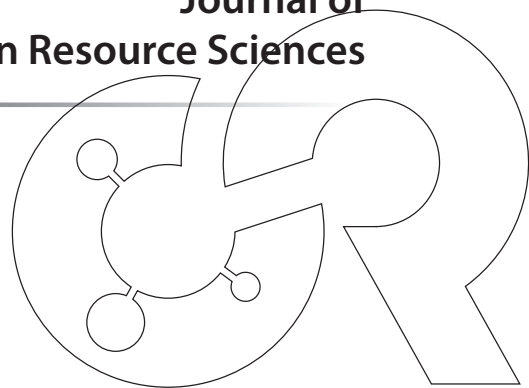

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Source-rock Potential of the Middle to Late Miocene Turbidite in Majalengka Sub-basin, West Java Indonesia: Related to Magmatism and Tectonism

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Majalengka sub-basin is located at the middle part of West Java. This basin, regionally, is part of Bogor trough, a back-arc basin. The basin is sedimentary basin formed during the early Tertiary. Getting into the middle to late Miocene, sedimentation in this basin was dominated by a turbidite derived from multiple-source, Northwest Java basin in the north and the South Mountain in the south. The occurrence of organic matter in this basin is estimated from the north sedimentation source. Based on rock-eval pyrolysis and vitrinite reflectance methods shows that the hydrocarbon source potential is dominated by immature to mature and gas prone type III kerogen. This kerogen type is mainly composed as a product from terrestrial material deposited into deltaic to shallow marine. Preservation of organic material in turbidite is interpreted as results from resedimentation or sedimentation transportation through the channel systems. In addition, magmatism and tectonism is the main parameter to generate organic matter become hydrocarbon.

1. Introduction

Related to the increase on the oil-exploration in Indonesia for decades, especially within the new hydrocarbon basin, the depression zone in the middle part of Java's island has been enhanced. The study area, the Majalengka sub-basin, is located in the western part of this zone. This basin is bounded by two main the geologic province, the Northwest Java basin in the north as a prolific basin for hydrocarbon resources in Indonesia and the Southern Mountain in the south as a remnant magmatic-belt in West Java.

Furthermore, this basin was filled by approximately more than the 4 km thick of turbidite, which was deposited during the middle to late Miocene. During this time the magmatic accompanied to tectonic evolved very active. According to K-Ar ages of the magmatic rocks in Java during the Tertiary, divided the volcanic activity into two stages¹⁾. The first stages belong to 40–18 Ma (Eocene-Oligocene to the early Miocene), while the second stage 12–2 Ma (the middle Miocene to the lower Pliocene). The break-magmatism during 18–12 Ma (the early to middle Miocene) occurred. Meanwhile, the other researcher mentioned that the tectonic events in West Java tend to increase toward the late Tertiary²⁾.

The geologic events, magmatism and tectonics, are two main parameters to be noted of the oil-exploration strategy. Moreover, the preservation of organic matter to generate the hydrocarbon source-rock within turbidite is considered insignificant. However, several researchers have reported that the oil-seeps have been found widely as long as the sedimentary rocks²⁻³⁾. As well as, the first well-exploration in Indonesia drilled by two Dutch in 1871 is located at the eastern part in this area and

considered the first oil-exploration in Indonesia. That indicates that the hydrocarbon-generation in this sub-basin has occurred.

The source-rocks evaluation in an area against the geologic effect is required in the oil-exploration. The purpose of this study is to provide original of source-rock determination and sandstone composition for assessing the effects of magmatism and tectonics, from the turbidite in the Majalengka sub-basin. The sedimentary rocks focused on the age interval during the middle to late Miocene, especially during the second stage magmatic arc events¹⁾. Finally, this study will provide implications for hydrocarbon exploration in Majalengka sub-basin.

2. Geological framework

The study area is located in Majalengka, West Java as shown in Fig. 1. The Majalengka sub-basin formed as an asymmetric basin, the deepest side is close to the south. Recently, this basin extends from Cimanuk River in the west to Kuningan in the east, near the flank of Ciremai Mountain covering about 715 km². Many researchers have studied the geology of Majalengka sub-basin and its adjacent areas since the first half of the 20th century³⁻⁷⁾. Some of study results were concluded and well documented²⁾. The database, based on outcrop data, exhibited good exposure in the entire basin area.

Lithologic units in Majalengka sub-basin could be divided into six units i.e. Cisaar, Cinambo, Cantayan (Halang and Bantarujeg Formations), Subang, Kaliwangu and Citalang Formations. Quaternary volcanic rocks and lahar entirely cover the sedimentary rocks. Physical properties of the rock indicate the paleoenvironment of basin is dominated by marine environment, from shallow

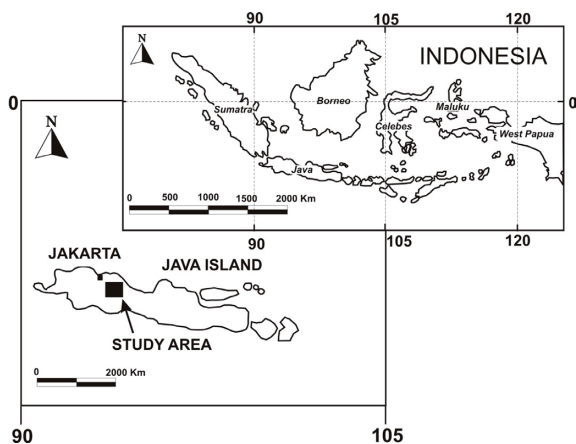


Fig. 1 Study area is located at Majalengka, West Java, Indonesia.

to deep marine. Provenance studies indicate that the source sediment is derived from multi-source sediments, from the north and south⁷.

