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Research Article

Source rock maturation studies using vitrinite reflectance and geothermal data from six wells in Gabo and Wabi fields, onshore Niger Delta, Nigeria

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The source rock maturation levels of six wells in GABO and WABI fields, Niger delta sedimentary basin were evaluated using vitirinite reflectance and geothermal data. The results of the analysis show that the source rocks are mature. Vitrinite reflectance was measured and analyzed in all wells containing greater than 1.0 percent Total organic carbon content (TOC). The thermal alternation index (TAI) values obtained show that temperature was sufficiently good to generate hydrocarbons in the source rock indicating the maturity of the source rock. The GABO and WABI fields have a good range of Vitrinite reflectance values which probably indicate the temperature that were reached in the fields. The average reflectance of Vitrinite in GABO and WABI fields are 0.35 and 0.75, respectively. These values are consistent and suggest that basinal source rocks have begun to generate hydrocarbon*.*

Key Words*:* Source rock, maturity, total organic carbon content, vitrinite reflectance, thermal alteration index

INTRODUCTION

Tertiary Niger Delta Basin is an important area for Hydrocarbon exploration. The Basin is a major petroleum province. Intensive petroleum exploration and exploitation activities in the Niger Delta region during the last four decades had led to the accumulation of large amount of data which has been used to establish the hydrocarbon habitat and to reconstruct the history and evolution of the Niger Delta basin (Ekweozor and Daukoru,1994; Kulke,1995; Klettet al, 1997). Measured maturity values for possible source rocks are invaluable because they tell us much about the present status of hydrocarbon formation. It has been generally established in recent years that both time and temperature are important factors in the process of oil generation (Abu and Mohammed, 2008). Studies of the source rock quality and the thermal history of the Niger delta basin will give a detailed picture of the generation of hydrocarbon. This information helps determine the source rock potential of the basin.

Source rock quality is a function of the amount and type of organic matter in a rock. The boundary between a fair and a poor clastic source rock is commonly defined at approximately 0.5 percent total organic carbon (TOC) content (Tissot and Welte, 1978). Carbonate with as little 0.3% TOC can be fair source rock. Good clastic source rocks generally contains greater than 0.1%TOC and good carbonate source rocks, greater than 0.5% TOC. The adequate amounts of organic matter present in the Niger Delta Basin source rocks, led to the commercial quantities of hydrocarbon generated from the basin.

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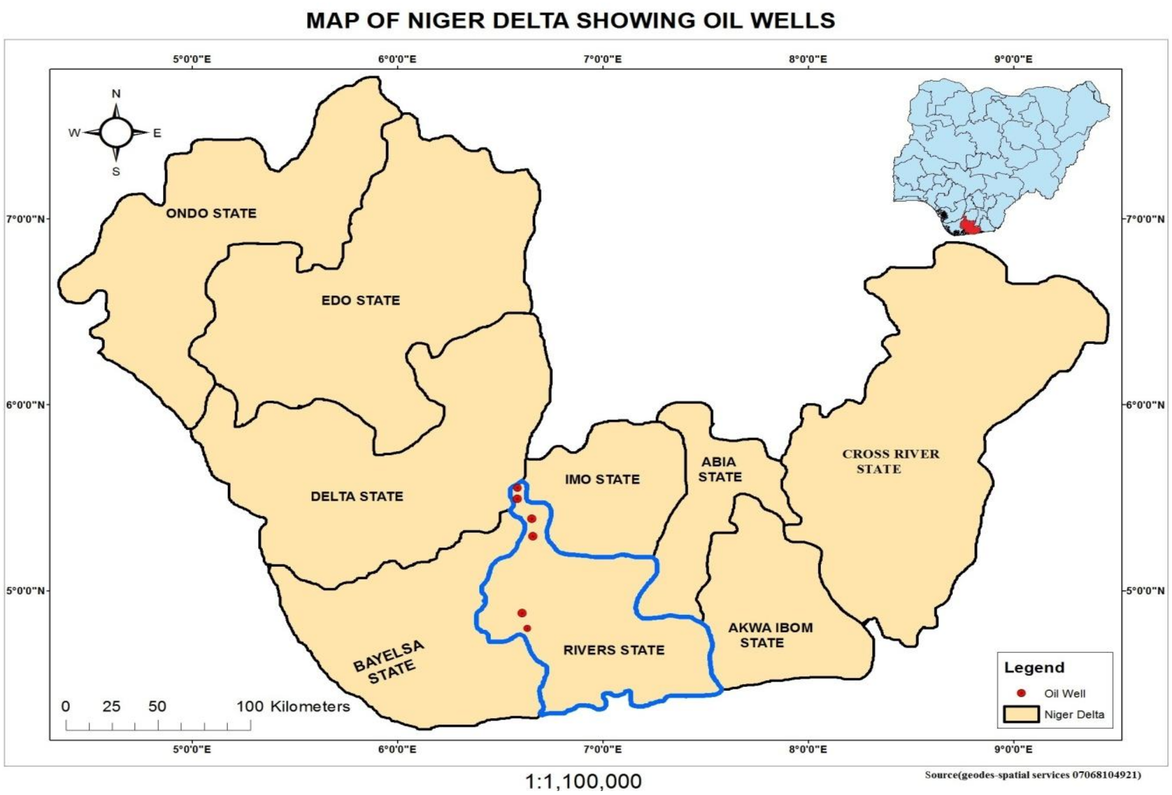

