Biostratigraphic implications of *Hedbergella sigali* Moullade (foraminifera) and *Ephedripites multicostatus* Brenner (pollen): Evidence for Berriasian – Turonian age for the Mfamosing Limestone and Ekenkpon Shale in the Calabar Flank, South Eastern Nigeria

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Integrated biostratigraphic analysis was carried out on three shallow wells (A, B & C) drilled in the Calabar Flank, southeastern Nigeria, in order to determine the age of the study wells. Standard biostratigraphic sample preparation / separation and analytical approaches were applied on seventeen (17) core samples obtained from the study wells. Berriasian - Turonian age was assigned to the recovered sediments based on the co-occurrences of *Ephedripites multicostatus*, *Ephedripites jansonii*, *Classopollis spp*, *Classopollis classoides*, *Classopollis jardinel*, *Triorites africaensis*, *Cretaceiporites mulleri*, *Cretaceiporites polygonalis*, *Trifosapollenites rugosa*, *Triorites africaensis* and *Steevesipollenites binodosus* (palynoflora) as well as the co-occurrences of *Hedbergella sigali*, *Hedbergella delrioensis*, *Hedbergella crassa*, *Hedbergella planispira*, *Hedbergella sp.*, *Hedbergella simplicissima*, *Heterohelix moremani*, *Heterohelix reussi*, *Heterohelix sp.*, *Haplophragmoides sp.*, *Triffosapollenites rugosa*, *Steevesipollenites binodosus*, *Ammotium cf nkalagum*, *Ammotium cf nwalium* and *Globigerinelloides caseyi* (microfauna). The occurrence of *Hedbergella sigali* points to an age of Barremian – Aptian and the foraminifera zone indicating this age is named after this foraminifera (*Hedbergella sigali* zone). *Ephedripites multicostatus* points to an age of Berriasian – Velanginian (Neocomian), the pollen zone indicating this age is named after this palynomorph (*Ephedripites multicostatus* zone). The co-occurrence of some age diagnostic palynomorphs (*Classopollis spp*, *Classopollis classoides*, *Classopollis jardinel*, *Triorites africaensis*, *Cretaceiporites mulleri*, *Trifosapollenites rugosa* and *Steevesipollenites binodosus*) as well as some age-diagnostic microfauna (*Hedbergella crassa*, *Hedbergella planispira*, *Heterohelix moremani*, *Heterohelix reussi* and *Globigerinelloides caseyi*) point to the Aptian – Turonian age bracket. It was on this basis that the Hauterivian - Turonian age was assigned to the Ekenkpon Shale and Berriasian – Albian for the Mfamosing Limestone.

**Keywords**: foraminifera, palynomorphs, Albian, Berriasian, Hauterivian, Turonian, Mfamosing Limestone, Ekenkpon Shale, Calabar Flank

**INTRODUCTION**

The stratigraphic positions of the Ekenkpon Shale and Mfamosing Limestone on the global chronostratigraphic chart have been a topical issue for quite some time. Several researches have been conducted on outcrop and core samples obtained from the Ekpenkon Shale and Mfamosing Limestone, Calabar Flank to determine their ages. Several authors have given attention to the ages of these formations (Ekpenkon Shale and Mfamosing Limestone) in the Calabar Flank in the course of their research. Some of the authors include: Reyment (1955; 1965), Dessauvagie (1968), Fayose (1979), Nair et al. (1982), Zaborski (1982), Petters (1980, 1982, 1983), Petters & Ekweozor (1982), Nyong and Ramanthan (1985), Akpan (1985, 1992,1996) Petters et al.(1995), Ramanathan and Nair (1984), Adegbie and Bassey (2007), Ukpong et al. (2008), Ukpong and Ekhalialu (2015, 2018) and Ukpong et al. (2018).

