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Petroleum Generation Potentials of the Upper Cretaceous Dukul and Numanha Formations Of The Yola Sub – Basin, Upper Benue Trough, Northeastern Nigeria

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ABSTRACT

Nigeria's current petroleum and gas reserves are put at 35 billion barrels and 170 Trillion standard cubic feet (TCF) respectively. The above figures call for caution and the need for continuous and more aggressive exploration strategy to find more oil fields if the nation will continue to rely on crude oil exportation as one of its foreign earnings. The research is aimed at determining the Petroleum Generation Potential of rock samples from the Upper Cretaceous Dukul and Numanha Formations in Yola Sub-Basin using Geochemical Analysis where the organic matter quality (Type), quantity (Richness), thermal maturity and the hydrocarbon generation potentials will be determined. Also the research work in aim at determining the influence of localized volcanic activity on the rock samples maturity and its relationship to hydrocarbon generation using temperature at maximum (T_{max}). The total organic carbon (TOC) content were determined to be generally low in all the samples analysed (0.25 wt %) – 0.65 wt %). The rock samples are classified as being fair to relatively good source rocks for petroleum generation. The kerogen type was observed to be predominantly Type III and IV indicating the rock samples are rich in gas with limited quantity of liquid hydrocarbon. Vitrinite reflectance (R_o) and pyrolysis data (T_{max}) showed that the samples analysed have entered oil window to post matured stage. High thermal maturities of the samples clearly indicate that the localized volcanic activity has influenced the nature of the organic matter thereby cracking the organic matter into thermogenic gas within the sub-basin.

Keywords: Hydrocarbon, Generation Potential, Pyrolysis, Source Rocks.

INTRODUCTION

Nigeria's current petroleum and gas reserves are put at 35 billion barrels (bbls) and 170 Trillion standard cubic feet (TCF) respectively (Obaje et al, 2006, Sarki Yandoka, 2015). The above figures call for caution and the need for continuous and more aggressive exploration strategy if the nation will continue to rely on crude oil exportation as one of its foreign earnings. Most of the multinational oil companies operating in Nigeria are business profit oriented and mostly rely on the exploration works of their initial oil prospectors for their current production. However, in 1994 the Federal Government of Nigeria employed the big oil companies like shell, Chevron and Elf to explore the possibility of hydrocarbon fields in the Northern Benue trough it wasn't only the scanty geological data that warranted that decision. Perhaps it was Chad, Niger and Sudan. The discovery was related to three petroleum systems; the Lower Cretaceous oil prone lacustrine sediments, the Upper Cretaceous gas-prone marine sediments and the Palaeogene oil- prone lacustrine and marine sediments. These prospective sedimentary basins of Chad, Niger and Sudan Republics occur within same West and Central

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African Rift system (Figure 1). They have same geological setting, time equivalence and origin with the Upper Benue Trough. They have also been affected by similar geological activities.