Figure 1. Showing the location map of the study wells

Furthermore, sufficient temperatures must be needed to generate hydrocarbon from dissemination begins at temperature around 65^{0}c (150^{0}F) (Pussey, 1973). There is also an element in hydrocarbon formation; oil may form at lower temperatures, given long exposure time (Dow, 1978). Optical properties of the organic materials remaining in source rocks, especially kerogen colour and vitrinite reflectance are influenced by both time and temperature; therefore they can be used as indicators of thermal maturity (Tissot and Welter, 1978). Source rock quality and thermal maturity data are combined to evaluate hydrocarbon potentials of Niger Delta

Regional Setting of the Niger Delta

Niger delta covers 7,000 square kilometer area within the Gulf of Guinea, West Africa, Nigeria. Although the modern Niger delta formed in the early tertiary sediment began to accumulate in this region during Mesozoic rifting associated with the separation of the Africa and South America continents (Weber and Daukoru, 1975; Doust and Omatsola 1990). Synrift marine clastic and carbonates accumulated during a series of transgression and regressive phases between the Cretaceous to early Tertiary; the oldest dated sediments are Albian age. These synrifting phases ended with basin inversion in the late Cretaceous (Santonian). Proto–Niger Delta regressive phases continued as continental margins. Subsidence resumed at the end of the Cretaceous (Maastrichtian). Niger Delta progradation into the gulf of Guinea accelerated from the Miocene onward in response to evolving drainages of the Niger Delta, Benue and cross-rivers and continued continental margins subsidence (Ejdawe, et. al. 1982).

Tertiary Niger delta deposits are characterized by a series of depobelts that strike northwest-southeast, sub-parallel to the present day shoreline. Depobelts become successively younger basin ward, ranging in age from Eocene in the north to Pliocene offshore of the present shoreline. Depobelts define a series of penetration in the progradation of this deltaic system. As deltaic sediment loads increase, underlying delta front and prodelta of marine shale begin to move upward and basin ward. Mobilization of basal shale caused structural collapse along normal faults and created accommodation for deposit in alluvial or upper coastal plain environment during progradation of the Delta. The information thins basin ward and near the shell edge.

As shale withdrawal nears completion, subsidence slow dramatically leaves little room for further sedimentation. Most hydrocarbon bearing structures in Niger delta deposit are close to these structures building faults, in complexly collapse crest and faulted anticline structures. Growth faults and antithetic faults play an essential role in trap configuration. Antithetic faults have less throw (generally less than a hundred meters), can be linear or aculeate in plain **v**iew and they rarely succeed ten kilometers in length. (Figure 1).

Stratigraphy of Niger Delta

The Stratigraphy of the Niger delta is divided into three chachromous unit of Eocene to recent age that forms a major regressive cycle. The uppermost unit, the Benin formation comprises continental fluviatile and back swarmp deposits up to 2500km thick. The top of the formation is the current sub aerially exposed delta top of the youngest underlying marine shales, extents to a depth of about 1400m.The age is of Oligocene to recent. Shallow parts of the formation are composed entirely of non-marine sands.

The Agbada formation which underlies the Benin formation is parallel, brackish to marine, coastal and fario-marine deposits, organized into coursing upward “offlap” cycles. The formation occurs throughout the Niger delta clastic wedge, has a maximum thickness of about 3900m and ranges in age from Eocene to Pleistocene. It crops out in southern Nigeria, where it is called the Ogwashi-Asaba formation. The lithology consists of upward alternating sands silts and shales with progressive upward changes in gain size and bed thickness. The strata are generally interpreted to have formed in fluovio deltaic environment (Stacher 1995).

