Biopalaeeoecology and palaeoecology

Biostratigraphy and palaeoenvironment of deposition of Nsukka Formation, Anambra Basin, southeastern Nigeria

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Abstract Biostratigraphy investigation of Nsukka Formation was carried out by subjecting well cutting samples obtained from Nzam-1 well to palynological studies with the view towards determining the relative geologic age and palaeoenvironment of deposition of the sediments. Samples were treated in the laboratory through digestion with hydrofluoric acid, sieving with 5 μm, oxidation with Nitric acid and mounting of the slides into sections with DPX mountant. A fairly high abundance and diversity of miospores were recovered, while the interval (847–1372 m) contains distinctive and diagnostic palynomorphs which are stratigraphically important.

A Spinizonocolpites baculatus assemblage zone was established based on the basal occurrence of S. baculatus, Spinizonocolpites echninus, Constructipollenites ineffectus, Periretisyncolpites sp. Periretisyncolpites giganteus, Monocolpites sp 1, Foveotriletes margaritae, Syncolporites marginatus, and Longapertites marginatus. The upper part of the interval is marked by association of Anacolosidites luidonis (at top), Mauritiidites crassibaculatus, Retistephanocolpites williamsi, Proteacidites dehaani, Echitriporites trianguliformis, Proxapertites cursis, Retidiporites magdalenensis, S. baculatus, Retiriculolpites gigeonetti, F. margaritae and Araucariacites sp. The Nsukka Formation is dated as Late Maastrichtian based on the co-occurrence of recovered index fossils. Importantly, Cretaceous–Tertiary (K/T) boundary is marked by high fossil content in the Maastrichtian sediments compared to paucity in palynomorph that characterise the overlying Paleocene facies. Palaeoenvironment of the analyzed section varies alternately from marginal marine to continental setting based on the presence of land-derived miospores and dinoflagellates.

Keywords Biostratigraphy, Palaeoenvironment, Assemblage, Gonyaulacacean/Peridinacean ratio, Index fossil, Anambra Basin

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1. Introduction

The Anambra Basin is an inland intracratonic basin located adjacent to Niger Delta, Nigeria (Fig. 1). Its study continues to attract attention of many geologists because of proven hydrocarbon reserves present. The Anambra Basin ranks almost next to Niger Delta in terms of richness in hydrocarbon reserves. Despite enormous amount of work done on the geology of the basin including the petroleum geology, biostratigraphy and sedimentology, there are no much details available on the biostratigraphy of Nsukka Formation. Therefore, there is need to further understand the stratigraphic stacking pattern especially the biostratigraphy of Nsukka Formation in terms of age and palaeoenvironment of deposition which could serve as a correlation platform for regional stratigraphic study. Such study would help to optimize hydrocarbon exploration and exploitation in the basin. These parameters are the main focus of this research work.

2. Geologic setting

The Anambra Basin is a major inland sedimentary basin in Nigeria (Fig. 1). Its evolution was based on the theory of the separation of the African and South American Plates during the Middle Mesozoic period (Burke et al., 1972; Nwachukwu, 1972). The theory ascertains that the Anambra Basin contains Albian—Santonian sediments in the eastern half referred to as Abakaliki depression while the other half proto-Anambra was a platform consisting of post Santonian sediments (Benkhelil, 1982; Murat, 1972; Nwachukwu, 1972; Nwajide and Reijers, 1996, 1997; Obi, 2000).

Past research works showed that the northern and western parts of the Anambra Basin mainly consist of post Santonian sediments. However it has been proven otherwise that the northern and the western parts of the basin in Onitsha and Edo state respectively, contain Middle Cretaceous to Late Tertiary sediments (Ola-Buraimo, 2013a, 2013b; Ola-Buraimo and Akaegbobi, 2012; Ola-Buraimo and Akaegbobi, 2013a). The Santonian period marked the stage when the basin experienced tectonic event that involved deformation, folding, faulting and uplifting of the pre-Santonian sediments in the Onitsa area which evolved as depression to the uplift (Benkhelil, 1987). However, this depression was limited in extent excluding the northern part of the Anambra Basin and southwestern part of the basin (Ola-Buraimo and Akaegbobi, 2013b).

The stratigraphic sequence of the Anambra Basin has been discussed extensively by several workers including Agagu et al. (1985); Dessauvagie (1975);...
Ladipo (1986); Murat (1972); Nton and Bankole (2013); Ola-Buraimo and Akaegbobi (2013b); Reyment (1965); Though, sedimentation in the Anambra Basin was based on the long standing assumption that it started and ranged from late Santonian to Eocene but recent research work of Ola-Buraimo and Akaegbobi (2012) on Ogwashi—Asaba Formation has shown that the formation in actual fact is of Late Miocene to Pliocene age based on the presence of dinoflagellate cysts. It has also been advanced that the oldest sediment in the basin like the other known parts is Asu-River Group, dated as Albian to early Cenomanian (Ola-Buraimo and Akaegbobi, 2013b) through the use of pollen and spores assemblages.

