Journal of Mining and Geology Vol. 57(1) 2021. pp. 75 - 84 0022-2763

Planktic and Benthic Foraminiferal Forms; Evidence for the Influx of Benguela / Canary Current into Part of the Gulf of Guinea (Niger Delta), Nigeria during the Late Eocene – Early Oligocene

Ukpong, A.J. and Ekhalialu, O.M.
Department of Geology, University of Calabar, Calabar - Nigeria.
Corresponding E-mail: **andyukpong@yahoo.com**

Abstract
Planktic and benthic foraminifera are useful in deciphering past climatic conditions and palaeocirculation patterns since their ratio, abundance and diversity of the planktic foraminiferal test as well as the ratio, abundance and diversity of the shell types of the benthic foraminiferal preserved hold significant records. This research attempts to use foraminiferal forms for palaeocirculation analysis. Information from three (3) deep wells that tested the Eocene – Oligocene interval in the Niger Delta was utilized for this study and standard foraminiferal sample preparation method was employed. The sea-level history of the study wells show an overall transgressive episodes with intermittent regressive phases characterized by alternation of sandstone and shale. The foraminiferal assemblages recovered from the study wells are associated with clastic deposition and occur as shallow inner neritic - outer shelf assemblages. The distribution pattern of the planktic foraminifera is dominated by *Globigerina spp.* with a few *Globorotalia spp.* This distributional patterns together with the low diversity of foraminifera as well as the presence of subarctic – subantarctic forms depict periods of cold water influx into the Gulf of Guinea (Niger Delta) from the Canary or the Benguela current during the Late Eocene (Priabonian) – Early Oligocene (Rupelian) epoch therefore affecting the normal regional warm water circulation that characterize tropical regions. The dominance of the hyaline and arenaceous test over the hyaline and porcelaneous test further support this interpretation. This indicate significant oceanic heat exchange during the Priabonian – Rupelian age which in turn influenced the distributional patterns of foraminiferal forms in the Niger Delta.

Keywords: *Benthic foraminiferal, planktic foraminifera, palaeocirculation, Canary current, Benguela current.*

Introduction

Foraminiferida informally called foraminifers / foraminifera or forams (as a short form) are significant order of single celled protozoa that float on the water column (planktic) or live on the sea floor (benthic) (Armstrong and Brasier, 2005). Forams are important as biostratigraphic indicators for different ages and for determining particular palaeoenvironment which are capable of revealing controls on sedimentary successions to provide particularly reliable data as they are very sensitive to changes in the ocean environment (Armstrong and Brasier, 2005). Both the planktic and benthic foraminiferal are useful for palaeoclimatic / palaeocirculation study because the ratio, abundance and diversity of mineralized shells of forams keep a record of the ocean's climatic conditions due to their interaction with complex external factors making them very important for such studies.

The oceans cover approximately 71% of the earth and are undoubtedly the world's largest storage of heat derived from solar insolation. As a result of this, there is direct contact between the ocean and the sun's energy. The part of the ocean that takes this insolation is the surface ocean and is of paramount importance because the upper most layer (~3.5m) of the ocean contains similar heat as the entire atmosphere (Trenberth, 2001). The upper ocean layer in a way controls ocean-atmosphere heat exchange as well as the formation of pressure gradients and wind fields. It also drives the formation and circulation of water masses that comprise the oceanic thermohaline circulation. As a consequence, the surface ocean is involved in both deep and shallow circulation, both of which are crucial for heat transport around the world oceans. It is therefore, an operatic factor of the world climate (Mortyn and Martínez-Botí, 2007).

Location of the Study Wells

The study wells are deep wells drilled in the Northern Delta depobelt of the Niger Delta which forms a segment of the Niger Delta petroleum province of Nigeria (Fig. 1). The Niger Delta Basin is situated at the apex of the Gulf of Guinea on the west coast of Africa and is one of the most prolific deltaic hydrocarbon provinces in the world. The sedimentary basin called Niger Delta occupies a total area of about 75,000 km2 and is at least 11 km deep in its deepest parts (Tuttle *et al*, 1999). It is located between Latitudes 3° and 6° N and Longitudes 5° and 8° E respectively in the Gulf of Guinea, on the margin of West Africa (Fig. 1) (Tuttle *et al*, 1999).

The Niger Delta is described by Doust and Omatsola

(1990) as one of the largest deltaic systems in the world. The formation of the Niger Delta basin began in the Early Cretaceous; it was developed at the triple junction between South Atlantic, Gulf of Guinea Margin and Benue Trough (Burke, 1972). The Niger Delta deltaic system is known to prograded over an area of three hundred kilometers (300 km) since the Late Eocene (Short and Stauble, 1967; Burke, 1972; Evamy *et al*., 1978; Whiteman, 1982; Stacher, 1995). The development of the Niger Delta continues from Late Eocene till the Holocene, building out on African continental margin and its associated oceanic crust. The study by Evamy *et al*. (1978), Knox and Omatsola (1987) and Stacher (1995) point out that the evolution of the Niger Delta is controlled by pre- and synsedimentary tectonics. The delta has prograded southwestward, forming depobelts known as the most active sections / portions of a delta during each stage of its development (Doust and Omatsola, 1990). Kulke (1995) and Hospers (1965) defined the Niger Delta as one of the largest regressive deltas in the world and it covers an area of approximately 300,000 km^2 with a sediment volume of 500,000 km^3 respectively. Kaplan *et al.* (1994) proposed a sediment thickness of over 10 km in the basin depocenter. The Niger Delta is a delta at equilibrium state due to the equal contribution from fluvial, wave and tidal influence. Research by Evamy *et al.* (1978) and Doust and Omatsola (1990) suggested that the structural configuration and the stratigraphy of the Niger Delta were largely influenced by the interaction between the rates of sediment supply and subsidence.

