Palynological and Paleoenvironmental investigation of the Campanian Asata/Nkporo Shale in the Anambra Basin, Southeastern Nigeria.

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ABSTRACT
Ditch cutting samples of interval 2216-2716m recovered from Nzam-1 well located in Anambra Basin, Nigeria were investigated for sedimentological, palynological age dating and paleoenvironment of deposition. Different lithologic units were delineated, an intercalated gypsiferous shale and shale facies; overlain by sandy shale and shaly gypsum of varying gypsum content. Palynological zone of Milfordia spp acme zone was established. The zone is characterized by maximum development of Milfordia spp, Longapertites sp 3 and first uphole appearance of Buttinia andeevi. Other forms that mark the zone are regular occurrence of Cupanieidites reticularis, Syncolporites subtilis, Cingulisporites ornatus, Trichotomosulcites sp 1, Periretisyncolpites sp, Auriculiidites sp, Tricolpites gigantoreticulatus Foveotrilletes margaritae, Cupanieidites reticularis, Auriculiidites sp and Constructipollenites ineffectus. The top of the zone is marked by the final appearance of Trichotomosulcites sp 1, Milfordia jardinei, Cupanieidites reticularis and relative increase in Longapertites marginatus, Monocolpites marginatus, stephanocolporate pollen. The interval is particularly marked by maximum development of Milfordia spp depicting Campanian to Lowermost Maastrichtian age.

The paleoenvironment of deposition is marginal marine in nature defined by higher percentage of peridinaceans such as Senegalinium spp. and Andalusiella spp. over Gonyaulacysta forms. The relative position of the sea level and climatic condition is manifested on the lithofacies, characterized by the intercalation of shale and gypsum representing different times of transgression and lowstand phases.

Key Words: Lowermost Maastrichtian, Peridinacean, Gonyaulacacean, Gypsiferous shale
**Introduction**

The Anambra Basin of southern Nigeria was said to have evolved during the Santonian. This assertion is strongly criticized in the sense that going by the definition of Anambra Basin it includes all area or region which include the following states- Anambra, Enugu, Ebonyi, Delta, Kogi and part of Benue (Akaegbobi, 2005), while most of the work done by the author has revealed in contrary that the basin contains pre Santonian sediments such as Asu-River Group, Aze Area and Awgu Formations (unpublished). Most of the efforts of some researchers have been restricted to the southern part of the basin, most especially around Onisha and Enugu area. One other limiting factor to some of the activities carried out on the basin in term of biostratigraphic study has been documentation mainly on ammonite, brachiopods, and microforaminifera. Few works on the basin done by past researchers have been on outcrop samples or samples taken from open mines.

Nkporo shale was investigated by Mebrado, (1990) when he worked on Enugu shale otherwise known as Nkporo Formation and Iva Valley Shales (Mamu Formation) at Oyeama mines. His palynological investigation revealed Campanian-Maastrichtian age sediments. A further comparison of the palynomorph assemblages show that both the Enugu shale and Iva Valley Shale contain similar miospores but different on the account that the Enugu Shale contains dinoflagellates which Iva Valley lacks. He attributed the palynological content differences to gradual regression of the sea in the area.

This study was embarked upon to evaluate Asata/Nkporo Shale sequence from an exploratory well located in the northwestern part of the basin (Figure 1) on the basis of sedimentary and palynology in the order to understand the stratigraphic sequence, age dating and determination of the paleoenvironment of deposition of the sediments. It is strongly believed that data obtained from ditch cutting samples would be more reliable and result oriented than those obtained from out crop or mines which may suffer contamination and weathering.
Figure 1: Geological map of Anambra state showing location of Nzam-I well.
**Geologic setting and stratigraphy**

Sedimentation history of the Anambra Basin is related to the Lower Benue Trough evolution which is usually linked to separation of the Gondwana during the Middle Cretaceous time. The evolutionary trend of Anambra Basin is patterned by east to west shifting of the depocenters (Akaegbobi, 2005). The initial area of active sedimentation was located in the Abakaliki Trough from Aptian to Santonian. However, recent studies have shown that the active sedimentation was not restricted to the Abakaliki Trough alone but also took place within the graben of the faulted block segments of the Anambra Basin (authors unpublished Ph.D work). The pre Santonian formations are the Asu River Group, Eze Aku and Awgu Formations.

