

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*, *Cingulispores ornatus*, *Trichotomosulcites* sp 1, *Periretisyncolpites* sp, *Auriculiidites* sp, *Tricolpites gigantoreticulatus* *Foveotriteles 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

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31 Introduction

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37  Aze  Aka and Awgu Formations ( unpublished).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

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

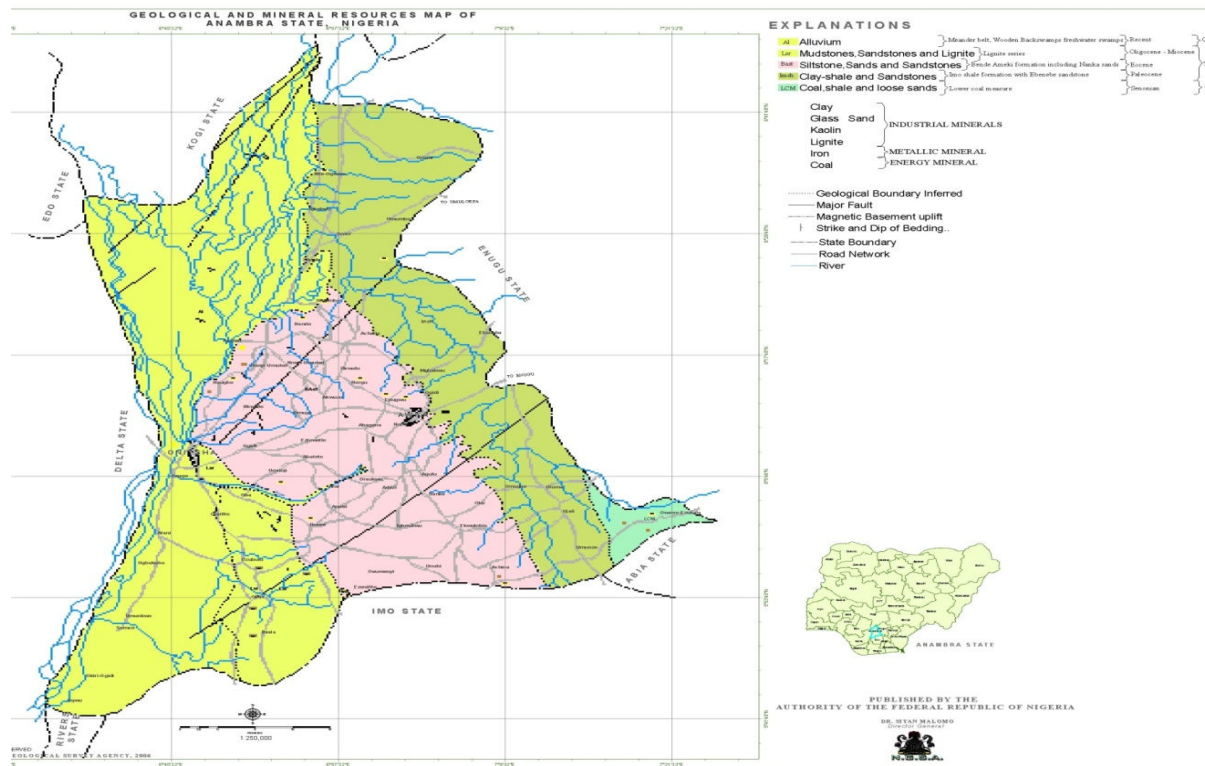
50 This study  was embarked upon to evaluate Asata/Nkporo Shale sequence from an
51 exploratory well located in the northwestern part of the basin (Figure 1) on the basis of
52 sedimentary and palynology in the order to understand the stratigraphic sequence, age dating and
53 determination of the paleoenvironment of deposition of the sediments.  It is strongly believed that
54 data obtained from ditch cutting samples would be more reliable and result oriented than those
55 obtained from out crop or mines which may suffer contamination and weathering.

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Figure 1: Geological map of Anambra state showing location of Nzam-1 well 

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71 **Geologic setting and stratigraphy**

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

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

85 The deltaic system was aborted during the Maastichtian by the commencement of major
86 marine transgression (Akaegbobi, 2005). The basin extends northward to the Lower Benue
87 River, and also forms a boundary with the Tertiary Niger Delta to the south. The Tertiary period
88 was characterized by deposition of Imo Shale (Paleocene), Ameki (Eocene), Ogwashi-Asaba
89 Miocene-Pliocene, unpublished work by author) and finally overlain by Benin Formation (See
90 Figure 2). 