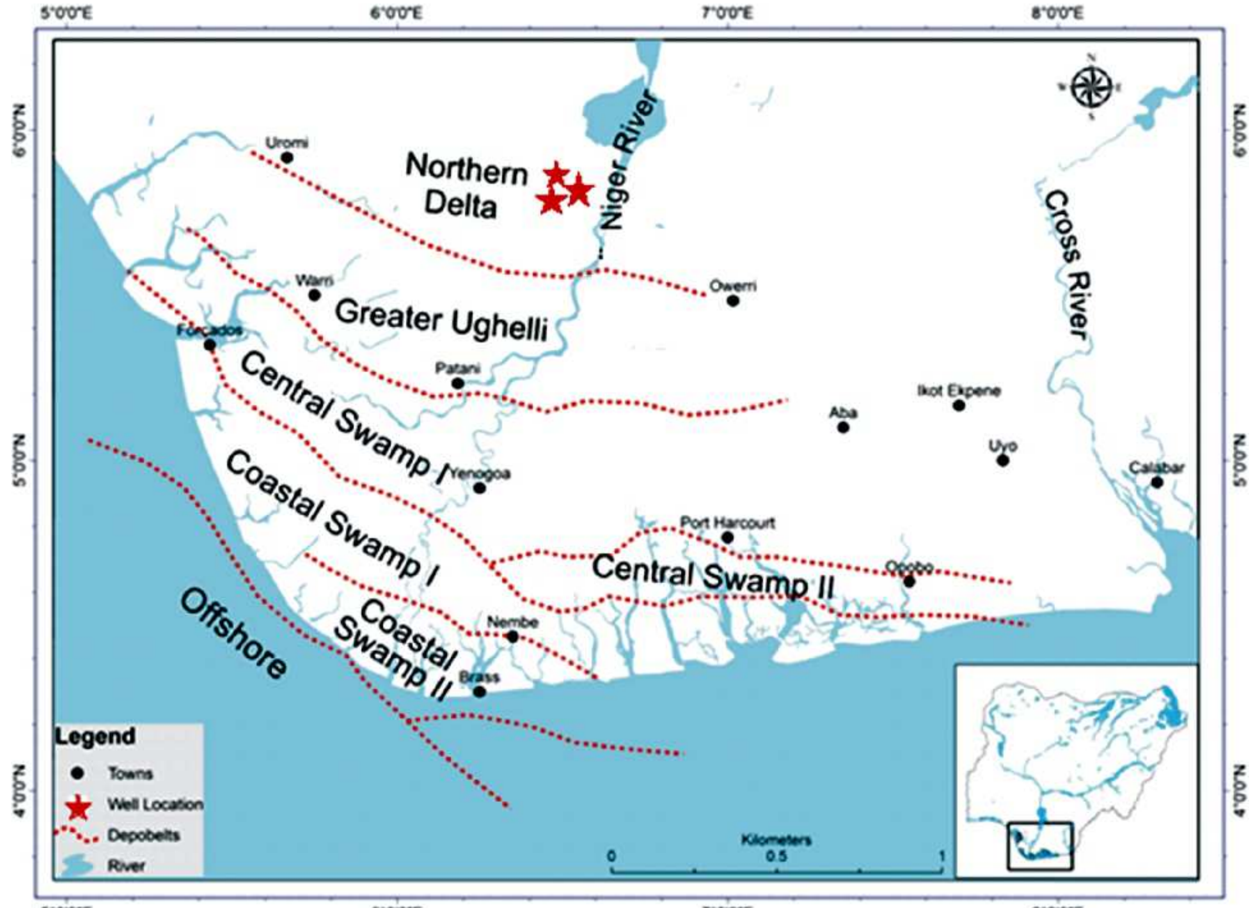

Fig. 1: Map of the Niger Delta showing the location of the study wells.

Materials and Methods

Materials

Ditch cutting samples from three (3) deep wells were utilized for this study. A total of one hundred and thirty seven (137) ditch cutting samples were used; thirteen (13) samples from well C (interval 2410 – 2800m) collected at thirty (30) metres intervals; sixty seven (67) samples from well F (2000m – 3320m) collected at 20metres and fifty seven (57) samples from well Tango (2640 – 3088m) collected at 8metres interval were used.

Methods

The anhydrous sodium carbonate (Na_2CO_3) approach of Armstrong and Brasier (2005) was adopted for the micropalaeontological sample processing. The method involves soaking and wet sieving, drying, picking and sorting as well as foraminiferal analysis.

The lithologic description was based on their textural parameters. In line with this, the proper depth by depth description of all samples was made. It involves rock type, facies type, colour, presence and absence of carbonaceous materials, grain size, grain shapes, sorting, hardness, grain constituents and other observable features. Ten percent (10%) dilute Hydrochloric acid was used on the samples to infer the presence or absence of calcareous materials.

Results and discussion

A detailed sedimentologic / lithologic description of ditch cutting samples and the foraminiferal counts as well as palaeobathymetric interpretation is presented in the distribution charts (figures 2, 3 and 4). The penetrated sediments are characterized by alternation of sandstone/sand and shale, the shale is dark grey in colour, sub fissile – fissile and moderately hard – hard while the sand is smoky white – brown, fine - coarse grained, sub-angular - rounded, poorly - well sorted and occasionally ferruginized, carbonaceous, glauconitic and predominantly unconsolidated – consolidated. These sediments of heterogeneous sequence of alternating shale and sand/sandstone belong to the Middle - Lower units of the paralic Agbada Formation described by Short and Stauble (1967), Doust and Omatsola (1990) and Whiteman (1982) as a lithostratigraphic subdivision of the Niger Delta subsurface.

The foraminifera forms recovered include planktic and benthic foraminifera (calcareous benthic and arenaceous benthic foraminifera). Some foraminifera forms are long ranging in terms of stratigraphic occurrences while others have restricted stratigraphic occurrences with regional – cosmopolitan distribution. The following materials (Ukpong and Ekhalialu, 2017; 2018; Ukpong et al. 2018) should be consulted for the age and palaeoenvironment of the study wells.

Sea level history of the study wells shows an overall transgressive episode with intermittent regressive phases (figures 2, 3 and 4). The sediments reflect continual cyclic patterns of transgressive - regressive lithologic units which contain facies that are rich in marine faunal assemblages directly succeeded vertically by variety of coarse grained clastic materials that are carbonaceous and occur in repetitive sequences. This is suggestive of parallic settings for the cyclic sediments on shelf-edge deltaic system based on marine and non- marine evidences. The vertically stacked sequences most probably resulted from climate-driven eustatic changes based on their time span (0.9 – 3Ma)

The calcerous and arenaceous foraminiferal assemblages recovered for the study wells are associated with clastic deposition and they constitute as a shallow inner neritic - outer shelf assemblage of approximately 0-200m water depth. The Niger delta is located at the apex of the Gulf of Guinea within the tropical region which is characterized by extremely hot weather condition but the recovered microfaunas are unusual of any tropical region and are suggestive of cold water forms.