The underlying Akata formation comprises up to 6500m of marine pro-delta days. Marine plank tonic foraminifera suggest a shallow marine shelf depositional setting ranging from Paleocene to recent in age. These shales are exposed onshore in the northeastern part of the delta where they are referred to as the Imo shale. This formation also crops out offshore in diapers along the continental slopes where they are deeply buried. Akata shales are typically over pressured. Akata shales have been interpreted to be prodelta and deeper water deposit that shoal vertically into the Agbada formation (Stacher 1995). Shale of the Akata formation constitutes a world-class source rock. Deeper water turbidities sands also exist within this formation.

The modern Nigerdelta is a mixed wave, tide and fluvial deltaic system. The delta is reworked by wave action along arcuate coast with barrier islands, back-barrier lagoons and coastal ridges. A thick mangrove borders the coastline of the lower Niger delta plain.

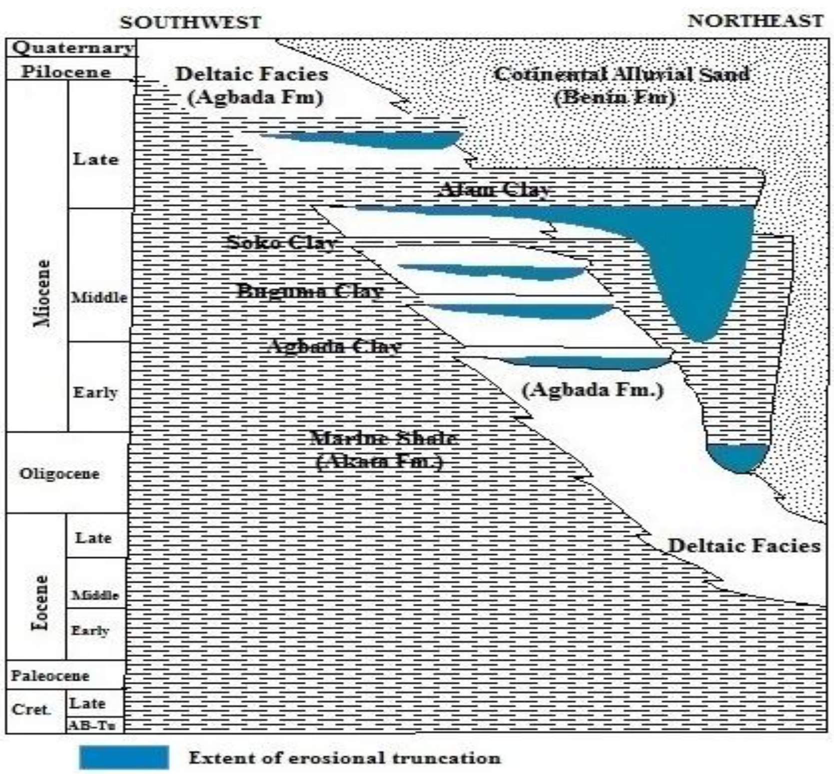

Figure 2. Stratigrtaphic column showing the three formations of the Niger Delta modified from Shaanon and Naylor(1989) and Doust and Omatsola(1990)

Techniques used in this study

Normal palynological preparation techniques were used to concentrate the organic matter from the sediments. Crushed samples were dissolved in hydrochloric acid and washed. The samples were not subjected to oxidative or heating treatment. This is to ensure that the particles were not dispersed readily. The remaining organic residues were then embedded in a cold setting epoxy resin to make briquettes, which were subsequently

Table 1. Data presentation of the TOC (W%)for six wells in Gabo and Wabi Fields.

Depth(M)		WELL NAME				
	Gabo 1	Gabo2	Gabo 3	Wabi 1	Wabi 2	Wabi 3
1000	0.20	0.60	1.30	0.10	0.40	0.30
1500	1.20	1.20	1.30	1.20	1.00	1.20
1800	0.20	0.12	0.70	2.10	1.50	0.90
2000	1.60	1.20	0.90	0.90	1.80	0.80
2200	2.10	1.60	1.25	2.10	1.40	1.70
2400	1.30	1.60	1.00	1.20	0.90	1.50
2600	2.60	3.00	2.20	1.60	2.10	1.10
2800	1.90	2.00	2.10	2.20	2.60	1.90
3000	2.00	1.60	1.80	2.00	1.80	2.60
3200	1.90	2.30	2.10	1.00	1.30	1.20
3400	2.50	2.90	3.50	2.50	2.10	1.90
3600	2.10	1.20	1.80	2.20	2.00	2.80
3800	2.10	2.50	1.20	2.40	2.90	3.10
4000	2.60	3.00	2.70	2.90	2.50	2.20
Average	1.58	1.77	1.63	1.67	1.77	1.65