3. Methodology

Rock-Eval analysis and vitrinite reflectance (VR) were methods used in the evaluation of hydrocarbon potential in this study. Forty-five source rock samples consist of shale and claystone, were analyzed at the Geochemical Laboratory at the Institute of Technology, Bandung, Indonesia. The shale samples were characterized by their dark color and high carbonaceous content. Meanwhile, the claystone is indicated by black to dark-grey in color, occasionally is found coal fragments.

Therefore, most samples were collected on the basis of the field investigation of turbidite. Basically, this sedimentary rock according to Mutti and Ricci Lucchi facies's classification could be divided into two parts, lower and upper parts⁸.

This lithofacies is widely distributed in the middle part of the study area and according to this classification; it could be classified into Facies E (Fig. 2). This facies nomenclature is used for submarine fan environment and associated turbidite facies⁹. This analysis was done to make a fundamental understanding of the hydrocarbon source rock potential, which is divided by three critical factors:

1. Source rock generative potential to decide the quantity of kerogen (Total Organic Carbon and S₂ values).
2. Type of organic matter to determine the hydrocarbon type, oil or gas types.
3. Level of thermal maturation (Vitrinite reflectance and T_{max} values) to determine the maturation level.

This analysis was conducted by using DELSI-Nermag Rock Eval II-Plus TOC machine and performed in three stages. The first stage, the 100 mg of sample was heated in the oven until 300 °C during three minutes. This heating process was conducted within the inert-Helium condition. In this stage was resulted in the

S₁ discharged of hydrocarbon-free, or normally was called as an evaporation stage. Entering second stage, the temperature was increased from 300 °C until 550 °C during ten minutes. The cracking stage of organic material was begun, which as results of the heavy-hydrocarbon (C₄₀) evaporation. After the temperature peak achieved, the kerogen maturation has begun and was considered as a S₂ peak, or normally called as a T_{max} value. The last stage is the CO₂ released in cooling down pyrolysis, where the temperature decreases from 390 °C to 300 °C and the S₃ released.

Moreover, thirty-four of sandstone samples were collected from the field for geochemical analysis in laboratory. X-ray fluorescence (XRF) analysis of the major and trace element was conducted at Economic Geology laboratory, Kyushu University, Japan. Bulk chemical composition of sedimentary rock was analyzed using a Rigaku RIX 3100 X-ray (50 kv 80 mA) Fluorescence (XRF) machine. Pressed-powder pellets, which 10 mm diameter to determine of sediment composition, were prepared. Loss on ignition (LOI) was determined by evaporating the H₂O content at 105 °C for 1.5 hours and then followed by heating to reach 500 °C during half hours and 950 °C for 1 hour. The LOI value, the percentage loss in sample weight less the H₂O less, was calculated.

Both samples were collected at same location, but in different interval of stratigraphic sequence of turbidite.

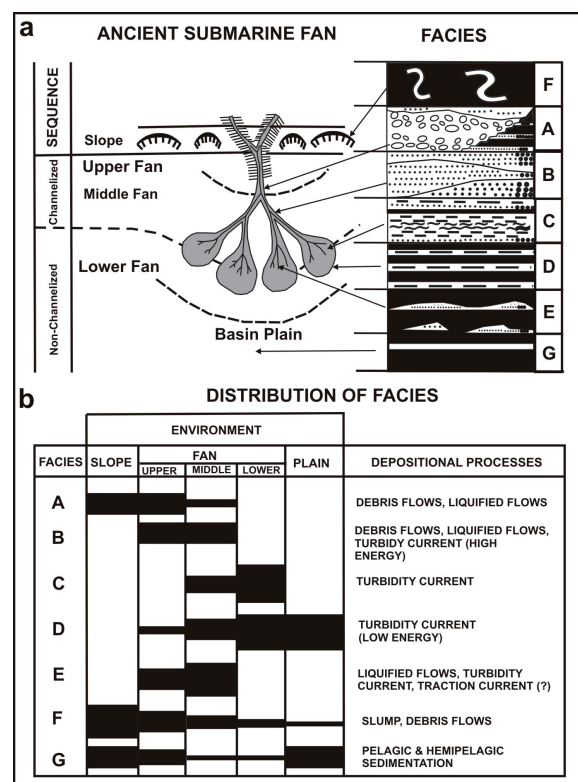


Fig. 2 Submarine fan environment and associated turbidite facies⁹ and facies nomenclature⁸.

4. Results

4.1 Characteristics of source rocks

The presence of organic matter as a component of sedimentary rock indicates the possibility of hydrocarbon occurrence even if it is present in very low concentration. Three parameters are used to determinate and evaluate organic matter in this study i.e. source generative

potential, organic matter type, and level of organic maturation, by use of total organic carbon content (TOC) and Rock-Eval pyrolysis including vitrinite reflectance (VR) analyses.

Source samples are taken from two interval layers *i.e.* Cisaar-shale and lower Cinambo Formation. The results of analysis were summarized in Table 1.

Table 1 Results of Rock-Eval pyrolysis and Vitrinite reflectance.

