Determining the Hydrocarbon Generative Potential of the Turonian Eze-Aku Shale from Ibii, Lower Benue Trough in Southeastern Nigeria

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The Nigeria Benue Trough is an intracratonic rift structure whose evolution is related to the early Cretaceous opening of the South Atlantic Ocean and the Gulf of Guinea. Study of the lower Benue Trough has revealed that the lower Benue Trough is rich in organic matters and as such capable of yielding significant quantity of hydrocarbons. The Eze-Aku shale in Ibii area is located in the lower part of Benue Trough. Five (5) representative Turonian Eze-Aku Shale samples were collected and analyzed to assess the petroleum generative potential by sediment logical analysis. The Shale (Eze-Aku Shale) is dark grey in color and highly fissile. From analysis carried out the Total Organic Carbon (TOC) content of the Eze-Aku Shale sample from the five (5) sections ranges from 0.51 to 1.17wt. %. The amount of Organic Carbon Content exceeds the minimal 0.5 wt. % threshold for a potential source rock, which indicates that the Shale can generate oil and gas, also the percentage of Organic Matters (OM) as shown ranges from 91.90% to 98.00% suggest a high contribution of organic matter which supports the accumulation of hydrocarbon

**Key words**: Eze-Aku, Kerogen, Total Organic Carbon Content, Organic Matters, Shale, Hydrocarbon

**INTRODUCTION**

The increasing demand and decreasing reserves of hydrocarbons in Nigeria required increased activities in petroleum exploration and an improvement in the exploration success ratio. New oil and gas fields must be found and explored areas should be reassessed for additional oil and/or gas pools. At the core of petroleum exploration is the evaluation of the petroleum-generative potentials of prospective source rocks. The main objective of this study is to geochemically characterize the Eze-Aku Shale in terms of organic richness, organic matter type, thermal maturity and the hydrocarbon generation potential. The Afikpo basin in the southeastern Nigeria is formed from the evolution of the Benue Trough, it a smaller and shallow basin compared to the Anambra basin and presently an economically viable in hydrocarbon deposits. It is characterized by lithological heterogeneity in both lateral and vertical extension derived from a range of paleo environmental setting ranging from Campanian to recent. Akaegeobi (2000) The research for economical crude oil in the Afikpo basin in Nigeria has remained a real source of concern specially to oil companies. Initial efforts by scientist were unrewarded and this lead to the neglect of this basin in favour of the Niger delta basin. However, the increasing global energy demand, the advent of improved exploration tool, integrated basin analytical methods, Afikpo basin oil and gas exploration should take a new dimension. It is against this background that this research focuses on providing information about the Eze- Aku shale in the southeastern Nigeria.

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The geology of Santonian to Maastrichtian sediments in the lower Benue Trough of Nigeria has been studied by notable workers; which have reported that the Nkporo and Eze-Aku shale constitute the main source rock and the percentage of the organic carbon to the Santonian shale was quite comparable to those of the nearby Niger Delta basin.

Unomah and Ekweozor (1990) have assessed the petroleum source rock potential of the Eze-Aku shale and concluded that the organic facies are provincial with the Calabar flank having the highest oil prone marine derived organic matters (OM). Eze-Aku shale in the Afikpo syncline was reported to contain terrestrially derived organic matters that are essentially gas prone. The organic facies, hydrocarbon source potential and reconstruction of the depositional environment of the Campano-Maastrichtian Eze-Aku shale have been studied by Akaegbobi et al (1998). Their results showed that the source rock composed of kerogen type II and III with dominance of terrestrial derived organic matters (OM) and low contribution from marine organic matters (OM).

**LOCATION OF STUDY AREA**

The study area covers the lower part of the Benue trough, bounded by Anambra basin and the basement complex at the Western and Northern edges. The area lies between latitude 7°N to 8°5" and longitude 6°5" to 8°5". The geology of the study is consistent with the general geology of the Anambra basin.

![Fig 1. Map of Nigeria Showing Area of Study (Ogbonnaya, 2012)](image-url)
GEOMORPHOLOGY OF THE STUDY AREA

Geomorphology simply means the scientific study of land form and the process by which the landforms are formed. The geomorphic setting associates with geomorphic features like topography and landform, climate, superficial deposits and drainage that are found in Afikpo region. The area consists of gently undulating lowlands with alternating sandstone ridges. Thus the landscape of the studied area is made up of an alternation of high and low lands (i.e. hills and valleys). The average elevation of the study area is about 100m above sea level. Elevation within the sandstone ridges could however be up to 120m above sea level. The outcropping rocks differ in their resistance to weathering or erosion. This is controlled by the Lithology as well as the structure of the rocks.