Sea level history of the study wells shows an overall transgressive episode with intermittent regressive phases (figures 2, 3 and 4). The sediments reflect continual cyclic patterns of transgressive - regressive lithologic units which contain facies that are rich in marine faunal assemblages directly succeeded vertically by variety of coarse grained clastic materials that are carbonaceous and occur in repetitive sequences. This is suggestive of parallic settings for the cyclic sediments on shelf-edge deltaic system based on marine and non- marine evidences. The vertically stacked sequences most probably resulted from climate-driven eustatic changes based on their time span (0.9 – 3Ma).

The calcerous and arenaceous foraminiferal assemblages recovered for the study wells are associated with clastic deposition and they constitute as a shallow inner neritic - outer shelf assemblage of approximately 0-200m water depth. The Niger delta is located at the apex of the Gulf of Guinea within the tropical region which is characterized by extremely hot weather condition but the recovered microfaunas are unusual of any tropical region and are suggestive of cold water forms.

The ecological preferences of some planktic foraminifera are presented here based on the study of Spezzaferri *et al.* (2002) and Bicchi *et al*. (2003) who used *Globigerina* (except *Globigerina diplostoma*) and *Turborotalia* as cool water indicators while *Globorotalia* and *Globoturborotalia* are considered warm water indicators. Diversity of planktic

