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Initial Geochemical Assessment of Coaly Source Rocks in Sumatera, Java, and Kalimantan

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ABSTRACT. One of the hydrocarbon source rocks in Western Indonesia's petroleum system was deposited in the paralic-deltaic environment with high organic content, categorizing it as coaly source rock. This study initially assesses the geochemical characteristics of 25 coal and coaly shale samples from rock outcrops and wells representing the Central Sumatra, South Sumatra, South Central Java, Barito, and Kutai Basin. Total Organic Carbon (TOC) analysis and Rock-Eval Pyrolysis (REP) were carried out to reveal the source rock's geochemical characteristics and maturity. The TOC analysis showed a 0.5–67.73 wt.% value, indicating excellent source rock potential. Further REP analysis exhibits kerogen type II/II–III (excluding samples from Ngimbang Fm.) with gas-dominated hydrocarbon. The Hydrocarbon Index ranging from 4–308 mg/gC indicates a possible low to moderate quantity of hydrocarbon that the source rocks can generate. Despite the overall fair to good source rock potential, the Tmax of the samples indicates an inferior maturity level, with only Upper Talang Akar as the mature candidate. Thus, it can be concluded that young source rock candidates in Western Indonesia (limited to the basins studied in this research) initially have the potential to generate hydrocarbons if it were not for the immature level of most coaly source rock formations..

Keywords: Geochemical assessment · Coaly Source Rocks · Sumatera · Java · Kalimantan.

1 INTRODUCTION

Doust and Noble (2007) propose that Indonesia encompasses 34 petroleum systems within its Tertiary basins, highlighting its significant potential as a source for oil and gas exploration. Some are composed of source rocks with various characteristics deposited in different depositional environments. Coaly source rocks deposited in a paralic-deltaic environment are noteworthy potential oil and gas reservoirs.

This study aims to contribute to the optimization of conventional oil and gas exploration through an understanding of the general characteristics of the coal and coaly shale source rocks in western Indonesia, which includes Balikpapan Fm. in Kutai Basin, Warukin Fm. in Barito Basin, Talang Akar Fm. in South Sumatra and Northwest Java Basin, Nanggulan Fm. in Kulon Progo, Muara Enim Fm. in South Sumatera Basin, and Petani Fm. in Central Sumatera Basin.

Sykes & Snowdon (2002) provide the guidelines for assessing the petroleum potential of coaly source rocks using Rock-Eval Pyrolysis (REP), highlighting the hydrocarbon significance of coaly source rocks. It provides improved identification of the rank thresholds for oil generation and expulsion and the determination of effective HI values for oil generation from coals. Therefore, research on the characteristics of coal source rocks from various grades must be conducted to determine the

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maturation trend and the feasibility limit of coal source rocks as oil and gas producers in the Western Indonesia region.

This paper provides in-depth geochemical and physical characteristics of coaly source rocks from several Western Indonesia Basins to assess their potential for oil and gas. We report hydrocarbon geochemistry data, including total organic carbon (TOC, wt.%) and REP, Hydrogen Index (HI), S1, and S2), accompanied by Tmax values. We also compiled published works on vitrinite reflectance analysis and organic petrography from the respective basin to better understand the maturation pathway of coaly source rocks in Western Indonesia.

2 MATURITY PARAMETERS FOR COALY SOURCE ROCKS

The research area is spread over five hydrocarbon-prolific basins in Western Indonesia: Central Sumatera, South Sumatera, South Central Java, Kutai, and Barito Basin. The analyzed coal and carbonaceous shale samples were deposited in Miocene to Early Pliocene (Petani, Talang Akar, Muara Enim, Warukin, and Balikpapan Fm.) and Eocene (Nanggulan Fm.).

Sykes & Snowdon (2002) divide the maturity level of coal into (1) oil generation, (2) gas generation, and (3) oil expulsion (Figure 1). The generation phase begins when the distribution of the BI values (S1/TOC) increases with changes in the Tmax value. The decrease in BI value after being constant at a certain saturation point indicates the gas generation process, the cracking of petroleum molecules into gas, or petroleum expulsion. The results showed that the oil generation phase started from the interval Tmax ±420–430°C (Ro ±0.55–0.60) and ended at Tmax ±445–450°C (Ro ±0.90–1.0) (Sykes & Snowdon, 2002). The upper and lower limits of the coal maturation pathway are determined on the Hydrogen Index (HI, S2/TOC) analysis of coaly source rock samples. The results of HI analysis can also be combined with BI analysis of changes in Tmax to determine the upper and lower limits of the coal maturation pathway (Sykes & Snowdon, 2002). Peters and Cassa (1994) propose a method to determine the thermal maturity of source rocks using REP parameters. The critical parameters for this purpose are the vitrinite reflectance (Ro), the temperature at which the maximum pyrolysis occurs (Tmax), and the production index (PI). The method involves the following steps: (1) Tmax determination, (2) PI calculation, (3) Ro assessment, and (4) correlation of these parameters with the maturity levels.

