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Evaluation of Organic Matters, Hydrocarbon Potential and Thermal Maturity of Source Rocks Based on Geochemical and Statistical Methods: Case Study Miocene of the Seblat and Lemau Formation, Bengkulu Basin

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Abstract. 32 rock samples have been studied by means of geochemical and statistical analyses for evaluating source rocks. The geochemical analysis includes pyrolysis data. The results show that the Miocene Source rock are fair to excellent hydrocarbon potential level, with kerogen contained is included into Type II that have the capability of generating oil and limited gas. The analyzed data were treated statistically to find some factors, clusters, and relations concerning the evaluation of source rocks. These factors analysis can be classified into two factors. (1) Variables S2, TOC%, S1, and HI which determine the organic richness, hydrocarbon potentiality and the type of organic matter. (2) Variables PI, HI, and Tmax which determine the thermal maturity. In addition, cluster analysis separated the source rocks in the study area into two major groups. (1) Source rocks characterized by HI <400 (mg/g), TOC from 0,22 to 11,53%, S1 from 0.00 to 1.05(mg/g) and S2 from 0.04 to 23.64 (mg/g)) indicating fair to good source rocks with kerogen of type II and III capable of generating oil and gas. (2) Source rocks characterized by HI 350 - <703 (mg/g), TOC from 5.39 to 23.58%, S1 from 0.24 to 0.88 (mg/g) and S2 from 29.62 to 84.48 (mg/g) indicating good to excellent source rocks with kerogen of type II capable of generating oil and limited gas. Moreover, Pearson's correlation coefficient shows a strong positive correlation between TOC and SI, S2 and positive correlation between TOC and HI, and negative correlation between TOC and Tmax.

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Keywords: Organic matter, Hydrocarbon potentiality, Factors, Clusters, and Pearson's correlation

1. Introduction

Oil and gas are a source of foreign exchange for the country, the main energy sources include industry, transportation and household needs. With the increasing demand for oil and gas in Indonesia, the consumption of oil and gas cannot be covered by petroleum production in Indonesia so that Indonesia needs to import fuel needs to be fulfilled. In this case the process of the formation of an oil and natural gas takes a long time. There are 3 kinds of theories that explain the process of oil and gas formation (Louis and Maryfieser, 1950) : 1. Organic theory, this theory states that oil and gas nature is formed from various organic bodies such as animals and plants that die and are buried in sand and mud deposits. 2. Inorganic theory, this theory says that petroleum is formed based on the alkaline chemical process of heat with CO2. 3. Duplex theory, this theory is a combination of results from organic and inorganic theories.

Petroleum geochemistry is basic science to understand the characteristics of source rocks, productive and non-productive zones, oil migration all produce more efficient exploration, oilfield development and sustainable production. Due to the influence of time, temperature, and pressure, the sludge sediment turns into sedimentary rock. Soft rock that comes from mud which contains oil spots is known as source rock. The parent rock is one of the main elements of the hydrocarbon system

In this case the thermal maturity or temperature is the factor to determine whether the host rock can produce oil, gas, and condensate. In evaluating stone sources many laboratory methods are used. This time the method used is Rock-Eval pyrolysis. From laboratory methods, the Rock-Eval pyrolysis method has been widely used, throughout the world, for oil and gas exploration in sedimentary basins, this method has been widely used in industry as a standard method in petroleum exploration. This method is used in determining kerogen heat maturation. Behar et al. define heat parameters based on maximum temperature (Tmax) which can be used to determine the dimensions of the oil window. According to that definition, the Tmax value for the start of the oil window is usually 445-435 ° C, for the peak is 450-445 ° C, and for the end is 470-450 ° C. The thermal maturity of the sample can be determined by plotting the value of Tmax versus HI. In this study, we used geochemical and statistical analysis to evaluate source rocks in the Bengkulu basin.

Although organic material undergoes many types of evolution, thermal maturation is important in assessing hydrocarbon formation. In this work, three main characteristics need to be studied to determine the potential of petroleum from source rocks: (1) geochemical properties of organic matter, (2) thermal maturation, and (3) abundance of hydrocarbons. Organic material maturity is one of the most important parameters in oil-gas evaluation. In this study, both geochemical and statistical analyzes were used to differentiate maturity and the potential of Miocene source rock hydrocarbons in the Bengkulu basin area.

