

CHARACTERIZING THERMAL MATURITY AND HYDROCARBON POTENTIAL OF SOURCE ROCK USING ROCK-EVAL 6 PYROLYSIS TECHNIQUE

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Abstract— Organic geochemical evaluation of source rock within a petroleum system is important considering its role as the source of hydrocarbon. Subsurface samples at depth of 2361m (outer shelf) and 2613m (lower slope) from Pologbene-1 Well located within the northern delta depobelt were analysed using Rock-Eval pyrolysis analytical technique. This technique involves the temperature programmed heating of samples in an inert environment. Inference was drawn from Rock-Eval geochemical parameters, which include S1, S2, TOC, and T_{max} . Others are Hydrogen Index (HI), Oxygen Index (OI) and Production Index (PI). The results were compared with the inner shelf (1716m) and the upper slope (2595m) of the same well. Two geochemical models were established: HI/OI and HI/ T_{max} , for the outer shelf and upper slope source rock of Pologbene-1 Well. The two models were derived from HI values of 502 and 548, OI value of 14 and 15 and T_{max} value of 429°C and 419°C (outer and upper slope respectively). The model indicate that the samples are oil and gas prone, are type II source rock containing type II kerogen. S1, S2 and TOC values of 7.96mg/g, 328mg/g and 65.36wtpercentage for outer shelf and 7.51mg/g, 325mg/g, 59.37 percentage for upper slope respectively indicate good to excellent source capacity and high petroleum potential for Pologbene-1 Well.

Keywords— Organic geochemical evaluation; source rock, depositional environment; kerogen type; Niger Delta Basin

I. INTRODUCTION

The relationship between the occurrence of organic compound in sedimentary deposits and petroleum deposit has long been of interest. Studies of ancient sediments and rock provide insights into the origins and sources of oil petroleum geochemistry and the biochemical antecedents of life.

In petroleum geology, source rock refers to rock from which hydrocarbon have been generated or are capable of being generated. They are sedimentary rocks that are, or may

become, or have been able to generate petroleum (Tissot et al. 1984). They are organic-rich sediments that may have been deposited in a variety of environments including deep water, marine, lacustrine and deltaic, and one of the necessary elements of a working petroleum system.

Various methods have been employed over time to determine the petroleum potential of source rock, their stages of thermal maturation, type and class of inherent kerogen. The generative source potential and the main product expelled at peak maturity is also of basic interest.

This study therefore seeks to determine the thermal maturity and petroleum generative potential of source rock in the northern delta depobelt of the Niger Delta Basin, using Rock-Eval pyrolysis approach.

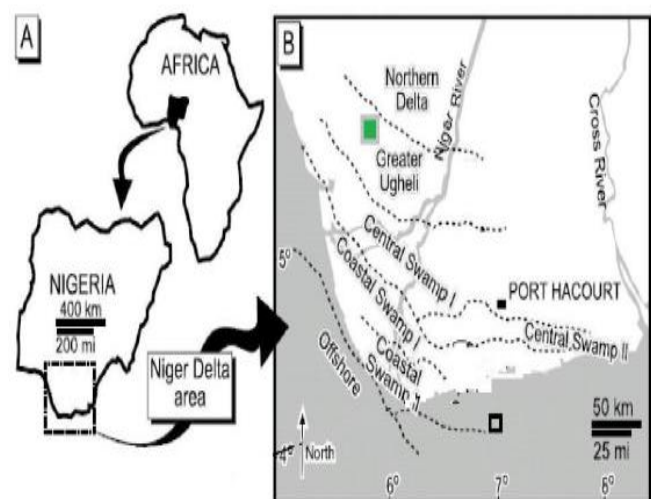


Figure 1: Map of study area

II. METHODOLOGY

The major method employed for this study is the Rock-Eval 6 pyrolysis, which aim is to identify the type and maturity of organic matter and to detect petroleum potential in sediments.

Subsurface samples at depth of 2361m (outer shelf) and 2613m (lower slope) from Pologbene-1 Well were analysed using Rock-Eval pyrolysis analytical technique, which involves the temperature programmed heating of samples in an inert environment.

Procedures for Determining Direct Measurements

The parameters, which are a result of direct measurement from the Rock-Eval pyrolysis procedure, include S1, S2, S3 and Tmax.

25g of the sample is prepared. It is crushed, disaggregated, and then passed through a 25um sieve. The samples are placed in a temperature programmed muffled furnace, which is built to model an inert environment, an environment devoid of oxygen. The temperature is programmed at 100°C with a steady rise of 25°C per minute, between 300 – 350°C, the first reading for S1 is taken. S1 represent the already generated hydrocarbon (oil and gas) in the rock.