3 RESEARCH METHOD

3.1 Sample selection

This research utilized 25 coaly source rock samples representing five sedimentary basins in Western Indonesia, including Central Sumatera, South Sumatera, South Central Java, Kutai, and Barito Basin. The majority of the samples are gathered from outcrops. Samples equivalent to the Ngimbang Formation of the Northeast Java Basin were taken from the Nanggulan Formation, a distinct stratigraphic unit characterized by a comparable depositional age and phase. Published data from the Offshore Northwest Java Basin were also utilized to add a broader perspective to interpretation.

3.2 Analytical method

TOC (Total Organic Carbon) analysis was performed using Elementar Soli TOC Cube v1.1.0 at GetIn-CICERO Laboratory, Universitas Gadjah Mada (UGM). TOC analysis converts burnt organic material in burnt rock samples into CO_2. The CO_2 content at the end of the combustion process will indicate the rock's organic material content expressed in units of wt.% of dry rock.

Samples are covered by aluminum foil to protect them from contamination. This is particularly important in geochemical sampling, as any contamination could affect the accuracy of the analysis.

Samples are then cleaned up and hand-crushed to avoid material loss if crushed by the machine. The samples are then filtered to exceed the 200 mesh size. Approximately 5 grams of crushed samples will be analyzed for their TOC contentThe catalytic combustion process for the determination of TOC in solids complies with EN 15936 (the European standard specifying the method of determining TOC in samples containing >1 gram carbon/kg dry matter (0.1%)). During the combustion process, the organic carbon contained in the

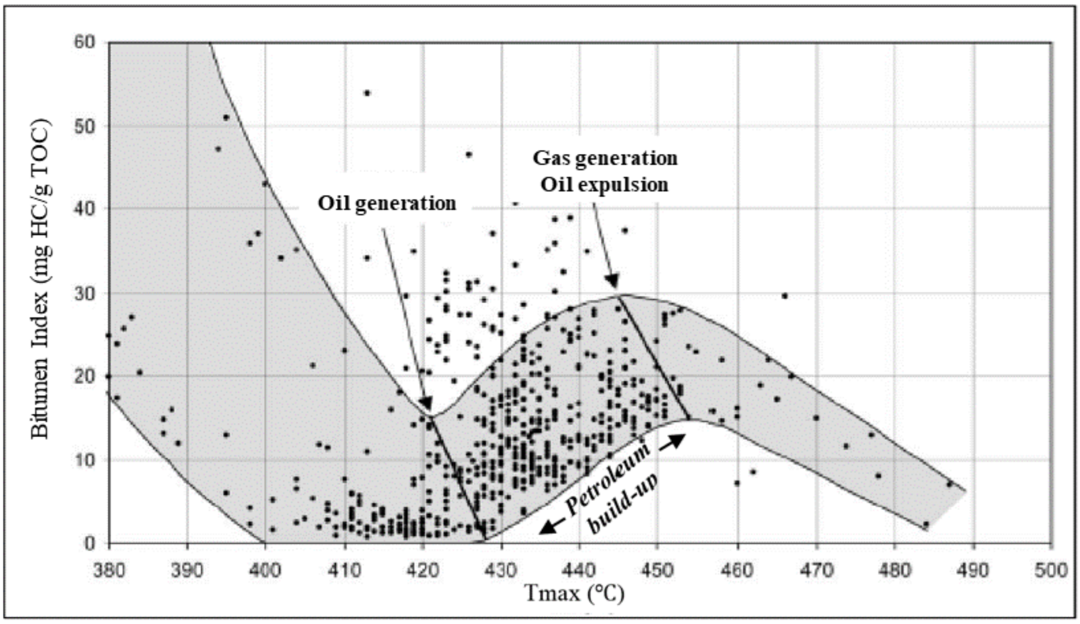

FIGURE 1. Graph of BI (S1/TOC) vs. Tmax of 200 coal samples from New Zealand to determine the phases of oil generation, gas generation, and oil expulsion (Sykes & Snowdon, 2002 with modifications).

sample will be converted into carbon dioxide (CO_2). The amount of CO_2 produced from combustion indicates the amount of organic carbon in the rock.

