# Structural Evolution, Magmatism, and Effects of Hydrocarbon Maturation in Lower Benue Trough, Nigeria: A Case Study of Lokpaukwu, Uturu, and Ishiagu.

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## ABSTRACT

The Benue Trough of Nigeria has been affected by at least two episodes of deformation in the Cenomanian and Santonian times. The deformations generated NE-SW trending structural features, which accommodated massive igneous activities in the Trough. The Lokpaukwu–Uturu–Ishiagu magmatic belt of the Lower Benue Trough is an example of these structurally controlled igneous intrusions. The igneous rocks are predominantly intermediate to basic in character, rich in plagioclase and ferromagnesian minerals and have impacted high maturity on the source sediments due to thermal effect. Total organic carbon contents of the mudrock inclusions in the pyroclastics range from 0.60%wt – 0.86%wt. It is apparent that prior to the eruption, an initial shaly source rock with higher organic carbon content was cooked during the eruption, thereby reducing the source quality of the rocks. Thus, heat from the igneous intrusions raised the temperature of the source rocks above the liquid oil window limit, and thus inhibited the preservation of the essential constituents of petroleum in the shales within the Lower Benue Trough.

(Keywords: petroleum, petroliferous formations, geology, intrusions, mudrock structures)

## INTRODUCTION

The study area (Lokpaukwu, Uturu and Ishiagu), which lies within latitudes $5^0 52^l$N - $5^0 57^l$N and longitude $7^0 25^l$E -$7^0 34^l$E, is part of the deep linear sedimentary Benue Trough with elevation ranging from 60m to 114 m and extends for over 700 km from the Niger Delta to northeast Nigeria (Figure 1). This Trough, like other similar geologic structures such as Gulf of Suez, is petroliferous, and may be prospective and productive (Nwachukwu, 1985). The Lokpaukwu-Uturu-Ishiagu axis of the southern end of the Trough is associated with the occurrence of igneous intrusives and volcanics within thick sedimentary series. The igneous activities have affected the sedimentary units, which they intruded.

The present work is thus aimed at assessing the relationship of the igneous activities with the structural development in the Trough and to determine the effects of the magmatism on the accumulation of hydrocarbon in the surrounding host sedimentary units within the Trough.

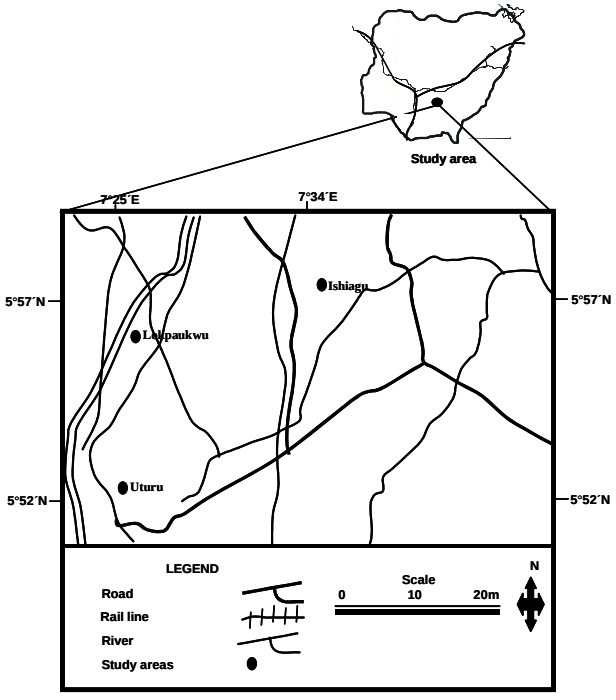


**Figure 1:** Location Map of Uturu, Lokpaukwu, and Ishiagu (Inset: map of Nigeria Showing the Study Area).

## GEOLOGIC SETTING

The Benue Trough is a graben, representing the failed arm of a triple junction. The generated faults in the Trough range from major to small and micro types (Ofoegbu, 1985). The sediment infilling of the Benue Trough ranges from about 7km, at its boundary with the Niger Delta, to about 5km, at contact with the basement complex in the Upper Benue Trough. These sediments have suffered deformations along NE–SW trending axis producing multiple folds and fractures that run parallel to the fold axis (Ofoegbu, 1985). The folds and the NE–SW trending fractures are cut by steeply dipping N–S and NW–SE trending tensional faults and fracture systems (Ajakaiye *et al.*, 1986). The deformations are believed to mark the continental extension of transform faults of the Proto–Atlantic shear zone (Benkhelil, 1982). The Trough is therefore associated with the separation of Africa and South America and the opening of South Atlantic Ocean (Fairhead and Okereke, 1987).