ground flat and polished using magnesiumoxide as the final step. Equipment used was a Leitz MPV3 photometer microscope. Viewing and measurements were made through a Leitz Del 50X/0.8 5 P objective using oil immersion with refractive index n• 1.518. Illumination was through a green filter with peaks transmission at 546nm. For photometer calibration, a Leitz glass-standard with a reflectance of Ro • 0.517 was used. The reading was carried out using a stationary stage. This has become more or less standard in vitrinite reflectance determinations on clastic samples. It is less time consuming, permits smaller particles to be measured and the results obtained do not deviate significantly from those obtained using a rotating stage as long as the vitrinite reflectance values stay below Ro • 1.4 (De Vries and Bokhoven, 1968).

RESULTS AND DISCUSSION

The results have been separated into organic geochemistry and vitrinite reflectance.

Organic Geochemistry

The application of organic geochemistry with reference to the generation of hydrocarbon in the source rocks, their migration pathways into reservoir rocks and their trapping and acumination, has been widely documented (Tissot and Welte 1798).

Organic geochemistry is accepted as one of the appraisal of basins petroleum potential. The contribution of organic geochemistry to petroleum exploration includes three main aspects, source appraisal analysis of hydrocarbon occurrences and the comparison between source rock organic matter and oil-gas composition. Maturity parameters are measured through screening methods namely TOC measurements, Rocks-Eval Pyrolysis and Vitrinite reflectance which allow one to evaluate the petroleum potential of a source rocks at present, the type of organic matter and its thermal evolution including source rocks maturation (Tissot and Wlte 1978).

Geochemical Analysis of Total Organic Carbon Content

The total organic carbon (TOC) content can be measured as the amount of organic matter present in a sedimentary rock. It has been established from several studies that TOC content of 0.5% is the threshold value for clastic source rock to generate petroleum.

Total organic carbon content across the six wells in Gabo and Wabi fields ranges between 0.1 and 3.5 percent (Table 1).

Results obtained from the six well show that the values across the wells with respect to depth are greater than 0.5 percent TOC and as such are considered fair to very good source rocks. The highest values of TOC occurred in well Gabo 3 with value of 3.5% at depth of 3400m. Gabo 1, Wabi 1 and Wabi 2 sediments (shales) contain up to 2.9% TOC and are poor to very good sources. The highest value of TOC occurs in well Gabo 3 at a depth of 3400m and the lowest occurs in Wabi 1 at a depth of 100m.

These results from the six wells in Gabo and Wabi fields indicate that potential hydrocarbon source rocks are present in the various well drilled.

However, the type of organic matter in the rocks influences the kind of hydrocarbons that will form and at what temperature they will be generated.

Table 2. Thermal alternation index (TAI) values for the study wells
TAI and Palynofacies observations

W-11	Depth m/rT	Laboratory sample number	PALYNOFACIES (					TAI
			MOA	MOV	MOX	MOB1	MOB2	
GABO-3		990 230	10	15	5	20	50	2.5
GABO-1		990 240	20	10	5	15	50	2.5
GABO-2		990 245	25	20	5	10	40	2.5
GABO-2		990 246	10	20	5	5	60	2.5
GABO-2		990 258	30	10	5	5	50	2.5/2.5
WABI-1		990 259	20	10	5	15	50	2 3
WABI-2		990 261	40	5	5	20	30	$2.5^{+}/3$
WABI-2		990 265	10	5	10	25	50	
WABI-2		990 269	10	5	5	40	40	
WABI-3		990 275	50	5	10	30	50	

MOA = Amorphous (non-sapropelic) organic matter(corresponding to degraded ligneous matter)
MOV = cellular organic matter
MOX = opaque structureless organic matter
MOB1 = opaque ligneous organic matter
MOB2 = light ligneous organic matter

Kerogen is insoluble organic matter with high molecular weight and is found in shales and other sediment. It consists mainly of plants material, including amorphous sapropel, algal debris, spones, pollen, plant cuticle, woody tissue (Vitrinite), and inert coaly material. Amorphous sapropel and algal debris are generally of marine origin (Tissot and Welte, 1978). This type kerogen is rich in liquids, hydrocarbon rich compounds are considered to be the precursors of liquid hydrocarbon and is the most important source of liquid hydrocarbons. The other forms of kerogen have lower lipid content and originate mainly from terrestrial plants. Humic material forms dry gas at higher temperatures than are needed to form oil from lipid-rich kerogen (Dow, 1978). For potential source beds to generate hydrocarbons, sufficient temperature must be realized base on the type of kerogen present.