No	ID	Latitude	Longitude	Lithology	Rock eval Pyrolysis			S1+S2 (PY)	S2/S3	PI	HI	OI	Thermal M		Tmaks	
					TOC	S1	S2						VR	SCI		
1	CMK 23	108.21	-6.90	SHALE	0.56	0.03	0.47	-	0.50	-	0.04	88.00	-	0.44	3.30	433
2	CNB 123	108.21	-6.90	SHALE	0.77	0.06	0.58	-	0.64	-	0.08	80.00	-	0.46	5.62	442
3	CNB 124	108.21	-6.91	SHALE	0.41	0.01	0.29	-	0.30	-	0.03	77.00	-	0.47	-	429
4	CNB 125	108.21	-6.92	SHALE	0.97	0.06	1.05	-	1.11	-	0.05	110.00	-	0.45	-	437
5	CNB 126	108.21	-6.92	SHALE	0.63	0.04	0.56	-	0.60	-	0.07	95.00	-	0.40	3.40	430
6	CNB 127	108.22	-6.91	SHALE	0.70	0.02	0.60	-	0.62	-	0.03	88.00	-	0.50	4.60	439
7	CSR 314	108.22	-6.91	SHALE	1.60	0.03	1.71	-	1.74	-	0.16	112.00	-	0.72	6.76	460
8	CSR 303	108.23	-6.92	SHALE	0.34	0.02	0.16	-	0.18	-	0.13	50.00	-	0.59	-	432
9	CSR 306	108.21	-6.90	SHALE	0.51	0.03	0.26	-	0.29	-	0.10	55.00	-	0.55	5.60	444
10	CSR 321	108.21	-6.90	SHALE	0.66	0.02	0.63	-	0.65	-	0.19	100.00	-	0.56	-	-
11	CSR 333	108.22	-6.91	SHALE	1.15	0.01	0.42	-	0.43	-	0.26	40.00	-	0.55	-	-
12	CSR 336	108.21	-6.91	SHALE	0.46	0.00	0.00	-	-	-	-	-	-	0.54	-	-
13	CSR 335	108.21	-6.90	SHALE	0.30	0.00	0.00	-	-	-	-	-	-	0.58	-	-
14	CLT 45	108.21	-6.90	CLAYSTONE	0.71	0.00	0.00	-	-	-	-	-	-	0.90	-	-
15	CLT 36	108.21	-6.90	CLAYSTONE	1.15	0.23	1.20	-	1.43	-	0.20	85.00	-	1.06	7.90	472
16	CLT 19	108.21	-6.90	SHALE	0.70	0.00	0.00	-	-	-	-	-	-	0.68	-	-
17	CLT 20	108.24	-6.90	SHALE	0.71	0.00	0.00	-	-	-	-	-	-	0.69	-	-
18	CLT 38	108.23	-6.92	CLAYSTONE	1.22	0.19	1.17	-	1.36	-	0.18	84.00	-	0.98	6.98	470
19	CSL 201	108.23	-6.92	SHALE	0.66	0.00	0.00	-	-	-	-	-	-	0.97	-	-
20	CSL 209	108.24	-6.92	SHALE	0.80	0.00	0.00	-	-	-	-	-	-	0.89	-	-
21	CMT 12	108.24	-6.92	SHALE	1.37	0.50	1.23	-	1.73	-	0.28	90.00	-	1.09	-	480
22	CMT 7	108.24	-6.91	SHALE	1.39	0.40	1.29	-	1.69	-	0.23	95.00	-	1.00	-	482
23	CMT 8	108.24	-6.91	SHALE	1.43	0.46	1.30	-	1.76	-	0.25	95.00	-	0.92	6.76	481
24	CMT 9	108.24	-6.91	SHALE	1.41	0.05	1.33	-	1.38	-	0.25	100.00	-	1.08	7.28	481
25	CMT 13	108.23	-6.90	SHALE	1.32	0.46	1.19	-	1.65	-	0.29	95.00	-	1.13	6.81	486
26	CLT 18	108.21	-6.90	SHALE	0.71	0.00	0.00	-	-	-	-	-	-	0.89	-	-
27	BTM 23	108.21	-6.91	CLAYSTONE	1.49	0.29	1.66	-	1.95	-	0.16	97.00	-	0.79	6.09	460
28	CMT 1	108.14	-6.88	CLAYSTONE	0.57	0.14	0.82	0.10	0.96	8.20	-	144.49	17.62	0.49	-	435
29	CMT 2	108.11	-6.88	CLAYSTONE	0.45	0.11	0.48	0.12	0.59	4.00	-	105.77	26.44	0.66	-	432
30	CMT 3	108.12	-6.90	CLAYSTONE	0.47	0.08	0.00	0.76	0.08	-	-	0.00	163.0	0.59	-	458
31	CMT 4	108.11	-6.92	CLAYSTONE	0.55	0.03	0.00	0.68	0.03	-	-	-	124.7	0.65	-	-
32	CMT 5	108.23	-6.91	CLAYSTONE	0.60	0.06	0.00	0.35	0.06	-	-	-	58.57	0.66	-	-
33	CMT 6	108.23	-6.92	CLAYSTONE	0.53	0.07	0.00	0.32	0.07	-	-	-	60.43	0.61	-	-
34	CSR 203	108.22	-6.93	CLAYSTONE	0.50	0.17	0.34	0.08	0.51	4.25	-	68.44	16.10	0.75	-	458
35	CSR 205	108.25	-6.96	CLAYSTONE	0.23	0.05	0.15	0.03	0.20	5.00	-	66.37	13.27	0.64	-	438
36	CSR 206	108.10	-6.87	CLAYSTONE	0.40	0.09	0.12	0.30	0.21	0.40	-	29.89	74.72	0.51	-	424
37	CSR 209	108.11	-6.92	CLAYSTONE	0.19	0.04	0.09	0.07	0.13	1.29	-	47.37	36.84	0.60	-	439
38	CSR 313	108.10	-6.91	CLAYSTONE	0.18	0.04	0.05	0.03	0.09	1.67	-	28.46	17.07	0.66	-	435
39	BTM 30	108.10	-6.93	CLAYSTONE	0.67	0.04	0.47	0.28	0.51	1.68	-	70.03	41.72	0.62	-	424
40	BTR 34	108.18	-6.90	CLAYSTONE	0.68	0.07	0.35	0.24	0.42	1.46	-	51.18	35.09	0.63	-	421
41	BTR 43	108.20	-6.91	CLAYSTONE	0.51	0.03	0.23	0.25	0.26	0.92	-	45.21	49.14	0.57	-	422
42	BTR 44	108.19	-6.91	CLAYSTONE	0.62	0.05	0.34	0.14	0.39	2.43	-	54.70	22.52	0.69	-	422
43	CHM 48	108.18	-6.87	CLAYSTONE	0.51	0.04	0.24	0.35	0.28	0.69	-	46.62	67.99	0.69	-	428
44	CHM 52	108.22	-6.91	CLAYSTONE	0.44	0.04	0.15	0.16	0.19	0.94	-	33.76	36.01	0.59	-	431
45	CHM 57	108.18	-6.91	CLAYSTONE	0.57	0.07	0.29	0.29	0.36	1.00	-	63.14	63.14	0.69	-	423

