Paleoecology, Paleoenvironment, and Petroleum Potential of middle-upper Cretaceous Calabar Flank Sediments, Southeastern Nigeria

Moshood Olayiwola, Ernest Durugbo, Olugbenga Fajemila, Olaonipekun Oyebanjo, Adedotun Aderogba, Olufemi Olaleye-Otunla, and Adebayo Aderanti

Abstract

Three Upper Cretaceous sections belonging to Mfamosing, Ekenkpon and New Netim Formations from the Calabar Flank, southeastern Nigeria, have been investigated to evaluate ammonite, palynology and palynofacies, and to interpret their paleoecology, paleoenvironments and hydrocarbon potentials. Mfamosing Formation is composed predominantly of limestone with shale intercalations. Ekenkpon Formation is made up mainly of shale with mudstone and sandy-mud intercalations. The New Netim consists mainly of marl with shale and sandstone intercalations. The presence of shell fragments and ferruginous materials suggests a shallow marine environment for the deposition of the Mfamosing Formation. The palynomorphs recovered in this study are moderately to poorly preserved. The Mfamosing and Ekenkpon Formations were dated to early Albian and early to late Cenomanian, respectively. Four types of palyno-debris were recognized in this study. They comprise phytoclasts (degraded and structured), opaque, amorphous organic matter (AOM) and palynomorphs. These palynofacies suggested highly proximal shelf or basin and marginal dysoxic-anoxic basin paleoenvironments of deposition. In addition, Kerogen type III was revealed, which has moderate potential for hydrocarbon generation. Morphometric analysis revealed that the conch shape of ammonite taxa was thin to thick, discoidal and involute. The degree of whorl overlap was strongly embracing and the whorl cross-section shape was weakly compressed. The Westermann Morphospace analysis revealed that the studied ammonite shell shapes correspond to oxycone (i.e., low umbilical exposure, low inflation and high whorl expansion) with assumed nektonic life modes. This study contributes to understanding the sediment deposition and petroleum resources of the Calabar Flank regions.

Keywords

Ammonite • Morphometric analysis • Morphospace analysis • Palynology • Palynofacies

1 Introduction

Paleoecology and paleoenvironment are mainly concerned with reconstructing past biota, populations, communities, landscapes and ecosystems from available geological and paleontological data preserved in the rock record (e.g., Bishop, 2018; Terry, 2009). Equally, petroleum potential is the thermal maturity and ability of source rocks' organic matter (kerogen) constituents to produce hydrocarbon (e.g., Atta-Petters et al., 2015). The present work aimed at integrating invertebrate paleontology (using ammonite species), palynology and palynofacies analyses to reconstruct the paleoecology and paleoenvironment, and to infer petroleum potentials of the Mfamosing, Ekenkpon and New Netim Formations of Calabar Flank, southeastern Nigeria (Fig. 1).

M. Olayiwola (✉) · O. Oyebanjo · O. Olaleye-Otunla · A. Aderanti
A. G. Leventis Museum of Natural History, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria
e-mail: moshood.adegboyega@gmail.com; mayiwola@oauife.edu.ng