REP was carried out using the Rock-Eval 5 series analysis tool at PT. Geoservices, Ltd. The analyzed samples were heated under anoxic conditions, and the temperature increased slowly, generally in the range of 250–550 °C. Pyrolysis is one of the methods in hydrocarbon geochemical exploration where we can simulate processes that occur in nature in the laboratory. When heating begins in this analysis, the hydrocarbons will be expelled (S1). The heating is continued to the temperature of 350 °C, where the cracking of kerogen produces the second type of hydrocarbon stream (S2). The maximum intensity of S2 formation through cracking reaches a maximum temperature of around 420–460 °C. During the pyrolysis process, carbon dioxide is detected by a thermal conductivity detector. Based on the following guidelines (see Table 1), we can classify the source rock's petroleum potential (quantity) using the TOC, S1, and S2 (Bissada & Peters, 1991; Peters & Cassa, 1994). Meanwhile, Waples's (1985) classification of source rock potential is not applied in this study due to its limitation by only considering TOC as the parameter.

We use the Hydrogen Index, S2, and S3 from REP to determine the kerogen type and hydrocarbon stage (oil, gas, or mixture of both) following the recommended values/threshold from Peters and Cassa's (1994) (Table 2). We also plot the Oxygen Index vs. Hydrogen Index on a modified pseudo-Van Krevelen diagram to determine the kerogen type and hydrocarbon phase that can be generated.

Coal (or coaly lithology) rank and maturity, which comprise this study's source rock, are two different things. Rank is defined as the degree of coalification controlled by the history of deposition, whereas maturity is related to the oil generation controlled by thermal stress (Wilkins & George, 2002). Peters & Cassa (1994) have classified source rocks into immature, mature, and post-mature based on their level of maturity (see Table 3). In this study, the determination of the source rock's thermal maturity level was carried out by using the Tmax vs Hydrogen Index parameter.

Tmax is determined as the temperature at which the maximum pyrolysis of the organic matter in the rock occurs during the REP analysis. The PI is calculated using the formula PI = S1 / (S1+S2), where S2 is the amount of hydrocarbons generated by pyrolysis of the rock, and S3 is the amount of carbon dioxide generated. Vitrinite reflectance (Ro) measures the thermal maturity of the organic matter in the rock. It

TABLE 1. Guidelines for determining source rock's petroleum potential (Peters & Cassa, 1994).

Petroleum Potential	Organic Matter			Bitumen		Hydrocarbons
	TOC (wt.%)	Rock-Eval				
		S1	S2	(wt.%)	(ppm)	(ppm)
Poor	0–0.5	0–0.5	0–2.5	0–0.05	0–500	0–300
Fair	0.5–1	0.5–1	2.5–5	0.05–0.10	500–1000	300–600
Good	1–2	1–2	5–10	0.10–0.20	1000–2000	600–1200
Very Good	2–4	2–4	10–20	0.20–0.40	2000–4000	1200–2400
Excellent	>4	>4	>20	>0.40	>4000	>2400

TABLE 2. Guidelines for determining kerogen type and expelled product (Peters & Cassa, 1994).

Kerogen Type	HI (mg HC/g TOC	S2/S3	Atomic H/C	Main Expelled Product at Peak Maturity
I	>600	>15	>1.5	Oil
II	300–600	10–15	1.2–1.5	Oil
II/III	200–300	5–10	1.0–1.2	Mixed oil & gas
III	50–200	1–5	0.7–1.0	Gas
IV	<50	<1	<0.7	None

is determined microscopically by analyzing the reflectance of vitrinite particles in the rock. Correlation of parameters with maturity levels: The results of Ro, Tmax, and PI measurements are then correlated with known maturity levels to assess the thermal maturity of the source rock.

Parameters from TOC and REP analysis, combined with results from previous studies, are then used to interpret the source rock potential, including the quantity of hydrocarbons that can be produced, the quality of the source rock, and thermal maturity. The TOC analysis shows that the rock's organic material content determines the quantity of hydrocarbons. In contrast, the basic parameters of the REP analysis, which include S1, S2, and Tmax, are used to determine the source rock's quality (kerogen type) and thermal maturity.

4 RESULTS AND DISCUSSION

4.1 Geochemistry parameters from laboratory analysis

The result of TOC and Rock-eval pyrolysis of 25 analyzed samples is listed in Table 2. A carbonaceous black shale from Central Sumatera's Petani Formation shows TOC values of 12.76 wt.%. HI for this sample is 137 mg/gC, while OI is 12 mg/gC. REP analysis suggests that the Tmax for this source rock candidate is 428 °C, with kerogen type III (gas-prone). The samples have the potential to generate hydrocarbon with low quantity and have good source rock potential. The source rock maturity is im-

TABLE 3. Guidelines for determining source rock's thermal maturation (Peters & Cassa, 1994).