2. Geological Setting

The rocks that settle the Bengkulu area are alienated into two strips, the Bengkulu Line and the Barisan Line. The Barisan lines were composed of Hulusamping Formation, intrusion rock, Bal Formation, Ranau Formation, and volcanic rock. While in Bengkulu Line the rock units that fill it contain the Seblat Formation, Lemau Formation, Simpangaur Formation, Bintunan Formation, and quarterly volcanic rock units (**Fig 1**)

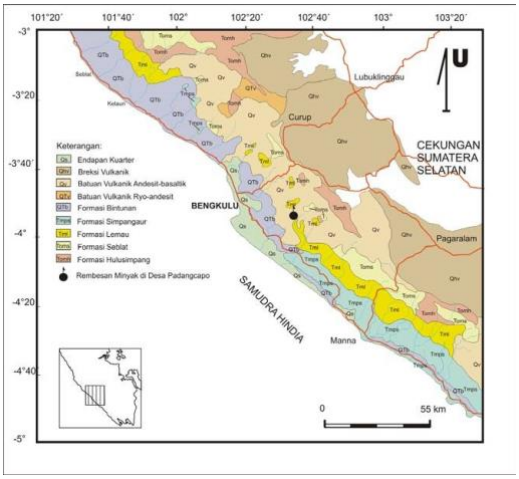


Figure 1. Geological Map of Bengkulu Basin (Simplification from Gafoer drr.,1992 and Amin drr., 1994).

The Bengkulu Basin stratigraphy column is shown in **Fig 2**, showing rock units containing rock units in the Miocene age. The Hulusimpang Formation which is consisted of lava, volcanic breccia, and tuff is the oldest rock exposed in this area. The upper part of this formation is fingered with the lower part of the Seb¬lat Formation, which is in the Lower Miocene to Middle Miocene, and consists of interlocking claystone, side-by-side claystone, limy claystone with sandstone and conglomerate inserts. Middle Miocene intrusion rock, granite to diorite, penetrated the Hulusimpang Formation and Seblat Formation [7] [1] .

The Seblat Formation is unconformally overlapped by the Lemau Formation (claystone, siltstone, coal, sandstone, and conglomerate), Middle Miocene-Late and deposited in transition to shallow marine [21] .

The Lemau Formation is unconformally overlapped by the Simpangur Formation (conglomeratic sandstone, mudstone contain molusca shell, and tuffaceous sandstone), Middle Miocene-Late and deposited in transition.

The Bintunan Formation (tuffaceous rock, polimic conglomerate, and tuffaceous claystone contains lignite and plant fossil) Plio-Plistosen and deposited in transition to shallow marine, unconformally overlapped by Simpangur Formation (Gafoer drr., 1992) , whereas according to Yulihanto drr,1995 (**Fig 2**) The lower part of Bintunan Formation is fingered with the upper part of Simpangur Formation.

Bintunan Formation is equal with Ranau Formation that exposed on Manna Geological Map (Amin drr, 1994), consists of vulcanic breccia (pumice and rhyolitic-andesitic tuff). Yellow, soft, not layered, the component is pumice, the matriks is andesitic-basaltic lava in sandy tuff [1] .Quarter deposite is alluvium that contains boulder, cobble, sand, silt, mud and clay.

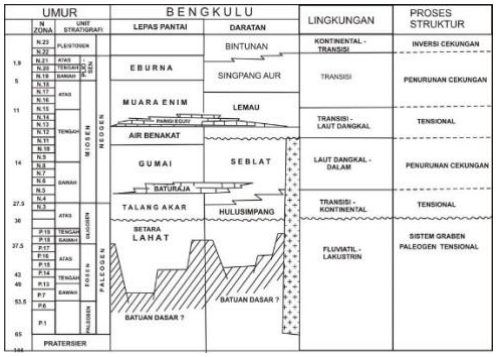


Figure 2. Correlation of the offshore and terrestrial stratigraphy in the Bengkulu Basin (modified by Yulianto drr., 1995).

3. Materials and Methods

In this study 32 samples were obtained from early-middle Miosen Seblat Formation and middle-end Miosen Lemau formation source rocks. Each sample was analyzed using geochemical like TOC and Pirolisis data of Seblat and Lemau Formation in the area of Bengkulu values obtained that conducted by Rachmat Heryanto on Journal Of Geology Indonesia, Vol. 2 No. 2 Juni 2007: 99-111. the amount of free hydrocarbons (gas and oil) in the sample (in milligrams of hydrocarbon per gram of rock). S_2 is the amount of hydrocarbons generated through thermal cracking of nonvolatile organic matter. S_2 is an indication of the quantity of hydrocarbons that the rock has the potential of producing should burial and maturation continue. S_3 is the amount of CO_2 (in milligrams CO_2 per gram of rock) produced during pyrolysis of kerogen. And T_{max} is the temperature at which the maximum release of hydrocarbons from cracking of kerogen occurs during pyrolysis (top of S_2 peak). The type and maturity of organic matter in petroleum source rocks can be characterized from Rock Eval pyrolysis data [4] . Using the following parameters: HI is a parameter used to characterize the origin of organic matter. PI is used to characterize the evolution level of the organic matter.