Nomenclature : S1(Volatile hydrocarbons) = mg HC/g rock; S2 (Hydrocarbon derived from kerogen pyrolysis) = mg HC/g rock; S3 (CO₂ derived from kerogen pyrolysis) = mg CO₂/g rock; PI = S1/(S1+S2); HI = mg HC/gTOC; OI = mgCO₂/gr TOC; VR = Ro(%), Vitrinite Reflectance = Ro; SCI = Spore Color Index (Thermal Alteration, or TAI = Thermal Alteration Index, a measure of kerogen maturity obtained by observing the color of bisaccate pollen grains in transmitted light under a microscope; Tmax = °C.

4.2 Source rock generative potential

The results of analysis show the TOC values vary from 0.18 wt% to 1.6 wt% with an average of approximately 0.73 wt%. The minimum acceptable TOC value for potential source rock is 0.5 wt%, less than this value is considered to be insignificant for hydrocarbon source rock potential¹⁰. The marginal value of the hydrocarbon source rock potential is around 0.5 wt% and 1.0 wt%, whereas more than 1.0 wt% reflects substantial source potential. Meanwhile, a TOC value above 2.0 wt% indicates excellent source potential. Thus, the analysis results indicate that all samples belong to a marginal value of the source rock.

Quantity variation of analyzed TOC values is such that 22.2% for poor quantity (0-0.5 wt%), 55.6% for fair quantity (0.5-1.0 wt%), and 22.2% for good quantity (1.0-2.0 wt%). None of the samples belong to very good quantity. The good quantity samples were taken from the western-part of Cimaningtin village, which is concentrated in an isolated depression zone (Fig. 3a).

In source rock evaluation, the TOC content does not focus on the amount of organic matter even though it is necessary. For example, one region with high TOC content occasionally exhibited slight oil-source potential, attributed to the dependence of kerogen type. Woody-rich or highly oxidized organic matter can be a poor-source for oil-generation.

Nevertheless, the TOC content can be used as a screening method for determining the potential areas for next-step exploration.

Furthermore, the second parameter is S1 and S2, which indicates the differences in peak temperature during analysis (Fig. 3b).

S1 indicates the first-peak at a pyrolysis temperature up to about 300 °C while the zone below this temperature is related to the amount of free hydrocarbon in rock (mg HC/gram rock), the soluble organic matter of the source

rock. Meanwhile, S2 is the second peak and shows the amount of hydrocarbon formed by the breakdown of kerogen (mg HC/gram rock) or the amount of hydrogen-rich source rock. This value also presents information about T_{max} , a maximum temperature reached in analysis. This temperature value (T_{max}) can be used as an indicator for maturity level, which is higher than hydrocarbon generation in nature.

The temperature in the natural environment for hydrocarbon generation is 80-165 °C for oil-generation and 145-220 °C for gas-generation¹¹. An increase in the temperature of this basin is probably derived from magmatic activity, related with the increase in stratigraphic intervals¹². Magmatism in West Java during the middle to late Miocene was an important event, which influenced the organic matter occurrence.

Results of analysis show the average value of S1 is very low, only 6.67% close to fair quantity. The value is around 0 to 0.5 mg HC/g rock, and the average is 0.09 mg HC/g rock. The other parameter S2 shows similar result where all of samples fall below 2.5 mg HC/g rock, and 77.78% of them below 1mg HC/g rock. The average value is 0.47 mg HC/g rock, whereas the range value is 0 to 1.71 mg HC/g rock. Both of the parameters belong to poor quantity and also for almost 22.22% sample. The S2 value is lower indicating that organic matter is not enough for hydrocarbon formation. Because of most of samples was taken from the outcrops (Fig. 3).

4.3 Type of organic matter

To determine a type of organic matter, two parameters are used: the diagram of Hydrogen Index (HI) and S2/S3 ratio. The HI is calculated as:

$$HI = \frac{S2}{TOC} \times 100 \quad (1)$$

that represents the total amount of hydrocarbon

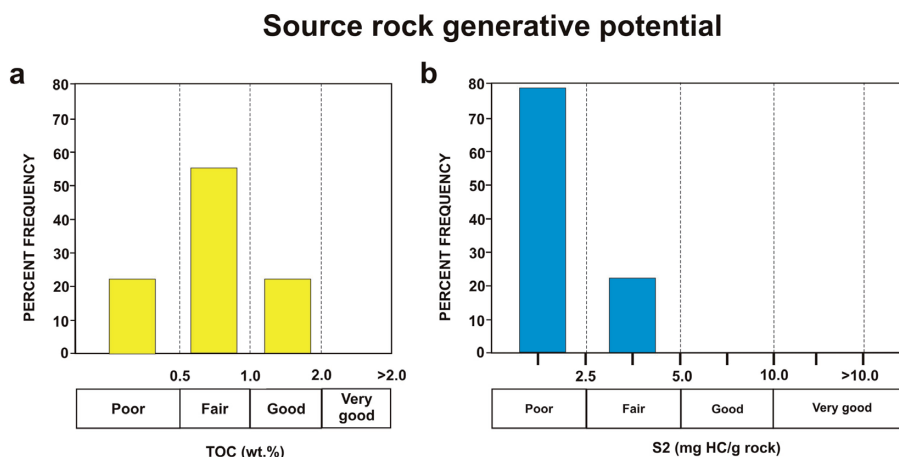


Fig. 3 (a) Summary of TOC for all samples distribution in Majalengka sub-basin. (b) Pyrolysis S2 yields, approximately 75% of samples fall in the poor category. (n = 45 samples belong to shale and claystone)

independently, which is closely related to the elemental composition in kerogen. Meanwhile, the S2/S3 ratio demonstrates the kerogen type related to the production of hydrocarbon gas-generation.