Trapped CO₂ in the sample starts evolving when the temperature is increased slightly. At temperature range of 350 – 390°C when CO₂ evolves, S3 is measured. S3 is the amount of CO₂ produced during pyrolysis of kerogen. It represents the amount of oxygen in the sample. With increase temperature of pyrolysis, S2 is measured within a temperature range of 300-600°C. The maximum temperature, T_{max} is the temperature of maximum release of hydrocarbon during Rock- Eval pyrolysis. It occurs at top of the S2 peak between the temperature of 300 – 600°C. Above 650°C the value of S4 is measured. CO and CO₂ are both component of S4.

S1: This is the already generated oil in the rock. These are the free hydrocarbons (oil and gas) already present in the sample, and they are distilled out of the sample at initial heating of the sample to a temperature of 350°C, free hydrocarbon increases with depth. These values may be anomalously high from migration and contamination by drilling fluids and mud.

S1= 1.0mg HC/g dry rock-Minimum value for good source rocks.

S2: The amount of hydrocarbon generated through thermal cracking of nonvolatile organic matter (kerogen) when the sample temperature is increased to 550°C. S2 is an indication of the quantity of hydrocarbon that parameter normally decreases with burial depth >1km.

S2 >=5.0 mg HC/dry rock – Minimum value for good source rocks

S3: The trapped CO₂ released during pyrolysis up to a temperature of 390°C. This value is proportional to the Oxygen present in the kerogen. Carbonate rock may increase S3 values.

Maximum Temperature (Tmax°C): Defines the temperature at maximum release of hydrocarbon occurs during Rock- Eval pyrolysis. This occurs at the top of the S2 peak. T max is a maturation parameter that is kerogen – dependent.

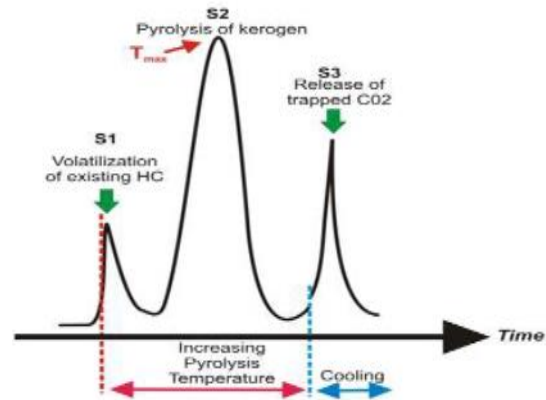


Figure 2: Model showing parameters derived from Roc Eval Pyrolysis

Determination of Derived Measurement Hydrogen Index (HI) = (S2/TOC) * 100

The ratio of S2 hydrogen (in mg HC/g dry rock) to total organic carbon (TOC) in grams. The hydrogen index is a measure of the hydrogen richness of the source rock, and when the kerogen type is known, it can be used to estimate the thermal maturity of the rock. When plotted against the oxygen index (OI), the HI can be used to provide a good assessment of the petroleum generative potential in a source rock (Peters and Moldowan, 1993).

Oxygen Index (OI) = (S3/TOC) * 100

The ratio of S3 (mg CO₂/g dry rock) to TOC (in grams). The parameter measures the oxygen richness of a source rock and can be used in conjunction with the hydrogen index to estimate the quality and thermal maturity of source rocks. This index is unreliable in rocks with high carbonate content. High OI value (>50 mg/g) are characteristic of immature hydrogens.

Production Index (PI) = S1 / (S1 + S2)

The production index is the ratio of already generated hydrocarbon to potential hydrocarbons. Low ratios indicate either immaturity or extreme post mature organic matter. High ratios indicate the mature stage or contamination by migrated hydrocarbons or drilling additives. The PI increases steady with depth and associated hydrocarbon generation.

Determination of Total Organic Carbon (TOC)

To determine the values of TOC, the samples are pyrolysed to temperature greater than 850°C in an oven. A process known as oxidation. This gives the organic carbon evolved above this temperature.

Determination of Total Percentage of Hydrocarbon (TPH)

10g of the sample is placed on top a glass chromatographic column packed with activated silica gel. 100ml of xylene is poured through the column. Silica gel attracts and absorbs aromatics. Because of this strong through the column. The fraction of aromatics and non-aromatics are weighed and measured as A and B

A = weight of aromatics recovered

B = weight of non-aromatics recovered

Aromatic fraction (wt%) = (A/(A+B)) * 100

Non-aromatic fraction (wt%) = (B/ (A + B)) * 100



Materials used for the analysis include spectrophotometer, temperature-programmed muffled furnace, carthometer, cuvette, mortar and pestle, chromatographic glass column.