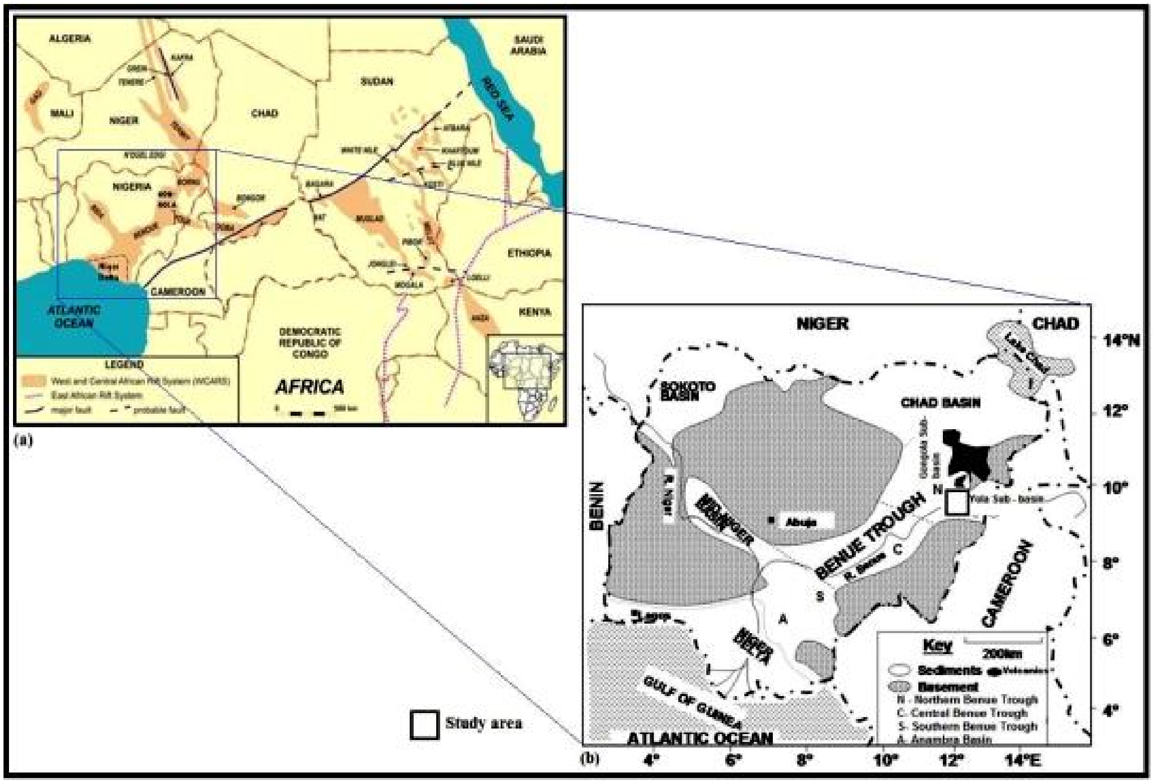

Figure 1: Regional Tectonic map of Western and Central African rift basins showing the Nigerian Benue trough and the study area (from Sarki Yandoka, 2015)

Increase in industrialization and electrification of developing nation like Nigeria as well as fast population growth, is causing an increase of petroleum energy consumption. The energy that has become a security concern in the face of its scarcity and rising prices; it has become more crucial to both private and public sectors alike. Even though oil prices have decreased significantly during the past few months, motivated by an oversupply, the financial crisis and unstable world market, the search for new reserves, as well as continuous investment must be done in order to reach the global oil demand for future use.

In principle, one of the essential steps in hydrocarbon exploration and exploitation is to understand the petroleum source rock and to know the rich sediments containing organic matter through the use of Geochemical source-rock evaluation. The geochemical evaluation helps provides valuable information to be used for upgrading areas under investigation and concentrating exploration activities in certain places to reduce risk and cost.

Geology and Stratigraphy

The Upper Benue Trough is a geographical subdivision of the Nigerian Benue Trough that shares the same tectonic origin with the West and Central African Rift system (WCARS-Fig 1). The origin and tectonic history of the Benue Trough is associated with the separation of Africa and South American plate

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(break-up of Gondwanaland) during the early Cretaceous time (Benkhelil, 1989). The break-up was followed by the drifting apart of the continents which resulted to the opening of the South Atlantic Ocean and the growth of the mid – Atlantic ridge. The Upper Benue Trough is further sub-divided into Gongola and Yola arm.