Each sample was analyzed statistically using a NCSS Data Analysis 12 version as Factor Analysis, Cluster Analysis, and Pearson's Correlation. Factor Analysis that is used to reduce the data or summarize, from the old variable lot transformed into a bit of a new variable called factors, and still contains most of the information contained in the original variable [16] . If the Factor analysis (R factor Analysis) aiming at the reduction of variable, Cluster analysis (Q factor Analysis) is more aimed at pegging or variable objects

based on similarity of characteristics. While the Pearson's Correlation is a measure of the strength of a linear association between two variables and is denoted by *r*.

No.	No. Sample	TOC (%)	S1 Kg/Ton	S2 Kg/Ton	PY Kg/Ton	PI	Tmax (°C)	HI	Formation
1.	05RH11	1,37	0,45	3,89	4,34	0,10	440	284	Seblat
2.	05RH17	1,37	0,45	3,89	4,34	0,10	440	284	Seblat
3.	05RH20B	1,54	1,04	0,79	1,83	0,57	453	51	Seblat
4.	05RH27	1,16	0,55	1,15	1.70	0,32	452	99	Seblat
5.	05RH30	1,40	0,44	1,86	2,30	0,19	455	133	Seblat
6.	05RH32	0,22	0,13	0,35	0,48	0,27	447	159	Seblat
7.	05RH34	1,22	0,75	1,53	2,28	0,33	418	126	Seblat
8.	05RH37	1,24	0,27	3,09	3,36	0,08	439	250	Seblat
9.	05RH50D	8,68	0,50	14,77	15,27	0,03	426	170	Lemau
10.	05RH50G	1,55	0,21	2,47	2,68	0,08	440	159	Lemau
11.	05RH50H	9,57	1,05	23,64	24,69	0,04	433	247	Lemau
12.	05RH50J	6,09	0,66	21,44	22,10	0,03	443	352	Lemau
13.	05RH51A	3,53	0,08	0,10	0,18	0,44	570	3	Lemau
14.	05RH51D	1,05	0,03	0,04	0,07	0,43	577	4	Lemau
15.	05RH52A	3,15	0,06	0,11	0,17	0,35	572	3	Lemau
16.	05RH53C	11,53	0,95	20,12	21,07	0,05	453	174	Lemau
17.	05RH54B	0,65	0,11	0,12	0,23	0,48	510	19	Lemau
18.	05RH60C	3,01	0,62	9,16	9,78	0,06	427	304	Lemau
19.	05RH65	0,85	0,02	0,74	0,76	0,03	435	87	Lemau
20.	05RH71A	14,71	3,62	113,68	117,30	0,03	426	773	Lemau
21.	05RH73B	8,59	0,75	60,36	61,11	0,001	426	703	Lemau
22.	05RH74D	3,85	0,32	4,57	4,89	0,07	416	119	Seblat
23.	05RH75A	5,39	0,40	29,62	30,02	0,01	434	550	Lemau
24.	05RH81	8,65	0,64	48,96	49,60	0,01	427	566	Lemau
25.	05RH84	9,81	0,88	55,68	56,56	0,02	426	568	Lemau
26.	05RH85D	27,09	1,04	187,84	188,88	0,001	426	693	Lemau
27.	05RH85I	4,45	0,17	15,08	15,25	0,001	430	339	Lemau
28.	05RH87B	2,73	0,00	4,23	4,23	0,00	435	155	Lemau
29.	05RH101D	23,58	0,24	84,24	84,48	0,00	421	357	Lemau
30.	05RH102C	0,72	0,03	1,16	1,19	0,03	502	161	Lemau
31.	05RH104B	2,62	0,17	10,46	10,63	0,02	435	399	Lemau
32.	05RH107B	0,64	0,01	0,47	0,48	0,02	569	74	Lemau

Table 1. TOC and Pirolisis data of Seblat and Lemau Formation in the area of Bengkulu conducted by Rachmat Heryanto on Journal Of Geology Indonesia, Vol. 2 No. 2 Juni 2007: 99-111

4. RESULTS AND DISCUSSION

4.1. Geochemical Methods

The organic carbon content and source rock maturity evaluated with different factors including quality and quantity of organic matter, generating potentialities, type of organic matter and thermal maturation were considered.

