Geochemistry and Potential Hydrocarbon Source Rocks of Rambatan Formation in Karangkobar Area, Central Java

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Abstract: *The purpose of the study in the Karangkobar area was to investigate the source rock potential of the fine-grained surface samples of clastic sediments. The use of surface samples for source rock potential study in Indonesia is still limited. We conducted geochemical laboratory analyses in this research, including Total Organic Carbon (TOC), Rock-Eval Pyrolysis (REP), and Gas chromatography–mass spectrometry (GCMS). Seventeen samples have been analyzed for their TOC content. The result shows that TOC values varied between 0.36–1.55%, indicating that the source rock potential level based on the surface samples is poor to fair organic richness. REP was conducted on 16 samples, and the results show that the hydrocarbon-generating characteristics (HI values) ranged from 15 to 163 mg HC/g TOC. The kerogens identified included type II and III kerogen, which indicated the oil and gas-generating potential. Pyrolysis temperature is at maximum (T_{max}) in the 276–458 °C, indicating that the samples were thermally immature to mature. GCMS analysis of source rock indicated that the depositional environment of the organic material derived from an open marine and plankton environment. This study is essential to complete the understanding of the petroleum system in Central Java.*

Keywords: *fine-grained sediment; TOC; REP; hydrocarbon; source rocks; potential; Karangkobar Central Java*

■ INTRODUCTION

Hydrocarbons are an important energy resource for the Indonesian economy. The increasingly limited discovery of oil fields in conventional areas, as has been found so far, has spurred the thought of oil exploration towards basins in the frontier region. The understanding of the frontier here is mainly intended not on the geographical aspects, but more emphasized on the geological aspects.

In the petroleum system, in addition to the cover rock (seal layer), there are two main elements associated with the presence of hydrocarbons in a basin. These two important elements are the presence of source rock and reservoir rock [1]. Source rocks are generally fine-grained rocks that are rich in organic materials, while reservoir rocks are formed from clastic (siliciclastic) and non-clastic (carbonate) rocks. Therefore, concerning the study of source rock, especially in conventional exploration, there is a tendency for more exploration activities to be carried out to determine the type of hydrocarbon traps and detailed studies of the bedrock from which the seepage originated.

Research on the characteristics and potential of hydrocarbon source rocks in Indonesia has been studied by several researchers in several locations, including in the Bogor Basin by Praptisih [1] and Jatmiko and Praptisih [2]. Studies in the Sumatra area were conducted by Zajuli and Panggabean [3-4], Syaifudin [5], and Sutriono et al. [6]. On the other hand, similar studies in the Kalimantan area were conducted by Subroto [7] and Santi and Panggabean [8], and in Timor by Permana et al. [9]. In central Java, research on source rocks and their relationship with oil seepage has been investigated by Praptisih [10], while the potential of source rocks was investigated by Winardi et al. [11]. Around the world outside Indonesia, research on the characteristics and potential of hydrocarbon source rocks has been conducted intensively, including in China [12-15], Turkey [16-17], New Zealand [18], Egypt [19], Pakistan [20] and Libya [21]. However, the characteristics and potential of source rocks in Karangkobar have never been carried out, so this is probably the first research conducted in this area.

The results of the 2004 survey by the Research Center for Geotechnology LIPI in the Banyumas and Banjarnegara areas provided information on indications of oil and gas seepage in the Miocene or younger rocks [11]. However, their study raised the question of the hydrocarbon origin. The oil seepage might have come from rocks older than Miocene (Paleogene) or Lower Miocene age. To test this hypothesis, observations and rock samples were taken in the fine-grained sediments, which have a dark color in the Rambatan Formation under the Halang Formation and Paleogene-aged sediments in the North Serayu Basin and its surroundings.

Considering the importance of the origin of oil seepage that emerged in the sedimentary basins in Central Java, especially in the North Serayu Basin, the study of the source rock was carried out in the Rambatan Formation in the Karangkobar, Central Java, and surrounding areas to find a general description of the source rock geochemical characteristics. Physiographically, the study area belongs to the North Serayu mountain range and South Serayu Mountains, occupied by Pre-Tertiary and Tertiary rocks. Fig. 1 shows the geological map of the study area. The stratigraphy of the study area has been well-reported by Amin et al. [22]. The early history of tectonic development and the depositional basin of the study area is related to the collision between the Southeast Asian Continent plate and the Indian-Australian plate in the Late Cretaceous or Early Tertiary.

