http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 6 No 3 2021

RESEARCH ARTICLE

Total Organic Carbon (TOC) Value Prediction in Source Rock Potential at North East Java Basin, Indonesia.

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Received: Apr 5, 2021; Accepted: Aug 30, 2021.
DOI: 10.25299/jgeet.2021.6.3.6644

Abstract

This research aims to determine the potential of the source rock in the Kujung and Cepu Formations in the North East Java Basin, using Total Organic Carbon (TOC). TOC is calculated using the Passey method. The Passey method is used by overlaying the sonic log and the resistivity log and determining the baseline to get the separation of Δlog resistivity, which is then used to predict the TOC log by including the LOM (Level of Organic Maturity) variable obtained from the data of vitrinite reflectance. After the TOC log value is obtained, a correlation is made with the TOC core value. The prediction result of TOC log in a PM-1 well is 2.16%, which means it has excellent quality. The prediction of TOC log in a PM-2 well is worth 2.68%, which means it has excellent quality. The correlation value between the TOC log and the TOC core of the PM-1 well is 0.67, which means the correlation is strong. In PM-2 well, the correlation between the TOC log and TOC core is 0.92, which means that the correlation is robust.

Keywords: TOC, Correlation, Passey method.

1. Introduction

The North East Java Basin is one of the most productive petroleum producing-basins in Indonesia. In exploration and research, oil and gas exploration often focused primarily on evaluations of reservoirs and traps. In contrast, the evaluation of hydrocarbon charge includes evaluating hydrocarbon-producing source rocks. Its migration was often simplified or underreported, even though this evaluation could answer the time (when) and the amount of oil formed in a hydrocarbon basin in Indonesia (Dewanto et al., 2017).

Shale hydrocarbon plays are one of the most popular hydrocarbons plays of the last five years. In shale hydrocarbon plays, source rock and reservoir rock are often the same rock. Total organic carbon (TOC), as a percentage of the total rock volume, is an important parameter in shale hydrocarbon play assessments and is also regarded as one of the key variables that directly affects the rock quality, shale hydrocarbon in place estimations, and hydraulic fracturing design. Often the availability of TOC data on shale as source rock are very limited. Therefore, we need a method to predicting the TOC of shale rock as the source rock. TOC Prediction will be validating with TOC data, which is derived from core rocks of oil and gas wells (Basyir et al., 2020).

In general, the source rock is the rock that contains sufficient amounts of organic material, has reached a certain maturity, and is rich in the elemental content of carbon atoms obtained from fossil shells deposited in the rock to become the raw material for the formation of hydrocarbons. TOC is the quantity of organic carbon deposited in the rocks. The higher the Organic Carbon value, the better the source rock will be, and also, the possibility of hydrocarbon formation will usually be higher. This study uses The ΔlogR methodology of Passey et al., (1990) determines total organic carbon (TOC) from the separation apparent when a properly scaled porosity log and resistivity log are overlain and a maturity factor applied. In water-saturated, organic-lean rocks the two curves parallel each other because both respond to variations in formation porosity. In both hydrocarbon reservoirs and organic-rich non-reservoir rocks a separation between the curves, termed ΔlogR, is present. Reservoir rocks are eliminated from the analysis by their gamma-ray response and by other well data such as the lithology from mudlog and well samples, where available.

The TOC of the source rock intervals is then calculated based on the ΔlogR separation measured in logarithmic resistivity cycles and thermal maturity expressed as LOM (level of organic metamorphism) using the empirical relationships. In immature rocks the ΔlogR separation is due primarily to the response of the porosity log, e.g., the longer transit time of the sonic or acoustic log responding to the lower density organic matter. In thermally mature rocks the separation is also caused by longer transit times, but additionally by higher resistivity due to the presence of generated unexpelled hydrocarbons. We applied the method using the differential transit time log (DT), also known as the sonic or acoustic log, and the deep induction log (ILD) as recommended by (Passey et al., 1990). We used thermal maturity data from vitrinite, converted to LOM (Keller et al., 1999).

