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Petrographic Analysis and Total organic content (TOC) of Mudstone Inclusions in Igneous Intrusives in Lower Benue Trough, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author NU designed the study, wrote the protocol, wrote the first draft of the manuscript, managed the literature searches, performed the petrographic analysis. Author EEE managed the experimental process of Total Organic Content of the Mudstone Inclusions in the intrusive rocks. Both authors read and approved the final manuscript.

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ABSTRACT

The lower Benue trough is a linear, intracratonic, graben basin, trending ne-sw. The trough is characterized by an uplifted basement block, flanked by deep basin containing about 6km of sediments. The study area which is part of the lower Benue trough comprises of igneous rock types that are predominantly intermediate to basic in nature. From petrological studies, the rocks are made up of intermediate to high temperature minerals. Total organic carbon (TOC) content tests were conducted on the mudstone inclusions in the pyroclastics, and values range from 0.60%wt-0.86%wt. The classification of source quality by total organic content (TOC) percent shows that the source quality is fair. This indicates that prior to the eruption, the study area may have had higher organic carbon content but the heat that accompanied the eruption baked the source rock into mudstones thereby reducing the source rock quality. The thermal effect of the igneous intrusions may have increased the temperature above the oil window limit.

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Keywords: Benue trough; igneous rock; intracratonic; graben basin; early cretaceous.

1. INTRODUCTION

The Benue Trough like most similar geological structures in different part of the world (e.g the Gulf of Suez) is known to be petroliferous. Thus by analogy, one would expect the Benue Trough to be prospective [1]. Ishiagu area of the southern end of the Lower Benue Trough of Nigeria is associated with the occurrence of dolerite, monzonite and syenite igneous intrusions among others and volcanic (pyroclastic rocks) with sedimentary rocks. These igneous intrusives have affected the sedimentary series which they intruded. This paper is aimed at determining the effects of increased temperature brought about by magmatism on the petroleum potentials of the sedimentary rocks in the study area by analyzing the mudstone inclusions within the pyroclastic rocks and the temperature of formation of the various igneous rock bodies in the study area.

1.1 Location and Accessibility

The study area (Ishiagu) which lies within latitudes 5°52´ - 6°00´ N and longitudes 7°30´ - 7°35´ E is part of the geologic complex called Benue Trough –a deep linear sediment filled basin which extends from the Niger Delta for over 700km towards the northeastern part of Nigeria (Fig. 1). It is bounded in the north by Awgu and Aninri areas (Enugu State), in the south by. Ugwueke, Isiukwuato (Abia State), in the west by Lokpa and Lekwensi (Abia State) and in the east byAkaeze (Ebonyi State). The southeastern railway line runs from Enugu traversing Ishiagu (with both sub-station and main station) down to Port Harcourt.

1.2 Stratigraphic Overview

The stratigraphy of Ishiagu area (in the Lower Benue Trough) is dominated by the shale strata of Asu River Group dated as Upper Albian by [2]. The shale is folded into a symmetrical anticline trending northwest with an average dip magnitude of 27º to the NW-SE. It lie uncomformably on the basement [2,3], used ammonite assemblage collected from the old brickfield at Ishiagu to date the Asu River Group as Albian sediments. The flaggy, slaty shale is darkgrey to black and finely laminated with occasional limestones, and distinctly fissile shale and silt band. The sequence has an estimated stratigraphic thickness of 1800m [4,5]. The position of Cenomanian deposits over the SE part of lower Benue trough is one of the unsolved problems in the stratigraphy of SE Nigeria sedimentary basin. Great efforts have been made by some workers to explain this Cenomanian enigma [4]. Contended convincingly that an early period of deformation (Cenomanian) occurred immediately after Albian sedimentation and prior to the well-known Santonian episode. In agreement [6], observed that this early episode of deformation during the Cenomanian created a marine regression that confined carbonate sedimentation (Odukpani Formation) only to the Calabar flank. The absence of Cenomanian bars over much of the southeastern part of the Benue trough (including Ishiagu district) is an indication of the existence of a break in sedimentation during the period and hence a major unconformity between Albian and Turonian sediments. The sandstone unit of the Ezeaku Formation is exposed on the northern and southern parts of the Ishiagu area and is generally grayish white (turned brown by weathering), fine grained and poorly sorted. It trends SE, and rests unconformably on the shale unit of Ezeaku Formation which is grey, carbonaceous, bedded, flaggy and fissile on weathering. Both the Albian and Turonian successions in the study area are folded/refolded into an open symmetrical anticline with the fold axis trending northeasterly. The earliest sediments deposited in the Lower Benue Trough were the 3,000m thick Asu River Group. The Cenomanian was transgressive culminating in the deposition of Odukpani Formation. The Turonian transgression resulted in the deposition of the Eze - Aku Group and the marine Agwu shale. The Turonian – Coniacian sequence varies from 1,300 – 2,000m thick [7]. The Campanian – Maastrichtian sequence is represented by the Nkporo Shale, Enugu Shale, Mamu, Ajali and Nsukka Formations [7].