The Asu-River Group has varied lithologic unit, dark grey to black coloured shale, variously ferruginized, deposited in environment varying from continental through marginal marine to open marine systems (Ola-Buraimo and Akaegbobi, 2013b). This is overlain by Eze-Aku Formation, composed of predominantly dark shale, dated late Cenomanian to Turonian (Ola-Buraimo, 2013a). Awgu Shale dated Coniacian (Ola-Buraimo, 2013b) overlies the Eze-Aku Formation and marked the end of the first phase of sedimentation in the Anambra Basin before the commencement of tectonic event in the Santonian. The dislocation of the depocenter into the Anambra platform resulted into the deposition of the Nkporo Shale (Nwajide, 1990). The Nkporo Group comprises of Nkporo Shale, Owelli Sandstone, and Enugu Shale dated late Cenomanian to Turonian (Ola-Buraimo, 2013a). However, study based on palynology has dated the Asata/Nkporo Shale to be earliest Maastrichtian age (Ola-Buraimo and Akaegbobi, 2013b).

The Nkporo Shale is overlain by Mamu Formation deposited during early Maastrichtian (Kogbe, 1989; Obi, 2000). It is composed of siltstone, shale, coal seams and sandstone (Kogbe, 1989; Nton and Bankole, 2013). The age dating Mamu Formation has been further refined and recently dated to range from early to middle Maastrichtian based on pollen and spores recovered (Ogala et al., 2009). The Ajali Sandstone broadly dated Maastrichtian age overlies the Mamu Formation (Nwajide, 1990; Reyment, 1965). The sandstone is unconsolidated, coarse to fine grained, poorly cemented, with little mudstone and siltstone (Kogbe, 1989).

The Ajali Sandstone is overlain by Nsukka Formation dated Maastrichtian—Danian. This is also known as Upper Coal Measures (Obi, 2000; Reyment, 1965). The Imo Shale (Paleocene) overlies the Nsukka Formation (Nwajide, 1990) while it is successively overlain by Ameki Group, dated Eocene (Obi, 2000); Ogwasi-Asaba Formation consists of dark grey shale and sandy shale, characterized by evidence of sediment reworking and dated Late Miocene—Pliocene (Ola-Buraimo and Akaegbobi, 2012). The most recent sediment in the basin is the Benin Formation deposited by fluvial processes and is suggested to belong to Pliocene to recent in age based on stratigraphic position. The detailed stratigraphy of the basin is given below in Table 1.

3. **Methodology**

Twenty two ditch cutting samples of Nzam-1 well situated in the Anambra Basin ranging in depth from 847 m to 1372 m were used for the preparation of the palynological slides. The samples were taken for preparation at 24 m interval except where samples are not available. The sample preparation was carried out in the laboratory following the common practice (Green, 2001; Wood et al., 1996). Indurated samples were crushed with mortar and pestle in order to enhance maximum recovery of pollen and spores.

The crushed samples along with the friable ones of about 20 g weight (20 gm) were poured into labelled plastic beakers which were initially treated with dilute hydrochloric acid (HCl, 10%) in order to eliminate carbonate substance present in them. They were later soaked in 60% hydrofluoric acid (HF) overnight for about 20 h and stirred intermittently in order to achieve near complete digestion of silica and silicates. The samples were not oxidized in order to avoid corrosion, but were sieved with 5 μm mesh in order to maximize concentration of miospore grains and in

<table>
<thead>
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<th>Age</th>
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<th>Afikpo Basin</th>
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<td>Eze Aku Group (including Amasiri Sst)</td>
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<td>Cenomanian Albian</td>
<td>Asu River Group</td>
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**Palaeoenvironment**
- Marine
- Fluviatile
- Marine
- Marginal marine
- Marginal marine
- Marginal marine
- Marginal marine
- Marginal marine
- Marginal marine
- Marginal marine
- Marine

**Microforaminiferal wall lining**
- Botrococcus braunii
- Pediastrum
- Fungalspore

**Age**
- Late Maastrichtian
order to achieve clean slides for easy petrographic analysis. Other stages of preparation include heavy liquid separation of the macerals before they were finally mounted on glass slides with Deepex (DPX) mountant.