4.1.1. Quality and Quantity Of Organic Matter

The organic carbon richness of the rock samples (TOC%), is important in the evaluation of sediments as a source for petroleum. Tissot and Welte , Peters and Cassa and Peters presented a scale for the assessment of source rocks potentiality, based on the TOC% and Rock–Eval pyrolysis data, such as S1 and S2.

The result data in **Table 1** show that the total organic carbon content values for the Seblat Formation source rocks are between 1.16 and 3.85 wt% indicating poor to Fair source rocks. Whereas the values for the Lemau Formation source rocks are between 1.16 and 15.08 wt% only two samples have values less than 1 wt% indicating good to excellent source rocks. This conclusion is confirmed by the plot of TOC (wt%) versus S2 **(Fig. 3a).**

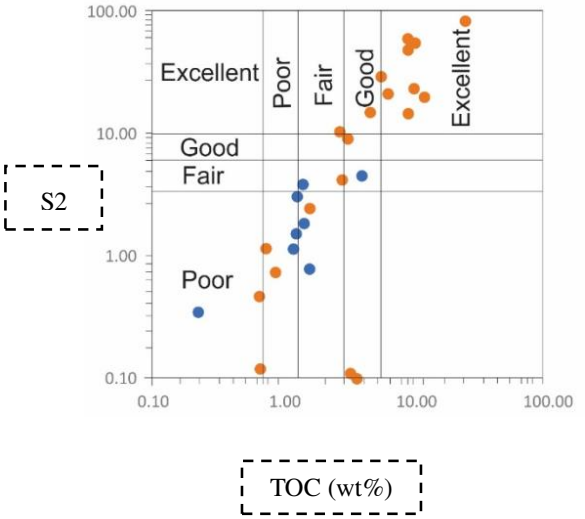


Figure 3a. TOC (wt%) versus S2

Nevertheless, the plot of S1 versus TOC **(Fig. 3b)** can be used to discriminate between non-indigenous (allochthonous) and indigenous hydrocarbons (autochthonous). This relation shows that the majority of the studied rock samples for the Seblat Formation and Lemau formation source rocks were characterized by autochthonous hydrocarbons indicating that the oil produced in the source rock itself.

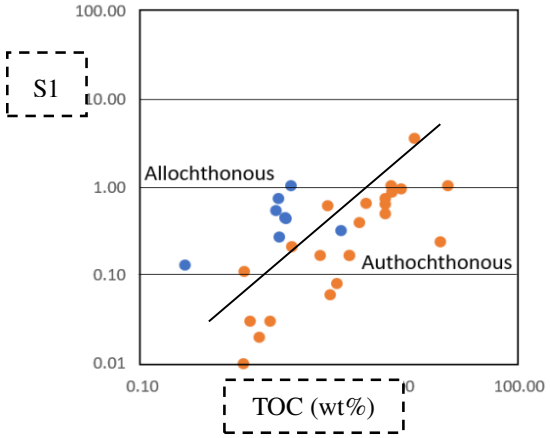


Figure 3b. TOC (wt%) versus S1

4. 1.2. Generating Potentialities

To identify the generation potential of source rock is by processing the data from the geochemical pyrolysis of the rock. The sum of S1 and S2 determines pyrolysis Yield (PY) in source rock. According to Hunt (1996), source rock which has PY values <2 (Poor), 2-5 (Fair), 5-10 (good), and> 10 (very good) is the potential of its generation. The relationship between PY and TOC to determine the potential of generation in the Seblat Formation shows that source rock there has a generation potential level dominated by (Fair) potential of its generation [19] . Whereas the Lemau Formation has a generation potential level from (poor) to (excellent) but is dominated by (very good-Excellent) **(Fig 4a).**