1.3 Magmatism in the Lower Benue Trough

The lower Benue Trough is characterized by extensive magmatic activity as evidenced by the wide spread occurrence of intrusive and extrusive rocks in the Trough (Fig. 2). These igneous rocks occur over a distance of 500km from Ishiagu in the lower Benue Trough to Zurak in the upper Benue Trough. The igneous rock types are predominantly intermediate to basic in nature [8,9]. There appears to be a close association between the igneous rock and the main structural features in the Lower Benue Trough with these rocks favoring well developed and steep anticlines [9,10].

1.4 Physiography of the Area

Ishiagu area is generally a dominant low lying to gentle undulating shaly terrain of 85-100m above sea level [11], and punctuated by few isolated low hills. Non-resistant shales have given rise to relief whereas highly laterised intrusives formed the low hills such as Ugwuajirija and Ugwuadu, Ugwu-Amonye, a crushed rock industries quarry site with a maximum height of approximately 106m above sea level [12]. The area lies essentially in the guinea savanna; however the natural vegetation has beenintensely disturbed by bush burning and other agricultural practices. Several streams such as Ike, Uru, Okuiyi and Aku, drain the area in a typical dendritic system marked by tree-like pattern of tributary streams meandering and joining the main channel implies that right angles. This pattern of drainage implies that underlying rocks exhibit uniform resistance to erosion and indicates remarkable structural control. The land surface is usually marshy in wet season which prevails from April to October yielding mean annual rainfall of between 1200-2000mm.

1.5 Objectives

The objectives of this research are: To map the igneous intrusions in the Lower Benue Trough, establish the effects of the accumulation of the intrusions in the study area, examine the mode of emplacement of the igneous intrusions in order to determine its effects on the surrounding wall rock and determine the relationship of the structures to the tectonic activities that affected the study area.

