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ORIGINAL RESEARCH

Potent Tools in Reconstruction of Palaeoclimatic Condition of Sedimentary Facies in Zuma Coal Mine, Ankpa, Anambra Basin, North Central Nigeria.

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ABSTRACT

The formation of sedimentary rocks, especially those associated with coal seams, depends on several factors, including climatic conditions. This is a strong factor that is responsible for the sea level changes and is indirectly responsible for weathering, sediment transportation, deposition and vegetation. Therefore, reconstruction of the palaeoclimatic conditions of Zuma sedimentary facies was carried out by integrating eustatic change in sea levels through the application of sequence stratigraphy with change in vegetation patterns through the application of various palynomorphs such as pollen, spores, dinoflagellate, algae and fungal spores. The lithofacies samples studied indicate intercalation of coal seams bounded by claystone/shale facies at intervals which tend to vary with vegetation pattern and sea level changes. The basal part of the sequence consists of marginal marine claystone deposits characterized by a quantitative abundance of palynomorphs. This suggests the presence of a TST system tract belonging to a wet climatic condition due to an increase in sea level. The middle part of the sequence consists of coal deposits with a substantial amount of palynomorph abundance and diversity, marking the onset of the rising sea level (TST), of which the coastline migrated landward as a result of a shift in climatic conditions from dry climate to wet climatic period. Above the middle part of the sequence indicates a climatic change from a wet to a dry climatic condition, which is characterized by low palynomorph abundance and paucity in palynomorph diversity, having a low-stand systems tract of a fall in sea level. As a result of the dry climatic conditions in this interval, there is low organic matter content at this interval compared to the basal part of the sequence, which has abundant organic matter content and potential for hydrocarbon generation in the area.

Keywords: Climatic condition; Palynomorph; Marginal Marine; Zuma Coal Mine; Anambra Basin.

Introduction

Palaeoclimatic condition is a strong factor that is responsible for the sea level changes, and which is indirectly responsible for weathering, sediment transportation, deposition and vegetation (Ola-Buraimo and Ehinola, 2022). The damage caused by global warming intensifies daily, making it important and necessary to study and understand the dynamic nature of the Earth's climate system in the past. Thus, it helps in predicting current and future climate changes using different approaches/applications (Peters et al., 2005; Ayinla et al., 2017).

Some of the recent studies in the Okobo area, and Anambra Basin in general, involve Palynozonation/Chronostratigraphy, sequence stratigraphy and organic matter/maceral/palynomorph evaluation to determine the hydrocarbon potential of the basin (Ola-Buraimo, 2020; Ola-Buraimo and Ehinola, 2022; Ayinla et al., 2023, 2024). Ayinla et al. (2023 and 2024) focused on the ETA coal mine using Palynological tools to determine the age, biozonation, biostratigraphic correlation, paleo-depositional environment, organic matter type, organic matter quality and thermal maturity for hydrocarbon generation. These earlier works serve as an eye-opener for the current research, which involves careful evaluation of palynomorphs in terms of their abundance and diversity to reconstruct the paleoclimatic conditions.

The Application used for this study was investigated from two perspectives: by considering sea level changes through the application of sequence stratigraphy and by considering the change in vegetation through the application of various palynomorphs, such as pollen, spores, dinoflagellate, algae and fungal spores.

Different authors lean towards either of the two approaches. The sea level changes are usually related to contemporaneous deposits in which genetically related facies are known as systems tracts. The systems tracts represent the time when there was a reduction in sea level, equivalent to the low-stand systems tract; the rising of sea level is equivalent to transgressive systems tracts, and the high sea level is referred to as the high-stand systems tract (Vail and Wornardt 1991; Morley 1995 and Ola-Buraimo 2013; Ola-Buraimo and Ehinola 2022).

The central part of Nigeria, otherwise referred to as the middle belt, is similar in pattern to the climate of other parts of Nigeria described as humid tropical or tropical wet and dry, otherwise known as rainy and dry seasons, respectively (Obianuju et al., 2021). The natural vegetation varies from tropical rain forest in the southern part to the Guinea Savanna in the northern area.

The sequence stratigraphy method adopted here is widely practiced and pioneered by Vail and Wornardt (1990, 1991); Powell (1992, 1993); Morley (1995); Ola-Buraimo and Ehinola (2022). This research work will be based on the use of palynomorph abundance and diversity calculated from the prepared palynological slides. The interpretation in this study was adopted after the work of Ola Buraimo (2013), which was a modified fashion after the guidelines prescribed by Morley (1990); whereby, the total number of forms recovered in the petrographic slide represents the population, while the diversity account for the difference species encountered per slide. Therefore, according to Ola-Buraimo (2013), the population and diversity of palynomorphs recovered suggest the systems tracts and also reflect the corresponding paleoclimatic conditions that existed at the time of sediment deposition.