E. Durugbo
Department of Biological Sciences, Redeemer's University, P.M.B. 230 Ede, Osun State, Nigeria

O. Fajemila
Department of Geological Sciences, Osun State University, Osogbo, Osun State, Nigeria

A. Aderogba
Department of Geology, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

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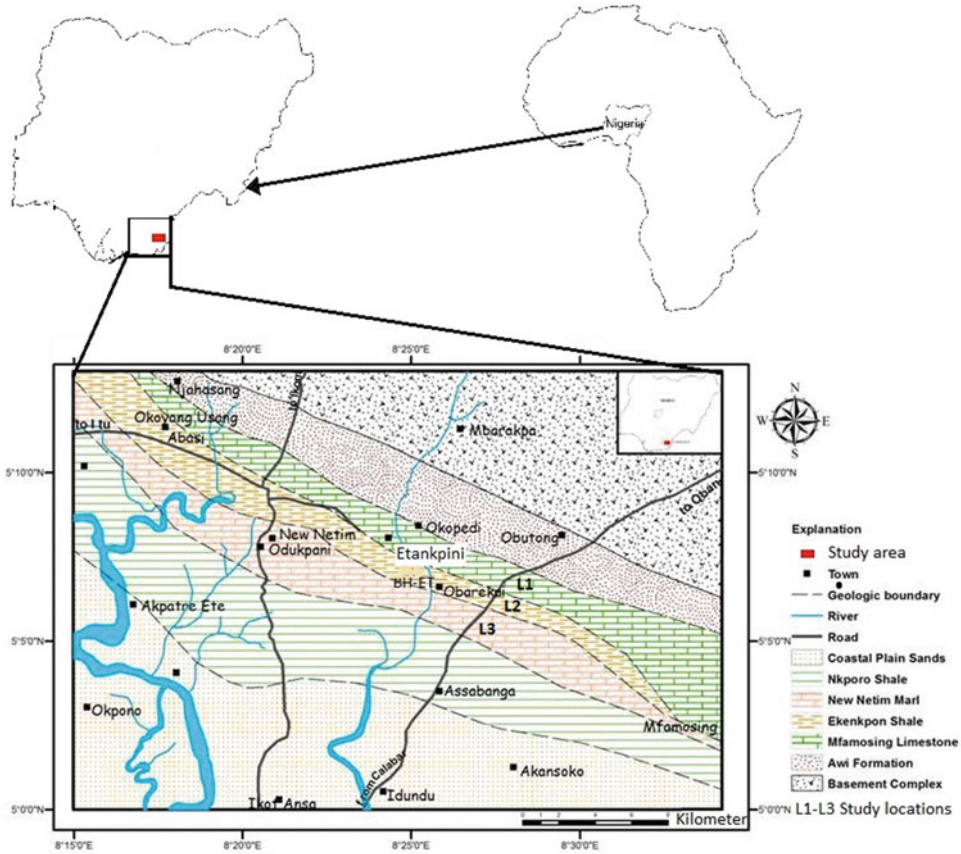


Fig. 1 Location map of the study area in the southeastern offshore Niger Delta (modified after Ukpong et al., 2018)

2 Materials and Methods

Fifteen (15) rock samples and twelve (12) ammonite mold samples were collected at different outcrop locations L1, L2 and L3, respectively (Fig. 1). Rock samples were subjected to standard lithostratigraphic description techniques for roundness, textures, color, sphericity, sizes and sorting of the sand particles. The presence and absence of accessory minerals such as ferruginous materials, glauconite, carbonaceous detritus, pyrites, calcites and shell fragments were also noted for each sample. Rock samples were further subjected to the standard palynological procedures based on the work of Faegri and Iversen (1989) to recover palynomorphs and organic matter particles (palynofacies). Ammonite mold samples were carefully cleaned with water and a paintbrush, and those embedded in rock were exposed with a chisel. The measurement of three cardinal conch parameters, conch diameter (Cd), whorl width (Ww) and whorl height (Wh), was carried out based on the works of Raup (1967). These parameters were used to generate Morphospace (i.e., the conch proportion and the expansion rate), which comprises conch width index (CWI), whorl width index (WWI), umbilical width index (UWI), whorl expansion rate (WER) and imprint zone rate (IZR).

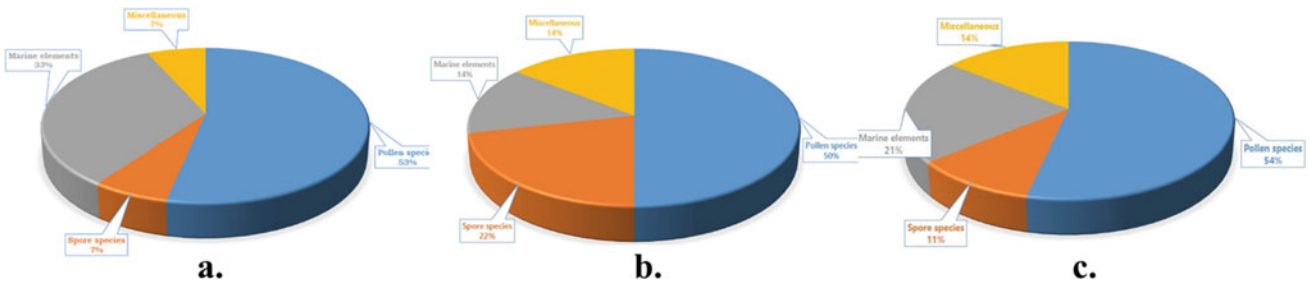


Fig. 2 Chart showing the distribution of palynomorphs species of the studied section of Calabar Flank. **a** Mfamosing formation at location L1, **b** Ekenkpon formation at location L2, and **c** New Netim Formation at location L3