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The earliest biostratigraphic study conducted on the Calabar Flank was done by Reyment (1955, 1965) using ammonites to study the Odukpani Formation, north of Calabar. Reyment (1955, 1965) assigned a Cenomanian age to the rocks which constitute the Odukpani Formation in which the Mfamosing Limestone and the Ekenkpon Formation form the middle units with the Awi Formation making up the basal unit. Adeleye and Fayose (1978) subdivided the Odukpani Formation into two distinct formations based on their tectonism and lithologic identity. Adeleye and Fayose (1978) went on and proposed the name “Awi Formation” for the basal arkosic sandstones and conglomerates of the Odukpani Formation (Reyment, 1965) and delineated the type section but retained the Odukpani Formation for the rest of the succession. Petters (1983) erected the Mfamosing Limestone as a new lithostratigraphic unit from the remaining Odukpani Formation and retained same for the rest of the succession. Petters et al. (1995) and Nyong (1995) further subdivided the rest of the Odukpani Formation into New Netim Marl, Nkporo Shale and the Benin Formation based on their lithologic identity, delineated the type sections and abandoned the name Odukpani Formation. Petters et al. (2010) elevated the Odukpani Formation of Reyment (1965) to Odukpani Group with the exception of the Awi Formation.

Dessauvagie (1968) reported the occurrence of a foraminiferal species *Trocholina odukpaniensis* from this limestone and proposed a Late Albian age based on this. Forster and Schulz (1979) dated the Mfamosing Limestone Albian using ammonite. Forster (1978) and Forster and Schultz (1979) presented ammonite biostratigraphic evidence for a Late Albian age for the base of the Ekenkpon Shale and the top of the Mfamosing Limestone. The study of Fayose (1979) on the carbonate/shale sequence of the Eze-Aku Shales, exposed at the Nkalagu Limestone quarry in the Lower Benue Trough, found abundant species of *Heterohelix* and *Hedbergella* suborder and some ostracodes such as *Brachychythere*, *Oxovutheridea* and *Paryacypris* which gave a Lower Turonian age.

The Mfamosing Limestone was described by Nair et al. (1982) to be barren of age diagnostic foraminifera but assigned a Late Albian – Early Cenomanian age based on ammonite biostratigraphic analyses. Petters (1982) used the co-occurrence of *Globigerinelloides caseyi*, *Hedbergella planispira* and *Hedbergella sigali*, in the Nkalagu Formation exposed near Calabar to assign Cenomanian age. Ramanathan and Nair (1984) recorded the occurrence of forms such as *Anomalina plummerae*, *Gavelinella intermedia*, *Patellina subcretacea*, *Ammobaculites coprolithiformis*, *Ammobaculites fisheri* and *Ammobaculites irregulariformis*. Based on these species, they suggested an age ranging from Late Aptian to Albian for the Gboko Limestone and correlated it to the Mfamosing Limestone in the Calabar Flank. The study of Akpan (1992) recorded the Ilerid gastropod, *Peruviella dolium* in the Mfamosing Limestone for the first time and assigned a Mid – Albian age to this limestone unit. Zaborski (1982) assigned Upper Albian - Lower Cenomanian to be base of the shale (Ekenkpon Shale) immediately overlying the Mfamosing Limestone based on ammonites (*Mariella m. ochletti, Puzosia of antianmangaensis, Pachydesmoceras cf., radaodyi, Desmoceras d., latidorsatum and Flickia quadra*). Based on these ammonites, he assigned an Albian age for the underlying Mfamosing Limestone. The occurrence of some known Albian ammonite from the hard ground which forms the top of the Mfamosing Limestone gave evidence for an Albian age for the limestone unit (Zaborski, 1982).