Late Cretaceous - Paleocene tectonic activities caused groups of ophiolites and pelagic sediments that formed on the ocean floor to be dragged and mixed with flysch sediments to form the Luk Ulo melange complex. During the Eocene, the olistostromes deposits of the Karangsambung Formation were deposited, and during the Early Oligocene - Early Miocene, the deposits of the Totogan Formation olistostromes were deposited above the accretionary deposit zone. During the Early Miocene, there was an increase in volcanic activity and deposition of turbidite deposits in the Waturondo Formation. Starting from the Middle Miocene, tectonic activity was reduced, and the turbidite deposits of the Panosogan Formation in the South and the Rambatan Formation in the North were deposited. Early Middle Miocene - Pliocene activities began with tectonic and volcanic activities forming the Halang turbidite sediment. During the Pliocene, the Peniron Formation and the Tapak Formation were deposited. Plio-Pleistocene tectonic activities may reactivate previously formed structures and cause lifting, folding, and enlargement in the study area. Some of these deposits were covered by Pleistocene and Holocene volcanic deposits.

The Rambatan Formation in the study area generally consists of alternating sandstone and claystone. The sandstone layer is gray with calcite insertion and sedimentary structures of parallel laminated, convolute, graded, and load cast. The thickness of the layer ranged from 30–60 cm thickness. The claystone layer is dark gray with a thickness of 1–3 meters [20]. The claystone sample is interpreted as the probable source rock in the petroleum system. The Early Miocene to Middle Miocene Rambatan Formation is stratigraphically situated below the Halang Formation, where oil seeps are found in the Banjarnegara area. The Rambatan Formation that was consists of fine-grained

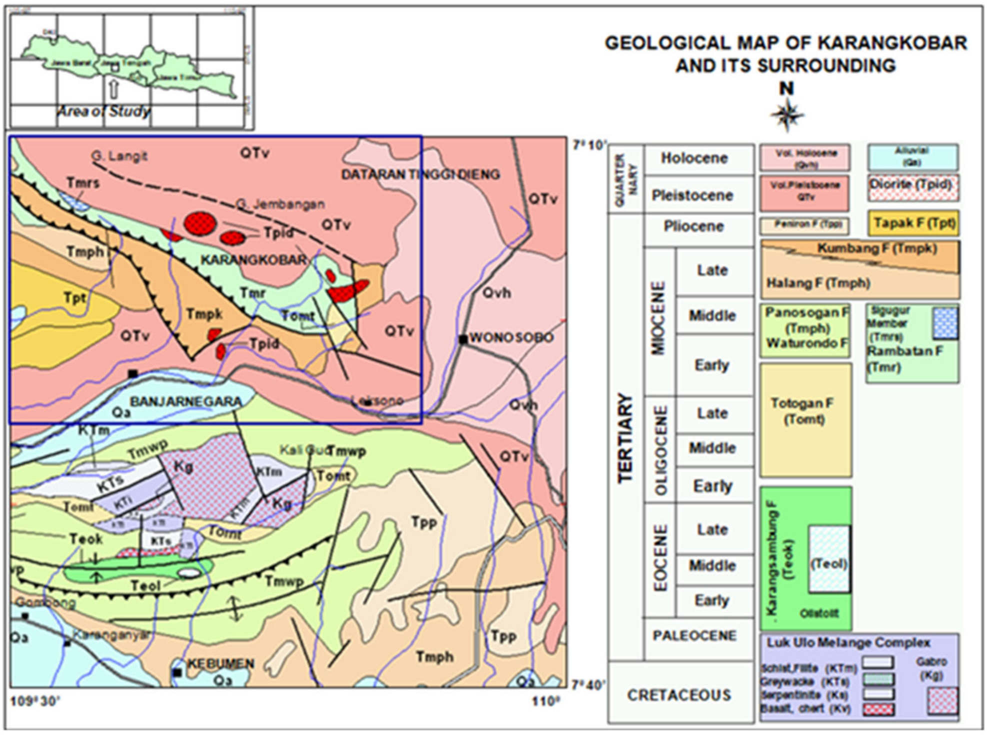


Fig 1. Geological Map of Karangkobar and surrounding area [22]

rock that meets the requirements criteria for hydrocarbon source rock. The Rambatan Formation is older than the oil seeps in the area. For this reason, this research is focused on the possibility of potential source rocks in the Karangkobar area, which is necessary for hydrocarbon exploration in the Central Java area.

EXPERIMENTAL SECTION

Location and Sampling

The research methods were carried out by fieldwork and laboratory analysis. Fieldwork was conducted in Karangkobar and surrounding areas. First, we observed the nature and characteristics of fine-grained clastic sedimentary rocks, which were hypothesized to contain organic material. In addition, the samples of the fine-grained sediments were collected during the fieldwork. Sampling in the field was conducted by taking a fresh sample on the surface by removing the weathered part of the sample. Observation of rock outcrops was performed on Rambatan Formation at selected locations. The location of observation and sampling of rocks can be seen in Fig. 2. The total number of claystone for geochemical analysis is 17 samples from Rambatan Formation were analyzed from the location of Pandaarum (PA-1), Kali Gendel (PG-02E), Kali Genteng (PG-03B), Karangmanggu (LW-01D), Jambean (LW-03B), Pesegaran (LW-05), Sirongge (LW-06), Kali Gintung (GT-01G) and Kali Keruh, Kali Desel (KK-1), Kali Urang (KU-02), Karangjati (KRJ-01), Kalibombong (SB-03), Pekacangan (KC-02), Kaliaris (KAR-07), and Kaligintung (KA-01).