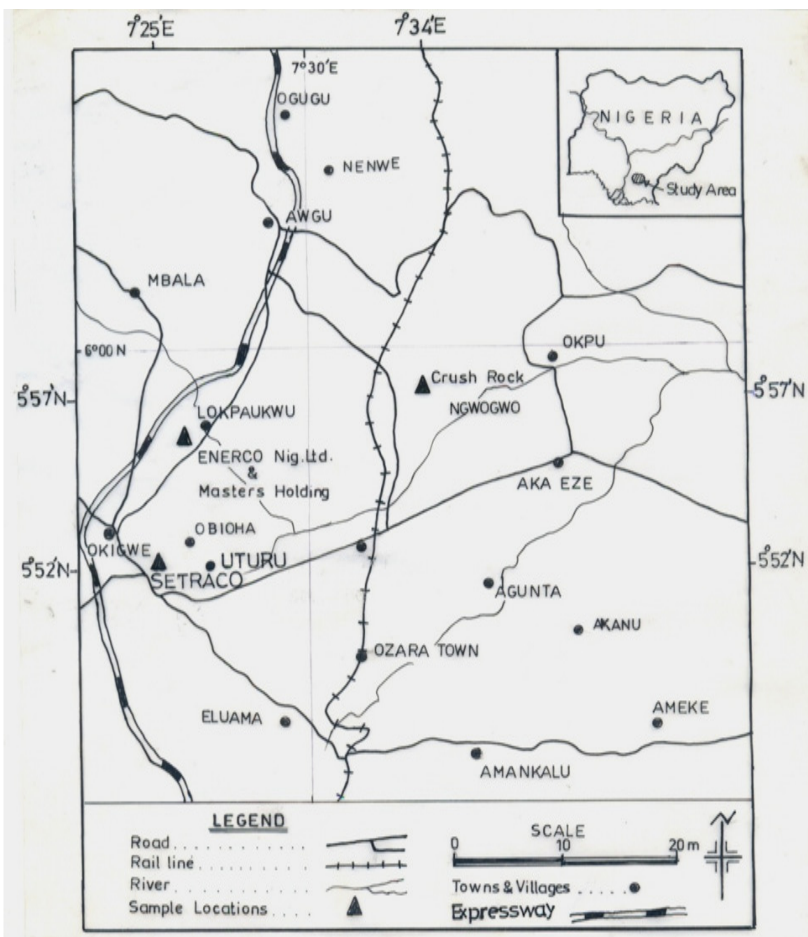

Fig. 1. Location Map of the study area

Fig. 2. Photograph of fractured and weathered Dolerite in Uturu

2. METHODOLOGY

Elevenrock samples were cut and polished into 0.03mm thick and was mounted on a polarizing microscope and analyzed in the laboratory. The samples were studied under plane polarized light and cross polarized light with magnification of 2.5, 0.08 pol. This helped in identifying themineral contents of the rock samples. Photomicrographs of the various thin sections were taken as well as photographs of hand specimens. The hand specimen was studied under hand lens which aided in determining the colour and texture of the rock samples. A standard laboratorytechnique of total organic carbon content (TOC) was determined by the sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture on the mudstone inclusions in the four pyroclastics. After complete oxidation from the heat of solution and external heating [13], the unused or residual $K_2Cr_2O_7$ (in oxidation) is titrated against ferrous ammonium sulphate. The differences between the total used $K_2Cr_2O_7$ and residual $K_2Cr_2O_7$, gives a measure of total organic carbon content.

3. RESULTS AND DISCUSSION

3.1 Presentation of Results

The mineralogical compositions of the igneous rocks in the study area were analyzed using QAPF ternary diagram. The QAPF ternary diagram is a double triangle diagram which is used to classify igneous rocks based on mineralogical composition [14]. The acronym, QAPF, stands for "Quartz, Alkali feldspar, Plagioclase, Feldspathoid (Foid)". These are the mineral groups used for classification in QAPF diagram. Q, A, P and F percentages are normalized (recalculated so that their sum is 100%). Figs. 3, 6 and 9; for Dolerite, Monzonite and Syenite respectively. Using the QAPF ternary diagram, an exact name of a rock can be given only if the mineralogical composition is known, which cannot be determined in the field but through thin-sections prepared in the laboratory and studied under a petrographic microscope.

The mineralogical compositions of the igneous rocks in the study area are predominantly intermediate to basic rocks of both volcanic and hyperbysal mode of occurrence. The minerals identified were mainly plagioclase (labrodorite, andesine, oligoclase, and orthoclase), augite, hornblende, quartz occurring in minor amount and zircon occurring as accessory mineral. From Bowen reaction series, these minerals are of high to intermediate temperature. The rock types were name using the QAPF ternary diagram: a classification scheme adopted by International Union of Geological Sciences [14]. Intodolerite, monzonite, syenite, andesite and diorite.