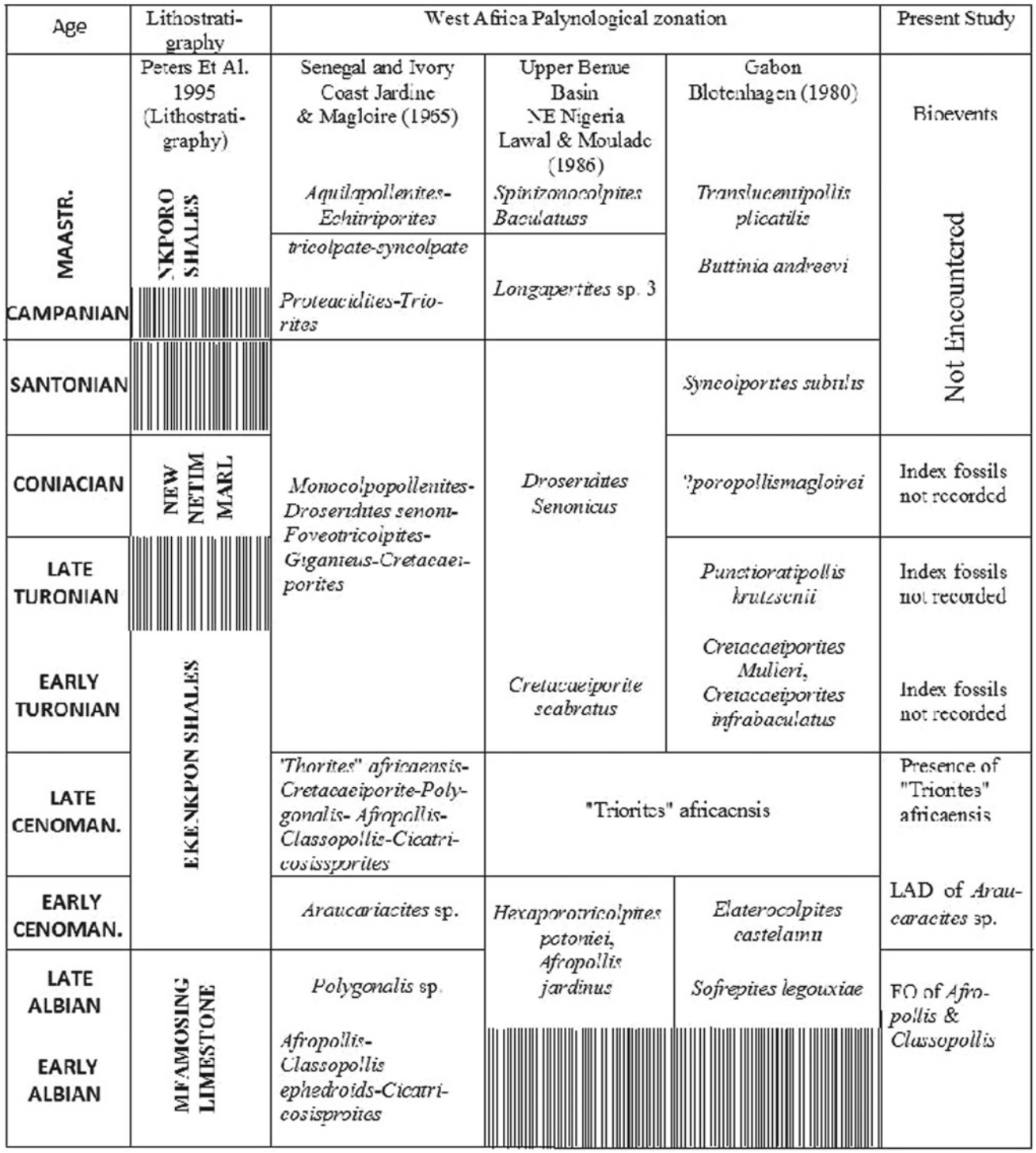
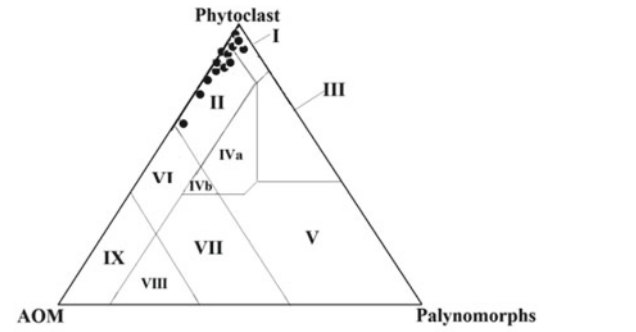


Fig. 3 Correlation charts of Cretaceous palynological biozonation in West Africa and the palynological zonation proposed in the present study. FO = First occurrence and LAD = Last appearance datum (Modified after Schrank 1992)



