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HYDROCARBON POTENTIAL AND EXPLORATION IN VOLCANIC MARGINS: FRONTIER LEADS IN BENUE TROUGH OF NIGERIA

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Abstract

Since the first discovery of volcanic hydrocarbon reservoirs in the San Joaquin Basin in California,United States, in 1887, many volcanic rock provinces have become important targets for oil and gas exploration. This led to the discovery of other hydrocarbon-bearing volcanic basins such as the Jatibarang oil and gas fields in Indonesia with other prolific discoveries in many other countries including Azerbaijan, Australia, Japan, Venezuela, Cuba, and China. In these areas, the hydrocarbon-bearing volcanic rocks range in age from Precambrian to Cenozoic. Using key geological indices of these productive fields as analogues, the volcanic margins of the southern Benue Trough of Nigeria was investigated through petrological and geochemical analyses. Magmatism in the area resulted in the emplacement of igneous rocks (e.g. syenodiorites, dolerites, basalts, gabbros, and pyrocastics) . Porosities in the rocks occur as fractures and secondary pores that are probably controlled by hydrothermal venting. It is considered that magmatic activity rather than being a destructive influence on hydrocarbon potentials would lead to high paleogeothermal gradient and thermal fluids which would accelerate source rock maturity and further provide pathways for fluid emplacement and migration.

Keywords: Hydrocarbon; volcanic margin; Benue Trough; oil and gas exploration.

1. Introduction

The sedimentary sequence of the southern Benue Trough hosts volcanic rocks which can serve as a reservoir for hydrocarbons. These volcanic rocks were emplaced during the Cretaceous when south America separated from the Africa. The tectonism was accompanied by magmatism, which led to the emplacement of the volcanic rocks. This tectonism gave rise to triple rift (RRR), and the failed arm of this triple rift, gave rise to the Benue trough.

The features of the volcanic rocks in the southern Benue Trough creates excellent opportunities for assessing the hydrocarbon as well as extracting the hydrocarbon in the volcanic active zones. Igneous rocks are products of magma and the heat from the magma is capable of maturing the source rocks. In some scenario where the heat is extremely high at the time it came in contact with the source rock; it can result to over maturing of the source rocks, thereby giving rise to gasses. The sub-sediment is being affected by the heat of the magmatic intrusion [plate 1]. The emplacement of the igneous rocks on the sub-sediment exerts pressure on the source rocks. The increase in temperature and in pressures plays vital roles in the formation of hydrocarbon. This phenomenon implies that there is a tendency for hydrocarbon production in the study area(volcanic area).Transient heat from igneous rocks can cause maturation procedures in sediments that have been heated rapidly by magmatic intrusion and hydrocarbon can occur within and around igneous rocks, sometimes in commercial quantity, [15,12] stated that igneous rocks come as a package of heat source and reservoir rocks and that in some basins, the hydrocarbon system occur beneath the volcanic cover.

Igneous rocks have served as a reservoir in many hydrocarbon regions. The basic properties that classify volcanic rocks as reservoir rocks for hydrocarbon are found in the igneous rocks of southern Benue trough. This paper is to encourage in-depth work on the hydrocarbon potential and on the hydrocarbon reservoir rocks of southern Benue Trough.

2. Geologic setting

The Benue Trough is an elongated rifted depression in which the sediments reach over 5000m thickness in places and have been strongly folded [16]. Southern Benue Trough is a portion of the failed arm of a triple rift, that accompanied the separation of South America from Africa, in the Cretaceous times [1,11].

The sediments in the southern Benue Trough were formed by the transgressive/regressive sedimentary cycles, the sediments have suffered two episodes of deformation in the Cenomanian and Santonian along NE–SW axis. The Santonian deformation produced the Abakaliki Anticlinorium which has two synclinal basins on its flanks (Anambra Basin on the western flank and Afikpo basin on the eastern flank) [5], the deformations of the pre-Santonian sediments gave rise to series of fractures and fold along the fold axis [2,7,9].