2. Geology

Geologically (Figure 1), the formation of the North East Java Basin is controlled by two fault systems, that is, the horizontal fault system trending northeast-southwest and east-west direction. This basin is formed by several main structural elements from south to north, namely: Kendeng Zone - The Madura Strait is elongated in the east-west direction which is characterized by a fold structure, normal faults and many upward faults. South Rembang Zone and Randublatung which are negative zones with east-west trending structural patterns characterized by folds. There is a dome structure that is associated with a fault structure. The North Rembang Zone and North Madura, the anticlinorium structure that was elevated and eroded in Pliocene-Plistocene associated with a horizontal fault system drifted in a continuous northeast-southwest direction to South Kalimantan.

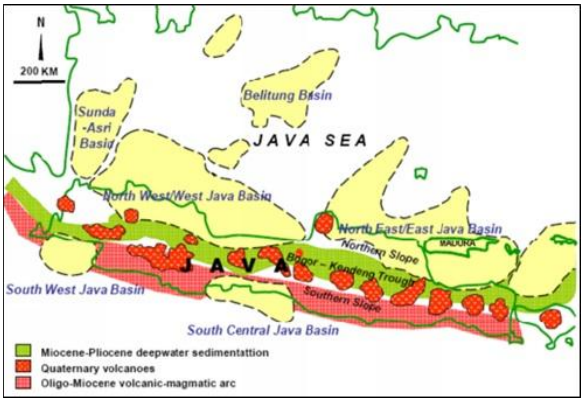

Fig. 1. Regional geological map of the North East Java Basin (Sribudiyani et al., 2003).

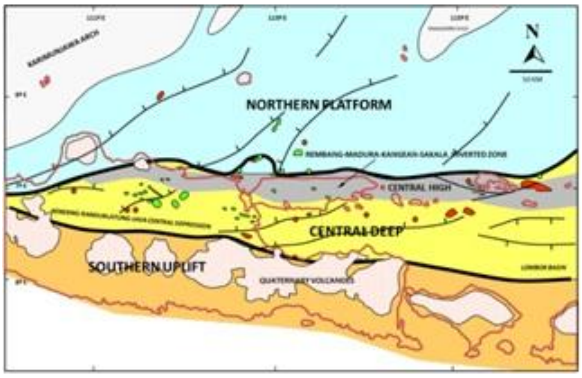

Fig. 2. Geologic setting of East Java Basin (Satyana, 2005).

Geologic setting of East Java consisting of Northern Platform, Central Deep, and Southern Uplift (Figure 2), and North East Java basin is located on the southeastern margin of a stable Sundaland micro continent. The basin is bounded by Karimun Java arch to the west, Masalembo High to the north, Doang High to the east and volcanic arc to the south. The basin was initiated at mid- Cretaceous age by collision between microplates at the southeastern margin of Sundaland. This collision created a suture zone between microplates and later on becomes a structural grain lineament of half and graben in North East Java Basin. The extensional phase that creates graben system in North East Java Basin began in Paleogene to Early Neogene time. It is interpreted to be formed by slab roll-back system between Australian to Eurasia-Sundaland plate subduction. The compressional phase has occurred during Neogene to the present time as an implication of Indian oceanic plate subduction to the south of Java Island, a westward stress due to Buton-Tukang Besi and Banggai-Sula collision to the western part of Sulawesi, and due to large sinistral strike slip RMKS (Rembang-Madura-Kangean-Sakala Fault. During the Late Oligocene, Kujung Formation carbonates were deposited over the Ngimbang Formation and on existing pre-Tertiary basement highs with reefal build-ups developed throughout the East Java area. Patch reefs developed along the central basin edges with pinnacle-type reefs occurring in the isolated highs of deeper water area (Satyana and Purwaningsih, 2003).