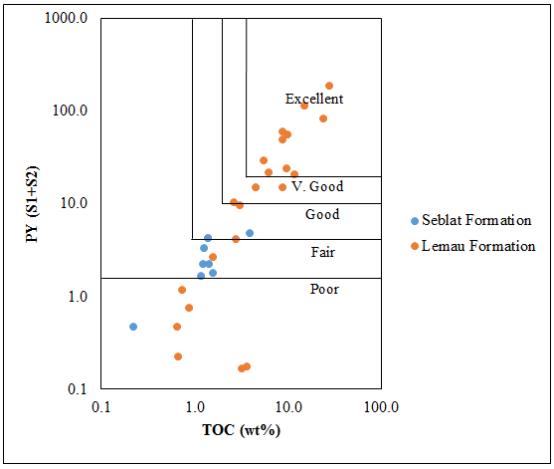


Figure 4a. The relationship between PY and TOC

In the graph of the relationship between HI (Hydrogen Index) and TOC to find out the Hydrogen content of source rock shows that in the Seblat formation contains limited oil, but there is a slight dominant gas in it. While the Lemau formation contains a limited oil and there is also limited gas in it **(Fig 4b)**.

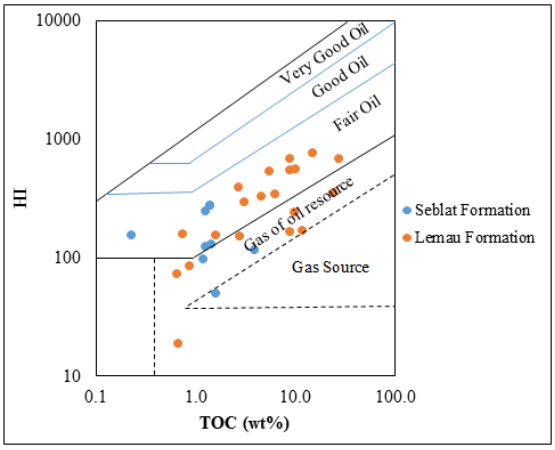


Figure 4b. TOC versus HI

4.1.3. Genetic Type of Organic Matter

To identify types of source rock based on kerogen content, is used to find out the potentially of oil and gas. According to Waples (1985), the known levels of HI (Hydrogen Index) from a source rock explain the kerogen types contained in these rocks. Having hydrogen <150 mg / g can be indicated that source rock can potentially generate gas (usually kerogen type III), has hydrogen 150-300 mg / g can be indicated that source rock can potentially generate a mixture of oil and gas, but more gas (kerogen type II and III)

In this study, using a method of comparing S2 and TOC in graphical form (Langford and Blanc-Valleron, 1990) to determine the kerogen type of several data source rock of seblat and lemau formations. It was found that the Seblat formation, the source rock has the characteristics of kerogen type III / II mixed with III, whereas the lemau formation has the characteristics of a more varied kerogen type that is from kerogen type III to kerogen type I but is dominated by kerogen type III **(Fig 5).**

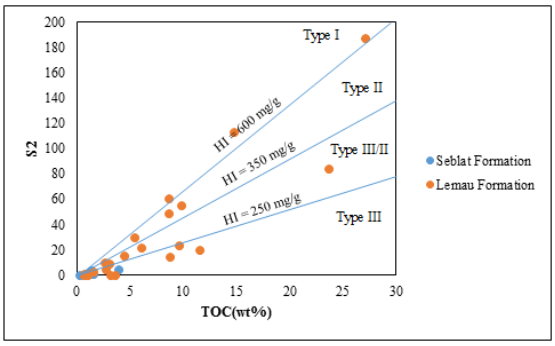


Figure 5. Kerogen type diagram which represents the plot TOC versus S2

4.1.4. Thermal Maturation

Based on pyrolysis data kerogen classification diagrams were constructed using the HI versus Tmax plot as carried out by previous workers which is used to determine the kerogen type and maturity

(Fig. 6a). The result show Lemau Formation samples are plotted in the immature zone with dominat kerogen type I-II and then grading to mature – post mature zone. While the analyzed Seblat Formation sample are plotted in the immature zone (only two sample) with kerogen type II-III.

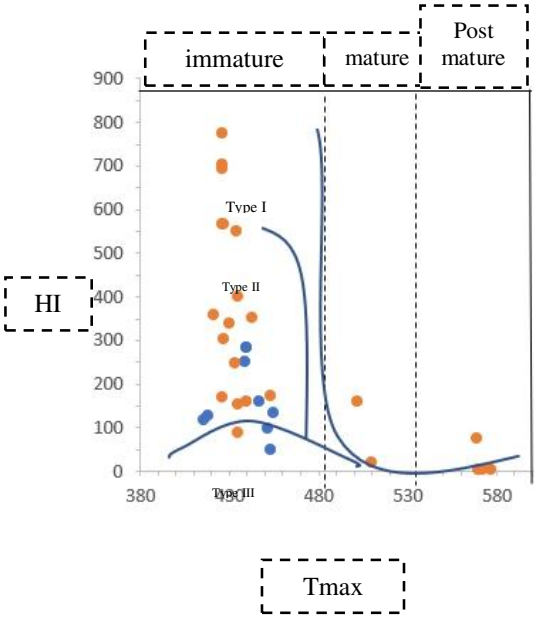


Figure 6a. kerogen type and maturity

Based on diagram Tmax vs PI (S1+S2) **(Fig. 6b)** , the majority sample of Lemau Formation and Seblat Formation are plotted in the Stain or Show Zone.

