m): Globigerinelloides algerianus Total range zone

The zone of *Globigerinelloides algerianus* is defined as the total range of the taxon. The highest occurrence (HO) of *Globigerinelloides algerianus* is at 204.2 m and lowest occurrence (LO) at 244 m indicates late Aptian age. The diversity of Planktonic species is slightly lower compared to the interval above and abundance varies from rare to abundant. Preservation varies from poor to moderate. This interval lies within the *Globigerinelloides algerianus* of the total range zone. This interval contains species of *Globigerinelloides* and common late Aptian hedbergellids (see table 4.7 and plates 3.3 - 3.5).

Benthic foraminifera are diverse and abundance varies from rare to common. Calcareous benthic forms encountered in this interval include *Astacolus* sp., *Conorotalites aptiensis, Lenticulina (Lenticulina) nodosa* and others. At 238-244 plant remains and pyrite in rare amounts (see table 4.7 and plate 3.16-3.17, & plates 3.20). Agglutinated forms are diverse in this interval and abundance varies from rare to few and some from common to abundant. Species present include *Ammodiscus cretacea, Hyperammina sp., Lagenammina alexanderi, Reophax spp*., and others (see table 4.7 and plates 3.16, 3.19 - 3.20 & 3.24). Gastropods and plant remains are present at 225.6 m.

4.7.2.2 Late Aptian (131.1– 201.2 m): Paraticinella eubejaouaensis Taxon range zone

The zone of *Paraticinella eubejaouaensis* is a biostratigraphic interval with the total range of *Paraticinella eubejaouaensis*. The lowest occurrence (LO) of *Paraticinella eubejaouaensis* at 201.2 m and highest occurrence (HO) at 131.1 m indicates latest Aptian age. This interval is rich in planktonic foraminifera with moderate diversity, and abundance varies from rare to abundant. Preservation of foraminifera at this interval is poor to moderate. Planktonic species present in this interval include the common late Aptian hedbergellids, *Globigerinelloides* spp., and *Paraticinella eubejaouaensis* (see table 4.7 and plates 3.4, 3.6 and plates 3.9 - 3.10).

Calcareous benthic foraminifera diversify and abundance varies from rare to abundant. Benthic species encountered in this interval include *Astacolus* sp.; *Conorotalites bartensteini aptiensis, Gavelinella barremiana, Saracenaria triangularis* and others (see table 4.7 and plates 3.16, 3.17, & plates 3.25).

Agglutinated forms with high diversity and abundance vary from rare to few and common to abundant. Species present include common early Cretaceous agglutinids and others (see table 4.7 and plates 3.16 – 3.25). Plant remains are present at 131.1 m– 158.5 m, at 161.5 m – 179.8 Ostracods and pyrite cubes are in rare amounts, and at 189 m, gastropods and pyrite are present and at 201.2 m ostracods are rare.

4.7.2.3 Early - Middle Albian (79.3m - 128 m): Microhedbergella rischi Partial range Zone

The zone of *Microhedbergella rischi* is a biostratigraphic interval from the lowest occurrence (LO) of *Microhedbergella rischi* (formally *Hedbergella rischi*) to the lowest occurrence (LO) of *Ticinella madecassiana* (Moullade, 1974). The lowest (LO) occurrence of *Microhedbergella rischi* at 128 m indicates early to middle Albian age. In this interval *Ticinella madecassiana* is within *Ticinella primula* interval and therefore this zone is beneath the *Ticinella primula* zone. In this interval species diversity is very low with rare abundance of planktonic species. Species present at this interval include *Microhedbergella rischi, Ticinella* spp., and others (see table 4.7 and plates 3.8, and plates 3.13 - 3.14).

Both calcareous and agglutinated benthic foraminifera diversified with abundance varies from rare to abundant and few with common to abundant. Species present such as *Conorotalites bartensteini aptiensis*, *Gavelinella intermedia,* and others (see table 4.7 and plates 3.17-3.18). Agglutinated species present include *Ammodiscus cretacea*, *Marsonella oxycona*, *Tritaxia pyramidata*, *Trochammina* sp., and rare in ammonites. Ostracods and pyrite cubes seen at 79.3 m, 106.7 m, 115.8 m, and pyrite and plant remains at 118.9-128.0 m in rare amounts (see table 4.7 and plates 3.16, 3.21 & 3.25).

4.7.2.3 Middle Albian (67.1-76.2): Ticinella primula Partial range zone

The lowest occurrence (LO) of *Ticinella primula* at 76.2 m and throughout this interval indicates a middle Albian age. Planktonic foraminiferal species diversity is low and abundance varies from rare to abundant. Species encountered in this interval include *Biticinella subbreggiensis, Ticinella primula,* and others (see table 4.7 and plates 3.2, 3.8, & 3.13).

Benthic foraminifera diversified and vary in abundance from rare to frequent and few with common to abundant. There are agglutinated diverse species such as *Tritaxia pyramidata, Tristix excavata, Lagenammina alexanderi,* and others (see table 4.7 and plates, 3.17, 3.25). Calcareous foraminifera present include species of *Epistomina, Gavelinella, Lenticulina Orthokarstenia, Osangularia* and others including ostracods and pyrite cubes in rare amounts (see table 4.7 and plates 3.17, 3.18, 3.21 – 3.22)

4.7.2.4 Late Albian (46-64.0 m): Biticinella breggiensis Interval zone

The lowest occurrence (LO) of *Biticinella breggiensis* at 64 m and its occurrence throughout this interval indicate late Albian age. This interval falls in the *Biticinella breggiensis* zone. The diversity of planktonic species is moderate and abundance varies from few to abundant and few with rare abundance. Preservation varies from poor to moderate. The species present include *Biticinella breggiensis, Muricohedbergella* spp., *Ticinella* spp., and others (refer to table 4.7 and pPlates 3.1, 3.9, and plate 3.12,). Pyrite cubes and ostracods are present with rare abundance and gastropods at 61 m.

Both benthic foraminiferal species diversity is high and abundance varies from rare to few and few with common to abundant. Benthic species present include *Gavelinella intermedia Osangularia schloebanchi* and others (see table 4.7 and plates 3.17 & 3.22). The present agglutinated forms include: *Ammobaculites* sp., *Glomospirella* sp., *Hyperammina gaultina,* and many others (see table 4.7 and plates 3.16, 3.18 – 3.19).

4.7.3 Synthesis:

The summary stratigraphy of the Kizimbani-1 borehole is shown in Figure 4.7. The Aptian to Albian succession is relatively complete in comparison to the more northerly boreholes although the section is more condensed. There may be a hiatus at the base of the Ticinella primula zone (79.3 m) as the interval corresponding to the Ticinella madecassiana zone appears to be missing. However, this could also be due to the rarity of the zone fossils. Similarly another short hiatus may be present at the base of the Microhedbergella rischi Zone at 131.1 m where there is a thin bed of sandstone. Planktonic: benthic ratios suggest a slight shallowing trend in the Aptian followed by deepening in the Albian. Overall the P:B ratios are high indicating a relatively deep water environment.

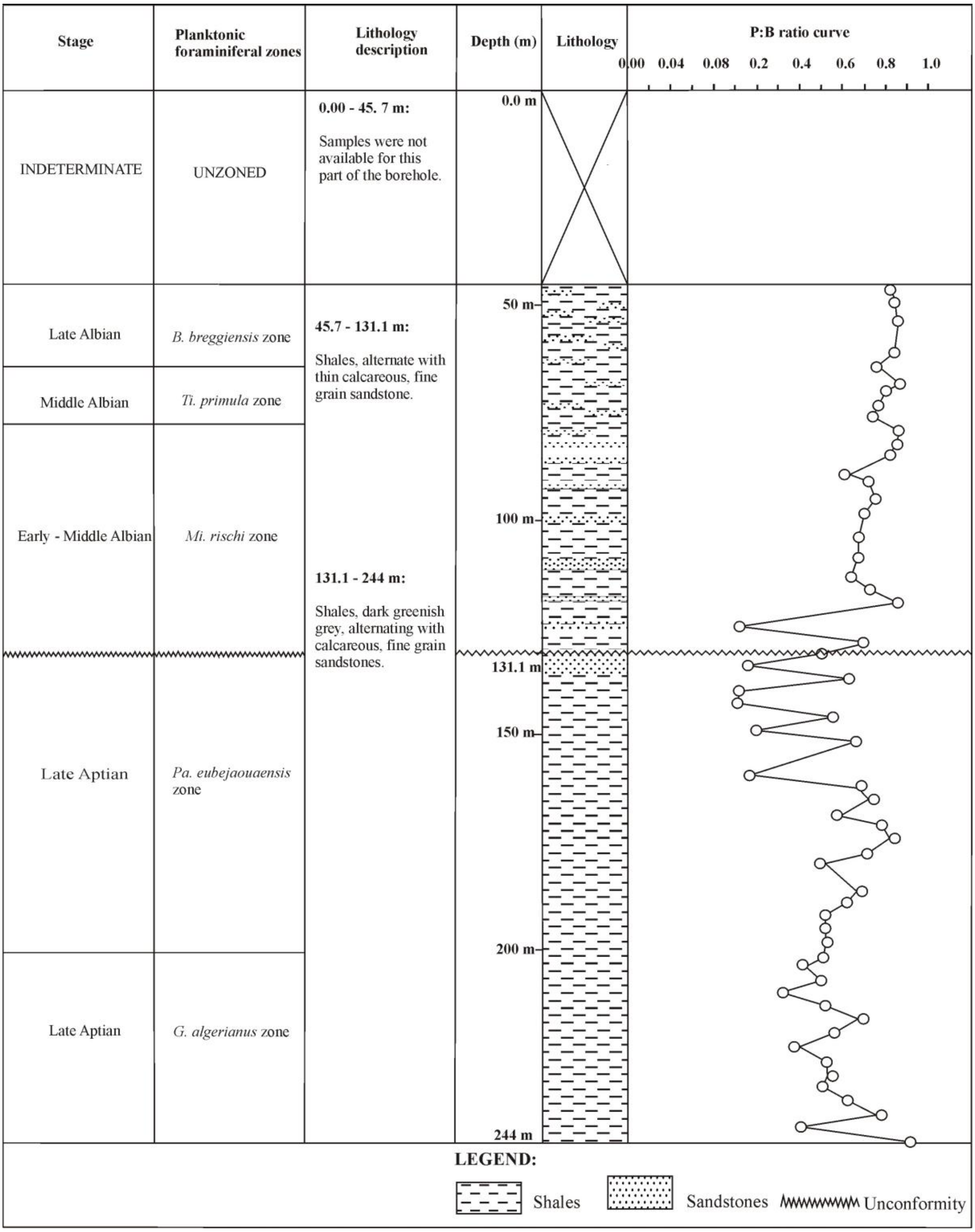


Figure 4.7: Summary biozonation, lithostratigraphy and P/B ratio curve for Kizimbani-1 borehole. Note: *B. = Biticinella, G. = Globigerinelloides, Mi. = Microhedbergella, Pa. = Paraticinella, Ti. = Ticinella*

Table 4.7: Kizimbani-1 borehole planktonic and benthic foraminifera range chart.

Well name	Sample depth (m)	Stage	Planktonic Foraminiferal zone	Preservation	*Hedbergella aptiana*	*Caucasella hoterivica*	*Hedbergella sigali*	*Hedbergella infracretacea*	*Hedbergella similis*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Globigerinelloides ferreolensis*	*Hedbergella trochoidea*	*Paraticinella eubejaouaensis* (sp. 1)	*Paraticinella eubejaouaensis*	*Muricohedbergella delrioensis*	*Muricohedbergella albiana*	*Ticinella primula*	*Microhedbergella rischi*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex*	*Ticinella praeticinensis*	*Biticinella subbreggiensis* (sp. 2)	*Biticinella breggiensis*	*Ticinella raynaudi*	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Loeblichella* sp.	*Ticinella* sp. 1	*Tucunella* sp. 2	*Ticinella madecassiana*	Ammonites	
Kizimbani-1	46	Late Albian	*B. breggiensis* zone	P-M														A	F			R	A	C	R		A	R	R					R		
Kizimbani-1	49			P-M														A	F			R	A	F			A	R								
Kizimbani-1	55			P-M														A	F			R	A	F			A							R		
Kizimbani-1	61			P-M														A	F			R	A	C			A									
Kizimbani-1	64			P-M														A	F			R	C	F	R		A	R		R				R		LO of *B. breggiensis*
Kizimbani-1	67.1	Middle Albian	*Ti. primula* zone	M-G														A		R			A	F		R										
Kizimbani-1	70.1			P-M														C		R			R								R			R		
Kizimbani-1	73.2			P-M														C		R																
Kizimbani-1	76.2			M-G														F		R																LO of *Ti. primula*
Kizimbani-1	79.3	Early - Middle Albian	*Mi. rischi* zone	P-M														F			R											R				
Kizimbani-1	82.3			P-M														F			R															
Kizimbani-1	85.3			P-M																																
Kizimbani-1	88.4			M-G																																
Kizimbani-1	91.4			P-M																																
Kizimbani-1	95			P-M																																
Kizimbani-1	98			P-M																														R		
Kizimbani-1	104			P-M																																
Kizimbani-1	107			M-G																	R											R				
Kizimbani-1	113			M-G																																
Kizimbani-1	116			P-M																																
Kizimbani-1	119			P-M																	R											R			R	
Kizimbani-1	125			M-G																	R															
Kizimbani-1	128			P-M																	R															LO of *Mi. rischi*

Note: B. = Biticinella, Mi. = Microhedbergella, Ti. = Ticinella,, P-M = Poor to Moderate, M-G = moderate to good, R = Rare; 2 - 5 specimens, F = frequent; 6 - 10 specimens,
C = Common, 11 - 20 specimens, A = Abundant; 21 ≥ specimens, LO = Lowest Occurrence, HO = Highest occurrence

Table 4.7: Kizimbani-1 borehole planktonic and benthic foraminifera range chart continued.

Well name	Sample depth (m)	Stage	Planktonic foraminiferal zones	Preservation	*Hedbergella aptiana*	*Caucasella hoterivica*	*Hedbergella sigali*	*Hedbergella infracretacea*	*Hedbergella similis*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Globigernelloides ferreolensis*	*Hedbergella trochoidea*	*Paraticinella eubejaouaensis* (sp. 1)	*Paraticinella eubejaouaensis*	*Muricohedbergella delrioensis*	*Muricohedbergella albiana*	*Ticinella primula*	*Microhedbergella rischi*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex*	*Ticinella praeticinensis*	*Biticinella subbreggiensis*	*Biticinella breggiensis*	*Ticinella raynaudi*	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Loeblichella sp.*	*Ticinella sp. 1*	*Ticinella sp. 2*	*Ticinella madecassiana*	*Ammonites*	
Kizimbani-1	131.1	Late Aptian	*Pa. eubejaouaensis* zone	P-M		R		R		R	A						R																			HO of *Pa. eubejaouaensis*
Kizimbani-1	134.1	Late Aptian	*Pa. eubejaouaensis* zone	P-M							F																									
Kizimbani-1	137.2	Late Aptian	*Pa. eubejaouaensis* zone	P-M						R	F					R	R																			
Kizimbani-1	140.2	Late Aptian	*Pa. eubejaouaensis* zone	P-M							R						R																			
Kizimbani-1	143.3	Late Aptian	*Pa. eubejaouaensis* zone	P											F																					
Kizimbani-1	146.3	Late Aptian	*Pa. eubejaouaensis* zone	M-G						R	A				F		R																			
Kizimbani-1	149.4	Late Aptian	*Pa. eubejaouaensis* zone	P- M	R			F							C																					
Kizimbani-1	152.4	Late Aptian	*Pa. eubejaouaensis* zone	P-M				A			F				F		R																			
Kizimbani-1	159	Late Aptian	*Pa. eubejaouaensis* zone	P-M											F																					
Kizimbani-1	162	Late Aptian	*Pa. eubejaouaensis* zone	P-M	C			A			A				F																					
Kizimbani-1	165	Late Aptian	*Pa. eubejaouaensis* zone	P-M				A			A				C		R																			
Kizimbani-1	168	Late Aptian	*Pa. eubejaouaensis* zone	P-M						R	F				F																					
Kizimbani-1	171	Late Aptian	*Pa. eubejaouaensis* zone	M-G	R										F		R																			
Kizimbani-1	174	Late Aptian	*Pa. eubejaouaensis* zone	P-M							R				F																					
Kizimbani-1	177	Late Aptian	*Pa. eubejaouaensis* zone	P-M							R				F		R																			
Kizimbani-1	180	Late Aptian	*Pa. eubejaouaensis* zone	M-G	R			A							F		R																			
Kizimbani-1	186	Late Aptian	*Pa. eubejaouaensis* zone	P-M						R	R				F		R																			
Kizimbani-1	189	Late Aptian	*Pa. eubejaouaensis* zone	P-M	R										F		R																			
Kizimbani-1	192	Late Aptian	*Pa. eubejaouaensis* zone	P-M				R			R				F		R																			
Kizimbani-1	195.1	Late Aptian	*Pa. eubejaouaensis* zone	P-M						R	R				F		R																			
Kizimbani-1	198.1	Late Aptian	*Pa. eubejaouaensis* zone	P-M	R			F			F				F																					LO of *Pa. eubejaouaensis*
Kizimbani-1	201.2	Late Aptian	*Pa. eubejaouaensis* zone	P-M							R						R																			
Kizimbani-1	204.2	Late Aptian	*G. algerianus* zone	P-M	R			F			F	F		R	R																					HO of *G. algerianus*
Kizimbani-1	207.3	Late Aptian	*G. algerianus* zone	P-M	F			F		R	F	F		R	F																					
Kizimbani-1	210.3	Late Aptian	*G. algerianus* zone	P-M				F		R		F																								
Kizimbani-1	213.4	Late Aptian	*G. algerianus* zone	M-G	R			F		R	R	R		R																						
Kizimbani-1	216.4	Late Aptian	*G. algerianus* zone	M-G	R			F				R	R	R	R																					
Kizimbani-1	220	Late Aptian	*G. algerianus* zone	M-G								R		R																						
Kizimbani-1	223	Late Aptian	*G. algerianus* zone	M-G						R	R																									
Kizimbani-1	226	Late Aptian	*G. algerianus* zone	P-M								R																								
Kizimbani-1	229	Late Aptian	*G. algerianus* zone	M-G				F				R																								
Kizimbani-1	232	Late Aptian	*G. algerianus* zone	M-G						R	R	R		R																						
Kizimbani-1	235	Late Aptian	*G. algerianus* zone	M-G										R																						
Kizimbani-1	238	Late Aptian	*G. algerianus* zone	M-G	R				R		R	R			R																					
Kizimbani-1	241	Late Aptian	*G. algerianus* zone	P-M			R		R		R	R			R																					
Kizimbani-1	244	Late Aptian	*G. algerianus* zone	P-M							R				R																					LO of *G. algerianus*

Table 4.7: Kizimbani-1 borehole planktonic and benthic foraminifera range chart continued.

Well name	**Sample depth (m)**	**Stage**	**Planktonic foraminiferal zones**	**Preservation**	*Ammodiscus cretacea*	*Bathysiphon* sp.	*Glomospira charoides*	*Trochammina* sp.	*Hyperammina* sp.	*Hormosina* sp.	*Lagennamina alexanderi*	*Globulina* aff. *prisca*	*Lenticulina muensteri*	*Lenticulina* sp. A	*Astacolus* sp.	*Nodosaria* sp.	*Gyroidinoides gracillima*	*Ammobaculites* sp.	*Glomospira* sp.	*Marssonella oxycona*	*Glomospirella* sp.	*Saccammina* sp.	*Gavelinella intermedia*	*Reophax* sp. 1	*Hormosina* sp.	*Reophax* sp. 2	*Tritaxia pyramidata*	*Pseudogaudryinella* sp.	*Pseudogaudrinella dividens*	*Epistomina hetchi*
Kizimbani-1	46	Late Albian	*B. breggiensis* zone	P-M	R	R	R	C	R				F					F		A		R	F						R	
Kizimbani-1	49			P-M		R	R	F	R				F		R	R		R		C		R	C				R		R	
Kizimbani-1	55			P-M		R	R	R	R									R					C							
Kizimbani-1	61			P-M		R			R				F		R					F		R	F							
Kizimbani-1	64			P-M	R		R	F	R				F		R	R			R	F		R	F							
Kizimbani-1	67.1	Middle Albian	*Ti. primula* zone	M-G	R	R	R	F					F					R		F			A					C		
Kizimbani-1	70.1			M-G	R	F			F		C							F		F			C	R			R			
Kizimbani-1	73.2			P-M	R	R		R	R				R					R		C		R	F	R						
Kizimbani-1	76.2			M-G	R	R	R	R	R		C		R			R				R			F							
Kizimbani-1	79.3	Early - Middle Albian	*Mi. rischi* zone	P-M	R		R	F	R		C							R		F			F		R					
Kizimbani-1	82.3			P-M	R	R		R					F			R		R		R			F							R
Kizimbani-1	85.3			P-M	R	R		R	R									R					R		R					
Kizimbani-1	88.4			M-G	F	F	R		R						R			R		R		R	C	R						
Kizimbani-1	92			P-M	F			C	R				R		R					F	R		A	R	R	R	R			
Kizimbani-1	95			P-M	F	R		A	R									R		C			A							
Kizimbani-1	98			P-M		R			R							R							R							
Kizimbani-1	104			P-M	R	R		R	R	R		R	R							R			F	R	R					
Kizimbani-1	107			P-M	R	F			R											F	R			R						
Kizimbani-1	113			M-G	R	F												R					A							
Kizimbani-1	116			P-M		R			R											R			A							
Kizimbani-1	119			P-M	R	R		F	R						R	R				R	R		C							
Kizimbani-1	125			M-G	R	R		R	R				R			R				R			F							
Kizimbani-1	128			P-M	R	R	R	R							R			R				R	C							

Table 4.7: Kizimbani-1 borehole planktonic and benthic foraminifera range chart continued.

Well name	Sample depth (m)	Stage	Planktonic foraminiferal zones	Preservation	*Ammodiscus cretacea*	*Bathysiphon sp.*	*Glomospira charoides*	*Trochammina sp.*	*Hyperammina sp.*	*Hormosina sp.*	*Lagennamina alexanderi*	*Globulina aff. prisca*	*Lenticulina muensteri*	*Lenticulina sp. A*	*Astacolus sp.*	*Nodosaria sp.*	*Gyroidinoides gracillima*	*Ammobaculites sp.*	*Glomospira sp.*	*Marssonella oxycona*	*Glomospirella sp.*	*Saccammina sp.*	*Gavelinella intermedia*	*Reophax sp. 1*	*Hormosina sp.*	*Reophax sp. 2*	*Tritaxia pyramidata*	*Pseudogaudryinella sp.*	*Pseudogaudrinella dividens*	*Epistomina hetchi*
Kizimbani-1	131.1	Late Aptian	*Pa. eubejaouaensis zone*	P-M	R	R		R	R				R								R									
Kizimbani-1	134.1			P-M	R		R	R	R									R			R									
Kizimbani-1	137.2			P-M	R	C		R	F			R	R																	
Kizimbani-1	140.2			P	R	R		R	F												R									
Kizimbani-1	143.3			P					R						R															
Kizimbani-1	146.3			M-G	R	R		F	R					R	R			R			R	R								
Kizimbani-1	149.4			P-M	R			F	R				R							R										
Kizimbani-1	152.4			P-M	R			F	R		R					R				C										
Kizimbani-1	159			M-G	R		R	F					R					R			R									
Kizimbani-1	162			P-M		R			R			R						R		F	R									
Kizimbani-1	165			P-M	R	R	F	F	R		R				R		R	R			R	R								
Kizimbani-1	168			P-M	R		R	C	F		R		R		R			R			R									
Kizimbani-1	171			M-G	R		R	F	R									R		R	R									
Kizimbani-1	174			P-M	R		R	C	R								R	C			R									
Kizimbani-1	177			P-M		R										R		F			R									
Kizimbani-1	180			M-G				C	F		R							R		C										
Kizimbani-1	186			P-M	R			R	R				R																	
Kizimbani-1	189			P-M		R		F	F				R		R			R												
Kizimbani-1	192			P-M				F	C						R			R		R										
Kizimbani-1	195.1			P-M	R				F								R	F												
Kizimbani-1	198.1			P-M				F	F				R				R	R		R										
Kizimbani-1	201.2			P-M	R			R	R		R				R			R		R										
Kizimbani-1	204.2	Late Aptian	*G. algerianus zone*	P-M	R			F	C		F				R			F												
Kizimbani-1	207.3			P-M	R				C						R			R												
Kizimbani-1	210.3			P-M		R		C	R				R		R	R														
Kizimbani-1	213.4			M-G		R		F	R		R					R	R	F												
Kizimbani-1	216.4			M-G					R		F																			
Kizimbani-1	220			M-G	R			C	R						R		R													
Kizimbani-1	223			M-G	R			F	F		R		R		R		R	R												
Kizimbani-1	226			P-M	R			F	F								R	R												
Kizimbani-1	229			P-M	R	R		R	F		R				R															
Kizimbani-1	232			M-G	R			R	C									R												
Kizimbani-1	235			M-G	R			R	C		R		R		R				R											
Kizimbani-1	238			M-G	R				R							R	R	R												
Kizimbani-1	241			P-M	R				F		R				R	R														
Kizimbani-1	244			P-M	R			C	R		R		R																	

Table 4.7: Kizimbani-1 borehole planktonic and benthic foraminifera range chart continued.

Well name	**Sample depth (m)**	**Stage**	**Planktonic foraminiferal zones**	**Preservation**	*Psammosphaera* sp.	*Spiroplectammina* sp.	*Conorotalites bartensteini aptiensis*	*Lagenammina* sp.	*Reophax* sp. 3	*Laevidentalina communis*	*Globorotalites* sp.	*Hyperammina gaultina*	*Lenticulina ex. gr. muensteri*	*Lenticulina* sp. aff. *saxocretacea*	*Rhizammina* sp.	*Lenticulina (Saracenaria) spinosa*	*Ramlina* sp. 3	*Saracenaria triangularis*	*Pseudonodosaria* sp.	*Patellina subcretcea*	*Pleurostomella* sp.	*Ramulina tetrahedralis*	*Lenticulina* sp. A	*Gyroidinoides* sp 1.	*Quinqueloculina antiqua*	*Ramulina sp.1*	*Tristix excavata*	*Orthokastenia* sp.	*Psilocitherella* sp.	*Psilocitherella recta*	*Ramulina* sp. 2	*Ammodiscus* sp.	*Pseudonodosaria humilis*	*Pleurostomella reussi*	*Epistomina chapmani*	*Epistomina spinulifera*	*Ramulina spandeli*	*Osangularia schloebanchi*	*Verneulina* sp.	*Orthokarstenia* aff. *shastaensis*	*Gaudryina* sp.	*Bivalve*	*Gastropod*	*Ostracods*	*Plant remains*	*Pyrite cubes*
Kizimbani-1	46	Late Albian	*B. breggiensis* zone	P-M	R	F				F	R	R								R	R	R			R		R		R					R			R							R		R
Kizimbani-1	49			P-M		R				F		R					R	R		R	R	R		R	F		R	F				R					R							R		F
Kizimbani-1	55			P-M									R												R									R				R			R			R		R
Kizimbani-1	61			P-M						R			F							R		R			F		R											R					R	R		R
Kizimbani-1	64			P-M						R									R	R					F					R				R	R	R								R		R
Kizimbani-1	67.1	Middle Albian	*Ti. primula* zone	M-G	R	R				R										R		R			F	R	R			R				R	R				R	R				R		R
Kizimbani-1	70.1			M-G	R					F							R			R		R			R										R	R	R							R		R
Kizimbani-1	73.2			P-M						R								R	R						F				R	R				R	R	R	R	R						R		R
Kizimbani-1	76.2			M-G		R				R			R		R					R					R					R		R			R									R		R
Kizimbani-1	79.3	Early - Middle Albian	*Mi. rischi* zone	P-M		R				R			F					R		R										R						R								R		R
Kizimbani-1	82.3			P-M				F												R										R						R										
Kizimbani-1	85.3			P-M																R				R																						
Kizimbani-1	88.4			M-G	R					F					R		R			F			R										R			R										
Kizimbani-1	91.4			P-M		R				R		R			R					R							R								F		R									
Kizimbani-1	95			P-M						R		R	R				R										R			R														R		R
Kizimbani-1	98			P-M		R				R					R		R																				R									
Kizimbani-1	104			P-M	R					R							R																													
Kizimbani-1	107			P-M		R									R		R																		R		R							R		R
Kizimbani-1	113			M-G											R												R																			
Kizimbani-1	116			P-M						F							R			R							R								F									R		R
Kizimbani-1	119			P-M	R					R							R			R				R								R	R												R	R
Kizimbani-1	125			M-G											R		R			R																									R	R
Kizimbani-1	128			P-M		R	R	R									R																												R	R

Table 4.7: Kizimbani-1 borehole planktonic and benthic foraminifera range chart.

Well name	Sample depth (m)	Stage	Planktonic Foraminiferal zone	Preservation	*Hedbergella aptiana*	*Caucasella hoterivica*	*Hedbergella sigali*	*Hedbergella infracretacea*	*Hedbergella similis*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Globigerinelloides ferreolensis*	*Hedbergella trochoidea*	*Paraticinella eubejaouaensis* (sp. 1)	*Paraticinella eubejaouaensis*	*Muricohedbergella delrioensis*	*Muricohedbergella albiana*	*Ticinella primula*	*Microhedbergella rischi*	*Favusella washitensis*	*Macroglobigerinelloides bentonensis*	*Muricohedbergella simplex*	*Ticinella praeticinensis*	*Biticinella subbreggiensis* (sp. 2)	*Biticinella breggiensis*	*Ticinella raynaudi*	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Loeblichella* sp.	*Ticinella* sp. 1	*Tucunella* sp. 2	*Ticinella madecassiana*	*Ammonites*	
Kizimbani-1	46	Late Albian	*B. breggiensis* zone	P-M														A	F			R	A	C	R		A	R	R					R		
Kizimbani-1	49			P-M														A	F			R	A	F			A	R								
Kizimbani-1	55			P-M														A	F			R	A	F			A							R		
Kizimbani-1	61			P-M														A	F			R	A	C			A									
Kizimbani-1	64			P-M														A	F			R	C	F	R		A	R		R				R		LO of *B. breggiensis*
Kizimbani-1	67.1	Middle Albian	*Ti. primula* zone	M-G														A		R			A	F		R										
Kizimbani-1	70.1			P-M														C		R			R								R			R		
Kizimbani-1	73.2			P-M														C		R																
Kizimbani-1	76.2			M-G														F		R																LO of *Ti. primula*
Kizimbani-1	79.3	Early - Middle Albian	*Mi. rischi* zone	P-M														F			R											R				
Kizimbani-1	82.3			P-M														F			R															
Kizimbani-1	85.3			P-M																																
Kizimbani-1	88.4			M-G																																
Kizimbani-1	91.4			P-M																																
Kizimbani-1	95			P-M																																
Kizimbani-1	98			P-M																														R		
Kizimbani-1	104			P-M																																
Kizimbani-1	107			M-G																	R											R				
Kizimbani-1	113			M-G																																
Kizimbani-1	116			P-M																																
Kizimbani-1	119			P-M																	R											R			R	
Kizimbani-1	125			M-G																	R															
Kizimbani-1	128			P-M																	R															LO of *Mi. rischi*

Note: B. = *Biticinella, Mi.* = *Microhedbergella*, *Ti*. = *Ticinella*,, P-M = Poor to Moderate, M-G = moderate to good, R = Rare; 2 - 5 specimens, F = frequent; 6 - 10 specimens,
C = Common, 11 - 20 specimens, A = Abundant; 21 ≥ specimens, LO = Lowest Occurrence, HO = Highest occurrence

Table 4.7: Kizimbani-1 borehole planktonic and benthic foraminifera range chart continued.