The exposed sedimentary sequences in the study area (Anambra basin) consist of Asu River Group (Albian). The Asu River Group is the oldest sediment in the study area. It is made up of brownish shales, micaceous sandstones, and mudstones. Nkporo Shale (Late Turonian) lies on the Asu River shale; it is made up of dark gray shales, sandy shales, and sandstones. Mamu Shale (Middle Maestritchian), comprises sandstones, dark gray shales, and sandy shale , Mamu shales contain mudstone that alternates with sandstone. Ajali sandstone (Upper Maestritchian) is friable, whitish in colour, cross-bedded. It contains some mudstone, and there is the presence of bioturbations. Igneous rocks (basalt, dolerite, and pyroclastics, syenodiorites) form topographic highs, in the Afikpo basin(study area), the exposed sedimentary sequences are the Asu River Group, the Eze-Aku Formation(Lower Turonian), this Formation has some calcareous shales and sandstones. They are grey in colour.

3. Field and sampling techniques

Field studies were carried out to determine the contact relationship of the volcanic rocks with the host sedimentary rocks. Most of the igneous rocks in the study area occurred as dykes and sills. In Uturu and Afikpo, the dolerites occurred as dykes in the sedimentary sequence, in Afikpo, Lokpaukwu and Ishiagu, few basalts outcrops occur as sills. Syenodiorites exposed as dyke in the host rocks of Ishiagu. The rocks samples were collected from the quarry and stream channels. The geomorphology/shape of the volcanic rocks was studied. The eruptions of some of the rocks were massive, and the magmatic rocks were structurally controlled to the Abakaliki Anticlinorium.

The structural features of the volcanic rocks were studied, and it was discovered that there were presence of primary and secondary structures on the rocks. The primary structures could be products of cooling and expansion of the crystallized rocks or products of Santonian deformation or due to the pressure from the overburden. The secondary fractures were generated in the rocks probably at the time of exploration or blasting of the rocks for construction purposes. The rocks were further studied megascopically, basalts have aphinitic textures and melanocratic in colour, it occurs as an extrusive rock at the study area, dolerites were hyperbysal but got exposed by the processes of erosion that have washed out the overburden sediments. Dolerites of the study area are melanocratic in colour and have fine to medium grain sizes. The gabbro is phaneritic in texture and appears slightly mesocratic. Syenodiorite occurred as an intrusive rock in the sedimentary rocks in Ishiagu, the syenodiorites are of two parts, some of them are leucocratic in colour and the other mesocratic colour. The syenodiorites have porphyritic texture. Pyroclastics occurred in the Anambra basin and in Afikpon basin. The pyroclastics of each location have distinct features from the other. The Akpoha pyroclastics are leucocratic in colour, and composed chiefly of consolidated volcanic ash and volcanic bombs. The pyroclastics in Ishiagu area are grey in colour and have aphinitic textures, the pyroclastics in Lokpaukwu consist of volcanic tuffs and lapilli. They have fragmented textures. Fresh rock samples were collected from different pockets in the igneous suite. Thin sections of the volcanic rocks were prepared in order to determine the mineral compositions. Knowledge of the constituent minerals gave insight on the temperature that existed in the study area at the time of emplacement of the rocks. The thin sections were described using a petrological microscope. There are presence of high temp minerals in the rocks

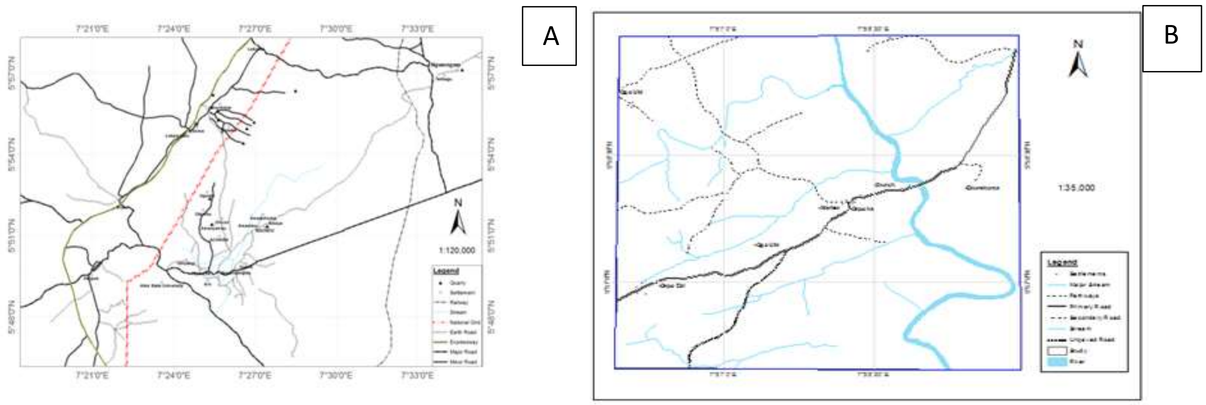

Figure 1. A=Map of some part of Anambra basin showing the study area; B=Map of some part of Afikpo basin showing the study area.