GEOLOGY OF THE STUDY AREA

The Benue Trough is unique, is being occupied by upper Cretaceous sediments which have been compressionally folded in a non-organic shield environment. Its origin has been a source of speculative discussion for at least the past three decades.

King (1950) was the first to suggest that the evolution of the Trough was related to stress (rift depression) which accompany the continental separation of Africa and South America. Though there is no geological evidence of rift faulting along the trough margins except in a few places and those of doubtful significance (Lees, 1952; Carter et al., 1963).

Though the Benue Trough has been mentioned in literature, but its mechanism of evolution has not been described in detail (King 1950, Catchfly and Jones1965, McConnell 1949, Wright 1968) made the first attempt; they investigated the trough as a tensional Fracture, which widened progressively from South while reaming in contact with the coastline West of Nigeria. When the continents finally separated, the Africa plate was no longer subjected to doctorial stresses, and in ensuring crustal readjustment, the tensional regime responsible for initiation of the Benue Trough was replaced by slight compression ones, closing the Trough slightly and folding the sediments within it. The amount of closure, based on the width of the trough and the degree of folding has been more than 6.8km (Wright 1968).

Although paleontological data are in some respects consistent with part of this picture (Reyment 1969, Reyment and Tall 1972), they show that finally, separation took place in lower Turonian times, and the first confirmed folding movement did not occur till the Santonian, although Nwachukwu (1972) suggested possible slight movement in the Cenomanian which appears to have affected the south eastern part of the trough. Whereas, a final Maastrichtian folding episode extended the whole length of the trough, this attempt therefore correlates the Santonian folding with cessation of distortional stresses placed the date of final separation some ten to twenty million years before it happened.

The Benue Trough is part of the RRR triple junction system in which the arms developed at different times and presumably at different rate. The South arms were first to become active, in the lower Cretaceous, followed by the Benue arms in about Albam times. The North western arm probably became active later, since there was no complete seaway between North and South Atlantic until the Turonian (Reyment and Tait 1972). The limited spreading beneath the Benue arm must have ceased soon after the north western arm began for the first major folding episode in Santonian age. It must be emphasized that it has so far been recorded only from the Southwestern portion of the trough. There is no unequivocal evidence for it in the Northeast (Carter et al. 1963, Dessauvagie et al. 1972).

The Maastrichtian transgression which spread not only to right up to the Benue Trough, but also for the first time up to the middle Niger valley, must have been the result of further subsidence, but weather it was as a result of renewed tension across the trough is not known presently. The post Maastrichtian folding movement affected all the sediments in the trough, but appears to be less intense than the Santonian episode. The result is that, sediments in the North Eastern part (the upper Benue) are relatively gently and uniformly folded, whereas, in the South West (lower Benue), the Santonian and the older sediments were folded twice, so they are much stronger deformed than the overlying younger sediments, by which they are separated by a mark of erosional surface (Burke et al., 1972). Uplift and erosion of the folded sediments in the Paleocene gave rise to molasses accumulation in the Northern part of the folded belt, the Keri Keri formation of probably Paleocene in age (Carter et al, 1963).

As the effect of the Cretaceous disturbance died away and the Benue Trough once more became structurally part of the Nigeria Cameroun domes. Cenozoic alkaline to peralkaline volcanism broke out within and adjacent to it.

TECTONIC SETTING OF THE BENUE TROUGH

The regional tectonic setting of the area is confined to the southern part of the Abakaliki - Benue Trough which began in the lower Cretaceous times, during the fragmentation of the continent over the globe leading to separation of the South America and Africa plates and the formation of basins in Nigeria. At least, two episodes of tectonics have been identified in the trough. During the Cenomanian time, it experienced a minor tectonic event, which resulted in uplift in the Northeast and South West directions as proposed by Nwachukwu (1972). The earlier Cenomanian episode affected only Albam sediments. According to Olade(1975),
the cause of the episode is temporary cessation of the mantle contraction. In Santonian time, an intensive tectonic event occurred. The Santonian phase affected all pre-Santonian sediments within the depression. The Santonian tectonism terminated in the Turanian to Conacian marine depositional cycle in the Benue Trough. The Pre-Santonian incomplete beds were folded, faulted intruded and uplifted to give rise to the Abakaliki - Okigwe Anticlinorium. The Abakaliki-Okigwe Anticlinorium trends Southeast, North - West and is flanked on the west by the major Anambra basin and on the East by a smaller Afikpo basin (study area). The Anambra basin became the major depositional centers.