Kerogen colour using Thermal Alternation Index (TAI)

Kerogen darkens progressively from colourless to dark brown and black with increasing temperature. The colour indicates the degree of thermal alternation index or TAI (Staplin 1969). By this System, kerogen colour is measured on a scale of light yellow to black, corresponding to thermal alternation from 1 (non-alternation) to 5 (severe alternation). A modification of these systems was a TAI scale from 1.0 to 8.0. The TAI values of the various well in the Wabi and Gabo fields (Table 2) average 2.5 which corresponds to TAI of 2.5 in the Steplin system which indicates slight alternation. Kerogen colour (TAI) can be related to paleo-temperatures and zone of hydrocarbon generation. A TAI value of 2.5 corresponds to a temperature of about 62^oC (140^oC) which is slightly lower than the temperature of 64^oC (150^oC) given by Pussey (1973) as the temperature at which oil generation begins. However, only organic matter rich in lipid will begin to generate oil.

Vitrinite Reflectance

The amount of light reflected by Vitrinite particles (R_o) is reflected by time and temperature of burial and is therefore another paleo-temperature indicator for source rocks (Tissot and Welte, 1978). Vitrinite reflectance can also be related to hydrocarbon generation (Tissot and Wlte 1978).

Vitrinite reflectance value for Gabo 1 average $0.4R_o$ (Table 3) which is near the thermal alternation index of value of 2.5 reflectance values for Gabo2 (average R_o = 0.30%), Gabo 3 (average R_o =0.34%) are somewhat lower and reflect the lower burial depths and temperature (Table 2). According to Tissot and Welter (1978), Vitrinite reflectance between0.5 to 0.7% indicates that source rocks are immature, whereas reflectance between 0.5 to 0.7and 1.3% indicates that source rocks have reached the principal zone of oil generation.

Table 3. Results of Vitrinite Measurement

LOCATION OF SAMPLES				REFLECTANCE	
WELL	RESERVOIR LEVEL	CORE NUMBER	DEPTH m/RT	NUMBER MEASUREMENT	MEAN R_O
GABO-2	I BASAL	7	2 090.40	16	0.30
GABO-2	6A-6B	11	2 289.90	41	0.30
GABO-12	8-9	23	2 485.25	20	0.39
GABO-1	9	25	2 509.20	22	0.41
GABO-2	10	34	2 662	30	0.36
GABO-3	10	1	2 795	30	0.34
WABI-2	O	2	3 527	30	0.74
WABI-2	R	7	3 795.70	30	0.73
WABI-2	R	11	3 841.40	30	0.75
WABI-1	So	1	3 946	30	0.71
WABI-3	So	6	4 146	30	0.85
WABI-3	So/S_1	7	4 163	16	0.73

No sharp boundary exists between maturity and immaturity because organic matter with different composition responds at different rates to increase (Tissot and Welte 1978).
From the analysis and results obtained from the six wells, the vitrinite reflectance values for well in Gabo field ranges between 0.30 - 0.40 (Table 3). This indicates that the source rocks are immature (Tissot and Welter 1978);the well in Wabi field exhibits some degree of maturity. The vitrinite reflectance values for the source rocks have reached the principal zone of oil generation. This vitrinite values corresponds to the TAI values. Considering the TOC values from the well at the various depths, the source rocks may conclusively be rated as good source beds.

CONCLUSION

The results presented in this work indicate that the studied well exhibit some degree of maturity with the TOC values ranging from 0.1% to 3.55. This shows that some rocks are considered fair to very good source rocks.
In terms of quality and thermal maturity of the source rock, the analyzed well are virtually indistinguishable. In terms of hydrocarbon source potentials, the source rocks are potential oil and gas producers. The studies indicate that adequate thermal maturity has been attained.
Organic carbon richness (TOC) of source rocks of the studied fields indicate mainly good quality hydrocarbon generation with few beds of poor, fair and excellent organic contents.
Paleo-temperature data, thermal alternation index (TAI) and vitrinite reflectance-indicate that temperature of 145^{o}F was reached in the source beds indicating source rocks maturity. However, only organic matter rich in lipid will begin to generate oil.

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