Instrumentation

The main instruments used in the research were Leco WR 112 Carbon Analyzer, Rock-Eval 5, and Perkin Elmer GC-MS. TOC and Rock-Eval pyrolysis analysis were performed in Lemigas Jakarta. GC-MS analysis was performed in BSI Lab Sapta Servisindo Tangerang.

Procedure

Total organic carbon (TOC)

Total organic carbon analysis measures the organic richness of rock in weight percent organic carbon. Organic richness is the first requirement for an oil or gas source rock. The analysis was also used as a screening method to determine which samples merit more detailed analysis. The dried samples are pulverized and treated

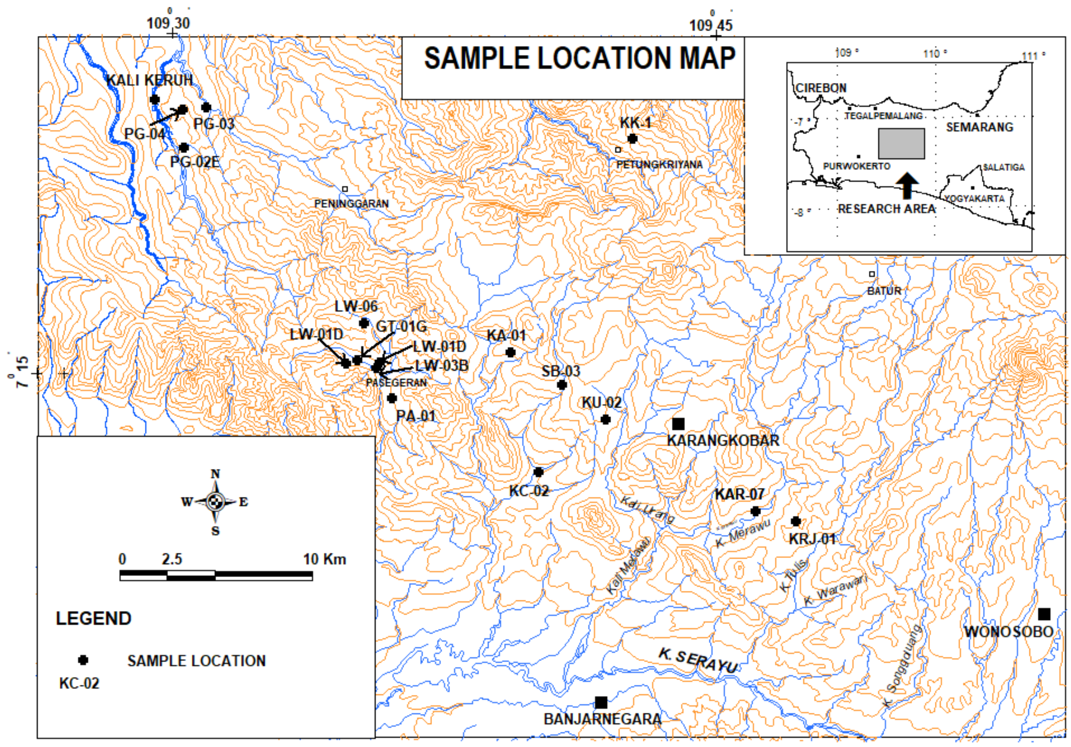


Fig 2. Location of observation and sampling of rocks in the Karangkobar area

with hot and cold hydrochloric acid to remove carbonates (inorganic carbon). After acid treatment, the organic carbon content was determined by combustion of the sample in the Leco WR 112 Carbon Analyzer. Blank, standards, and duplicates were routinely run to ensure highly reliable results.

Rock-eval pyrolysis

Rock-Eval Instrument utilized for petroleum-generative potential and thermal maturity of rocks. The Rock-Eval Instrument provides a rapid (25 min/sample) source rock analysis on a small (90–130 mg) powdered sample of rock by heating over a temperature range of 300–600 °C after an initial gas purge at 90 °C. This analysis quickly evaluates the concentration of volatile and soluble organic matter, the amount of pyrosable organic matter, and thermal maturity. The results are expressed as mg/g for the basic parameters of S1, S2, S3, and for T_{max}. The hydrogen Index (HI) is calculated from S2/TOC (mg HC/g TOC). Oxygen Index (OI) is calculated from S3/TOC (mg CO_2/g TOC). For immature rocks, bimodal S2 peaks and Production Index (PI) values over 0.2 indicate contamination. The results identify the possible source and reservoir intervals on which more detailed analyses may be performed.