Therefore, in this paper, two different applications (Palynology and Sequence stratigraphy) were used to reconstruct the paleoclimatic conditions of the Zuma mine sedimentary facies, giving information about the sea level changes and the change in vegetation patterns present within the area (Ayinla et al., 2023; 2024). The information obtained from these two applications deduces the various Paleoclimatic conditions that occurred during and after deposition.

Geological Setting of the Study Area

The Anambra Basin is a Cretaceous intracratonic basin situated in southern Nigeria (Fig. 1), with a unique geological framework shaped by tectonic and sedimentary processes (Benkhelil, 1989). Its evolution is closely tied to the broader geological history of the Benue Trough, a major structural feature in West Africa (Obaje, 2009). The basin's sedimentary fill includes the Enugu Shale, Mamu Formation, Ajali Sandstone, and Nsukka Formation, each contributing to its complex stratigraphic architecture (Nwajide, 1990).

The Anambra Basin's geological history reflects a combination of tectonic subsidence and sedimentation, influenced by regional tectonic events (Akande & Erdtmann, 1998). Its potential as a hydrocarbon province has been recognized, with ongoing exploration efforts aimed at assessing its resource potential (Obaje, 2009). The geological history of the Anambra Basin has been extensively studied, with research focusing on its age, paleoenvironmental conditions, and tectonic evolution (Reyment, 1965; Murat, 1972; Salami, 1983). These investigations have also explored the basin's lithostratigraphy, biostratigraphy, and potential for hydrocarbon reserves (Agagu et al., 1985; Akande et al., 1992; Nwajide and Reijers, 1996). More studies continued to refine our understanding of the basin's geological framework and its implications for fossil fuel exploration (Akande et al., 2007; Akinyemi et al., 2013; Ola-Buraimo and Ehinola, 2022). The sedimentary record of the Anambra Basin began during the Campanian period, marked by the deposition of the Nkporo Group, which includes the Nkporo and Enugu shales and the Owelli Sandstone (Reyment, 1965). These basal beds provide valuable insights into the basin's early geological history.

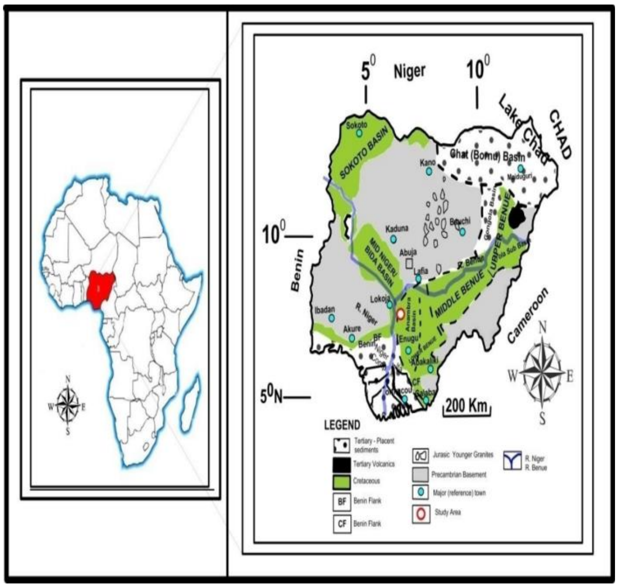


Figure 1: Geologic map of Nigeria showing the location of the Study area within the Anambra basin (Modified after Obaje, 2009).

Insights into the age of the Mamu Formation indicate that it dates back to the early to middle Maastrichtian period (Ogala et al., 2009). This formation is succeeded by the Ajali Sandstone, a Maastrichtian-age sand body characterized by its coarse-to-fine-grained texture and poor cementation (Kogbe, 1989). The Ajali Sandstone, in turn, is overlain by the Nsukka Formation, a sequence of coal-bearing sediments that span the Maastrichtian-Danian interval (Obi, 2000). The Nsukka Formation is followed by the Imo Shale, a Paleocene-age unit that is part of a larger sedimentary sequence (Nwajide, 1990). This sequence continues with the Eocene-age Ameki Group and culminates with the Ogwasi-Asaba Formation, a Late Miocene-Pliocene unit marked by sediment reworking (Ola-Buraimo & Akaegbobi, 2012). The detailed stratigraphy of the basin is given in Fig. 2.

Materials and Methods

Twenty samples comprising claystone/shale and coal recovered from ETA Zuma Coal Mine were subjected to palynological sample preparation. The samples were initially decarbonized with dilute hydrochloric acid. This was followed by sample digestion with hydrofluoric acid. After the digestion, the samples were sieved with a 10 µm mesh, allowing for the concentration of the organic matter and removal of clay-sized particles that might obscure the clarity under the microscope and clear photomicrographs.