The depositional history of the Lower Benue Trough is dominated by repetitive transgressive/regressive sedimentary cycles interspersed with two main episodes of structural deformations in Cenomanian and Santonian times. The Santonian deformation was characterized by compressive folding, generally along a NE–SW direction, parallel to Trough margin. Deposition in the southern Nigerian Basins was controlled by tectonic phases in the Trough involving movements along major NE–SW trending faults resulting from the separation of the South American from the African Continent (Murat, 1970 and Nwachukwu, 1972) (Figures 2 and 3).

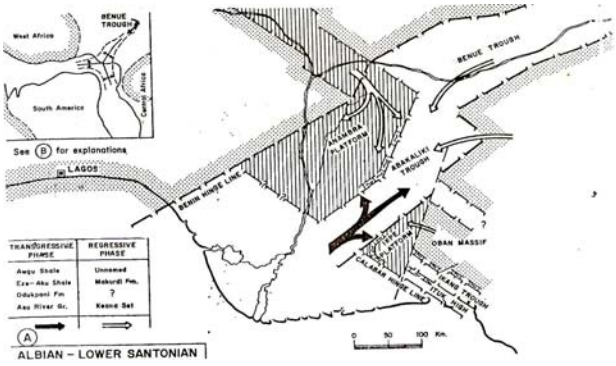


**Figure 2:** Tectonic Map of Southeastern Nigeria (Albian–Lower Santonian). (Adapted from Murat, 1970).

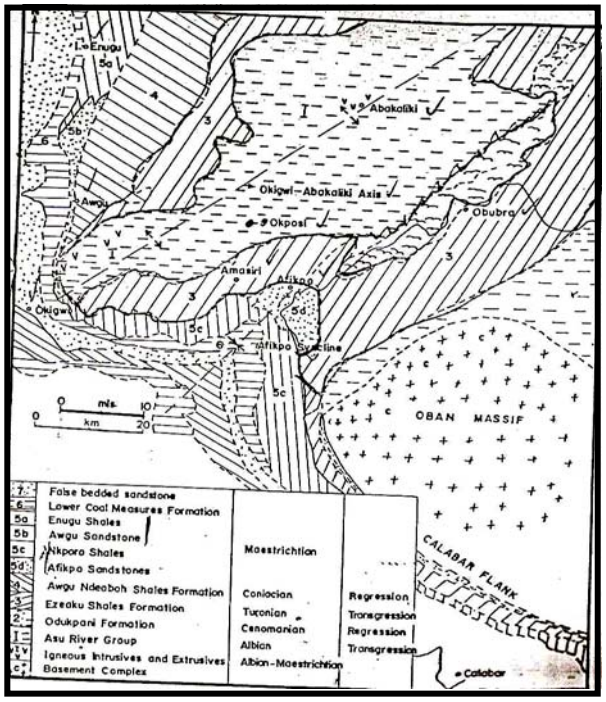


**Figure 3:** Generalized Geologic Map of Southern Nigeria. (Adapted from Nwacukwu 1972).

The Cenomanian episode affected only the Albian sediments, while the Santonian phase affected all pre–Santonian sediments within the depression. The rapid facies change has been interpreted by Short and Stauble (1967) as the first indication of onset of active tectonic phase of folding, faulting and upliftment, which ended during Santonian. These Santonian movements resulted in the folding and upliftment of the NE-SW striking Abakiliki-Okigwe Anticlinorium, which in turn led to the exposure and subsequent erosion of the Formations. Structural features associated with the later phase are well preserved and consequently are well documented (Short and Stauble, 1967). In contrast, the later sedimentary and deformational processes have largely obscured the Cenomanian episode.