Gas chromatography-mass spectrometry (GC-MS)

One of the best methods of correlating source to oil or oil to oil is by identifying the high molecular weight biological markers derived from the source material. Porphyrins, steranes, and triterpenes are particularly useful as they are relatively unaffected by weathering and loss of light ends. The combination of a gas chromatograph with a mass spectrometer as a detector provides the instrumentation to perform the resolution and detection of these molecules. A C15+ saturated hydrocarbon fraction is treated to remove the straight-chain saturated compounds, or an aromatic hydrocarbon fraction is injected onto a fused-quartz capillary chromatography column to resolve the complex mixture into individual compounds.

The compounds are then eluted into the mass spectrometer's ion source, where each compound is ionized by a stream of electrons and fragmented. The mass and relative intensities of the ions formed are detected and then recorded on a computer. The nature of the fragmentation depends on the structure of the original compound. Normally, the masses of one or two specific fragments can be used to distinguish a particular class of compounds. For example, triterpene and sterane compounds are identified from their *m/z* 191 and *m/z* 217 fragmentograms, respectively. Major peaks on the fragmentograms are identified by comparison with the parent ion mass chromatograms, published literature, and/or the use of standards. The degree of correlation between samples is determined by comparing the fragmentograms and calculated compound (peak) ratios. Fragmentograms and selected compound ratios are presented in the report.

■ RESULTS AND DISCUSSION

Geochemical Analysis

The geochemical analysis includes TOC analysis, Rock-Eval pyrolysis, and GC-MS. Pyrolysis Rock-Eval analysis was carried out for samples containing TOC > 0.5%. This value is the limit value that can produce hydrocarbons. Seventeen claystone samples were analyzed from the Rambatan Formation in the Karangkobar area. The TOC content of the Rambatan Formation samples ranged from 0.46 to 1.55%. Two samples were classified as low potential, 12 samples were classified as medium potential, and 3 samples were classified as good potential to form hydrocarbons. Rock-Eval pyrolysis analysis was conducted to determine the PI, HI, and the maximum temperature for the formation of hydrocarbons from kerogen. A total of 16 samples taken from the Rambatan Formation were analyzed. The results of the TOC analysis and Rock-Eval pyrolysis can be seen in Table 1.

The analysis result of samples from the Rambatan Formation shows that the TOC content ranged from 0.36–1.55% (Table 1). The data indicates that the claystone in the area is potentially poor to good in generating hydrocarbons according to the classification of Petter and Cassa [23].

The HI values for claystone samples from the Rambatan Formation ranged from 15–163 mg HC/TOC. Based on the facies classification by Jones [24], the samples can be grouped into three organic facies: organic D, CD, and C. Three samples were classified as organic D facies with an HI value of 15–47 mg HC/TOC.

Table 1. Results of TOC and Rock-Eval Pyrolysis Analysis in the Karangkobar and surrounding areas

No	Sample	Location	Lithology	TOC (%)	S1 mg/g	S2 Mg/g	S3 mg/g	PY mg/g	PI	T_{max} (°C)	HI	OI
1	PA-01	Pandaarum	Claystone	0.79	0.37	0.68	0.2	1.05	0.35	432	86	25
2	PG-02E	Kali gendel	Claystone	1.19	0.8	1.37	0.18	2.17	0.37	445	115	15
3	PG-03B	Kali Genteng	Claystone	0.95	0.67	0.81	0.26	1.48	0.05	443	85	27
4	PG-04	Karangmanggu	Claystone	0.97	0.56	0.93	0.16	1.49	0.38	435	96	16
5	LW-01D	Jambean	Claystone	0.78	0.32	0.63	0.13	0.95	0.34	444	81	17
6	LW-03B	Jambean	Claystone	1.55	0.82	1.78	0.14	2.60	0.32	448	115	9
7	LW-05	Pasegaran	Claystone	0.36	0.04	0	0.12	0.04	1	387	0	33
8	LW-06	Sirongge	Claystone	1.02	0.04	0	0.33	0.04	1	276	0	32
9	GT-01G	Kali Gintung	Claystone	0.76	0.37	1.24	0.18	1.61	0.23	436	163	24
10	K. Keruh	Kali Keruh	Claystone	0.91	0.29	0.14	0.14	0.43	0.67	355	15	15
11	KK-1	Kali Desel	Claystone	0.99	0.13	0.99	-	1.07	0.29	449	95	-
12	KU-02	Kali Urang	Claystone	0.63	0.08	0.22	-	0.30	0.27	431	53	-
13	KRJ-01	Karangjati	Claystone	0.68	0.02	0.32	-	0.34	0.06	434	47	-
14	SB-03	Kalibombong	Claystone	0.53	0.22	0.58	-	0.80	0.28	430	109	-
15	KC-02	Pekacangan	Claystone	0.94	0.22	0.44	-	0.66	0.33	458	47	-
16	KAR-07	Kaliaris	Claystone	0.57	0.57	0.61	-	0.68	0.10	439	107	-
17	KA-01	Kaligintung	Claystone	0.46	-	-	-	-	-	-	-	-