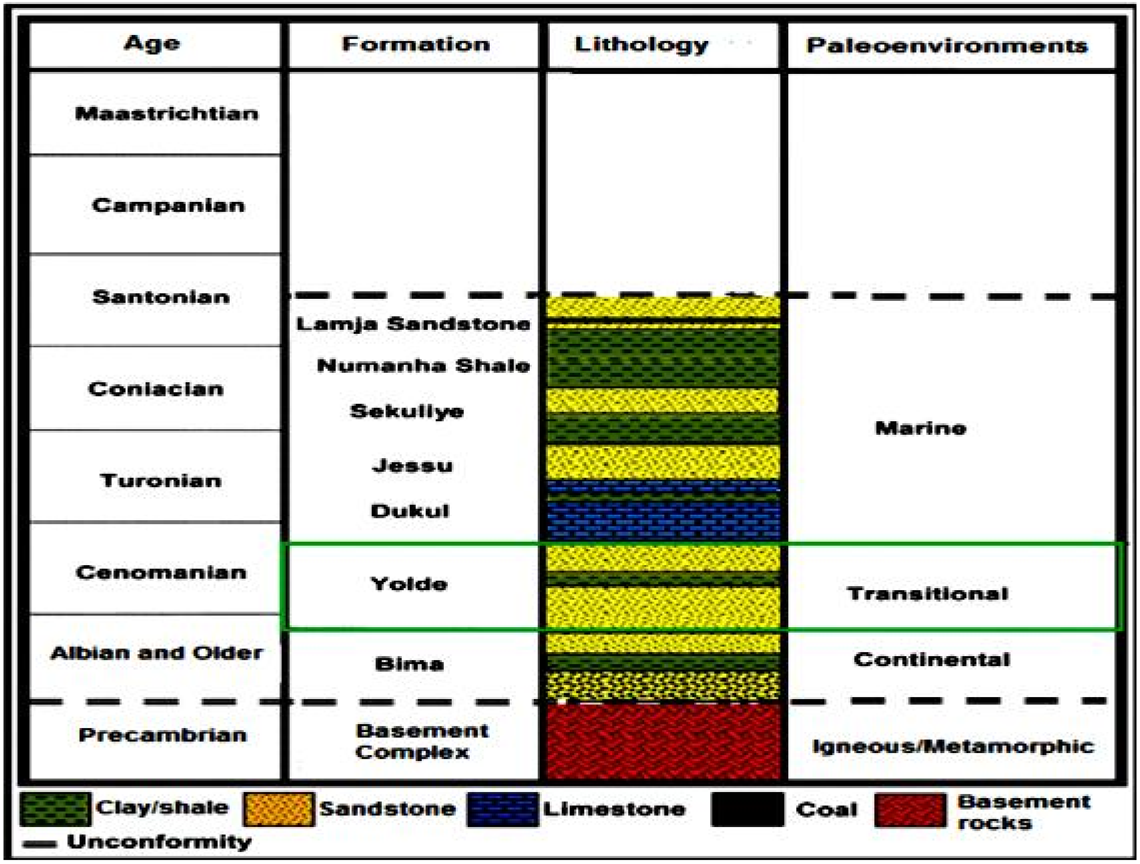

Figure 2: Generalized Stratigraphy of the Yola Sub.

The Stratigraphy of the Yola arm comprises of the continental Lower Cretaceous Bima Formation, the Cenomanian transitional marine Yolde Formation, which is overlain by the Dukul,Jessu, Sekuliye and the marine Late Cenomanian Numanha shales (Figure 2). The Lamja overlies the Numanha shales and marked the end of sedimentation within the Yola sub-basin (Carter et al, 1963; Abubakar 2006; Sarki Yandoka et al, 2014; Usman et al 2024). Quartenary volcanic plugs were intruded within the formations and are seen localized at the boundary between the Gongola and Yola arm of the basin.

The Dukul Formation generally consists of bedded shales and fossiliferous limestone (Carter et al, 1963). It is dated as early to basal middle Turonian based on the evidences od ammonites. On the faunal assemblage, the Dukul Formation was interpreted as deposition in littoral to open marine shelf environment (Ojo and Akande, 2000). At kutari and Lakun villages near Cham, dark gray shales of the Dukul are interbedded with limestone. The shales are laminated in some places and texturally medium to coarse grained. The Dukul Formation at Abare consists of marlstone, mudstone, limestone and siltstone.

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The Numanha shales consists of shales with bands of mudstone, sandstone and limestone. The formation was first recognised as argillaceous beds and deposited in shallow (shelf) environment (Carter et al, 1963; Cratchley and Jones, 1965; Falconer 1911; Sarki Yandoka, 2015). The lower part of the Numanha consist of gray – black shales with occasional nodules and nodular beds of mudstones (Carter et al, 1963; Sarki Yandoka, 2015).