The values of samples show that the type of hydrocarbon-generated is gas whereas most samples are below 150. Slight differences in results are produced by the S2/S3 ratio whereas only 71.43% of samples can be generated as gas, 23.08% mix and 7.14% as oil-prone.

Another parameter is Oxygen Index (OI), is given as,

$$OI = \frac{S3}{TOC} \times 100 \quad (2)$$

It indicates the amount of CO₂ produced from kerogen during Rock-Eval pyrolysis. OI is represented as mg CO₂/g TOC and is supposed to be related to the oxygen content of the kerogen¹³. Meanwhile, S3 is the third-peak in analysis which is expressed as mg CO₂/gram rock¹⁴. Correlation between HI and OI ratio, represented by the modification of van Krevelan, is used to describe the correlation between maturation stages and kerogen type¹⁴⁻¹⁵.

Using the van Krevelan diagram most samples are plotted on the region of kerogen type III as an indication that the hydrogen content is of sufficient quantity to generate gas-prone but is not enough to be oil-prone (Fig. 4).

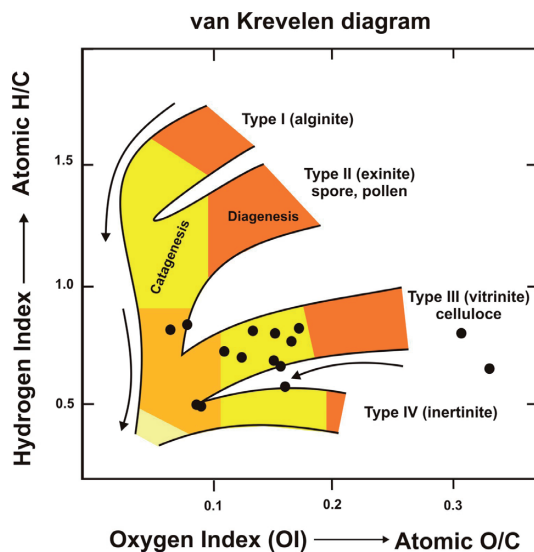


Fig. 4 van Krevelen diagram Oxygen Index (OI) against Hydrogen Index (HI), showing the hydrogen generative type, and most samples plot in the Type III (gas prone).

The kerogen type III is dominated by vitrinite, formed commonly from land plant wood, and produced on a coal-forming environment at the transition zone such as paralic swamps and abandoned river channels. This type is normally deposited in a deltaic to shallow marine environment. The occurrences of shallow marine detritus in a deep marine deposit are due to re-sedimentation of previous sediment through to channelized systems.

Furthermore, based on these diagrams they can be grouped into four sample population categories (1) 64.44% belong to very low OI and high HI, (2) 15.56% to low OI and low HI, (3) 8.89% to high OI and very low HI, and (4) 11.11% to high OI and low HI. Groups 1 and 2 indicate that the organic matter source is land-derived and dominated by erosion material from mature source rock. Meanwhile, groups 3 and 4 are representing as gas-prone organic matter, which generally forms as an immature-source. Finally, the three parameters above have a good tendency in to generate as a gas-prone. The type of kerogen is mainly vitrinite (51.85%), in while 40.74% consists of Alginite, Amorphous, and Exinite. Around 7.41% of samples belong to Inertinite¹⁰. Furthermore, the higher concentrations of gas-prone vitrinite are around 70.37% from all samples, some of them showed good quality. Approximately 18.52% the kerogen is generated to oil, which is dominated by Alginite, Amorphous and Exinite types. Meanwhile, 7.41% samples become wet-gas, and only one sample (3.70%), which was taken from Cisaar (crs 333), was barren (Fig. 5).

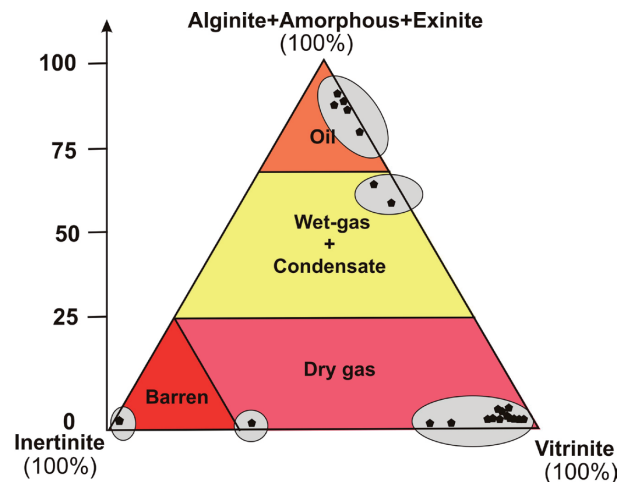


Fig. 5 Samples distribution of visual kerogen analyses and most samples fall in dry-gas, almost up to 70%¹⁰.