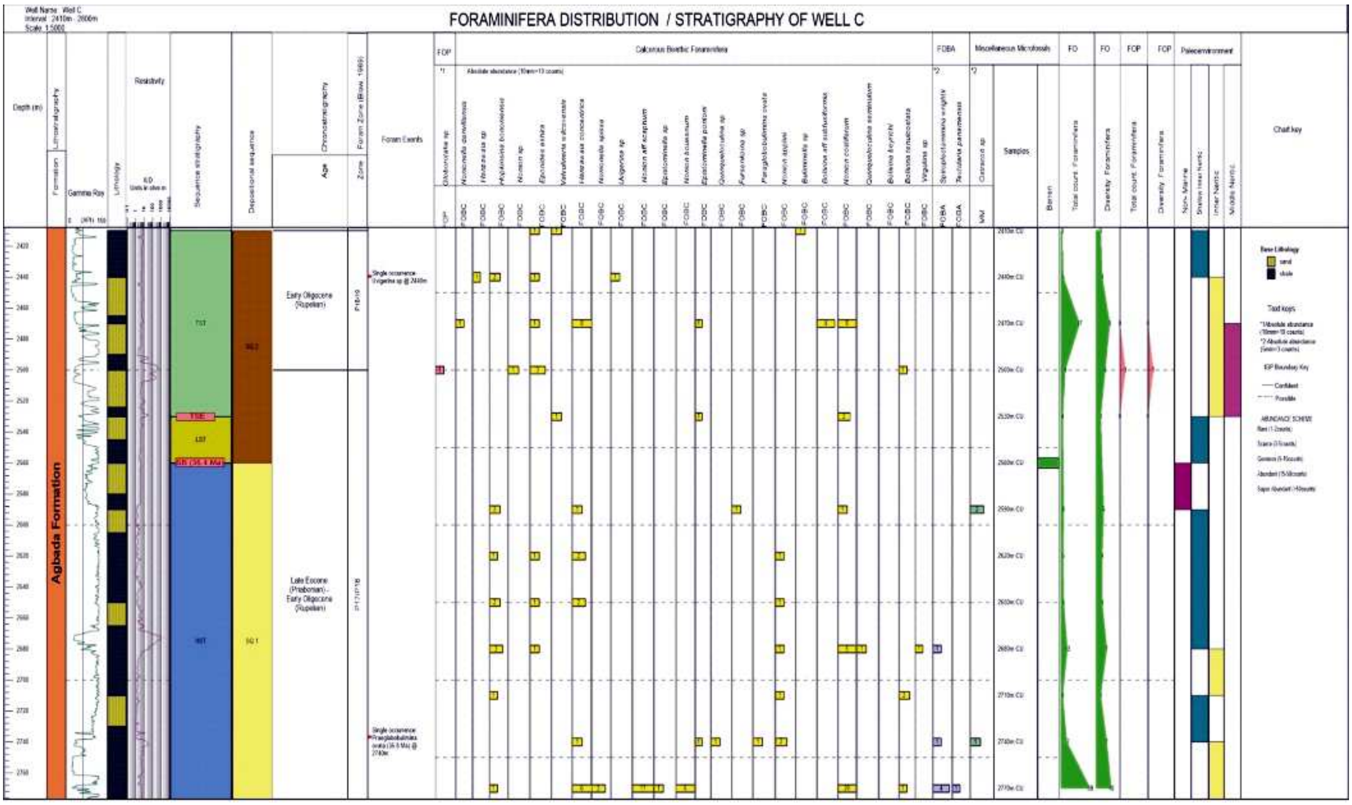

Fig. 2: Foraminiferal chart of well C

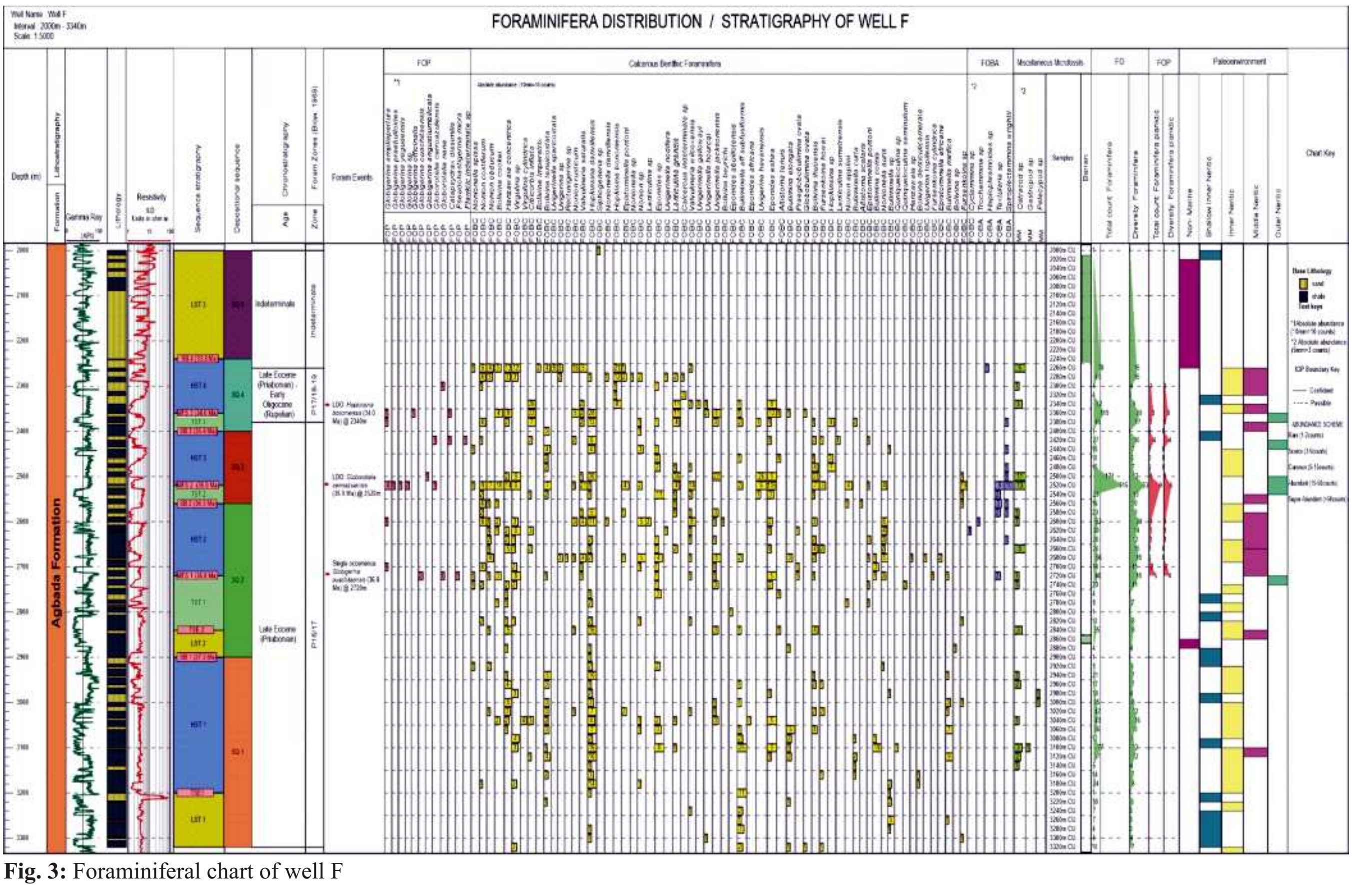

Fig. 3: Foraminiferal chart of well F

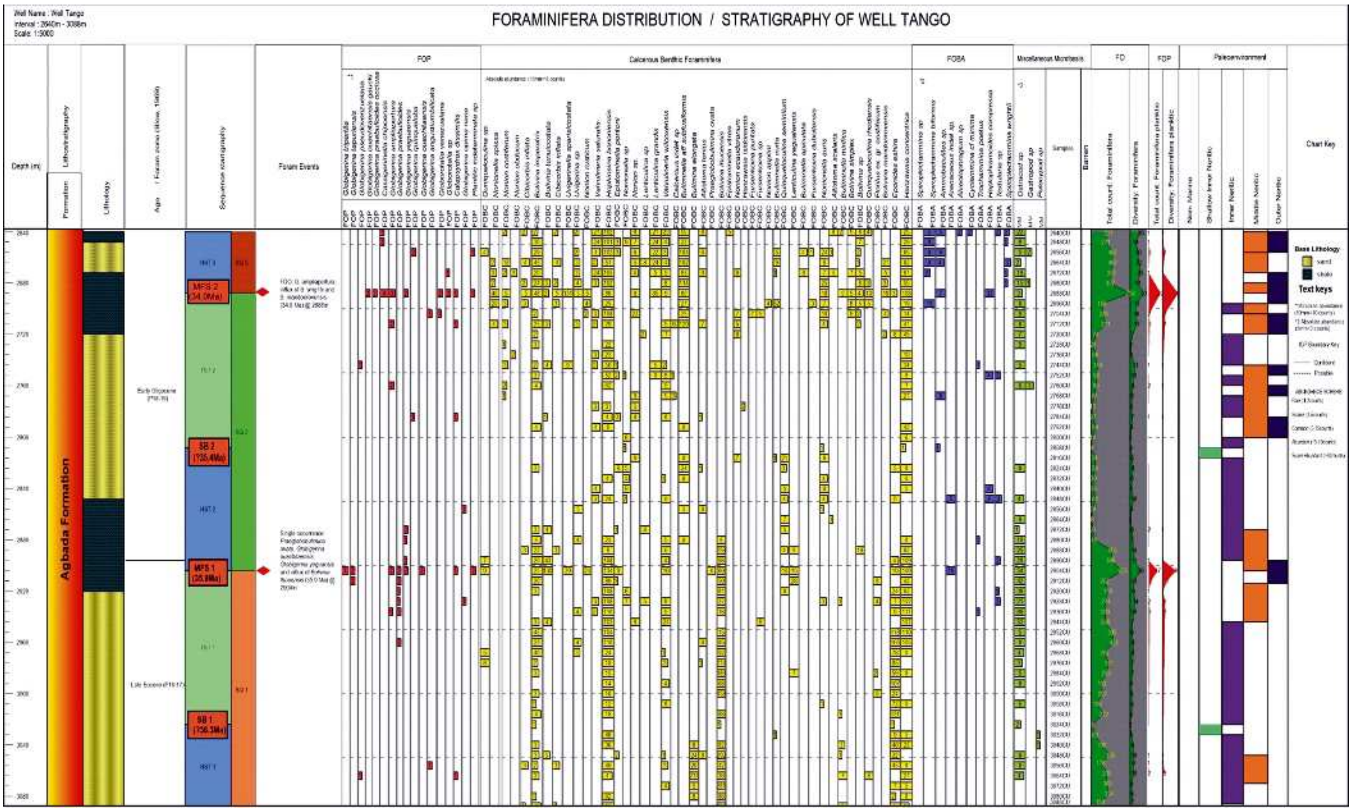

Fig. 4: Foraminiferal chart for well Tango

foraminiferal assemblages can also be used as an index of palaeo-temperature conditions. Boltovskoy and Wright (1976) reported lower diversity of planktic foraminifera in cool waters than in warm waters in modern oceanic conditions. Jones (1983) used the fisher diversity plot to differentiate between warm and cold provinces based on the fisher value. Figure 5 shows the fisher plot for the study wells. The recovered foraminifera from the study wells were categorized into cold water faunas (*Globigerina*) and warm water faunas (*Globorotalia*).