The petroleum system consists of important components, source rock is the main hydrocarbon parent rock in the East Java Basin originates from carbonate flakes derived from marginal marine, deltaic, and lacustrine environments. The Ngimbang Formation, mainly originating from the Central Deep Basin (Nainggolan, 2018) with kerogen types II and III so as to produce hydrocarbon (oil and gas). Deep sea flakes at the bottom of the Kujung Formation are also potential as host rock. Reservoirs are rocks with porosity and permeability that are good for storing and flowing hydrocarbons. The main reservoirs in this basin are the carbonate rocks of the Ngimbang Formation and the Kujung interval I Formation as well as the siliciclastic reservoir of the Ngimbang Formation, Tuban Formation and the Ngrayong Formation. Hydrocarbon migration divided into primary migration is the transfer of hydrocarbon fluid from the host rock to reservoir rock and secondary migration is the movement of fluid in the reservoir through the trap. Stone hoods have a role as non-permeable insulation such as claystone. The rock seals in this basin are shale of the Ngimbang Formation, Tuban Formation, Wonocolo Formation, and Tongue Formation. Shale Formation Tuban is a covering rock that has a thickness of 500 ft – 1500 ft in the North East Java Basin (Sribudiyani et al., 2003) The types of traps in all East Java petroleum systems generally have similarities. This is due to tectonic evolution that occurs in all sedimentary basins along the southern boundary of the Sunda plate so that the type of geological structure and trap mechanism become relatively similar. The structure traps that developed in the form of anticlines and faults and stratigraphic traps were found when the sandstone unit rested (onlap) and covered part of the bedrock heights (Satyana and Djumiati, 2003) The Kujung Formation was deposited after the Ngimbang Formation, a process of uplift and erosion accompanied by a decrease in eustatic sea-water resulting in a widespread regressive Mid-Oligocene event that explained the basis of the next Kujung cycle (30 million years). Although initially considered the eustatic event, some observations, both local (North East Java Basin) and regional suggested tectonic control. The end of the Kujung cycle corresponded to the end of the initial carbonate-dominated transgression. In most cases, this indicated the upper part of the Early Miocene limestone, the upper rock nature of the Kujung cycle meant that the Kujung cycle to the Tuban cycle limit was often a misalignment due to the time it took for sequential to onlap the rest of the reef. In the late Oligocene-early Miocene, the Kujung Formation (Figure 3.) was deposited with rocks that were dominated by limestone and marl with thin sandstone insertions and there were fossils of foraminifera, coral fragments, and algae in limestone. The Kujung Formation was widespread, covering the Purwodadi area to the east of Tuban and Madura. The Cepu Formation (Figure 3.) in the late Miocene Sedimentation in the Madura Basin clay, and silica sand. The structural process in the mid-Miocene had stopped, then filled with Cepu Formation consisting of marl and limestone from deposition of planktonic and nanoplankton (Nainggolan, 2018).

3. Well Logging Method

Well Logging is a method used to obtain more detailed drilling well record data which is depicted in the form of curves from the value of petrophysical parameters. The purpose of Well Logging is to obtain lithology information, porosity measurements, resistivity measurements, and fluid saturation. While the main purpose of using logs in this study is to determine the source rock zone and calculate the quantity of Total Organic Carbon (TOC).

The principle of the gamma ray log is a record of the level of natural radioactivity that occurs due to three elements, namely uranium (U), thorium (Th), and potassium (K) present in rocks. Gamma rays are very effective in distinguishing between permeable and non-permeable layers, because radioactive elements tend to be concentrated in non-permeable shale, and are not abundant in carbonate rocks or sand is generally permeable.

The resistivity log is a record of the formation resistivity when an electric current is passed, expressed in ohm-meters. Sonic log is an acoustic log with the working principle of measuring the travel time of sound waves at a certain distance in the rock layer. For the working principle of this tool is sound at regular intervals emitted from a sound source (transmitter) and the receiver will record the length of time the sound propagates in the rock (Δt) (Schlumberger, 1989).

4. Total Organic Carbon (TOC)

Total Organic Carbon (TOC) was a measure of organic wealth that described the amount of organic material in the source rock. TOC was represented by the weight percent of organic matter relative to the total weight of the rock. In general, the source rock was classified as poor quality if the TOC value was less than 0.5%; Medium if the TOC value was between 0.5% -1%; Good if the TOC value ranges from 1% -2%; and Very Good if the TOC value ranges from 2% - 4%; *Excellent* if more than 4% (Peters and Cassa, 1994).