4.4 Level of thermal maturation

The organic maturation can generate to be oil and gas depending on kerogen type of the source rocks^{10,15}. To determine the organic maturation in sample three parameters are used *i.e.* T_{max} (°C), vitrinite reflectance (VR) and production index (PI). For example, T_{max} (°C) is believed to be a good maturation index for kerogen type II and type III, but not recommended for kerogen type I¹³. It is caused by the range T_{max} (°C) variation in kerogen type I is narrower than kerogen type II and type III. The T_{max} (°C) value of the oil threshold (for types II and III range in between 430 to 435 °C) is lower than the gas threshold (type II approximately 430 to 455 °C, whereas type III is 465 to 470 °C). In the present study, the samples value of the T_{max} (°C) range in between 421

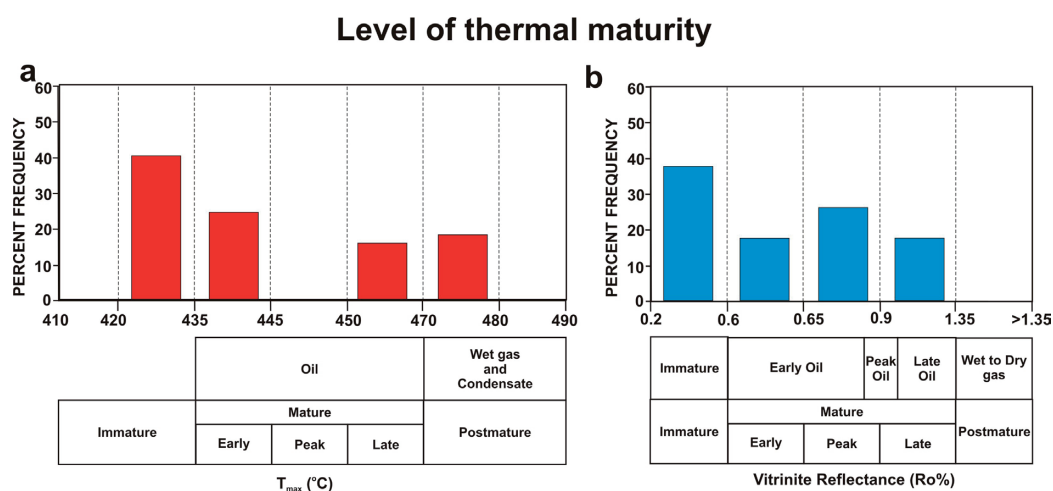


Fig. 6 (a) T_{max}, for overall samples in Majalengka sub-basin and (b) Distribution of Vitrinite Reflectance, and maturation scale¹⁶. (n = 45 samples belongs to shale and claystone)

to 486 °C indicating that mixing oil to gas generation has occurred (Fig. 6a).

The production index (PI) represented by the third equation is a second parameter for estimating the level of maturation of organic matter. The third equation is

$$PI = \frac{S1}{(S1+S2)} \quad (3).$$

The threshold for oil production is around 0.1 and continues to 0.4, where the gas threshold is produced. Most of the sample results are in the range 0.03 to 0.29 indicating they belong to the top of the oil window. A good correlation is shown with relationships between PI and vitrinite reflectance (VR) (Fig. 6b).

To denote the temperature maturation in organic content, vitrinite is used as maceral type in coal. Maceral is analogous with minerals in the rock. Vitrinite is a type of kerogen particle formed from humic gels thought to be derived from the lignin-cellulosa cell walls of higher plants¹⁷. Vitrinite is a common component of coals, and the reflectance of vitrinite particles was first observed to increase with increasing time and temperature in a predictable manner in coals¹⁸. Related with deep marine environment (Majalengka sub-basin), the occurrence of vitrinite in most organic matter is interpreted as a resedimentation process, or sedimentation through the channel system.

Paleobathymetry data, a transition zone between shallow marine and deep marine (bathyal zone), which combine with isopach maps indicate that the Majalengka sub-basin is an asymmetric basin in deep marine environment systems⁷.

Most of the samples collected from the shale part of turbidites yield vitrinite reflectance values between 0.40 and 1.13%, with a mean value of 0.69%. Thus based on the assessment of organic matter adapted from^{10,19}, the

all samples lie between the top and bottom of oil window on catagenetic stages (Table 2).

4.5 Geochemistry of sandstone

Related with magmatic arc provenance source has proposed the use of the ratio between (Al₂O₃ / SiO₂) vs (FeO + MgO) / (SiO₂ + K₂O + Na₂O)²⁰. The Al₂O₃ / SiO₂ ratio corresponds with comparison between feldspar to quartz as a representation of maturity level of the rocks. Meanwhile, (FeO + MgO) / (SiO₂ + K₂O + Na₂O) ratio shows a basicity index or B.I index, whereas the FeO + MgO represented mafic rocks and SiO₂ + K₂O + Na₂O represents felsic rocks (Fig. 7). The general evolution of the magmatic arc occurred from oceanic island arc (immature island arc) to continental island arc (mature magmatic arc).

According to the results of the field investigation, the samples could be divided into two parts, lower and upper parts of turbidite. Furthermore, on Fig. 7, the samples are distributed into two populations. In the lower part plotted in two fields (1) oceanic island arc, and (2) continental island arc, whereas in the upper part all samples were concentrated on oceanic island arc. This is the case indicating the iteration of subduction process occurred and related to magmatism.

5. Discussion

The result of analysis demonstrates the highest organic matter value according to total organic carbon, S2, T_{max} and vitrinite reflectance parameters is concentrated on a restricted area. Despite, mostly the analysis result indicates the poor value. It is due to the organic matter contained in turbidite influenced by the high content of matrix and volcanic fragment^{7, 21}. This local area is located in the centre part of the study area or the western part of Cimaningtin village. Moreover, the limited space for sedimentation accommodation accompanied by tectonic activity is the other aspect that the organic

Table 2 Application of Rock-Eval pyrolysis, TOC and Vitrinite reflectance.