The distribution pattern of the planktic foraminifera is dominated by *Globigerina sp.* with a few *Globorotalia sp.* Some samples in well F show high diversity and all samples from well C show low diversity while well Tango show a mixed characteristics. This depicts periods of cold water influx into the Niger Delta during the Late Eocene (Priabonian age) – Early Oligocene (Rupelian age) epoch which can be attributed to the increase in the intensity of the cold Benguela / Canary current or coastal upwelling of cold water from deeper depth around the Gulf of Guinea affecting the normal regional warm water circulation expected in a tropical region (figure 6). The study of Petters (1981, 1982 and 1983) supports this interpretation. Petters (1982) opined that the presence of phosphorites suggest coastal upwelling and the occurrences of temperate planktic forms as well as the subartic – subartartic foram forms further lends credence to the influx of the cold Benguela / Canary waters.

Murray (2006) observed the relative percentages of three (3) shell types (hyaline, porcelaneous and agglutinated tests) may permit the determination and evaluation of water temperature. The dominance of hyaline and porcelaneous shells indicates warm seas, while the dominance of hyaline and arenaceous shells indicates cold seas (figure 7). The dominance of the hyaline and arenaceous test over the porcelaneous test recorded in this study further supports the influx of the cold Benguela / Canary waters into the Gulf of Guinea as interpreted.

This interpretation shows that significant oceanic heat exchange occurred as far back as the Priabonian – Rupelian age which in turned influenced the distributional patterns of foraminiferal forms. The degree of bioprovinciality of the foraminifera forms (and perhaps other fossils) must have been compromised by the influx of cold water from the Benguela / Canary current during the final separation of Africa from South America. However, it helped to spurt the patterns of biodiversity of the foraminifera forms (and perhaps other fossils) which would not occur under warm water and uniform oceanic currents conditions of the Niger Delta areas. The study of Spezzaferri *et al.* (2002) and Bicchi *et al*. (2003) supports this interpretation. The top of one major transgression of interest dated 35.9Ma (Priabonian age) was picked in well F at 2520m and well Tango at 2904m. This transgression interval is characterized by diverse and abundant planktic foraminifera with good benthic foraminifera abundance and diversity.

This transgressive interval in well F is characterized by the following planktic foraminifera: *Globigerina praebulloides* (1), *Globigerina ampliapertura* (4), *Globigerina yeguaensis* (1), *Globigerina sp* (2) and *Globorotalia cerroazulensis* (1) with a total planktic abundance and diversity of nine (9) and five (5) as well as total foraminiferal (planktic and benthic) abundance and diversity of three hundred and sixteen (316) and thirty three (33) respectively was recorded. This transgressive interval in well Tango is also characterized by the following planktic foraminifera: *Globigerina triparita* (3), *Globigerina tepuriensis* (2), *Globigerina ampliapertura* (2), *Globigerina praebulloides* (3), *Globigerina yeguaensis* (2), *Globigerina ouachitaensis* (2), *Catapsydrax dissimilis* (1) and *Planktic indeterminate* spp. with a total planktic abundance and diversity of seventeen (17) and eight (8) as well as total foraminiferal (planktic and benthic) abundance and diversity of six hundred and five (605) and twenty six (26) respectively was recorded. This corresponds to the Latest Eocene transgression reported by Petters (1983) and the eustatic curve of Haq et al (1988) in the Niger Delta as well as the global timing of Early Eocene transgression. The transgressive interval was however not encountered in Well C probably due to its location further inland.

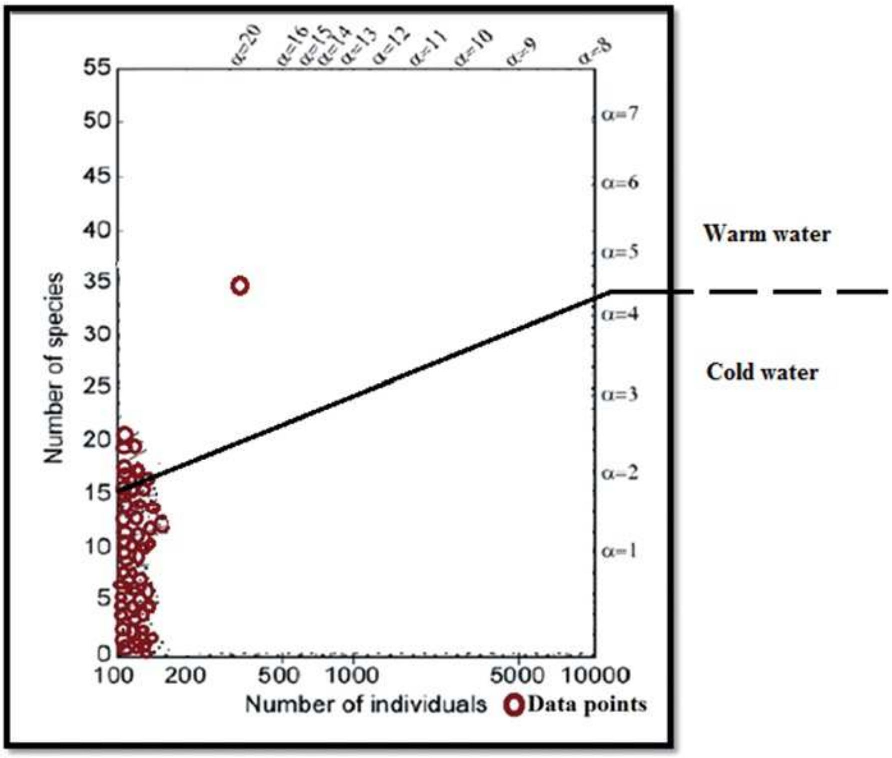

Fig. 5: Fisher plot of study wells showing the relationship between species diversity and water temperature (modified from Jones, 1983)

Summary and Conclusion

Recovered foraminiferal forms from one hundred and thirty seven (137) ditch cuttings obtained from three (3) study wells in the Niger Delta were applied to determine the influx of water masses into the some parts of the Gulf of Guinea based on the percentage of cool water and warm water foraminifera as well as the ratio of shell type together with the presence of subantarctic and subarctic foraminiferal assemblages.