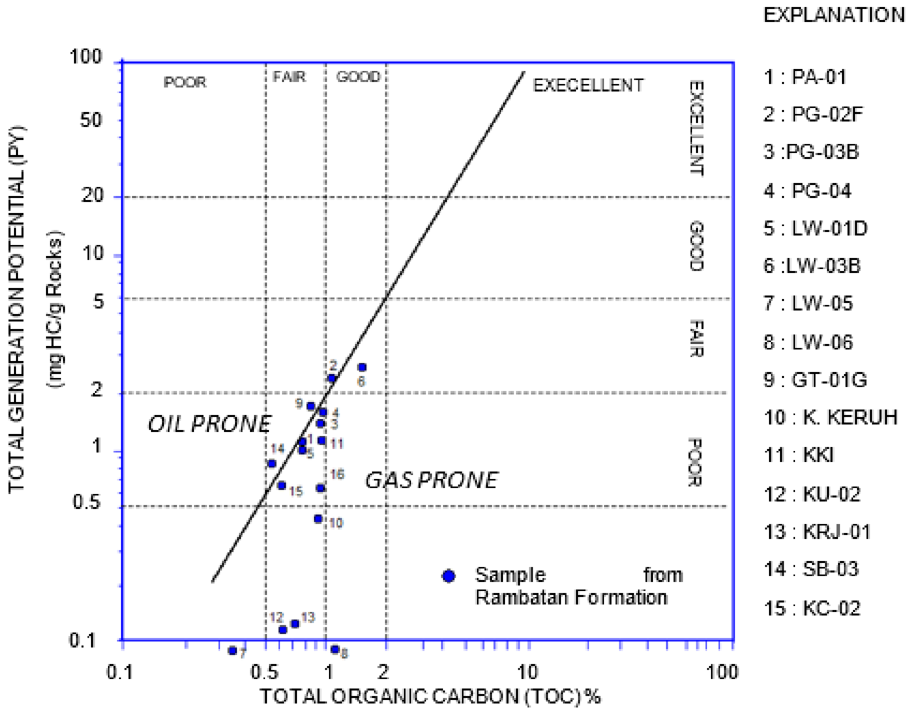


Fig 3. Diagram showing plotting Total Generation Potential Yield (PY) versus Total Organic Carbon (TOC) of The Totogan and Rambatan Formation

Ten samples were classified as organic CD facies with an HI value of 53–115 mg HC/TOC. Only one sample was classified as organic C facies with an HI value of 163 mg HC/TOC. Organic D and CD facies show the possibility of producing gas in small quantities, while organic C facies can produce oil and gas in small quantities.

Organic Richness

The TOC vs. PY diagram (Fig. 3) shows the potential for hydrocarbons in the study area, which is indicated by the richness of the organic material content [25]. Two claystone samples of the Rambatan Formation, which have TOC values of 1.19–1.55% and PY of 2.17–2.60 mg HC/g, indicate fair organic matter. While the other 14 samples contained TOC values ranging from 0.36–1.02 and PY value of 0.04–1.61, indicating the poor category [25].

Maturity Level and Organic Type

The diagram of the HI vs. T_{max} shows the type of kerogen and the study area's thermal maturity level (Fig. 4). Two claystone samples of LW-03B and GT-01G have HI values of 115–163 mg HC/TOC and are classified as type II kerogen with a T_{max} value of 436–448 °C, indicating the mature category. Meanwhile, the other 12 samples show HI values of 15–107 mg HC/TOC, including type III kerogen with a maturity level of 276–458 °C, indicating an immature-mature maturity level.

The results of this study show that the hydrocarbon source rock of the Rambatan Formation exposed in the Karangkobar area can generate oil and gas. The quality of the source rock samples of claystone from the surface of the Rambatan Formation in the study area varies. Two samples have a TOC of 0.53–1.19% and a PY of 0.80–2.17 mg HC/g are included in the category of oil-prone [25]. The other 14 samples had a TOC of 0.36–1.55% and a PY of 0.04–2.60 mg Hc/g, including the category of gas prone. Meanwhile, according to Waples [26], a total of nine samples having an HI value < 150 mg HC/TOC, classified as able to produce gas of small quantity, and 1 sample with an HI value of 163 mg HC/TOC able to produce oil and gas with small quantity.