Stage of Thermal Maturity for Oil	Maturation			Generation		
	Ro (%)	Tmax (°C)	TAI	Bitumen / TOC	Bitumen (mg/g rock)	PI [S1/(S1+S2)]
Immature	0.2–0.6	<435	1.5–2.6	<0.05	<50	<0.10
Early Mature	0.6–0.65	435–445	2.6–2.7	0.05–0.1	50–100	0.10–0.15
Peak Mature	0.65–0.9	445–450	2.7–2.9	0.15–0.25	150–250	0.25–0.40
Late Mature	0.9–1.35	450–470	2.9–3.3	–	–	>0.40
Post Mature	>1.35	>470	>3.3	–	–	–

mature. This aligns with the depositional age of the formation, which was Late Miocene to Pliocene, which did not provide sufficient pressure, temperature, and time to be a mature source rock candidate.

Eight samples are taken from South Sumatera's Upper Talang Akar Formation; three of them are coals with TOC ranging from 14.25–36.79 wt.%, while the rest are carbonaceous black shale with TOC ranging from 0.85–4.12 wt.%. HI for the Upper Talang Akar coal sample ranges from 91–206 mg/gC, while OI values are 11–121 mg/gC. For Upper Talang Akar carbonaceous shale, HI values range from 26–214 mg/gC, while OI values are 9–73 mg/gC. REP analysis suggests that Tmax for this formation ranges from 386–455 °C, with kerogen type II/III – III (mostly gas-prone). The samples have the potential to generate hydrocarbon with low quantity and have poor-excellent source rock potential. The source rock maturity ranges from immature to late mature. This partly aligns with the fact that Upper Talang Akar coaly source rock is the most prominent source rock candidate compared to the other sampled formations. Azizah *et al.* (2019) suggest that the source rock from this formation is categorized as mature enough to generate and expel oil with TOC ranging from 0.82–4.85 wt.%.

Muara Enim coals and carbonaceous shales are less regarded as petroleum source rock. Two samples are taken from South Sumatera's Muara Enim Formation. The lithology is coal with TOC ranging from 51.93–61.62 wt.%. HI for the Muara Enim sample ranges from 221–308 mg/gC, while OI is 62–68 mg/gC. REP analysis suggests that Tmax for this source rock candidates ranges from 400–405 °C, with kerogen type II – II/III (oil/gas-prone). The samples have the potential to generate hydrocarbon with low-moderate quantity and have very good-excellent source rock potential. Rocks from this formation are deemed immature as a source rock.

Six samples are taken from the Nanggulan Formation. The lithology is coaly shale with TOC ranging from 0.26–1.07 wt.%. HI for the Nanggulan sample ranges from 4–52 mg/gC, while OI is 56–276 mg/gC. REP analysis shows that Tmax for this source rock candidates ranges from 417–431 °C, with kerogen type IV (inert). The samples have the potential to generate hydrocarbon with low quantity and have poor source rock potential. The source rock maturity is immature. A previous study by Winardi *et al.* (2014) indicates that the Eocene shale within the Nanggulan Formation generally possesses low to very good potential as a source rock. The predominant kerogen type is Type III (humic/non-fluorescent amorphous), suggesting conditions conducive to gas generation. Surface samples from the study also indicate an immature stage, even though subsurface modeling indicates otherwise.

Two samples from Barito's Warukin Formation are coal with TOC values ranging from 48.42–53.18 wt.%. HI for the Warukin sample ranges from 130–159 mg/gC, while OI is 62–84 mg/gC. REP analysis indicates that Tmax for this source rock candidates ranges from 412–415 °C, with kerogen type III (gas-prone). The samples have the potential to generate hydrocarbon in low quantities and have very good to excellent source rock potential. The source rock maturity is immature. A previous Napitupulu & Sosrowidjojo (2002) study suggests that the Warukin Formation, a viable source rock in the Barito Basin, encompasses two significant facies for hydrocarbon generation: coal and carbonaceous shales. These formations exhibit promising hydrocarbon potential, characterized by Type II kerogens conducive to oil generation. Oil production is observed across different subbasins at depths ranging from 2300 to 3000 meters, dating back to approximately 1.9 million years ago.

Six samples from Kutai's Balikpapan Formation are coal with TOC values ranging from 9.45–67.3 wt.%. HI for the Balikpapan sample ranges from 101–215 mg/gC, while OI is 17–111 mg/gC. REP analysis shows that Tmax for this source rock candidates ranges from 406–422 °C, with kerogen type II/III – III (oil/gas-prone). The samples have the potential to generate hydrocarbon with low quantity and have good-excellent source rock potential. The source rock maturity is immature. This is contrary to the common Balikpapan source rocks' characteristics, which mostly possess a satisfactory to outstanding amount of organic material. They typically are type III kerogen, which suggests a significant input from terrestrial-based sources and the ability to produce gas. Most Balikpapan source rocks exhibit a moderate to outstanding capacity for hydrocarbon production, thus presenting promising source rocks. Maturity-wise, the Tmax from this study matches the previous analysis in some Balikpapan source rock samples, which are mostly immature-early mature (Permana *et al.*, 2018).