Sampling and Experimental Method

A total of ten (10) outcrop samples were collected from shale and limestone intervals within the Dukul Formation at Abare and sedimentary section of Numanha shales exposed at Numan village. The samples were collected knowing that weathering is always a factor of concern for organic geochemical studies of outcrop sediments, the weathered rock surfaces were removed by digging to approximately 0.5m in each sampling point. Before the analysis, the samples were scrubbed and thoroughly cleaned with distilled water to remove traces of surface dirt's and plant growth and then dried at 35°c for about 12hrs. The samples were analysed in a modern Organic Geochemistry and Petrographic laboratory in University of Malaysia, Malaysia. The samples were crushed into fine powder (< 150 NM) and screen using the SRA – Weatherford geochemical pyrolysis machine (Rock – Eval instrument). Pyrolysis analysis were performed on 80mg crushed samples, which were heated to 600 °c in a helium atmosphere and parameters such as S_1, S_2 and temperature of maximum Pyrolysis yield (T_{max}) were measured. Total organic carbon (TOC) content was determined using a multi EA 2000 Analyser. The organic richness, kerogen type, petroleum generation potential of the organic matter and its thermal maturity were determined and characterized (Peters and Cassa, 1994).

Organic Geochemistry

Table 1 presents the results of the Rock – Eval pyrolysis obtained from the analysed samples. The organic matter quantity (richness) was determined using pyrolysis S_2. The pyrolysis analyses of the samples were conducted based on whole-rock sample analysis. Generally, the samples have low TOC values ranging from 0.24 – 0.56 w%. The TOC contents and Pyrolysis (S_2) yielded values that are accepted to be standards of a source rock with fair to relatively good oil potential.

Table 1: Bulk Geochemical Data and Pyrolysis analysis

S/N	Formation	Sample ID	S_1 (mg/g)	S_2 (mg/g)	Tmax (°C)	HI	PI	TOC (wt %)	%R_o
1	Dukul	DMI 1	0.22	0.06	431	24	0.06	0.25	0.73
2	Dukul	DMI 2	0.33	0.22	442	12	0.18	0.53	0.65
3	Dukul	DMI 3	0.23	0.08	442	24	0.07	0.33	0.75
4	Dukul	DMI 4	0.23	0.08	438	24	0.07	0.42	0.73
5	Dukul	DMI 5	0.38	0.28	441	50	0.25	0.56	0.62
6	Numanha	NMI 1	0.13	0.31	440	94	0.29	0.33	1.42
7	Numanha	NMI 2	0.11	0.38	443	97.4	0.22	0.39	0.73
8	Numanha	NMI 3	0.06	0.34	451	109	0.15	0.31	1.34
9	Numanha	NMI 4	0.20	0.74	443	113	0.21	0.65	1.26
10	Numanha	NMI 5	0.07	0.31	449	75.6	0.09	0.41	0.85

S_1 = Volatile Hydrocarbon (HC) content, mg HC/g rock;
S_2 = Remaining HC generative Potential, Mg HC/g rock;
HI = Hydrogen Index = S_2 X 100/TOC, mg HC/g TOC
TOC = Total Organic Carbon, wt%

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PI = Production Index = S_1 (S_1 + S_2)
Tmax = Temperature at maximum
% R_o = Vitrinite Reflectance.

Kerogen Type I and II are derived from Lacustrine and marine source rocks which are capable of generating hydrocarbons while Type III kerogen comprise of woody material is gas prone but Type IV comprises inert materials with no hydrocarbon potential.