3.2 Dolerite

Dolerite is the medium-grained equivalent of basalt - a basic rock dominated by plagioclase and pyroxene. Dolerite can contain clinopyroxene and/or orthopyroxene and plagioclase is more calcic than andesine (50% anorthite). Dolerites also often include olivine or quartz and can be alkali basalts, olivine tholeiites or quartz tholeiites. They can contain a wide range of accessory minerals including hornblende and biotite. Dolerites usually have an ophitic texture. Figs. 3, 4 and 5 show the QAPF ternary diagram of dolerite, photograph of hand specimen of dolerite and photomicrographs (ppl&xpl) of dolerite respectively.

3.3 Monzonite

Monzonite is a coarse-grained igneous rock with less than 20 vol% quartz and roughly equal proportions of alkali and plagioclase feldspar. Mafic minerals present in monzonite include clinopyroxene, orthopyroxene, olivine, biotite and hornblende. Monzonite with 10-20% quartz is termed a quartz monzonite. Monzonites can also contain feldspathoids, but such rocks lack quartz. Olivine-bearing monzonites have been termed kentallenite. Hypersthene-bearing monzonites have been termed mangerite. The fine-grained equivalents of monzonite are latite and trachybasalt. Figs. 6, 7 and 8 show the QAPF ternary diagram of monzonite, photograph of hand specimen of monzonite and photomicrographs (ppl&xpl) of monzonite respectively.

3.4 Syenite

Syenite is a coarse-grained alkaline igneous rock dominated by essential alkali feldspar. Mafic minerals are usually present in small amounts and include clinopyroxenes such as augite, diopside, aegirine-augite and aergirine, and hornblende and biotite. Plagioclase can also be present. Titanite is a common accessory mineral. Syenite can contain both feldspathoids, including nepheline, sodalite and/or leucite, olivine or quartz. Feldspathoid syenites often have alkali pyroxenes, such as aegirine-augite and aegirine, or alkali amphiboles, such as reibeckite. Larvikite can be a variety of syenite dominated by perthitic feldspars with a moonstone schiller. Shonkinite is a mafic-rich potassic variety of syenite. Trachyte and phonolite are the fine-grained equivalents of syenite. Figs. 9, 10 and 11 show the QAPF ternary diagram of syenite, photograph of hand specimen of syenite and photomicrographs (ppl&xpl) of syenite respectively.

Based on colour in hand specimen, they range from leucocratic to melanocratic. Their textures are phaneritic to aphanitic. Photomicrograph of the thin sections where the minerals are highlighted with different colours of small arrows was taken as well as photograph of hand specimen (Figs. 3-8). The total organic carbon content (TOC) test conducted on the mudstone inclusions in the pyroclastic (andesite) ranges from 0.60% wt – 0.86% wt (Table 1).