4. Result and interpretation

Twenty two samples were prepared and analyzed petrographically for palynomorph content. Palynological result reveals that the samples were rich in pollen, spore and dinoflagellates. The lower part of the interval is moderately to highly rich in miospores, the middle part is rare to barren, while the upper part is increasingly highly rich in pollen, spore and dinoflagellates (Table 2). The forms encountered are quite rich in abundance and diversity and they are well preserved as indicated in the Figs. 2–9. Lithofacies sequence of the interval is mainly dark grey fissile shale but interval 1109–1116 m is composed of dark grey sandy shale with sand/shale ratio of 30.70%, fine to medium in grain size, angular to subangular in shape, and rarely ferruginized in nature. The assemblages of the pollen forms in the interval 847–1372 m are characterized mainly by Maastrichtian forms. The assemblage belongs to S. baculatus assemblage zone compared with the works of Lawal (1982), Lawal and Moullade (1986) for the Lower Benue Trough, Nigeria, Jardine and Magloire (1965) for Senegal and Cote D’Ivoire sedimentary deposits.

Palynozone: S. baculatus Assemblage Zone.

Interval: 847–1372 m.
Age: late Maastrichtian.
Characteristic: The base of the interval is marked by the co-occurrence of \( S. \) baculatus and \( S. \) echinatus in association with \( C. \) ineffectus, \( P. \) retisyncolpites sp, \( P. \) giganteus, \( M. \) monocolpites sp 1 (Fig. 10), reduced abundance of \( L. \) marginatus, \( P. \) cursus, and \( V. \) marginatus. The top of the zone is defined by the co-occurrence of \( A. \) luidonisis and \( M. \) crassibaculatus (Fig. 2). At the level (847 m) \( P. \) retisyncolpites spp shows first disappearance. Other forms still present at the top of the interval are increased angiosperm pollen, \( R. \) monocolpites sp, stephanoporate pollen, and \( M. \) monosulcites sp. The top of the zone is also placed where there is high abundance and diversity of recovered sporomorphs end; this conforms to the observations of Lawal and Moullade (1986), Ola-Buraimo (2012) in marking the boundary between late Maastrichtian and Paleocene (K/T boundary) (Table 2).
Assemblages of miospores recovered in this zone is equivalent in part to those of sequences III, II, I for the Maastrichtian sediments in Senegal and Côte d’Ivoire by Jardine and Magloire (1965). The interval is characterized by increased angiosperms and decreased gymnosperms. The lower part of the zone is marked by relatively moderate abundance and diversity of miospore, the middle part is poor to barren while the upper part is most fossiliferous and diverse in nature (Figs. 11 and 12). The forms that characterize the upper section of the interval include R. williamsi, P. dehani, E. trianguliformis, C. ineffectus, L. marginatus, P. cursus, R. magdalensis, S. bacillatus, Anacolosidites sp, R. gigeonetti, F. margaritae, and Araucariacites sp. This portion of the interval is suggested to belong to late Maastrichtian to Early Paleocene. The presence of Anacolosidites sp suggests the Early Paleocene deposit (Germeraad et al., 1968).

The lower part (924–1372 m) is less fossiliferous, sparse of miospores and rarely barren. The
microfloral present include *P. cursus*, *Longapertites* sp, *E. trianguliformis*, *F. margaritae*, *Tetradiites* sp, *Mauritiidites crasibaculatus*, *S. marginatus*, *Lycopodium* sp, and *Longapertites microfoveolatus*. This part is suggested to belong to late Maastrichtian age. The *S. baculatus* assemblage zone established in this well is similar to palynological content of *S. baculatus* Assemblage Zone 6 erected by Lawal and Moullade (1986). However, *Trichotomosulcites* sp 1, and *Mildfordia jardinei*, described by Lawal and Moullade (1986) for this zone for the Lower Benue Trough sediments are restricted to older sediments (Ola-Buraimo and Akaegbobi, 2013a). Those forms may be contaminants in the sediment analyzed by Lawal and Moullade (1986).

The assemblages of miospores present in this zone are similar to the forms described in late Maastrichtian or younger age sediments of other places. This was observed by Germeraad *et al.* (1968), Jan Du Chene (1977), Jan Du Chene *et al.* (1978), Jardine and

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Fig. 5 All magnification at ×400. 1—Subtilisphaera sp.; 2—Triporate pollen; 3—Stephanocolpites; 4—*R. magdalenensis* Van der Hammen and Garcia, 1965; 5—*L. microfoveolatus* (Jan du Chene and Adegoke, 1978); 6—*Longapertites verneendenburgi* (Germeraad *et al.*, 1968); 7—Oligosphaeridium sp.; 8—*Retitriporites* sp.; 9—*Subtilisphaera* sp. (Lawal, 1982); 10—*Cyathidites* sp.; 11,16—*L. marginatus* (Van Hoeken-Klinkenberg, 1964); 12—*Caningia* sp (Lawal, 1982); 13—*Botryococcus braunii*; 14—*Oligosphaeridium* sp (Lawal, 1982); 15—*Inaperturopollenites* sp.