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

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

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107 Methodology

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

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

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

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124 Result and Discussion

125 Sedimentology

126 The Asata/Nkporo Formation to a school of thought is the oldest deposit in the Anambra
127 Basin in which the author has a contrary view. It was described to consist of dark shales and
128 mudstones with occasional thin beds of sandy shale, sandstone, shally limestone and coal (Umeji
129 and Edet 2008). Current study from the well section through a thorough litho-description shows
130 five lithologic units; from the base gypsiferous shale sequence (2716m-2420m), intercalated with
131 shales, has an average gypsum/shale ratio percent of about 30:70% (See Figure 3). The top of
132 this unit 1 is marked by a thin gypsum layer (2420m).

The unit 2 varies from 2420-2295m 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 2173m; it ranges from 2295-2203m with a total thickness of 92m. The forth lithologic unit ranges from 2201-2182m (19m thick) characterized by dark fissile sandy shale interbedded with a dark gray fissile shale (See Figure 2). 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 7160-7100ft. 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.

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The origin of the gypsum is of interest because it is in high concentration to shale facies. The gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is an evaporate deposit. Large deposits of gypsum are derived from marine brines (Sonnenfeld, 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 (Sonnenfeld, 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 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.



UNDER PEER REVIEW

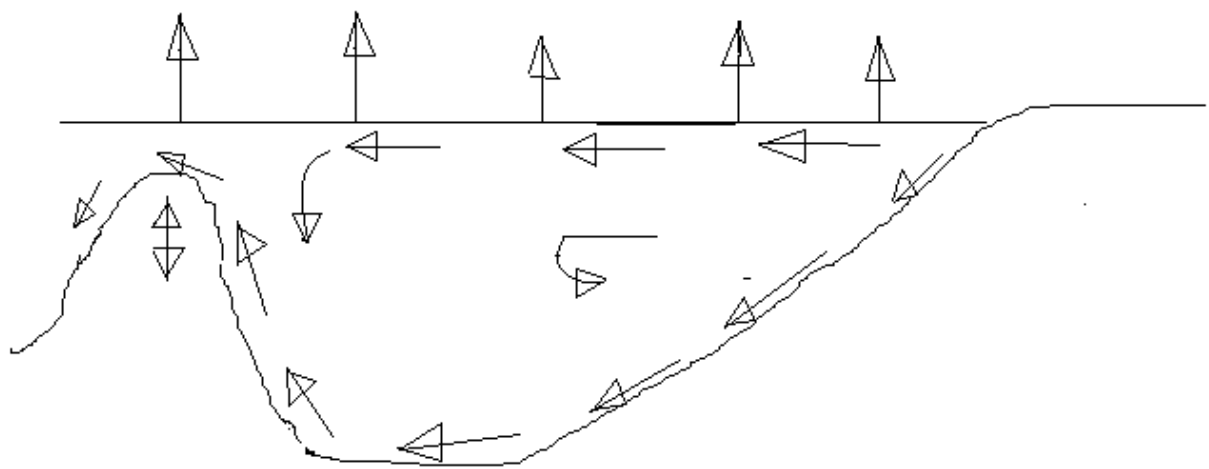


Figure 4: Cross section of the relationship of the Okitipupa Ridge to the Anambra Basin forming topographic reconstruction along with other factors responsible for gypsum crystallization.

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 *Zlvisporites blanensis*, stephanocolporate pollen, *Verrucatosporites sp*, *Monocolpites sp* and *Cyathidites 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*, *Tricolpites gigantoreticulatus* (Jardine and Magloire, 1965), *Retitricolpites 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*, *Retidiporites magdalenensis*, *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*, *Auriculiidites reticularis*, and *Cicatricosisporites sp*. Other miospores present within the interval are *Constantinisorites 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

Cingulatisporites ornatus have been reported by Boltenhagen, (1967, 1976); Sole de Porta, (1971, 1972a, 1972b); Herngreen, (1972, 1975a, 1975b); Jain, (1975, 1976); Elsik, (1974); Jan du Chene, (1977); Jan du Chene et al, (1978a, 1978b); Salard-Chebouldaeff, (1979); Baksi and Deb, (1981); Salami, (1983,1984,1985,1986,1988); Schrank, (1987); Oloto, (1987); Edet and Nyong, (1994); and Umeji, (2006).

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 *Auriculiidites 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*, *Cribroneridium 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).