Well name	Sample depth (m)	Stage	Planktonic foraminiferal zones	Preservation	*Psammosphaera sp.*	*Spiroplectammina sp.*	*Conorotalites bartensteini aptiensis*	*Lagenammina sp.*	*Reophax sp.3*	*Laevidentalina communis*	*Globorotalites sp.*	*Hyperammina gaultina*	*Lenticulina ex. gr. muensteri*	*Lenticulina sp. aff. saxocretacea*	*Rhizammina sp.*	*Lenticulina (Saracenaria) spinosa*	*Ramlina sp. 3*	*Saracenaria triangularis*	*Pseudonodosaria sp.*	*Patellina subcretacea*	*Pleurostomella sp.*	*Ramulina tetrahedralis*	*Lenticulina sp. A*	*Gyroidinoides sp 1.*	*Quinqueloculina antiqua*	*Ramulina sp.1*	*Tristix excavata*	*Orthokarstenia sp.*	*Psilocitherella sp.*	*Psilocitherella recta*	*Ramulina sp. 2*	*Ammodiscus sp*	*Pseudonodosaria humilis*	*Pleurostomella reussi*	*Epistomina chapmani*	*Epistomina spinulifera*	*Ramulina spandeli*	*Osangularia schloebanchi*	*Verneulina sp.*	*Orthokarstenia aff. shastaensis*	*Gaudryina sp.*	*Bivalve*	*Gastropod*	*Ostracods*	*plant remains*	*Pyrite cubes*
Kizimbani-1	131.1	Late Aptian	*Pa. eubejaouaensis zone*	P-M													R									R																			R	R
Kizimbani-1	134.1			P-M		R									R		R											R		R	R														R	R
Kizimbani-1	137.2			P-M																								R	R																R	R
Kizimbani-1	140.2			P						R					R											R	R																		R	R
Kizimbani-1	143.3			P											R									R		R																			R	R
Kizimbani-1	146.3			M-G			R		R	F			R					F					R																						R	R
Kizimbani-1	149.4			P-M			R		R						R		R																												R	R
Kizimbani-1	152.4			P-M						F			F		R			R																											R	R
Kizimbani-1	159			M-G											R		R																												R	R
Kizimbani-1	162			P-M			R			R					R																															
Kizimbani-1	165			P-M																																										
Kizimbani-1	168			P-M					R	R					F																															
Kizimbani-1	171			M-G		R	R	R							R																															
Kizimbani-1	174			P-M		R		A	R						F																															
Kizimbani-1	177			P-M				R							R																															
Kizimbani-1	180			M-G						R					R	R																														
Kizimbani-1	186			P-M					R	R																																				
Kizimbani-1	189			P-M		R		C		R					F																															
Kizimbani-1	192			P-M		R									C																															
Kizimbani-1	195.1			P-M				R							R																															
Kizimbani-1	198.1			P-M		R									R																															
Kizimbani-1	201.2			P-M	R	R	R								R																															
Kizimbani-1	204.2	Late Aptian	*G. algerianus zone*	P-M																																										
Kizimbani-1	207.3			P-M				R	R	R																																				
Kizimbani-1	210.3			P-M						R																																				
Kizimbani-1	213.4			M-G			R			R			R	R																																
Kizimbani-1	216.4			M-G				R																																						
Kizimbani-1	220			M-G		R		R	R																																					
Kizimbani-1	223			M-G					F		R	R																																		
Kizimbani-1	226			P-M																																										
Kizimbani-1	229m			P-M		R			R																																					
Kizimbani-1	232			M-G		R		R	R	R																																				
Kizimbani-1	2335			M-G	R	R	R																																							
Kizimbani-1	238			M-G																																										
Kizimbani-1	241			P-M																																										
Kizimbani-1	244			P-M																																										

4.8 New outcrop sampling

Fieldwork was conducted in 2009 and a fifty-one outcrop samples were collected and analyzed for this thesis. These outcrops were collected from several areas where mid-cretaceous sediments are exposed along newly cut roads. The locations of the outcrops are given in chapter 2 of this thesis and their lithology and planktonic foraminiferal biostratigraphy is given in this chapter. Outcrop samples were collected from Msanga-Vikumburu track in the Ruvu Basin (AK22-01 to AK22-14), along the Chalinze-Tanga Road (AK23-01 to AK23-07), along the Tarawanda - Malivundo track (AK23-08 - AK23-09), along the Tarawanda-Lugoba Track; AK23-10-AK23-13, and along the Msata-Bagamoyo Road, AK23-14 - AK23-24. Further samples were collected in Kilwa area (AK28-01 & AK29-01 - AK29-05 (see figs. 2.1b - 2.1l; outcrop location map).

4.8.1 Lithostratigraphy

The lithologies of the outcrop samples are summarized according to their stratigraphic positions from top to base.

4.8.1.1 Middle - Late Cenomanian: Wami River Series

AK22-03, AK22-05, AK23-02: Clay, olive greyish green, calcareous.

4.8.1.2 Early Cenomanian: Wami River Series

AK22-04: Clay, olive greyish green, calcareous.

4.8.1.3 Late Albian: Kingongo Formation

AK22-02: Claystone, sandy, olive greenish grey friable.

4.8.1.4 Late Albian: Kingongo Formation

AK22-10 (1): Light to olive greenish grey claystone, slightly chalkish, AK23-19, AK23-22 - AK23-24: Olive greyish green claystone, calcareous, AK23-20: Dark greenish grey claystones.

4.8.1.5 Middle Albian: Kingongo Formation

AK22-06-AK22-09, AK22-13: Claystone; dark greenish grey, hard, blocky and calcareous, AK22-10 (2), AK22-11, & AK22-14: Claystone, light olive greenish grey, slightly chalkish and friable.

4.8.1.6 Unzoned interval (Uppermost Aptian): Kihuluhulu Formation

AK23-01, AK23-04, AK23-08, AK23-13, AK28-01: Clay, friable, dark greenish grey.

4.8.1.7 Unzoned interval

AK23-07 and AK23-09: Olive greenish grey claystone, friable, calcareous, AK23-12: conglomeratic sandstone, AK23-10; Olive greenish grey claystone, friable, calcareous.

4.8.1.8 Barren interval

(AK22-01, AK22-12, AK 23-05-AK23-06, AK23-14-AK23-18, AK23-21, AK29-03-AK29-05)

AK22-01: Claystone, sandy, olive greenish grey, friable, AK22-12: olive greenish grey clay.

AK23-14-AK23-15; Dark olive green clay, calcareous,

AK23-16-AK23-17: Claystone, friable, slightly calcareous, olive greenish grey, AK23-18: None calcareous clay stone, olive greenish grey,

AK29-03 - AK29-05: claystone.

4.8.2 Planktonic foraminiferal biostratigraphy

Samples are described in stratigraphic order using their planktonic and benthic foraminiferal content from the base to the top.

(AK23-01, AK23-04, AK23-08, and AK23-13 & AK28-01)

Outcrop samples have few species of late Aptian and few benthic. Only three samples have planktonic foraminifera species of *Globigerinelloides aptiensis, Hedbergella aptiana,* *Praehedbergella ruka*, and *Hedbergella sigali*. The co-occurrence of the late Aptian species of hedbergellids and *Globigerinelloides* with the absence of any zonal marker species, with their extinction limits in the uppermost late Aptian indicates that these outcrop samples are of the uppermost late Aptian age (see plates 3.3-3.6 and plate 3.12).

The present benthic species include *Gavelinella barremiana, Lenticulina (Astacolus) spinosa, Lenticulina muensteri, Lenticulina* sp., *Psilocitherella* sp., (see plates 3.17, 3.20 – 3.23). Ostracods and gastropod present in one of the samples (AK23-10).

4.8.2.1 Indeterminate: Unzoned

(AK22-01 & AK22-12, AK 23-05 - AK23-06, AK23-14 - AK23-18, AK23-21, AK29-03 - AK29-05). These samples are barren.

4.8.2.2 Late Aptian: Paraticinella eubejaouaensis Taxon range zone

(AK28-03 - AK28-07, AK29-01 - AK29-02)

The diversity of planktonic species is very high and abundance varies from frequent to abundant and few with rare abundance and preservation are poor to moderate. The occurrence of *Paraticinella eubejaouaensis* in these samples indicates a latest Aptian age. Species present in this interval include *Paraticinella eubejaouaensis, Globigerinelloides aptiensis, Hedbergella aptiana, Hedbergella similis, Praehedbergella ruka, Hedbergella gorbachikae, Hedbergella infracretacea, H. trocoidea, Hedbergella sigali,* and *Globigerinelloides* sp.,(see plates 3.3-3.6 , 3.9-3.10, and plate 3.12,).

Calcareous benthic foraminifera have low diversity and abundance varies from rare to common. Species present are *Gavelinella barremiana, Lenticulina* sp., *Osangularia* sp., and others with no agglutinated forms (see plate 3.17- 3.18, and plates 3.20 and 3.22).

4.8.2.3 Ticinella primula Partial range zone

(AK22-06 - AK22-09, AK22-10 (2), AK22-11, AK22-13 & AK22-14):

In this interval, the diversity of planktonic species is low and abundance varies from rare to abundant and preservation varies from poor to moderate.

The mentioned above outcrop samples analyzed have planktonic foraminifera of the Middle Albian age. The lowest occurrence (LO) of *Ticinella primula* in sample AK22-06 through to AK22-05 and the rest of the samples indicates Middle Albian age. Species present such as, *Muricohedbergella albiana, Muricohedbergella delrioensis, Muricohedbergella planispira, Muricohedbergella simplex* and *Ticinella primula* (see plates 3.2, 3.8-3.9, plate 3.13).

Calcareous benthic species with high diversity and abundance varies from rare to abundant Species encountered in this interval include *Conorotalites bartensteini aptiensis, Laevidentalina communis, Eoguttulina* sp., *Gavelinella intermedia, Gavelinella* sp., *Lagena globosa, Globorotalites* sp., *Gyroidinoides* sp. 2, *Lenticulina* sp., *Linguligavelinella* sp., *Marginulinopsis* sp., *Osangularia schloebanchi, Pleurostomella* sp., and *Ramulina tetrahedralis* (see plates 3.17 - 3.22).

Low species diversity of agglutinated forms and abundance vary from frequent to common and few with rare and very few with good abundance. Species present include *Marsonella oxycona, Pseudogaudryinella* sp., and *Tritaxia pyramidata* (see plates 3.21-3.22 & 3.25).

4.8.2.4 Biticinella breggiensis Interval zone

(AK22-10(1), AK23-03, AK23-19, AK23-20, AK23-22 - AK23-24)

The occurrence of *Biticinella breggiensis* in these samples is a direct indication of upper Albian stratigraphic level of these samples. Planktonic foraminiferal species diversity in this interval is high and abundance varies from rare to frequent and some vary from common to abundant and preservation varies from poor to moderate. Species present at this interval include *Biticinella breggiensis, Favusella washitensis, Macroglobigerinelloides bentonensis, Muricohedbergella albiana,* *Muricohedbergella delrioensis, Muricohedbergella simplex, Muricohedbergella planispira, Mi. pseudoplanispira, Ticinella praeticinensis, Ticinella raynaudi, Ticinella raynaudi digitalis,* and *Ticinella roberti* (see plates 3.1, 3.9 and plates 3.12-3.14).

Calcareous benthic foraminifera species diversity is high and abundance varies from frequent to abundant and few with rare abundance. Species present include *Astacolus* sp., *Citharina sp., Laevidentalina communis, Frondicularia* sp., *Gavelinella intermedia, Gavelinella* sp., *Lagena* sp., *Gyroidinoides* sp. 2, *Lenticulina* sp., *Linguligavelinella* sp., *Marsonella oxycona, Marginulinopsis* sp., *Orthokarstenia* sp., *Osangularia schloebanchi* and *Saracenaria* sp. (see plates 3.17-3.22).

Agglutinated forms with moderate diversity and rare abundance. Species present include *Ammobaculites* sp. 1, *Ammodiscus cretacea, Bathysiphon* sp., *Glomospira charoides, Pseudogaudryinella sp., Reophax* sp., *Tritaxia pyramidata,* and *Trochammina* sp. One sample has Ostracods (AK23-23) (see plates 3.16, 3.18, and plates 3.23- 3.25).

4.8.2.5 Late Albian: Thalmanninella appenninica Interval zone (AK22-02):

The occurrence of *Thalmanninella appenninica* in these samples indicates uppermost Albian stratigraphic level of this sample. Planktonic foraminiferal species diversity is low and the abundance varies from rare to frequent and few of them vary from common to abundant. Preservation varies from moderate to good. Planktonic forms occurring in the sample include *Thalmanninella appenninica, Macroglobigerinelloides bentonensis, Favusella washitensis, Muricohedbergella delrioensis Muricohedbergella planispira, Muricohedbergella simplex, Muricohedbergella albiana, Planomalina buxtorfi, Praeglobotruncana delrioensis,* and *Ticinella raynaudi* (see plates 3.3, 3.7-3.11) These samples fall within the *Thalmanninella appenninica* interval zone and probably in the lower part of the zone due to co-existence with *Planomalina buxtorfi* Calcareous benthic foraminifera are extremely low in diversity and abundance varies from rare to frequent. Species present include *Gavelinella* sp., *Lenticulina sp., Orthokarstenia* sp., *Tristix excavata* (see plates 3.18, 3.22 and plate 3.25). While agglutinated forms are extremely rare with species of *Gaudryina* sp. and *Tritaxia pyramidata* (see plates 3.25).

4.8.2.6 AK22-04: Early Cenomanian: Thalmanninella globotruncanoides Interval zone

The occurrence of *Thalmanninella globotruncanoides* in these samples indicates Early Cenomanian age. Planktonic species diversity is low and their abundance varies from rare to abundant but preservation varies from moderate to good. Species present include: *Favusella washitensis, Macroglobigerinelloides bentonensis, Muricohedbergella delrioensis, Muricohedbergella planispira, Muricohedbergella delrioensis,*

Muricohedbergella simplex, Praeglobotruncana delrioensis, Praeglobotruncana stephani, and pyrite cubes are frequent in this interval (see plates 3.7, 3.9 & plate 3.11).

Calcareous benthic foraminiferal diversity is very low and abundance varies from frequent to abundant. Species are very few such as *Laevidentalina* sp., *Gavelinella intermedia*, *Gavelinella* sp. and species of agglutinated forms only *Dorothia* sp. and *Ammodiscus cretacea* (see plates 3.16-3.17, 3.20).

4.8.2.7 Middle - Late Cenomanian: Rotalipora cushmani Total range zone

(AK22-03, AK22-05, AK23-02):

This is confirmed by the occurrence of *Rotalipora cushmani* throughout this interval. Planktonic foraminiferal species diversity is low and abundance varies from rare to abundant and preservation varies from poor to moderate and moderate to good. Samples analyzed are of middle to late Cenomanian age. Species present in this interval include *Rotalipora deekei, R. greenhornensis, Heterohelix moremani, Muricohedbergella planispira, Muricohedbergella delrioensis, Muricohedbergella simplex, Macroglobigerinelloides bentonensis, Praeglobotruncana delrioensis, Praeglobotruncana stephani* and *Praeglobotruncana gibba* (see plates 3.9, 3.11- 3.12).

Calcareous benthic foraminifera are rare and few species present include *Lenticulina* sp., *Ramulina* sp., *Eoguttulina* sp., *Ramulina tetrahedralis*, *Gavelinella intermedia* and *Laevidentalina* sp., and no agglutinated benthic forms or pyrite cubes (see plates 3.17 – 3.20).

4.8.3 Synthesis

Also shown schematically on Figure 4.9 are lines representing shallowing or deepening trends inferred from the planktonic: benthic ratios.

It can be seen from these plots that in general the thickest deposition is in the Ruvu Basin in the north. In general the succession thins to the south and is thinnest in the Mandawa Basin. Sedimentation occurred everywhere along the Tanzanian margin during the latest Aptian as the *Paraticinella eubejaouaensis* zone was deposited. The only Aptian - Albian boundary sedimentation occurred at the northernmost borehole, Makarawe-1, and possibly also Kizimbani-1 in the south. For the other sites there is a regional hiatus before sedimentation began again in the *Ticinella primula* zone (or slightly later in Luhoi-1).

From the Planktonic: Benthic ratios, there is no clear pattern of transgression or regression in the late Aptian. In the Albian there seems to be a general tendency for gradual deepening between the middle Albian and the Cenomanian. This could either be due to global sea level rise (Leckie and others, 2002) or local subsidence.

Unfortunately the preservation of foraminifera is everywhere poor to moderate and the entire mid-Cretaceous interval has infilled tests. Some attempts were made to crush these and separate the foraminifer test walls from the infilling, where preservation was found to be best (in the Kizimbani-1 borehole), but the infilling was very firmly attached. Therefore none of the material was thought suitable for isotope geochemistry of the shells. Study of the boreholes and outcrop samples indicate that the best area to attempt to core the Aptian-Albian boundary is either in the north Ruvu Basin (near Makarawe-1) or in the south Mandawa Basin near Kizimbani-1. Outcrop samples suggest that the Albian *T. primula* zone occurs at the surface in the Kilwa area in the vicinity of Kizimbani-1. The sitting of TDP Site 40 and results of drilling are described in the next chapter.

4.9. Depositional and sea level history

The seven studied sites through the three principal depositional centres in the region (south, central and northern basins) show increased thickness of mid-Cretaceous marine sediments towards the north with the thickest deposition in the Ruvu Basin. In general the succession thins to the south and is thinnest in the Mandawa Basin. The Aptian - Albian boundary was found in the northernmost borehole, Makarawe-1, and possibly also Kizimbani-1 in the south. A condensed sequence through this boundary was recovered in TDP Site 40, which is close to Kizimbani-1. For the other sites there is a regional hiatus before sedimentation began again within or close to the *Ticinella primula* zone.

4.9.1 Late Aptian to early Albian

Rapid diversification, increase in size test modifications and common abundance planktonic and benthic assemblages, containing both shallow and deep dwelling planktonic species, this shows the strengthening of the thermocline at this interval of the upper Aptian supported by the high P/B ratios. The mixed assemblage and the first appearance of the intermediate forms indicate a mixed layer, and the deposition of sediments in intermediate water of the water column (Premoli Silva and Silter, 1999). Results from Site TDP40 indicate that in the uppermost Aptian-lower Albian interval is a stratigraphic level where a major extinction of all Aptian hedbergellids, ticinellids, and *Globigerinelloides* occurred. This coincides with a decrease in P/B ratio.

Elsewhere in Tanzania planktonic foraminifera are completely barren during this interval lowermost Albian only arenaceous forms are present Kiwangwa-1, Kisarawe-1, Luhoi-1, Songo Songo-4 and Kizimbani-1 well or in some boreholes foraminifera are completely barren. These observations suggest a fall in sea level, as has been identified globally at the Aptian/Albian boundary (Leckie and others, 2002). The dissolution of calcium carbonate at the basal Albian was the only answer in the past until lately when studies done by Huber and Leckie, 2011 and Petrizzo and Huber, 2006 and Petrizzo and others, 2012 indicates that planktonic index markers including others are very small in size and weakly calcified and the normal usage of larger sieve mesh size of 63 micron for washing samples is a high possibility of loosing basal Albian planktonic forms. Hence most of the previous studies in the basal Albian indicated that there is dissolution of calcium carbonate at the boundary and concluded either a stratigraphic hiatus or barren. Although no evidence for organic rich sediments, as occur elsewhere, were found in this work.

In the early Albian of site TDP40, assemblages dominated by small hedbergellids planktonic species are typical. These species suggest environmental stress and/or relatively shallow water compared to the late Aptian (Premoli Silva and Sliter, 1999). Benthic species present are of cool water forms such *Conorotalites, Globorotalites, Gyroidinoides, Osangularia* and arenaceous forms. In other boreholes such as Kiwangwa-1, planktonics are totally dissolved at this level. There is a stratigraphic hiatus below the mid Albian level at Site Kiwangwa-1, Songo Songo-1, and Kisarawe-1. This is concluded because other zone like the Zone of *Ticinella madecassiana* is not recognized. The Zone of *Miniglobularis miniglobularis* is also missing just above the *Paraticinella eubejaouaensis* zone for most of the industrial sites studied. Therefore, I conclude that there is a regional unconformity at the base of the Albian sequence. Based on the dominance of hedbergellids a shallow shelf Paleoenvironment is suggested.

The bulk sediment organic carbon stable isotope analysis provides an internally consistent correlation to global carbon isotopes curves (Herrle and others, 2004) through the interpreted Aptian/Albian boundary interval. There is no evidence for the expression of Oceanic Anoxic Event OAE1b in terms of organic rich low oxygen sediments or measured organic carbon in the sequences studied, although other indications, such as shift to small opportunistic (hedbergellids) planktonic foraminifera are seen.

4.9.2 Middle - late Albian

In industry borehole data show that in the middle to late Albian there was a return to abundant and diverse planktonic foraminifera after the harsh conditions in the early Albian. This suggests deeper water caused by marine transgression from the mid Albian and above (see fig. 4.1 - 4.7). During this time larger and more robust-shelled planktonic foraminifera species evolved including various ticinellids and rotaliporiids which are single keeled forms. Biticinellids, which are thought to have lived in deep marine Paleoenvironment (Hart, 1999) together with increased P/B ratios, support this view. The abundance of middle to upper bathyal benthic trochospiral forms, such as *Conorotalites*, *Epistomina*, *Osangularia* and *Globorotalites*; provide further support to this idea. Further increases in P/B ratios in Makarawe-1, Kiwangwa-1 and Songo Songo-4, boreholes suggest a further sea level rise in the latest Albian. The transgression was related either to global sea level rise or local subsidence.

4.9.3 Cenomanian

In Songo Songo-4 borehole planktonic foraminifera species diversity is low but abundant and benthic diversified with low abundance. In Kiwangwa-1, and Makarawe-1 boreholes planktonic and benthic species diversity and abundance is low. In Kisarawe-1 borehole have moderate planktonic species diversity and abundant, the benthic forms are diversified with low abundance. A decrease in sea level rise at the latest Albian-early Cenomanian and an increase in sea level accompanied by high planktonic: benthic ratios which falls under the global sea level rise (Haq et al., 1988) (see figure 4.7).

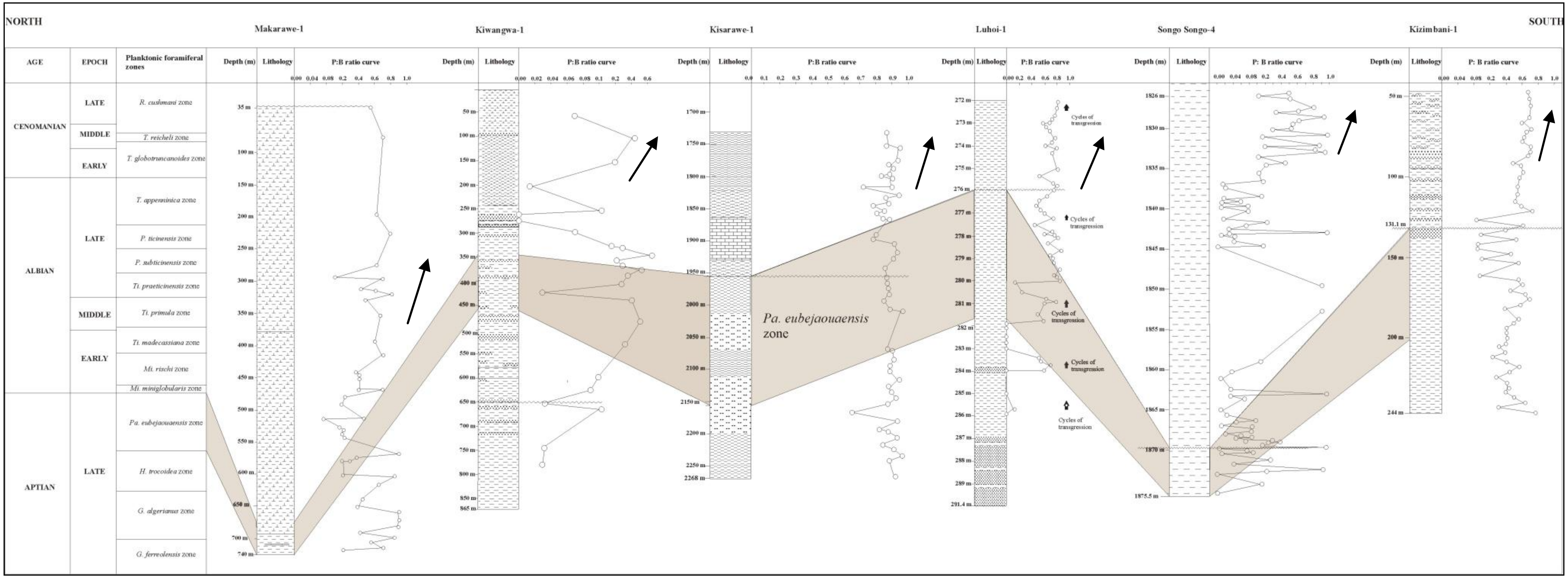


Figure 4.9: Stratigraphic correlation of the six Bore Holes. Arrows indicate increase in sea level across the coastal basin inferred from increased P/B ratios, suggesting deeper water.

Chapter 5 Integrated mid-Cretaceous foraminiferal biostratigraphy and geochemical records from TDP Site 40

5.1 Introduction

The six boreholes examined in chapter 4 provide insight into the mid-Cretaceous stratigraphy preserved across the three major north-south trending coastal basins of Tanzania (Ruvu Basin, Rufiji Trough, and Mandawa basin). Coring and sampling of these boreholes, however, was discontinuous and insufficient for detailed micropalaentological and environmental analysis. This project, therefore, benefited greatly from the drilling and recovery of two new shallow boreholes, which are TDP Holes 40A and 40B that were made specifically for this project (see Chapters 1 and 2 for background to the TDP and drilling operations). The TDP40 cores provided the opportunity for more continuous sampling, especially with respect to studying the signature of global environmental events associated with the Aptian and Albian interval on the Tanzanian margin. Specific goals of the drilling were to:

1) determine whether mid-Cretaceous planktonic and benthic foraminifera can be directly correlated to global Tethyan and Atlantic records;
2) determine whether the Aptian/Albian boundary is present in the Tanzanian coastal basins; and
3) determine whether Aptian – Early Albian sediments are organically carbon rich, which has implications for hydrocarbon exploration.

As outlined in chapter 1, existing geochemical and micropalaentological reconstructions of the latest Aptian to early Albian show a major transition in the nature of mid-Cretaceous tectonics, sea level, climate, lithofacies, and marine plankton communities, including deposition of several prominent black shale (OAEs) on continental margins and oceanic highs around the world (Weissert and Lini, 1991; Leckie and others, 2002; Herrle and others, 2004; Robinson 2004; 2008; Huber and Leckie, 2011). Site TDP40 record is the first scientific drill core that was drilled with the hope of penetrating through the Aptian/Albian boundary interval from this region and is important for providing information about the basinal extent of associated OAEs in theIndian Ocean region of the ancient Tethys Ocean.

In this chapter, the lithostratigraphy, biostratigraphy and chemostratigraphy of the upper Aptian to Albian of Tanzania are described based on the results of drilling at TDP Site 40B. These include new foraminiferal data, % TOC, % Nitrogen, % $CaCO_{3,}$ and organic carbon stable isotope data ($\delta^{13}C$). An attempt is made to correlate the $\delta^{13}C$ results to world wide data from the same interval using my interpretation of the stratigraphy of TDP Hole 40B based on planktonic foraminifera biostratigraphy. The results of the findings are discussed and interpreted with respect to contemporaneous global environmental changes.

5.2 Drilling objective

TDP Site 40 was drilled 400 m NE off the main road to Nangurukuru, 43 km to the South of the road junction at Nangurukuru (UTM 37L 574233, 8892237; 9°11’15.42” S; 39°22’19.68” E). The TDP Hole A and B were positioned adjacent to a surface sample that contained the lower-middle Albian planktonic foraminifera marker *Ticinella primula*, which was collected during reconnaissance field sampling. The main goal was to drill through the lower Albian and into the Aptian (Kingongo and Kihuluhulu Marls) (Balduzzi and others, 1992; Nicholas and others, 2006), with the hope of recovering a complete Aptian/Albian boundary sequence.Site TDP40 is approximately 50 km southeast of Kizimbani-1 borehole.

5.2.1 Lithostratigraphy of Hole TDP40A

TDP Hole 40A was drilled to 88.5 m depth with good to moderate recovery from the surface to 60.8 m, and from moderate to poor recovery from 60.8 m to the bottom of the hole. Drilling was terminated due to poor recovery in sandstones sequence. The top 5 m (cores 1 to 3) of TDP Site 40 shows weathered, massive sandy claystones and siltstones (see fig. 5.1). From 5 to 26.12 m depth (cores 4 to 11), lithologies are mainly formed of pale olive and greenish black, massive to weakly bedded siltstones, more clay-rich intervals and irregular bioturbation mottling. Within this interval, much coarser sediments occur between the bottom of core 8 and the top of core 9 (16.1 to 18.3 m) (fig. 5.1), where at least two layers of light gray, partly conglomeratic, calcareous sandstones.

From 26.1 to 60.4 m depth (core 12 to upper part of core 23), the main lithologies consist of greenish black, massive, moderately to intensely bioturbated, calcareous, silty claystones and siltstones.

Belemnite, calcite veins occur at 30.2, 31.3 and 43.1 m, and ammonite shell remains between 46.6 and 46.8 m. Also, scattered pyrite cubes are found at the top of core 12 and in cores 19 and 20. From 60.4 to 60.8 m, up to larger size, sandstone occurs within similar greenish black, silty claystones and siltstones to those recovered in cores 12-23. Below, core 23 sediments show a significant increase in grain size (fig. 5.1).

5.2.2 Lithostratigraphy of TDP Hole 40B

TDP Site 40B (see figure 5.2) was drilled 200 m to the SE of TDP Site 40A. The goal for this site was to try to increase the amount of microfossils recovered from the Aptian-Albian sequence, which was relatively low in the samples processed on site for TDP Site 40. Because of the proximity of the two sites, the lithostratigraphy and foraminiferal zonation in TDP Site 40B was expected to be identical to TDP Site 40. The site was drilled to 70 m, with good recovery from the top to 60 m, and low recovery from 60 m to the bottom of the hole. Drilling ended on the last day of the 2009 field season in hard, sandstones of Aptian age.

The top 14 m (cores 1 to 6) of TDP Site 40B exhibits weathered, massive, and weakly bedded, silty claystones, with occasional bioturbation mottling, pyrite nodules and calcite veins (fig. 5.2). From 14 to 58.4 m (core 7 to lower part of core 22), the lithologies that are recovered mainly consist of olive grey and dark greenish grey, from massive to weakly bedded, calcareous, siltyclaystones,with sporadic plant debris in cores 10 and 11. This interval is moderately bioturbated, especially in the upper part, and shows common, mm-sized, pyrite nodules scattered in the lower part and an ammonite shell fragment at 38.5 m (fig. 5.2). Also, between the bottom of core 7 and the top of core 8 (15.8 to 17.6 m), massive, medium-grained, calcareous sandstones are observed.

From 62.5 m to 69.0 m (core 24 to the upper part of core 26), lithologies that are recovered represent greenish gray, massive, medium-to coarse-grained, calcareous sandstones, with common plant debris. At 69.0 m, a sharp contact gives way to an interval with greyish black, massive to weakly bedded, moderately to intensely bioturbated, fine-grained, calcareous sandstones and siltstones, with common plant debris to the bottom of the hole. Much coarser sediments occur below a sharp and irregular contact at 58.4 m to the bottom of the hole. Up to boulder-sized, sandstone occur between 58.4 and 58.7 m (lower part of core 22;) (see fig. 5.2), which might represent the lateral equivalents to the conglomeratic interval that is found at core 23 in TDP Site 40A(see fig. 5.3). From 58.7 m to the bottom of the hole, the sediments recovered mainly represent greenish grey to black, massive, medium- to coarse-grained, calcareous sandstones, with a conglomeratic interval between 68.2 to 68.3 m (see fig. 5.2).

5.2.3 Foraminifera analysis

Preliminary analysis of nannofossil and foraminifera contents was conducted at the drilling site for the purpose of monitoring the formation as it is drilled. One hundred and twenty-eight samples were studied in detail to assess planktonic and benthic foraminiferal assemblage composition and produce foraminiferal biostratigraphy after the expedition was completed (see Methods Chapter 2). Planktonic foraminifera were present in 125µm sieve mesh size and calcareous and agglutinated foraminifera were abundant in 250 µm and 300 µm sieve mesh size. Counting of 300 specimens in a 125µm sieve mesh allows calculating and plotting the P:B ratio and assessment the abundance of planktonic foraminifera across the Aptian and Albian intervals.

Foraminifera biostratigraphy was based on the published literatures of Caron (1985); Premoli Silver and Sliter (1999 & 2002); Premoli-Silva and Verga (2004); Huber and Leckie (2011); Leckie and others (2002); BouDagher-Fadel and others (1997); Loeblich and Tappan (1987); and others (see chapter 3). The zonal scheme that was used is presented in chapter 3. The biostratigraphy is very similar in Holes TDP40A and TDP40B, so they are discussed together here. Preservation in both boreholes varies from poor to moderately good and all tests are in filled with calcite.

TDP40A and TDP40B are similar in both holes that they penetrated similar stratigraphic intervals of the Barremian to mid- Albian period. (see figure 5.1). Also they have similar lithologic units and similar biostratigraphic zones (*Ticinella primula* zone, *Microhedbergella rischi* zone, *Paraticinella eubejaouaensis* zone and *Hedbergella trocoidea* zone; see figure 5.2). At 17 m depth in both holes (a horizon shaded by orange colour in Figure 5.3) and at 60 m in TDP40A and at 58 m in TDP40B both holes penetrated a coarse conglomeratic bed (a horizon shaded by blue colour) the marker beds probably indicate the presence of a stratigraphic gaps in the two holes, since both beds happen to occur in sequences where planktonic foraminifera are extremely rare or absent in sequence 2 and 3 and most probably due to dissolution or unconformity. Also the two holes have similar planktonic and similar benthic foraminiferal assemblages.

Biostratigraphically, the succession is divided into three sediment sequences that are also divided by two coarse conglomerate beds (at ~17 m and ~ 60 m depth) that likely correspond to substantial hiatuses.

Sequence 1: In the top sequence 1, (upper Aptian to middle Albian), planktonic foraminifera are moderately abundant and diverse and the standard zonation can be applied, although with caution because some of the index fossils and secondary markers are very rare (see figs. 5.1-5.3).