Foraminifera biostratigraphic analysis of sediments penetrated by the study wells revealed similar ages of Late Eocene – Early Oligocene and consist of four (4) foram zone: P16 -17 / P18-19 (*Globorotalia cerroazulensis / Pseudohastigerina micra - Globigerina*

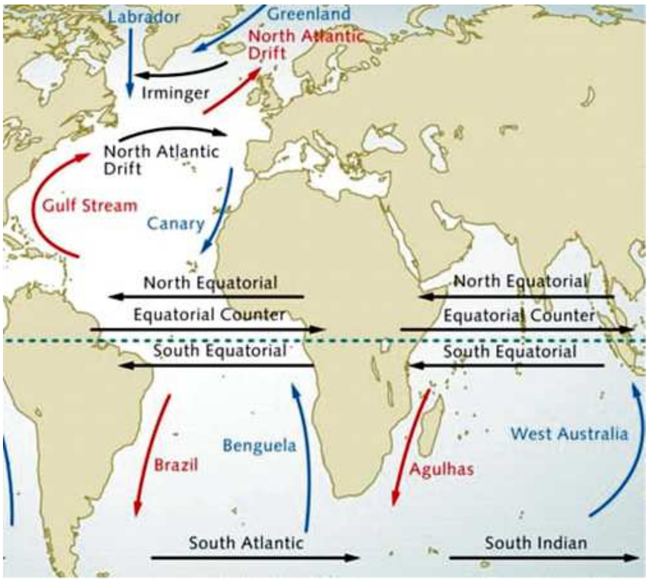

Fig. 6: Recent oceanic circulation similar to the Eocene – Oligocene.

ampliapertura zone). This study clearly indicates the occurrence of Latest Eocene transgression in the Niger Delta and the migration of cold water foraminifera forms into West Africa in the Eocene – Oligocene and significant oceanic heat exchange which occurred as far back as the Priabonian – Rupelian age.

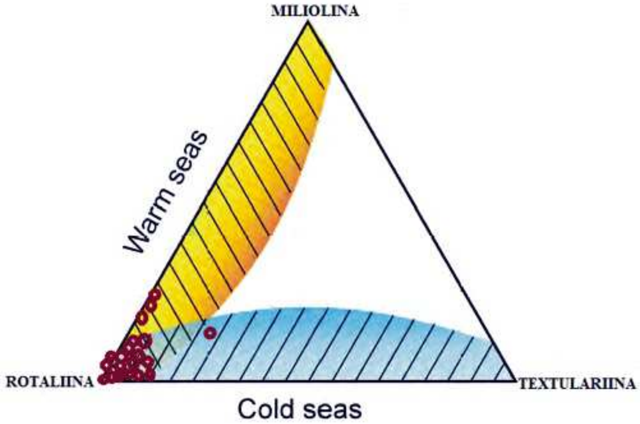

Fig. 7: The MRT plot showing relationship between shell type and sea temperature (Murray, 2006)

Acknowledgements

The authors are grateful to the Department of Geology, University of Calabar, Department of Petroleum Resources (DPR) and Nigeria Agip Oil Company (NOAC) for providing the study materials for the study. Discussion with Professor S. W. Petters greatly added value to this manuscript.

References

Armstrong, H.A., and Brasier, M.D. (2005). *Microfossils*. Oxford, England: Blackwell Publishing.

Bicchi, M., Ferrero, E. and Gonera, M. (2003). Palaeoclimatic interpretation based on middle Miocene planktic Foraminifera: the Silesia Basin (Paratethys) and Monferrato (Tethys) records. *Palaeogeography, Palaeoclimatology, Palaeoecology, 196*, 265-303.

Boltovskoy, E. and Wright, R. (1976). *Recent Foraminifera*: The Hague: Springer Science Media.

Burke, K. (1972). Longshore drift, submarine canyons and submarine fans in development of Niger Delta. *American Association of Petroleum Geologists Bulletin,* 56, 1975-1983.

Doust, H., and Omatsola, E. (1990). Niger Delta. In J. D. Edwards, and P. A. Santogrossied, (Eds.), *Divergent / passive margin basins* (pp. 201-238). American Association of Petroleum Geologists.

Evamy, B.D., Haremboure, J., Kamerling, P., Knaap, W.A., Malloy, F.A. and Rowlands, P.H. (1978). *Hydrocarbon habitat of Tertiary Niger Delta*. American Association of Petroleum Geologists Bulletin*,* 62, 1-39.

Haq, B.V., Hardenbol, J. and Vail, P.R. (1988). Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. In C. Wilgus, B.S. Hastings, C.G. Kendall, H.W. Posamoentier, C.A. Ross, and J.C. Van Wagoner (*Eds*.)*, Sea level changes: an integrated approach* (pp. 72-108). Society of Economic Paleontologist and Mineralogists.

Hospers, J. (1971). The geology of the Niger Delta area. In P. M. Delany (Ed.), *The geology of the east Atlantic continental margin* (pp. 125-142). London: International Council for Scientific Unions.

Jones, R.W. (2014). *Foraminifera and their applications*. London: Cambridge University Press.

Kaplan, A., Lusser, C.U., and Norton, I.O. (1994). Tectonic map of the world. *American Association of Petroleum Geologists*, panel 10.

Knox, G.J. and Omatsola, E.M. (1989). Development of the Cenozoic Niger Delta in terms of the 'escalator regression' model and impact on hydrocarbon distribution. In W. J. M. Van der Linden, S. A. P. L. Cloetingh, J. P. K. Kaasschieter, J. A. M. Van der Gin. *Coastal Lowlands, Geology and Geotechnology* (pp. 181-202). Dordrecht: Kluwer Academic Publishers.

Kulke, H. (1995). Nigeria, In H. Kulke (Ed.), *Regional petroleum geology of the world.Part II: Africa, America, Australia and Antarctica* (pp. 143-172). Berlin: Brüder Borntraeger.

Mortyn, P.G. and Martínez-Botí, M.A. (2007). Planktic foraminifera and their proxies for the reconstruction of surface-ocean climate parameters. *Contributions to Science*, 3 (3): 371–383.

Murray, J.W. (2006). *Ecology and applications to benthic foraminifera*. Cambridge: Cambridge University Press.

Petters, S.W. (1981). Eocene foraminifera from clastic and phosphatic beds of the Gulf of Guinea. In J. W. Neale, and M. D. Brasier (Eds.), *Microfossils from recent and fossil shelf Sea* (pp. 214-230). Chichester, England: Ellis Horwood.

Petters, S.W. (1982). Central West African Cretaceous - Tertiary benthic foraminifera and stratigraphy. *Palaeontographica,* 179, 1-104.

Petters, S.W. (1983). Gulf of Guinea planktic foraminiferal biochronology and geological history of the South Atlantic. *Journal of Foraminiferal Research,* 13, 32 – 59.