4. Results of Petrography and Mineralogy

The studied rocks are basalts, dolerites, gabbro, syenodiorites, pyroclastics. In the thin sections the average mineral compositions in the basalts are olivine (20%), pyroxene (10%), biotite (10%), plagioclase (50%), iron oxide (8%). Dolerites have average mineral compositions of pla-gioclase (45%), olivine (15%), pyroxene (20%), biotite (10%) and iron oxide (10%). The average mineral compositions of the gabbro are olivine (25%), pyroxene (10%), biotite (8%), plagioclase (55%) and traces of quartz. Dolerites, gabbros, and basalts have the same mineral compositions but different in their textures which could be as a result of their modes of emplacements.

The basaltic magmas in the study area probably resulted from a single magma source. The syenodiorites consist of plagioclase (45%), potassium feldspar (20%), pyroxene (15%), amphibole (10%), biotites (8%), and iron oxide as accessory mineral. The average mineral compositions in the pyroclastics are plagioclase (50%), olivine(15%), pyroxene (20%) biotite (10%), iron oxide (3%), quartz occurs as an accessory mineral in some samples. The rocks are characterized mostly by high temperature minerals (olivine, plagioclase, pyroxene), the presence of high tempera-ture minerals in the rocks is an indication that the study area was a thermo-tectonic active zone which as well has an impact on the source rocks of the area. Volcanic rocks supply thermal heat to organic matter which can result to the maturation of neighbouring source rocks.

5. Discussions on the Hydrocarbon potential in the volcanic margin of the southern Benue Trough

Basaltic magma is formed at very high temperature probably at the range of 950-1200^{o}C. The high temperature minerals are stable at such high temperature. During the evolutionary stage of magma to the place of crystallization, the temperature gradually drops. Olivine is the first mineral to fractionate out of the magma as the temperature starts dropping. Assuming that there are some remnants of silica in the magma after fractionation of olivine, then silica reacts with the olivine crystals to form pyroxene. The presence of olivine and pyroxene in the rocks depicts that some of the source rocks were heated by high temperature. Olivine has been discovered as one the minerals that can act as a catalyst in converting organic matter to hydrocarbon [4,6].

The study area which was formed by marine transgression and regression must have harboured some kerogen. The intrusion of magma generated heat on the source rock which over time has the tendency to convert kerogen into liquid hydrocarbon or gaseous hydrocarbon depending on the degree of temperature exerted by the magma at the time of the intrusion into the sediments. Hydrocarbon have been found in almost all types of volcanic rocks, basalts have the largest proportion followed by andesites, rhyolites, and pyroclastics [12].

The sediments in the study area can be grouped into two, the pre-Santonian sediments and the post Santonian sediments.

5.1. Pre-Santonian Sediments

The field occurrence shows that the magmatic rocks intruded the pre-santonian sediments (the sub-sediment).The Santonian deformation was associated with magmatism [11].The contact association of the magma and the sediments at the early stage of eruption can exert very high temperature on these sediments thereby destroying the biomass in the sediments, when the biomass is destroyed, neither petroleum nor gas will be formed. Natural conversion of organic matter to hydrocarbon is a slow procedure, but the intrusion of magma and cooling pattern of the magma can accelerate maturation of adjacent and neighboring sediments [14] stated that there is the presence of oil show in Eze-Aku Formation and that Eze-Aku Formation was partly involved in the Santonian folding.