III. RESULT

Inference from Hydrogen Index (HI) and HI/OI Geochemical Model for Pologbene-1

The hydrogen index (HI) gives an indication of the hydrogen richness of source rocks. Hydrogen rich samples have higher hydrocarbon production potential. The hydrogen index (HI) also gives insight to the type of kerogen present in the sample. (Peters and Cassa, 1991).

Comparing result gotten from Rock-Eval pyrolysis with standard range by Peters and Cassa in table 6 shows that the samples at this depth are of type II source rock. In addition, a

cross plot of HI /T_{max} on a modified Van Krevelen plots into the kerogen type II region thus confirming the same inference from HI. The sample could be either of the several type of type II kerogen which include **exinite** (formed from the casings of pollen and spores), **cutinite** (formed from terrestrial plant cuticle), **resinite** (formed from terrestrial plant resins and animal decomposition resins) and **liptinite** (white are formed from terrestrial plants lipids and marine algae). Type II kerogen are formed from lipids deposited in a reducing condition. It can also be inferred that the sample have Hydrogen to Carbon ratio (H:C) of <1.25 and Oxygen to carbon ratio (O:C) ranging between 0.03 to 0.58 which are typical of type II kerogen source rocks. They all have great tendencies to produce petroleum.

Table 1: Showing Result from Rock-Eval pyrolysis (direct and derived measurement)

DEPOSITIONAL ENVIRONMENT	DEPTH (m)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	S4 (mg/g)	Tmax (oc)
Pologbene-1 Well (Outer shelf)	1716	8.81	271	4	0.58, 0.31	453
Pologbene-1 Well (Inner shelf)	2361	7.96	328	9	0.58, 0.13	429
Pologbene-1 Well (Upper slope)	2595	7.43	321	8	0.57, 0.17	419
Pologbene-1 Well (Lower slope)	2613	7.51	325	9	0.56, 0.18	420

DEPOSITIONAL ENVIRONMENT	DEPTH(m)	TOC (wt %)	THC (wt %)	HI	OI	TPH (wt %)
Pologbene-1 Well (Outer shelf)	1716	0.751	1797	361	5	71.9
Pologbene-1 Well (Inner shelf)	2361	0.654	1576	502	14	63.1
Pologbene-1 Well (Upper slope)	2595	0.602	1524	533	14	61.03
Pologbene-1 Well (Lower slope)	2613	0.594	1504	548	15	60.24

Inference from HI/T_{max} Geochemical Model for Pologbene -1 WELL

This model was established by plotting value of HI from Rock-Eval against OI on a modified Van Krevelen diagram to deduce the type of source rock the analysed sample belong.

The cross-plot marker fell within the region of type II source rock on the geochemical model therefore, it can be inferred that the analysed samples are possibly **type II source rocks**. It therefore means that the analysed sample contains marine

planktonic remains preserved under anoxic condition in a marine environment.

Type II source rocks produce both oil and gas when thermally cracked during deep burial.

IV. CONCLUSION

Organic geochemical studies afford a holistic evaluation and characterization of source rocks and are useful in petroleum exploration. It also provides information needed to make maps of the richness, type and thermal maturity of a source rock. These maps are a necessary step towards determining the



stratigraphic and geographic extent of a pod of active source rock in a petroleum system and they are based on geochemical analysis of source rock sample from outcrop and wells.

From the geochemical evaluation of ditch cutting samples from Pologbene-1 well at depth of 2361m (outer shelf) and 2613m (lower shelf) and further comparison with results of similar studies on the same well at depth of 176m (inner self) and 2595m (upper slope), it can be concluded that Pologbene-1 well is oil and gas prone. This inference was drawn directly from individual parameter and an interplay or combination of parameters.

TOC, S1 and S2 geochemical parameter indicated samples that have good to excellent source capacity and excellent petroleum potential.

Tmax and Production Index (PI) value shows that the source rocks are immature. Thermally immature source rocks have been affected by diagenesis without any pronounced effect of temperature. Immature source rocks do not produce hydrocarbon.

Hydrogen Index (HI) and HI/OI geochemical model indicated kerogen type II for these samples while it was deduced from HI/OI geochemical model that the samples are type II source rock capable of producing a mixture of oil and gas.

Conclusively, it can therefore be said that the samples have the right quality (type) and quantity (amount) of organic matter with excellent source potential, but it is immature. However, at peak maturity the samples will generate a mixture of oil and gas.

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