Ukpung et al. (2008) discussed the age of the Ekenkpon Shale from landslide section along Calabar- Itu road and assigned a Late Cenomanian- Late Turonian age to this section based on the co-occurrences of *Heterohelix pulchra, Heterohelix moremani, Heterohelix globulosa, Hedbergella delrioensis, ammobaculites spp* and *Praebulimina spp*. Ukpung and Ekhalialu (2015, 2018) using core samples assigned a Cenomanian – Turonian age based on the recovered foraminifera (*Heterohelix moremani, Heterohelix reussi, Heterohelix planata, Heterohelix reussi, Hedbergella delrioensis, Hedbergella crassa, Hedbergella planispira, Globigerinelloides caseyi*) and palynomorphs (*Stevespillenites binodosus, Ephe dipites sp, Leioti hile sp, Classopolis sp, Classop sp, Classopolis classoides, Classopolis annulatus Eaphidipites jansonii, Cretaceaeiporites mulleri*, *Cretaceaeiporites polygonalis, Galeacornea clavis and Triorites af ricaensis*). Ukpung et al. (2018) assigned Cenomanian - Early Turonian to core sample from the Ekenkpon Shale based on *Guembelitria harrisi, Hedbergella crassa, Hedbergella delrioensis, Hedbergella simplicissima, Hedbergella planata, Heterohelix reussi, Hedbergella planispira and Hedbergella sigali*.

The investigated wells (A, B, & C) were drilled in the Calabar Flank and core samples were obtained to determine the age of the formations (Ekenkpon Formation and Mfamosing Limestone) under study (fig 1) based on their foraminifera and palynomorphs assemblages. Well A was drilled at Etankpini while Wells B and C were drilled at Mbarakpa, Calabar Flank.

**Geologic setting and stratigraphy**

The Calabar Flank (Murat, 1972) is an epeirogenic basin situated in the easternmost part of the sedimentary basins in Southern Nigeria (Nyong and Ramanathan, 1985). It is bounded by the Cameroon volcanic trend to the east, the Ikpe platform to the west, the Oban Massif and the Calabar hinge line to the north and south respectively (fig 2). It was thought to be the south – eastern extension of the Benue Trough trending in a Northwest – Southeast (NW-SE) and lying between latitudes 4°50’ - 5°50’N and longitudes 7°50’ - 8°50’E (Petters, 1982). The origin of the Calabar Flank is closely associated with the Rift System that formed the Benue Trough during the final opening of the South Atlantic from Africa (Petters, 1982, Petters et al., 1995). Sedimentation in
the Calabar Flank started with the deposition of Fluvio-
deltaic shale, mudstone and arkosic sandstone of the Awi
Formation dated to be of the Aptian age (Adeleye and
Fayose, 1978). Ekhalialu et al. (2016) carried out detailed
description of the Awi Formation. The Awi Formation
unconformably overlies the Precambrian Oban Massif (it
consists of weathered granite, schists, migmatite and
gnisses). Carbonate platform of the Mfamosing
Limestone directly overlies the Awi Formation (Petters,
1982) believed to be deposited during the marine
transgression in the gulf of Guinea in the Mid-Albian times
(Akpan, 1992). The Mfamosing Limestone is overlain by
thick sequence of black to grey shale unit, the Ekenkpon
Formation (Petters and Reijers, 1987). The formation is
characterized by minor intercalation of marls; calcereous
mudstone and oysters beds (Akpan, 1996). This shale unit
was deposited during the Late Cenomanian-Turonian
times. The Ekenkpon Shale is overlain by a thick marl unit;
the New Netim Marl (Petters et al., 1995). This unit is
nodular and shaly at the base and is interbedded with thin
layer of shales in the upper section. Foraminefera age
suggest Early Coniacian age for this marl unit (Nyong and
Ramanathan, 1985). The New Netim Marl is
unconformably overlain by carbonaceous dark grey shale,
the Nkporo Formation which was deposited during the late
Campanian - Maastrichtian times (Petters et al., 1995). The
Nkporo Shale caps the Cretaceous sequence in the
Calabar Flank. The Nkporo Shale sequence is overlain by
a pebbly sandstone unit of the Tertiary Benin Formation
(Petters et al., 1995). Table 1 shows correlation of Calabar
Flank with adjacent basins.
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Table 1: Stratigraphic correlation between Calabar Flank and other Nigerian Sedimentary basins (Nyong, 1995)