4. DISCUSSION

The most vital condition for the generation of hydrocarbon is the presence of organic carbon in the sediment. A general consensus among petroleum geochemists categorizes source quality by total organic carbon content percentage (TOC %) (Table 2). Total organic carbon content (TOC) test conducted on the mudstone inclusions in the pyroclastics (andesites) range from 0.60 %wt – 0.86 %wt (Table 1). Thus according to classification of source rock quality by total organic carbon content percentage [15]. (Table 2), it shows that the source quality is fair. This indicates that prior to the eruption, the study area may have had higher organic carbon content but the heat that accompanied the eruption baked the surrounding source rock into mud stones thereby reducing the source quality. The only elements essential to the constitution of petroleum are hydrogen and carbon, the transformation must be such that the oxygen and nitrogen of the original organic matter are largely removed and the lipids (fats) and hydrogen – rich organic residue are largely preserved. This outcome is impossible if the decomposition of the organic matter takes place in an oxygenated atmosphere. The organic matter must therefore, be subjected to no prolong exposure to the atmosphere, to aerated surface or subsurface waters carrying acids or bases, to elemental sulfur, or to volcanicity or other igneous activities [15]. In the study area, the organic matter has been subjected to igneous activities which are contrary to the preservation of the essential constituents of petroleum and generation. The effects of the igneous intrusion on the organic matter include the rapid increase in temperature beyond which petroleum constituents are unstable. The transformation of organic matter to kerogen (Diagenesis) proceeds from shallow depth of burial to depths of about 1000m with temperature up to about 50℃ [16]. On further burial and heating, the large molecules crack to form lower, molecular weight hydrocarbons in the depth and temperature range of 1000m – 6000m and 50 – 175℃. The pre – Santonian sediments were buried such that the transformation of organic matter to kerogen and from kerogen to smaller, lower, molecular weight hydrocarbons could take place. The thermal effect of the igneous intrusions could have caused chemical reactions that break off the small fragment of kerogen as oil or gas. Fractured igneous rocks which are not basement, form commercial reservoirs in a few areas where they happened to be underlain or overlain by a source rock or intruded into it. By far the commonest cases are of fragmental rocks, especially tuffs. The natural fracturing provides porosity but sandfrac treatment is still necessary to achieve commercial production [15]. Whether or not there is the possibility of these accumulations, and is of economic quantity in the study areas is subject to further investigations. The dominant agents in the transformation of organic matter to petroleum therefore include temperature and pressure as variables that increase with depth of burial of the source rock under younger sediments [15]. The optimal depths of petroleum generation lie between 2– 4km. Since the petroleum potentials of the study area is largely dependent on the post – Santonian sediments. The study area is characterized by shallow depth due to the igneous intrusions on which the younger source sediments are being laid on. Very high temperatures for instance 300-400ºC are not called for because oils contain too many components that are unstable at such temperature and the temperatures themselves are not achieved in sediments at which oils actually occur. Looking at the mineral composition of the igneous rocks in the study area, they crystallizes out at high to intermediate temperature (Bowen`s reaction series) and the heat of the intruding magma which is from 750 – 1250℃ [17], shows that the temperature for the generation of oil in the pre – Santonian source rocks have been exceeded by the high temperature of the magma and the heat of crystallization of the minerals. Hydrocarbon generation is a rate – controlled, thermo catalytic process referred to as maturation. There is thus, a range of temperatures through which the generation of oil can take place if the source sediments are suitable. At temperature below the critical "jump" [15] temperature of about 60℃, the sediments are immature. At temperatures beyond some higher critical temperature typically about 120℃, they are post mature. Maturity studies shows that the top of the Eze Aku and Agwushales – Lower Santonian are of intermediate maturity , while the lower part (Lower Turonian – Cenomanian) and the Asu River Group (Albian) indicate high maturity (over cooked facies) [18]. The very high maturity attained by the sediments in the study area is on the account of the thermal effect of the igneous intrusions. Though temperature is the critical factor in the maturation of source sediments, it is not the only one. The time factor is also vital. It combines with thermal energy (rather than with actual temperature) to provide an effective exposure time, popularly referred to as the "cooking time" [15]. Conventionally, it is calculated as the time that the sediments spent within 15℃ of the maximum temperature, if reached. The time factor of the post – Santonian sediments which were not affected by the igneous intrusions, may not have attained an effective exposure time ("cooking time") because of exposure to the atmosphere due to quarrying activities of the igneous rocks. The temperature range of oil generation was called [19], the "liquid window"; it applies to the range of true generation and expulsion of the oil and should not be extended to include oils that have been subjected to extensive vertical migration into much younger and cooler rocks. The actual temperatures at the top and base of the liquid window are therefore dependent on the age of the sediments and their geothermal gradient. The pre – Santonian sediments were within the age and geothermal gradient limit but the thermal effects of the igneous intrusions increased the temperature above the liquid oil window limit. The top and bottom of the liquid windows are controlled by critical temperatures; the thickness of the window is a function of the geothermal gradient (30 – 35℃ km-1). The higher the gradient the shallower and more efficient the generation and entrapment of oil provided geological conditions are suitable for these. At least a high geothermal gradient promotes higher porosity, higher permeability in the carrier beds, lower viscosity of the oil and increase in the fluid pressures.Such geological conditions are not obtainable in the study areas despite the high geothermal gradient due to thermal effect of the igneous intrusions and exposure of the younger source sediment to the atmosphere through quarrying activity of the igneous intrusives. Fracture production comes from two distinct rock regimes: from fractures in strata forming integral parts of petroliferous successions, and from fractures in basement or igneous rocks unconnected with the generative sediments and otherwise incapable of production. A productive fractured stratum may be its own source rock. Open fractures are avenues of nearly infinite permeability and may then serve as escape channels rather than as reservoirs, causing transfer or loss of oil if they destroy the integrity of the seals [15]. The study area is characterized by fractures. These fracture zones were exploited by the molten magma which solidifies and act as a trap to the hydrocarbon. But this magma has a temperature range of 750 -1250℃ which is higher than that required for the accumulation of hydrocarbon; hence, increasing the escape of the hydrocarbon. The bottom of the liquid window, the temperature above which oils are converted to thermo genic gas is between 100℃ and 150℃. Above about 200℃, processes become wholly thermal and destructive and can fairly be referred to as metamorphic, leading to the conversion of all hydrocarbons to the two end – members, methane and graphite. Optically active compounds like those occurring in natural oils are decomposed.