Our results suggest that most analyzed samples are immature source rock candidates, except for Upper Talang Akar Fm. Most of these samples possess good organic material, which leads to good potential as a source rock. However, the samples analyzed in this study had a low capacity to produce large amounts of hydrocarbons. Shallow core samples from Nanggulan Fm. are categorized as type IV kerogen, indicating poor potential for generating significant amounts of hydrocarbons compared to other kerogen types. While it may contain organic material, the conditions necessary for its conversion into hydrocarbons may not be favorable, or the organic material may be too immature or of the wrong composition to generate significant amounts of hydrocarbons.

4.2 Qualitative source rock potential

When TOC is the only parameter, samples in this study are mainly classified as having fair-excellent source rock potential. However, when S1 and S2 values from REP analysis are considered, the potential turns out to be more pessimistic, ranging from poor to excellent. The lowest potential is observed in coaly shale samples of Nanggulan Fm. (Ngimbang Fm. equivalent). Meanwhile, Upper Talang Akar, Muara Enim, Warukin, and Balikpapan Fm have the highest potential. The interpretation of each sample's source rock quality category is based on Peters and Cassa's (1994) classification, as shown in Table 1. It is worth noting that the quality implied in this context only refers to the organic material content that can generate hydrocarbon, regardless of the overburden thickness, burial age, and pressure or temperature that can help the maturation of the rocks.

Most Upper Talang Akar samples are defined as fair-excellent source rock candidates with most TOC >0.5 wt.%. This means the formation has a higher potential for hydrocarbon generation because more organic material is available to be converted into hydrocarbons. Samples with good to excellent quality as source rock are also encountered in Petani, Muara Enim coal, Warukin coal, and Balikpapan coal. Samples from all the formations have TOC >0.5 wt.% and have a high potential to generate hydrocarbon, considering longer burial time and higher pressure and temperature. These values indicate that good – excellent source rock potential is possible due to the richness of organisms in each depositional environment. Coal lithology indicates terrestrial, marsh, or muddy anoxic environment with higher-level vegetation. These factors result in rich organic carbon content in the deposited sediments. Compared to the black shale or coaly shale samples, coal tends to have a higher TOC level due to its 100% carbon content. This characteristic is superior to other lithologies with siliciclastic material mixture in the composition.

Contrary to the others, six Nanggulan samples in this study are said to have lower quality to generate hydrocarbon. The OI vs HI plotting on the Van Krevelen diagram (see Figure 2) indicates that these samples are categorized as Type IV kerogen (inert). Kerogen Type IV refers to a specific classification of kerogen, an organic material found in sedimentary rocks that can generate hydrocarbons under appropriate conditions. Its very low organic content characterizes Kerogen Type IV and is primarily composed of inert, non-hydrocarbon organic material such as woody plant material or other organic debris that is not typically associated with significant hydrocarbon generation.

The Nanggulan Formation's sedimentary environment transitioned from a shallow marine setting during the Late Eocene to an estuarine (salt marsh) environment during the Early Eocene (Amijaya *et al.*, 2016). This transition led to the accumulation of sediment with elevated TOC levels. Conversely, sediment deposition in the estuarine (tidal flat) environment during the Middle Eocene resulted in lower TOC content. Additionally, volcanic activities during the Middle Eocene diminish organic material preservation due to the increased presence of inorganic materials.

Another possible explanation for these unproductive Nanggulan samples might be the

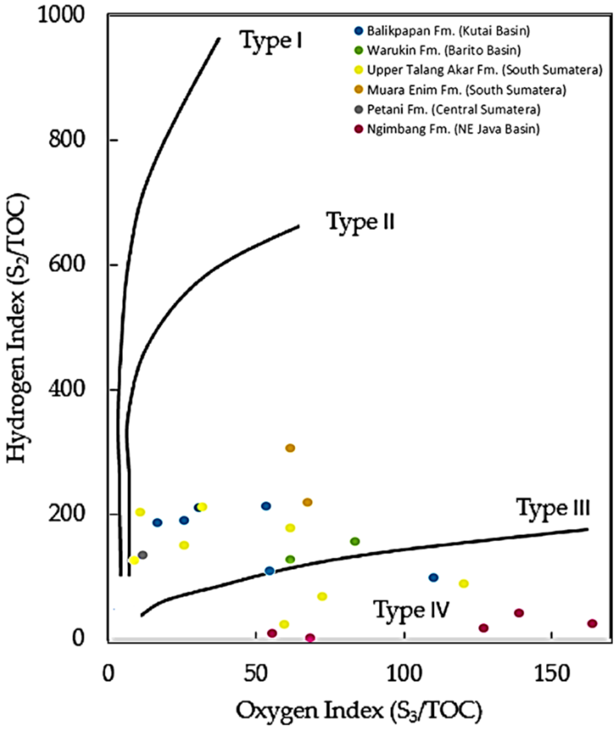

FIGURE 2. Plotting of OI vs. HI on Modified Van Krevelen diagram (Hunt, 1996) to determine the sample's kerogen type. It can be seen that most samples fall in type II/III and type III kerogen, except all samples from Nanggulan Fm. (eq. Ngimbang Fm.).