The Santonian tectonism changed the regional sedimentation pattern in the Abakaliki-Benue Trough from essentially Northeast-Southwest to the East west direction. However, the cause of Santonian tectonic event according to OJade (1975-1978) was as a result of the reactivation of mantle upwelling in Turanian times with attendant mantle expansion and contraction.

STRATIGRAPHIC SETTING OF BENUE TROUGH

During the formation of the Benue Trough, a marine transgression invaded the basin in mid Altaian times depositing shales of the Asu River Group. During Cenomanian, the sea regressed depositing the only known marine sediment at Odukpani around Calabar. An extensive Turonian transgression involving the merging of the Gulf of Guinea in the South and the Tethys sea resulting in the deposition of the Ezeaku Shales. During Coniacian, regression started and the Agwu Shale were deposited, also in the Santonian times, there was an upliftment of the pre-Santonian deposits leading to the formation of the Abakaliki Anticlinorium and contemporaneous formation of the two basins, the bigger and shallower Anambra Basin to the west and the smaller and deeper Afikpo Syncline to the East.

A Campanian to Maastrichtian transgression resulted in the deposition of the Nkporo Shale in these basins. Transgression resulted in the formation of the Mamu, Ajali, and Nsukka Formation in the terminal Cretaceous stage by the Paleocene time. Another transgression occurred depositing the Imo, Ewekoro Limestone and from Eocene till date the sea regressed depositing the Ameki Formation, Ogwashi - Asaba Formation (coastal plain sands).
REGIONAL STRATIGRAPHY OF STUDIED AREA

Regionally, the mapped area is within the Southern end of the Benue Trough. The oldest sedimentary rocks in Nigeria are in this trough and they are of lower Cretaceous age. The Cretaceous stratigraphic record of the Southern Benue Trough is represented by sediments deposited by three main marine depositional cycles: Albian-Conomanian; Turonian-Santonian and Campano-Maastrichtian. (Reyment, 1965, Ofoegbu, 1985). Shortly after the breakup of African and South America, a continental condition favorable for the deposition of fluvio-deltaic sediment which occurred in the Albian age. The Aptian sediment is presented by the Ogoja Sandstones.

The first marine transgression in this trough occurred in the middle Albian age with the deposition of the Asu River Group sediments with type locality along the banks of Asu River (Reyment, 1965). The sediments consist of rather poorly bedded sandy Shales with Sandstone and sandy-limestone lenses. The regressive phase of the first marine transgression led to the deposition of the Conomanian sediments. The beds of this age are located in the Southeastern part of Nigeria, around Calabar. These beds have been assigned as the Odukpani Formation (Reyment, 1965). The beds consists of arkosic Sandstones, Limestone, alternating Limestone and Shale that became gradually more predominantly of Shales in its uppermost parts (Reyment, 1965).

The Turonian is overlain by sediments of Coniacian age. The Coniacian is represented by the Awgu Formation (Reyment, 1965). The formation consists of bluish grey, well bedded Shales. The Santonian age was heralded by a tectonic event. This tectonic epigenetic event led to the uplift, folding and wide spread erosion of the Pre-Santonian sediment in the trough.

The Campano-Maastrichtian experienced the third sedimentary cycle in this trough. It started with the deposition of the Nkporo Formation (Nkporo Shales). It consists of dark Shales and mudstone with occasional thin beds of sandy shales and Sandstones. A regressive phase of this transgression occurred in middle Maastrichtian with the deposition of the Mamu Formation and subsequent deposition of Ajali Sandstones. A minor transgression occurred in late Maastrichtian with the deposition of Nsukka Formation.

METHODOLOGY/ MATERIALS USED

This section simply explains all procedures plans and principle applied in ensuring that the field samples and laboratory procedures are successfully carried out. The samples were obtained from Ezeaku shale at Ibi in Afikpo area of Ebonyi State. Care was taking to avoid weathered material sufficient for various laboratory analyses. Samples were taken at regular intervals in the field.

At the field the base map was divided into grid, in order to have better and detailed coverage. The Lithologic and sedimentological characteristics of the outcrop sections were captured using a logging format designed to provide an insight into the vertical variation in lithology, texture, sedimentary structures, fossil content, bed thickness, and contact types. The laboratory tests carried on the samples include a variety of Physical and Mineralogical tests. The tests include; Total Organic Carbon (TOC), Soluble Organic Carbon (SOM) and Organic Matter (OM).