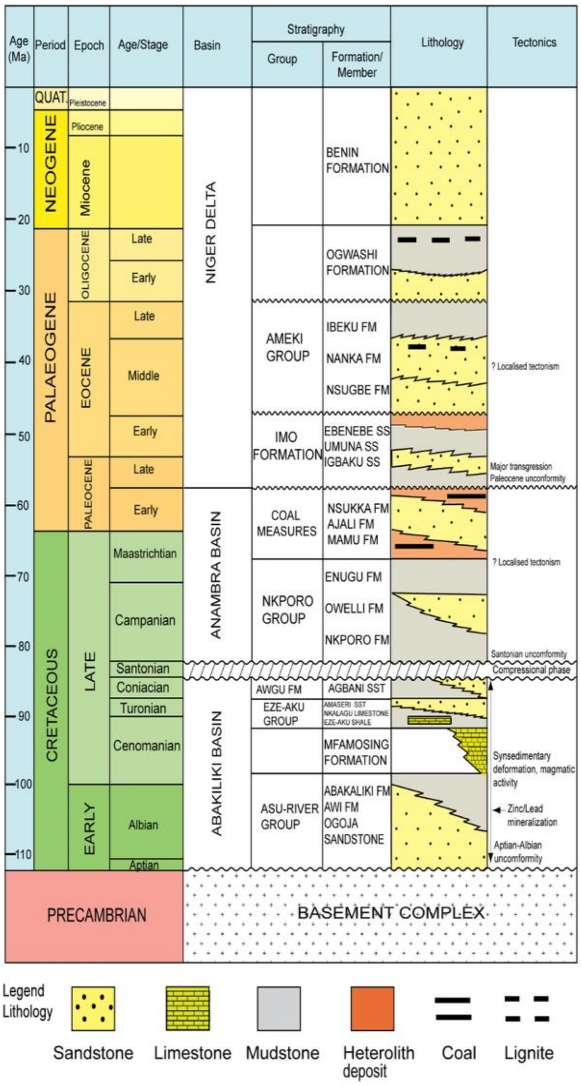


Figure 2: Stratigraphic Succession in the Anambra Basin and Outcropping Niger Delta (after Ekwenye and Nichols, 2016).

Other sample processing includes maceral separation through heavy liquid separation using zinc bromide. This stage was followed by the oxidation of the organic matter using nitric acid. The separated organic macerals were rinsed with ethanol before being mounted on the glass slides for microscopic analysis and photography of the preserved forms.

Results

Lithostratigraphic Succession

Field observation of the studied section in the ETA Zuma coal mine revealed that the coal mine comprises of four (4) lithologies which are claystone, argillaceous shale, coal and laterite (Table 1 and Fig. 3). The coal bed within the sedimentary session is about 1.9 m thick and laterally extentive with some intercalation of shale and claystone facies (Table 1, Fig. 3).

Palynomorph Abundance and Diversity

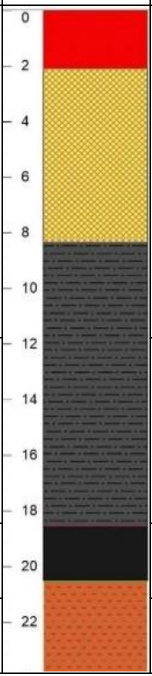
Table 1 shows the result of the palynological analysis carried-out on ETA Zuma samples which reveal predominance and diversity of palynomorph in the coal and mudstone samples from 12.5 m downwards (Table 1). The results show a systematic increase in the palynomorph abundance and diversity across the studied interval which is a reflection of the more organic matter input within the period (Tables 1 and 2). Based on this, Table 2 presents the systems tracts and climatic conditions inferred from the palynomorph data. The results indicate a range of systems tracts, including low-stand, transgressive, and high-stand systems tracts, and corresponding climatic conditions.

Table 1: Palynomorph abundance and diversity in the analysed samples (Modified after Ayinla et al., 2023)

S/N	Sample No.	Depth Point (m)	Palynomorph Abundance	Palynomorph Diversity	Lithofacies
1	1A	0.5	4	4	Clay-stone
2	1B	2.0	5	4	Clay-stone
3	2A	3.5	6	5	Clay-stone
4	2B	5.0	5	3	Clay-stone
5	2C	6.5	5	4	Clay-stone
6	3A	9.5	4	4	Clay-stone
7	3B	11.0	3	4	Shale
8	3C	12.5	22	11	Shale
9	3D	17.0	20	13	Shale
10	4A	18.7	20	11	coal