The results of the source rock research from surface samples of the Cibulakan Formation in the Palimanan area, Cirebon [1], show types II and III. Therefore, they

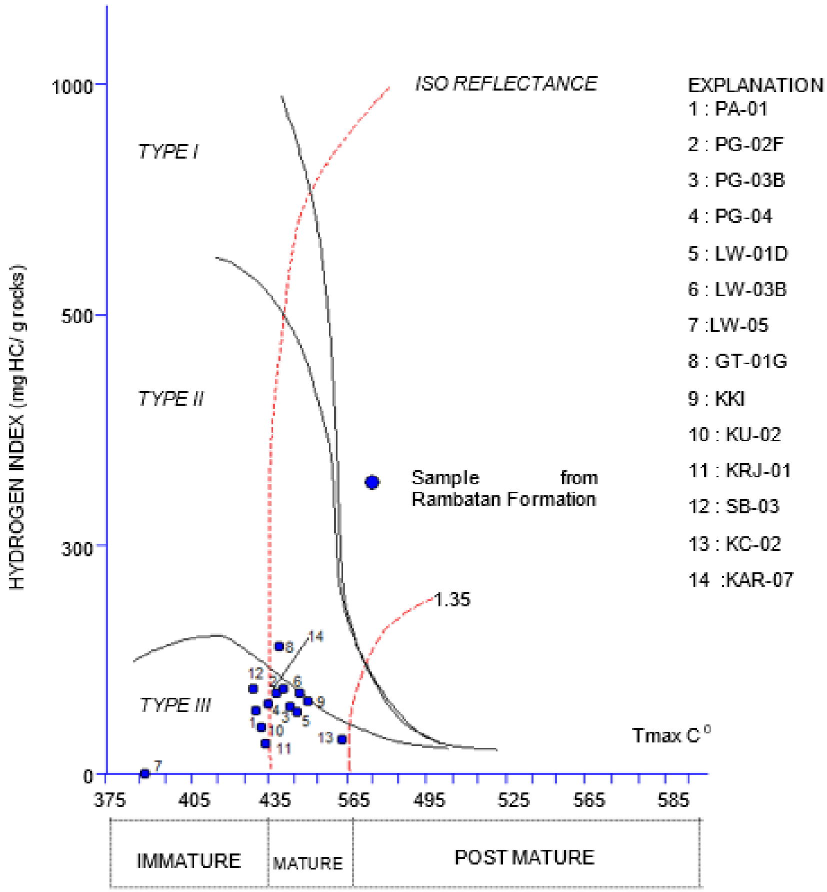
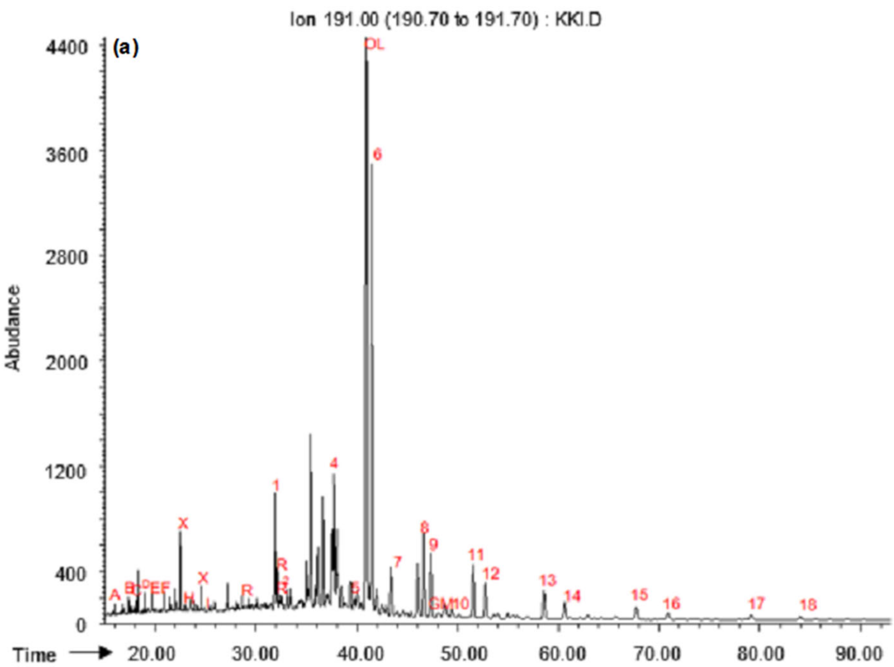