Beyond 300℃, many hydrocarbons – associated molecules become thermally unstable. As the magma begins to cool, new minerals crystallizes out at different temperature which is higher than that of hydrocarbon and the country rock. The thermal effect of crystallization of these minerals at these fractureszones caused the trapped crude oil to convert to natural gas through the process of thermal cracking, which then escapes as volatiles as the temperature continues to increase.

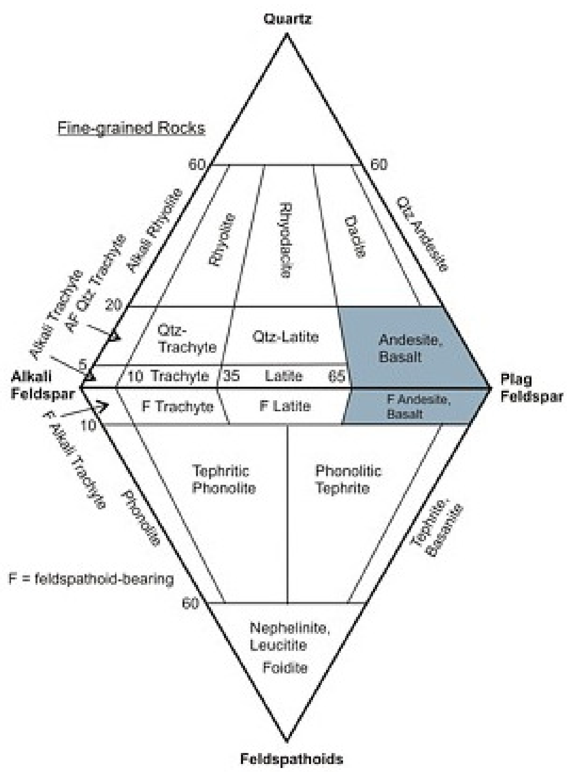

Fig. 3. QAP ternary diagram for Dolerite [14]

Fig. 4. Photograph showing hand Specimen of Dolerite at Setraco Industries, Ishiagu

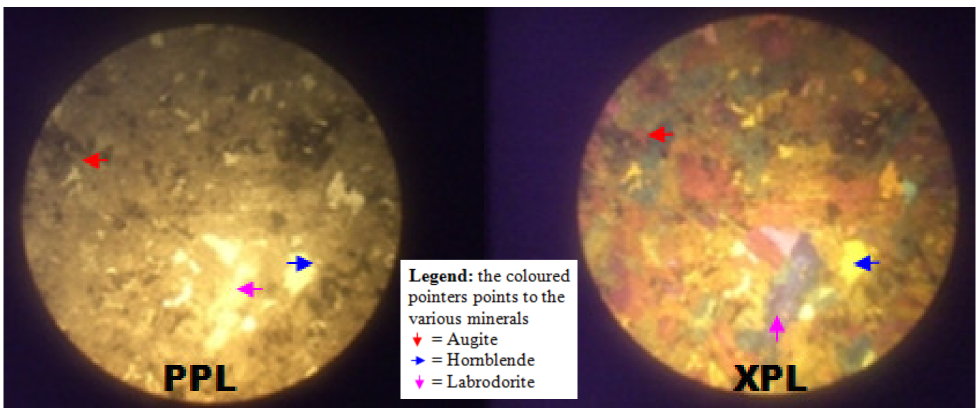

Fig. 5. Photomicrographs of Dolerite at Uturu (magnification 2.5, 0.08 pol.)