Short, K.C., and Stauble, A.J. (1967). Outline of Geology of Niger Delta. *American Association of Petroleum Geologists Bulletin,* 51, 761-779.

Spezzaferri, S., Ćorić, S., Hohenegger, J. and Rogl, F. (2002). Basin- scale paleobiography and paleoecology: an example from Karpatian (Latest Burdigalian) benthic and planktic foraminifera and calcareous nannofossils from the Central Paratethys. *Geobios, 35*, 241-256.

Stacher, P. (1995). Present understanding of the Niger Delta hydrocarbon habitat. In M.N. Oti, and G. Postma, (Eds.), *Geology of deltas* (pp. 257-267). Rotterdam: Balkema.

Trenberth K.E. (2001), The Earth system: physical and chemical dimensions of global environmental change, in MacCracken M.C. and Perry J.S., Eds., Earth system processes, Encyclopedia of Global Environmental Change, John Wiley and Sons, p. 13-30

Ukpong, A.J. and Ekhalialu, O.M. (2017). Evaluation of palaeo-oxygen conditions of Priabonian – Rupelian sediments of the Agbada Formation, Niger Delta based on Fisher's diversity index and benthic foraminifera oxygen index. *EPRA International Journal of Research and Development (IJRD)*, 2 (12): 65-80.

Ukpong, A.J. and Ekhalialu, O.M. (2018). Foraminiferal Approach to Palaeoenvironmental Interpretations: Case Study of Priabonian – Rupelian Sediments of the Niger Delta, Nigeria. *International Journal Geology and Mining*. 4 (2), 165-178.

Ukpong, A.J., Ekhalialu, O.M., Osung, W.E., and Omoko, E.N. (2018). Foraminiferal Biozonation and Biochronology of Priabonian – Repulian sediments of the Agbada Formation, Niger Delta. *International Journal of Scientific and Research Publications*, 8 (1): 425-441.

Whiteman, A. (1982). *Nigeria- its petroleum geology, resources and potential.* London: Graham and Trotman.

PLATE 1

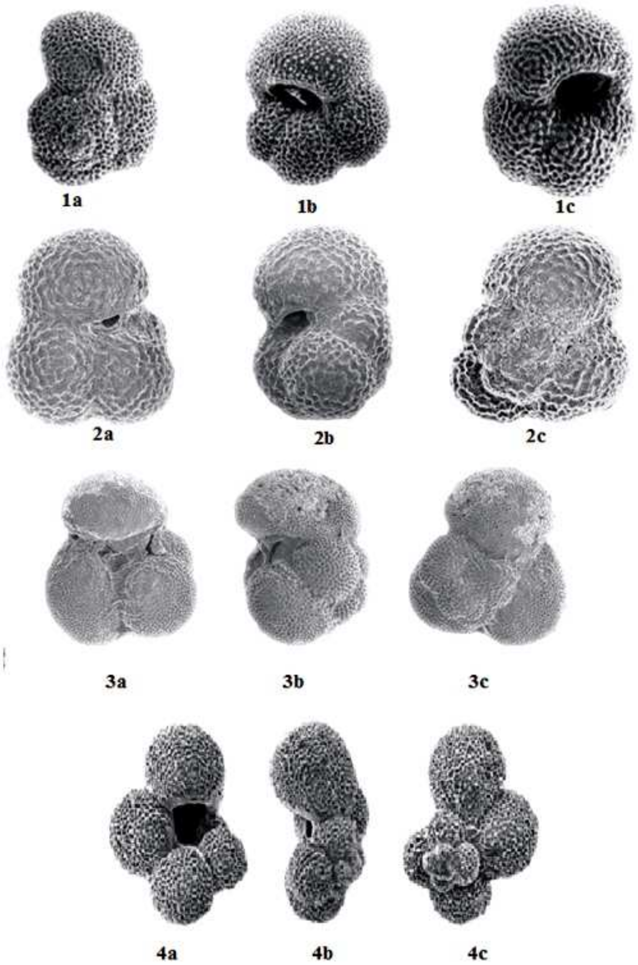

Plate 1
Planktic foraminifera species
Globigerina ampliapertura Bolli, 1957
Fig. 1 a, b and c (x151)
Globigerina officinalis Subbotina 1953
Fig. 2a, b and c (x181)
Globigerina yeguaensis Weinzierl and Applin, 1929
Fig. 3 a, b and c (x121)
Globigerina sp Hecht, 1938
Fig. 4a, b and c (x95)

PLATE 2

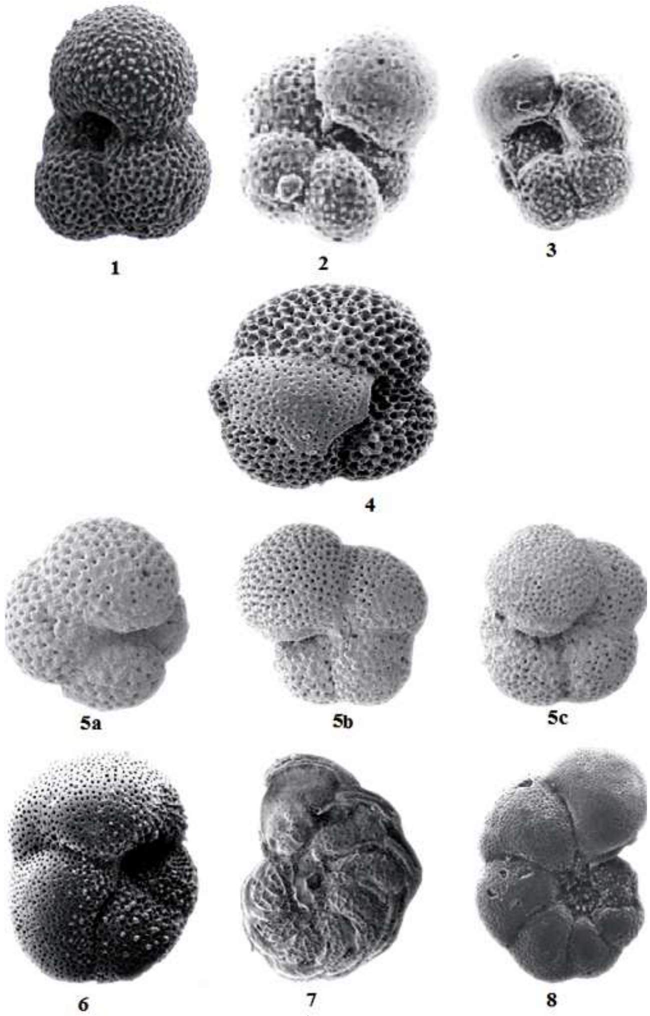

Plate 2
Planktic foraminifera species
Globigerina praebulloides Blow, 1959
Fig. 1(x101)
Globigerina angustiumbilicata Bolli, 1957
Fig. 2 (x82)
Globigerina ouachitaensis Howe and Wallace,1932
Fig. 3 (x121)
Catapsydrax dissimilis Cushman and Bermudez, 1937
Fig. 4 (x85)
Globorotalia nana Bolli, 1957
Fig. 5a, b and c (x82)
Globorotalia cerroazulensis Cole 1928
Fig. 6 (x92)
Globorotalia sp Chapmin, Parr and Collins, 1934
Fig. 7 (x101)
Pseudohastigerina micra Cole 1927
Fig. 8 (x82)