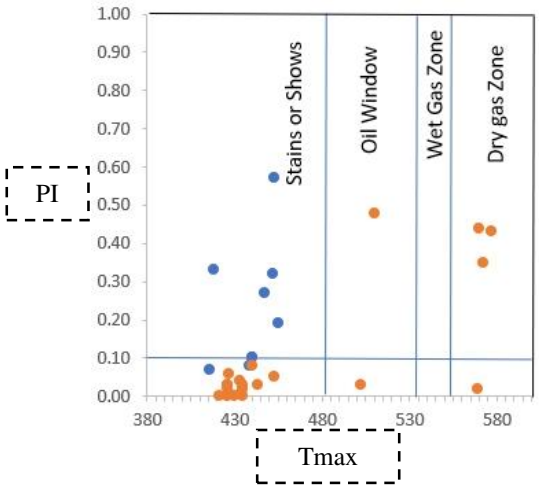


Figure 6b. Majority sample

4.2. Statistical Methods

Each sample was analyzed statistically using a NCSS Data Analysis 12 version as Cluster Analysis, Factor Analysis, and Pearson's Correlation.

4.2.1. Cluster Analysis

Cluster analysis is a technique to group similar observations into a number of clusters based on the observed values of several variables for each individual. Cluster analysis is similar in concept to discriminant analysis [15] . Cluster analysis is an exploratory data analysis tool for organizing observed data or cases into two or more groups [13] . The NCSS Data Analysis 12 version program calculates 'distances' between data points in terms of the specified variables. A hierarchical tree diagram, called a dendrogram on NCSS, can be produced to show the linkage type as Group Average. The clusters are linked at increasing levels of dissimilarity.

Applying Hierarchical cluster analyses on the studied samples shows two clusters reflect two types of source rocks. Cluster I are Source rocks characterized by HI <400 (mg/g), TOC from 0,22 to 11,53%, S1 from 0.00 to 1.05(mg/g) and S2 from 0.04 to 23.64 (mg/g) indicating fair to good source rocks with kerogen of type II and III capable of generating oil and gas. Cluster II are Source rocks characterized by HI 350 - <703 (mg/g), TOC from 5.39 to 23.58%, S1 from 0.24 to 0.88 (mg/g) and S2 from 29.62 to 84.48 (mg/g) indicating good to excellent source rocks with kerogen of type II capable of generating oil and limited gas.

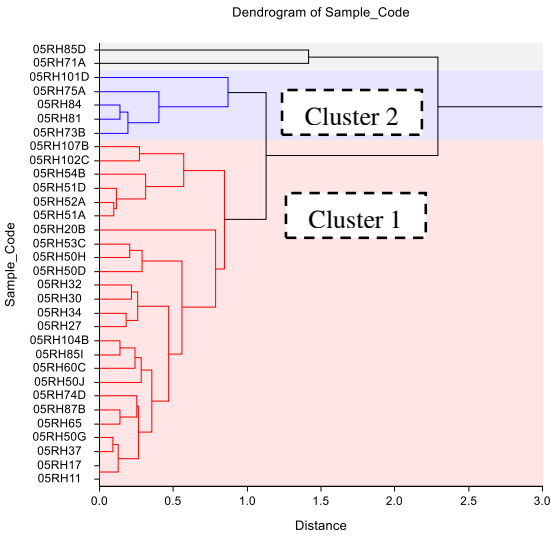


Figure 7. Cluster Analysis

4.2.2. Factor Analysis

Applying factor analysis on Rock–Eval pyrolysis variables shows that there are two factors affecting the evaluation of source rocks. Factor "1" includes Variables S2, TOC%, S1, and HI which determine the organic richness, hydrocarbon potentiality and the type of organic matter. Factor "2" include Variables PI, HI, and Tmax which determine the thermal maturity. So, factor analysis shows that evaluating the source rocks depends on determining organic richness, hydrocarbon potentialities, type of organic matter, and thermal maturity.