The principles of magma differentiation (assimilation and contamination), can result in the pre-Santonian sediments being more mineralized. Magma are characterize based on their minerals/ elementals constituents [8]. The contact of the magma with the host rock (especially the pre-Santonian sediments) can result to the mineralization of the host rocks. Most oil is formed between 100 and 150°C; and most gas between 150 and 220°C [13]. In the Santonian, most of the pre-Santonian sediments were folded. The presence of oil show in Eze-Aku formation as recorded by Reyment [14] could be due to the fact that Eze-Aku Formation was not fully involved in the folding and probably, the cooling stage of the magma exerted thermal heat of Eze-Aku Formation which resulted to the presence of the oil show. The contact of the intruded magma and the the pre-Santonian sediments can cause some of the sediments to metamorphose. Part of the pre- Santonian sediments appear to be poor prospects for hydrocarbon.

5.2. Post Santonian Sediments

The field association shows that sediments of Late Santonian to Maestritchian times were not intruded by igneous rocks. The mode of emplacement and the textures of the igneous rocks in the study area shows that the cooling of the magma was not abrupt, so the post Santonian sediments probably were exposed to the less geothermal environment than the pre-Santonian sediments. The total organic carbon of the post santonian shales in the study area range from 1.14-2.04%; these values exceeded the value of 0.5% total organic carbon which was considered the minimum for an effective source rock. The geothermal environment of these two groups of sediments (pre and post Santonian sediments) suggest that there is more prospect for hydrocarbon in the post Santonian sediments than the pre-Santonian sediments of the southern Benue Trough, though intensive geologic mapping, the geochemistry, and remote imagery may be of tremendous assistance in evaluating the hydrocarbon potential.

5.3. Exploration potentials in the volcanic rocks

The igneous rocks of the study area have so many geometry and shapes which serve as a vacuum for hosting hydrocarbon (Plate 3-4), thereby being a good reservoir in which the hydrocarbon can be trapped. The absence of solid layers to trap the hydrocarbon results to loss of the hydrocarbon to the environment. Hydrocarbon traps in the study area involved structural styles in which each pattern is interrelated of geologic features with some spatial arrangement (Plate 3) and the stratigraphic features which involved porosity and permeability are also present in reservoir rocks of the study area. Pyroclastics in the Afikpo, Ishiagu, Lokpaukwu and Uturu have some fragments of volcanic ash, lapilli, and bombs; these attributes can enhance porosity and permeability which can make the pyroclastics to serve as a reservoir rock for hydrocarbon. The intergranular characteristic of the igneous rocks serves as primary porosity while fracturing and hydrothermal alterations serve as the secondary porosity.

The intrusion of the magma into the sediment to the point of emplacement also creates channels which serve as a pathway for hydrocarbon migration (Plate 3). The igneous rocks of the study area have good sealing properties (Plate 4).Timing plays important roles in the production of the hydrocarbon. The time of deposition, the prevailing time of geothermal processes of the hot magma and the degree of the heat determines whether petroleum or gas will be produced or both (petroleum and gas). Drilling through the volcanic margin appears to be difficult and expensive, but the geological features in the rocks (faults and fractures) creates access for easy penetration of the drilling bits and also less tedious. Cost analysis, geophysical techniques, geochemical analysis, remote imagery, the intensive geological mapping will assist in yielding comprehensive information about the hydrocarbon potential of Southern Benue Trough.

Plate 1. Exposure of the relationship of the igneous rock with the sub-sediment and supra sediment in Uturu

Plate 2. Exposure of the relationship of the igneous rock with the sub and supra-sediment in Afikpo

Plate 3a. Structural features in the volcanic rock of southern Benue Trough

Plate 3b. Structural features in the volcanic rock of southern Benue Trough

Plate 3c. Structural features in the volcanic rock of Ishiagu southern Benue Trough

Plate 4a. The sealing properties in the volcanic rocks of Anambra Basin

Plate 4b. The sealing properties in the volcanic rocks of Anambra Basin

6. Conclusion

The association of magmatic rocks with the source rocks in the Anambra and Afikpo basins requires in-depth study of the hydrocarbon potential. The study area host source rocks and reservoir rock and the condition (thermal decomposition) required for hydrocarbon formation have existed in the study area, Some of the conditions like the microbial processes are still taking place in the basin. Prospecting for hydrocarbon in the southern Benue trough is encouraged as to determine the economic prospect of the area as regards to hydrocarbon

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