Samples were crushed using the mortar and pestle, oven dried and weighed appropriately. 5ml of concentrated H2SO4 was added to each flask which was heated on the electro-thermal heater for 15mins. Titrate phosphorous ammonic sulphate against the sample, ferrous ammonium which acts as an indicator, to get a reddish coloration, titrate to a volume of your choice to get the coloration. Add 100ml of distilled water in both flasks, and then take 10ml which is the aliquot. Add ferron to each flask, add few drops of it, and titrate with ferrous ammonium.

**Table 1.** (Modified from Reyment (1965), Murat (1972)

<table>
<thead>
<tr>
<th>AGE</th>
<th>FORMATION</th>
<th>SEDIMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plicocene</td>
<td>Benin Formation</td>
<td>Niger delta Basin</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Ogwashi-Asaba Formation</td>
<td></td>
</tr>
<tr>
<td>Eocene</td>
<td>Ameke Formation</td>
<td></td>
</tr>
<tr>
<td>Paleocene</td>
<td>Imo Shale</td>
<td>Anambra Basin</td>
</tr>
<tr>
<td>Maastrichtian</td>
<td>Nsukka Formation, Ajali Sandstone, Mamu Formation</td>
<td></td>
</tr>
<tr>
<td>Campanian</td>
<td>Nkporo/Enugu Shale (INCLUDING Afidpo Sandstone and Owerri Sandstone)</td>
<td></td>
</tr>
<tr>
<td>Santonian</td>
<td>Coniacian, Agwu Shale</td>
<td>Abakaliki</td>
</tr>
<tr>
<td>Turonian</td>
<td>Ezeaku Formation</td>
<td></td>
</tr>
<tr>
<td>Conomanian</td>
<td>Odupkani Formation</td>
<td></td>
</tr>
<tr>
<td>Albian</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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RESULTS AND DISCUSSION

The analyzed result has been separated into total organic carbon content, Soluble organic matter (SOM) and organic matter (OM).

The data are represented in their summarized form:

<table>
<thead>
<tr>
<th>Sample Identity</th>
<th>TOCMg/kg</th>
<th>SOMMg/kg</th>
<th>OM(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. S-I EZEAKU</td>
<td>0.93</td>
<td>75.00</td>
<td>91.90</td>
</tr>
<tr>
<td>2. S-2 EZEAKU</td>
<td>0.51</td>
<td>217.50</td>
<td>96.80</td>
</tr>
<tr>
<td>3. S-3 EZEAKU</td>
<td>0.84</td>
<td>150.00</td>
<td>97.40</td>
</tr>
<tr>
<td>4. S-4 EZEAKU</td>
<td>1.17</td>
<td>150.00</td>
<td>98.00</td>
</tr>
<tr>
<td>5. S-5 EZEAKU</td>
<td>0.57</td>
<td>150.00</td>
<td>97.70</td>
</tr>
</tbody>
</table>

**Fig 3:** showing Plot of Total Organic Carbon (TOC) against depth

**Fig 4:** showing Plot of Soluble Organic Matter (SOM) against depth.

**Fig 5:** showing Plot of Organic Matter (OM) against depth.
RELATIONSHIP BETWEEN TOC, SOM AND DEPTH

Quantitative relationship between SOM and temperature has been recognized (Callsenet, et al., 2003). In general, SOM is increases with precipitation and decreases with depth or temperature (Burke, et al. 1989). From fig 5 showing plot of SOM against depth, it is observed that the highest SOM occur at a depth of 6m and with lower SOM at a depth of 15m.

Soluble organic matter is used to determine the source rock potential, maturity and depositional environment. The significant of this is the extraction of and determination of yield of SOM allow for identification of hydrocarbon rich sediments (Peter and Casa1994).

Total organic matter is another important sediment parameter. Organic matter is a primary source of food for benthic organisms, and is therefore an important structuring factor for the composition of the benthic fauna. Furthermore, the amount of organic matter will influence the partitioning of contaminants in sediments; when the sediments contain a large amount of organic matter a large part of the contaminants will generally be in a particulate form, while sediments containing a small amount of organic matter may have a larger part of the contaminants present in the pore water. The amount of nutrients in the sediment also has a direct role in determining the redox potential in the sediment, which again is a regulating mechanism for the partitioning of contaminants a plot of TOM vs. depth for all reference and regional stations in EZE-AKU is given in Figure 5. Here, it appears to be a weak trend with increasing level of TOM with increasing depth.

GEOCHEMICAL ANALYSIS OF TOTAL ORGANIC CARBON

The Total Organic Carbon (TOC) content of the Eze-Aku Shale sample from the five (5) samples above ranges from 0.51 to 1.17wt. %. The amount of Organic Carbon Content exceeds the minimal 0.5wt % threshold for a potential source rock, which indicates that the Shale can generate oil and gas (Miles 1989). The highest Total Organic Carbon content(TOC) value of 1.17wt. % exists in sample S-4 EZEAkU.