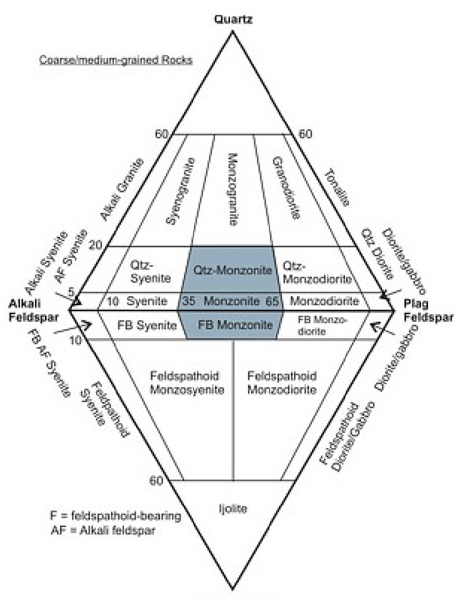

Fig. 6. QAP ternary diagram for Monzonite [14].

Fig. 7. Photograph showing hand Specimen of Monzonite at Ishiagu

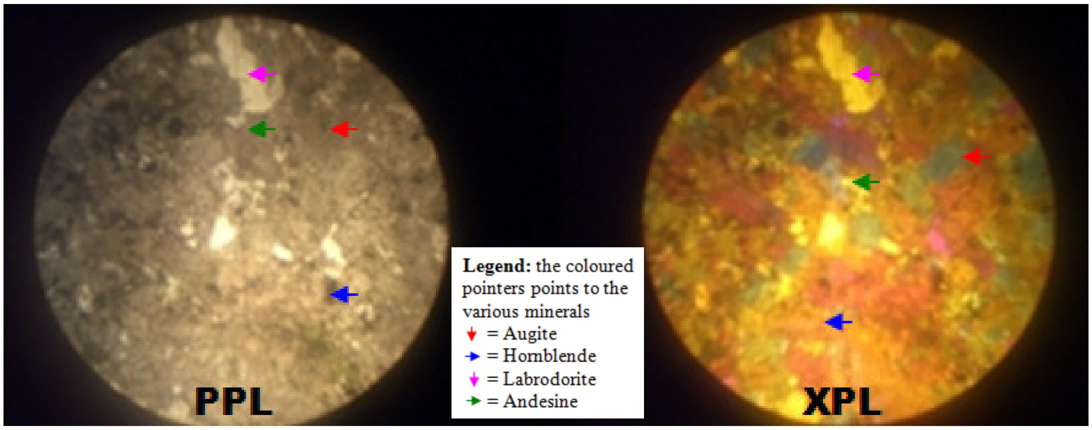

Fig. 8. Photomicrographs of Monzonite at Ishiagu (magnification 2.5, 0.08 pol.)

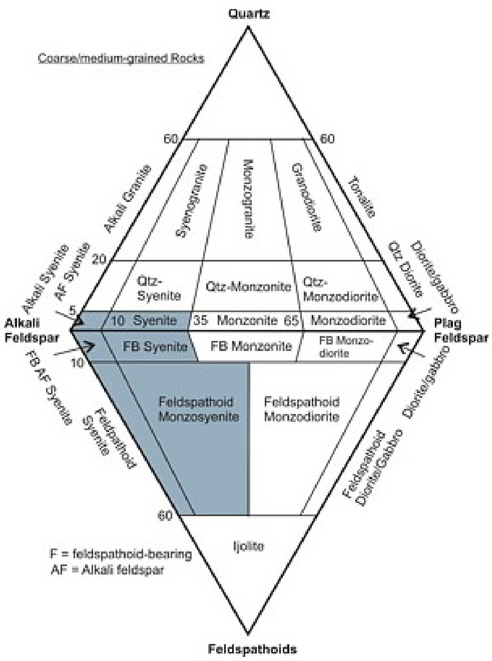

Fig. 9. QAP ternary diagram for Syenite [14].