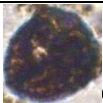
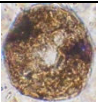
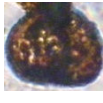
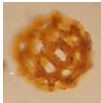
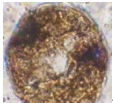
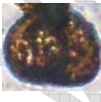
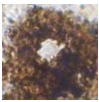
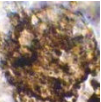
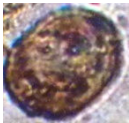
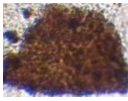
Lithology	Litholog	Formation	Marker fossil range	Age
2216m	---	Nkporo	  Cupaniidites reticularis M. jardiniei	Lowermost Maastrichtian
2271	---		  M. Sp2A Buttinia	
2304	---		  Milfordia jardiniei M sp2A	
2411	---		 Milfordia sp Z	Campanian
2521	---		M. sp M. Sp 3 M. Sp2D M sp 4	
2548	---		  Milfordia sp 2B M. jardiniei	
2603	---		 Milfordia sp 2A	
2716	---		  Milfordiasp Long. sp 3	

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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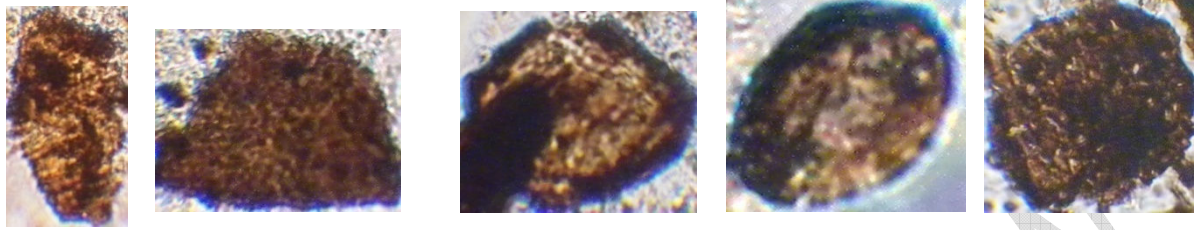
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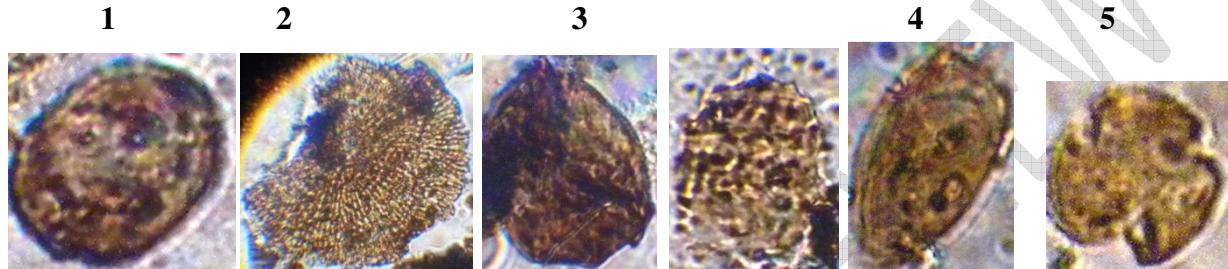
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PLATE 1

447 All magnification at X400



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Monosulcites sp

Longapertites sp 3 Lawal, 1982.

Stephanocolporate pollen

Monocolpopollenites sphaeroidites

Milfordia sp 3 Lawal, 1982.

Milfordia sp

Trichothyrites sp (microthyriaceous fungal fruiting body) Ruta et al, 2007.

Andalusiella laevigata Malloy, 1972.

Dinogymnium sp

Longapertites sp 3 Lawal and Moullade, 1986.

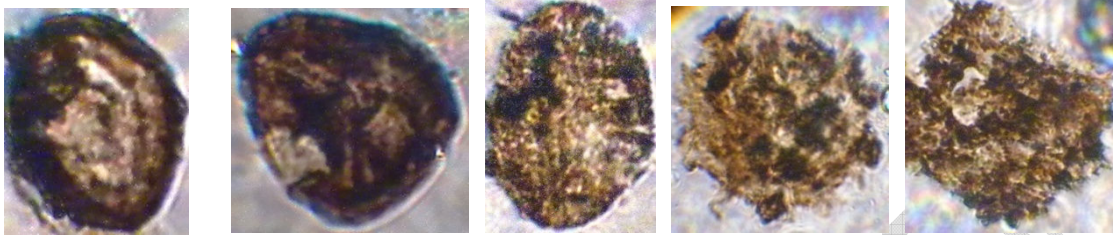
Tricolpites sp 1 Jardine & Magloire, 1965.