oxidation during lithification or coalification, causing the lignin and the coal tissues to evolve into inertinite. This oxidation factor can also explain extremely low TOC measurement in other samples (if any), resulting in no hydrocarbon the formation can produce.

4.3 Kerogen type, hydrocarbon stage, and hydrocarbon quantity

Classification by Peters and Cassa (1994) suggests that samples from Petani, Talang Akar, Warukin, and Balikpapan Fm. might be able to produce gas or mixture of oil and gas with HI ranging from 70-215 mg/gC and S2/S3 of mostly between 1–10 (see Table 4). On the other hand, two samples from Muara Enim Fm. are more likely to produce oil or a mixture of both, indicated by HI between 221-308 mg/gC and S2/S3 of + 5. Meanwhile, coaly shale samples are equivalent to Ngimbang Fm. show extremely low HI and S2/S3, resulting in inert kerogen on the Van Krevelen diagram with no hydrocarbon generated. Based on the HI value alone, only a low to moderate quantity of hydrocarbon is expected to be produced by each sample due to the HI value of mostly <300 mg/gC (Peters and Cassa, 1994). Figure 2 shows the results from REP analysis (Oxygen Index vs Hydrogen Index) on a modified Van Krevelen diagram to define the samples' kerogen type.

Based on the plotting and classification by Peters and Cassa (1994), most coal samples in this study – conceptually deposited within a paralic to deltaic environment – are classified as Type III kerogen, which tends to generate gas. Only two samples of Muara Enim coal are classified as Type II to II/III kerogen, which means oil-prone or oil/gas-prone.

Type III kerogen tends to generate gas due to its composition, which contains sufficient hydrogen to be gas-generative but not enough to be oil-prone. Its pure form is composed of vitrinite, a maceral formed from land plant wood. The original hydrocarbon generation potentials of type III kerogen are lower than other types, with a value of 85 mg/g TOC (Hui et al., 2023). This composition makes it more prone to gas generation compared to oil. The amount of hydrogen and the typical depositional environment are the key factors influencing the hydrocarbon potential of different kerogen types. Therefore, the composition of type III kerogen makes it more inclined to generate gas than oil. On the other hand, samples from Nanggulan Fm. are classified as inert kerogen, which prevents them from generating any hydrocarbon phase, as explained in the previous sub-chapter.

4.4 Maturity level of western Indonesia's coaly source rocks

In this study, the determination of the source rock's thermal maturity level was carried out by using the Tmax vs Hydrogen Index parameter (Figure 3). It can be concluded that most of the samples analyzed display immature maturity levels. Only a few samples from the Talang Akar Formation have reached mature levels with HI ranging from 4–308 mg/gC and Tmax between 386–455 °C. The immature stage implies that the samples have not yet generated hydrocarbons. Immature source rocks are characterized by low thermal maturity, low hydrogen content, and insufficient thermal maturity for hydrocarbon generation (Al-Areeq, 2018).

TABLE 4. TOC and Rock-eval Pyrolysis results.