Fig 4. The plot of the HI vs. T_{max} for the Totogan and Rambatan Formation



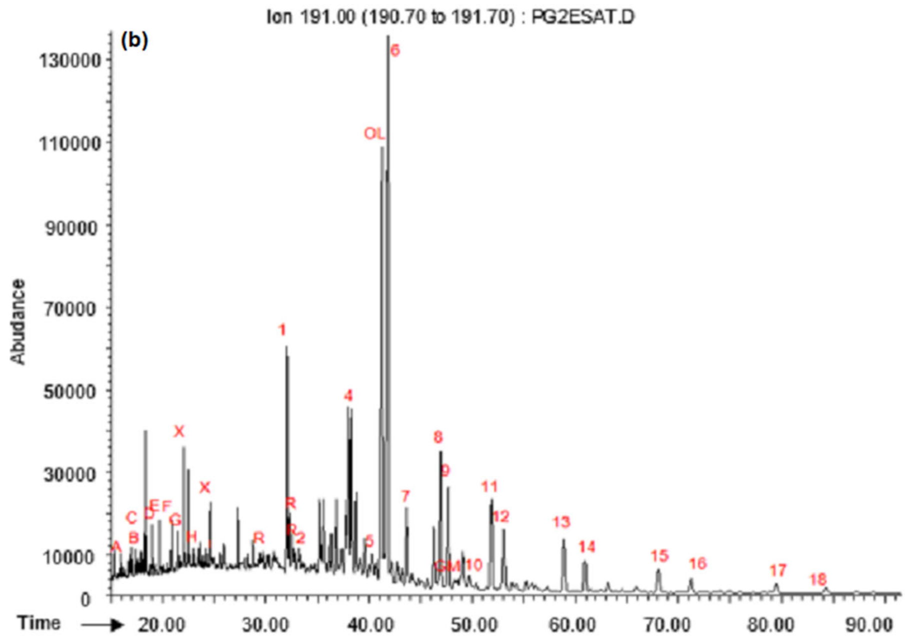
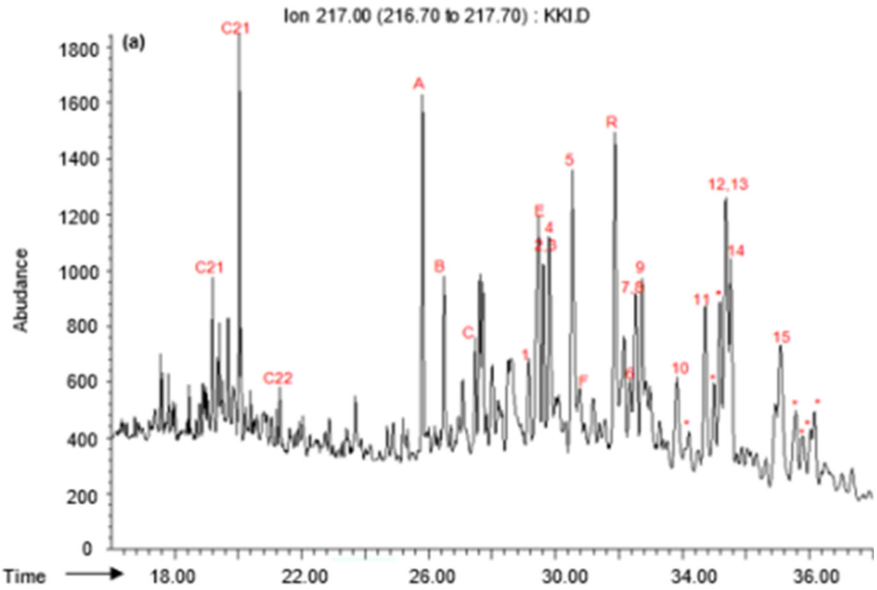


Fig 5. The mass fragmentogram of the terpene biomarker (*m/z* 191) from (a) KK1 and (b) PG-02E

are included in the category of oil-prone and gas prone. It can produce medium-quality oil and medium-quality gas based on the HI value. Meanwhile, in the Karawang area of the Jatiluhur Formation, all samples tend to form gas [1], including type III and the category of gas prone, and based on the value of HI, can produce gas with a small quantity.

Gas Chromatography-Mass Spectrometry Analysis

GC-MS analysis was carried out on rock extract samples of the Rambatan Formation taken from the locations of the Desel (KK-1) and Kaligendel (PG-02E) rivers. The mass fragmentogram of the terpene biomarker (*m/z* 191) (Fig. 5(a) and (b)) has a tricyclic terpene distribution with the number of carbon atoms ranging from C19 to C26 (compounds A-I). In addition, the amount of C23 (Peak F) of tricyclic compounds is relatively high compared to C19 and C20. Peak A-C indicates that the source of facies was from algal material. Fragmentogram *m/z* 191 shows the presence of 18α (H)-Oleanane (OL) and bicadina (R) resin from the