Variable	Eigenvalue	Individual Percent	Cumulative Percent
TOC "wt%"	2.310924	56.98	56.98
S1	1.678796	41.39	98.37
S2	-0.284328	7.01	105.38
PI	0.123603	3.05	108.43
Tmax	-0.097560	-2.41	106.02
HI	-0.244199	-6.02	100.00

Table 2. Eigenvalues after Varimax Rotation

Variable	Factor 1	Factor 2
TOC "wt%"	0.712929	0.054069
S1	0.340203	0.019947
S2	0.847041	0.094191
PI	0.027879	0.679122
Tmax	0.037402	0.407856
HI	0.345470	0.423609

Table 3. Communalities after Varimax Rotation

Number of Sample	Factor 1	Factor 2
05RH11	0.5188	0.4572
05RH17	0.5188	0.4572
05RH20B	-0.9599	-2.7674
05RH27	0.0907	-1.1667
05RH30	0.3932	-0.4634
05RH32	0.7715	-0.4718
05RH34	-0.0054	-0.8091
05RH37	0.8071	0.6052
05RH50D	-0.5149	0.2419
05RH50G	0.8846	0.4319
05RH50H	-1.5265	-0.1460
05RH50J	-0.6810	0.3761
05RH51A	-0.4779	-3.4338
05RH51D	-0.1084	-3.3129
05RH52A	-0.2300	-2.9840
05RH53C	-1.6732	-0.6377
05RH54B	0.0714	-2.6456
05RH60C	0.1241	0.6491
05RH65	1.3832	0.7533

05RH71A	-7.4057	-1.2995
05RH73B	-2.1576	0.8628
05RH74D	0.5668	0.5265
05RH75A	-0.5407	1.0751
05RH81	-1.6950	0.7325
05RH84	-2.2886	0.4603
05RH85D	-8.1889	-1.4483
05RH85I	0.3211	1.0099
05RH87B	1.0931	0.9079
05RH101D	-4.0154	-0.4949
05RH102C	1.0196	-0.0068
05RH104B	0.6084	1.1526
05RH107B	0.8094	-1.0091

Table 4. Factor Score after Varimax Rotation

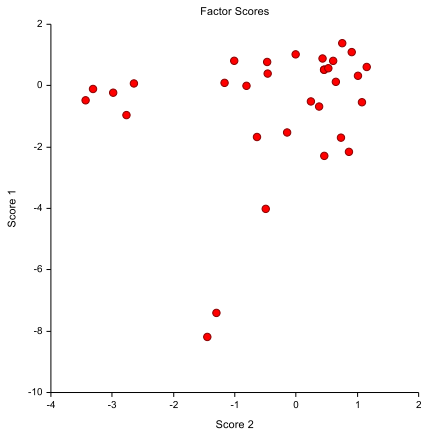


Figure 8. Factor Scores

4.2.3. Pearson's Correlation

Pearson's Correlation are used in statistics to measure how strong a relationship is between two variables. There are several types of correlation coefficient: Pearson's correlation (also called Pearson's *R*) that commonly used in linear regression. The correlation coefficient can range from −1 to +1, with −1 indicating a perfect negative correlation, +1 indicating a perfect positive correlation, and 0 indicating no correlation at all. (A variable correlated with it will always have a correlation coefficient of 1).

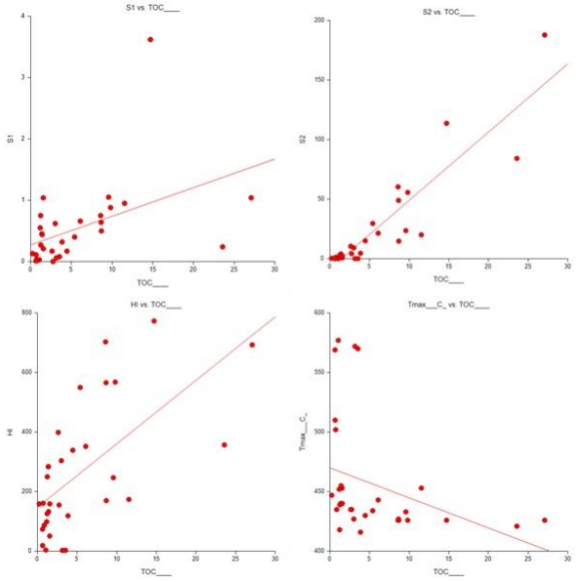
Correlation is an effect size and so we can verbally describe the strength of the correlation using the guide that Evans (1996) suggests for the absolute value of *r*:

• .00–.19	"very weak"
• .20–.39	"weak"
• .40–.59	"moderate"
• .60–.79	"strong"
• .80–1.0	"very strong"

Applying Pearson's correlation analysis shows a very strong positive correlation between TOC and S2 is indicates the contribution of S2 from TOC. Furthermore, strong positive correlation between TOC and S1 and HI, weak negative correlation between TOC and Tmax, moderate negative correlation between TOC and PI is indicate that the maturity of source rocks is independent of the amount of organic matter. Moderate positive correlation between S1 and S2 and also strong positive correlation between S2 and HI in addition to moderate negative correlation between Tmax and HI illustrate that the highest HI occurs at certain maturities and does occur in stages of less maturity and strong negative correlation reverse correlation between HI and PI was also shown.

Variable	TOC	S1	S2	Tmax	HI	PI
TOC	1					
S1	0.600	1				
S2	0.910	0.570	1			
Tmax	-0.333	-0.351	-0.333	1		
HI	0.633	0.587	0.780	-0.555	1	
PI	-0.406	-0.135	-0.381	0.536	-0.609	1

Table 5. Pearson's correlation coefficient (*r*) between Rock–Eval parameters for the studied samples



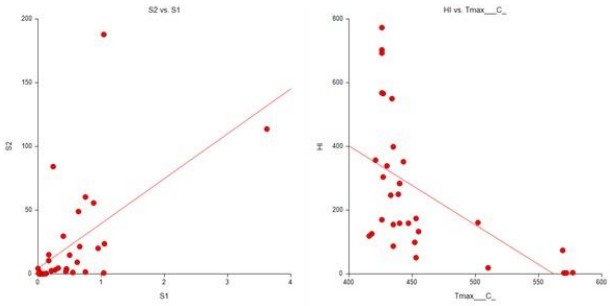


Figure 9. Pearson's correlation coefficient of the studied samples

5. Conclusions

The geochemical and statistical analyses for evaluating source rocks in Bengkulu area show that:

1. The Seblat formation indicating Poor to Fair source rocks while The Lemau formation indicating Good to Excellent source rocks.

2. Based on Relationship between HI (Hydrogen Index) and TOC to find out the Hydrogen content of source rock shows that in the Seblat formation contains limited oil, but there is a slight dominant gas in it. While the Lemau formation contains a limited oil and there is also limited gas.

3. The majority sample of Lemau Formation and Seblat Formation are plotted in the Stain or Show Zone.

4. Seblat formation has kerogen type II that are capable of generating oil and limited gas, while Lemau formation has kerogen type I-II and are capable of generating oil and limited gas.

5. Applying Hierarchical cluster analyses on the studied samples shows two clusters reflect two types of source rocks. Cluster I are Source rocks characterized by HI <400 (mg/g), TOC from 0,22 to 11,53%, S1 from 0.00 to 1.05(mg/g) and S2 from 0.04 to 23.64 (mg/g) indicating fair to good source rocks with kerogen of type II and III capable of generating oil and gas. Cluster II are Source rocks characterized by HI 350 - <703 (mg/g), TOC from 5.39 to 23.58%, S1 from 0.24 to 0.88 (mg/g) and S2 from 29.62 to 84.48 (mg/g) indicating good to excellent source rocks with kerogen of type II capable of generating oil and limited gas.

6. Applying factor analysis on Rock–Eval pyrolysis variables shows that there are two factors affecting the evaluation of source rocks. Factor "1" includes Variables S2, TOC%, S1, and HI which determine the organic richness, hydrocarbon potentiality and the type of organic matter. Factor "2" include Variables PI, HI, and Tmax which determine the thermal maturity. So, factor analysis shows that evaluating the source rocks depends on determining organic richness, hydrocarbon potentialities, type of organic matter, and thermal maturity.

7. Applying Pearson's correlation analysis shows a very strong positive correlation between TOC and S2 is indicates the contribution of S2 from TOC. Furthermore, strong positive correlation between TOC and S1 and HI, weak negative correlation between TOC and Tmax, moderate negative correlation between TOC and PI is indicate that the maturity of source rocks is independent of the amount of organic matter. Moderate positive correlation between S1 and S2 and also strong positive correlation between S2 and HI in addition to moderate negative correlation between Tmax and HI illustrate that the highest HI occurs at certain maturities and does occur in stages of less maturity and strong negative correlation reverse correlation between HI and PI was also shown.

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