According to Keller et al., (1999) the source rock potential was determined by calculating a net organic-richness based on the ΔlogR TOC profiles and then using maturity scaling factors applied to present-day thermal maturity from vitrinite reflectance using the methods of Dembicki and Pirkle, (1985). Dembicki and Pirkle, (1985) use "richness" to mean the thickness of an effective source rock times the average TOC for that "effective" interval. We use "net richness" in the same way they used "richness" to distinguish it from richness as organic carbon concentration. We define net or effective source rock as the thickness of rock with ≥2 wt % TOC for rocks with predominantly marine organic matter and ≥1 wt % TOC for rocks with predominantly terrigenous organic matter. Note that TOC is not the only measure of source rock quality and is impacted by additional maturity caused by heat and/or burial.

Oil deposits in shale oil is quite high, estimated as relatively large reserves spread across several regions of Indonesia. To determine the content of oil shale in the basin necessary to evaluate the condition of the reservoir, by determining and analyzing the reservoir parameters. Determination and analysis of reservoir parameters is done by two methods, namely core analysis in the laboratory and log interpretation in the field. On the source rock, testing pyrolysis is used to determine the organic content (TOC), the maturity of organic material, detecting the content of oil or gas produced and is also used to identify the type of some mixed material (Mulyatno et al., 2018).

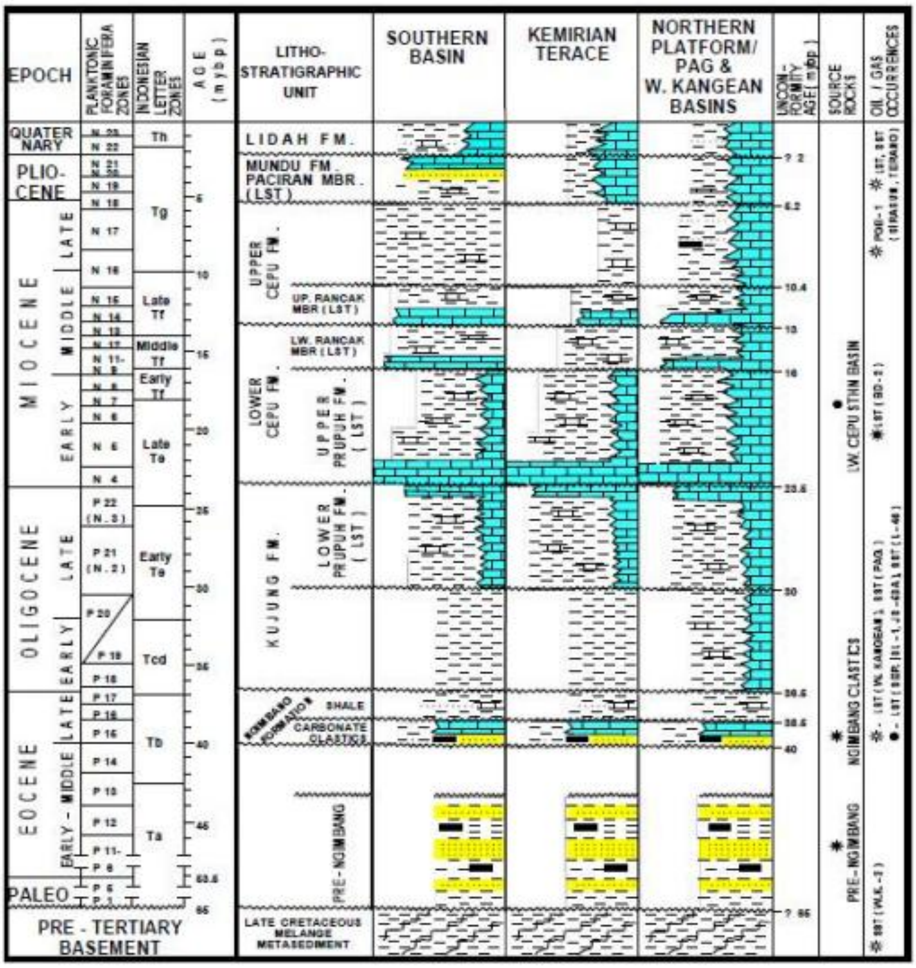

Fig. 3. Stratigraphy column of Kangean block (Davies, 1989).