On the contrary, literature indicated that Anambra Basin became an active depocenter after the Santonian tectonic event (Reyment, 1972). Therefore, the Anambra Platform prograding deltaic started to subside and an east - west prograding deltaic system developed while Nkporo Shale and Lower Coal Measures were deposited in the basin center. Within the studied section of the well, the Asata/Nkporo Shale is not entirely shaly but contains some gypsum content.

The deltaic system was aborted during the Maastichtian by the commencement of major marine transgression (Akaegbobi, 2005). The basin extends northward to the Lower Benue River, and also forms a boundary with the Tertiary Niger Delta to the south. The Tertiary period was characterized by deposition of Imo Shale (Paleocene), Ameki (Eocene), Ogwashi-Asaba Miocene-Pliocene, unpublished work by author) and finally overlain by Benin Formation (See Figure 2).
### Table: Correlation Chart for Early Cretaceous strata in southeastern Nigeria

<table>
<thead>
<tr>
<th>AGE</th>
<th>ABAKALIKI-ANAMBRA BASIN</th>
<th>AFKPO BASIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.Y 30</td>
<td>Oligocene Ogwashi-Asaba formation</td>
<td>Ogwashi-Asaba formation</td>
</tr>
<tr>
<td>54.9</td>
<td>Eocene Ameki/Nanka formation/ Nsugbe sandstone (Ameki group)</td>
<td>Ameki formation</td>
</tr>
<tr>
<td>65</td>
<td>Paleocene Imo formation</td>
<td>Imo formation</td>
</tr>
<tr>
<td>73</td>
<td>Maastrichtian Ajali formation Mamu formation</td>
<td>Ajali formation Mamu formation</td>
</tr>
<tr>
<td>83</td>
<td>Campanian Npkoro Oweli formation/Enugu shale</td>
<td>Npkoro shale/Afikpo sandstone</td>
</tr>
<tr>
<td>87.5</td>
<td>Santonian Non-deposition/erosion</td>
<td>Non-deposition/erosion</td>
</tr>
<tr>
<td>88.5</td>
<td>Coniacian Agbani sandstone/Awgu shale</td>
<td>Eze Aku Group (include Amasiri sandstone)</td>
</tr>
<tr>
<td>93</td>
<td>Turonian Eze Aku Group</td>
<td>Asu River Group</td>
</tr>
<tr>
<td>100</td>
<td>Cenomanian-Albian Asu River Group</td>
<td>Asu River Group</td>
</tr>
<tr>
<td>119</td>
<td>Aptian Barremian Hauterivian Unnamed Group</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2:** Correlation Chart for Early Cretaceous strata in southeastern Nigeria (After Nwajide, 1990)
Methodology

Nineteen ditch cutting samples were obtained from Nzam-1 well for palynological slides preparation. The samples range in depth from 2216-2716m for both sedimentological description and palynological content. The first stage of the laboratory analysis was lithological sample description. The samples were described under the microscope by considering the colour, textural features of the grains, fossil content and post deposition diagenetic effects.

The weighted samples of about 20gm were labeled in plastic containers. Dilute HCl was added to the samples in order to remove the carbonate mineral present. This is followed by digestion of the samples in 60% grade Hydrofluoric acid (HF) stirring intermittently overnight. The samples were later sieved with 5um mesh in order to remove the clay size particles that might obscure clarity of the slides. Other stages involved include non-oxidation of the samples and heavy liquid separation of the macerals before they were finally mounted on glass slides with DPX mountant.

Counts of the pollen, spores, dinoflagellates, algae, fungi and other stratigraphically important forms present were made to determine the relative frequency of each species in the sample; upon which diagnostic species photographs were taken.

Result and Discussion

Sedimentology

The Asata/Nkporo Formation to a school of thought is the oldest deposit in the Anambra Basin in which the author has a contrary view. It was described to consist of dark shales and mudstones with occasional thin beds of sandy shale, sandstone, shally limestone and coal (Umeji and Edet 2008). Current study from the well section through a thorough litho-description shows five lithologic units; from the base gysiferous shale sequence (2716m-2420m), intercalated with shales, has an average gypsum/shale ratio percent of about 30:70% (See Figure 3). The top of this unit 1 is marked by a thin gypsum layer (2420m).
The unit 2 varies from 2420-2295 m characterized by mainly dark grey, fissile carbonaceous shale but with minor intercalated gypsum at the upper part of the interval. The lithologic sequence unit 3 is gypsiferous shale facies unit with a thin interbed of gypsum at 2173 m; it ranges from 2295-2203 m with a total thickness of 92 m. The forth lithologic unit ranges from 2201-2182 m (19 m thick) characterized by dark fissile sandy shale interbedded with a dark gray fissile shale (See Figure 3). Sand particles vary in size from medium to pebble; rounded to subangular, moderately sorted. The grading sequence shows an uphole increase in sand content which depicts a prograding deposit in a deltaic setting.