Fig. 10. Photograph showing hand Specimen of Syenite at Ishiagu

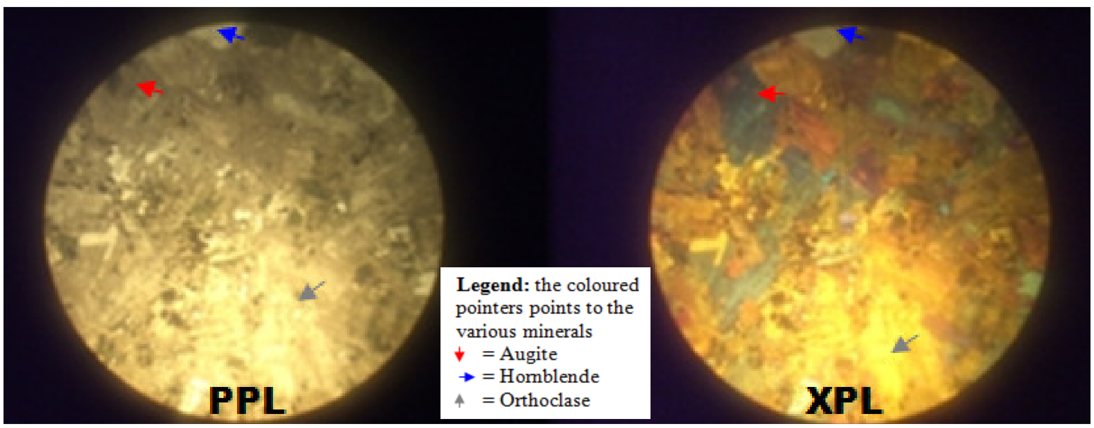

Fig. 11. Photomicrographs of Syenite at Ishiagu (magnification 2.5, 0.08 pol.)

Table 1. Total organic carbon content (TOC) on the mudstone inclusions in the pyroclastics (andesite)

Sample locations	Total Organic Carbon Content (TOC) values (weight percent)
13	0.60
17	0.86
18	0.72
22	0.66

Table 2. Source rock quality classification (according to North, 1987)

Total Organic Carbon Content (TOC) values (Weight percent)	Quality
0.0-0.5	Poor
0.5-1.0	Fair
1.0-2.0	Good
2.0-4.0	Very good
4.0 upwards	Excellent

5. SUMMARY AND CONCLUSION

Ishiagu area of the lower Benue Trough is characterized by basic to intermediate igneous intrusions and extrusions. The igneous rocks are coarse grained and the QAP ternary diagram of the rock minerals showed synite, monzonite, diorite and dolerite igneous rock types. Their field relationship and petrographic studies of the rock suggest that the surrounding sedimentary rocks were intruded by the igneous rocks. Oil cannot be generated from its source sediments without the achievement of some minimum temperature to break down the kerogen molecules. The achievement of this temperature – barring the intervention of intrusive activity involves some minimum depth of burial, the actual amount depending upon the temperature gradients between 60 -65°C. This depth of burial itself requires some minimum amount of time for the accumulation of the younger sediments. The accumulation of hydrocarbons in the study area, especially the lower Cretaceous and pre – Santonian upper Cretaceous rocks are not rated highly because, although the shales and other fine grained sediments accumulated to more than 6,000m in thickness (Asu River Group etc) and intercalated marginally with coarser clastics , these rocks have been intruded extensively by basic to intermediate intrusives. Igneous intrusion and thermal effects on the accumulation of hydrocarbon in Ishiagu area of the Lower Benue Trough in terms of source quality and increase in temperature are beyond condition which petroleum constituents could be realized.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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