No.	Sample ID	Lithofacies	Basin	Formation	TOC (wt.%)	HI (mg/gC)	OI (mg/gC)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	T Max (°C)	Kerogen Type	Hydrocarbon Stage	Hydrocarbon Quantity	Source Rock Quality (TOC)	Maturity
1	JJ- black shale- 47	Carbonaceous shale	Sumatera Tengah	Petani	12.76	137	12	0.14	17.42	1.54	428	III	Gas	Low quantity	Excellent	Immature
2	JJ- Coal- 46	Coal			51.309	152	14	0.33	78.16	7.16	424	III	Gas	Low quantity	Excellent	Immature
3	JJ- Coal- 38	Coal	Sumatera Selatan	Upper Talang Akar	14.25	91	121	1.15	13	17.3	418	III	Gas	Low quantity	Excellent	Immature
4	JJ- Coal- 41	Coal			36.79	206	11	1.6	75.75	3.96	442	II/III	Mix	Low quantity	Excellent	Early Mature
5	JJ- Coal- 48	Coal			17.81	180	62	2.17	32.12	11.08	425	III	Gas	Low quantity	Excellent	Immature
6	JJ- black shale- 36	Carbonaceous shale			0.85	153	26	0.58	1.3	0.22	444	III	Gas	Low quantity	Fair	Early Mature
7	JJ- black shale- 37	Carbonaceous shale			0.97	70	73	0.45	0.68	0.71	455	III	Gas	Low quantity	Fair	Late Mature
8	JJ- black shale- 40	Carbonaceous shale			1.16	128	9	0.6	1.48	0.1	440	III	Gas	Low quantity	Good	Early Mature
9	JJ- black shale- 42	Carbonaceous shale			4.12	26	60	0.09	1.06	2.48	386	IV	-	Low quantity	Excellent	Immature
10	JJ- black shale- 43	Carbonaceous shale			0.91	214	32	0.36	1.95	0.29	442	II/III	Mix	Low quantity	Fair	Early Mature
11	JJ- Coal- 23	Coal	Sumatera Selatan	Muara Enim	61.62	308	62	5.29	190	37.94	400	II	Oil	Moderate quantity	Excellent	Immature
12	JJ- Coal- 21	Coal			51.93	221	68	1.72	114.56	35.55	405	II/III	Mix	Low quantity	Excellent	Immature
13	JJ- Coal- 22	Coal			48.921	121	46	0.83	59.02	22.51	426	III	Gas	Low quantity	Excellent	Immature
14	JJ- coaly shale- 49	Carbonaceous shale	Jawa Tengah Selatan (Area Nanggulan, Kulon Progo)	Nanggulan	0.26	4	69	0	0.01	0.18	431	IV	-	-	Poor	Immature
15	JJ- coaly shale- 50	Carbonaceous shale			0.4	20	128	0	0.08	0.51	417	IV	-	-	Poor	Immature
16	JJ- coaly shale- 51	Carbonaceous shale			0.93	27	165	0.01	0.25	1.53	417	IV	-	-	Fair	Immature
17	JJ- coaly shale- 52	Carbonaceous shale			0.98	44	140	0.02	0.43	1.37	425	IV	-	-	Fair	Immature
18	JJ- coaly shale- 53	Carbonaceous shale			1.07	11	56	0.01	0.12	0.6	421	IV	-	-	Good	Immature
19	JJ- coaly shale- 54	Carbonaceous shale			0.5	52	276	0	0.26	1.38	421	IV	-	-	Fair	Immature
20	JJ- Coal- 3	Coal	Barito	Warukin	53.18	130	62	1.06	69.09	33.03	412	III	Gas	Low quantity	Excellent	Immature
21	JJ- Coal- 1	Coal			55.959	162	42	3.29	90.41	23.41	416	III	Gas	Low quantity	Excellent	Immature
22	JJ- Coal- 2	Coal			52.714	152	62	6.27	80.37	32.79	390	III	Gas	Low quantity	Excellent	Immature
23	JJ- Coal- 4	Coal			56.86	177	50	1.04	100.8	28.64	392	III	Gas	Low quantity	Excellent	Immature
24	JJ- Coal- 5	Coal			53.799	175	51	1.49	94.35	27.21	398	III	Gas	Low quantity	Excellent	Immature
25	JJ- Coal- 6	Coal			50.562	98	71	2.11	49.52	35.92	400	III	Gas	Low quantity	Excellent	Immature
26	JJ- Coal- 7	Coal			48.42	159	84	1.13	77.21	40.5	415	III	Gas	Low quantity	Excellent	Immature
27	JJ- Coal- 26	Coal	Kutai	Balikpapan	67.3	189	17	0.43	126.95	11.59	421	III	Gas	Low quantity	Excellent	Immature
28	JJ- Coal- 43b	Coal			64.18	192	26	0.64	123.06	16.77	422	III	Gas	Low quantity	Excellent	Immature
29	JJ- Coal-17	Coal			23.561	3	79	0.04	0.65	18.5	392	IV	-	-	Excellent	Immature
30	JJ- Coal-10	Coal			53.413	314	50	6.62	167.55	26.97	395	II/III	Mix	Medium quantity	Excellent	Immature
31	JJ- Coal-12	Coal			53.557	240	39	2.42	128.4	21.14	407	II/III	Mix	Low quantity	Excellent	Immature
32	JJ- Coal- 16	Coal			9.45	101	111	1.13	9.51	10.48	406	III	Gas	Low quantity	Excellent	Immature
33	JJ- Coal- 14	Coal			59.5	111	55	0.72	66.08	32.75	414	III	Gas	Low quantity	Excellent	Immature
34	JJ- Coal- 13	Coal			43.76	215	54	2.41	93.87	23.54	406	II/III	Mix	Low quantity	Excellent	Immature
35	JJ- Coal- 11	Coal			57.88	213	31	0.56	123.23	18.16	413	II/III	Mix	Low quantity	Excellent	Immature
											DETERMINANT:	**HI & S2/S3**	**HI & S2/S3**	**HI**	**TOC, S1, S2**	**Tmax, HI**