The unit 4 is overlain by lithologic unit 5 ranging in depth from 7160-7100 ft. It contains a dark grey to whitish fissile shaly gypsum; average gypsum content is over 75%. The gypsum distribution trend with depth shows an upward stratigraphic increase in gypsum content which may suggest a shoaling upward paleobathymetry.
<table>
<thead>
<tr>
<th>Depth(m)</th>
<th>Litho-log</th>
<th>Description</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>2216</td>
<td>Gp-.</td>
<td>Dark grey, fissile shaly gypsum, average gypsum content is over 75%</td>
<td>Uphole increase in gypsum content (Shoaling water body)</td>
</tr>
<tr>
<td>2182</td>
<td>Gp-.</td>
<td>Dark grey, fissile sandy shale intercalated with dark grey fissile carbonaceous shale. Sand size varies from medium to pebble; rounded to subangular and moderately sorted.</td>
<td>Prograding in a deltaic setting</td>
</tr>
<tr>
<td>2201</td>
<td>Gp-.</td>
<td>Dark grey to whitish gypsiferous shale with a thin layer of interbedded gypsum</td>
<td>Marginal marine deposit</td>
</tr>
<tr>
<td>2295</td>
<td>Gp-.</td>
<td>Mainly dark grey, fissile shale sequence, but gypsiferous at the upper part and underlain by a thin gypsum layer</td>
<td>Relatively deeper marine deposit</td>
</tr>
<tr>
<td>2420</td>
<td>Gp-.</td>
<td>Gypsiferous shale sequence with intercalated shale intervals. Gypsum/shale ratio is about 30:70</td>
<td>Contains higher percentage of shale to gypsum</td>
</tr>
</tbody>
</table>

**Figure 3:** Lithostratigraphy of the analyzed section (2216-2716m) of Well-N 1, Anambra Basin, Southeastern Nigeria.
The origin of the gypsum is of interest because it is in high concentration to shale facies. The gypsum (CaSO$_4$.2H$_2$O) is an evaporate deposit. Large deposits of gypsum are derived from marine brines (Sonnefed, 1985, 1989). Though evaporate minerals could as well appear in veins, cavities and even atoll cliff roofs, but this is most unlikely to be applicable to gypsum found in Anambra Basin, Nigeria. Thus, most occurrences of silistone are formed by the crystallization of salts from concentrated hydrous solutions (brines). Factors that control formation of such deposits include climate, hydrographic conditions (e.g. currents and density of brines and water), the chemistry of invading solutions, and the basin geometry (Sonnefed, 1989).

Evaporites generally have reported to form in arid regions (playas) of desert basins, in sabkha along the hot coastal regions and in extremely restricted to isolated marine basins along dry coastlines which is suggested for the Anambra Basin during the Campanian – Maastrichtian period of gypsum formation. Logan, (1987) gave conditions necessary for evaporates formation to include a water-balance deficit; that is the rate of evaporation must exceed periodical inflow of water into the basin. In essence this condition requires a constrain whereby the entrance to a basin is topographically or geographically restricted so that evaporation exceeds water inflow due to combination of topographic and climatological or hydrographic factors.

On the other hand a continental basin like Anambra Basin is more likely to experience high evaporation greater than rate of inflow of fluid. It is argued in other quarters that irrespective of the shape of the basin, less saline, lower density water that enters the basin will begin to spread across the top of the ambient fluid. The inflow fluid at the surface will undergo evaporation and consequent density increase. As salinity and density increase, the fluid precipitates evaporate minerals in restricted basin; sink to levels that preclude their escape from the basin.

It is further advanced that in continental basins, evaporation occurs at a distance from the mouth of streams that contribute less saline water to the basin. All these possibilities of evaporate formation could account for gypsum formation in the basin. However, the most favorable
concept is that where the basin is restricted from inflow of both fresh and marine waters into the basin as a result of topography high, climate (hot temperature) and hydrographic condition.

