Characterization of Oil Shale in the Indragiri Hulu Regency, Indonesia, Based on Organic Geochemistry and Petrography

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Abstract. Oil shale now becomes important in Indonesia as promising unconventional energy since the conventional oil is decreasing. This study may be classified as a reconnaissance in trying to evaluate oil shale in the Indragiri Hulu Regency, Indonesia that may become source rock of the future unconventional oil. A set of samples comprising thirty-four sediment outcrops have been collected. All samples were screened their richness by analysing their total organic carbon (TOC) and introduced to Rock-Eval pyrolysis apparatus to identify their maturity, type, and also richness. Out of the thirty-four samples, fourteen selected ones were analysed using gas chromatography (GC), sixteen samples for analysis gas chromatography-mass spectrometry (GC-MS), and twenty samples for organic petrography. The sediments could be classified as very good to excellent for their organic richness, in the stage of immature to relatively mature, comprising a mixture between Type I and II kerogens which show oil prone. Petrographic analysis indicates that lamosite contained in the sediments belongs to Rundle type. The Rundle type lamosite that were mainly originated from Pediastrum organisms might indicate that the sediments were deposited in a lacustrine paleoenvironment, i.e. in a specific type of balanced fill basin. It is proven that the studied formation is promising to be source rock for the shale oil that could be exploration target in the near future time.

1. Introduction

Indonesia is one of countries that may produce shale oil and gas. Shale oil is one of the unconventional hydrocarbons that could be hoped for Indonesia, since there are some basins that are promising to be explored for such a hydrocarbon. In general, geography of Indonesia may be divided into two parts, western and eastern. In the western part of Indonesia, oil shale, as source of the shale oil, is expected in some basins, such as North Sumatra, Central Sumatra, South Sumatra, Kutai, and Tarakan Basins. With the decline of conventional oil and gas production in the country, as a consequent, exploration for oil shale becomes very important.

Indonesia has more than sixty sedimentary basins and their geological age is mainly Tertiary, only some of them (generally in the eastern part) with pre-Tertiary setting. Studies with regard to the unconventional hydrocarbons are relatively new in Indonesia. Such studies are mainly categorised as reconnaissance, e.g. [1][2][3], so is this study. This study has been done in an area namely Indragiri Hulu Regency at Riau Province, Sumatra (figure 1, left). The study area belongs to the Central Sumatra Basin. This basin is one of the biggest hydrocarbon producers in Indonesia, where some active fields exist. Objectives of this study were: (1) to characterize the organic geochemistry of the oil...
shale of the formation in terms of its quality, quantity, and maturity, (2) to interpret depositional environment of the shale, (3) to define the type of oil shale at the Kelesa Formation, and (4) to define the future role of this formation as source rock of the shale oil.

2. Geological setting
The study area belongs to the Central Sumatra Basin. This is a back-arc basin that was formed due to subduction of the Indian plate into Eurasian plate during early Tertiary time (Eocene to Oligocene). In general, structural patterns in the Central Sumatra could be divided into two directions, i.e. N-S and NW-SE, where the N-S structures are older than the NW-SE ones [4]. The N-S structures predominate in the subsurface, whereas the NW-SE on the surface. The N-S structures were formed during Palaeogene time and the NW-SE during Late Neogene [5]. Figure 1 also shows position of the Central Sumatra Basin within the Sumatra Island. General stratigraphy of the study area is given in figure 2. In general, there are seven formations of the Tertiary geological age lay on the basement of the Permian-Carbon Gangsal Formation. During this study, the interested formation that has been expected to be the source of shale oil is Kelesa. This formation crops out in the study area (figure 3).

Figure 1. Map of Indonesia (left, not to scale) and position of the Central Sumatra Basin and others in the Sumatra Island (right) [5].

Figure 2. General stratigraphy of the study area. Kelesa Formation (red) is the target in this study.

Figure 3. Geological map of the region in the Central Sumatra Basin around the study area. There are six Tertiary age formations in the study area. Please note that Lakat Formation in this area is equivalent with Talangakar Formation in South Sumatra Basin. Kelesa Formation is the target for shale oil during this study.
3. Samples and analyses
During this study, thirty-four outcrop sediments of the Kelesa Formation have been collected. The samples condition was relatively fresh since they were collected from around 25 to 50 cm deep. All samples were then sent to the BSI Lab in Bumi Serpong Damai, South Tangerang, Indonesia for all geochemical analyses. The samples were introduced to some standard geochemical apparatus, such as LECO Carbon analyser (34 samples), Rock-Eval pyrolysis (34 samples), organic petrography (20 samples), gas chromatography (GC) (14 samples), and gas chromatography-mass spectrometry (GC-MS) (16 samples). LECO carbon analyser used is WR-112 type and the pyrolysis is Rock-Eval II. Standard operation for LECO and Rock-Eval pyrolysis is very common and could be found elsewhere. GC used in this study is Perkin Elmer Clarus 600 type equipped with capillary column Ultra-2 or CP-Sil-5CB 50 m x 0.32 mm x 0.12 μl. Temperature for injector is set to 300°C and for detector 310°C. Initial column temperature program is set to 28°C and is gradually increased by 6°C per minute to 280°C. For other biomarker analysis, the GC is combined with mass spectrometry Perkin Elmer Clarus SQ 8 C.