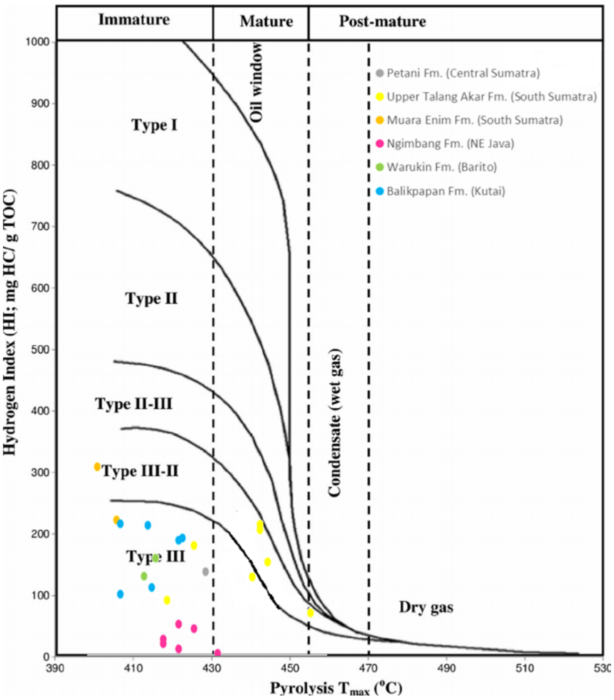

FIGURE 3. Modified van Krevelen diagram (Hunt, 1996) indicating mainly kerogen type-III for coaly source rock samples from various basins in Western Indonesia.

Based on the current TOC analysis and pyrolysis results, the overall problem encountered is the immature stage of almost all source rock candidates. Previous studies and explorations – on the other hand – have indicated older formations such as Ngimbang (in NE Java Basin) and Talang Akar Fm. (in Northwest Java Basin) to be thermally mature and considered as producing source rock. The Type IV (inert) kerogen observed on the Nanggulan Fm. samples might be because they are mainly derived from charcoal and fungal bodies, which might differ from the well-known Ngimbang source rock characteristics, composed of fluvial-deltaic coals.

5 CONCLUSION

This study has revealed the geochemical characteristics of coaly source rock candidates in Western Indonesia. A total of 25 samples are analyzed, representing Miocene-Early Pliocene coaly lithology, including coal and carbonaceous shales from Central Sumatra, South Sumatra, Barito, and Kutai Basin, and also older equalization of Eocene Ngimbang Fm. in Northeast Java Basin.

TOC and REP analysis show that the younger coaly source rock candidates deposited in the paralic-deltaic environment mainly consist of type II/III – type III kerogen with gas or a mixture of oil and gas as the expected hydrocarbon to be generated. The low HI value of almost all samples implies only a low-moderate quantity of hydrocarbon that can be produced. By examining TOC, S1, and S2, it is known that the coaly source candidates observed in this study are dominated by poor-excellent source rock potential, where the lowest potential is observed in the coaly shale of Ngimbang Fm. equivalent, and the highest potential is owned by Muara Enim, Warukin, and Balikpapan Fm. The overall moderate to good characteristics are absent in the Nanggulan samples as Eocene Ngimbang equivalent. Based on the modified Van Krevelen diagram, this interval is interpreted to contain inert kerogen, resulting in it not producing hydrocarbon.

Despite the characteristics of the source rock itself, maturity also plays a vital role in deciding if a potential source rock candidate might generate and expel hydrocarbon. Based on the Tmax vs. Hydrogen Index plotting, it is known that most of the samples fall in the immature category, causing them to fail in generating and expelling hydrocarbons. The only formation with early-late mature indication is the Upper Talang Akar Fm. from the South Sumatra Basin, with Tmax ranging from 386-455oC. Despite the moderate quality of source rock, coal and carbonaceous shale of the formation hold the highest possibility of producing hydrocarbon due to their maturity level. Thus, the value of geochemical characteristics (especially TOC, HI, Tmax) from the current study can be used as a benchmark for evaluating coaly source rocks in other parts of the basins or Western Indonesia.

Further interpretation of vitrinite reflectance (Ro), organic petrography, and plotting in various charts such as Tmax vs. Ro, Tmax vs. HI, and Tmax vs. Bitumen Index are required to conclude in a more valid determination of the samples' feasibility limits in producing hydrocarbon.

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