The Anambra Basin is bounded to the west by the Benin Hinge line and to the west of it is the Okitipupa Ridge (Adegoke, 1969). It is suggested that during the Campanian-Maastrichtian period the Okitipupa Ridge which was supposedly submerged was raised isostatically in such a way that it formed a topographically or geographic restriction to the basin whereby inflow of water into the basin was reduced (Figure 4). These in combination with hot tropical climate and probably hydrographic factors led to high evaporation of the brine water and subsequent precipitation and crystallization of gypsum mineral. This was found intercalated with shale beds due to transgression and tectonic adjustment otherwise referred to as dynamic topography.
Figure 4: Cross section of the relationship of the Okitipupa Ridge to the Anambra Basin forming topographic reconstruction along with other factors responsible for gypsum crystallization.
Palynology

The base of the zone at 2716m is defined by the first appearance of *Longapertites sp 3* (Lawal and Moullade, 1986), continuous occurrence of *Zlavisporites blanensis*, stephanocolporate pollen, *Verrucatosporites sp, Monocolpites sp* and *Cyathiditess sp*. At the near base of the interval is the appearance of new forms such as *Milfordia spp, Syncolporites subtil*, *Cingulatisporites ornatus* and *Monocolpites marginatus*. The top of the zone is characterized by the disappearance of *Milfordia spp*, and *Cupanieidites reticularis*. Within this zone, there is a variety of *Milfordia* taxa showing a continuous occurrence along with *Cupanieidites reticularis*. They are both restricted within the zone.

The top of the zone is marked by the disappearance of *Cupanieidites reticularis*, *Tricopites gigantoroticulatus* (Jardine and Magloire, 1965), *Retiricolpites gageonnetii* (Boltenhagen, 1976), *Milfordia jardine* and appearance of Stephanocolporate pollen. Many forms that are Maastrichtian markers have their offshoot within this zone; they include *Buttinia andreevi, Retidioporites magdalensis, Periretisyncolporites sp, Proxapertites cursus* and *Cingulatisporites ornatus*. However, some forms became extinct within this zone such as *Milfordia spp*, *Cupanieidites reticularis*, *Triorites africaensis*, *Ephedripites multicostatus*, *Auriculidites reticularis*, and *Cicatricosisporites sp*. Other miospores present within the interval are *Constantinisporites jacquei, Tricolporopollenites sp* (S. 152 of Jardine and Magloire, 1965), *Ulmoideipites sp*, Tricolpate pollen, *Monoporites sp*, *Leiotriletes sp*, *Inaperturopollenites sp, Verrucosisporites sp, Gemmatricolpites sp, Laevigatosporites sp*, and dinoflagellate cysts. The *Milfordia spp* acme zone is equivalent to *Longapertites sp 3 Assemblage Zone* of Lawal and Moullade, (1986). This zone is well represented in Nzam – 1 well, Anambra Basin, Nigeria.

Some of the miospores reported in this zone have been described in the Campanian-Maastrichtian sediments of Africa, South America and India. They are reported in the works of Van de Hammen, (1954); Van der Hammen and Wijmstra, (1964); Paeltova, (1961); Van Hoeken Klinkenberg, (1964, 1966); Jardine and Magloire, (1965). *Cupanieidites reticularis* and

The *Milfordia spp* acme zone is similar to other zones observed in Senegal and Cote d’Ivoire; equivalent in part to sequence IV-II of Jardine and Magloire, (1965); palynomorph assemblages from Campanian sediments of Egypt described by Sultan, (1985), Schrank, 1987); Upper Senonian sediment described from Brazil, Herngreen, (1972, 1975a, 1975b); Upper Cretaceous dinoflagellate assemblage reported from Cauvery Basin.

The presence of *Buttinia andreevi* and *Auriculidites sp* in the Upper part of the interval, appearing first in the stratigraphic column conform with the observations of Jardine and Magloire, (1965); Petrosgrants and Trofimov, (1971); Herngreen, (1975a), dating the sediments Campanian – Lower Maastrichtian age.

Nyong and Ramanathan (1985) established a Late Campanian for the Nkporo Shale on the basis of exclusive planktonic foraminiferal assemblages of *Globotruncana fornicate* (Plumer), *Rugoglobigerina rugosa* (Plummer), *Heterohelix pulchra* (Brotzen) and *H. globulosa* (Ehrenberg). However, ammonite fauna including *Libycoceras crossense* (Zarborski, 1982); *L. afikpoense* (Reyment, 1955) and *Sphenoidiscus lobatus* (Tuomey, 1956) assigned a Late Campanian age. Therefore, the interval 2216-2716m of the *Milfordia sp* acme zone is here conveniently dated Campanian to Lowermost Maastrichtian age.