The analyzed interval is equivalent to the upper part of Gombe Formation characterized by decrease in gymnosperms and by development of angiosperms such as sulcate, triporate, tricolpates (Salard-Cheboldaeff, 1990). This zone is also equivalent to *P. dehaani* zone established by Germeraad et al. (1968) for the pantropical regions. The sediment of the zone is equivalent to Nsukka Formation in this well which shares the same sporomorphs with those found in the Iullummeden Basin in the North-West, Nigeria (Boudouresque, 1980); upper part of Fika Formation in Bornu Basin, Nigeria (Ola-Buraimo, 2012).

It is noted in this zone that some of the floral observed such as Proxapertites operculatus, *M. crassibaculatus*, *S. echinatus*, tricolpate grains, *R. williamsi* were also reported in Kerikerri Formation in the

![Fig. 6](image_url)
northeast. The Gombe Formation in the northwest (Iullemmeden Basin), Ewekoro Formation in the southwest (Dahomey Embayment) and Ebenebe Formation in the southeast were assigned Paleocene age. However, the assemblages of miospores described for the Mamu Formation Coal Seam Measure (Ogala et al., 2009) seem to be similar in part with those observed in this interval, but well correlated with established forms for the Lower Benue Trough, Nigeria which belong to the S. baculatus assemblage zone (Lawal and Moullade, 1986). Therefore, the interval is dated late Maastrichtian age and lithologically equivalent to the Nsukka Formation of the Anambra Basin, southeastern Nigeria.

5. Palaeoenvironment of deposition

Palaeoenvironment deduction of the analyzed interval was based on the presence of environmentally
significant forms. The presence of marine derived forms such as dinoflagellate and microforaminifera wall lining would suggest marine environment while preponderance of terrestrially derived miospores without recovery of dinoflagellate forms in the assemblage is suggestive of continental deposit. Therefore, interval 847–896 m is characterized by substantially high abundance of dinoflagellates such as Batiacasphaera sp, Polysphaeridium sp, Caningia capilata, Trichdinium sp, Andalusiella laevigata, Andalusiella sp, Andalusiella polymorpha, Subtilisphaera sp and Thalassiphora sp. Others are Trichodinium delicatum, Histrichodinium pulchrum, Oligosphaeridium complex, Cyclonephedinium distinctum, Criproeridinium edwardil, senegalidinii sp and microforaminiferal wall lining. The interval (847–896 m) is suggested to belong to marginal marine environment. Interval 896–1234 m is defined by
paucity of miospores mainly of terrestrially derived pollen and spores, thus, a continental environment of deposition is suggested for the interval. The underlying interval 1234–1271 m is characterized by association of terrestrially derived forms and marine grains such as Batiacasphaera sp, A. polymorpha and other forms of dinoflagellates. The sediments were deposited in marginal marine setting. Interval 1271–1320 m has similar characteristic like interval 896–1234 m, associated with continental deposit. The basal interval 1320–1372 m has combined recovery of miospores and dinoflagellates. Among the dinocysts present are Oligosphaeridium sp, Senegalinium sp, Polysphaeridium sp 1, dinoflagellate cysts and microforaminifera wall lining. The interval is suggested to belong to marginal marine setting. In a nut shell the analyzed interval varies alternately from marginal marine to continental environment of deposition.
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**Fig. 10** Palynology of marker fossils appearances with depth in interval 847–1372 m.
6. Conclusions

Detailed palynological study of interval 847–1372 m revealed that the pollen, spores and dinoflagellates contained varied from moderate at the base through few to barren at the middle to very fossiliferous at the upper part of the interval. The interval belongs to S. baculatus assemblage zone based on the co-occurrence of S. baculatus, C. ineffectus, P. spp, Monocolpites sp, and F. margaritae. The top of the interval is characterized by very high fossil abundance and diversity, and appearance of A. luidonisis (marked Paleocene) in association with M. crassbaculatus, R. williamsi and other typical Maastrichtian grains such as P. dehaani, E. trianguliformis, P. cursus, R. magdalenensis and F. margaritae. The interval is mainly shaley lithologically with minor heterolith of sandy shale at the middle part of the interval while the palaeoenvironment of deposition varies alternately from marginal marine to continental setting.

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