The lithostratigraphic units are known to surround igneous rocks (Okeke *et al.*, 1988), which preceded them by limited basaltic lava flow of Late Jurassic/Early Cretaceous age. Olade (1978) is of the view that the oldest rocks within the Southern Benue rift are lava flow and volcaniclastic rocks, in the Abakiliki pyroclastics. Thus, the first Albian transgression was preceded by an earlier phase of mafic–alkaline volcanism in the Aptian to Early Albian times. However, the

Benue Trough is characterized by extensive magmatic activities as evidenced by the wide spread occurrence of intrusive and extrusive rocks in the Trough. These igneous rocks occur over a distance of 500km from Ishiagu in the Lower Benue Trough to Zurak in the Upper Benue Trough with the number of this occurrences increasing from Zurak towards the South Eastern part of the zone. The igneous rock types are varied but are predominantly intermediate to basic in character (Wright, 1976; Ofoegbu, 1985). Closely associated with the Santonian deformation was the emplacement of numerous mafic intrusives and alkaline/calc–alkaline lava and tuffs (Wright, 1968).

## METHOD OF STUDY

Representative samples of both the igneous and shale samples were collected during field mapping for petrographic analysis and determination of Total Organic Carbon content (TOC), respectively. The TOC was determined using sulphuric acid and aqueous Potassium Dichromate ($K_2Cr_2O_7$) mixture on the mudrock. The process involves allowing for complete oxidation of samples from the solution and external heat. The residual $K_2Cr_2O_7$ is titrated against ferrous ammonium sulphate to get a measure of Total Organic Carbon content.

## RESULTS

**Petrology:** The intrusions in the study areas occur concordantly and or discordantly (Figures 4 a and b). There are widespread occurrences of pyroclastics, basalts and dolerites at Lokpaukwu. The igneous rocks are predominantly intermediate to basic rocks with common minerals mainly plagioclase, augite and hornblende, and phaneritic to aphanitic textures.

Highly fractured dolerite dykes with high angle dip fracture surfaces ($60^0$ - $69^0$) occur at Ugwuele Uturu of Abia State (Figures 5 a and b). The fractures vary in width from 0.6m to 2m. Lateritic infillings mark fracture and dilation planes. At Ajaba–Amanyanwu Uturu, three exposures of quarried pyroclastics show ubiquitous mudrock inclusions (Figure 6). The pyroclastics are mainly lapilli stones and mixture of angular to sub–rounded lithic fragments in the matrix.

(a)

(b)

**Figure 4:** Intrusions Appear Concordant (a) or Discordant (b) in the study areas. (b) Shows Structurally-Controlled Dolerite Dyke at Ishiagu.

Different varieties of igneous rocks, ranging from leucocratic to melanocratic types abound in Amangwu Ishiagu of Ebonyi State. Stretched and strained mudrock inclusions trend along the axis of a highly fractured NE-SW trending zone (Figure 7).

The mudrock inclusions occur in fault zones. Also epigenetic calcite veins, marking inflow of saline water, form infillings in the fractures in the igneous bodies (Figures 8 a and b). Ishiagu lies within the saline zone of Nigeria.

(a)

(b)

**Figure 5:** (a) The Igneous Bodies show Intense Fracturing (b) with Steep Dipping Joints at Ishiagu.

**Figure 6:** Mudrock Inclusions in the Pyroclastics at Nkume Ajaba-Amanyanwu in Uturu.

**Figure 7:** Stretched Mudrock unit along a Major Fracture Zone at Ishiagu.

(a)

(b)

**Figure 8 a and b:** Calcite veins in the intrusives at Ishiagu.

**Geochemistry:** The Total Organic Carbon content (TOC) test conducted on the mudrock inclusions in pyroclastics ranges from 0.60% wt – 0.86% wt (Table 1). The samples show fairly uniform TOC values within and across the three locations.

**Table 1:** Total Organic Carbon Content (TOC) on the Mudrock Inclusions in the Pyroclastics.

| Sample locations | TOC values (weight percent) |
|---|---|
| 1 | 0.60 |
| 2 | 0.86 |
| 3 | 0.72 |
| 4 | 0.66 |

## DISCUSSION

**Structural Development and Magmatism:** Folds are generally large with dips rarely exceeding $30^0$ in the study area. The Santonian tectonic episode largely obliterated the Cenomanian structures with compressive folds along NE–SW direction, to form the Abakiliki-Okigwe anticlinorium. Similarly, the major fracture is in the NE-SW direction, defining axial planar structures. Reyment (1965) was of the view that the Uturu pyroclastics was surrounded by the marine Asu River Group sediments of the Albian age. Olade (1978) documented similar relationship for the Abakaliki pyroclastics because, according to him, the pyroclastics at Abakaliki and Uturu underlie the oldest Albian marine beds, and therefore concluded that on stratigraphic relationship, the tectonic setting of these pyroclastics was related to the origin of the Benue Trough. This therefore suggest that both units (Uturu and Abakaliki pyroclastics) might be Pre–Albian in age and laterally extensive in the subsurface.