Application	Parameters			
	Quantity	TOC (wt.%)	S1	S2
Source rock generation potential	Poor	0.0 - 0.5	0.0 - 0.5	0.0 - 2.5
	Fair	0.5 - 1.0	0.5 - 1.0	2.5 - 5.0
	Good	1.0 - 2.0	1.0 - 2.0	5.0 - 10.0
	Very good	> 2.0	> 2.0	> 10.0
	Type	HI	S2/S3 (Kerogen Type)	
Type of hydrocarbon generated	Gas	0 - 150	0 - 3	
	Gas + Oil	150 - 300	3 - 5	
	Oil	> 300	>5	
	Maturation	PI	Tmax (°C)	Ro (%)
Level of thermal maturation	Top of oil window	0.1	430-445 (430-435)	0.5*
	Bottom of oil window	0.4	470 (450-455)	1.35* (1.1)

Nomenclature : S1 = mg HC/g rock; S2 = mg HC/g rock; S3 = mg HC/g rock; HI = mg HC/g Corg; PI = S1/(S1+S2). Assumes level of thermal maturation equivalent to Ro = 0.6%.

± Values are approximate. Many parameters (particularly Tmax) are dependent on the type of organic matter. Values in parenthese are for Type II kerogen.

* Result of the analysis yield vitrinite reflectance values between 0.40 and 1.13 % with a mean value of 0.69%.

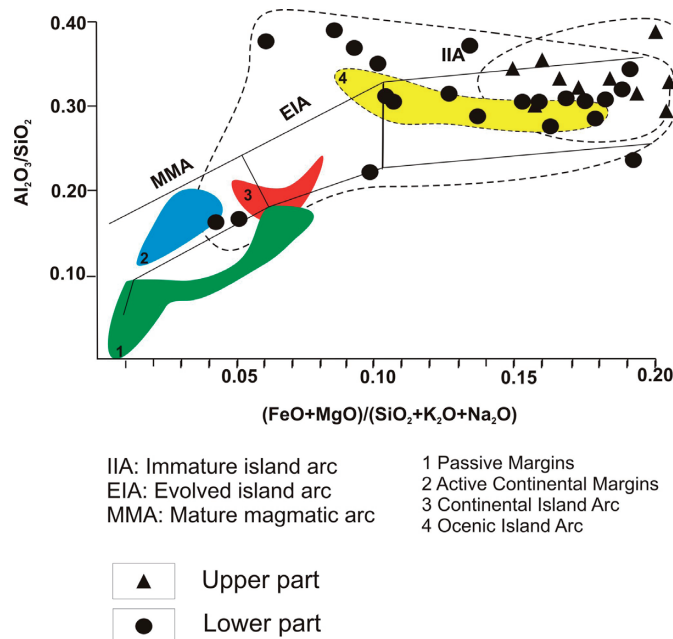


Fig. 7 Sample distribution of sedimentary rock related with magmatic arc provenance²⁰.

preservation is difficult to occur⁶.

The organic matter is dominated by kerogen type III, a kerogen type that is commonly arranged by the accumulation of terrestrial detritus. This kerogen type gathered in a zone from transition to delta facies in the Northwest Java basin⁷. During the break magmatism in the middle Miocene accompanied by sea level drop, the material transported and resedimented into the basin deep in the southern part^{1,7,22}. The sedimentation process from the source to the basin passed through a channel system, which the main direction is northwest to south⁷.

Related to the accumulation zone of the organic matter, interpreted that this area was formed due to a paired strike-slip fault such as the pull-apart basin⁷. This basin according to isopach maps forms a depression zone asymmetrically, where the western flatter than the eastern sides⁷. The main shape of this basin forms the northwest to southwest direction or almost parallel with the Sumatra trends. In the South Sumatra basin according to the SAR-maps interpretation, interpreted the main lineament of the fault system trending in this direction²³. This trend is normally termed as the 300 degree-line and considered as a plane boundary of the basin. This basin is commonly contains the hydrocarbon such as Palembang sub-basin and Jambi sub-basin. Continued toward to the south, on the Java Island during the middle Tertiary boundary was indicated by this trend that was shown with the lineament trend in Banten-block, the west-part of West Java²⁴.

Entering the late Miocene the active magmatism occurred, which is associated with tectonics in the overall basin area¹. The deepest zone slightly moves to the south accompanied with the thrust-fault formation. Fig. 8 shows the development of the source-rock maturation from the vitrinite reflectance analysis that is influenced by the thrust-fault system. This fault is also having a role as a hydrocarbon trapping in this basin. The zero value on the ordinate line indicates the maximum surface of the sea-level rise during the late Miocene, which is determined on the basis of the fossil foraminifera analysis^{7, 22}. This geologic event is accompanied with uplifting and magmatism in the southern-part and depression in the basin³. From this figure indicate that the mature to near the post-mature value on the depression zone, the shale sample was taken from -200 to -250 meter depth. Several researchers have reported that there are interactions very closely between magmatism and maturation on hydrocarbon generation²⁵⁻²⁹. Moreover, an increase of the magmatic activity toward the late Miocene is also accompanied the sediment provenance changing, sediment source from the north is stopped and the source changed over became from the south, the Southern Mountain⁷.

Results of analysis indicate that in the Majalengka sub-basin the shale sample tends to act as a good preservation of the organic matter compared to the claystone sample.