Sequence 2: The middle Sequence 2 (lower Aptian to Barremian) contains moderately abundant and diverse benthic and few planktonic foraminifera. The planktonic foraminifera can be used to indicate a general age but the benthic are more useful in this respect (see figs. 5.1-5.3).

Sequence 3 : The lower sequence 3 is barren of both benthic and planktonic taxa. Plant debris is common and the depositional environment may be fluvial. No biostratigraphic age assignment was possible (see figs. 5.1-5.3).

5.2.4 Planktonic foraminiferal biostratigraphy

Holes TDP40A and TDP40B are discussed below from base to top. Preservation varies from poor to moderate and very few with moderate to good and all shells are infilled with calcite. Sequence 1, (upper Aptian to middle Albian), planktonic foraminifera are moderately abundant and diverse and the standard zonal scheme can be applied, although with caution because some of the index fossils and secondary markers are very rare. The middle sequence 2 (lower Aptian to Barremian) contains moderately abundant and diverse benthic foraminifera and few planktonics. The planktonics can be used to indicate a general age but the benthics are more useful in this respect.No biostratigraphic age assignment was possible.

A summary of the stratigraphically important planktonic foraminifera in TDP40A and TDP40B is illustrated in Table 5.1 and Table 5.2. Foraminifera that are present in the two holes are described here from base to top.

Sequence 3 (cores 23-33, TDP40A and core 22-26, TDP40B) comprises a well lithified sandy limestone with plant fragments, but foraminifera and other indicators of a marine environment are absent, suggesting that this may be a freshwater deposit.

Sequence 2 (cores 8-22, TDP40A and TDP40B) is bounded at the top by conglomerate and sandstone beds that are barren of foraminifera. This interval marks a significant unconformity as the underlying silty claystones contain early Aptian foraminifera unzoned assemblage that includes *Hedbergella aptiana*, *Gorbachikella kugleri*, *Caucasella hoterivica*, and *Globigerinelloides blowi* in the upper part (core 10) and only benthic foraminifera below 11 m. The benthic foraminifera include a number of calcareous species assigned to *Lenticulina*, *Gavelinella*, *Gyroidinoides*, *and Conorotalites*, *Epistomina* as well as various agglutinated species. Presence of *Gavelinella barremiana* and *Conorotalites bartensteini aptiensis* below 9.2 in TDP40A and 9.1 m have been recorded as ranging from the Barremian to lower Aptian by Bartenstein and Bettenstaedt (in Bolli and others, 1994).

Sequence 1: Late Aptian-Mid Albian

The LO of *Paraticinella eubejaouaensis* in sample TDP40A/5/3, 65-90cm and sample TDP40B/5/3, 60-70 cm marks the base of the *Pa. eubejaouaensis* Zone. Also occurring within this zone are *Hedbergella gorbachikae* and *Hedbergella trocoidea*. The *Hedbergella trocoidea* Zone, which includes occurrences of *Hedbergella infracretacea*, *Hedbergella excelsa* and *Hedbergella gorbachikae*, is identified below sample 40A/8/1, 1-25 cm and sample TDP40B, 7/2, 1-25 cm (see table 5.1-5.2).

The *T. primula* Zone is underlain by the early Albian *Microhedbergella rischi* Zone, which extends down to Sample 40A/5/1, 1-25 and TDP40B/5/1, 1-25 cm and contains *Mi. renilaevis* and *Mi. praelippa* (see table 5.1-5.2). The middle Albian *Ticinella primula* interval Zone is defined from the LO of *Ti. primula* in TDP40A/4/1, 1-26 cm and TDP40B/4/2, 1-25 cm to the top of the hole based on the presence of relatively abundant *Ticinella primula* and the absence of *Biticinella* *breggiensis*. Also occurring within this zone is *Ticinella madecassiana*, *Ticinella roberti*, *Microhedbergella rischi, Favusella washitensis, Microhedbergella pseudoplanispira, and Microhedbergella raynaudi* (uppermost samples). Absence of *Ticinella madecassiana* from samples below indicates the *Ticinella madecassiana* Zone is missing because of a hiatus

5.2.5 Benthic foraminiferal biostratigraphy

Benthic foraminifera vary in abundance and diversity and in some of the samples are barren (see tables 5.1 and 5.2). However, the interval between Core 10 to 23 in Hole TDP40A and Core 10 to 22 in Hole TDP40B has more diverse assemblages with several representatives that are potentially of biostratigraphic value, especially as planktonic foraminifera are rare or absent in the same interval.

The genus *Lenticulina* predominates in this interval. Most of the species of this and other genera have formerly been described by Bartenstein and Bettenstaedt (in Bolli and others, 1994), from the "lower Cretaceous" (actually Barremian to Aptian) of the Cuche Formation of Trinidad where they are assigned to the *Lenticulina (Lenticulina) ouachensis ouachensis* benthic foraminiferal zone (stratigraphically correlative with the *Leupoldina protuberans* planktonic foraminiferal zone).

The most stratigraphically important calcareous benthic foraminifera present in the interval TDPHole 40A Cores 11 to 23 and Hole 40B, Core 11 to Core 22 are *Gavelinella barremiana, Conorotalitesbartensteini intercedens*, *Lenticulina (Lenticulina) eichenbergeri*, *Lenticulina (Lenticulina) ouachensis*, *Epistomina hetchi*, *Lenticulina (Saracenaria) spinosa, Lenticulina Astacolus crepidularis, Lenticulina (Lenticulina) nodosa*, *Epistomina caracolla* and *Lenticulina (Marginulinopsis) robusta.* Many other long ranging benthic foraminifera species were observed in the studied section (see range charts in table 5.1 and table 5.2) but the few mentioned here are the most important for justification of the age of the lowermost section of the TDP Site 40 boreholes. Of potential stratigraphic use is the distribution of the related subspecies *Conorotalites bartensteini intercedens* and *Conorotalites bartensteini aptiensis.* These have been reported from many parts of Europe in the same stratigraphic order and are regarded as reliable index forms. *Conorotalites bartensteini intercedens* ranges stratigraphically from the Barremian to lower Aptian whereas *Conorotalites bartensteini aptiensis* stratigraphically ranges from the upper

Aptian to lowermost Albian and (Bolli and others, 1994). Similar ranges have been reported in theSouth Caribbean region (Bolli and others, 1994). In both TDP40A and TDP40B, *Conorotalites bartensteini aptiensis* is present throughout the succession below the conglomerate at ~17m whereas *Conorotalites bartensteini intercedens* was observed only in the lower part of the succession.

In TDP40A, *Conorotalites bartensteini intercedens* was observed from Sample TDP40A /11/2, 1-25 cm, to 22/1, 1-28 cm while in TDP40B, specimens of *Conorotalites bartensteini intercedens* were observed from Sample TDP40B/13/2, 1-25 cm, to TDP40B 20/3 1-25 cm.

Lenticulina (Lenticulina) ouachensis ouachensis and *Lenticulina (Lenticulina) eichenbergi* have been reported from the middle and upper Valanginian to lower Aptian worldwide andin Trinidad, from the middle Barremian to lower Aptian. In Hole TDP40A, specimens of *Lenticulina* (*L.*) *ouachensis ouachensis* are present from Sample TDP40A/10/3, 88-112 cm to Sample TDP40A/22/3, 1-25 cm. In Hole TDP40B *Lenticulina (L.)ouachensis ouachensis* is present from Sample TDP40B /8/1, 75-90 cm to Sample TDP40B/19/3, 25-50 cm. Therefore, the presence of the two species in the lower succession of the studied boreholes (TDP40 Site) indicates that the succession probably drilled from the lower Aptian through to the Barremian.

Specimens of *Epistomina* have been observed in the studied sequence although preservation is often very poor and hence some were difficult to identify. *Epistomina hetchi* and *Epistomina caracolla* have been reported from the upper Valanginian to Barremian worldwide. *Epistomina hetchi* was found from Sample TDP40A/12/1, 8-25 cm to TDP40A13/3 1-26 cm. Its presence helps constrain the stratigraphic age of the lowermost part of the drilled succession as Barremian of older. Likewise *E. caracolla* occurs from Sample TDP40B/12/1, 1-25 cm to TDP4OB/22/3, 1-25 cm.

Lenticulina (Astacolus) crepidularis and its closely related *Lenticulina (Astacolus) tricarinella* have similar stratigraphic ranges. These species have been reported worldwide in the Middle Jurassic to Early Aptian. In Trinidad they have been reported from the Middle Barremian to Early Aptian (Bolli and others, 1994). Similar taxa occur in the middle part of the succession of the TDP Site 40 and may have the same stratigraphic range, most probably within the Barremian to early Aptian.

Gavelinella barremiana and *G. intermedia* are reported to range from the middle Barremian to lower Aptian and lower Aptian to lower Cenomanian respectively (Barnard and others, 1994). These species both occur at TDP Site 40. *Gavelinella barremiana* only occurs below 9.21m in Holes TDP40A and 10.35 m in Hole TDP40 B, and *G. intermedia* occur only above 29.25 m in Hole TDP40A and 42.55 m in Hole TDP40B. *Gavelinella barremiana* appears to persist into the upper Aptian in Tanzania.

Other species present in the two boreholes include; *Lenticulina (Saracenaria) spinosa* (Eichenberg) which has been reported worldwide in the Aptian to lowermost Albian, *Lenticulina (Marginulinopsis) robusta* ranges from the upper Aptian to lower Albian and *Lenticulina excentrica* is a late Aptian species and others such as *Lenticulina muensteri, Osangularia schloebanchi, Lenticulina (Lenticulina) saxocretacea, Lenticulina (Lenticulina) praegaultina* and agglutinated forms such as *Glomospirella gaultina, Lagenammina alexanderi, Pseudogaudrinella dividens*, and *Tristix excavata*, and many others are illustrated in the range chart (see Tables 5.1-5.2).

Over the about ~10 m interval at the top of the core where planktonic foraminifera occur, the planktonic: benthic ratio shows large variability. The P: B ratio is ~0.4 - 0.6 in the top 5 m, and then decreases to 0.2 or less from 7-9 m depth. At ~ 10 m it returns to >0.6 before falling to zero by 11 m depth as the planktonics disappear (see figure 5.4).

In summary, if the correlations from the Caribbean and Europe can be extended to East Africa, this indicates that the middle part of the succession in both holes at TDP Site 40 should be assigned to the Barremian to lower Aptian.

5.2.6 Geochemistry

There was a hope that exceptionally preserved ‘glassy foraminifera’, as have been recovered elsewhere in Tanzania (Pearson and others 2001) would be found. Unfortunately, as elsewhere in the mid-Cretaceous of Tanzania (Chapter 4) the preservation of the planktonic foraminifera is not glassy and they are infilled with secondary calcite so that geochemical studies were restricted to bulk sediment analysis. The geochemical analysis (see Methods in Chapter 2) was based on 92 bulk rock samples spaced at an interval of 1.0 cm apart through cores from core 1 to core 22 of

TDP Hole 40B (Table 2.7).The results of % TOC, % $CaCO_3$, % Nitrogen and organic carbon $\delta^{13}C$ are presented in figure 5.4.

5.2.6.1 Calcium carbonate and Nitrogen content

$CaCO_3$ content of the TDP40B samples range from 4% to 25% with an average value of 10% (see figure 5.4). Average values are slightly higher, typically > 10%, in cores 19-22 but this average decreases to about ~7% in up core. In the mid-Albian (*Ticinella primula* zone) the $CaCO_3$ content vary from 5% to 15%. In the early Albian (*Microhedbergella rischi* zone) $CaCO_3$ values vary from 5% while the late Aptian, *Paraticinella eubejaouaensis* zone ranges from 5% to 10% and in the *Hedbergella trocoidea* zone varies from 3% to 23%;, Unzoned interval (?Early Aptian*;* $CaCO_3$ content vary between 7% and 14%. Barremian-early Aptian section has four peaks of high values of $CaCO_3$ contents and these are; 19%, 21%, 23% and 25% but generally they range between 5% and 25%. There are high values of $CaCO_3$ content corresponding to high P/B ratio and low values of TOC and Nitrogen in the studied section (see figure 5.4; Appendix II preparations and Appendix III results).

Nitrogen content varies between 0.019% and 0.032%, with average values of about ~0.02%. This remains relatively stable through the section, apart from a small increase in values to a maximum of 0.032% at about ~24 m depth and a drop to minimum values at about ~ 10 m depth. Core 1-6 of this borehole constitute of weathered massive and weakly bedded silty claystones. Nitrogen contents investigated in each stratigraphic interval are as follows: In the *Ticinella primula* zone nitrogen content is in the range of 0.024,in the *Paraticinella eubejaouaensis* zone vary from 0.01% – 0.025%, *Hedbergella trocoidea* zone,0.015%-0.025% unzoned interval; 0.015% - 0.020%and Barremian- early Aptian; 0.015 - 0.03%. (see figure 5.4; Appendix II preparations and Appendix III results). % N generally is too low to measure accurately and % C has reproducibility of ± 0.1% and need to be reported in one decimal place.

5.2.6.2 Total organic contents (TOC)

Samples analyzed contain low (<1.0%) TOC contents. High values of 0.5% TOC were found in TDP40B in the Barremian-early Aptian, upper Aptian, and early to middle Albian. The high values of TOC matched with decreasing in $CaCO_3$ content (see figure 5.4). Other individual samples with low $CaCO_3$ content representing clay samples selected for micropalaeontology analysis. The concentration of organic carbon in Hole TDP40B is low varying between 0.01% and 0.5% throughout the core. The average values are lowest (~0.02) in the upper 12 m and increase abruptly between at 10-12 m depth to ~0.30%. There is a short peak in values (up to 0.5%) at ~22 m depth. In the *Ticinella primula* zone TOC of 0.01% (only on data point), *Microhedbergella rischi* zone; TOC values are of 0.05%, while in the *Paraticinella eubejaouaensis* zone vary between 0.01% and 0.2%; *Hedbergella trocoidea* zone range between 0.01 and 0.3%, while unzoned interval (?early Aptian); TOC range between 0.24% and 0.3% and Barremian- early Aptian; varies between 0.02-0.5% (see Appendix III and fig. 5.4).

5.2.6.3 Bulk sediment organic carbon $\delta^{13}C$

The results show a number of broad fluctuations in $\delta^{13}C$ at different intervals but values generally vary from -24‰ to -28‰ with an average value of -26‰. Maxima in C-org $\delta^{13}C$ occur at depths of 10-11 m, about ~33 m and 56 m, with the most coherent minima at about ~38 m depth. The magnitude of change over these fluctuations is about ~2‰ $\delta^{13}C$. The following values of $\delta^{13}C$ are obtained from the studied intervals of the TDP40B Hole. The Barremian-early Aptian interval has $\delta^{13}C$ values ranging from -24.5‰ to -28.5‰; Unzoned interval (?early Aptian); $\delta^{13}C$ varies between -25.5‰ to -27.5‰; *Hedbergella trocoidea* zone$\delta^{13}C$ values vary between -24.5‰ and -27.5‰. In the *Paraticinella eubejaouaensis*zone$\delta^{13}C$ values range between -24‰ to -26.5‰, *Microhedbergella rischi*zone*;* $\delta^{13}C$ value is of -26‰ and *Ticinella primula* zone $\delta^{13}C$ value is -26.5‰ (see Appendix III and fig. 5.4).

Using the record of Santa Rosa Canyon section (Bralower and others, 1999), the results of the present study allow detailed correlation between foraminiferal biostratigraphy for the Barremian to mid-Albian interval. Carbon isotopes measured on the organic carbon fraction, show identical stratigraphic changes to detailed $\delta^{13}C_{org}$ curves from Santa Rosa Canyon (Bralower and others, 1999 see figs. 5.4 and 5.6). High resolution Barremian-middle Albian of TDP40B shows several segments and these are: a significant increase in $\delta^{13}C$ values (segment C2), followed by a marked decrease in $\delta^{13}C$ values (segment C3), followed by an increase in $\delta^{13}C$ (segment C4), and an interval of variable $\delta^{13}C$values but somehow constant values (segment C5) followed by a decrease in $\delta^{13}C$ values (segment C8) and a sharp increase in $\delta^{13}C$ values (C9) and an increase in $\delta^{13}C$ values (segment C10); see figure 5.4 and 5.6).

5.2.6.4 C/N ratios:

Bulk abundance of carbon and Nitrogen has been used as an indicator of organic matter flux and diagenesis (Meyers, 1994; 1997). Although a large number of factors influence the various TOC and TN values of sediments, three major variables; input flux of organic matter, diagenesis, and sedimentation rate (Tyson, 1995). Atomic C/N ratios and isotopic analysis of bulk sediment have been widely used to differentiate various organic sources in order to reconstruct depositional environments, vegetation changes (Tenzer and others, 1999; Schubert and others, 2001). The C/N ratio is a good indicator of the protein content in sediments. Plants, in general have higher cellulose content. The C/N ratios of organic matter derived from lacustrine primary production have an average value between 5 and 6, whereas that of higher terrestrial plants are usually higher than 20 (Meyers, 1997). Bordovskiy (1965) concluded that a C/N ratio of < 8 indicates an origin of aquatic organic source, while ratio of > 12 represents the dominance of a terrestrial organic source (Prahl and others, 1980; Thevenon and others, 2012) (see Appendix III and figs. 5.5 and 5.5b).

The $\delta^{13}C$ values of organic carbon have been recognized as providing the syn-depositional signals for source identification (Arthur and others, 1988) and are relatively conservative in comparison with nitrogen values or C/N ratios (Thomson , 1999). Isotopic ratios are affected by a number of factors such as CO_2, temperature and climate which leave their fingerprints in the carbon isotope ratios. Besides the primary producer (i.e. algae), particulate organic matter buried in sediments is often a mixture of material derived from different sources (e.g. aquatic biomass, and terrestrial plants; Meyers, 1994). Each of these sources is characterized by different isotopic values (Deines, 1980).

Primary producers and macrophytes have wide range $\delta^{13}C$ values from -17 to -27‰. The source of terrestrial plants dominated by two distinct vegetation groups, C3 and C4 plants employing different photosynthesis pathways that produce different $\delta^{13}C$ values: C3: -27.1 ± 2.0 ‰; C4: -13.1±1.2‰ (Deines, 1980; Leary, 1988). C3 grows under humid conditions and C4 plants under relatively arid conditions (Weiku and others, 2007; Adate and others, 2012).

5.3 *Results*

The C/N ratios values generally fall within the range of aquatic plankton (C/N <10) and the high values in the range of a strong terrestrial input (>10; Meyers, 1997); see figures 5.5 and CD Appendix III; TDP40B Master Sheet 1-2. C/N ratios of TDP40B vary considerably between the lowest values of 2.9 at 5.5 m and the highest of 21.1 at 58.4 m,while $\delta^{13}C$ values vary from -24‰ to -28 ‰. The C/N ratio of the interval 5.5 m to 13.1 m varies from 2.9 to 8.8 and the $\delta^{13}C$ values vary from -24.2‰ to -26.7‰. The C/N ratios of the interval 15.0 m to 58.4 m vary from 12 to 21.4, and $\delta^{13}C$ vary from -25‰ to 28‰. At 2.0 m the C/N ratio is about 10.3 and $\delta^{13}C$ is -26.5‰, while at 12.9 m, the C/N ratio is 12.2 and $\delta^{13}C$ is -27.4‰. (see figure 5.5 and TDP40B Master sheet 1-2 in Appendix III).

The plot of C/N versus $\delta^{13}C$ demonstrates that the organic matter source is mainly from source of low C/N at the interval of 5.5 m to 13.1 m depth, therefore the values of $\delta^{13}C$ (-24‰ to -26.7 ‰) and the C/N ratios < 10 are typical of algal derived organic matter from insitu production (Deines, 1980; TDP40B Master Sheet 1-2 in Appendix III and Figure 5.5).

The trend of terrestrial input of plant tissue in the interval from 15 m to 58.4 m that have high C/N ratios between 11.8 (~12) and 21.4 and $\delta^{13}C$ values between 25‰ and 28‰ are indicative of the source as of terrestrial plants and most probable of C_3 which has been described in literatures varying in $\delta^{13}C$ between -26‰ and -28‰ are more less close to TDP40B values. Therefore the studied sequence from 2.0 m to 13 m the C/N ratios are 3 and 10 which is similar to modern aquatic organic matter that was primarily constrained by the aquatic primary production and the high $\delta^{13}C$ reduced contribution of terrestrial input (Deines, 1980), (TDP40B Master Sheet 1-2 in Appendix III and figure 5.5).

5.4 *Depositional history*

The Aptian/Albian boundary is one of the most remarkable boundaries in the geologic history of planktonic foraminifera evolution, showing a series of extinctions, as well as major changes in test size and shell ornamentation that indicate major changes in oceanic and climatic conditions at this time (Leckie and others, 2002). These changes are clearly seen in the TDP Site 40 planktonic foraminifera assemblages with robust and keeled planktonic foraminifera species of the upper Aptian and are absent in the upper section indicating that they extinct at the end of Aptian and the boundary section was not identifiable and the appearance of fragile tests of *Microhedbergella* species at the lower Albian (*Microhedbergella rischi* Zone) and replaced by robust strongly ornamented forms in the middle Albian. The zone of *Microhedbergella miniglobularis* was difficult to place and the zone of *Microhedbergella rischi* Zone was easily identifiable hence the lowermost Albian planktonic forms were lost through washing. The planktonic foraminifera found such as *Microhedbergella miniglobularis, Microhedbergella rischi, Microhedbergella renilaevis*, are smooth, microperforate with portical flap and species of *Paraticinella eubejaouaensis, Hedbergella infracretacea Paraticinella transtoria* and many others seen in the Late Aptian of Tanzania have walls with perforation cones and apertures with no lip (Huber and Leckie, 2011).

The lower part of the *Paraticinella eubejaouaensis* zone (upper Aptian) is present but the boundary section could not be demarcated with certainty due to rarity of the marker fossils and randomly distributed in the succession. Specimens having an indication of this age are present but are extremely rare and unreliable. Therefore, no Aptian/Albian boundary is present in the studied sequence.

The contents of the planktonic foraminifera assemblages suggest that TDP Site 40 was either drilled through the Aptian/Albian boundary or not but there is no appropriate proof. This is also based on the sequence of species occurrences that allows identification of the *Microhedbergella rischi,* and *Paraticinella eubejaouaensis* Biozones that have been shown not to penetrate the boundary. Cores 11-22 are unzoned because planktonics are extremely rare or absent in this interval. Here benthic assemblages provide broad indications of a lower Aptian through Barremian age.

TDP Site 40 cores suggest hemipelagic deposition during the lower Albian, likely on the presence of species of *Gavelinella, Gyroidinoides, and Conorotalites*, arenaceous forms are characteristic of neritic to upper bathyal but hedbergellids are shallow and also can survive in open marine settings. Such mixed assemblage expected to live in restricted oceanic in intermediate waters possibly in the range of 100-150 m. There was a heavy influence of land derived clays as well as variable components of silt and sand that significantly diluted the carbonate fraction, which is typically composed of pelagic calcareous nannoplankton and foraminifera. The yellowish colour of the upper 5 m indicates weathering, the effect of which decreases rapidly down core giving way to more clay rich layers. Sandy limestone in TDP40A cores 8 and 9 suggests shallow water conditions, and or the down slope transport of limestone forming beds from shallower regions. The occurrence of plant debris in cores of 10-11 of TDP 40B supports an increase influx of terrestrial organic debris at this time.

Belemnite and ammonite containing, bioturbated calcareous silty claystones between 26-60 m again suggest moderate slope water depths and oxygenated conditions at the sea floor. The lack of planktonic foraminifera, presence of benthic species and presence of pyrite nodule in these deeper sediments suggest abundant organic matter in the sediment that might have resulted in reduced pH and ultimately dissolution of planktonic foraminifera. This would explain the extremely low planktonic benthic ratio below 10 m. Below 60 m the increase in grain size suggests shallower conditions with involving formation of shallow water limestones and a greater influence of fluvial sediments including plant debris, in the lower Aptian and Barremian. The lack of planktonic foraminifera, presence of benthic species and presence of pyrite nodules in the sediment suggests deposition of sediments in shallow marine inner shelf environments.

In deep exploration wells most of the lowermost Albian section is missing. Barremian to early Aptian interval is present in all boreholes drilled through this section and contain similar foraminifera assemblage of benthic and planktonic foraminifera are either extremely rare or absent (see chapter 4 and tables 4.1 - 5.2). Also pyrite cubes and plant remains are also present in the studied wells. There is a trend of regional unconformity or surface of none deposition between the topmost Aptian and middle Albian and the earliest Albian interval in all of the studied boreholes is missing except in the deep well of Makarawe-1.

Carbon isotope stratigraphy has been shown to be a reliable tool for the correlation of middle to upper Cretaceous hemipelagic sediments as well as a tool for hydrocarbon exploration (Scholle and Arthur, 1980; Herrle and others, 2004). Using planktonic foraminifera based stratigraphic interpretation, a tentative correlation of the upper Aptian (planktonic foraminfera-bearing) part of TDP40B C-org $\delta^{13}C$ to $\delta^{13}C$ reference curves from the Vocontian Basin (Herrle and others, 2004) and ODP Site 1049 (Blake Plateau, N. Atlantic) (Huber and others, 2011; figure 5.6). The TDP

Site 40 $\delta^{13}C$ record is of extremely low resolution compared to the studies of Herrle and others, (2004) and Huber and Leckie (2011) and only one horizon was easily correlated to the reference sections.

The present study, however, provides indications of general $\delta^{13}C$ fluctuations, especially the relative occurrence of $\delta^{13}C$ maxima and minima with respect to only one biozone that is consistent with the other records. According to Herrle and others, (2004) the upper Aptian carbon stratigraphic interval correlates with Ap12/Ap15 and has defined as the interval of transition from low to increasing in $\delta^{13}C_{org}$ values and lies within the lower part of the *Paraticinella eubejaouaensis* zone (see figure 5.6).

5.4.2 Comparison of the TDP carbon stable isotopes to global records

The main correlative feature is the peak in $\delta^{13}C$ values (~-25 to -24‰) that falls within the *Paraticinella eubejaouaensis* zone. Although highly condensed in the TDP40B section and comprising only 13 data points, this peak in $\delta^{13}C$ correlates with the broad sequence of $\delta^{13}C$ 'high's corresponding to the combined C-isotope stages Ap12/Ap15 (see figure 5.6) after Herrle and others (2004), which can be recognized in both the ODP Site 1049 and Vocontian Basin sequences. Above the *Paraticinella eubejaouaensis* biozone there are only 5 data points in the TDP40B record. Among these, the 3 that fall within the overlying interval interpreted as the *Microhedbergella rischi* Zone are distinctly lighter by > 1.0‰ $\delta^{13}C$, as seen in the Vocontian Basin record at the equivalent time. The *Microhedbergella miniglobularis* Zone was not possible to be identified in the sequence due to its random distribution. This interpretation is consistent with an upper Aptian age for this part of the TDP Hole 40B sequence, and supports the uncertainty of a proof for the presence of a complete, Aptian/Albian boundary in the studied sequence.

No attempt is made to make detailed correlations in the interval between 15-60 m, although we note that the high in $\delta^{13}C$ values (~-25‰) occur at 32 m depth in the lower Aptian-Barremian interval may correlate to the high $\delta^{13}C$ values found elsewhere associated with OAE1a, the Selli Event (Bralower and others, 1994; 1999; Menegatti and others, 1998) and most probably correlates to AP7c/Ap7d (transition from high values to low in ‰ $\delta^{13}C_{org}$ (uppermost part of ? *Leupoldina cabri;* see figure 5.6).

5.4.3 Organic carbon, carbonate and nitrogen

Increased sedimentary organic carbon content is a common feature of mid-Cretaceous OAEs that is thought to be caused by increases in preservation of organic matter at the sea floor,and/or enhanced marine productivity or delivery of terrestrially derived organic matter (Jenkyns, 1980; Leckie and others, 2002).The very low values of TOC in the TDP Site 40 cores suggests organic deposition in fully oxic waters, however, anoxic conditions likely developed within the sediments as pyrite is abundant throughout the core material. The absence of distinctly black, organic carbon-rich sediments visible in the cores, as well as the consistently low TOC values at TDP Site 40 indicates there was no black shale deposition during the late Aptian or lower Albian in this region of Tanzania. The slightly TOC enriched interval at one horizon (~0.5–0.6% vs. 0.3% typically) does not correlate with any $\delta^{13}C$ excursion. It does, however, correlate with observations of plant debris in TDP 40b Cores 10 and 11, which may have contributed to the bulk signal. A corresponding peak in % nitrogen, which is a nutrient tracer, is consistent with the peak organic inputs at this time.

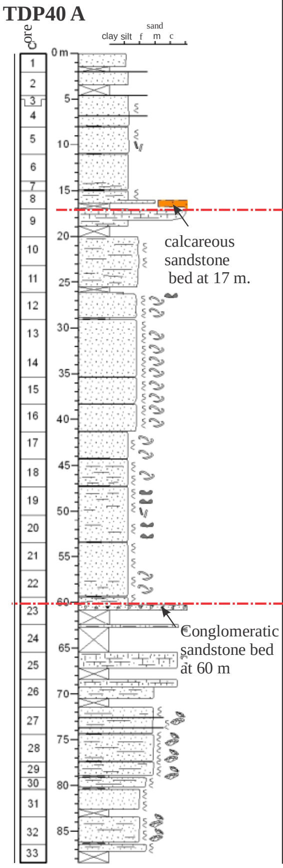
The evidence suggests the organic change is related to an increase in terrestrial organics rather than overall increase in surface ocean productivity and or preservation of organic matter on the sea floor. The low TOC values in the upper 10 m may be caused by oxidation from recent weathering. However, planktonic foraminifera abundance (increased P:B ratio) is the highest in this interval suggesting that the low TOC signal reflects lower Albian sedimentary conditions where low organics resulted in higher pore water pH, compared to the upper Albian and older, that helped foraminiferal calcite preservation.

5.5 Conclusions

Scientific drilling of two boreholes at TDP Site 40 resulted in recovery of hemipelagic outer slope silty claystones to possibly inner slope sediments of early Aptian to possible Barremian age. The upper 10 m of TDP40 Holes A and B are rich planktonic and benthic foraminifera, whereas below 10 m depth planktonics disappear leaving only benthics down to 57 m. Below 57 m depth sandy limestones suggest shallower conditions allowing growth of shallow water limestones or down slope mass transport of shallow water limestone, as is seen in the Palaeogene and upper Cretaceous of Tanzania (Nicholas and others, 2006). This suggests changes in water depth over the studied interval controlled either by tectonic movements and/or subsidence, or sea level change.

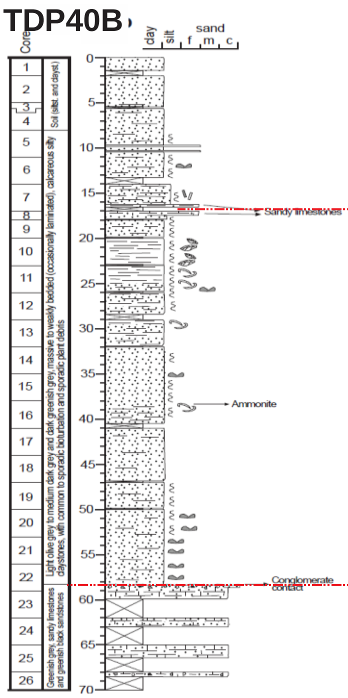
It was hoped that exceptionally preserved ‘glassy foraminifera’, as has been recovered elsewhere in Tanzania (Huber and others 2002), would be found. Unfortunately the preservation of the planktonic foraminifera is not glassy and they are infilled with pyrite and or secondary calcite so that geochemical studies were restricted to bulk sediment analysis. The planktonic assemblages; however, are diverse and good for assemblage and biostratigraphic studies. In general the planktonic and benthic assemblages are consistent with those from the Tethys, which is important for correlating the Tanzanian section to global Tethys records. Using the taxonomy and Biozonation defined from these world-wide records there is an absence of sequence covering the lower Albian (seefigure 3.4 chapter 3).

The organic carbon and nutrient tracers (%TOC and % nitrogen), as well as the lithostratigraphy, provide no evidence of significant organic carbon deposition in this region, as has been found associated with OAEs elsewhere. The small relative increase in TOC at one horizon correlates with the occurrence of fossilized plant debris in the cores. This suggests that organic changes at TDP Site 40 are related to increases in terrestrial organic inputs rather than overall increase in surface ocean productivity and or preservation of organic matter on the sea floor. The indication, therefore, is no lowermost Albian sequence encountered in the southern Tanzania Mandawa Basin and cannot produce any data regarding its potential for the hydrocarbon source-rocks because the section of the boundary was not easily identifiable.



FORMATION	STAGE	PLANKTONIC FORAMINIFERAL ZONES	SEQUENCES
Kingongo Formation	Early - mid Albian	*T. primula* zone	Sequence-1
		Mi. rischi zone	
Kihuluhulu Formation	Late Aptian	*Pa. eubejaouaensis* zone	
		H. trocoidea zone	
	Indeterminate	Unzoned	
	Early Aptian	Unzoned	Sequence -2
	Indeterminate	Unzoned	
	Barremian to Early Aptian	Unzoned	
Kipatimu Formation	Indeterminate (Barren)	Unzoned	sequence-3

Figure 5.1: Lithostratigraphy and biostratigraphy of TDP40A Hole.