Amajor and Ofoegbu (1988) classified the Uturu and Abakaliki pyroclastics as within continental–plate alkaline basalts, and agreed that their eruption might have preceded the break–up of this part of the continent, which subsequently resulted in the formation of the Trough. Hoque (1984) countered this when he argued that on the basis of the field relationships, the pyroclastics at Abakiliki, Ezillo and Uturu are younger than the Asu River Group sediments.

Field mapping of Lokpaukwu, Uturu and Ishiagu revealed abundance of mudrock inclusions of the Asu River Group, which point to the fact that these pyroclastics are rather related to the post Albian structural development of the Abakiliki-Okigwe anticlinorium than the precursor continental breakup that initiated the formation of the Benue Trough and deposition of sediments in the Trough.

Field observations in all locations mapped conform to the observation of Hoque (1984). Apart from the structural relationships abundant mudrocks of the Asu River Group are ubiquitous in the pyroclastics. This suggests that the sediments of the Asu River Group are either older than the pyroclastics volcanism or the sediments are syn-depositional with the volcanism. Santonian deformation appears to be very penetrative as to permit mantle upwelling that gave rise to intrusion of intermediate to basic igneous rocks within the structural control in the Benue Trough. These NE-SW trending fractures were exploited by magmatism. Minor NW trending fractures also occur and are considered to be a result of gravity settling of the intrusions. Thus, the close association between the igneous rocks and the main structural features of the Abakiliki-Okigwe anticlinorium is suggested by the alignment of the igneous bodies along the axis of the anticlinorium.

**Effect of igneous intrusion on source rocks:** The essential elements in the constitution of petroleum are substantial removal of the oxygen and nitrogen of the original organic matter and the lipids (fats) and adequate preservation of hydrogen–rich organic residue. The source quality of which is measured by the percentage of the Total Organic Carbon content in the sediment. Total Organic Carbon content (TOC) test conducted on the samples of the mudrock inclusions in the pyroclastics range from 0.60 %wt – 0.86 %wt (Table 1).

It is apparent the heat that accompanied the eruption of magma had baked the surrounding source rock, which had higher TOC thereby reducing the source quality of the sediments. In other words, the organic matter in the samples studied must have been subjected to heating during igneous eruptions such that the rapid increase in temperature caused chemical

reactions and instability of pre–Santonian petroliferous source sediments that resulted overcooking. From the mineral paragenesis, the igneous rocks in the areas intruded at very high temperatures of at least 1000 C. This temperature level far exceeds the temperature of about 120 C at which petroliferous components are stable. Maturity studies of the Asu River Group (Albian) indicate high maturity (over cooked facies) (Petters and Ekweozor, 1982). The very high maturity attained by the sediments in the study area is due to the thermal effect of the igneous intrusions.

## CONCLUSION

Ishiagu–Uturu–Lokpaukwu area of the Lower Benue Trough is characterized by basic to intermediate igneous intrusives and volcanics. The igneous rock types are mainly syenite, monzonite, diorite, dolerite, basalts, and pyroclastics. The intrusions are structurally controlled and are highly fractured and weathered. Fracturing is columnal.

The accumulation of hydrocarbon in the study area, especially the Lower Cretaceous and pre–Santonian Upper Cretaceous rocks is not rated highly because although the shales and other fine grained sediments accumulated for more than 6,000 m in thickness, these rocks have been intruded extensively by basic to intermediate intrusives at temperatures too high for petroliferous materials to be stable. Thus, the magmatism and its attendant thermal effects on the accumulation of hydrocarbon in Lokpaukwu-Uturu-Ishiagu areas of the Lower Benue Trough increased the temperature that caused the petroleum constituents to be unstable and reduced source quality.

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