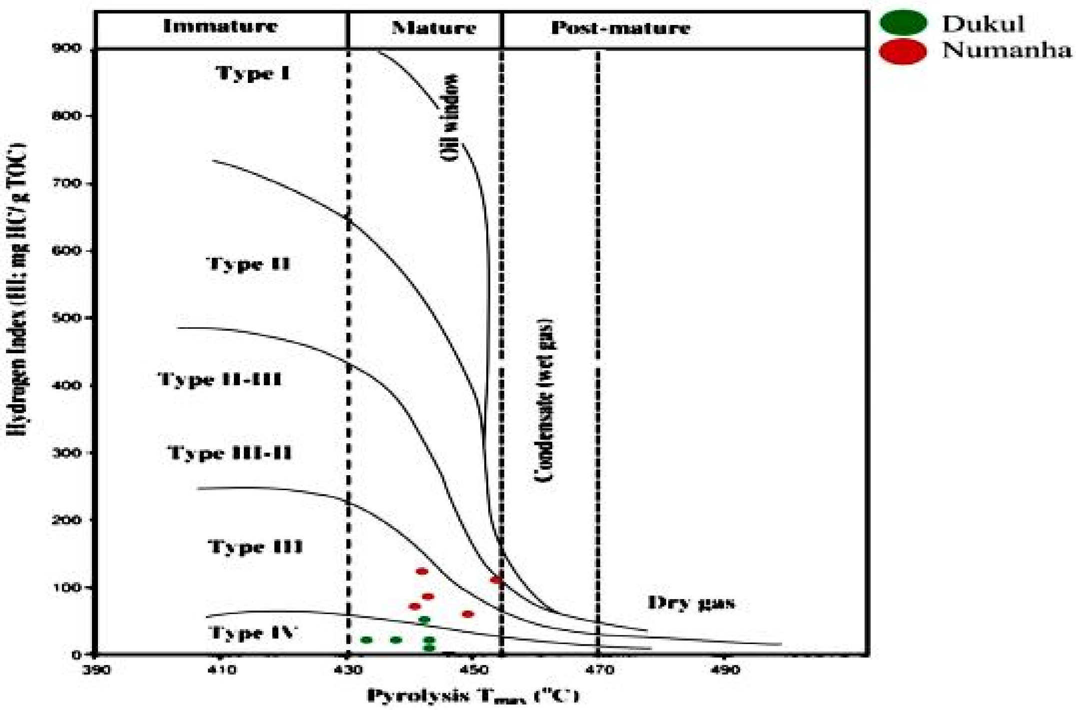

Figure 3: Plot of Hydrogen Index (HI) against Pyrolysis T_{max}.

The Hydrogen Index (HI) against Pyrolysis T_{max} (Fig. 3) indicates predominantly Type III and IV for all the samples. It is seen that the kerogen from the Numanha Shales are slightly transformative from Type III to Type II, indicating traces of oil due to small quantity of Type II kerogen. Most of the samples have Hydrogen Indices (HI) values of approximately 50 mg HC/g TOC; thus contain mainly gas, while those with Hydrogen Indices less than 50 mg HC/g TOC do not possess any oil generation potential and can only produce thermogenic gas or inert hydrocarbons.

Heat generally converts kerogen to bitumen, and finally to petroleum (oil and gas). The thermal maturity data showed that the Vitrinite reflectance (%R) and the Pyrolysis Tmax values may be affected by the depositional environment and matrix lithology respectively. The Integration of Pyrolysis parameters and petrography (Vitrinite reflectance) has shown that the source rocks have entered oil window to post matured stage. The measured Vitrinite reflectance illustrated a good relationship with the pyrolysis T_{max} (Fig. 4).

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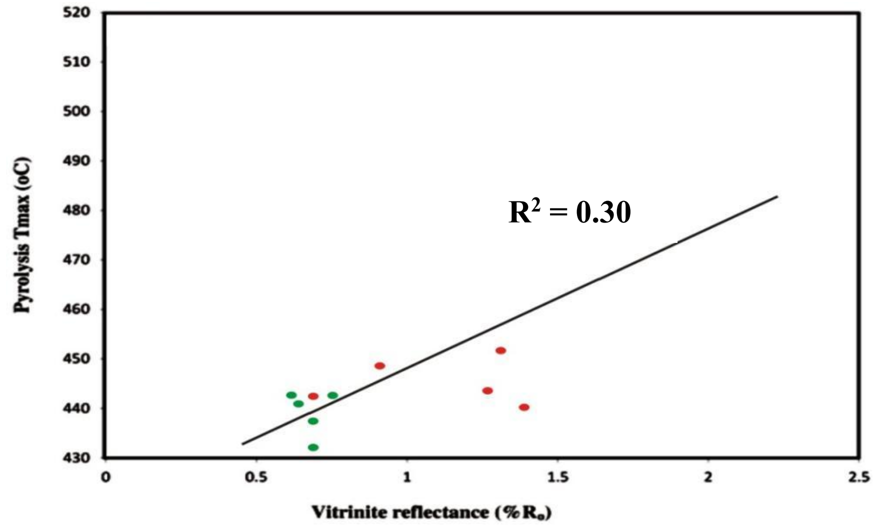