METHODOLOGY

Sample collection
Seventeen (17) core samples were employed for this study, obtained from three wells (A, B, C). Nine samples were obtained from well A at five (5) metres interval drilled to a depth of 42.12m. These samples were later composited at ten (10) m interval to produce five (5) samples. Twelve (12) core samples were obtained at five metres interval from well B drilled to a depth of sixty-five (65) metres and eleven (11) core samples were collected from well C at five (5) metres interval drilled to seventy (70) metres. Core samples from both wells were composited at 10m interval to produce six (6) samples each for the two wells (B and C). Well A was drilled at Etankpini while Wells B and C were drilled at Mbarakpa, Calabar Flank. The obtained samples were subjected to lithologic description based on their physical characteristics (colour, texture, hardness, fissility and rock type) and 10% dilute Hydrochloric acid (HCl) were used to determine the presence of calcareous materials.

Biostratigraphic sample preparation
Foraminifera
Each core sample was subjected to foraminifera sample preparation discussed by Brasier (1980) and Armstrong and Brasier (2005). The identification of the foraminifera was done using a binocular microscope and comparing picked forms with previously published forms. Quantitative analysis was done using the number of species count per sample to establish abundance and diversity of foraminifera species.

Palynology
The core samples recovered from the three (3) study wells were also analyzed in order to determine their palynomorphs content. Samples preparation was done by acid maceration techniques discussed by Doher (1980) and Traverse (1988) for acid insoluble microfossils. The acid maceration techniques include the following steps: dissolution of carbonates and silicate, acid neutralization and dissolution of humic matter. Concentration of palynomorphs was achieved by sieving using 200 and 400 mesh nylon screens and pipetting the organic residue from a watch glass. Slides of temporary strew mounts using glycerin jelly was made for each of the samples. Transmitted light microscope was used for studying the palynomorphs. The palynomorphs were counted and recorded. Analysis was done by comparison with published works to identify the various forms of palynomorphs.
RESULTS AND DISCUSSION

Lithostratigraphy

The lithologic units of the three (3) study wells (A, B, C) is summarized in Table 2,3 and 4. Three distinct lithologic units were recognized in the study wells. They include the New Netim Marl, the Ekenkpon Shale and the Mfamosing Limestone outlined by Nyong (1995), Petters et al. (1996) and Petters et al. (2010). New Netim Marl and The Ekenkpon Shale occur in well A while Ekenkpon Shale and Mfamosing Limestone occur in wells B and C.

<table>
<thead>
<tr>
<th>Table 2: Lithology of well A</th>
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<tr>
<td>DEPTH (M)</td>
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<tr>
<td>0-5</td>
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<tr>
<td>5-25</td>
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<td>25-42.12</td>
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<th>Table 3: Lithology of well B</th>
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<tr>
<td>DEPTH (M)</td>
</tr>
<tr>
<td>0 – 5</td>
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<tr>
<td>5 – 55</td>
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<td>55 – 65</td>
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</tbody>
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<th>Table 4: Lithology of well C</th>
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<tbody>
<tr>
<td>DEPTH (M)</td>
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<tr>
<td>0-15</td>
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<tr>
<td>15-50</td>
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<tr>
<td>50-70</td>
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</tbody>
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The core samples obtained from the three (3) wells yielded some foraminifera and palynomorph that are paleontological useful for age determination. Figs 3, 4 and 5 show biostratigraphic charts for well A, B and C respectively.

Foraminifera biostratigraphic analysis

Foraminiferal analysis of the study wells (A, B and C) is characterized by diverse assemblages of planktonic and agglutinated foraminifera with the planktonic exhibiting higher diversity and abundance than the agglutinated forms. No calcereous benthic foraminifera (FOBC) was recovered from wells A and C while only one species of calcereous benthic form with one (1) count was present in well B. The upper section (0-20m) of well A was devoid of foraminifera while the middle – basal section (20-42.12m) contained abundant and diverse foraminiferal species. The upper section (0-20m) of well B was also devoid of foraminifera while the middle section (20-50m) yielded abundant and diverse foraminiferal species with the lower section (55-65m) of the well been barren of foraminifera. The upper section (0-20m) of well C is devoid of foraminifera. The middle section (20-50m) contain abundant and diverse foraminiferal species while the basal section (50-70m) is devoid of foraminifera species.