5. Correlation

Correlation is an analysis technique that is included in one of the techniques of measuring association / relationship (measures of association). Association measurement is a general term that refers to a group of techniques in bivariate statistics that are used to measure the strength of the relationship between two variables. The correlation coefficient is a statistical measure of the covariance or association between two variables. The magnitude of the correlation coefficient ranges from +1 to -1. Correlation coefficient indicates the strength (strength) of the linear relationship and the direction of the relationship between two random variables. If the correlation coefficient is positive, then the two variables have a unidirectional relationship. To make it easier to interpret the strength of the relationship between the two variables, the authors provide the following criteria:

a. 0 : No correlation
b. > 0 - 0.25 : Very weak correlation
c. > 0.25 - 0.5 : Fair correlation
d. > 0.5 - 0.75 : Strong correlation
e. > 0.75 - 0.99 : Very strong correlation
f. = 1 : Perfect correlation (Sarwono, 2006).

6. Methods

Analysis of Total Organic Carbon (TOC) in this study used two well data, which specifically carried out the research on the Kujung formation (a PM-1 well) and Cepu formation (a PM-2 well). The flow of this research was as follows:

1. Performing a zone analysis of the source rock using Gamma-Ray Log, Resistivity log, and Sonic log.
2. Calculating the TOC value of each source rock zone using log Passey et al., (1990). With the following formula:

$$\mathrm{TOC} = (\Delta \mathrm{Log\ R}) \times 10^{(2.297-0.1688 \times \mathrm{LOM})} \qquad (1)$$

$$\Delta \mathrm{LogR} = \mathrm{Log}\left(\frac{\mathrm{R}}{\mathrm{Rbaseline}}\right) + 0.02 \times (\mathrm{T} - \mathrm{Tbaseline}) \qquad (2)$$

With:
TOC = Total Organic Carbon (wt%); LOM = Level of Maturity; Log R = Curvature on overlay sonic/ resistivity logs; R = Measured resistivity of the logging tool (ohms-m); T = Measurement of transit time (µsec / ft); Rbaseline = The same resistivity value as Tbaseline when the baseline curve is in clay-rich rocks (non source); 0.02 = Based on the ratio at 50 µsec / ft per 1 resistivity cycle.

3. Determine the correlation coefficient between the two TOC Core data and the TOC Log.

7. Results and Discussion

In the PM-1 well sample (Table 1), the average TOC value of the 24 samples was 2.16%. The minimum TOC value was 0.49% at a depth of 8254 ft and the maximum TOC was 5.09% at a depth of 8848 ft. According to the TOC classification system (Peters and Cassa, 1994), it could be classified that the source rock in this Kujung Formation study was a good in terms of organic richness because the average TOC content varies in dominance between 1% and 2%. In the PM-2 well sample (Table 2), the average TOC value of the 14 samples was 2.68%. The minimum TOC value was 0.58% at a depth of 6685 ft and the maximum TOC was 6.49% at a depth of 5812 ft. According to the (Peters and Cassa, 1994) TOC classification system, it could be classified that the source rock in the Cepu formation study was a fairly good in terms of organic richness because the average TOC content varied in dominance between 0.5% to 2%.

Table 1. The results of the quantification of the TOC value in the PM-1 well (Kujung fm).

Depth (ft)	LOM	TOC Log (wt%)
7010	5.7	4.84
7139	5.7	2.24
7248	5.5	1.65
7335	5.6	1.9
7447	5.5	0.67
7754	5.4	2.54
7967	5.4	3.49
8034	5.6	2.35
8142	5.7	3.11
8217	5.7	1.83
8254	5.8	0.49
8314	5.8	1.47
8538	5.9	4.4
8695	5.9	3.37
8848	6	5.09
8920	6.1	0.81
8960	6.1	1.55
9018	6.2	1.61
9093	6.1	1.64
9200	6.3	1.89
9366	6.4	0.8
9525	6.5	0.69
9828	6.7	1.03
9970	7.2	2.41

Table 2. The results of the quantification of the TOC value in the PM-2 well (Cepu fm).