It is important to consider that TOC decreases with increasing thermal maturity. A TOC of 0.5wt. % is regarded as the minimum value for defining a petroleum source rock. The accepted average TOC value of all Shales is about 0.9wt. % and the average TOC of source rocks Shales is 2.2wt. % (Miles 1989). The average TOC of carbonate (Mudstone) source rock is 1.9wt. % and 0.7wt. % respectively. The average TOC of all source rocks is about 1.5wt. % a value much higher than minimum value for defining potential source rocks.

ANALYSIS OF ORGANIC MATTER

The TOC is a primary parameter in source rock appraisal, with a threshold of 0.5-1.0 wt % at the immature stage for potential source rocks. The value of 1.17wt % of the Shale studied in S-4 EZEAkU exceeds this threshold. High TOC obtained exceed the threshold of oil generation. However, high TOC is not a sufficient condition for oil generation. Coals for instance usually have high TOCs that exceed 50wt. % but do not generate oil except when rich in Latinate, indicating the relevance of maceral composition. In contrast, deltaic sediments may have TOCs below 1wt. % but generate commercial accumulations of petroleum due to deposition of large volume of sediments, as seen in the Niger Delta. TOC content in shale indicates favorable conditions for preservation of organic matters produced during deposition. This may be related to the redox condition, with high oxygen favoring organic matter oxidation, but also amount of organic matter produced. The percentage of Organic Matters as shown on the table above range from 91.90% to 98.00% suggests a high contribution of organic matter which supports the accumulation of hydrocarbon. In general, results obtained across the analyzed sample indicates that hydrocarbon source rock are present.

SOLUBLE ORGANIC MATTER

Many organism contribute to the our present in petroleum source rock, since organisms differ in their content of carbohydrates, lipid, protein, resin etc. the preserved organic matters exhibit paired diversity, sedimentary, diagenesis, catagenesis and metagenesis processes which modified the original constituents of the rock quantity. organic materials must be present from a geological unit to be considered a potential source rock. From the result obtained from the analysis shows that the amount of Organic Matters present ranges from 91.90%-98.00% which indicate the Shale are rich in Organic Matter, hence it can be called a source rock.

DEPOSITIONAL ENVIRONMENT

The composition of the Eze-Aku Shales permits facies classification and deductions of the paleo-current and paleo-environments reconstruction of the Shale deposits. The accumulation of this shale indicates a deep marine environments deposit, quiet water environment with low energy of water current. The samples collected for analysis shows a high amount of Organic Matter which favorably indicates condition for preservation of organic matters produced during deposition. This may be related to the redox condition, with high oxygen favoring organic matter oxidation, but also amount of organic matter produced.
HYDROCARBON GENERATIVE POTENTIAL

For the fact that organic carbon content alone cannot be used to establish the presence of potential and or effective petroleum source rocks in view of the constraints that differentiate organic matter types have different hydrocarbon yields for the same organic carbon content a more direct measure of source rock capability to generate hydrocarbons is required for detailed assessment.

The SOM to TOC ratio for the samples is 0.92mg: 75mg for S-I EZEAKU. According to Tissit and Wettes 1984, rock lower than 2mg Hcg/rock have little or nolsource rock potential, hence from the above sample S-I EZEAKU suggests immature to marginal mature source rock.

CONCLUSION

This investigation was carried out at expose section in Ibii area, the lower part of the Benue Trough, which consists of the Eze-Aku Shale Formation. The source rocks (Shale) are moderately to fairly rich in Total Organic Carbon (TOC) with value of 1.1 7wt %. The S-I EZE-AKU sample exceeds the threshold of 0.5%. The high TOC obtained exceed the threshold of oil generation. However, high TOC is not a sufficient condition for oil generation. The percentage of Organic Matters as shown on the table above range from 91.90% to 98.00% which suggest a high contribution of organic matter which supports the accumulation of hydrocarbon and can therefore be considered as potential source rock. While exploration efforts for oil and gas have been concentrated more on the adjacent Tertiary Niger Delta Basin, very little attention have been paid to the Cretaceous inland basins especially the southern segments of the trough with obvious stratigraphic continuity despite the commercial discoveries of the structural related rift basins of the Niger, Chad, Sudan and Cameroon within the same trend. Prior studies which included kerogen studies of the successions revealed a number of organic rich intervals capable of yielding significant quantities of hydrocarbons in the Cretaceous Sediments.

REFERENCES


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Accepted 11 October 2017,


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