FORMATION	STAGE	PLANKTONIC FORAMINIFERAL ZONES	SEQUENCES
Kingongo Formation	Early - Mid Albian	*T. primula* zone	Sequence-1
		Mi. rischi zone	
		Unzoned	
	Late Aptian	*Pa. eubejaouaensis* zone	
		H. trocoidea zone	
Kihuluhulu Formation	Early Aptian	Unzoned	Sequence-2
	Barremian - Early Aptian	Unzoned	
Kipatimu Formation	Indeterminate (Barren)	Unzoned	Sequence-3

Figure 5.2: Lithostratigraphy and biostratigraphy of TDP40B Hole.

Table 5.1: TDP Site 40A planktonic and benthic foraminifera range chart.

Well name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth below surface (m)	Age	Planktonic foraminiferal zones	Preservation	*Gorbachikella kugleri*	*Hedbergella aptiana*	*Caucassella hoterivica*	*Hedbergella ruka*	*Praehedbergella sigali*	*Globigerinelloides blowi*	*Hedbergella infracretacea*	*Hedbergella sp.*	*Hedbergella excelsa*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Hedbergella trochoidea*	*Paraticinella eubejaouensis*	*Pseudoguembelitria sp.*	*Hedbergella prelippa*	*Microhedbergella renilaevis*	*Microhedbergella pseudoplanispira*	*Ticinella sp.*	*Ticinella primula*	*Microhedbergella rischi*	*Globigerinelloides bentonensis*	*Favusella washitensis*	*Ascoliella aff. nitida)*	*Ascoliella sp. 1*	*Ticinella raynaudi*	*Ticinella roberti*	*Ticnella madecassiana*	
TDP40A	1	1	0.00	30	58	0.4	MIDDLE ALBIAN	*Ticinella primula* zone	P-M																		R	R		R	R	R	R	R	R	R	
TDP40A	1	2	0.00	25	41	1.3			P-M																		R	R		R	R	R	R	R	R		
TDP40A	1	3	0.00	20	40	2.30			P-M																	R	R	R	R	R	R	R	R		R		
TDP40A	2	1	2.00	33	62	2.5			M-G																		R	R		A	R	R	F		R		
TDP40A	2	2	2.00	25	50	3.4			M-G																		F	R		A	R	R	R		R		
TDP40A	2	3	2.00	1	25	4.1			P-M																		R	R		A	F		R		R		
TDP40A	2	3	2.00	15	37	4.3			M-G																		R	R		A	F		R		R		
TDP40A	3	1	4.60	1	25	4.7			P-M																		F			A	R	R	R				
TDP40A	4	1	5.00	1	26	5.1			M-G																		F	R		A	R		R		R		LO of *Ti. pimula*
TDP40A	4	3	5.00	26	50	7.4	EARLY ALBIAN	*Microhedbergella rischi* zone	P-M															R	R												
TDP40A	5	1	8.00	1	25	8.1			M-G																				R								HO of *Pa. eubejaouaensis*
TDP40A	5	2	8.00	8	33	9.2	LATE APTIAN	*Paraticinella eubejaouaensis* zone	P-M		R								R	R	F	R		R													
TDP40A	5	2	8.00	65	90	9.80			P-M																												
TDP40A	5	3	8.00	65	90	10.8			P-M		R		R		R	F			R		R	R	RR														LO of *Pa. eubejouaensis*
TDP40A	6	1	11.00	25	53	11.40	LATE APTIAN	*Hedbergella trocoidea* zone	P-M		F				R	R	R	R	R		C																
TDP40A	6	2	11.00	25	55	12.40			M-G		R				R	R	R				F																
TDP40A	6	3	11.00	1	29	13.20			P-M						R		R	R	R		F																
TDP40A	7	1	14.00	1	25	14.10			P-M						R																						
TDP40A	8	1	15.00	1	25	15.10			P-M		R			F		R					R																
TDP40A	8	1	15.00	74	96	16.00	INDETERMINATE	UNZONED	P-M																												
TDP40A	9	1	17.00	1	32	17.20			B																												
TDP40A	9	1	17.00	45	48	17.50			B																												
TDP40A	10	1	20.00	1	25	20.10	INDETERMINATE	UNZONED	M-G	R	R				R																						? HO of *G. algerianus*
TDP40A	10	2	20.00	1	25	21.10			M-G		R	R																									
TDP40A	10	3	20.00	3	88	22.50			P-M	R																											
TDP40A	10	3	20.00	88	112	23.00	BARREMIAN- EARLY APTIAN	UNZONED	P-M																												
TDP40A	11	1	23.12	1	25	23.30			P-M																												
TDP40A	11	2	23.12	1	25	24.30			P-M																												
TDP40A	12	1	26.12	8	25	26.30			P-M																												
TDP40A	12	3	26.12	1	25	28.30			P-M																												
TDP40A	13	1	29.12	1	25	29.30			P-M																												

Table 5.1: TDP Site 40A planktonic and benthic foraminifera range chart continued.

Well name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth below surface (m)	Age	Planktonic foraminiferal zones	Preservation	*Astacolus* aff. *gratus*	*Conorotalites bartensteini aptiensis*	*Gavelinella barremiana*	*Globorotalites* sp.	*Lenticulina muensteri* (sp. 2)	*Lenticulina (Lenticulina) nodosa*	*Lenticulina (L) subgaultina*	*Lenticulina (Lenticulina) eichenbergi*	*Lenticulina (Marginulinopsis) robusta*	*Lenticulina (L.) ouachensis ouachensis*	*Trochammina* sp.	*Epistomina* sp. aff. *hetchi*	*Epistomina caracola*	*Laevidentalina communis*	*Lenticulina (Lenticulina) saxocretacea*	*Lenticulina (Saracenaria) spinosa*	*Lingulogavelinella* sp. 1	*Lenticulina (Astacolus)* aff. *gratus*	*Globorotalites* sp.	*Osangularia schloenbachi*	*Ramulina tetrahedralis*	*Osangularia* sp.	*Gyroidinoides* sp.	*Nodosaria* sp.	*Reophax* sp. aff. *scorpiurus*	*Reophax* sp. 3	*Orbitolinids*	*Gavelinella intermedia*	*Pseudonodosaria humilis*	*Marsonella kummi*	*Hyperammina* sp.	*Glomospirella* sp. aff. *gaultina*
TDP40A	1	1	0.00	30	58	0.4	MIDDLE ALBIAN	*Ti. primula* zone	P-M	R																	RR									A	R				
TDP40A	1	2	0.00	25	41	1.3			P-M																																
TDP40A	1	3	0.00	20	40	2.30			P-M																				A	RR							F				
TDP40A	2	1	2.00	33	62	2.5			M-G					R									RR						A	RR	A	R					F			R	RR
TDP40A	2	2	2.00	25	50	3.4			M-G					R									RR					RR	F	RR	R	R					F				
TDP40A	2	3	2.00	1	25	4.1			P-M																	R															
TDP40A	2	3	2.00	15	37	4.3			M-G					F									RR			R		RR		RR		R					F				
TDP40A	3	1	4.60	1	25	4.7			P-M																																
TDP40A	4	1	5.00	1	26	5.1			M-G					F									RR							RR							F			R	
TDP40A	4	3	5.00	26	50	7.4	EARLY ALBIAN	*Mi. rischi* zone	P-M					F									RR							RR							R			F	RR
TDP40A	5	1	8.00	1	25	8.1			M-G																									R							
TDP40A	5	2	8.00	8	33	9.2	LATE APTIAN	*Pa. eubejaouaensis* zone	P-M		R		R	F						R			RR					R	A	RR	R			R			C	R		R	
TDP40A	5	2	8.00	65	90	9.80			P-M					A									RR					R	A		C			R			R	R			
TDP40A	5	3	8.00	65	90	10.8			P-M					F						R			RR						A		R			R			R	R		F	
TDP40A	6	1	11.00	25	53	11.40	LATE APTIAN	*H. trocoidea* zone	P-M					R						R			RR						A								F			R	
TDP40A	6	2	11.00	25	55	12.40			M-G					R						R									A											F	
TDP40A	6	3	11.00	1	29	13.20			P-M					F						R			RR						A											R	
TDP40A	7	1	14.00	1	25	14.10			P-M					F									RR														R	R			
TDP40A	8	1	15.00	1	25	15.10			P-M					F						R			RR						A	RR	R						R	R			
TDP40A	8	1	15.00	74	96	16.00	INDETERMIN-ATE	UNZONED	P-M																																
TDP40A	9	1	17.00	1	32	17.20			B																																
TDP40A	9	1	17.00	45	48	17.50			P-M																																
TDP40A	10	1	20.00	1	25	20.10	INDETERM-INATE	UNZONED	M-G					C																			R								
TDP40A	10	2	20.00	1	25	21.10			M-G					A																											
TDP40A	10	3	20.00	3	88	22.50			P-M					A																											

Table 5.1: TDP Site 40A planktonic and benthic foraminifera range chart continued.

Well name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth below surface (m)	Age	Planktonic foraminiferal zones	Preservation	*Astacolus* aff. *gratus*	*Conorotalites bartensteini aptiensis*	*Gavelinella barremiana*	*Globorotalites* sp.	*Lenticulina muensteri* (sp. 2)	*Lenticulina (Lenticulina) nodosa*	*Lenticulina (L) subgaultina*	*Lenticulina (Lenticulina) eichenbergi*	*Lenticulina (Marginulinopsis) robusta*	*Lenticulina (L.) ouachensis ouachensis*	*Trochammina* sp.	*Epistomina* sp. aff. *hetchi*	*Epistomina caracola*	*Laevidentalina communis*	*Lenticulina (Lenticulina) saxocretacea*	*Lenticulina (Saracenaria) spinosa*	*Lingulogavelinella* sp. 1	*Lenticulina (Astacolus)* aff. *gratus*	*Globorotalites* sp.	*Osangularia schloenbachi*	*Ramulina tetrahedralis*	*Osangularia* sp.	*Gyroidinoides* sp.	*Nodosaria* sp.	*Reophax* sp. aff. *scorpiurus*	*Reophax* sp. 3	*Orbitolinids*	*Gavelinella intermedia*	*Pseudonodosaria humilis*	*Marsonella kummi*	*Hyperammina* sp.	*Glomospirella* sp. aff. *gaultina*
TDP40A	10	3	20.00	88	112	23.00	BARREMIAN - EARLY APTIAN	UNZONED	P-M					C					R														R				R			R	
TDP40A	11	1	23.12	1	25	23.30			P-M					A	R				R				RR		R										RR				R	R	
TDP40A	11	2	23.12	1	25	24.30			P-M		R			A					R				RR	R									R								
TDP40A	12	1	26.12	8	25	26.30			P-M					A					R		R	R	RR		R																
TDP40A	12	3	26.12	1	25	28.30			P-M					F					R		R	R	RR																		
TDP40A	13	1	29.12	1	25	29.30			P-M					C					R		R	R	RR		R																
TDP40A	13	2	29.12	1	26	30.30			M-G												R	R	RR																		
TDP40A	13	3	29.12	1	26	31.30			P-M												R	R																			
TDP40A	14	1	32.37	1	25	32.50			P			R		R					R						R																
TDP40A	14	2	32.37	1	27	33.50			P																																
TDP40A	15	1	35.37	1	26	35.50			P					R																											
TDP40A	15	2	35.37	1	26	36.50			P			R																													
TDP40A	15	3	35.37	1	25	37.50			P					R																											
TDP40A	16	1	38.37	1	25	38.50			B																																
TDP40A	16	2	38.37	1	25	39.50			B																																
TDP40A	16	3	38.37	1	25	40.50			P			R		F						R																					
TDP40A	17	2	41.37	1	25	42.50			P-M			R		C						R																					
TDP40A	17	3	41.37	1	25	43.50			P-M		R	F		A					R	R			R		R																
TDP40A	18	1	44.37	1	21	44.50			P-M			C		A									R		A																
TDP40A	18	1	44.37	74	96	45.20			P-M		R	F																													
TDP40A	18	2	44.37	26	55	45.80			P-M					R				R				R																			
TDP40A	18	3	44.37	29	57	46.80			P-M		R			A					R				R	R	A																
TDP40A	19	1	47.37	1	24	47.50			P-M		R			R								R	R		R																
TDP40A	19	2	47.37	1	25	48.50			P-M					F																											
TDP40A	19	3	47.37	1	25	49.50			P-M			R				R		R							R																
TDP40A	20	1	50.45	1	25	50.60			P					R																											
TDP40A	20	2	50.45	1	25	51.60			P			R		R																											
TDP40A	21	2	53.45	1	26	54.60			P-M		C	R		C			F		R																						
TDP40A	21	3	53.45	1	28	55.19			P		C			F			F				F	F		R																	
TDP40A	22	1	56.45	1	28	56.60			P-M		C	F		A			R		R				R	R	R																
TDP40A	22	2	56.45	1	27	57.60			P-M					C							R	R																			
TDP40A	22	3	56.45	1	25	58.60			P-M		R			A			R		R																						
TDP40A	23	1	59.45	0	25	59.60			P		A	A		A																											
TDP40A	24	1	62.45	1	25	62.60	INDETERMINATE	UNZONED	B																																
TDP40A	25	1	65.45	1	24	65.60			B																																
TDP40A	26	1	68.45	1	25	68.60			B																																
TDP40A	27	1	71.45	1	25	71.60			B																																
TDP40A	28	3	74.45	1	25	76.60			B																																

Note: A=Abundant; ≥ 21 specimens, C= Common; 11-20 specimens, F= Frequent; 6-10 specimens, R= Rare; 2-5 specimens, RR= rare; 1 specimen, B= Barren, M-G= Moderate to good, P-M= Poor to moderate, P= Poor,

H.=Hedbergella, Mi.= Microhedbergella, Pa.= Paraticinella, Ti.= Ticinella .

Table 5.1: TDP Site 40A planktonic and benthic foraminifera range chart continued.

Well name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth below surface (m)	Age	Planktonic foraminiferal zones	Preservation	*Reophax* sp. 3	*Pseudonodosaria* sp. aff. *mutabilis*	*Psilocitherella* sp.	*Psilocitharella* aff. *arguta*	*Gaudryinopsis gradata*	*Tritaxia pyramidata*	*Ammodiscus* sp.	*Nodosaria obscura*	*Ammodiscus cretacea*	*Patellina subcretacea*	*Lenticulina (Astacolus) crepidularis*	*Lenticulina (Astacolus) tricarinella)*	*Psilocitherella recta*	*Psammosphaera* sp.	*Pseudogaudryinella pyramidata*	*Saracenaria triangularis*	*Tristix excavata*	*Gaudryina gradata*	*Ammodiscus sp*	*Glomospira charoides*	*Verneullina* sp.	*Ammonites*	*Gastropods*	*Bivalves*	*Ostracods*	*Pyrite cubes*	*Belemnite*	*coal fragments*	*Iron nodules*
TDP40A	1	1	0.00	30	58	0.4	MIDDLE ALBIAN	*Ti. primula* zone	P-M																R							R	R	R				A
TDP40A	1	2	0.00	25	41	1.3			P-M																									R				A
TDP40A	1	3	0.00	20	40	2.30			P-M																		R					R		R				A
TDP40A	2	1	2.00	33	62	2.5			M-G					R				R	R					R					R			R	R	R				A
TDP40A	2	2	2.00	25	50	3.4			M-G			R		R	R	R		R	R					R				R		R	R	R		R				A
TDP40A	2	3	2.00	1	25	4.1			P-M																						R	R	R	R				A
TDP40A	2	3	2.00	15	37	4.3			M-G			R		F					F			R		R			C				R	R	R	R				A
TDP40A	3	1	4.60	1	25	4.7			P-M																									R				A
TDP40A	4	1	5.00	1	26	5.1			M-G			R		F					F			R		R		R								F		R		A
TDP40A	4	3	5.00	26	50	7.4	EARLY ALBIAN	*Mi. rischi* zone	P-M			R												R	R						R	R		R	R			A
TDP40A	5	1	8.00	1	25	8.1			M-G																									R				A
TDP40A	5	2	8.00	8	33	9.2	LATEST APTIAN	*Pa. eubejaouaensis* zone	P-M																						R	R	R	R				A
TDP40A	5	2	8.00	65	90	9.80			P-M		RR	R							R						R						R	R		F	F			
TDP40A	5	3	8.00	65	90	10.8			P-M			R	RR					R	R				R											R	F			
TDP40A	6	1	11.00	25	53	11.40	LATE APTIAN	*H. trocoidea* zone	P-M								RR		R															R	F			
TDP40A	6	2	11.00	25	55	12.40			M-G																									R	C	R		
TDP40A	6	3	11.00	1	29	13.20			P-M			R				R	RR														R			R	A			
TDP40A	7	1	14.00	1	25	14.10			P-M							R															R	R		R	A			
TDP40A	8	1	15.00	1	25	15.10			P-M																						R	R		R	C		R	
TDP40A	8	1	15.00	74	96	16.00	INDETERMINATE	UNZONED	P-M																										F		R	
TDP40A	9	1	17.00	1	32	17.20			B																												R	
TDP40A	9	1	17.00	45	48	17.50			P-M																													
TDP40A	10	1	20.00	1	25	20.10	INDETERMINATE	UNZONED	M-G																									R	R		R	
TDP40A	10	2	20.00	1	25	21.10			M-G																													
TDP40A	10	3	20.00	3	88	22.50			P-M																							R		R				

Table 5.1: TDP Site 40A planktonic and benthic foraminifera range chart continued

Well name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth below surface (m)	Age	Planktonic foraminiferal zones	Preservation	*Reophax* sp. 3	*Pseudonodosaria* sp. aff. *mutabilis*	*Psilocitherella* sp.	*Psilocitharella* aff. *arguta*	*Gaudryinopsis gradata*	*Tritaxia pyramidata*	*Ammodiscus* sp.	*Nodosaria obscura*	*Ammodiscus cretacea*	*Patellina subcretacea*	*Lenticulina (Astacolus) crepidularis*	*Lenticulina (Astacolus) tricarinella)*	*Psilocitherella recta*	*Psammosphaera* sp.	*Pseudogaudryinella pyramidata*	*Saracenaria triangularis*	*Tristix excavata*	*Gaudryina gradata*	*Ammodiscus sp*	*Glomospira charoides*	*Verneullina* sp.	*Ammonites*	*Gastropods*	*Bivalves*	*Ostracods*	*Pyrite cubes*	*Belemnite*	*coal fragments*	*Iron nodules*
TDP40A	10	3	20.00	88	112	23.00	BARREMIAN - EARLY APTIAN	UNZONED	P-M		RR																											
TDP40A	11	1	23.12	1	25	23.30			P-M	R		R	RR																		R	R	R	F	A		R	
TDP40A	11	2	23.12	1	25	24.30			P-M												RR										R	R	R	F	A		R	
TDP40A	12	1	26.12	8	25	26.30			P-M											RR	RR										R	R	R	F	A	R	R	
TDP40A	12	3	26.12	1	25	28.30			P-M											RR											R			F	A		F	
TDP40A	13	1	29.12	1	25	29.30			P-M																						R	R	R	F	A		A	
TDP40A	13	2	29.12	1	26	30.30			M-G																										A			
TDP40A	13	3	29.12	1	26	31.30			P-M																										A			
TDP40A	14	1	32.37	1	25	32.50			P																										A			
TDP40A	14	2	32.37	1	27	33.50			P																										A			
TDP40A	15	1	35.37	1	26	35.50			P																										A			
TDP40A	15	2	35.37	1	26	36.50			P																										A			
TDP40A	15	3	35.37	1	25	37.50			P																										A			
TDP40A	16	1	38.37	1	25	38.50			B																													
TDP40A	16	2	38.37	1	25	39.50			B																													
TDP40A	16	3	38.37	1	25	40.50			P																												R	
TDP40A	17	2	41.37	1	25	42.50			P-M																												R	
TDP40A	17	3	41.37	1	25	43.50			P-M																										A			
TDP40A	18	1	44.37	1	21	44.50			P-M																										A			
TDP40A	18	1	44.37	74	96	45.20			P-M																													
TDP40A	18	2	44.37	26	55	45.80			P-M																													
TDP40A	18	3	44.37	29	57	46.80			P-M																							R			A		F	
TDP40A	19	1	47.37	1	24	47.50			P-M																										C		F	
TDP40A	19	2	47.37	1	25	48.50			P-M																										F		F	
TDP40A	19	3	47.37	1	25	49.50			P-M																										F		F	
TDP40A	20	1	50.45	1	25	50.60			P																										A		C	
TDP40A	20	2	50.45	1	25	51.60			P																										A		A	
TDP40A	21	1	53.45	1	28	53.60			P-M																										C		A	
TDP40A	21	2	53.45	1	26	54.60			P																										A		F	
TDP40A	22	2	56.45	1	27	57.60			P-M																										A		F	
TDP40A	22	3	56.45	1	25	58.60			P-M																										A		C	
TDP40A	23	1	59.45	0	25	59.60			P																										A		C	
TDP40A	24	1	62.45	1	25	62.60	INDETERMINATE	UNZONED	B																												R	
TDP40A	25	1	65.45	1	24	65.60			B																												A	
TDP40A	26	1	68.45	1	25	68.60			B																												A	
TDP40A	27	1	71.45	1	25	71.60			B																												A	
TDP40A	28	3	74.45	1	25	76.60			B																												A	

Table 5.2: TDP40B planktonic and benthic foraminifera range chart

Well Name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)	Age	Planktonic Foraminiferal zone	Preservations	*Gorbachikella* sp. aff. *kugleri*	*Hedbergella aptiana*	*Caucasella hoterivica*	*Hedbergella* sp.	*Hedbergella sigali*	*Praehedbergella ruka*	*Globigerinelloides blowi*	*Hedbergella infracretacea*	*Hedbergella similis*	*Hedbergella excelsa*	*Hedbergella occulta*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Hedbergella trocoidea*	*Paraticinella eubejaouaensis*	*Paraticinella* aff. *transitoria*	*Pseudoguembelitria* sp.	*Microhedbergella*	*Muricohedbergella albiana*	*Microhedbergella miniglobularis*	*Microhedbergella renilevis* (sp. 1)	*Hedbergella praelippa*	*Ticinella primula*	*Microhedbergella rischi*	*Favusella washitensis*	*Macroglobigerinelloides*	*Ascoliella* sp. aff. *nitida*	*Ascoliella* sp. 1	*Ascoliella* sp. 2	*Ascoliella* sp. 3	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Ticinella* sp.	*Ticinella* sp. aff. *madecassiana*	*Ticinella madecassiana*	*Ammonites*	*Belemnites*	*Bivalves*	*Coal fragments*	*Gastropods*	*Iron nodules*	*Ostracods*	*Plant remains*	*Pyrite cubes*	
TDP40B	1	1	0	40	49	0.5	MIDDLE ALBIAN	*Ti. primula* zone	P-M																					R				R		R	A	R	R	R	F		R	R	C								R			
TDP40B	2	1	2	1	25	2.1			P-M																					R				R	R	R	A	F	F	R	R		R	R	C	R										
TDP40B	2	2	2	1	25	3.1			M-G																				R	R				R		R	A	R	R	R	R		R		F			R				R	F			
TDP40B	2	3	2	1	25	4.1			P-M																					R				R		F	A	F	F	R	R		R		C							R	R	R		
TDP40B	3	1	5	1	25	5.1			P-M																									R		F	F	F	F	R					F											
TDP40B	4	1	5.6	25	50	6			P-M																									R		R	A								A											
TDP40B	4	2	5.6	1	25	6.7			P-M																									R		R	R							RR	C		R	R								
TDP40B	4	3	5.6	1	25	7.7			P-M																									R		R	A								C				R				R			LO of *Ti. primula*
TDP40B	5	1	8	1	25	8.1	EARLY ALBIAN	*Mi. rischi* zone	P-M																						R	R	R		R												R		R							
TDP40B	5	2	8	1	25	9.1	INDETERMI-NATE	UNZONED	P																							R																				R		R		HO of *Pa. eubajaouaensis*
TDP40B	5	3	8	30	40	10.4	LATE APTIAN	*Pa. eubejaouaensis* zone	P		F				R			R									F	R	R																											
TDP40B	5	3	8	50	60	10.6			P-M		R					R	R		R	R	R				R				R																											
TDP40B	5	3	8	60	70	10.7			P							R										F																												R		LO of *Pa. eubejaouaensis*
TDP40B	5	3	8	70	80	10.8	LATE APTIAN	*H. trocoidea* zone	P		R					R	R					R			R		F		RR																							R	R			
TDP40B	5	3	8	80	90	10.9			P-M					R		R						RR						R																										R		
TDP40B	5	3	8	90	100	11			P-M								R									R																														
TDP40B	6	2	11	1	25	12.1			P-M					R		R						R				R																	R				R	R					R			
TDP40B	6	3	11	1	32	13.1			M-G																																						R	R				C	F	R	R	
TDP40B	7	1	14	1	25	14.1			P							R								R								R		R																R			R			
TDP40B	7	2	14	1	25	15.1			P-M																																									R			C			
TDP40B	7	3	14	1	25	16.1	LATE APTIAN	?*H. trocoidea* zone	P																																												R			
TDP40B	9	2	18	1	25	19.1			M-G							R																																					R			
TDP40B	10	1	20	1	25	20.1	EARLY APTIAN	UNZONED	P-M	R			RR																																		R				R		F		A	
TDP40B	10	2	20	1	25	21.1			P-M													R																												F			F		A	
TDP40B	10	3	20	1	25	22.1			P-M	R	R					R																															R				R		F		A	

Table 5.2: TDP40B planktonic and benthic foraminifera range chart.

Well Name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)	Age	Planktonic Foraminiferal zone	Preservations	*Gorbachikella* sp. aff. *kugleri*	*Hedbergella aptiana*	*Caucasella hoterivica*	*Hedbergella* sp.	*Hedbergella sigali*	*Praehedbergella ruka*	*Globigerinelloides blowi*	*Hedbergella infracretacea*	*Hedbergella similis*	*Hedbergella excelsa*	*hedbergella occulta*	*Hedbergella gorbachikae*	*Globigerinelloides aptiensis*	*Globigerinelloides algerianus*	*Globigerinelloides barri*	*Hedbergella trocoidea*	*Paraticinella eubejaouaensis*	*Paraticinella* aff. *transitoria*	*Pseudoguembelitria* sp.	*Microhedbergella*	*Muricohedbergella albiana*	*Microhedbergella*	*Microhedbergella renilevis* (sp.	*Hedbergella praelippa*	*Ticinella primula*	*Microhedbergaella rischi*	*Favusella washitensis*	*Macroglobigerinelloides*	*Ascoliella* sp. aff. *nitida*	*Ascoliella* sp. 1	*Ascoliella* sp. 2	*Ascoliella* sp. 3	*Ticinella raynaudi digitalis*	*Ticinella roberti*	*Ticinella* sp.	*Ticinella* sp. aff. *madecassiana*	*Ticinella madecassiana*	*Ammonites*	*Belemnites*	*Bivalves*	*Coal fragments*	*Gastropods*	*Iron nodules*	*Ostracods*	*Plant remains*	*Pyrite cubes*
TDP40B	10	3	20	25	50	22.4	BARREMIAN- EARLY APTIAN	UNZONED	P-M																																														A
TDP40B	11	1	23	1	25	23.1			P																																						R		R		R				A
TDP40B	11	2	23	1	25	24.1			P-M																																									F					A
TDP40B	11	3	23	1	25	25.1			P-M																																						R								A
TDP40B	12	1	26	1	25	26.1			P																																									C					C
TDP40B	12	2	26	25	50	27.4			P																																														F
TDP40B	12	3	26	25	50	28.4			P-M																																														
TDP40B	13	1	29	1	25	29.1			P																																														C
TDP40B	13	2	29	1	25	30.1			P-M																																														
TDP40B	13	2	29	25	50	30.4			P-M																																														A
TDP40B	13	3	29	25	50	31.4			P-M																																														F
TDP40B	14	1	32	1	25	32.1			P																																							R			A				A
TDP40B	14	2	32	1	25	33.1			P																																														
TDP40B	14	3	32	1	25	34.1			P-M																																							R			A			R	A
TDP40B	15	1	35	1	25	35.1			P																																														A
TDP40B	15	3	35	1	25	37.1			P																																										A				A
TDP40B	16	1	38	1	25	38.1			P-M																																													R	A
TDP40B	16	1	38	51		38.8			P-M								R		R																													R			R			R	C
TDP40B	16	2	38	1	25	39.1			P-M									R			R	R																														R	R		
TDP40B	16	3	38	1	25	40.1			P-M																																										F				F
TDP40B	17	1	41	1	25	41.1			M-G												R																														A				A
TDP40B	17	1	41	25	50	41.4			P																																														
TDP40B	17	2	41	42	67	42.6			P-M											R																																			
TDP40B	17	3	41	25	50	43.4			M-G																																														
TDP40B	17	3	41	68	100	44			P																																														
TDP40B	18	2	44	1	25	45.1			P-M	R																																						R							C
TDP40B	18	2	44	25	50	45.4			P-M																																							F							A
TDP40B	18	3	44	25	50	46.4			P-M																																							R							A
TDP40B	19	1	47	1	25	47.1			P-M																																														
TDP40B	19	1	47	25	50	47.4			P-M																																										A				
TDP40B	19	2	47	1	25	48.1			P-M																																										A				
TDP40B	19	3	47	25	50	49.4			P-M																																							R							A
TDP40B	20	1	50	25	50	50.4			P-M																																										A	R			A
TDP40B	20	2	50	1	25	51.1			P-M																																							R			A	R			A
TDP40B	20	3	50	1	25	52.1			P-M																																							R							A
TDP40B	21	3	53	25	50	55.4			P-M																																													A	A
TDP40B	22	1	56	1	25	56.1			P-M																																													A	A
TDP40B	22	2	56	1	25	57.1			P-M																																													A	A
TDP40B	22	3	56	1	25	58.1			P-M																			R																										A	A

Table 5.2: TDP Site 40B planktonic and benthic foraminifera range chart continued.