Figure 4: Plot of pyrolysis T_{max} against vitrinite reflectance (%R_o)

Hydrocarbon Generation Potential

Analysis of the samples showed HI values less than 200mg HC/g TOC. It is clear that samples with HI values less than 200 mg HC/g TOC generate gas; while samples with HI values higher than 200mg HC/g TOC generate oil. Thermal maturity results have showed that the organic matter is expected to generate mainly gas and very small amount of oil. High gas generation potential is due to high thermal maturities experienced by the samples. This is illustrated by the cross-plot of pyrolysis *T*max against production index (Fig. 5), indicating that samples are within main hydrocarbon generation.

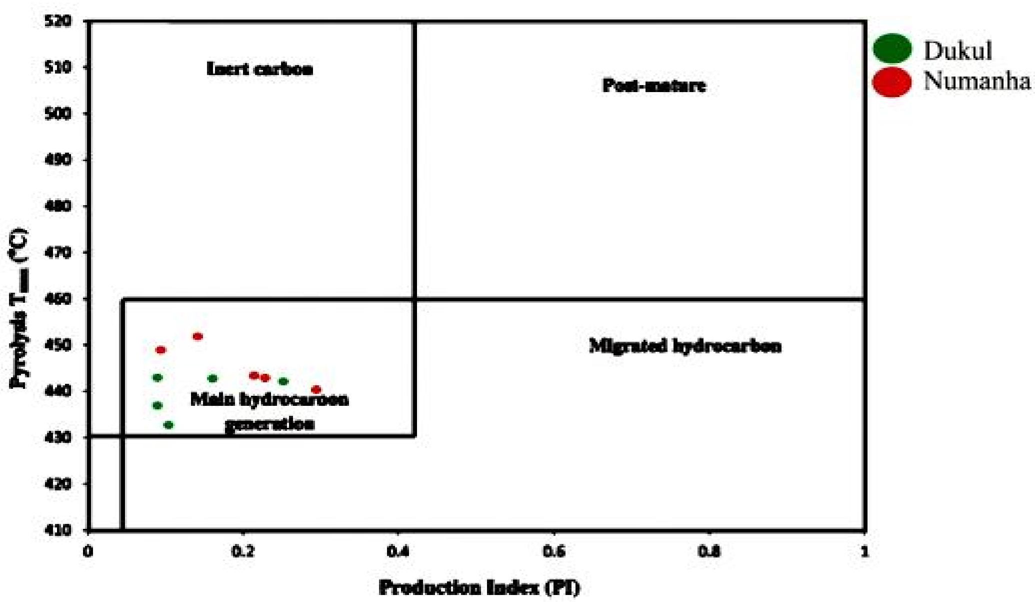

Figure 5: Plot of pyrolysis *T*max versus production index (PI)

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Generally the samples have shown that they are within the window of hydrocarbon generation with high gas generation potentials due to high thermal maturity experience by the samples. This also indicates that the volcanic activity within the sub-basin has influenced the nature of the organic matter thereby cracking the organic matter into thermogenic gas within the sub-basin.

CONCLUSION

The Petroleum Generation Potential of rock samples from the Upper Cretaceous Dukul and Numanha Formations in Yola Sub-Basin using Geochemical Analysis where conducted. The organic matter type, quantity (richness), thermal maturity and the hydrocarbon generation potentials analyses revealed that:

1. The total organic carbon (TOC) content were generally low in all the samples analysed (0.25 wt %) – 0.65 wt %) and the rock samples are classified as being fair to relatively good source rocks for petroleum generation
2. The samples contain low values of S_2 (< 1.0 mg/g), and low Hydrogen index values of 12-113 mg HC/g TOC thus indicating the samples contain mainly gas.
3. The kerogen type was observed to be predominantly Type III and IV indicating the rock samples are rich in gas with limited quantity of liquid hydrocarbon.
4. Vitrinite reflectance (R_o) and pyrolysis data (T_{max}) showed that the samples analysed have entered oil window to post matured stage.
5. High thermal maturities shown by the samples clearly indicate that the localized volcanic activity has influenced the nature of the organic matter thereby cracking the organic matter into thermogenic gas.

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