Palynofacies field	Environment of deposition
I.	Highly proximal shelf or basin
II.	Marginal dysoxic-anoxic basin
III.	Heterolithic oxic shelf (proximal shelf)
IV.	Shelf to basin transition
V.	Mud-dominated oxic shelf (distal shelf)
VI.	Proximal suboxic-anoxic shelf
VII.	Distal dysoxic-anoxic shelf
VIII.	Distal dysoxic-oxic shelf
IX.	Proximal suboxic-anoxic basin

Fig. 4 Ternary kerogen plots of the outcrop samples (Modified after Tyson, 1993)

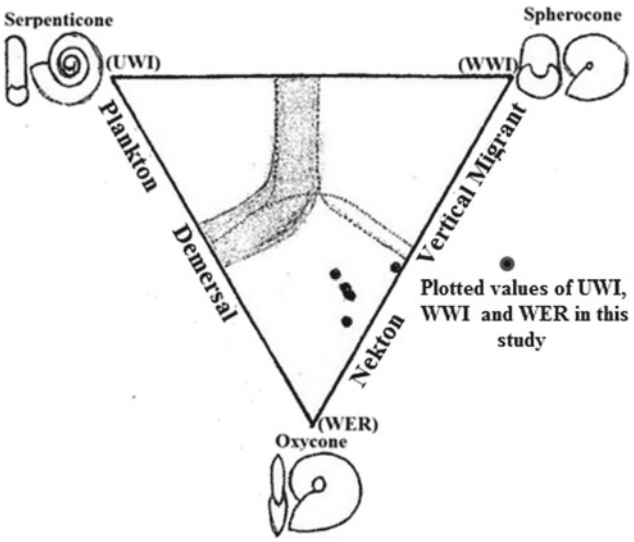


Fig. 5 Plots of values of umbilical width index from Mfamosing, Ekenkpon, and New Netim Formations (UWI)), whorl width index (WWI), and the expansion rate (WER) on Westermann Morphospace ternary diagram (Modified after Westermann, 1996)

3 Results and Discussion

The detailed lithostratigraphic analysis revealed the predominance of limestone lithofacies with shale intercalation in the Mfamosing Formation (e.g., Boboye & Okon, 2014). The present study shows that the Ekenkpon Formation lithologies are mainly shale with intercalation of thin bands of calcareous nodules, limestone and mudstone (e.g., Ukpong et al., 2018). The New Netim Formation lithologies are mostly marl with intercalation of shale and thin bands of limestone (e.g., Ayodele et al., 2017). A total of 32 palynomorphs that comprises 18 pollen, five spores, four marine elements and three miscellaneous elements are recovered from Mfamosing, Ekenkpon and New Netim Formations (Fig. 2a–c). The palynological assemblages in this study suggest shallow to the marginal marine depositional environments (e.g., Itam et al., 2019). Mfamosing and Ekenkpon Formations were dated early Albian to late Cenomanian due to the first occurrences (FOs) of Afro-pollis sp. and Classopollis sp., the last appearance datum (LAD) of Araucariacites sp. and the presence of Triorites africaensis (Jardine & Magloire, 1965; Lawal & Moulade, 1986; Fig. 3). The recorded palynofacies assemblage revealed a dominance of phytoclast with low percentages of AOM and rare occurrence of palynomorphs, which are types I and II of Tyson (1993) and interpreted as type III Kerogen (gas prone). They indicate fluctuation between highly proximal shelf or basin and marginal dysoxic-anoxic basin environments of deposition (Fadiya et al., 2020; Fig. 4). The paleontological analysis revealed sparse occurrence of ammonite taxa that comprised of genera Placenticeras, Coilopoceras and Acompsoceras. This study shows that the ammonite taxa are characterized by low umbilical exposure, low inflation and high whorl expansion similar to what has been previously described and correlated to oxycone shell shape with assumed nektonic life modes, which is associated with pelagic habitat (e.g., Westermann, 1996; Fig. 5).

4 Conclusion

This study has concluded that four lithologies were deposited in Mfamosing, Ekenkpon and New Netim Formations: marl, shale, limestones and sandstone. The palynological assemblage was dominated by terrestrial palynomorphs that helped in dating Mfamosing and Ekenkpon Formations to have ranged from early Albian to late Cenomanian age, and shallow to marginal marine depositional environment were suggested. The palynofacies assemblage was dominated by terrestrial kerogen, which is generally gas prone. The whorl conch shape of the ammonite taxa is characterized by thin to thick discoidal, involute, weakly compressed, low umbilical exposure, low inflation and high whorl expansion rate.

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