Well Name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)	Age	Planktonic Foraminiferal zone	Preservations	*Ammobaculites* sp. 1	*Ammobaculite* sp. 2	*Ammobaculites subcretacea*	*Astacolus* sp. 2	*Bathysiphon* sp.	*Conorotalites bartensteini aptiensis*	*Conorotalites bartensteini intercedens*	*Dorothia kummi*	*Epistomina caracolla*	*Epistomina* sp. aff. *hetchi*	*Gavelinella barremiana*	*Gavelinella* sp. 2	*Globulina* sp.	*Gyrodinoides* sp. 3	*Hyperammina* sp.	*Laevidentalina communis*	*Laevidentalina* sp.	*Lagenammina* sp. aff. *alexanderi*	*Lenticulina* sp. 1	*Lenticulina* sp. ex. gr. *muensteri*	*Lenticulina (L) ouachensis wilssemani*	*Lenticulina (L) ouachensis ouachensis*	*Lenticulina (A) crepidularis*	*Lenticulina (A) tricarinella*	*Lenticulina saxocretacea*	*Lingulina* sp.	*Pseudogauryinella* sp.	*Reophax* sp.1	*Reophax(sp. 2)* aff. *deckeri*	*Reophax* sp. aff. *scorpiurus*	*Trochammina* sp.
TDP40B	10	1	20	1	25	20.1	EARLY APTIAN	UNZONED	P-M				F				R				F		F		R		F					R					F			
TDP40B	10	2	20	1	25	21.1			P-M				F								F		F		R										R					
TDP40B	10	3	20	1	25	22.1			P-M				C		R						R				R															
TDP40B	10	3	20	25	50	22.4	BARREMIN-EARLY APTIAN	UNZONED	P-M					R										R																
TDP40B	11	1	23	25	50	23.1			P				F	R							C	R	C	R		R						R								
TDP40B	11	2	23	1	25	24.1			P-M				F									R		R	R						R	F	R						R	
TDP40B	11	3	23	1	25	25.1			P-M				F	R							C			R	R							F	R				R			
TDP40B	12	1	26	1	25	26.1			P									R							R							F					R			
TDP40B	12	2	26	25	50	27.4			P				R		R																	C					R			
TDP40B	12	3	26	25	50	28.4			P-M				C													R						F					R			
TDP40B	13	1	29	1	25	29.1			P	R	R							R			R										R	C		R				R		
TDP40B	13	2	29	1	25	30.1			P-M						R	R																C								
TDP40B	13	2	29	25	50	30.4			P-M									R														F								
TDP40B	13	3	29	25	50	31.4			P-M									R														F								
TDP40B	14	1	32	1	25	32.1			P				R		R										R						R						R			
TDP40B	14	3	32	1	25	34.1			P												F						R													
TDP40B	15	1	35	1	25	35.1			P-M				R									R															R			
TDP40B	15	3	35	1	25	37.1			P				F													R						C								
TDP40B	16	1	38	51	100	38.8			P				F																		R	C					R			R
TDP40B	16	2	38	1	25	39.1			P-M				R								F				R	R						C			R		R			
TDP40B	16	3	38	1	25	40.1			P-M																															
TDP40B	17	1	41	1	25	41.1			P-M				R	R							R		A			R			F		F			F	R		R			R
TDP40B	17	2	41	42	67	42.6			P-M				A	R							F		A	R	R					R	R		R			R				
TDP40B	17	3	41	25	50	43.4			M-G				C					R			R		A		F				R		F	F	F		R					
TDP40B	17	3	41	68	100	43.8			P				C								R		A		F				R		F		F		R					
TDP40B	18	2	44	1	25	45.1			P-M				F		A	R											R		R	F										
TDP40B	18	2	44	25	50	45.4			P-M			R	F		C	R					R					R									R		R			
TDP40B	18	3	44	25	50	46.4			P-M				F		A						R					F		R		C			F	C						
TDP40B	19	1	47	1	25	47.1			P-M				R		R						R								F											
TDP40B	19	1	47	25	50	47.4			P-M				F		R						C								R					R						
TDP40B	19	2	47	1	25	48.1			P-M				F		R			R			R				R				R				F	R						
TDP40B	19	3	47	25	50	49.4			P-M						R														R	C				R						
TDP40B	20	1	50	25	50	50.4			P-M				F	R	C	R						R		R	F	F									R	R				
TDP40B	20	2	50	1	25	51.1			P-M				F	R	A	R													R	R	R	R	R	R			R			
TDP40B	20	3	50	1	25	52.1			P-M				F		A	R					R	R																		
TDP40B	21	3	53	25	50	55.4			P-M				R	R	R		R	R	R		R				R		R													
TDP40B	22	1	56	1	25	56.1			P-M						F						F									R			R				R			R
TDP40B	22	2	56	1	25	57.1			P-M				C		F						A				R				F				F				R			
TDP40B	22	3	56	1	25	58.1			P-M						R			R	R		C								R											

Table 5.2: TDP Site 40B planktonic and benthic foraminifera range chart continued

Well Name	Core	Section	Top core drilled (m)	Top interval (cm)	Bottom interval (cm)	Depth (m)	Age	Planktonic Foraminiferal zone	Preservations	*Ammodiscus cretacea*	*Ammodiscus* sp.	*Astacolus* aff. *gratus*	*Gavellinella intermedia* (sp. 2)	*Gavelinella* sp. 3	*Glomospira charoides*	*Gyroidinoides* sp. 4	*Lenticulina muensteri* (sp. 1)	*Lenticulina ex. gr. muensteri*	*Lenticulina (L) praegultina*	*Lingulogavellinella* sp.	*Marssonella oxycona*	*Nodosaria obscura*	*Nodosaria* sp.	*Osangularia schloebanchi*	*Orithostella indica*	*Orithostella* sp. 2	*Patellina* sp. aff. *subcretacea*	*Pseudogaudryinella* sp.	*Saccammina* sp.	*Tristix excavata*	*Tritaxia pyramidata*	*Verneullina* sp.
TDP40B	1	1	0	40	49	0.5	MIDDLE ALBIAN	*Ti. primula* zone	P-M		R		R				F						R	C	R			R		R		
TDP40B	2	1	2	1	25	2.1			P-M								F	A					R				R					
TDP40B	2	2	2	1	25	3.1			M-G								F			R					R						R	R
TDP40B	2	3	2	1	25	4.1			P-M								C	C			F		R	A								
TDP40B	3	1	5	1	25	5.1			P-M									F														
TDP40B	4	1	5.6	1	25	5.7			P-M				R					F						A								
TDP40B	4	1	5.6	25	50	6			P-M								F	F						A					R			
TDP40B	4	2	5.6	1	25	6.7			P-M								R	R						C								
TDP40B	4	3	5.6	1	25	7.7			P-M				R											R				R	R	R		
TDP40B	5	1	8	1	25	8.1	EARLY ALBIAN	*Mi. rischi* zone	P								F	F						C		R						
TDP40B	5	2	8	1	25	9.1	INDETERMI-NATE	UNZONE D	P			R																			R	
TDP40B	5	3	8	30	40	10.4	LATE APTIAN	*Pa. eubejaouaensis* zone	P-M								F	R						F								
TDP40B	5	3	8	50	60	10.6			P									F						A								
TDP40B	5	3	8	60	70	10.7			P								F	R														
TDP40B	5	3	8	70	80	10.8	LATE APTIAN	*H. trocoidea* zone	P-M				R	R				F						A								
TDP40B	5	3	8	80	90	10.9			P-M		R							F					R	A								
TDP40B	5	3	8	90	100	11			P-M								F	F						A								
TDP40B	6	2	11	1	25	12.1			M-G									F			R	R	R	C				RR			R	R
TDP40B	6	3	11	1	32	13.1			P						R	R	F	R			R											
TDP40B	7	1	14	1	25	14.1			P-M												R											
TDP40B	7	2	14	1	25	15.1			P												R			R				R		R		R
TDP40B	7	3	14	1	25	16.1	LATE APTIAN	*?H. trocoidea* zone	P-M								R															
TDP40B	8	1	17	75	90	17.8			M-G								A	A									R					
TDP40B	9	2	18	1	25	19.1			P-M								A	A											A			

Table 5.2: TDP Site 40B planktonic and benthic foraminifera range chart continued

Well Name	**Core**	**Section**	**Top core drilled (m)**	**Top interval (cm)**	**Bottom interval (cm)**	**Depth (m)**	**Age**	**Planktonic Foraminiferal zone**	**Preservations**	*Ammodiscus cretacea*	*Ammodiscus* sp.	*Astacolus* sp. aff. *gratus*	*Gavellinella intermedia* (sp. 2)	*Gavelinella sp. 3*	*Gaudryina dividens*	*Lenticulina ex. gr. muensteri*	*Lenticulina (L) praegultina*	*Lingulogavelinella sp.*	*Marssonella oxycona*	*Nodosaria sp.*	*Osangularia schloebanchi*	*Orithostella* sp. 2	*Palmula sp.*	*Patellina sp. aff. subcretacea*	*Pseudogaudryinella pyramidata*	*Saccammina* sp.	*Tristix excavata*	*Tritaxia pyramidata*	*Verneullina sp.*
TDP40B	10	1	20	1	25	20.1	EARLY APTIAN	UNZONED	P-M				R						R	R				R	R	C		R	
TDP40B	10	2	20	1	25	21.1			P-M												A						R		
TDP40B	10	3	20	1	25	22.1			P-M							A					R								
TDP40B	10	3	20	25	50	22.4	BARREMIAN-EARLY APTIAN	UNZONED	P-M	R																			
TDP40B	11	1	23	25	50	23.1			P	R						A													
TDP40B	11	2	23	1	25	24.1			P-M							A				R									
TDP40B	11	3	23	1	25	25.1			P-M		R									R					R	R			
TDP40B	12	1	26	1	25	26.1			P							A	R								R			R	
TDP40B	12	2	26	25	50	27.4			P							A									R			R	
TDP40B	12	3	26	25	50	28.4			P-M		R					C				R					R			R	
TDP40B	13	1	29	1	25	29.1			P							A							R					R	
TDP40B	13	2	29	1	25	30.1			P-M							C									R			R	
TDP40B	13	2	29	25	50	30.4			P-M							C				R					R				
TDP40B	13	3	29	25	50	31.4			P-M							C									R			R	
TDP40B	14	1	32	1	25	32.1			P							A												R	
TDP40B	14	3	32	1	25	34.1			P																				
TDP40B	15	1	35	1	25	35.1			P-M							R													
TDP40B	15	3	35	1	25	37.1			P		R					A													
TDP40B	16	1	38	51	100	38.8			P							A												R	
TDP40B	16	2	38	1	25	39.1			P-M							A													
TDP40B	16	3	38	1	25	40.1			P-M			R				F													
TDP40B	17	1	41	1	25	41.1			P-M																				
TDP40B	17	2	41	42	67	42.6			P-M																			R	
TDP40B	17	3	41	25	50	43.4			M-G		R																	R	
TDP40B	17	3	41	68	100	43.8			P																				
TDP40B	18	2	44	1	25	45.1			P-M											R									
TDP40B	18	2	44	25	50	45.4			P-M																				
TDP40B	18	3	44	25	50	46.4			P-M																				
TDP40B	19	1	47	1	25	47.1			P-M																				
TDP40B	19	1	47	25	50	47.4			P-M																				
TDP40B	19	2	47	1	25	48.1			P-M																				
TDP40B	19	3	47	25	50	49.4			P-M								R												
TDP40B	20	1	50	25	50	50.4			P-M																				
TDP40B	20	2	50	1	25	51.1			P-M																				
TDP40B	20	3	50	1	25	52.1			P-M																				
TDP40B	21	3	53	25	50	55.4			P-M																				
TDP40B	22	1	56	1	25	56.1			P-M																				
TDP40B	22	2	56	1	25	57.1			P-M																				
TDP40B	22	3	56	1	25	58.1			P-M																				

H.= Hedbergella, Mi.= Microhedbergella, Pa. = Paraticinella, Ti. = Ticinella , M-G = Moderate-Good, P-M = Poor -Moderate, P = Poor, RR = rare; 2-specimens, F = Few; 6-10 specimens, C = Common; 11-20 specimens, A= Abundant; equal or more than 21 specimens

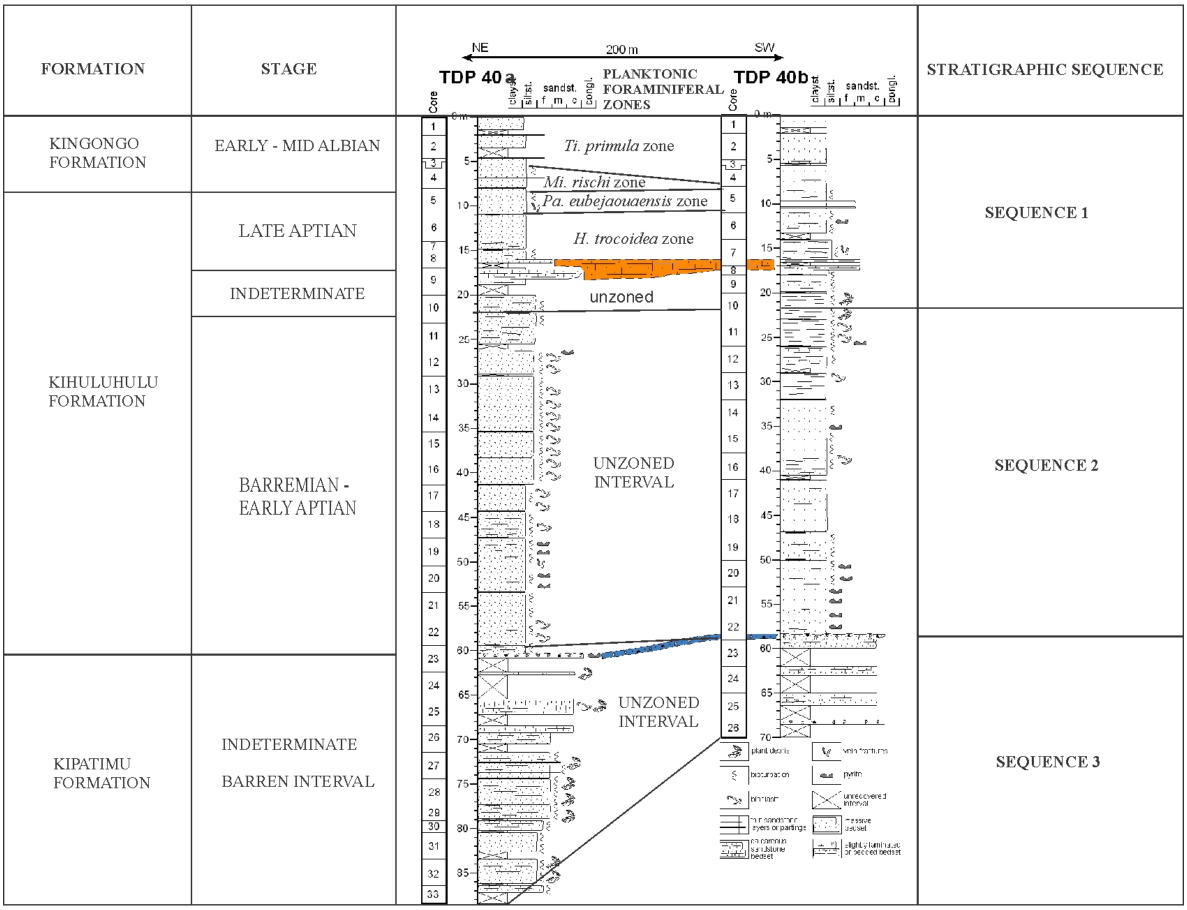


Figure 5.3: Biostratigraphic correlation of Hole TDP40A and TDP40B. Note: (*Ti.* = *Ticinella*; *Mi.* = *Microhedbergella*; *Pa.* = *Paraticinella*; *H.* = *Hedbergella*; *G.* = *Globigerinelloides.*

Calcareous sandstone bed present in both Holes at 17 m is shown in orange colour see fig. 5.3.

Conglomeratic sandstone bed present TDP40A & TDP40B at 60 m &58 m respectively is shown in blue colour see fig.5.3

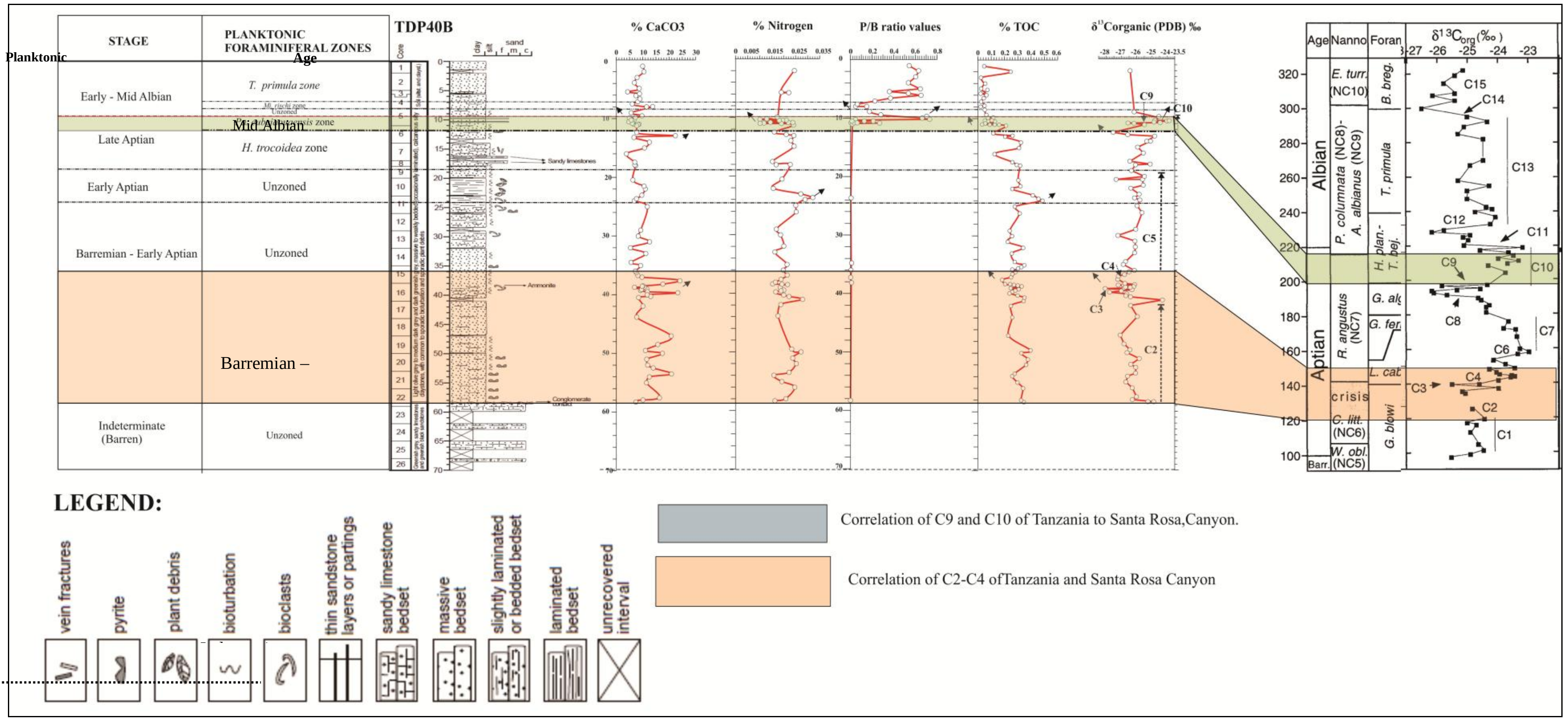


Figure 5.4: TDP Site 40B bulk sediment geochemical stratigraphy and down core P/B ratios. Note: An arrow (←) shows decreasing and (→) increasing in % TOC, % N, δ^{13}C and % Calcium carbonate, *G.* = *Globigerinelloides*, *H.* = *Hedbergella*, *Mi.* = *Microhedbergella*, and *P.* = *Paraticinella* and correlation of C2-C4 and C9-C10 of Tanzania to Santa Rosa Canyon data (Bralower and others, 1999).

$\delta^{13}C_{org}$
VPDB
‰Values

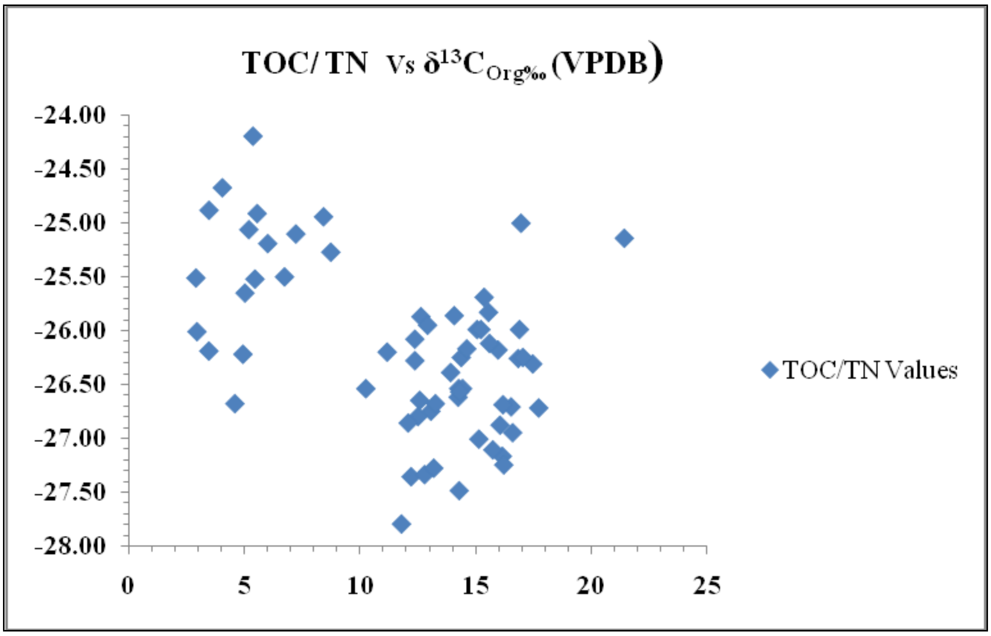


Figure 5.5: TOC/TN versus δ^{13}Corg ‰VPDB

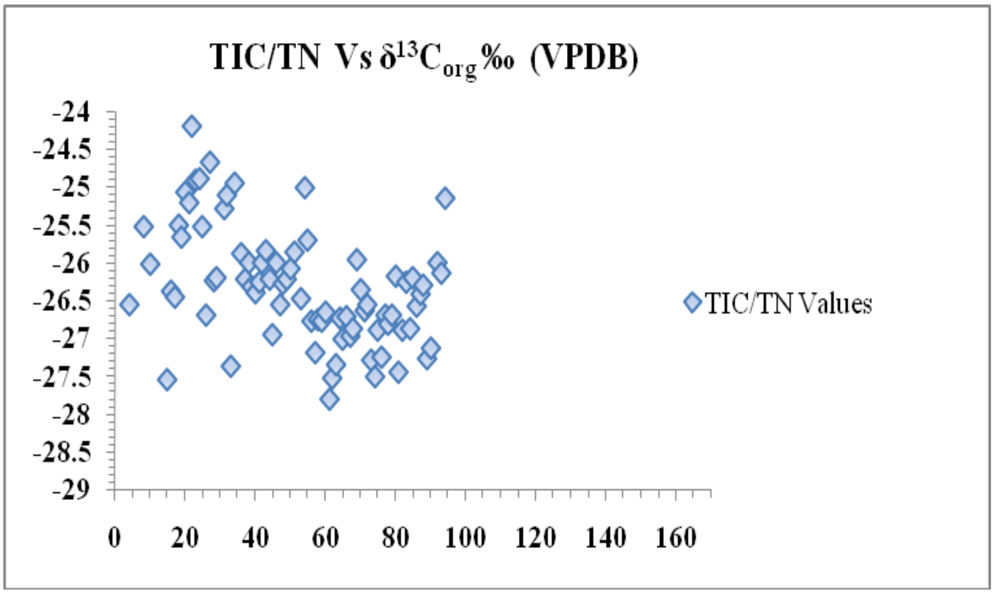


Figure 5.5b: TIC/TN versus δ^{13}Corg ‰VPDB (nitrogen values are very low and accurate measurement was not possible and hence this curve is not very useful.

Chapter 6 Synthesis and Conclusions

The main goal of this work was to develop an understanding of the stratigraphy, depositional environmental history of the mid-Cretaceous of Tanzania, which was previously very poorly known. The planktonic and benthic foraminifera recovered from boreholes and ditch cuttings have shown to be suitable for biostratigraphic correlation across the region and a recognizable set of twelve Biozones and two Subzones of the late Aptian to Cenomanian interval. The Biozones have been identified that fit with the global Tethys framework. The poor quality of preservation of foraminifera, especially the fact that they are mostly infilled with calcite and or pyrite, means they were unsuitable for geochemical palaeoclimate reconstructions. Therefore geochemical measurements were limited to bulk sediment analysis. Drilling of the TDP40 borehole was thought will provide a continuous record of mid-Cretaceous stratigraphy with a sequence through the Aptian/Albian boundary, unfortunately the boundary could not be demarcated due to lose of planktonic foraminifera index species of the basal Albian which are very tiny and gone through the 63 micron sieve mesh size through washing.

6.1 Applicability of Planktonic foraminiferal Biostratigraphy

Biostratigraphic analyses of samples recovered from six industry wells and two new boreholes have helped to identify and establish planktonic foraminiferal zones using modern taxonomic criteria and evidenced with biostratigraphic occurrence charts (see table 4.1 – 5.2 and table 3.4). Discovery and documentation of stratigraphically important short-ranging planktonic foraminifera zonal markers in Tanzania, including *Globigerinelloides algerianus, Paraticinella eubejaouaensis,* , *Hedbergella trocoidea, Microhedbergella rischi, Microhedbergella miniglobularis, Ticinella primula, Biticinella breggiensis, Ticinella praeticinensis, Pseudothalmanninella subticinensis, Thalmanninella appenninica, Thalmanninella globotruncanoides, Thalmanninella reicheli* and *Rotalipora cushmani* is a considerable step forward (see plates 3.1 - 3.15). The Zones of planktonic foraminifera spanning the upper Aptian to upper Cenomanian has allowed correlation to global records from the Tethys and Atlantic. Using both planktonic and benthic foraminifera biostratigraphy, a refined stratigraphical framework of upper Aptian to Cenomanian sediments of the coastal basin of Tanzania is presented (see plates 3.1 – 3.25). No oceanic anoxic event 1b is observed and no organic carbon rich sediments were encountered in the basal Albian. Most of the cases the basal Albian of Tanzania comprised of sandstones which are good hydrocarbon reservoirs.

6.2 Depositional and sea level history

The seven studied sites through the three principal depositional centres in the region (south, central and northern basins (see figure 4.9) show increased thickness of mid-Cretaceous marine sediments towards the north with the thickest deposition in the Ruvu Basin. In general the succession thins to the south and is thinnest in the Mandawa Basin. The Aptian – Albian boundary was found in the northernmost borehole, Makarawe-1, and possibly also Kizimbani-1 in the south. The Aptian/Albian boundary was not easy to identify in the two TDP Site 40 Holes, and no organic carbon rich sediments were recovered. This is not similar to other sites with a regional hiatus before sedimentation began again within or close to the *Ticinella primula* zone.

6.2.1 Upper Aptian to lower Albian

A morphogroups classification of the mid-Cretaceous foraminifera assemblages is shown in figure 6.1with their corresponding life position, feeding habits and environment (Hart, 1999, and Rükhem, 2006). The planktonic morphogroups assemblages present in the Tanzania studied section include PM1 - PM5, calcareous morphogroups CM1 - CM6 and arenaceous morphogroups of AM1 - AM4 (see table 6.1).

The upper Aptian is a period of rapid diversification and increase in test size, test modifications and common abundance of planktonic and benthic assemblages containing of both shallow and deep marine. Specimens of morphogroups PM1; *Pseudguembelitria*, PM2; *Hedbergella*, PM3; *Clavihedbergella*, PM4; *Globigerinelloides* and PM5; ticinellids including calcareous and agglutinated benthic foraminifera of the morphotypes CM1 - CM6 and AM1 - AM4 (see table 6.1). Marine conditions persisted in the Barremian to Cenomanian of the studied interval of the Tanzanian coastal basin. The predominance of specimens of hedbergellids indicates aerobic and eutrophic conditions of the surface waters (see table 6.1). The clavate forms are rare (morphotype PM3) in the upper Aptian indicates dysaerobic conditions in the upper water column. The occurrence of planispiral *Globigerinelloides*; morphotype PM4 confirms temporary mesotrophic conditions in the surface waters. The occurrence of the flat trochospiral ticinellids of morphotype PM5 indicates slightly deepening to more oligotrophic surface water in the late Albian to Cenomanian, and this is confirmed by the high P: B ratios (see figure 4.1 - 4.6 and 5.4). The calcareous benthic assemblages present in the Barremian to lower Aptian of Tanzania composed of morphogroups CM1 and CM3 and CM4 - CM6. The upper Aptian to upper Albian and Cenomanian consist of the calcareous benthic morphogroups CM1- CM6, while the arenaceous forms belong to morphogroupAM1-AM2 and AM4 (see table 6.1).

Results from Site TDP40 indicate that the upper Aptian/lower Albian interval was not identified although was easily identifiable in Makarawe-1 well and shows a stratigraphic level where a major extinction of all Aptian hedbergellids, ticinellids, and *Globigerinelloides* occurred. This coincides with a decrease in P/B ratio. Elsewhere in Tanzania planktonic foraminifera are completely barren during this interval lowermost Albian only arenaceous forms are present of morphogroups AM1-AM4 Kiwangwa-1, Kisarawe-1, Luhoi-1, Songo Songo-4 and Kizimbani-1 well or in some boreholes foraminifera are completely barren. These observations suggest a fall in sea level, as has been identified globally at the Aptian/Albian boundary (Leckie and others, 2002). No dissolution as previously was given as one of the reasons of not finding planktonic forms in the basal Albian but an appropriate size of washng sieves less han 63 micron mesh size is inevitable to avoid loosing the tiny planktonics foraminifera from the basal Albian. Although no organic carbon rich sediments were observed and the Aptian/Albian boundary was not easily identifiable due to rare scattered distributed lowermost Albian *microhedbergella miniglobularis* and few others..

In the lower Albian of Site TDP40, assemblages dominated by small hedbergellids (PM3) planktonic species are typical. These species suggest environmental stress and/or relatively shallow water compared to the late Aptian (Premoli Silva et al., 1999). Benthic species present are of cool water forms such *Conorotalites, Globorotalites, Gyroidinoides, Osangularia* (CM 1- CM 6) and arenaceous forms (AM1-AM-4). In other boreholes such as

Kiwangwa-1, planktonics are totally dissolved at this level (see table 6.1). There is a stratigraphic hiatus below the mid Albian level at Site Kiwangwa-1, Songo Songo-1, and Kisarawe-1. This is concluded because other zones like the Zone of *Ticinella madecassiana* are not recognized. The Zone of *Microhedbergella miniglobularis* is also missing just above the *Paraticinella eubejaouaensis* zone for most of the industrial sites studied. Therefore, I conclude that there is a regional hiatus at the base of the Albian sequence but further studies to support this is needed in the near future.

6.2.2 Middle - upper Albian

In industry borehole data show that in the middle to upper Albian there was a return to abundant and diverse planktonic foraminifera after the harsh conditions in the lower Albian. This suggests deeper water caused by marine transgression from the mid Albian and above (see figures 4.1 - 4 - 7, and 5.4). During this time larger and more robust-shelled planktonic foraminifera species evolved including various ticinellids and rotaliporids (PM5) which are single keeled forms (see table 6.1). Biticinellids (PM5), which is thought to have lived in deep marine paleoenvironments (Hart and others, 1999) together with increased P/B ratios, supports this view. The abundance of middle to upper bathyal benthic trochospiral forms, such as *Conorotalites, Epistomina, Osangularia, Globorotalites* and arenaceous forms provide further support to this idea. Further increases in P/B ratios in Makarawe-1, Kiwangwa-1 and Songo Songo-4, boreholes suggest a further sea level rise in the uppermost Albian. The transgression was related either to global sea level rise or local subsidence (Haq and others, 1988).

Table 6.1: Showing planktonic and benthic foraminiferal morphogroups with their respective life position, feeding habitat and environment (After Rükhem, 2006 and Hart, 1999).

Morphogroup	Test shape	Life position	Feeding habitat	Environment	Taxa
PM1	elongate triserial	floating in the water column	suspension feeder	pelagic, epicontinental sea, aerobic, highly eutrophic	*Guembelitria*
PM2	trochospiral	floating in the water column	suspension feeder	pelagic, epicontinental sea, shallow water aerobic, eutrophic	*Hedbergella*
PM3	clavate & elongate	floating in the water column	suspension feeder	pelagic, epicontinental sea, shallow water, aerobic/dysaerobic, mesotrophic/oligotrophic	*Clavihedbergella, Leupoldina*
PM4	planispiral	floating in the water	suspension feeder	pelagic, shallow water, aerobic, mesotrophic	*Globigerinelloides*
PM5	trochospiral flattened	floating in the water	suspension feeder	pelagic, shallow water, aerobic, oligotrophic	*Ticinella*
CM1	biconvex trochospiral to planoconvex trochospiral	epifaunal	deposit feeder	middle neritic to upper bathyal, aerobic, mesotrophic/eutrophic	*Conorotalites, Epistomina*
CM2	irregular meandrine	epifaunal	deposit feeder	neritic to upper bathyal, aerobic	*Ramulina*
CM3	planispiral to trochospiral	epifaunal	active deposit feeder	middle-outer shelf to upper slope, aerobic, eutrophic/masotrophic/oligotrophic	*Gavelinella, Gyroidinoides*
CM4	elongated flattened	shallow to deep infaunal	deposit feeder	neritic-upper bathyal, aerobic/dysaerobic, mesotrophic/eutrophic.	*Astacolus, Citharina, Frondicularia, Globulina, Lagena, Lingulina, Marginulinopsis, Nodosaria, Planularia, Psilocitherella, Saracenaria, Tristix, Vaginulinopsis*
CM5	elongated with straight periphery	shallow to deep infaunal	deposit feeder	neritic-upper bathyal, aerobic/dysaerobic/mesotrophic/eutrophic.	*Laevidentalina, Pseudonodosaria*
CM6	biconvex	epifaunal to deep infaunal	active deposit feeder	sublithoral-upper bathyal, aerobic/dysaerobic, eutrophic/mesotrophic/oligotrophic	*Lenticulina*
AM1	tubular	erect epifaunal	primary suspension feed	bathyal & abyssal/dysaerobic/quasi-anaerobic, eutrophic/mesotrophic/oligotrophic, low organic matter	*Rhizammina, Rhabdammina*
AM2	flattened planispiral and trochospiral	surficial epifaunal, phytal	active and passive deposit feeder	high energy-lagoon & estuarine, neritic &bathyal, dysaerobic/quasi-anaerobic/eutrophic/mesotrophic/oligotrophic	*Ammobaculites. Glomospira*
AM3	rounded planispiral	shallow infaunal	active deposit feeder	inner shelf to upper bathyal, aerobic/dysaerobic/mesotrophic/eutrophic	*Haplophragmoides, Recurvoides*
AM4	elongated subcylindrical & tapered	shallow to deep infaunal	Active deposit feeder	inner shelf to upper bathyal, dysaerobic/quasi - aerobic/mesotrophic/eutrophic/increase organic matter	*Ammobaculites, Gaudryina, Reophax, Textulariopsis, Triplasia, Veneuillinoides*

Note: PM = planktonic morphogroups; CM = calcareous benthic morphogroups; AM = arenaceous morphogroups.

The bulk sediment organic carbon stable isotope analysis provides an internally consistent correlation to global carbon isotopes curves (Herrle and others, 2004) through the interpreted upper Aptian interval and the Aptian/Albian boundary was not demarcated in the studied TDP40 boreholes. There is no evidence for the expression of Oceanic Anoxic Event OAE1b in terms of organic rich low oxygen sediments or measured organic carbon in the sequences studied, although other indications, such as shift to small opportunistic (hedbergellids) planktonic foraminifera are seen.

6.3 Relationship to oil and gas industry

The search for hydrocarbon occurrence in Tanzania has been going on since the early 1950's and until now discovery has been centred in the southern coastal basins in Songo Songo area (Rufiji Trough) and Mnazi bay (Ruvuma basin) and gas reserves have been discovered and some are being utilized for domestic use in the country. In the Mandawa basin no discovery has been made so far. The current results however, also show large regional differences in sediment thickness and it is possible that the northern Mandawa basin may yet yield organic carbon sediments associated with Cretaceous black shale deposition.