Depth (ft)	LOM	TOC Log (wt%)
5620	4.7	4.33
5812	4.9	6.49
5858	4.9	5.51
6129	5.1	2.72
6236	5.2	2.8
6347	5.4	2.59
6430	5.5	1.56
6532	5.6	3.3
6685	5.7	0.58
6784	5.8	2.18
6893	5.8	2.22
7016	5.9	0.72
7227	6	1.67
7385	6.1	0.86

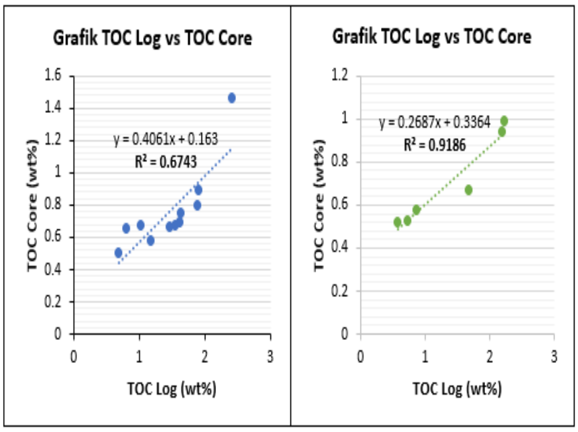

Fig. 4. Correlation graph of TOC Log vs TOC Core on PM-1 and PM-2 Wells.

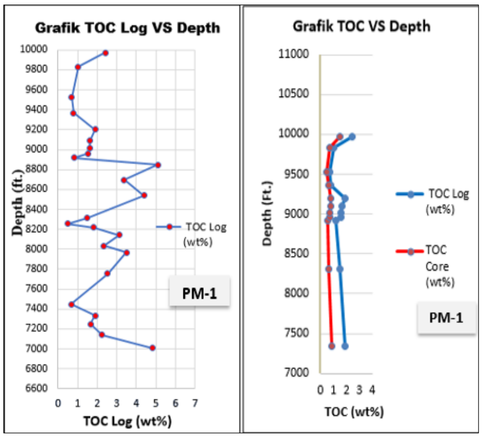

Fig. 5. Graph of the relationship between TOC and Depth in the PM-1 well.

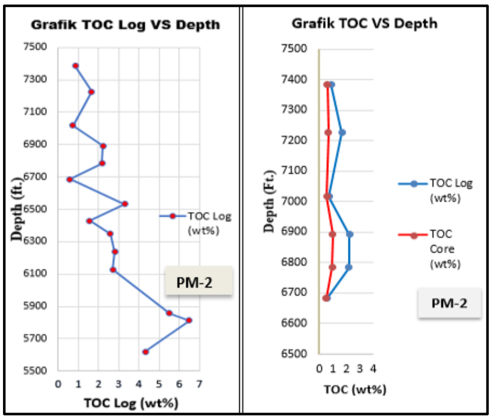

Fig. 6. Graph of the relationship between TOC and Depth in the PM-2 well.

8. Conclusion

From the whole research process, conclusions could be drawn, namely:

1. Quantitatively, from the 24 source rock zones of the PM-1 well, the average TOC value of the source rock was 2.16%, and according to the TOC classification of (Peters and Cassa, 1994) it could be defined as having very good quality.
2. From the 14 main rock zones in the PM-2 well, the average TOC value of the source rock was 2.68%, and according to the TOC classification of (Peters and Cassa, 1994) it could be defined as having very good quality.
3. The correlation between the value of TOC Core and TOC Log in the PM-1 well was 0.67 which meant that according to (Sarwono, 2006), it was a strong criterion.
4. The correlation between the TOC Core and TOC Log values in PM-2 well was 0.92 which meant that according to (Sarwono, 2006), it was a very strong criterion.

Acknowledgements

The authors thank the ESDM ministry for data access, and to the Geophysical Engineering, University of Lampung as the authors institution.

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