11	4B	18.9	23	12	coal
12	4C	19.1	8	6	coal
13	4D	19.3	20	11	coal
14	4E	19.5	12	7	coal
15	4F	19.7	24	13	coal
16	4G	20.3	5	5	coal
17	5A	20.8	3	2	Clay-stone
18	5B	21.3	22	14	Clay-stone
19	5C	22.3	20	14	Clay-stone
20	5D	23.8	27	11	Clay-stone

Table 2: Palynomorph abundance, diversity, systems tracts and climatic conditions

Sample depth	Litholog.	Abundance	Diversity	System track	Climate
0.5 11.0		4 3	4 3	Low-stand system tract	Dry
12.5 19.7		22.0 24	11 13	High-stand system tract	Wet
20.3 20.8		5 3	5 2	Transgressive system tract	Dry
22.3 23.8		2 27	14 11	Transgressive system tract	Wet

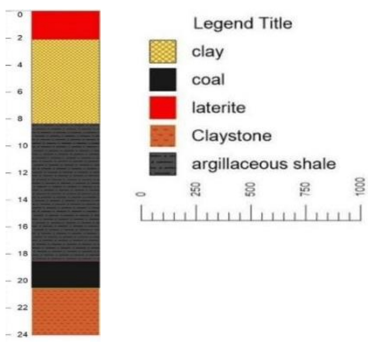


Figure 3: Litholog of ETA Zuma coal mine

Discussion

According to Ola-Buraimo (2013) the population and diversity of palynomorphs recovered suggest the systems tracts and also reflect the corresponding paleoclimatic conditions that existed at the time of sediment depositions. Therefore, the lithostratigraphic succession of the ETA Zuma coal mine indicates a complex intercalation of coal measure and claystone facies. The basal part of the stratigraphic sequence is characterized by a marginal marine claystone deposit, suggesting a transgressive systems tract (TST). The corresponding palynomorph abundance and diversity suggest a wet climatic condition (Ola-Buraimo 2013 and 2020).

The interval (20.3m–20.8m) is characterized by a paucity in palynomorphs and diversity, suggesting a dry climatic condition. This interval is interpreted to belong to the low-stand systems tract. The basal part of the stratigraphic sequence (21.3m–23.8m) is characterized by a quantitative abundance of palynomorphs and relatively high palynomorph diversity with a corresponding marginal marine claystone deposit.

The use of relative abundance of continentally derived pollen and spores compared to the amount of organic wall organism, such as dinoflagellates have been widely used in establishing the paleoenvironment of deposition and in the reconstruction of paleoclimatic condition that existed at various times due to eustatic changes in sea level. Researchers such as Chakir et al. (2020) and Ola-Buraimo (2020) have employed dinoflagellate abundance relative to pollen and spores in predicting paleo-climatic condition in Morocco and Anambra Basin respectively. The paleo-climatic condition of ETA Zuma coal mine, based on the use of dinoflagellates shows the same trend with the interpretation based on the use the of sea level changes. The results indicate a range of climatic conditions, including wet and dry climates, which are consistent with the interpretation based on sea level changes.

Furthermore, the paleoclimatic condition of the ETA Zuma coal mine, based on the use of dinoflagellates, shows a trend of wet climatic conditions during the Maastrichtian time, followed by a dry climatic condition, and then a return to wet climatic conditions. The dry climatic condition is short-lived and corresponds to the deposition of claystone facies (Ola-Buraimo 2013 and 2020). The dry climatic condition of the uppermost claystone facies spread over a relatively large area and geological time within the Cretaceous period, possibly suggesting a near Cretaceous Paleocene boundary reported to be characterized by poor palynomorph recovery (Lawal and Moullade 1986; Ola-Buraimo 2013 and 2020).

Conclusion

The Paleoclimatic condition of the ETA Zuma coal deposit indicates a wet-to-dry climate condition, suggested by the abundance of palynomorphs and the eustatic sea level during deposition. Thus, the lithofacies present in the ETA Zuma coal deposit have a dry climatic condition with a low abundance of palynomorphs at the top, a dry to wet climatic condition with a little abundance of palynomorphs at the middle and a wet climatic condition with a high abundance of palynomorphs at the bottom.

Declaration of Authors Contribution

Ayinla, H.A. designed and supervised the research. All the authors contributed to field work and sample collection. Ayinla, H.A., Abraham, G. and Ola-Buraimo, A.O. carried out the experiments, data analysis and wrote the initial manuscript draft. Sanni, Z., Toyin, A. and Ibrahim, A. reviewed and edited the manuscript for intellectual content. All the authors contributed to the development of the final manuscript and approved its submission.

Conflict of Interest

The authors declare no conflict of interest

Ethnics Approval and Informed Consent

Not applicable.

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