The results of this work will add more values to the studied basin and solved some of the unknown stratigraphic successions of the mid-Cretaceous of Tanzania coastal basin. It will also contribute to the ongoing exploration program in the deep offshore and shallow onshore basins. This research is intended to widen in the understanding of organic carbon rich sediments in the area and where to find the rich hydrocarbon reservoir in the country. Also to avoid risk of exploring for oil or gas in none organic carbon rich sequences. It will open up room for more research to be done in various mid-Cretaceous stratigraphic levels and will help to converse to a larger scientific community. Geological and biostratigraphical information are very few and unpublished, this will motivate other scientist in the country to update old data and publish. Very inadequate old publications are available, which are not accessible. Better understanding of geological processes in the basin will reduce the financial risks of oil exploration in the area and no more of drilling dry wells. This research will motivate students in my country to gain interest in this field and therefore will create new curriculum vitae to university of my country and create more jobs to specialists of my company. Future work should focus on identifying Aptian/Albian sequences with certainty in the north northern part of the coastal basin, i.e. in the Ruvu Basin (near Makarawe-1) where the succession is thicker.

Short ranging planktonic foraminifera taxa like *Globigerinelloides algerianus*, *Hedbergella trocoidea*, *Paraticinella eubejaouaensis*, *Microhedbergella miniglobularis*, *Microhedbergella rischi*, *Ticinella primula*, *Biticinella breggiensis*, *Pseudothalmanninella subticinensis*, *Thalmanninella appenninica*, *Thalmanninella globotruncanoides*, *Thalmanninella reicheli* and *Rotalipora cushmani* have helped to establish a new Tanzanian mid-Cretaceous planktonic foraminiferal zones of the upper Aptian to upper Cenomanian which can be compared with the established Tethyan scheme (see figure 3.4). Nevertheless a correlation of Tanzanian assemblages and Tethyan sections is still difficult because of few and absence of some of the index marker species in few stratigraphic intervals.

A refined stratigraphical framework of upper Aptian to upper Cenomanian sediments of Tanzania coastal basin has been established. The applied stratigraphical tool, planktonic foraminifera, stable carbon isotopes, indicates a hiatus of lowermost Albian age. A combination of the two methods resulted in a useful multi-stratigraphical scheme, refining the duration of the hiatus.

The results of the planktonic foraminiferal analyses presented in this study support the idea of major paleoenvironmental changes in the Aptian moreover it has been demonstrated the use of planktonic foraminifera for stratigraphical purpose is possible. An integrated bio- and chemostratigraphical zonation schemes is suggested in order to get more specific age assignment of marine sequences.

Preservation of planktonic foraminifera is generally poor-moderate (P-M) because most of the specimens show diagenetic alteration making it difficult for a detailed observation of their primary wall microstructure. Moderate – good (M-G) preservation when to some extent overgrowth with secondary calcite and wall structures (pore size, perforation cones) is visible. Poor (P) preservation is described for specimens that are strongly recrystallized and whose wall microstructure cannot be observed (see figure 2.6).

The incomplete mid-Cretaceous successions in the Tanzanian coastal basin however, hindered planktonic foraminiferal studies. Thus a comprehensive investigation of adequate sections has to be done first in the future. Further studies of mid-Cretaceous planktonic foraminifera from the Tanzanian coastal basin should be carried out in order to obtain a better understanding of their migration pattern and biogeographical distribution and identifying the most useful stratigraphic boundaries like the Aptian/Albian, Late Cenomanian/ Early Turonian and etc..

References

Abu-Zeid, R. H, 2007. Paleoenvironmental significance of Early Cretaceous foraminifera from Northern Sinai, Egypt. *Cretaceous Research* 28, p. 765-784, figs. 1-10.

Aitken, W. G., 1961. Geology and Palaeontology of the Jurassic and Cretaceous of Southern Tanganyika. *Bulletin No.* 31, *Geological Survey Tanganyika*, 144 p.

Anderson, T. F. and Arthur, M. A., 1983. Stable isotopes of oxygen and carbon and their application to sedimentologic and paleoenvironmental problems. *In*: Arthur, M. A., Anderson, F. T., Kaplan, I. R., Veizer, J., Land, L. S. (Eds.), Stable Isotopes in sedimentary Geology. SEPM Short Course 10, Tulsa, p. 1-151.

Ando, A., and Huber, B. T., 2007. Taxonomic Revision of the Late Cenomanian planktic foraminifera *Rotalipora greenhornensis* (Morrow, 1934). *Journal of Foraminifera Research* 37, p. 160-174, Washington.

Arthur, M. A., and Premoli Silva, I. 1982. Development of widespread organic carbon-rich strata in the Mediterranean Tethys. *In*: Schlanger, S. O., Cita, M. B. (Eds.). *Nature and Origin of Cretaceous Carbon-Rich Facies.* Academic Press, London, p. 7-54.

Arthur, M. A., Dean, W. E. & Schlanger, S. O., 1985. Variations in the global carbon cycle during the Cretaceous related to climate, volcanism, and changes in atmospheric CO_2: *In* Sundquist, E. T. S. & Broecker, W. S. (Eds.), The Carbon Cycle and Atmospheric CO_2: Natural variations Archean to Present. *Geophysical Monograph*, p. 504-529.

Arthur, M. A., Schlanger, S. O., and Jenkyns, H. C. 1987. The Cenomanian-Turonian Oceanic Anoxic Event II, paleoceanographic controls on organic matter production and preservation: *In* Brooks, J., and Fleet, A. (Eds.), Marine petroleum source rocks. *Geological Society London Special Publication* 24, p. 399-418.

Arthur, M. A., Dean, W. E., and Pratt, L. M., 1988. Geochemical and climatic effects of increased marine organic carbon burial at the Cenomanian /Turonian boundary. *Nature* 335, p. 714-717.

Arthur, M. A.; Brumsack, H. J., Jenkyns, H. C. & Schlanger, S. O., 1990. Stratigraphy, geochemistry, and palaeoceanography of organic carbon-rich Cretaceous sequences: *In* Ginsburg, R. N. & Beaudoin, B. (Eds.), *Cretaceous Resources, Events and Rhythms*, 75-119.

Avnimelech, M., 1952. Revision of the tubular *Monothalamia*, *Contributions of Cushman Foundation for foraminiferal Research* 3, p. 60-68.

Babazadeh, S. A., Robaszynski, F. & Courme, M. D., 2006. New Biostratigraphic data from Cretaceous planktic foraminifera in Sahlabad Province, Eastern Iran. *Geobios* 302, 10 p.

Balduzzi, A., 1956. Faunas from Maneromango area, Tanganyika, East Africa: Maneromango Geological Survey, p. 3-4 (AGIP Tanzania Ltd, unpublished report).

Balduzzi, A., 1957. Lindi-1 well, Biostratigraphic report, p. 6-7, AGIP Tanzania Limited Branch, (Unpublished report).

Balduzzi, A., 1974. Songo Songo-1 (Tanzania) Stratigraphic report, 9 p., AGIP Tanzania Limited (Unpublished report).

Balduzzi, A., 1979. Kizimbani-1 (Tanzania) Stratigraphic report. 7 p., AGIP Tanzania Limited Branch (Unpublished report).

Balduzzi, A. Msaky, E. Trincianti, E., Manum, S. B., 1992. Mesozoic Karoo and post Karoo formations in the Kilwa area, south-eastern Tanzania a stratigraphic study based on palynology, micropalaeontology, and well log data from Kizimbani well. *Journal of African Earth Sciences* 15, p. 405-427.

Banner, F. T., Desai, D., 1988. A review and revision of Jurassic-Early Cretaceous Globigerinina, with especial reference to the Aptian assemblages of Speeton (North Yorkshire, England). *Journal of Micropalaeontology* 7, p. 143-185.

Banner, F. T., Copestake, P., White, M. R., 1993. Barremian-Aptian Praehedbergellidae of the North Sea area: a reconnaissance. *Bulletin of Natural History Museum London* (*Geology*) 49, 1-30.

Barnard, P. C. & Futyan, A. R. I., 1984. A review of the stratigraphy and petroleum geochemistry of the coastal basin of Tanzania. 25 p., 13 tables, 14 figures, 1-Enclosure (SHELL Tanzania Limited, unpublished report).

Barron, E. J., Fawcett, P. J., Peterson, W. H., Pollard, D., and Thompson, S. L., 1995. "A simulation" of Mid-Cretaceous climate. *Paleoceanography* 10, p. 953-962.

Bartenstein, H., 1948. Entwicklung der Gattung *Lenticulina* (*Lenticulina*) Lamark 1804 mit ihren Unter-Gattungen. *Senckenbergiana* 29, p. 41-65.

Bartenstein, H. and Brand, E. 1951. Mikropalaontolgische Untersuchungen zur Stratigraphie des nordwest-deutschen Valendis. *Abhandlungen Senckenbergiana Naturforschenden Gesellschaft* 485, p. 239-336.

Bartenstein, H., Bettenstaedt, F., and Bolli, H. M., 1957. Die Foraminiferen der Unterkreide von Trinidad, B.W.I. Ersta Teil: Cuche- und Toco-Formation. *Eclogae Geologicae Helvetiae* 50, p. 5-67.

Bartenstein, H., and Bettenstaedt, F., 1962. Marine Unterkreide (Boreal und Tethys): *In* Simon, W., and Bartenstein, H. (Eds.). *Leitfossilien der Mikropaläontologie* (2 volumes), p. 225-297, Berlin: Gebrüder Borntraeger.

Bartenstein, H., 1965. Taxionomische Revision and Nomenklator zu Franz E. Hecht 'Standard-Gliederung der Nordwest-deutschen Unterkreide nach Foraminiferen' 1938. Teil 4, Alb, mit Beschreibungen von Arten aus verschiedenen Unterkreide-Niveaus. *Senckenbergiana Lethaea* 46, p. 327-366.

Bartenstein, H., 1974. *Lenticulina* (*Lenticulina*) *nodosa* Reuss, 1863 and its subspecies worldwide index foraminifera in the Lower Cretaceous. *Eclogae Geologicae Helvetiae* 67, p. 539-562, 2 pls.

Bate, R. H. and Bayliss, D. D., 1969. An outline account of the Cretaceous and Tertiary Foraminifera and of the Cretaceous ostracods of Tanzania. *Proceedings of the 3rd African Micropalaeontology Colloquium, Cairo,* p. 113-164.

Bate, R. H. and Bayliss, D. D., 1973. The Cretaceous of the Wami River area, Tanzania, *Newsletter of Stratigraphy* 2 (4), p. 155-162, 1 fig., 1 tab., Leiden.

Bate, R. H., Weston, J. F., Cooper, M. K. E., 1984. Biostratigraphy of 7 samples from Makarawe water well Northern Tanzania. 6 p., 1-Appendix. (International Stratigraphic Services (SSI, unpublished report).

Bé, A. W. H., 1977. Ecological, Zoographic and Taxonomic Review of Recent Planktonic Foraminifera. *In*: Ramsey, A. T. S. (Ed.), *Oceanic Micropalaeontology* 1, Academic Press, London, p. 1-100.

Bellier, J. P., Moullade, M. and Huber, B. T., 2000. Mid-Cretaceous planktic foraminifers from Blake Nose: revised biostratigraphic framework: *In* Norris, R. D., Kroon, D., and Klaus, A. (Eds.), *Proceedings of the Ocean Drilling Program, Scientific Results,* 171B: Ocean Drilling Program, College Station, Texas. ,http:// www-odp.tamu.edu/publications/171B-SR/chap-3/chap.

Bellier, J. P., and Moullade, M., 2002. Lower Cretaceous planktonic foraminiferal biostratigraphy of the western North Atlantic (ODP Leg 171B), and taxonomic clarification of key index species. *Reveu de Micropaleontologie* 45 (1), p. 9-26.

Ben Haj, A. N., 1987. Étude biostratigraphique du Crétacé (Aptien á Cénomanien) de la Région du Teboursouk (Tunisie septentrionale) sur la base des foraminifères planctoniques. *Notes du Service Géologique Tunisie* 54, p. 75-105.

Bermudez, P. J., 1952. Estudio sistematico de los foraminiferos rotaliformes. *Boletin de Geologia, Venezuela* 2 (4), p. 1-230.

Berner, R. A., In Press. GEOCARBSULF: A combined model for Phanerozoic atmospheric O_2 and CO_2. *Geochimica et Cosmochimica Acta.*

Berthelin, G., 1880. Mémoire sur les foraminiféres fossils de l étage Albien de Moncley (Doubs), *Mémoires de la Société des Géologique de France,* Ser. 3, 1 (5), p. 1-84.

Bertraim, H. and Kemper, E., 1982. Foraminiferen des späten Apt und frühen Alb Nordwestdeutschlands. *Geologisches Jahrbuch, Reihe A* 65, p. 481-497.

Bettenstaedt, F., 1952. Stratigrapisch wichtige Foraminiferen-Arten aus dem Barrêm vorwiegend Nordwest- Deutschlands. *Senckenbergian* 33, p. 263-295.

Bignot, G., 1985. *Elements of Micropalaeontology*. Graham and Trotman, London, 217 p.

Birkelund, T. Hancock, J. M., Hart, M. B., Rawson, P. F., Remane, J., Robaszynski, F. Schimid, F. and Surlyk, F., 1984. Cretaceous stage boundaries-Proposals. *Bulletin of the Geological Society of Denmark* 33, p. 3-20.

Blainville, H. M. D., 1825. Mankel de macologie et de conchyliologie (1827). Paris; F. 9, Levrault.

Blow, W. H. and Banner, F. T., 1962. The mid-Tertiary (Upper Eocene to Aquitanian) Globigerinacea, *in*: F. E. Eames et al., Fundamentals of mid Tertiary Stratigraphical Correlation, p. 61-151, Cambridge University Press, Cambridge.

Blow, W. H., 1979. Danian to Oligocene planktonic foraminiferal biostratigraphy, *in*: The Cainozoic Globigerinida. A study of the morphology, taxonomy, evolutionary relationships and the stratigraphical distribution of some Globigerinida (Mainly Globigerinacea). Leiden, E. J. Brill, p. ix & p. 753-1413.

Bolli, H. M., 1957. The genera *Praeglobotruncana*, *Rotalipora*, *Globotruncana* and *Abathomphilus* in the Upper Cretaceous of Trinidad. B. W. I. in Loeblich, A. R. Jr. and Tappan, H., studies in Foraminifera. *United States National Museum Bulletin* 215, p. 51-60, pls. 10-12.

Bolli, H. M., 1959. Planktonic foraminifera from the Cretaceous of Trinidad, B. W. W. I. *Bulletin of American Paleontology* 39, p. 257-277.

Bolli, H. M., 1966. Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera. *Boletin Informativo Associacion Venezolana de Geologia, Mineria y Petroleo* 9, p. 3-32.

Bolli, H. M., Saunders, J. B. and Perch-Nielson, K. (Eds.), 1985. *Plankton Stratigraphy.* Cambridge University Press, Cambridge, 1032 p.

Bolli, H. M, Beckmann, J. P and Saunders, J. B., 1994. Benthic foraminiferal biostratigraphy of the South Caribbean region, figs. 5-47, p. 11-227.

Bordovskiy, O. K., 1965. Accumulation and transformation of organic substances in marine sediments. *Marine Geology* 3, p. 3-114.

Borsetti, A. M., 1962. Foraminiferi planctonici di una serie Cretacea dei Dintorni di Piobbico (Prov. Di Pesaro). *Geophysical, Geological* Series 2, 29, p. 19-75.

BouDagher-Fadel, M. K. Banner, F. T., Gorbachik, T. N., Simmons, M. D., and Whittaker J. E., 1996. Evolution in the early Cretaceous planktonic foraminiferal genus *Blefuscuiana. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 202, p. 243-258.

BouDagher-Fadel, M. K., 1996. Re-evaluation of the phylogeny of Early Cretaceous Planktonic foraminifera (Praehedbergellidae). *Cretaceous Research* 17, p. 767-771.

BouDagher-Fadel, M. K. Banner, F. T., Whittaker J. E., and Simmons, M. D., 1997. The Early Evolutionary History of Planktonic Foraminifera. Chapman and Hall, Cambridge, UK. pl. 4.1 - 12.6, figs. 4.1-12.1, p. 53-227.

Brady, H. B., 1878. On the Reticularian and Radiolarian Rhizopoda (Foraminifera and Polycystina) of the North Polar Expedition of 1875-76. *Annals and Magazine of Natural History,* Ser. 5 (1), p. 425-440.

Brady, H. B., 1879. Notes on some of the Reticularian Rhizopoda of the “Challenger” Expedition, Part 1, on new or little known arenaceous types. *Quarterly Journal of Microscopical Science,* New Series 19, p. 20-63.

Brady, H. B., 1884. Report on the foraminifera dredged by H.M.S. Challenger, during the years 1873-1876, in *Report on the Scientific Results of the Voyage of the H. M. S. Challenger, during the years* 1873-1876. *Zoology* 9, 814 p.

Bralower, T. J., 1988. Calcareous nannofossil biostratigraphy and assemblages of the Cenomanian-Turonian boundary interval: Implications for the origin and timing of oceanic anoxia. *Paleoceanography* 3, p. 275-316.

Bralower, T. J., Silter, W. V., Arthur, M., Leckie, R. M., Allard, D., and Schlanger, S. O., 1993. Dysoxic/anoxic episodes in the Aptian - Albian (Early Cretaceous), in Pringle, M., Sager, W. W., Sliter, W., and Stein, S. (Eds.), Mesozoic of the Pacific. American *Geophysical Union, Geophysical Monograph* 77, p. 5-37.

Bralower, T. J. rthur, M. A., Leckie, R. M. Sliter, W. V., Allard, D. J., and Schlanger, S. O. 1994. Timing and paleoceanography of oceanic dysoxia/anoxia in the Late Barremian to Early Aptian (Early Cretaceous). *Palaios* 9, p. 335-369.

Bralower, T. J., Fullagar, P. D. Paul, C. K., Dwyer, G. S. and Leckie, R. M., 1997. Mid Cretaceous strontium-isotope stratigraphy of deep-sea sections: *Geological Society of American Bulletin* 109, p. 1421-1442.

Bralower, T. J., Coβaβe, E., Clement, B., Sliter, W. V., Osburn, C. I., and Longoria, J., 1999. The record of Global change in mid-Cretaceous (Barremian - Albian) sections from the Sierra Madre Northeastern Mexico. *Journal of Foraminiferal Research* 29 (4), p. 418-437.

Bréhéret, J. G., Caron, M., and Delamette, M., 1986. Niveaux riches en matiere organique dans l'Albien Vocontien; quelques caracteres du paleoenvironnement essai d' interpretation genetique, in les couches Riches en Matiere Organique et leurs Conditions de Depot, edited by J. G. Breheret, *Documents B. R. G. M.*, 110, p. 141-191.

Bréhéret, J. G. & Delamette, M. (1987). Séquences de dépôt et couches riches en matière organique (CRMO) dans les marnes bleues aptiennes et albiennes du bassin Vocontien, *In* Ferry, S. & Rubino, J.L. (eds.) Eustatisme et séquences de dépôt dans le Crétacé du Sud-Est de la France.- *Géotrope*, 1, 83-93.

Bréhéret, J.G. (1988). Episodes de sedimentation riche en matiere organique dans les marnes bleues d ´age aptien et albien de la partie pelagique du bassin vocontien.- *Bulletin Société Géologique de France* 8, p. 349-356.

Bréhéret, J. G. & Delamette, M. (1989). Faunal fluctuation relates to oceanographical changes in the Vocontian Basin (S-France) during Aptian - Albian time. *Geobios, Memoire speciale* 11, p. 267-277.

Bréherét, J. G., 1994. The mid-Cretaceous organic-rich sediments from the Vocontian zone of the French Southeast Basin, in *Hydrocarbon and Petroleum Geology of France*, edited by A. Mascle, p. 295-320, Springer-Verlag, New York.

Bréheret, J. G., 1997. L'Aptien et l'Albien de la Fosse Vocontienne (des bordures au basin). Evolution de la sedimentation et enseignments sur les evenements anoxiques: *Societies geologique de Nord, Publication* 25, 625 p.

Breistroffer, M., 1947. Sur les Zones d´Ammonites dans l´Albien de France et d´Angleterre.- *Travaux du Laboratoire de Géologie de l´Université de Grenoble* 26, p. 17-104.

Bronnimann, P., 1952. Globigerinidae from the Cretaceous (Cenomanian - Maastrichtian) of Trinidad, *B.W.I., Bulletin of American Paleontology* 34, p. 5-71.

Bronnimann, P., and Brown, N. K., 1956. Taxonomy of the Globotruncanidae. *Eclogae Geologicae Helvetiae* 48, p. 503-561.

Bronnimann, P. and Brown, N. K., Jr., 1958. *Hedbergella*, a new name for a Cretaceous planktonic foraminiferal genus. *Journal of Washington Academy of Sciences* 48, p. 15-17.

Brotzen, F., 1940. Flintrännans och trindelrännans Geologi, *Årsbok Sveriges Geologiska Undersökning* 349 (5), p. 1-33.

Brotzen, F., 1942. Die Foraminiferengattung *Gavelinella* nov. gen. und die Systematik der Rotaliformes. *Årsbok Sveriges Geologiska Undersokning* 36 (8), p. 1-60.

Caron, M., 1976. Rèvision des types de Foraminifères planctoniques dècrits dans la règion du Montsalvensis (Prèalpes fribourgeoises). *Eclogae Geologicae Helvetiae* 69, p. 327-33.

Caron, M., 1978. Cretaceous planktic foraminifers from DSDP Leg 40, p. 651-678. Washington DC: United States Government Printing Office.

Caron, M. Homewood, P., 1983. Evolution of early planktic foraminifers. *Marine Micropalaeontology* 7, p. 453-462.

Caron, M., 1985. Cretaceous planktonic foraminifera from DSDP Leg 40, Southeastern Atlantic Ocean. *In*; Bolli, H. M., Saunders, J. B. and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy*. Cambridge University Press, Cambridge, figs. 25-36, p. 17-86.

Caron, M and Spezzaferri, S., 2006. Scanning Electron Microscope documentation of the lost holotypes of Mornod, 1949: *Thalmanninella reicheli* and *Rotalipora montsalvensis*. *Journal of Foraminifera Research* 36 (4), p. 374-378.

Caron, M., and Premoli Silva, I., 2007. New description of the rotaliporid species *brotzeni* and *globotruncanoides* Sigal, 1948 based on re-examination of type material. *Rivista Italiana di paleontologia e Stratigrafia* 113 (3), 1 pl., p. 525-530.

Carpenter, W. B.., Parker, W. K. and Jones, T. R., 1862. *Introduction to the study of the foraminifera.* Ray Society, London, 139 p.

Carpenter, W. B., 1869. On the Rhizopoda fauna of the deep sea. *Proceedings of the Royal Society of London* 18, p. 59-62.

Carsey, D. D., 1926. Foraminifera of the Cretaceous of central Texas. *Texas University Bulletin* 2612, p. 1-56.

Cavalier-Smith, T., 2003. Protist Phylogeny and the high Classification of Protozoa. *Europe Journal of Protistol* 39, p. 338-348.

Chevalier, J., 1961. Quelques nouvelles éspecès de Foraminifères dans le Crétacé inférieur méditerranéen. *Revue de Micropaléontologie* 4, p. 30-36.

Coccioni, R., Erba, E. and Premoli Silva, I., 1992. Barremian - Aptian calcareous plankton stratigraphy from the Gorgo Cerbara Section (Marche, Central Italy) and implications for plankton evolution. *Cretaceous Research* 13, p. 517-539.

Coccioni, R. and Premoli Silva, I., 1994. Planktonic foraminifera from the Lower Cretaceous of Rio Argos sections (southern Spain) and biostratigraphic implications. *Cretaceous Research* 15, p. 645-687.

Coccioni, R. Luciani, V., and Marsili, A., 2006. Cretaceous anoxic events and radially elongated chambered planktonic foraminifera: Palaeocological and palaeoceanographic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 235, p. 66-92.

Coxall, H. K., Wilson, P. A., Pearson, P. N., Shackleton, N. J., and Hall, A. H., 2000. Palaeoecology of some extreme 'clavate' planktonic foraminifera from the Cretaceous to Recent. *Newsletter of Micropalaeontology* 66, 14 p.

Craig, H., 1957. Isotopic standards for carbon and oxygen and correction factors for mass spectrometric analysis of carbon-dioxide. *Geochimica, Cosmochimica Acta* 12, p. 53-92.

Cushman, J. A., 1910. A monograph of the foraminifera of the North Pacific Ocean. Pt. 1. Astrorhizidae and Lituolidae, *Bulletin of the United States National Museum* 71 (1), p. 1-134.

Cushman, J. A., 1911. A monograph of the foraminifera of the North Pacific Ocean. Pt. 2. Textulariidae. *Bulletin of the United States National Museum* 71 (2), p. 1-108.

Cushman, J. A., 1927. Some notes on the early foraminiferal genera erected before 1808. *Contributions of Cushman Laboratory for Foraminiferal Research* 3, p. 22-126.

Cushman, J. A. and Alexander, C. I., 1930. Some *Vaginulina* and other foraminifera from the Lower Cretaceous of Texas. *Contributions of Cushman Laboratory for Foraminiferal Research* 6 (1), p. 1-10.

Cushman, J. A., 1933. Some new foraminiferal general. *Contributions of the Cushman Laboratory for Foraminiferal Research* 9, p. 32-38.

Cushman, J. A., 1936. New genera and species of the families Verneuilinidae and Valvulinidae and of the subfamily Virgulininae. *Special Publication of Cushman Laboratory for Foraminiferal Research* 6, p. 1-71.

Cushman, J. A., 1937a. A monogram of the foraminiferal family Verneuilinidae. *Cushman Laboratory for Foraminifera Research, Special Publication* 8, 210 p.

Cushman, J. A. & Ten Dam, A., 1948. *Globigerinelloides*, a new genus of the Globigerinidae. *Contributions of Cushman Laboratory for foraminiferal Research* 24, p. 42-43.

d'Orbigny, A., 1826. Tableau méthodique de la classe des Céphalopodes, *Annales des Sciences Naturelles* 7, p. 245-314.

d'Orbigny, A. D., 1839. Foraminiferes in P. Barker-Webb and S. Berthelot, Histoire Naturelle des Iles Canaries 2 (2), *Zoologie, Paris Betruno*, p. 119-146.

d'Orbigny, A., 1840. Mémoire sur les foraminiféres de la Craie Blanche du Bassin de Paris. *Mémoire des Societés Geologique, France* 4, p. 1-51.

Dailey, D. H., 1970. Some new Cretaceous foraminifera from the Budden Canyon Formation, northwestern Sacramento valley, California. *University California Publication of Geological Sciences* 106, p. 1-111.

De Montfort, D., 1808. Conchyliologie Systématique et Classification Méthodique des Coquilles, 1, Paris, France.

Deines, P., 1980. The isotopic composition of reduced organic carbon. *Handbook of Environmental Isotope Geochemistry* 1, p. 329-406, Amsterdam-Oxford-New York.

Delage, Y., and Hérouard, E., 1896. Traité de Zoologie Concréte 1, La Cellule et les Protozoaire. Paris, Schleicher Fréres.

Dickens, G. R., Neil, J. R., Rea, D. K. and Owen, R. M., 1995. Dissociation of oceanic methane hydrate as a cause of the carbon isotope excursion at the end of the Palaeocene: *Palaeoceanography* 10, p. 965-971.

Dietrich, W. O., 1935. Zur Stratigraphie der Kolombianischen Ostkordillere, *Zentralblatt für Mineralogiie, Geologie und Pälaontologie* 1935B, p. 74-82.

Dilley, F. C., 1955. Faunas from the Maneromango area, Tanganyika, East Africa. *Maneromango Geological Survey Report no.* 3, 4 p.

Dilley, F. C., and Seymour, J. A., 1956. Faunas from the Msanga area, Tanganyika, East Africa. *Palaeontological Note No*. 26, 2 p.

Dilley, F. C., 1956. Stratigraphical revision of the Pugu-Maneromango area, Tanganyika, East Africa. *Paleontological Note* 31, 6 p.

Douglas, R. G. and Savin, S. M., 1975. Oxygen and carbon isotopic analyses of Tertiary and Cretaceous microfossils from North Pacific Ocean. *Initial reports of the Deep Sea Drilling Project* 32, p. 509-520.

Eames, T. D., 1964. Faunas of the Msanga area, Tanganyika. Kenya *Paleontological Note* 9, p. 1-13, 3 Appendices.

Eicher, D. L. and Worstell, P., 1970. Cenomanian and Turonian foraminifera from the Great plains, United States. *Micropalaeontology* 16 (3), p. 269-324.

Eichwald, C. E. von, 1830. *Zoologia specialis* 2, Vilnae: D. E. Eichwaldus, 1-323 p.

Eimer, G. H. and Fickert, T., 1899. Die Artbildung und Verwandtschaft bei den Foraminiferen. *Entwurf einer naturlichen Eintheilung derselben, Zeitschrift fur Wissenschaftliche Zoologi*e 65, p. 599-708.

Erba, E. 1992. Calcareous Nannofossil distribution in pelagic rhythmic sediments (Aptian-Albian Piobbico core, Central Italy). *Rivista Italia Palaeontologia Stratigraphia* 97, p. 455-484.

Erba, E., 1994. Nannofossils and superplumes: The Early Aptian "nannoconid crisis". Palaeoceanography 9, p. 483-501.

Erba, E., Chanell, J. E. T., Michele, C., Jones, C., Larson, R., Opdyke, B., Premoli Silva, I., Riva, A., Salvini, G., and Torricelli, S., 1999. Integrated Stratigraphy of the Cismon (Southern Alps, Italy): A "Reference Section" for the Barremian - Aptian Interval at low latitudes, *Journal of Foraminiferal Research* 29 (4), p. 371-391.

Erbacher, J., Thurow, J. and Leckie, R. M., 1996. Evolution patterns of radiolarian and organic matter variations: a new approach to identify sea level changes in mid-Cretaceous pelagic environments. *Geology* 24, p. 499-502.

Erbacher, J., & Thurow, J., 1997. Influence of oceanic anoxic events on the evolution of mid-Cretaceous radiolarian in the North Atlantic and Western Tethys. *Marine Micropalaeontology* 30, p. 139-158.

Erbacher, J., Gerth, W., Schmiedl, G. and Hemleben, C., 1998. Benthic foraminiferal assemblages of the late Aptian - early Albian black shale intervals in the Vocontian Basin, SE France. *Cretaceous Research* 19, p. 805-826.

Erbacher, J., Hemleben, C., Huber, B. T. and Markey, M., 1999. Correlating environmental changes during early Albian oceanic anoxic event 1b using benthic foraminiferal paleoecology. *Marine micropaleontology*, p. 7-28.

Erbacher, J., Huber, B. T., Norris, R. D., and Markey, M., 2001. Increased thermohaline stratification as a possible cause for an oceanic anoxic event in the Cretaceous period. *Nature* 409, p. 325-327.

Exploration Consultant Limited (ECL) 1979. Final well Report Songo Songo-5, 43 p., (Unpublished ECL report).

Fairway/TPDC, 1992. Tanzania Exploration Potential. Tanzania Petroleum Development Corporation, 23 figures, 412 p., (TPDC/Fairway unpublished report).

Fassel, M. L. and Bralower, T. J., 1999. A warm equable mid-Cretaceous: Stable isotopic evidence, in Berrera, E., and Johnson, C., (Eds.). The Evolution of Cretaceous Ocean/Climate Systems, *Geological Society of America Special Publication*, in press.

Fogel, M. L., Wooller, M. J. Cheeseman, J., Smallwood, B. J, Roberts Q., Romeo, I., and Meyers, M. J., 2008. Unusually negative nitrogen isotopic composition $\delta^{15}N$ of mangroves and lichens in an oligotrophic, microbially-influenced ecosystem. *Biogeosciences* 5, p. 1693-1704.

Ford, J. H., 1995. Chronostratigraphy of wells in Tanzania. Appendix C. 7 p. (Unpublished TPDC report).

Frakes, L. A., and Fransis, J. E., 1988. A guide to phanerozoic cold polar climates from high-latitude ice-rafting in the Cretaceous. *Nature* 333, p. 547-549.

Frakes, L. A., Francis, J. E. and Syktus, J. I., 1992. Climate modes of the Phanerozoic. Cambridge University Press, Cambridge, United Kingdom, 274 p.

Friedrich, O., Reichelt, K., Herrele, J. O., Lehmann, J., Pross, J. and Hemleben, C., 2003. Formation of the Late Aptian Niveau Fallot black shales in the Vocontian basin (SE France): Evidence from foraminifera 49, 65-85.

Friedrich, O., Nishi, H. Pross, J, Schmiedl, G. and Hemleben C., 2005. Millenium to centennial-scale interruptions of the Oceanic Anoxic Event 1b (early Albian, mid-Cretaceous) inferred from benthic foraminiferal repopulation events. *Palaios* 20, p. 64-77.

Fuchs, W., 1967. Über Ursprung und phylogenie der Trias- Ǵlobigerinen' und die Beurteilung dieses Formenkreises für das echte plankton. *Jahrbuch der Geologischen Bondesanstalt Wien* 1-2, p. 135-161.