The age determination of the sediments penetrated by the study wells (wells A, B and C) were based on age diagnostic planktonic and arenaceous benthic assemblages identified and recorded in the samples. The planktonic foraminifera species include: *Hedbergella sigali*, *Hedbergella delrioensis*, *Hedbergella crassa*, *Hedbergella planispina*, *Hedbergella simplicissima*, *Heterohelix moremani*, *Heterohelix reussi*, *Heterohelix sp.*, *Haplophragmoides sp.*, *Globigerinelloides caseyi*, while the arenaceous benthic foraminifera species include: *Ammotium cf nkalagum* and *Ammotium cf nwalium* which confirm the Barremian - Turonian boundary interval. The study of Petters (1983), Adegbie and Bassey (2007), Ukpong et al. (2008), Ukpong and Ekhalialu (2015), Ukpong and Ekhalialu (2018) and Ukpong et al. (2018) recovered a similar assemblage of *Hedbergellids and Heterohelicids* from the Ekenkpon Shale. These authors interpreted the sediment unit (Ekenkpon Shale) as Cenomanian – Turonian, probably in line with the interpretation of the earliest author(s) that erected the formation.

The basis of using *Hedbergella sigali* as a Cenomanian – Turonian form is unclear, bearing in mind that the last downhole occurrence (top) of *Hedbergella sigali* is within *Ticinella bejaouaensis* zone (113.26-118.02Ma, top in Aptian stage) (Chronos database). First downhole occurrence (base) of *Hedbergella sigali* is at base of *Hedbergella sigali* zone (134.7Ma, in Valanginian stage). (Zonal marker from Timescale Creator). It is pertinent to

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Figure 3: Biostratigraphic chart of Well A
Figure 4: Biostratigraphic chart of well B
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Fig 5: Biostratigraphic chart of well C
state that Hedbergella sigali is unknown in Cenomanian sediments except when they occur in association with other forms that range into younger sediments. Banner et al. (1993) used Hedbergella sigali as a Barremian - Aptian index form. Moullade (1966) used Hedbergella sigali as a Barremian to Early Aptian index form. Carol (1985), Sigal (1977) and Van Hinte (1976) also used Hedbergella sigali as an index form for the Barremian – Aptain and named the zone after this form (Hedbergella sigali zone). The study of Bumba et al. (2017) further supports the stratigraphic limitation of Hedbergella sigali to an age not younger than the Aptain age. The co-occurrence of Hedbergella crassa, Hedbergella planispira, Heterohelix moremani, Heterohelix reussi and Globigerinelloides caseyi) point to the Aptain – Turonian age bracket. Based on these evidences, the lower boundary (limit) of the Ekenkpon Shale shall be extended from Cenomanian that is currently in force to the Hauterivian. The small size of planktonic foraminifera and the low – medium diversity of planktonic population dominated by Hedbergella in this study, were also reported in works of similar ages (Hauterivian – Albian) by Koutsoukos (1992) in Sergipe basin of Brazil, Breheret (1995) in Vocontian basin of Paris, Carol (1978) and Kochhann et al. (2013) in the Angolan basin and Bumba et al. (2017) in Cote Divoire sedimentary basin.

**Palynologic biostratigraphic analysis**

Palynological analysis of the three (3) study wells yielded high abundance and diversity of palynomorphs. In well A, the upper section (0-10m) is devoid of palynomorphs. The middle section (10-30m) contain high abundance and high diversity of spores, palmae with fewer dinoflagellate cyst and foraminiferal test lining while the lower section ((30-42.12m) contain high abundance and high diversity of spores and palmae with an increase in dinoflagellate cyst and foraminiferal test lining. In well B, the upper section (0-10m) is devoid of palynomorphs. The middle section (10-40m) contain high abundance and high diversity of spores and palmae with abundance dinoflagellate cyst while the basal section (40-75m) contain high abundance and high diversity of spores and palmae with a decrease in dinoflagellate cyst. In well C, the upper section (0-10m) is devoid of palynomorphs. The middle section (10-40m) contain high abundance and high diversity of spores, palmae with fewer dinoflagellate cyst while the basal section (40-75m) contain high abundance and high diversity of spores and palmae with an increase in dinoflagellate cyst.