The shale in this area is characterized by dark-color,

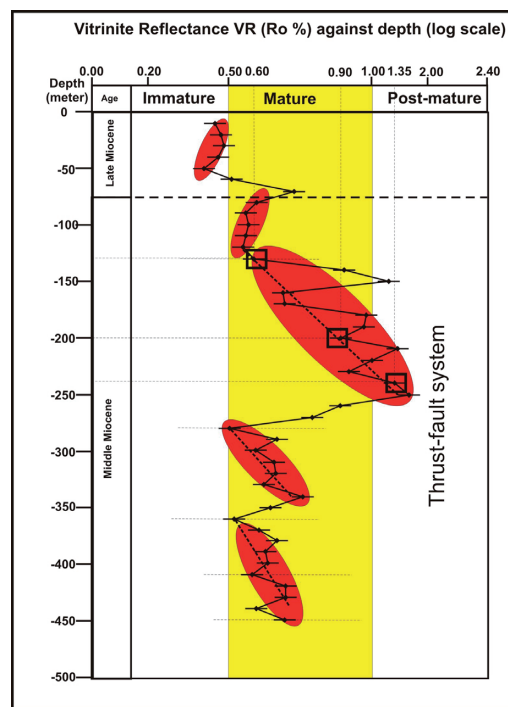


Fig. 8 Log vitrinite reflectance (VR) against to depth shows the thrust-fault systems. The samples were taken from the lower and the upper parts of the sediment turbidite. The distribution pattern of samples from bottom to top shows the thrust fault systems. It resulted from samples, shale and claystone.

fine to clay of the grain size and very high organic matter content. Meanwhile, the claystone in this area normally shows dark to grey in color and occasionally the fine sand fragment floating in mass body of the rock is found. The purity and uniformity of the grain size are considered as the main factor for organic matter accumulation.

6. Conclusion

Two geologic events which influenced on the hydrocarbon generation in Majalengka sub-basin are magmatism and tectonism. In this basin, the magmatism acts as thermal maturation during the late Miocene. Meanwhile, the tectonism have role as the accumulation place and trapping mechanism for hydrocarbon generation. Both the events have been increasing the source rock potential in the limited area. For the next exploration stage, the oil-investigation in the Majalengka sub-basin could be concentrated in this area.

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References

- 1) R. Soeria-Atmadja, R. Maury, R. C. Bellon, H. Pringgoprawiro, H. Polvé, B. Priadi, *Jour. of Southeast Asian Earth Sciences*, **9** (½), 3 (1994).
- 2) S. Martodjojo, Ph.D. Thesis, Bandung Institute of Technology, Bandung, Indonesia (1984).
- 3) R. W. van Bemmelen, *The Geology of Indonesia*, 1st A ed., Martinus Nijhoff The Hague, Netherlands (1949).
- 4) Djuri, *Geology map of Arjawinangun sheets*, 10/XIII-D, 1 (1995).
- 5) Djuhaeni and S. Martodjojo, *Geologi Indonesia*, **12**(1), 227 (1989).
- 6) A. W. Satyana and C. Armandita, *Indonesian Petroleum Association*, **2**, 293 (2004).
- 7) B. Muljana, Master Thesis, Bandung Institute of Technology, Bandung, Indonesia (2006).
- 8) E. Mutti and F. Ricci-Lucci, *Field Trip Guidebook A-11: International Sediment Congress*, **IX**, 21 (1975).
- 9) G. Shanmugam and R. J. Moiola, in *Submarine fans and related turbidite systems*, eds. by A. H. Bouma, W. R. Normark and N. E. Barnes, Springer-Verlag, New York, p.29 (1985).
- 10) B. P. Tissot and D. H. Welte, *Petroleum Formation and Occurrence*, 2nd ed., Springer, Berlin (1984).
- 11) C. Conford, *Encyclopedia of Geology*, 1st ed., Elsevier, Oxford, p. 268 (2005).
- 12) G. L. Fletcher and K. W. Bay, *Proceeding of Indonesian Petroleum Association, the 4th Annual Convention*, **2**, 211 (1975).
- 13) B. P. Tissot, R. Pelet and Ph. Ungerer, *Am. Assoc. Pet. Geol. Bull.*, **71**, 1445 (1987).
- 14) J. Espitalié, M. Madec, B. Tissot, J. J. Menning and P. Leplat, *Proceeding of the 19th Annual Offshore Technology Conference*, **3**, 439 (1977).
- 15) W. G. Dow, *Journal Geochemical Exploration*, **7**, 79 (1977).
- 16) M. L. Bordenave, *Applied Petroleum Geochemistry*, 1st ed., Editions Technip, Paris (1993).
- 17) M. Teichmüller, *International Journal of Coal Geology*, **12**, 1 (1989).
- 18) M. Teichmüller, *Textbook of Coal Petrology*, 2nd ed., Gebrüder Borntraeger, Berlin (1982).
- 19) K. E. Peters, *American Association of petroleum Geologist*, **70**, 318 (1986).
- 20) F. Kumon and K. Kiminami, *Proceedings of the 29th International Congress part. A*, p. 135, VSP BV, the Netherlands (1994).
- 21) B. Muljana, K. Watanabe and M. F. Rosana, *Proceeding of International Symposium on Earth Sciences and Technology 2011*, p. 429 (2011).
- 22) B. U. Haq, J. Hardenbol, P. R. Vail, *Science*, **235**, 1156 (1987).
- 23) A. Pulunggono, A. Haryo, S. C. G. Koesoema, *Proc. IPA. The 21st Annual Convention*, p. 339 (1992).
- 24) A. Pulunggono and S. Martodjojo, *Proceeding Geologi and Geologi Tektonik Pulau Jawa*, p. 37, Yogyakarta (1994).
- 25) Z. Chen, H. Yan, J. Li, Z. Ge, Z. Zhang, B. Liu, *AAPG Bull.*, **83**, 1004 (1999).
- 26) A. E. Kontorovich, A. V. Khomenko, L. M. Burshtein, I. I. Likhonov, A. L. Pavlov, V. S. Staroseltsev, A. A. Ten, *Petrol. Geosci.*, **3**, 359 (1997).
- 27) O. P. Polyanskii, V. V. Reverdatto, V. G. Sverdlova, *Geochem. Int.*, **40**, S69 (2002).
- 28) D. W. Waples, *Geochemistry in Petroleum Exploration: Geological Sciences Series*, International Human Resources Development Co., Boston (1985).
- 29) J. T. Sengftle and C. R. Landis, in *Source and Migration Processes and Evaluation Techniques*, ed. by R. K. Merrill, AAPG Treatise of Petroleum Geology, p.119 (1991).