Fuchs, W., 1975. Zur Stammesgeschichte der plankton foraminiferen und verwandter Formen im Mesozoikum. *Jahrbuch der Geologischen Bondesanstalt Wien* 118, p. 193-246.

Furguson, K. M., Gregory, R. T., and Constatine, A., 1999. Lower Cretaceous (Aptian-Albian) secular changes in the oxygen and carbon isotope record from high paleolatitude, fluvial sediments, southeast Australia. Comparisons to marine record in Evolution of the Cretaceous Ocean-Climate System, edited by E. Berera and C. C. Johnson. *Special Paper of the Geological Society of America* 332, p. 59-72.

Galeotti, S., 1998. Planktic and benthic foraminiferal distribution patterns as a response to changes in surface fertility and circulation: a case study from the Late Albian 'Amadeus Segment' (Central Italy). *Journal of Micropalaeontology* 17, 87-96.

Gandolfi, R., 1942. Recherché micropaleontologiche e stratigrafiche sulla Scaglia e sul flysch Cretacici dei Dintorni di Balerna (Canton Ticino). *Rivista Italiana di Paleontologia* 48, *Memoria* 4, p. 1-60.

Gandolfii, R., 1955. The genus *Globotruncana* in Northeastern Colombia. *Bulletin American Paleontology* 36, p. 7-118.

Gasinski, M. A., 1997. Tethyan-Boreal connection: influence on the evolution of mid-Cretaceous planktonic foraminiferida. *Cretaceous Research* 18, 505-514.

Georgescu, M. D., and Huber, B. T., 2009. Early Evolution of the Cretaceous Planktic Foraminifera (Late Albian - Cenomanian). *Journal of Foraminiferal Research* 39 (4), p. 335-360.

Glaessner, M. F., 1937. Studien über Foraminiferen aus der Kreide und dem Tertiär des Kaukasus, I. Die Foraminiferen der altesten Tertiärschichten des Nordwest- Kaukasus; problemy Paleontologii, *Paleontologischeskay Laboratoriya Moskovskogo Gosudarstvennogo Universiteta* 2-3, p. 349-410.

Glaessner, M. F., 1945. Major trends in the Evolution of the Foraminifera, p. 9-24.

González-Donoso J. M., Linares D., *in* Robaszynski, F., Caron, M., Amedro, F., Dupius, C., Hardenbol, J., González-Donoso, J. M., Linares, D., and Gartner, S., 1993. Le Cénomanién de la région de Kalaat Senan, Tunisie centrale: Litho-biostratigraphie et interprétation sé quenaelle, *Revue de Paléobiologie* 12, p. 351-505, Genéve.

Gonzalez- Donoso, J. M., D. Linares, Caron, M. and Robazynski, F., 2007. The rotaliporids, a polyphyletic group of Albian-Cenomanian planktonic foraminifera. Emendation of Genera. *Journal of foraminiferal Research, Washington* 37 (20), p. 175-186.

Gorbachik, T. N., and Moullade M., 1973. Caractéres microstructuraux de la paroi du test des foraminiféres planctoniques du Crétacé inférieur et leur signification sure le plan taxonomique: *Compte Rendus de'lAcadémie des Sciences*, *Paris* (Série D) 277, p. 2661-2664.

Gradstein, F. M., Agterberg, F. P., Ogg, J. G., Hardenbol, J., Van Veen, P., Thierry, J., and Hang, Z., 1995. A Triassic, Jurassic, and Cretaceous time scale. *SEPM, Special Publication* 54, p. 95-126.

Gradstein F. M., and Ogg, J. G., 2004. Geologic Time Scale 2004. *Lethaia*, 37, p. 175-181, Oslo, ISSN 0021-1164.

Gräfe, K. U., 1999. Foraminifera evidence for a Cenomanian sequence Stratigraphy and paleoceanography of the Boulonnais (Paris basin, northern France). *Palaeogeography, Palaeoecolology* 153, p. 41-70.

Graham, D. W., Bender, M. L., Williams, D. F., and Keigwin, L. D. Jr., 1982. Strontium-calcium ratios in Cenozoic planktic foraminifera. *Geochimica, Cosmochimica Acta* 46, p. 1281-1292.

Gröcke, D. R., Hesselbo, S. P., and Jenkyns, H. C., 1999. Carbon-isotope composition of lower Cretaceous fossil wood: Ocean-atmosphere chemistry and relation to Seal-level change, *Geology* 27, p. 155-158.

Gronstal, A. L. 2008. "Gasping for breath in the Jurassic: ra.http//www.space.com.Imagnova. Archived, p. 4-24.

Haekel, E., 1894. Systematische Phylogenie, Etwurf eines Naturlichen Systems der Organismen auf Grund chrer, Stammesgeschrichte (Stammesgeschichte) Theil l. *Systematische phylogenie Berlin Georgder protisten und pflanzen,* Berlin, Georg Reimer.

Haq, B. U., J. Hardenbol and Vail, P. R., 1987. Chronology of fluctuating sea levels since the Triassic. *Science* 235, p. 1156-1167.

Haq, B. U., Hardenbol, J. and Vail, P. R., 1988. Mesozoic and Cainozoic Chronostratigraphy and cycles of sea-level change, *in* Wilgus, C. K., Hastings, B. S., Kendall, C. S., Posamentier, H. W., Ross, C. A., and Van Wagoner, J. C., eds., Sea-level changes: An integrated approach: *Society of Economic Palaeontologist and Mineralogist Special Publication* 42, p. 71-108.

Hardenbol, J., Thierry, J., Farley, M. B. Jacquin, T., de Graciansky, P. C. and Vail, P. R., 1998. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. In: de Graciansky, P. C., Hardenbol, J., Jacquin, T., Vail, P. R. (Eds.), Mesozoic and Cainozoic Sequence Stratigraphy of European Basins, *Society of Economy Palaeontologist and Mineralogist Special Publication* 60, p. 763-781.

Hart, M. B., 1976. The mid-Cretaceous succession of Orphan Knoll (northwest Atlantic): micropalaeontology and Palaeoceanographic implications. *Canadian Journal of Earth Science* 13, p. 1411-1421.

Hart, M. B., and Bailey, D. D., 1979. The distribution of planktonic Foraminiferida in the Mid-Cretaceous of NW Europe. *Aspekte der Kreide Europas*, IUGS Series A6, p. 527-542.

Hart, M. B., 1980. A water depth model for the evolution of the planktonic Foraminiferida, *Nature* 286, p. 252-254.

Hart, M. B., 1999. The evolution and Biodiversity of Cretaceous planktonic foraminiferida. *Geobios* 32, p. 247-255.

Hart, M. B., Hylton, M. D., Oxford, M. J., Price, G. D., Hudson, W., Smart, C. W., 2003. The search of the origin of the planktic Foraminifera. *Journal of the Geological Society, London* 160, p. 341-343.

Haughton, S. H., 1938. Lexicon de Stratigraphie. Vol. 1, Africa, London Thomas Macby, p. 203 and 229.

Hansen, H. J., 1968. X-ray diffraction investigations of a radiate and granulate foraminifera. *Bulletin of Geological Society of Denmark* 18, p. 345-348.

Hastings, D. W., Russel, A. D., Emerson, S. R., 1998. Foraminiferal magnesium in *Globigerinoides sacculifer* as a paleotemperatures proxy. *Paleoceanography* 13, p. 161-169.

Hay, W. W., DeConto, R., Wold, C. N., Wilson, K. M., Voigt, S., Schulz, M., Wold-Rossby, A., Dullo, W. C., Ronov, A. B., Balukhovsky, A. N. and Soeding, E., 1999. Alternative global Cretaceous palaeogeography, *In*: Berrera, E. and Johnson, C. (Eds.): The Evolution of

Cretaceous Ocean/Climate Systems. *Geological Society of America Special Paper* 332, p. 1-47.

Haynes, J. R., 1981. *Foraminifera.* MacMillan publication limited, London, 433 p.

Haynes, R. C., Cooper, M. K. E. Bate, R. H., Taylor, W. & Trice, R. C., 1987. Stratigraphy of the Kiwangwa-1 well, Tanzania, 37 p., (Unpublished report).

Hecht, F. E., 1938. Standard Gliederung der Norwestdeutschen Unterkreide nach Foraminiferen. *Abhandlungen von der Seckenbergischen Naturforschenden Gesellschaft* 44, p. 33-42.

Hemleben, C., Spindler, M., Anderson, O. R., 1989. Modern planktonic Foraminifera. *Springer, New York*, 363 p.

Herb, R., 1974. Cretaceous planktonic foraminifera from the eastern Indian Ocean. *Initial Report Deep Sea Drilling Project* 26, p. 745-769.

Hermans, L., 1983. Source rock analysis of cores from wells; Chalinze-1, Mandawa-7, Msanga-1, Msanganya-1, Pemba-5, Pugu-2, Ruaruke-1, Ruaruke G-1, Ruaruke G-4 and Wingayongo-1, Tanzania, Figures 1 - 11, p. 22-37 (Unpublished report).

Herrle, J. O., and Muttarlose, J., 2003. Calcareous nannofossils from the Aptian - Lower Albian of southeast France; Palaeoecological and biostratigraphical implications. *Cretaceous Research* 24, p. 1-22.

Herrle, J. O., Köβler, P., Friedrich, O., Erlenkeuser, H., and Hemleben, C., 2003. High-resolution carbon isotope records of the Aptian to Lower Albian from SE France and the Mazagan Plateau (DSDP Site 545): a stratigraphic tool for paleoceanographic and paleobiologic reconstruction. *Earth and Planetary Science Letters* 218, p. 149-161.

Herrle, J. O., Pross, J., Friedrich, O, and Hemleben, C., 2003b. Short-term environmental changes in the Cretaceous Tethyan Ocean: Micropalaentological evidence from the early Albian ocean anoxic event 1 b. *Terra Nova,* 15, p. 14-19, doi: 10. 1046/J; 1365-3121. 2003.00448X.

Herrle, J. O., Koβler, P., Friedrich, O., Erlenkeuser, H., and Hemleben, C., 2004. High resolution carbon isotope records of the Aptian to lower Albian from SE France and the Maza gan tool for paleoceanographic and paleobiologic reconstruction, *Earth Planetary Science letters* 218, p. 149-161, doi: 10. 1016/S0012 – 821X (03)00646-0.

Hesselbo, S. P., Grocke, D. R., Jenyns, H. C., Bjerrum, C. J., Farrimnond, P., Morgans Bell, H. S. and Green, O. R., 2000. Massive dissociation of gas hydrates during a Jurassic oceanic anoxic event. *Nature* 406, p. 392-395.

Hofker, J., 1956. Die Globotruncanen von Nordwest-Deutschland und Holland. *Neues Jahrbuch fur Geologie und Palaontologie, Abhandlungen* 103, p. 312-340.

Hofker, J., 1960. The taxonomic status of *Praeglobotruncana, Planomalina, Globigerinella* and *Biglobigerinella*. *Micropalaeontology* 6, p. 315-322.

Holbourn, A. E. L., and Kaminski, M. A., 1995. Lower Cretaceous benthic foraminifera from DSDP Site: 263: micropalaentological constrains for the early evolution of the Indian Ocean. *Marine Micropaleontology* 26, p. 425-460 (and references therein).

Holbourn, A. E. L., and Kaminski, M. A., 1997. Lower Cretaceous deep-water benthic foraminifera of the Indian Ocean. *Grzybowski Foundation Special Publication* 4, p. 1-172.

Holbourn, A. E. L., and Kuhnt, W., 2001. No extinctions during ocean anoxic event 1 b: The Aptian - Albian benthic foraminiferal record of ODP leg 171, in Western North Atlantic Paleogene and Cretaceous paleoceanography, edited by Kroon, D., Norris, R. D, and Klaus, A., *Geological Society Special Publication* 183, p. 73-92.

Holbourn, A., Khunt, W., and Soeding, E., 2001b. Atlantic palaeobathymery, palaeoproductivity and paleocirculation in the late Albian: the benthic foraminiferal record: *Palaeogeography, Palaeoclimatology, Palaeoecology* 170, p. 171-196.

Huber, B. T., Hodell, D. A., and Hamilton, C. P., 1995. Middle-Late Cretaceous climate of the southern high latitudes: Stable isotopic evidence for minimal equator-to-pole thermal gradients, *Geological Society American Bulletin* 107, p. 1164-1191.

Huber, B. T., Norris, R. D., and Macleod, K. G., 2002. Deep-sea paleotemperature record of extreme warmth during the Cretaceous. Geology, 30, p. 123-126.

Huber, B. T., pers. comm., 2009 - 2011 and M-R Petrizzo, pers, comm., 2009-2011.

Huber, B. T., and Leckie, R. M., 2011. Planktic Foraminiferal species turnover across Deep-Sea Aptian / Albian Boundary Section. *Journal of Foraminiferal Research* 41 (1), p. 53-95.

Huon, S., Grousset, F. E., Burdloff, D., Bardoux, G. and Mariotti, A., 2002. Sources of fine-sized organic matter in North Atlantic Hein rich Layers: $\delta^{13}C$ and $\delta^{15}N$ tracers. *Geochimica, Cosmochimica Acta* 66, p. 223-239.

International Stratigraphic Service (SSI), 1987. Stratigraphy of the Kiwangwa-1 well, Tanzania. 1 enclosure, 1 appendix, 37 p., (Unpublished report).

Ion, J., 1983. Étude micropaléontologique (Foraminiféres planctoniques) du Crétacé supérieur de Tara Bĭrsei (Carpates Orientales). *Memorii Institutul de Geologie si Geofizica Bucarest* 31, p. 5-176.

Jahren, A. H., Arens, N. C., Sarmiento, G., Guerrero, J. and Amundson, R., 2001. Terrestrial record of methane hydrates dissociation in the early Cretaceous, *Geology* 29, p. 159-162.

Jancis, H. Ford., 1995. Chronostratigraphy of wells in Tanzania. Appendix C. 7 p. (Unpublished TPDC report).

Jenkyns, H. C., 1980. Cretaceous anoxic events: from continents to oceans. *Journal of the Geological Society, London* 137, p. 171-188.

Jenkins, D. G. and Murray, J. W., 1981. Stratigraphic Atlas of Fossil Foraminifera (1st Eds.) Published by Ellis Horwood Limited, England, p. 81-148, pls. 6.1.1-6. 3. 4.

Jenkyns, H. C., 1995. Carbon-isotope stratigraphy and paleoceanographic significance of the Lower Cretaceous shallow-water carbonates of Resolution Guyot, Mid-Pacific Mountains. *Proceedings of the Ocean Drilling Program, Scientific Results* 143, p. 99-104.

Jenkyns, H. C., Wilson, P. A., 1999. Stratigraphy, Paleoceanography, and evolution of Cretaceous Pacific Guyots: relics from a greenhouse earth. *American Journal of Science* 299, p. 341-392.

Jenkyns, H. C., 2010. Geochemistry of oceanic anoxic events. *Geochemistry, Geophysics* 11, Q03004, doi: 10.1029/2009GC002788.

Jimenez Berrocoso, A., MacLeod, K. G., Huber, B. T., Lees, J. A., Wendler, I., Bown, P. R., Mweneinda, A. K., Isaza Londono, C. & Singano, J. M., 2010. Lithostratigraphy, biostratigraphy and chemostratigraphy of Upper Cretaceous sediments from southern Tanzania: Tanzania Drilling Project Sites 21-26. *Journal of African Earth Sciences* 57, p. 47 -69.

Jones, T. R., and Parker, W. K., 1860. On the Rhizopoda fauna of the Mediteranean, compared with that of the Italian and some Tertiary deposits. *Quarterly Journal of the Geological Society of London* 16, p. 292-307.

Jones, C. E. and Jenkyns, H. C. 2001. Seawater strontium isotopes, oceanic anoxic events, and seafloor hydrothermal activity in the Jurassic and Cretaceous, *American Journal of Science* 301, p. 112-149.

Kaaya, E. Z., 1981. Report on Songo Songo-6 Borehole, 14 p., (Unpublished TPDC internal report).

Kaever, M., 1958. Uber *Globorotalites* Brotzen, 1942 und *Conorotalites* nov. gen., *Geologische Jahrbuch* 75, p. 433-436.

Kajato, H. K., 1986. The geology and hydrocarbon potential of Tanzania. Oil and gas exploration in the SADC region, Arusha Tanzania, 24 p. (Unpublished TPDC paper).

Kajato, H. 1982. Gas striken spurs search for oil, Tanzania, *Oil and gas Journal* 123, p. 123-131.

Kamen-Kaye, M., 1974. Permian to Tertiary faunas and biogeography, Somalia, Kenya, Tanzania, Mozambique, South Africa (Abstract). *American Association of Petroleum*

Geologist and Society of Economic Paleontologist. Mineral Annual Meeting Abstract 7, p. 51-52.

Kamen-Kaye, M., 1978. Permian to Tertiary Faunas and Palaeogeography: Somalia, Kenya, Tanzania, Mozambique, Madagascar, South Africa. *Journal of Petroleum Geology* 1.1, p. 79 -101.

Kaminski, M. A., Gradstein, F. M. Geroch, S., 1992. Uppermost Jurassic to Lower Cretaceous Deep-water Benthic foraminiferal assemblages from site 765 on the Argo Abyssal plain. *Proceedings of the Ocean drilling program, scientific results* 123, p. 239-269.

Kapilima, S., 1984. Foraminifera from the Lower Cretaceous rocks of the Chalinze Formation the Hinterland of Dar es Salaam (Tanzania) and their biostratigraphical implication. *Geological* Mediterranean XI (1), p. 101-115, 5 figs, 2 pls.

Karega, A. I. S., 1992. Distribution of mid-Jurassic (Callovian) benthic foraminifera from Tanzania. *In:* Studies in Benthic Foraminifera BENTHO's 90, Sendai, p. 339-354, Tokai University press.

Karega, A., Msaky, E., 1993. Biostratigraphical report of Luhoi-1 well, Tanzania, 15 p., 2 figures, 1 table, 1, chart (Unpublished TPDC internal report).

Karega, A., 1995. Cretaceous foraminifers from the Mandawa Basin, southern Tanzania: preliminary results *Marine Micropalaeontology* 26, p. 419-423.

Karega, A., Singano, J., 2003. Biostratigraphic report of Mkuranga-1 well, Tanzania. 32 p., 3 figures, 2 tables (Unpublished TPDC internal report).

Kemper, E., 1971. Zur Gliederung un Abgrenzung der nörd-deutschen Aptium mit Ammoniten. *Geologisches Jahrbuch* 89, p. 359-389.

Kemper, E., 1975b. Zur Biostratigraphie und palökologie der Schichtenfolge ober - Apt/ Unter-Alb im Beckenzentrum nördlich und östlich von Hannover, *Berich Naturhistorischen Gessellschaft* 119, p. 49-85.

Kemper, E., 1975. Die cephelopoden au dem Unter-Alb (Zone der *Leymeriella tardefurcata*) von Altwarmbuchem. *Berichte der Naturhistorischen Gessellschaft Zu* Hannover 119, p. 87-111.

Kemper, E., and Zimmerle, W., 1978. Die anoxischen Sedimente der praoberaptischen Unterkreide NW-Deutschlands und ih, *Palaogeographischer Rahmen. Geologisches Jahrbuch* A, 45, p. 3-41.

Kendall, C. and Caldwell, E. A., 1998. Fundamentals of Geochemistry. *Isotope Tracers in Catchment Hydrology*. Elservier Science B. V., Amsterdam, p. 51-56.

Kennedy, W. J. & Cooper, M. A., 1975. Cretaceous ammonite distributions and the opening of the South Atlantic. *Journal of the Geological Society, London* 133, p. 283-288.

Kent, P. E., 1954. Jurassic and Cretaceous rocks of the Bagamoyo District. D'Arcy Exploration Company Report PEK/49, 8 p., 4 figs (Unpublished report).

Kent, P. E., Hunt, J. A., Johnstone, D. W., 1971. Geology and geophysics of coastal sedimentary basins of Tanzania. Natural Environment Research Council, Tanzania; Institute of Geological Sciences, *Geophysical Paper No*. 6, p. 1-101, London.

Kent, P. E. and Perry, J. T., 1973. The development of the Indian ocean Margin in Tanzania, p. 113-131, *In*: *Sedimentary Basins of the African Coasts*, 233 p. Paris.

Kidston, A. G., Iqbal, J., Mliga, N. R., and Kilembe, E. A., 1997. East African Regional Hydrocarbon Study, Tanzania. *In*: The Hydrocarbon Potential of Tanzania. p. 1-147 (TPDC unpublished report).

Klaus, J., 1960. Etude Biomètrique et statistique de quelques espèces de Globotruncanidès. 1. Les espèces du genre *Praeglobotruncana* dans le Cènomanien de la Breggia. *Eclogae Geologicae Helvetiae* 53, p. 285-308.

Klemme, H. D., and Ulmishek, G. F., 1991. Effective Petroleum Source rocks of the world: Stratigraphic distribution and controlling depositional factors. *American Association of Petroleum Geologists Bulletin* 75, p. 809-811, & 851.

Kößler, P.; Herrle. J.O.; Appel, E.; Erbacher, J. & Hemleben, Ch. (2001): Magnetic records of climatic cycles from mid-Cretaceous hemipelagic sediments of the Vocontian Basin, SE-France.-*Cretaceous Research* 22, 331-341.

Koutsoukos, E. A. M., and Hart, M. B., 1990. Cretaceous foraminiferal morphogroup distribution patterns palaeocommunities and trophic structures: a case study from the Sergipe Basin, Brazil. *Transactions of the Royal Society of Edinburgh, Earth Sciences* 81, p. 221-246.

Koutsoukos, E. A. M., 1994. Early stratigraphic record a phylogeny of the planktonic genus *Guembelitria. Journal of Foraminiferal Research* 24, p. 288-295.

Koutsoukos, E. A. M., 2002. Biogeographic constraints and palaeoceanography of planktonic foraminifera in the late Aptian - Albian of the northern South Atlantic. Abstracts, *Geological Society of America.* Annual Meeting, p. 27-30 October, Denver, America.

Kucera, M., Darling, K. F., 2002. Cryptic species of planktonic foraminifera: Their effect on Palaeoceanographic reconstructions. *Philosophical Transaction of the Royal Society, London* A 360, p. 695-718.

Kump, L. R., Pavlov, A.,and Arthur, M. A. 2005. "Massive release of hydrogen sulphide to the surface ocean and atmosphere intervals of oceanic anoxia". *Geology* 33 (5) p. 397-400.

Kuhnt, W., and Moullade, M., 2007. The Gargasian (Middle Aptian) of La Marcouline section at Cassis - la Bédoule (SE France): Stable isotope record and orbital cyclicity-Carnets de Géologie. *Notebooks on geology*, Brest, Article 2007/02 (CG 2007/A02).

Kuypers, M. M., Blokker, M. P., Ebarcher, J., Kinkel, H., Pancost, R. D., Schouten, S., and Sinninghe Damste, J. S., 2001. Massive expansion of marine Archea during a mid-Cretaceous oceanic anoxic event. *Science* 293, p. 92-94.

Lamarck, J. B., 1804. Suite des mémoires sur les fossils des environs de Paris, *Annales Muséum National d'Histoire Naturelle* 5, p. 179-188.

Lamarck, J. B., 1812. Extrait du cours de Zoologie du Muséum d'Histoire Naturelle sur les animaux invertébres. Paris, d'Hautel, p. 1-127.

Langer, M. R., Silk, M. T. B., Lipps, J. H., 1997. "Global ocean carbonate and carbon-dioxide production. The role of reef foraminifera". *Journal of Foraminiferal Research* 27 (4), p. 271-277.

Larson, R.L. (1991): Geological consequences of superplumes. *Geology*, 19, 963-966.

Larson, R. L., Erba, E., 1999. Onset of the mid-Cretaceous greenhouse in the Barremian-Aptian: Igneous events and the biological, sedimentary, and geochemical responses. *Paleogeography* 14, p. 663-678.

Lea, I., 1833. Contributions to Geology. Philadelphia: Carey, Lea and Blanchard.

Lear, C. H., Bailey, T. R., Pearson, P. N., Coxall, H. K., Rosenthal, Y., 2008. Cooling and ice growth across the Eocene-Oligocene transition. *Geology* 36 (3), p. 251-254, doi: 10.1130/G24584A. 1; 1 figure; 1 table; data repository item 2008061.

Leckie, M.R. (1984): Mid-Cretaceous planktonic foraminiferal biostratigraphy off Central Morocco, Deep Sea Drilling Project Leg 79, Sites 545 and 547.- *Initial Reports of the Deep Sea Drilling Projects*, 79, 579-620.

Leckie, M.R. (1987): Palaeoecology of mid-Cretaceous planktonic foraminifera: A comparison of open ocean and epicontinental sea assemblages. *Micropalaeontology* 33, 164-176.

Leckie, R. M., 1989. A paleoceanographic model for the early evolution history of planktonic foraminifera. Oceanic anoxic events and plankton evolution: biotic response to tectonic forcing during the mid-Cretaceous. *Palaeogeography, Palaeoclimatology, Palaeoecology* 73, p. 107-138.

Leckie, R. M., Bralower, T. J., Cashman, R., 2002. Oceanic anoxic events and plankton evolution: biotic responses to tectonic forcing during the mid-Cretaceous. *Paleoceanography* 17, 1041 p.

Lehmann, R., 1966. Les Foraminifere pelagiques du Cretace du basin cotier de Tarfaya. 1. Planomalinidae et Globotruncanidae du sondage de Puerto Cansado (Albien superieur, Cenomanien inferieur*).* *Notes et Memoires du Service Geologique du Maroc* 175: p. 153-167.

Lipps, J. H., 1970. Plankton evolution. *Evolution* 24, p. 1-22.

Lipson-Benitah, S., 2008. Phylogeny of the middle Cretaceous (Late Albian - Late Cenomanian) planktonic foraminiferal genera *Parathalmanninella* nov. gen and *Thalmanninella*. *Journal of foraminiferal Research* 39 (2), p. 183-189.

Loeblich, A. R. Jr. and Tappan, H., 1946. New Washita Foraminifera. *Journal of Paleontology* 20, p. 238-258.

Loeblich, A. R. Jr. and Tappan, H., 1950. Foraminifera of the type Kiowa Shale Lower Cretaceous of Kansas, *University of Kansas Paleontological Contributions, Protozoa* 3, p. 1-15.

Loeblich, A. R. Jr. and Tappan, H., 1957. Eleven new genera of foraminifera. *Bulletin of the United States National Museum* 215, p. 223-232.

Loeblich, A. R. Jr. and Tappan, H., 1961. The type species of the foraminifera genus *Saccammina* Carpenter 1869. *Contributions of Cushman Foundation for Foraminiferal Research* 12, p. 79-80.

Loeblich, A. R. Jr. and Tappan, H., 1964. Protista 2. Sarcodina chiefly 'Thecamoebians' and Foraminiferida. *In*: Moore, R. C. (Eds.) *Treaties of Invertebrate Paleontology, Part C.*, 2 volumes. University of Kansas Press, Lawrence, 900 p.

Loeblich, A. R. Jr. and Tappan, H., 1982. Classification of the foraminiferida, in T. W. Broadhead (Ed.). Foraminifera, notes for a short course organized by M. A. Buzas and B. K. Sen Gupta, University of Tennessee, Department of Geological Sciences, *Studies in Geology* 6, p. 22-36.

Loeblich, A. R., Jr., and Tappan, H., 1986. Some new and revised genera and families of hyaline calcareous foraminiferida (Protozoa). *Transactions of the American Microscopical Society* 105, p. 239-265.

Loeblich, A. R. Jr. and Tappan, H., 1987. *Foraminiferal Genera and Their Classification.* 2 volumes. Van Nostrand Reinhold Company, New York, 2047 p. (and references therein).

Longoria, J. F. & Gamper, M. A., 1974. Albian planktonic foraminifera from the Sabinas Basin of northern Mexico, *Actes du Vlie Colloque Africain de Micropaléontologie*, Tunis 28, p. 39-71.

Longoria, J. F., 1974. Stratigraphic, morphologic and taxonomic studies of Aptian planktonic foraminifera. *Revista Espaňola de Micropaleontologia*, Numero extraordinario, p. 5-107.

Longoria, J. F. & Gamper, M. A., 1977. Albian planktonic foraminifera from the Sabinas Basin of northern Mexico. *Journal of Foraminiferal Research* 7, p. 196-215.

Luciani, V.; Cobianchi, M. & Jenkyns, H.C. (2001): Biotic and geochemical response to anoxic events: The Aptian pelagic succession of Gargano Promotory (southern Italy). *Geological Magazine*, 138, 277-298.

Luciani V., Cobianchi, M and Jenkyns, H. C., 2004. Albian high-resolution biostratigraphy and isotope Stratigraphy: the Coppa delta Nuvola pelagic succession of the Gargano Promontory (Southern Italy) *Eclogae Geologicae Helvetiae, Basel* 97, p. 77-92.

Ludvingson, G. A., Joeckel, R. M., Gonzalez, L. A., Gulbrason, E. R., Rasbury, E. T., Hunt, G. J., Kirkland, J. I., and Madsen, S., 2010. Correlation of Aptian-Albian carbon isotope excursions in continental strata of the Cretaceous Foreland Basin, Eastern Utah, U.S.A. *Journal of Sedimentary Research* 80, p. 955-974.

Luterbacher, H. P. and Premoli Silva, I., 1962. Note Prèliminaire sur une rèvision du profil de Gubbio. *Rivista Italiana di Paleontologia* 68, p. 253-288.

Magniez-Jannin, F., 1998. L' élongation des loges chez les foraminiféres planctoniques du Crétacé inférieur unie adaption á la sous-oxygénation des eaux. *Earth Planet Science* 326, p. 201-213.

Malapris, M., 1965. Les Gavelinellidae et formes affines du gisement Albien de Courcelles (Aube), *Revue de Micropaléontologie* 8, p. 131-150.

Marie, P., 1941. Les foraminiféres de la Craie a *Belemnitella mucronata* du Bassin de Paris, *Mémoires du Museum Nationale dé Historie Naturelle*, N Séries 12 (1), p. 1-296.

Murray, G. (1961): Geology of the Atlantic and Gulf coastal province of North America. 692 p.

Murray, J. W., 1976. A method determining proximity of marginal seas to an ocean. *Marine Geology* 22, p. 103-119.

Martin, F. C. R., 1957. The geology of the Lindi area, Tanganyika, *Palaeontology Notes* 2, 28 p. (Unpublished report).

Mbede, E. I., 1991. The sedimentary basins of Tanzania-reviewed. *Journal of African Earth Sciences* 13, (3/4), p. 291-297.

McMillan, I. K., 2003. The Foraminifera of the Late Valanginian to Hauterivian (early Cretaceous) Sunday River Formation of the Algoa basin, Eastern Cape Province, South Africa 106, 66 figures, 275 p., (and the references therein).

Menegatti, A. P., Weissert, H., Brown, R. S. Tyson, R. V., Farimond, P., Strasser, A., Caron, M., 1998. High resolution $\delta^{13}C$ stratigraphy through the early Aptian "Livello Selli" of the Alpine Tethys. *Paleoceanography* 13, p. 530-545.

Mesozoic Planktonic Foraminiferal Working Group (Huber, B. T., Coordinator), 2006. Mesozoic Planktonic Foraminiferal Taxonomic Dictionary, www.chronos.org.

Meyer, P. A., 1994. Preservation of elemental and isotopic source identification of sedimentary organic matter. *Chemistry, Geology* 114, p. 289-302.

Meyer P. A., 1997. Organic geochemical proxies of paleoceanographic, paleolimnologic, and paleoclimate processes. *Organic Geochemistry* 27, p. 231-250.

Meyers, P.A. & Doose, H. (1999): Sources, preservation, and thermal maturity of organic matter in Pliocene-Pleistocene organic-carbon-rich sediments of the Western Mediterranean Sea.- *In* Zahn, R.; Comas, M.C. & Klaus, A. (eds.) *Proceedings of the Ocean Drilling Program, Scientific Results* 161, p. 383-390.

Meyer, K. M., Kump, L. R. 2008. "Oceanic Euxinia in Earth history, causes and consequences". *Annual Review of Earth and Planetary Sciences* 36, p. 251-288.

Michael, F. Y., 1973. Planktonic foraminifera from the Comanchean Series (Cretaceous) of Texas. *Journal of Foraminiferal Research* 2, p. 200-220.

Montanaro Gallitelli, E., 1957. A revision of the foraminiferal family Heterohelicidae, *Bulletin United States National Museum* 215, p.133-154.

Montfort, A., 1808. *Conchyliologie systématique et classification méthodique des coquilles* 1, p. 331, F. Schoell Paris, text-fig. on p. 33.

Moore, W. R., McBeath, D. M., Linton, R. E., Terris, A. P., and Stonely, R., 1963. *Geological Survey of Tanganyika Quarter Degree Sheet* 256, 1:125,000 Kilwa, first (Ed.) Geological Survey Division, Dodoma.

Mornod, L., 1949-1950. Les Globorotalidés du Crétacé supérieur du Montsalvens (Pre'alpes fribourgeoises). *Eclogae Geologicae helvetiae basel* 42 (2), p. 583-584, text-fig. 5 (IV a-c).