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PLATE 2

469 All magnification at X400



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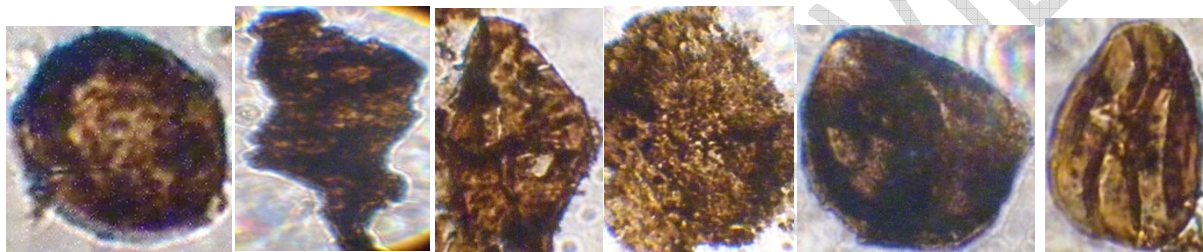
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475 1 *Cupanieidites reticularis* **Cookson and Pike, 1954.**

476 2 *Cyathidites* sp

477 3 *Retimonocolpites* sp

478 4 *Homotryblium* sp A **Oloto, 1987.**

479 5 *Phelodinium bolonienae* **Riegel, 1974.**

480 6 *Milfordia* sp 3 **Lawal, 1982.**

481 7 *Botryococcus brunii*

482 8 *Auriculiidites* sp 1 **Lawal, 1982**

483 9 *Dinocyst*

484 10 *Phelodinium belonienae* **Riegel, 1974.**

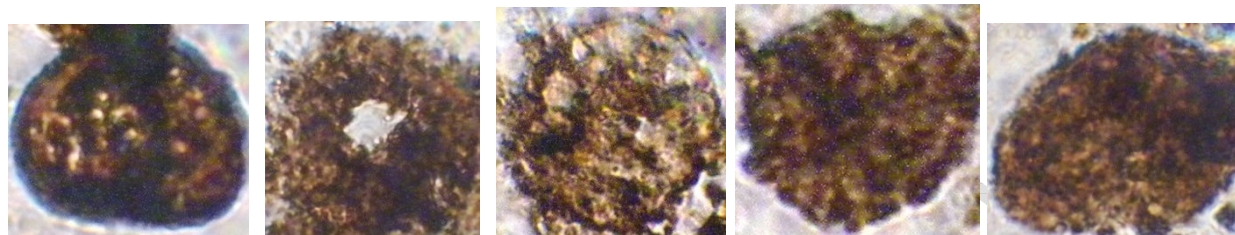
485 11 *Tricolpites* sp 2 **Jardine & Magloire, 1965.**

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PLATE 3

488 All magnification at X400



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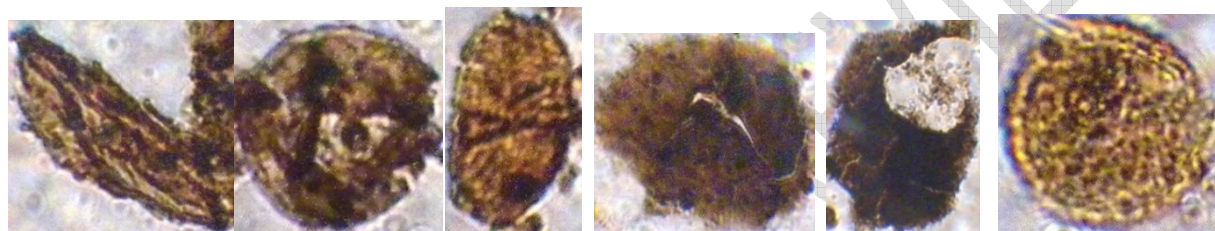
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493 1 Milfordia sp 2A

494 2 Milfordia sp 2B

495 3 Milfordia jardinei **Hochuli, 1979.**

496 4 Cf Zlivisporites blanensis

497 5 Milfordia sp

498 6 Ephedripites sp

499 7 Araucariacites australis **Cookson, 1947.**

500 8 Psilatricolporites diversus

501 9 Milfordia sp 2D

502 10 Forma Y

503 11 Cicatricosisporites sp

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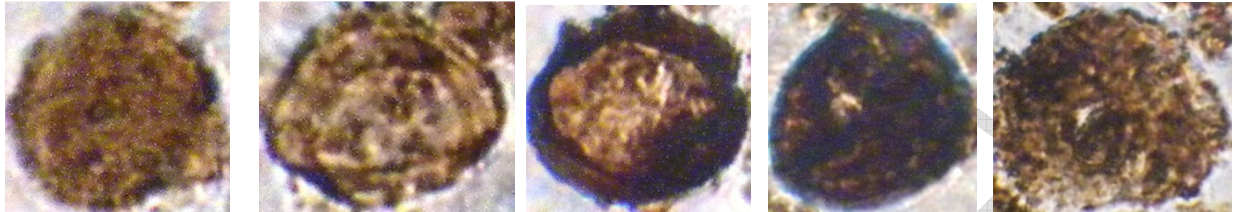
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PLATE 4