PLATE 3

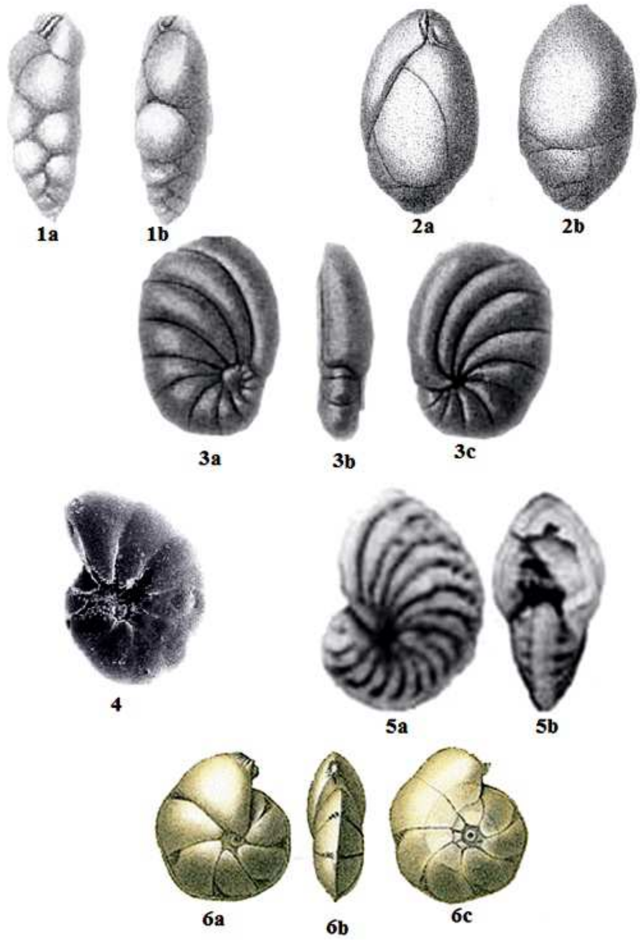

Plate 3
Benthic foraminifera species
Bulimina elongata d'Orbigny 1826
Fig. 1 a and b (x166)
Praeglobobulimina ovata d'Orbigny, 1846
Fig. 2a and b (x152)
Nonionella auris d'Orbigny, 1839
Fig. 3a, b and c (x127)
Nonionella sp Cushman 1933
Fig. 4 (x127)
Nonion cosiferum Cushman, 1990
Fig. 5a and b (x141)
Lenticulina grandis Cushman, 1931
Fig. 6a, b and c (x112)

PLATE 4

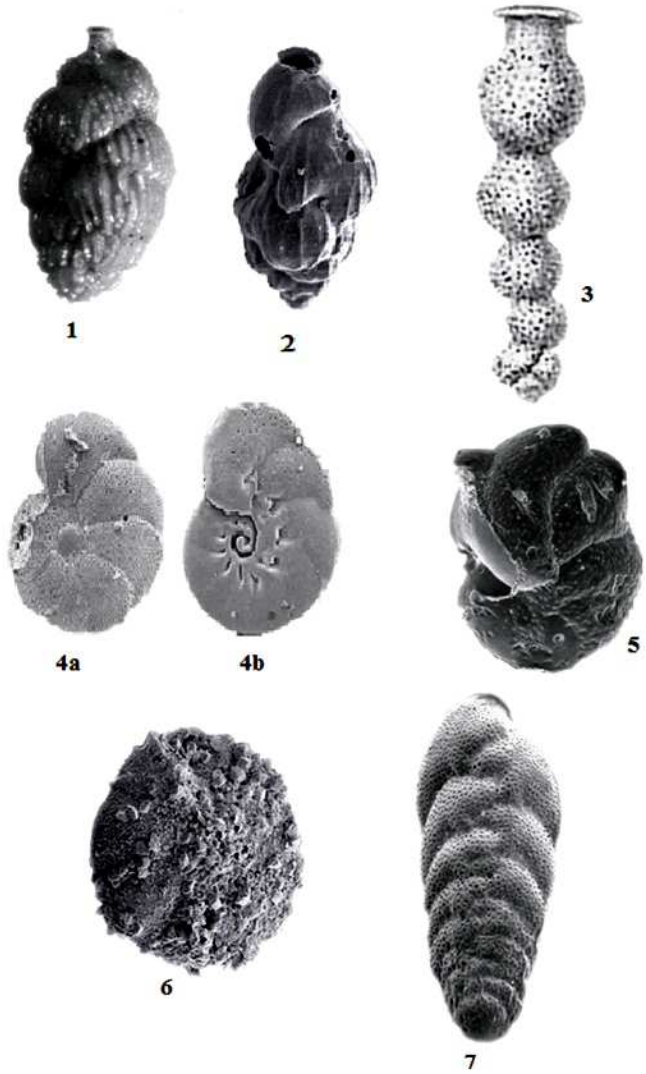

Plate 4
Benthic foraminifera species
Uvigerina gallowayi Cushman and Gray, 1940
Fig. 1 (x 115)
Uvigerina sp Cushman and Gray, 1946
Fig. 2 (x 161)
Siphogenerina sp Cushman and Renz, 1941
Fig. 3 (x 141)
Hanzawaia concentrica Cushman, 1918
Fig. 4a and b (x 121)
Hanzawaia sp Asano, 1944
Fig. 5 (x 106)
Epistominella pontoni Cushman, 1930
Fig. 6 (x 141)
Bolivina sp d'Orbigny, 1839
Fig. 7 (x 106)