The co-occurrences of age diagnostic palynomorphs such as: Ephedripites spp, Leiotriletes spp, Classopollis spp, Classopollis classoides, Classopollis annulatus, Ephedripites jansonii, Cretaceaeiporites mulleri, Cretaceaeiporites polygonalis, Galeacornella clavis, Classopollis jardinei, Triorites afrcicaensis, Cretaceaeiporites mulleri, Trifosapollenites rugosa and Steevesipollenites binodosus point to an age of Berriasian – Turonian. Ukpong and Ekhalialu (2015), Ukpong and Ekhalialu (2018) used a similar assemblage to define the Cenomanian – Turonian age for the Ekenkpon Shale in the Calabar Flank. Essien and Ufot (2007) also used Classopollis jardinei, Ephedripites procerus, Ephedripites striagatus, Elaterosporites protensus and Elaterosporites sp to define the Albian – Turonian for the Mfamosing Limestone in the Calabar Flank. The basis for using this palynomorphs assemblage for this age is unclear. It was probably based on earliest works on the Calabar Flank.

The presence of triporate pollen grains in the recovered sediment is generally accepted as being indicative of Late Cenomanian – Turonian (Jardine and Magloire, 1965). The occurrence of Ephedripites multicostatus in the sample allows a correlation with the Ephedripites multicostatus Zone (Berriasian – Hauterivian) (Scott and Robbin, 1977). Ephedripites multicostatus points to an age of Berriasian – Velanginian (Neocomian), the pollen zone indicating this age is named after this palynomorph (Ephedripites multicostatus zone). Habib (1977) reported the pollen in the sporomorph genus Ephedripites as Early Neocomian (Berriasian-Valanginian). Ephedripites multicostatus Brenner is stratigraphically persistent in the recovered sample and is considered to be a valuable zonal species. Ephedripites has long been considered a useful stratigraphic indicator for dating sediments as Barremian - Turonian (Habib, 1977). Couper (1964) indicated that "specimens of Ephedra-like pollen" enter the chronostratigraphic column in the upper Hauterivian or lower Barremian. Wolfe and Pakiser (1971) indicated a maximal age around the Hauterivian - Barremian boundary for assemblages in the Atlantic Coastal Plain containing taxa such as Ephedripites. This study attempt to extend the lower boundary (limit) of the Ekenkpon Shale from the Cenomanian that is currently in force to the Hauterivian based on the presented evidences while the lower and upper boundary of the Mfamosing Limestone is placed at Berriasian and Albian respectively.

**SUMMARY AND CONCLUSION**

An integrated biostratigraphic analysis was carried out on three shallow wells (A, B and C) drilled in the Calabar Flank, southeastern Nigeria, in order to determine the age of sediments penetrated by the study wells. Seventeen core samples obtained from the study wells were subjected to standard biostratigraphic sample preparation / separation and analytical approaches. Berriasian - Turonian age was assigned to the recovered sediments based on the co-occurrences of Ephedripites multicostatus, Classopollis spp, Classopollis classoides, Classopollis jardinei, Triorites africanaensis, Cretaceaeiporites mulleri, Trifosapollenites rugosa and Steevesipollenites binodosus (palynoflora) as well as the co-occurrences of Hedbergella sigali, Hedbergella crassa, Hedbergella planispira, Heterohelix moremani, Heterohelix reussii and Globigerinelloides caseyi (microfauna). This study assigned Hauterivian - Turonian age to the Ekenkpon
Shale and Berrasian – Albian for the Mfamosing Limestone. This implies that the lower boundary (limit) of the Ekenkpon Shale from the Cenomanian is adjusted to the Hauterivian while the lower and upper boundary of the Mfamosing Limestone is placed at Berrasian and Albian respectively based on the recovered foraminifera and palynomorphs.

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