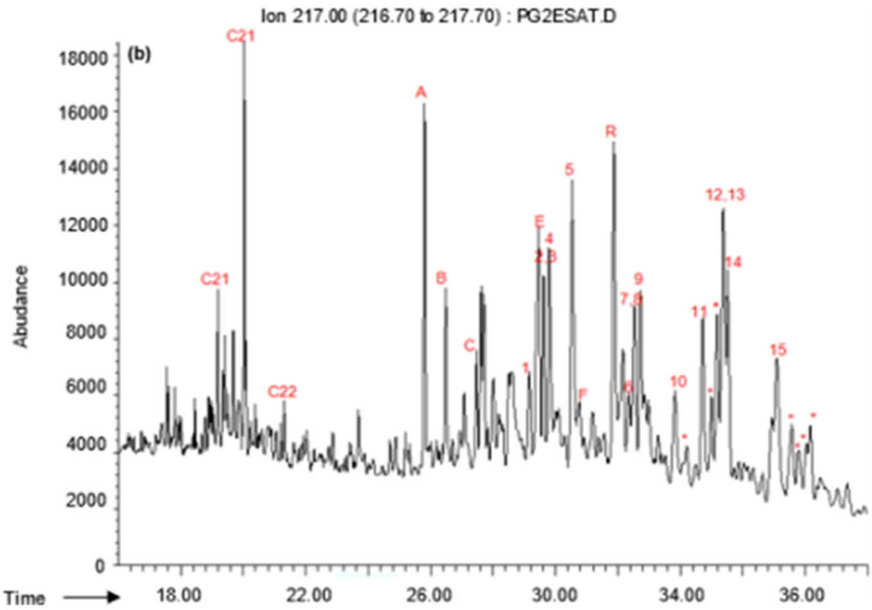


Fig 6. The mass fragmentogram of the biomarker sterane (m/z 217) from (a) KK1 and (b) PG-02E

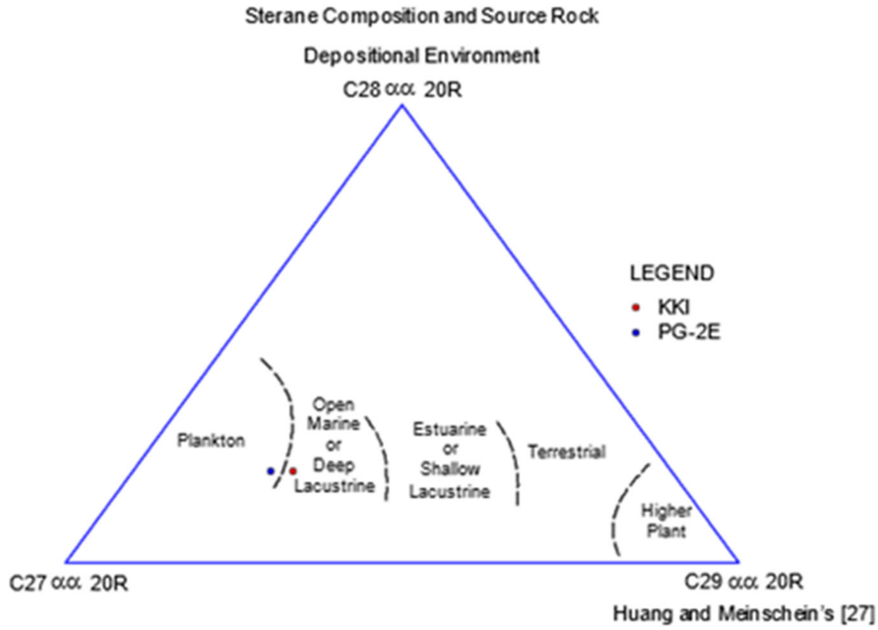


Fig 7. The composition of sterane and the depositional environment from the source rock material of the Rambatan Formation in the Karangkobar area

analyzed rock extract (Fig. 5(a) and (b)). These compounds are a direct indication of the presence of resinous materials. They are thought to have formed a terrestrial depositional environment, especially flowering plants or angiosperms that began to evolve in the Cretaceous. Oleannais often found in samples from deltaic sediments of the Cretaceous.

The mass fragmentogram of the biomarker sterane (*m/z* 217) (Fig. 6(a) and (b)) image shows a normal distribution showing that C27 sterane (55.76–59.98) has a more significant proportion than C29 sterane (23.23–26.71). This is evidence that the organic material was from algae. The depositional environment from the plotting of the C27, C28, and C29 sterane triangle diagrams Huang and Meinchein [27] (Fig. 7) shows that the source rock material for the Rambatan Formation in the Karangkobar area was deposited in an open marine and plankton environment.

■ CONCLUSION

The claystone of the Rambatan Formation in the Karangkobar area has a TOC value of 0.36–1.55%, indicating that the ability to generate hydrocarbons is poor to good. The TOC vs. PY diagram shows the category of low to moderate organic material richness. HI vs. T_{max} diagram showing kerogen type II and III with the level of maturity of immature to mature. HI, with a value of 15–163 mg HC/g TOC, can produce oil and gas in a small quantity and is included in the oil and gas prone. GC-MS analysis source rock in the study area has the depositional environment of the organic material derived from open marine and planktonic environments. This study is essential to complete the understanding of the petroleum system in Central Java.

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