508 All magnification at X400



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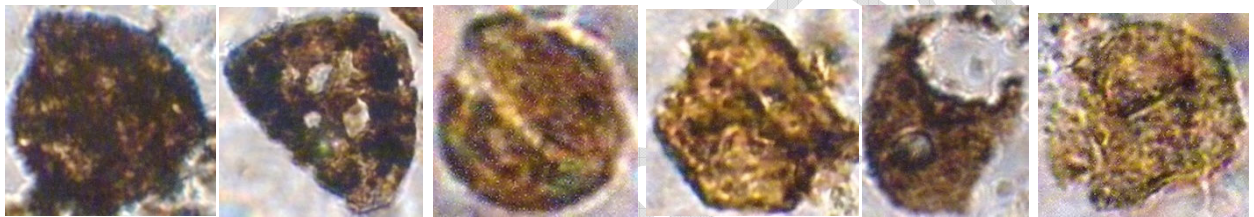
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513 1 Retidiporites magdalenensis **Van der Hammen & Garcia, 1965.**

514 2 Milfordia sp Z

515 3 Milfordia sp 2A

516 4 Cupanieidites reticularis **Cookson & Pike, 1954.**

517 5 Milfordia sp 3 **Lawal, 1982.**

518 6 Milfordia sp

519 7 Milfordia sp 4

520 8 Stephanocolporate **in Kuyl, Muller & Waterbolk, 1955**

521 9 Phelodinium bolonienae

522 10 Forma Y

523 11 Cf Cupanieidites reticularis

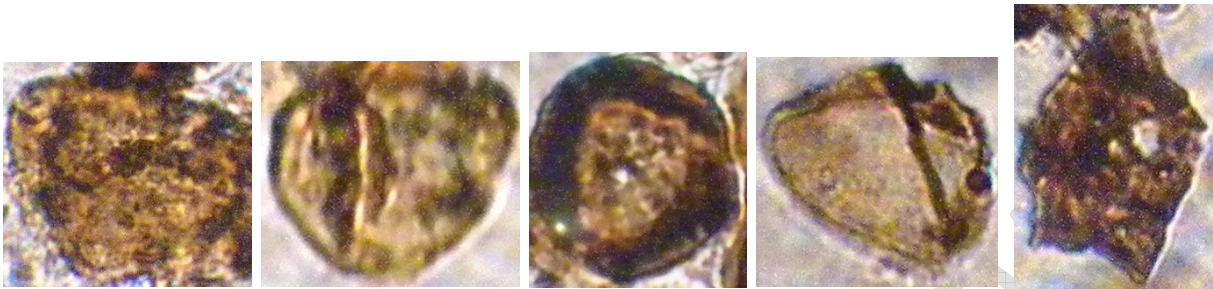
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PLATE 5

526 All magnification at X400

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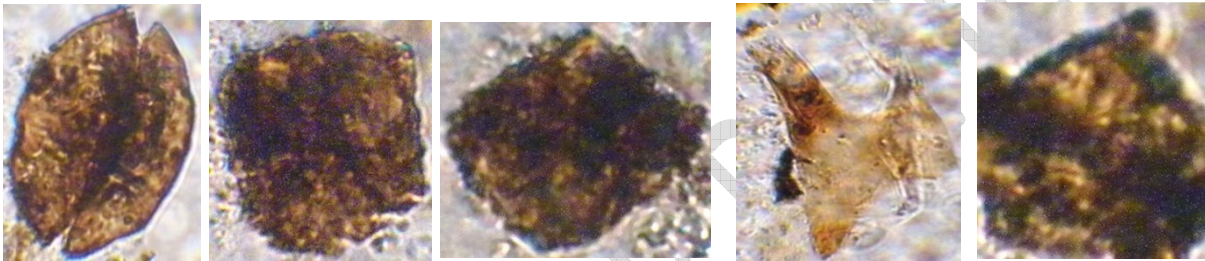
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531 1 Syncolporites ifeensis Jan du Chene, 1977.

532 2 Cupanieidites reticularis Cookson and Pike, 1954

533 3 Milfordia sp 2A

534 4 Cf Graminidites sp

535 5 Senegalinium sp sp

536 6 Monosulcites sp

537 7- Phelodinium bolonienae

538 9 Deflandre sp

539 10 Senegalinium sp 8 Lawal, 1982.

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