The paleoenvironment of deposition is characterized by organic wall organisms such as *Senegalinium spp*, *Andalusiella spp*, *Spinidium sp 1*, *Cribrageridium sp* (Lawal, 1982), *Spiniferites sp*, *Oligosphaeridium* and *Dinogymnium sp*. The assemblage of the preponderance peridinacean over the short spine dinocyst is suggestive of marginal marine environment for the stratigraphic interval studied (Harland, 1973; Ogala et al, 2009; Ola-Buraimo and Adeleye, 2010).
<table>
<thead>
<tr>
<th>Lithology</th>
<th>Litholog</th>
<th>Formation</th>
<th>Marker fossil range</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>2216m</td>
<td></td>
<td></td>
<td>Cupaniidites reticularis</td>
<td>M. jardiniei</td>
</tr>
<tr>
<td>2271</td>
<td></td>
<td></td>
<td>M. Sp2A</td>
<td>Buttinia andreevi</td>
</tr>
<tr>
<td>2304</td>
<td></td>
<td></td>
<td>Milfordia jardiniei</td>
<td>M. Sp2A</td>
</tr>
<tr>
<td>2411</td>
<td>Nkporo</td>
<td></td>
<td>Milfordia sp Z</td>
<td>Campanian</td>
</tr>
<tr>
<td>2521</td>
<td></td>
<td></td>
<td>M. sp M. Sp3 M. Sp2D M. Sp4</td>
<td></td>
</tr>
<tr>
<td>2548</td>
<td></td>
<td></td>
<td>Milfordia sp 2B</td>
<td>Lowermost Maastrichtian</td>
</tr>
<tr>
<td>2603</td>
<td></td>
<td></td>
<td>Milfordia sp 2A</td>
<td>M. jardiniei</td>
</tr>
<tr>
<td>2716</td>
<td></td>
<td></td>
<td>Milfordia sp 2B</td>
<td>M. jardiniei</td>
</tr>
</tbody>
</table>

**Figure 5:** Trend of appearance and evolutionary changes in Milfordia taxa.
Conclusion

There is no doubt that Asata/Nkporo Shale is a post Santonian sediment deposit in the Anambra Basin, Nigeria. One of the main features in this study is the stratigraphic succession that indicated different lithofacies relationship which varies from base gypsiferous shale, intercalated with dark grey fissile shale. The upper shale sequence is sandy and pebbly in nature suggesting a prograding deltaic setting. The uppermost lithofacies has over 75% gypsum content which increases upward and suggestive of shoaling paleobathymetry.

Palynological inferences show maximum development of Milfordia taxa within the interval (2216-2716m); characterized by lowermost appearance of Longapertites sp 3 (Lawal and Moullade, 1986), while the upper part of the interval is defined by the first uphole appearance of Buttinea andereevi, last appearance of Cupanieidites reticularis and Milfordia jardinei. Thus, the studied interval is dated Campanian to Lowermost Maastrichtian age and the paleoenvironment of deposition is generally marginal marine setting.

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All magnification at X400

1. Monosulcites sp
3. Stephanocolporate pollen
4. Monocolpopollenites sphaeroidites
6. Milfordia sp
9. Dinogymnium sp
All magnification at X400

2. Cyathidites sp
3. Retimonocolpites sp
7. Botryococcus brunii
8. Auriculiiidites sp 1 Lawal, 1982
9. Dinocyst
PLATE 3

All magnification at X400

1 Milfordia sp 2A
2 Milfordia sp 2B
4 Cf Zlivisporites blanensis
5 Milfordia sp
6 Ephedripites sp
7 Araucariacites australis Cookson, 1947.
8 Psilatricolporites diversus
9 Milfordia sp 2D
10 Forma Y
11 Cicatricosisporites sp
PLATE 4

All magnification at X400

1 Retidiporites magdalenensis Van der Hammen & Garcia, 1965.
2 Milfordia sp Z
3 Milfordia sp 2A
4 Cupanieidites reticularis Cookson & Pike, 1954.
5 Milfordia sp 3 Lawal, 1982.
6 Milfordia sp
7 Milfordia sp 4
8 Stephanocolporate in Kuyl, Muller & Waterbolk, 1955
9 Phelodinium bolonienae
10 Forma Y
11 Cf Cupanieidites reticularis
All magnification at X400

2. Cupanieidites reticularis Cookson and Pike, 1954
3. Milfordia sp 2A
4. Cf Graminidites sp
5. Senegalinium sp sp
6. Monosulcites sp
7. Phelodinium bolonienae
8. Deflandre sp