Morrow, A. L., 1934. Foraminifera and Ostracoda from the Upper Cretaceous of Kansas. *Journal of Palaeontology* 8 (2), pl. 31, figs. 2a-b, 4a-b., p. 199 (no Holotype designated, original specimen refigured by Bronnimann and Brown, 1956, pl. XX, figs. P. 10-12.

Moullade, M., 1966. Étude stratigraphique et micropalèontologique de Crètacè infèrieur de la 'Fosse Vocontienne' *Ducuments des Laboratoires de Gèologie de la facultè des Sciences de Lyon* 15, p. 1-369.

Moullade, M., 1974. Zones de Foraminifères du Crètacè infèrieur mesogéen. *Compte Rendu Hebdomadaire des Sèances de l'Acadèmie des Sciences, Paris* (Sèrie D) 278, p. 1813-1816.

Moullade, M., Bellier, J-P., Tronchetti, G., 2002. Hierarchy of criteria, evolutionary processes and taxocomic simplification in the classification of Lower Cretaceous planktonic foraminifera. *Cretaceous Research* 23, p. 111-148.

Moullade, M., Tronchetti, G., Bellier, J-P., 2005. The Gargasian (Middle Aptian) strata from Cassis-La Bedoule (Lower Aptian historical stratotype, SE France): planktonic and benthic foraminiferal assemblages and biostratigraphy. *Carnets de Geologie/ Notebooks on Geology*-Brest, Article 2005/02(CG2005_A02), p. 1-18.

Moullade, M, Tronchetti, G., Bellier, J-P., 2008. Planktonic and benthonic foraminifer's assemblages and biostratigraphy of the uppermost Bedoulian and lower Gargasian of the Tulie're- st-Saturnin- le's-Apt (area of the Aptian Stratotype, Vaucluse, and SE France. *Notebooks on Geology*-Article 2008/01 (CG2008-A01), p. 1-50.

Mpanda, M., 1997. Geology development of the East Africa Coastal Basin of Tanzania. *Stockholm Contributions in Geology* 45, (1), 121 p.

Msindai, J. P. A., 1993. Luhoi-1, Preliminary report. 8 p., (TPDC unpublished report).

Murray, J. W., 1976. A method determining proximity of marginal seas to an ocean. *Marine Geology* 22, p. 103-119.

Mutterlose, J. Bornemann, A., Luppold F. W., Owen, H. G., Ruffel, A., Weiss, W., Wray, D., 2003. The Vöhrum section (northwest Germany) and the Aptian/Albian boundary. *Cretaceous Research* 24, p. 203-252.

Nagy, J. 1992. Environmental significance of foraminiferal morphogroups in Jurassic North Sea delta. *Palaeogeography, Palaeoclimatology, Palaecology* 95, p. 111-134.

Price, N. A., Huber, B. T., Macleod, K. G., 2003. Planktonic Foraminifer depth ecologies across the Aptian/Albian Boundary in the Subtropical North Atlantic (ODPSite 1049). Abstracts, *Geological Society of America*, Annual Meeting, 2-5 September, Seattle America, p. 245.

National Institute of Standards & Technology, 1992. Report of Investigation, reference material p. 8543-8546.

Nederbraght, A. J., Fiorentino, A., and Klosowska, B., 2001. Quantitative analysis of calcareous microfossils across the Albian - Cenomanian boundary oceanic anoxic event at

DSDP Site 547 (North Atlantic): *Palaeogeography, Palaeoclimatology, Palaeoecology* 166, p. 401-421, doi: 10.1016 / S0081 – 0182 (00)00227-3.

Nicholas, C. J., Pearson, P. N., Bown, P. R., Jones, T. D., Huber, B. T., Karega, A., Lees, J. A., McMillan, I. K., Ó Halloran, A., Singano, J. M., Wade, B. S., 2006. Stratigraphy and sedimentology of the Upper Cretaceous to Palaeogene Kilwa Group, southern coastal Tanzania. *Journal of African Earth Sciences* 45, p. 431-466.

O'Leary, M. H., 1988. Carbon isotopes in photosynthesis. *Biosciences* 38, p. 328-336.

Olsson, R. K., Berggren, W. A., Hemleben, C., and Huber, B. T., 1999. Atlas of Paleocene Planktic Foraminifera. *Smithsonian Contributions to Paleobiology* 23, p. 1-13.

Oliver, F., Erbacher, J., Moriya, K., Wilson, P. A., Henning, K, 2008. "Warm saline intermediate waters in the Cretaceous tropical Atlantic Ocean". *Nature Geoscience* 1 (7): p. 1-453, doi:10.1038/ngeo217.

Owen, H. G., 1979. Ammonite Zonal stratigraphy in the Albian of North Germany and its setting in the hoplitinid faunal province. In: Wiedmann, J. (Ed.). *Aspekte der Kreide Europas.* IUGS Series A (6), p. 563-588.

Owen, H. G., 1984a. Albian stage and substage boundaries. *Bulletin of the Geological Society of Denmark* 33, p. 183-189.

Owen, H. G., 2002. The base of the Albian stage; comments on recent proposals; *Cretaceous Research* 23, p. 1-13.

Page, A. Zalasiewtcz, J. and Williams, M. 2007. "Deglacial anoxia in a long-lived early Palaeozoic icehouse In Budd, G. E., Streng, M., Daley, A. C.:William, S., Programme with Abstracts Annual Meeting, UppSala Sweeden,, p. 85.

Paquier, V., 1900. Recherché géologiques dans le Diois et les Baronnies orietales. *Thése Grenoble*, 402 p.

Parker, W. K., and Jones, T. R., 1860. On the nomenclature of the foraminifera IV (continued). n*Annals and Magazine of Natural History*, Ser. 3 (6), p. 29-40.

Pearce, C. R.; Cohen, A. S; Coe, A. L.; Burton, K. W., 2008. “Molybdenum isotope evidence for global ocean anoxia coupled with perturbations to the carbon cycle during the early Jurassic. *Geological Society of America* 36(3), p. 231-234. Doi:10. TI30/G2444619.

Pearson, N. P., 1998. Evolutionary Conceipts in Biostratigraphy. *In*: Doyle, P. and Bennett, M. R. 1998: Unlocking the Stratigraphical Record; Advances in Modern Stratigraphy, p. 123-144. John Wiley and Sons Limited, Baffins Lane, Chichester, West Sussex, England.

Pearson, P. N., Ditchfield, P. W., Singano, Harcourt- Brown, K. G., Nicholas, C. J., Olson, R. K., Shackleton, N. J., and Hall, M. A., 2001. Warm tropical sea surface temperatures in the Late Cretaceous and Eocene epochs. *Nature* 413, p. 481-487.

Pearson, P. N., Nicholas, C. J., Singano, J. M., Bown, P. R., Coxall, H. K., van Dongen, B. E., Huber, B. T., Karega, A., Lees, J. A., Msaky, E., Pancost, R., Pearson, M., Roberts, A. P., 2004. Palaeogene and Cretaceous sediment cores from the Kilwa and Lindi areas of coastal Tanzania: Tanzania Drilling Project Sites 1-5. *Journal of African Earth Sciences* 39, p. 25-62.

Pearson, P. N., Nicholas, C. J., Singano, ., Bown, P. R., Coxall, H. K., van Dongen, B. E., Huber, B. T., Karega, A., Lees, J. A., Macleod, K., McMillan, I. K., Pancost, R. D., Pearson, M., and Msaky, E., 2006. Tanzania Drilling project Site 6 to 10: Further Palaeogene and Cretaceous sediment cores from Kilwa area of coastal Tanzania. *Journal of African Earth Sciences* 45, p. 279-317.

Pearson, P. N., van Dongen, B. E., Nicholas, C. J., Pancost, R. D., Schouten, S., Singano, J. M., and Wade, B. S., 2007. Stable warm tropical climate through the Eocene epoch. *Geology* 35, p. 211-214.

Pearson, P. N., McMillan, I. K., Wade, B. S., Jones, T. D., Coxall, H. K., Bown, P. R. and Lear, C. H., 2008. Extinction and environmental change across the Eocene-Oligocene boundary in Tanzania. *Geology* 36 (2), p. 179-182.

Pessagno, E. A., Jr., 1962. The Upper Cretaceous stratigraphy and micropalaeontology of South-central Puerto Rico. *Micropalaeontology* 8, p. 349-368.

Pessagno, E. A. Jr., 1967. Upper Cretaceous Planktonic foraminifera from the Western Gulf Coastal plain. *Paleontographica Americana* 5, p. 245-445.

Petrizzo, M. R., and Huber, B. T., 2006. Biostratigraphy and taxonomy of late Albian planktic foraminifera from ODP Leg 171B (western North Atlantic Ocean). *Journal of Foraminifera Research* 36, p. 166-190.

Petrizzo, M. R., Huber, B. T., Andrew, S., Gale, Barchetta, A., Jenkyns, H. C., 2012. Abrupt planktic foraminiferal turnover across the Niveau Kilian at Col de Pre-Guittard (Vocontian basin, southeast France): new criteria for defining the Aptian /Albian boundary. *Newsletters on Stratigraphy* 45 (1), p. 55-74.

Pflaumann, U., Krasheninnikov, V. A., 1977. Early Cretaceous planktonic foraminifers from eastern North Atlantic, DSDP Leg 41, in Lancelot, Y., and Seibold, E., Shipboard Scientific Party (eds.*), Initial Reports of Deep Sea Drilling Project.* U.S. Government Printing Office, Washington, D. C. 41, p. 539-564.

Plotnikova, L. F., 1979. Tritaksii rodstuennye imformy v melovyich otlozheniiyakh Kryma I Prichernomorya (Tritaxias and related forms from Cretaceous deposits of the Crimea and Black Sea region. *Palaeontologichescy Sbornik* 16, p. 12-19.

Plummer, H., 1931. Some Cretaceous foraminifera of Texas. *Bulletin of the University of Texas Bureau of Economic Geology and Technology* 3101, p. 109-203.

Postuma J. A., 1971. *Manual of Planktonic Foraminifera*, Elsevier Publishing Company, Amsterdam, 420 p.

Prahl, F. G., Bennett, J. T. and Carpenter, R., (1980). The early diagenesis of aliphatic hydrocarbons and organic matter in sedimentary particulates from Dabob Bay, Washington. *Geochimica, Cosmochimica Acta* 44, p. 1967-1976.

Premoli Silva, I., and Sliter, W. V., 1994. Cretaceous planktonic foraminiferal biostratigraphy and evolutionary trends from the Bottacione section, Gubbio, Italy, *Paleontographia. Italica* 82, p. 1-89.

Premoli Silva, I., & Sliter, W. V., 1995. Cretaceous planktonic foraminiferal biostratigraphy and evolutionary trends from the Bottaccione Section *Gubbio*, Italy, *Palaeontographica Italiana* 81, p. 2-90.

Premoli Silva I. and Sliter W. V., 1999. Cretaceous paleoceanography: Evidence from planktonic foraminiferal evolution. *In*: evolution of the Cretaceous ocean - climate system (Eds.) Barrera, E. and Johnson, C.). *Geological Society of America, Special Paper* 332, p. 301-328.

Premoli Silva, I., Erba, E., Salvini, G., Locatelli, C., Verga, D., 1999. Biotic changes in Cretaceous oceanic anoxic events of the Tethys. *Journal of Foraminifera Research* 29, p. 352 -370.

Premoli Silva, I., Sliter, W. V., 2002. Practical Manual of Cretaceous Planktonic Foraminifera. Dipartimentodi Scienze della Terra, University of Perugia 462 p.

Premoli Silva, I., and Verga, D., 2004. Practical Manual of Cretaceous Foraminifera. International School on Planktonic Foraminifera, 3rd Course: Cretaceous. In Verga, D., and Rettori, R. (Eds.) Universities of Perugia and Milan. Tipografia Pontefelcino, Perugia, Milan, Italy, 283 p.

Premoli Silva, I., Caron, M., Leckie, R. M., Petrizzo, M., Soldan, D., and Verga, D., 2009. *Paraticinella* n. gen. and taxonomic revision of *Ticinella bejaouaensis* Sigal, 1966: *Journal of Foraminiferal Research* 39 (2), p. 126-137.

Price N. A., and Hart, M. B., 2002. Isotopic evidence for early to mid-Cretaceous ocean temperature variability. *Marine Micropaleontology* 46, p. 45-58.

Randrianasolo, A., and Anglada, R., 1998. About *Ticinella roberti* var. *bejaouaensis* Sigal 1966 and *Ticinella bejaouaensis* Sigal emended Moullade 1966, in Joint Regional Meeting of

IGCP Projects nos. 381 and 362, held in conjunction with the Cuban Geological Congress, Havana, Cuba, 24 March-1 April 1998; *Geologia y Mineira'198, Memorias, La Havana* 2, p. 298.

Raup, D. M., and Sepkoski, J. J. Jr., 1986. Periodic extinction of families and Genera. *Science* 231, p. 833-836.

Reed, J.A., Cervato, C., and Fils, D., 2007. CHRONOS's PSICAT: Core Logging and Data Capture in One Tool. *Computers and Geoscience Special Issue*: Geosciences Knowledge Representation for Cyber infrastructure, 15 p.

Reichel, M., 1950. Observations sur les *Globotruncana* du gisement de la Breggia (Tessin). *Eclogae Geologicae Helvetiae* 42, p. 596-617.

Renz, O., 1936. Stratigrafische und micropalaeontologische Untersuchung der Scaglia (Obere Kreide-Tertiär) im Zentralen Apennin. - *Eclogae Geologicae Helvetiae* 29 (1), 20 p., text-fig. 2.

Renz, O., Luterbacher, H., and Schneider, A., 1963. Stratigraphischepalaontologische untersuchungen im Albien und Cenomanien des Neuenburger Jura: *Eclogae Geologicae Helvetiae* 56, p. 1076-1116.

Report EP/12.1., 1983. (Bio) Stratigraphic review of wells Kisarawe-1 and Kisangire-1., 5 p., (Unpublished TPDC internal report).

Reuss, A. E., 1845. *Die Versteinerungen der Böhmischen Kreideformation, Erste Abtheilung*. Stuttgart: E. Schweizerbartsche Verlagsbuchhandlung and Druckerei.

Reuss, A. E., 1860. Die Foraminiferen der Westphalis Kreideformation, *Sitzungsberichte der K. Akademie der Wissenschaften in Wien, and Mathematisch-Naturwissenschaftliche Classe* 40, p. 147-238.

Reuss, A. E., 1862. Entwurf einer systematischen Zusammenstellung der Foraminiferen, *Sitzungsberichte der Kaiserlichen akademie der Wissenschaften in wien, Mathematisch-Naturwissenschaftliche Classe* 1861, 44 (1), p. 355-396.

Reuss, A. E., 1863. Die Foraminiferen des norddeutschen Hils und Gault. Eine Monographie. *Sitzungsberichte der Mathematisch-naturwissenschaftliche Klasse der Kaiserlichen Akademie der Wissenschaften, Wien* (for 1862) 46 (1), p. 5-100.

Rhumbler. L., 1906. Foraminiferen von Laysan und den Chatham-Inseln, *Zoologische Jahresbericht* 24, p. 21-80.

Rhumbler, L., 1911. Die Foraminiferen (thalamophoren) der Plankton-Expedition, Erster teil, Die allgemeinen Organizationsverhaltnisse der Foraminiferen, *Ergebnisse der Plankton-Expedition der Humboldt-Stiftung*, Kiel u. Leipzig, Bd. 3 L. C. (1909) p. 1-331.

Risch, H., 1969. Stratigraphie der hoheren Unterkreide der bayerischen Kalkalpen mit Hilfe von Mikrofossilien, Dissertation, Lundwig-Maximilian Universitat, Munchen, 180 p.

Robaszynski, F., and Caron, M. (Eds.) 1979. and the European Working group on planktonic Foraminifera. Atlas of mid Cretaceous Planktonic Foraminifera (Boreal sea and Tethys). *Cahiers Micropalaeontologie*, 366 p., Paris.

Robaszynski, F., and Caron, M., 1995. Foraminiféres planctoniques du Crétacé: Commentaire de la zonation Europe-Méditerranée. *Bulletin de la Société Géologique de France* 166, p. 99-108, Paris.

Robinson, S. A., Williams, T., and Bown, P. R., 2004. Fluctuations in biosiliceous production and the generation of early Cretaceous oceanic anoxic events in the Pacific Ocean (ODP Leg198, Shatsky Rise): *Paleoceanography* 19, doi: 10. 1029 / 2004PA00/010.

Robinson, S. A., Clarke, L. J., Nederbraght, A., 2008. Mid – Cretaceous oceanic anoxic events in the Pacific Ocean revealed by Carbon-isotope Stratigraphy of the Calera limestone, California, USA. *Geological Society of America Bulletin*, p. 1416-1427.

Roemer, F. A., 1839. *Die Versteinerungen des Norddeutschen oolithen-* Hannover: Hahn'schen Hofbuchhandlung.

Roemer, F. A., 1841. *Die Versteinerungen des Norddeutschen Kreidegebirges*. Ein Nachtrag. Hannover: Hahn'schen Hofbuchhandlung.

Rohling E. J., Sprovien, M., Cane, T., Casford, J. S. L., Cooke, S., Bouloubassi, I., Emeis, K. C., Schiebel, R., Rogerson, M., Hayes, A., Jorris, F. T., Kroon, D., 2004. Reconstructing past planktic foraminiferal habitats using stable isotope data: a case history for Mediteranean sappropel. *Marine Micropalaeontology* 50, p. 89-123.

Ruckheim, S., Bornemann, A., Mutterlose, J., 2006. Integrated Stratigraphy of an Early Cretaceous (Barremian –Early Albian) North Sea borehole (BGS 81 /40), *Cretaceous Research* 27, p. 447-463.

Rzehak, A., 1885. Bemerkungen Über einige Foraminiferen der Oligocän Formation. *Verhandlungen des Naturforschenden Vereins in Brunn* (1884) 23, p. 123-129.

Rzehak, A., 1895. Ueber einige merkwurdige Foraminiferen aus osterreichichen ter, *Annalen Naturhistorisches Hof museum,* Wien 10: 213-230 p.

Saidova, Kh. M., 1981. *Osovremennom sostoyanii sistemy nadvidovykh taksonov Kaynozoyskikh bentosnykh foraminifer* [On an up to date system of supraspecific taxonomy of Cenozoic benthonic foraminifera]. Moscow: Institut Okeanologii P. P. Shirshova, Akademiya Nauk SSSR.

Salman, G., Abdula, I., 1995. Development of the Mozambique and Rovuma Sedimentary Basins, offshore Mozambique. *Sedimentary Geology* 96, p. 7-41.

Sars, M. in Sars, G. O., 1872. Undersogelser over Hardangerfjordens fauna. *Forhandlinger i Videnskasselskabet i Kristiania* 1871, p. 46-255.

Sastry, M. V.A. and Sastri V. V., 1966. Foraminifera from the Utatur stage of the Cretaceous formations trichinopoly district, Madras. *Records of the Geological Survey of India* 94, p. 277-296.

Scheibnerova, V., 1972. Some interesting foraminifera from the Cretaceous of the Great Artesian Basin, Australia. *Micropaleontology* 18, p. 212-222.

Scheibnerova’ V., 1978. Aptian - Albian benthonic foraminifera from DSDP led 27, Sites 259, 260 and 263, Eastern Indian Ocean, p. 697-734.

Schiebel, R., 2002. Planktonic foraminiferal sedimentation and the marine calcite budget. *Global Biogeochemical Cycles* 16, 1065 p.

Schijfsma, E., 1956. Stratigraphical revision of the Pugu-Maneromango area, Tanganyika, East Africa, 23 p. 2-figs. *Palaeontological Note* 31 (Unpublished report).

Schlanger, S. O., Arthur, M. A., and Jenkyns, H. C., 1976. Cretaceous oceanic anoxic events: causes and consequences. *Geologie en Mijnbouw* 55, p. 179-184.

Schlutze, F. E., 1875. Zoologische Ergebnisse der Nord-seefahrt, vom 21 Juli bis 9 September, 1872, I, Rhizopoden, II, *Jahresberichte Kommission zur Untersuchung der Deutschen Meer inKiel fur die Jahrbuch* 1872, 1873, p. 99-114.

Scholle, P. A., and Arthur, M. A., 1980. Carbon isotope fluctuations in Cretaceous pelagic limestone. Potential stratigraphic and petroleum exploration tool: *Bulletin of the American Association of Petroleum Geologists* 164, p. 67-87.

Schouten, S., Hopmans, E. C., Schefuss, E., and Sinninghe Damsté, J. S., 2002. Distributional vari-ations in marine crenarchaeotal membrane lipids: A new organic proxy for reconstructing ancient sea water temperatures?, *Earth Planet. Sc. Lett*., 204, 265-274,

Schubert, C. J. and Calvert, S. E., 2001. Nitrogen and Carbon isotopic composition of marine and terrestrial organic matter in Arctic Ocean sediments: implications for nutrient utilization and organic matter composition. *Deep- Sea Research* (I) 48, p. 789-810.

Sen Gupta, B. K., 1999. Systematics of modern foraminifera. In: Sen Gupta, B. k. (Eds.), Modern foraminifera. Khimer Academic Press, Dordrecht, p. 7-36.

Shackleton, N. J., 1977. ^{13}C in *Uvigerina*: tropical rainforest history and the equatorial Pacific carbonate dissolution cycle. In: Anderson, N., Malahof, A. (Eds.), Fate of Fossil Fuel CO_2 in the Oceans. *Plenum*, New York, p. 401-427.

Sigal, J., 1948. Notes sur les genres de foraminifères *Rotalipora* Brotzen, 1942 et *Thalmanninella*. *Revue de Pétrole Institute* Paris, France 3/4, p. 95-103, Paris.

Sigal, J., 1952. Aperçu stratigraphique sur la micropalèontology du Crètacè. In: XIX *Congrès Gèologique International, Monographies Règionales*, (Sèrie 1), Algèrie 26, p. 1-47.

Sigal, J., 1956. Notes micropaleontologique nord-africaines; 4 *Biticinella breggiensis* (Gandolfi), nouveau, genre, *Compte Rendu Sommaire des Seancesde la Societe Geologique de France* 3, p. 35-37.

Sigal, J., 1958. La classification actuelle des familles de foraminifères planctoniques du Crètacè. *Compte Rendu des Séances, Société Géologique de. France* 16, p. 262-265.

Sigal, J., 1966. Contribution a' une monographie des Rosalines I. lé genre Ticinella Reiichel, souches des Rotalipores, *Eclogae Geologicae Helvetiae* 59, p. 187-217.

Sigal, J., 1969. Contribution á une monographie des Rosalines. 2. L' espèce *Rotalipora appennica* (Renz, 1936), origine phylètique et taxinomie. *Proceedings of the 1st International Conference on Planktonic Microfossils* 2, p. 622-639, Brill, Leiden, Netherland.

Sigal, J., 1977. Essai de zonation du Cretace mediterraneen a l'aide des foraminiferes planctoniques. *Geologie Mediterraneenne* 4, p. 99-108.

Sikora P. J. and Olsson, R. K., 1991. A paleoslope model of late Albian to early Turonian foraminifera of the Western Atlantic Margin and North Atlantic basin. *Marine Micropaleontology* 18, p. 25-72 p., figs. I-V. Elsevier Science Publisher B. V., Amsterdam (and references therein).

Simmons, M. D., BouDagher-Fadel, M. K., Banner, F. T., Whittaker, J. E., 1997. The Jurassic Favusellacea, the earliest Globigerinina. In: BouDagher-Fadel, M. K., Banner, F. T., Whittaker, J. E. (Eds.). The Early Evolution History of Planktonic Foraminifera. Chapman and Hall, London, p. 17-51.

Singano, J. M. & Srivastava, V., 1985. Comments on Report EP - 61970 by SHELL on Biostratigraphy of Well Ruaruke North-1, Tanzania (Unpublished TPDC internal report).

Singano, J. M., and Karega, A. I. S., 2000. An Atlas of the Carboniferous to Tertiary Micropalaeontology of the SADC region of southern Africa. Published by Tanzania

Petroleum Development Corporation. Printed by Kul Graphics Limited, Mombasa, Road, Nairobi, Kenya. ISBN9987-8880-2X. 230 p.

Sliter, W. V. and Baker, R. A., 1972. Cretaceous bathymetric distribution of benthic foraminifers. *Journal of Foraminiferal Research* 2, p. 167-183.

Sliter, W. V., 1989. Biostratigraphic zonation for Cretaceous planktonic foraminifers examined in thin sections. *Journal of Foraminiferal Research* 19, p. 1-19.

Sliter, W. V., 1992. Cretaceous planktonic foraminiferal biostratigraphy and paleoceanographic events in the Pacific Ocean with emphasis on indurated sediment- In Ishizaki; K. S. and Saito, T. (eds.). *Centenary of Japanese Micropalaeontology,* p. 281-299.

Stanley, S. M., and L. A. Hardie, 1998. Secular oscillations in the carbonate mineralogy of reef building and sediment-producing organisms driven by tectonically forced shifts in seawater chemistry, Palaeogeogr. Palaeoclimatol. Palaeoecol., 144, 3-19,

Stanley, S. M., 1999. Earth System History. W. H. Freeman and Company, New York, 615 p.

Steinneck, P. L., and Fleisher, R. L., 1978. Towards the classical evolutionary reclassification of Cenozoic Globigerinacea (Foraminiferida): *Journal of Palaeontology* 52, p. 618-635.

Stoll, H. M. & Schrag, D. P., 2000. High resolution stable isotope records from the Upper Cretaceous rocks of Italy and Spain: Glacial episodes in a greenhouse planet? *Geological Society of America, Bulletin* 112, p. 308-319.

Subbotina, N. N., 1953. Fossil foraminifera of the USSR. Globigerinidae, Hantkeninidae and Globorotalidae. *Trudy Vsesoyuznogo Neftyanogo Nauchno-issledovatel' skogo geologo-razvedochnogo Instituta (VNIGRI),* (New Series), 76, p. 1-296 p. (in Russian).

Takashima, R., Nishi, H., Huber, B. T., Leckie, R. M., 2006. Greenhouse World and the Mesozoic ocean. *A quarterly Journal of Oceanography Society* 19 (4), p. 82-92.

Tappan, H., 1940. Foraminifera from the Grayson Formation of northern Texas. *Journal of Paleontology* 14, p. 93-126.

Tappan, H., Loeblich, A, R., 1973. Evolution of the oceanic plankton, *Earth Science Review* 9, p. 207-240.

Tenzer, G. E., Meyers, P. A., Robbins, J. A., Eadie, B. J., Morehead, N. R. and Lansing, M. B., 1999. Sedimentary organic matter record of recent environmental changes in the St. Marys River ecosystem, Michigan-Ontario border. *Organic Geochemistry* 30, p. 133-146.

Terquem, O., 1883. Sur un nouveau genre de foraminiféres de Fullérs earth de la Moselle, *Bulletin de la Société Géologique de France* (1882-1883), Sér. 3 (11), p. 37-39.

Terris, A. P. & Stonely, R., 1955. The geology of the Kilwa area, Tanganyika, Report APT. 3, RS. 1. 46 p., Appendices; 14 p. Including *Kilwa Geological Survey Report No.* 1, 6 p (Unpublished report).

The mid-Cretaceous paleogeographic map reconstructed from the ODSN website: http://www.odsn.de/odsn/services/palaeomap/palaeomap.html).

Thevenon, F., Adate, T., Spangenberg, J. E., Anselmetti, F. S., 2012. Elemental (C/N ratios) and isotopic ($\delta^{15}N$ and $\delta^{13}C_{org}$) compositions of sedimentary organic matter from a high altitude mountain Lake (Meidsee, 2661 m a.s.l., Switzerland): Implications for late glacial and Holocene Alpine landscape evolution. *Research paper: The Holocene* 22 (10) p. 1135-1142.

Thomsen, E., 1987. Seasonal variability in the production of Lower Cretaceous calcareous nannoplankton. *Geology* 17, p. 715-717.

Thornton, S. F. and Mcmanus, J., 1994. Application of organic carbon and nitrogen stable isotope and C/N ratios as source indicators of organic matter provenance in estuarine systems: evidence from the Tay Estuary, Scotland. *Estuary Coast Shelf Science* 38, p. 219-233.

Tornaghi, M. E., Premoli Silva, I., Ripepe, M., 1989. Lithostratigraphy and planktonic foraminiferal biostratigraphy of the Aptian - Albian "Scisti a Fucoidi" in the Piobbico core, Marche, Italy: background for cyclostratigraphy. *Rivista Italiana di Paleontologia e Stratigrafia* 95, p. 223-264.

TPDC/Fairway Report, 1992. Petroleum Potential of Tanzania. 409 p., figures; I.I-VI.VIII, enclosures; II.I-V.I (Unpublished report).

Tiraboschi, D., Erba, E., and Jenkyns, H. C., 2009. Origin of rhythmic Albian black shales (Piobbico core, central Italy) Calcareous nannofossil quantitative and statistical analysis and paleo-ceanographic reconstructions, *Paleoceanography* 24, PA2222, doi:10.1029/2008PA001670 2009.

Towe, K. M., Cifelli, R., 1967. Wall ultrastructure in the calcareous foraminifera: Crystallographic aspects and a model for calcification. *Journal of Palaeontology* 41, p. 742-762.

Tyska, J. 1994. Response of middle Jurassic benthic foraminiferal morphogroups to dysoxic/anoxic conditions in the Pieniny Klippen Basin, Polish Carpathian. Palaeogeography, Palaeoclimatology, Palaecology 110, p. 55-81.

Tykoezinski, H. G. R., 1982. Well Songo Songo-5. Biostratigraphical analysis of core samples (2191-6451.6 ft) Palaeoservices Ltd. (UK) Project 876. 10 p., (Unpublished report).

Tyson, R. V., (1995). Abundance of organic matter in sediments: TOC, hydrodynamic equivalence, dilution and flux effects. Sedimentary Organic Matter: *Organic Facies and Playnofacies*, p. 81-118, Chapman and Hall.

Van Morkhoven, F., and Schroeder, A. G., 1986. Atlas of planktonic foraminifera part 2, Cretaceous. Report EP36 – 1068, 21 plates, SIPM/EPX/36, *Society of Stratigraphic Services*.

Van Wagoner, J. C., Mitchum, R. M., Campion, K. M., and Rhamanian, V. D., 1990. Siliciclastic sequence stratigraphy in well logs, cores, and outcrops. *American Association of Petroleum Geologists Methods in Exploration* Series 7, p. 1-55.

Verga, D. & Premoli Silva, I., 2002. Early Cretaceous planktonic foraminifera from Tethys: The genus *Leupoldina*. Department of Science University of Milano, Italy, Revised Manuscript Mangiagalli 34, p. 1-201, Milano, Italy.

Verga, D. & Premoli Silva I., 2003. Early Cretaceous planktonic foraminifera from the Tethys: The large many chambered representatives of the genus *Globigerinelloides*: *Cretaceous Research* 24, p. 661-690. (and references therein).

Verga, D. & Premoli Silva I., 2003a. Early Cretaceous planktonic foraminifera from Tethys: the small few chambered representatives of the genus Globigerinelloides. *Cretaceous Research* 24, p. 305-334.

Verga, D. & Premoli Silva I., 2003c. Lower Cretaceous planktonic foraminifera from the Tethys. The genus *Leupoldina*; palaeoecological and taxonomical implications. *Geophysical Research Abstracts,* 5, EGS - AGU - EUG Joint Assembly, 6-11 April, Nice, France.

Website: en.wikipedia.org/wiki/APIgravitywww.metric-conversions.org/volume/cubic-feet-to cubic metres.htm.

Weier, H., 1987. Geology of the Wami River. 5 p., (TPDC unpublished internal report).

Weiku, H., Chen, Y. G., Chan, P.S., Lin, C. C., 2007. Paleoenvironmental evolution as revealed by analysis of organic carbon and nitrogen: A case of coastal Taipei Basin in Northern Taiwan. *Geochemical Journal* 41, p. 111-120.

Weissert, H. and Lini, A., 1991. Ice age interludes during the time of Cretaceous Greenhouse Climate: *in* Muller, D. W.; McKenzie, J. A., and Weissert, H. (Eds.) Controversies in modern geology: Evolution of geological theories *in*: *Sedimentology, Earth History and Tectonics,* p. 173-191.

Werner, R. A., Brand, W. A., 2001. Referencing strategies and techniques in stable isotope ratio analysis. *Mass spectrum* 15, p. 501-519.

Williams, R. G., and Follows M. J. 1998. Eddies make ocean deserts bloom, *Nature* 394, p. 228-229.

Wilson, P. A., Norris, R. D., 2001. Warm tropical ocean surface and global anoxia during the mid-Cretaceous period. *Nature* 412, p. 425-429.

Wonders, A. A. H., 1975. Cretaceous planktonic foraminifera of the *Planomalina buxtorfi* group from El Burrueco, Southern Spain. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen* (Series B) 78, p. 83-93.

Wonders, A. A. H., 1978. Phylogeny, classification and biostratigraphic distribution of keeled Rotaliporinae. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen,* Amsterdam Series B, *Palaentology, geology, physics, chemistry* 81, p. 113-144.

Wonders, A. A. H., 1980. Middle and Late Cretaceous planktonic foraminifera of the western Mediteranean area. *Utrecht Micropalaeontology Bulletin* 24, p. 1-157.