Organic petrography analyses have been done in the Organic Laboratory of the Center of Geological Survey Bandung. Two types of microscopic works have been applied; first is to determine the vitrinite reflectance and the second is to assess kerogen type. Vitrinite reflectance (Ro) provides a method for determining the thermal alteration history of a sediment. Vitrinite particles, originating from wood, are found dispersed throughout most sedimentary rock samples which are younger than Silurian in age. Since vitrinite reflectance increases regularly with increased thermal alteration, a reflectance measurement can be used to determine the degree of thermal maturation of that sediment. In order to perform reflectance readings, the sedimentary outcrop rock fragments were embedded in an epoxy resin plug. The hardened plug was then polished and the reflectance of the individual vitrinite particle was identified and measured using an Axioplan 2 imaging Zeiss microscope. Another analysis using microscope is to assess kerogen composition. High-powered microscope examination of kerogen in transmitted light determines the type of organic matter that is favourable for petroleum generation. The focus of kerogen composition examination was on alginite macerals, although other macerals such as exinite, liptinite, inertinite and so on were also examined.

4. Results and discussion

4.1. Source richness
Quantity of organic materials in the sediments have been assessed based on two parameters, i.e. total organic carbon (TOC) and pyrolysis S2. From the data in Table 1, it can be seen all sediments contain good to excellent organic matter (1.18 to 9.63% TOC). Poor S2 values (1.26 and 1.42) were only detected in two samples, whereas excellent S2 (6.19 to 70.72 mg HC/g TOC) for the rest.

| No | Sample code | TOC (%) | S2  | No | Sample code | TOC (%) | S2  | No | Sample code | TOC (%) | S2  |
|----|-------------|---------|-----|----|-------------|---------|-----|----|-------------|---------|-----|
| 1  | MH02C       | 5.33    | 39.03 | 13 | MH02P       | 5.74    | 32.1 | 25 | NS29O       | 7.17    | 46.44 |
| 2  | MH02D       | 4.34    | 51.71 | 14 | MH02Q       | 4.71    | 43.63 | 26 | NS29P       | 3.74    | 14.92 |
| 3  | MH02E       | 3.58    | 35.16 | 15 | MH02R       | 3.22    | 29.03 | 27 | NS29Q1      | 5.49    | 33.28 |
| 4  | MH02G       | 4.18    | 30.08 | 16 | MH02S       | 3.09    | 17.58 | 28 | NS29Q2      | 2.31    | 6.19  |
| 5  | MH02H       | 1.18    | 12.6  | 17 | NS 29A      | 3.05    | 12.02 | 29 | NS30A       | 4.76    | 24.1  |
| 6  | MH02I       | 1.34    | 16.5  | 18 | NS29B       | 3.37    | 18.42 | 30 | ES13C       | 4.06    | 21.06 |
| 7  | MH02J       | 2.19    | 14.2  | 19 | NS29C       | 3.1     | 14.68 | 31 | ES14A       | 5.66    | 22.4  |
| 8  | MH02K       | 2.47    | 10.51 | 20 | NS29G       | 7.93    | 61.28 | 32 | ES15C       | 9.63    | 70.72 |
| 9  | MH02L       | 4.25    | 27.91 | 21 | NS29I       | 4.06    | 26.22 | 33 | ES16B       | 5.2     | 25.68 |
| 10 | MH02M       | 6.39    | 36.37 | 22 | NS29K       | 5.43    | 40.48 | 34 | ES18A       | 5.96    | 47.16 |
| 11 | MH02N       | 5.93    | 43.66 | 23 | NS29M       | 4.98    | 33.64 |   |             |         |      |
| 12 | MH02O       | 2.92    | 44.42 | 24 | NS29N       | 3.4     | 11.8  |   |             |         |      |

Table 1. Source richness data for the sediment samples.
4.2. Source type

Source type has been evaluated on the basis of hydrogen index (HI) parameter. HI values vary from 65 to 1522 (table 2). Only one sample that has HI value less than 100. The others’ values are higher than 100 and mostly higher than 200. To reconfirm HI values, the samples were also analysed using microscope to recognize the content of dominant maceral. Most of the HI values agree with the results obtained from the microscopic examination (table 2). However, some of them are not fit each other. In this case, the result from the kerogen typing is preferable, because this technique was done under microscope examination operated by person, thus not depending entirely to the machine.

**Table 2.** Analyses results of pyrolysis hydrogen index and kerogen typing for the sediment samples.

| No | Sample code | HI | Dom mac* | Type | No | Sample code | HI | Dom mac* | Type |
|----|-------------|----|----------|------|----|-------------|----|----------|------|
| 1  | MH02C       | 732| NDA      | I    | 13 | MH02P      | 559| NDA      | II   |
| 2  | MH02D       | 1191| NDA     | I    | 14 | MH02Q     | 927| NDA     | I    |
| 3  | MH02E       | 983| NDA      | I    | 15 | MH02R     | 902| NDA      | I    |
| 4  | MH02G       | 720| A       | I    | 16 | MH02S     | 569| A       | I    |
| 5  | MH02H       | 107| NDA      | III  | 17 | NS29A     | 394| A       | I    |
| 6  | MH02I       | 1236| A | I   | 18 | NS29B     | 547| A       | I    |
| 7  | MH02J       | 65| L       | III  | 19 | NS29C     | 474| A       | I    |
| 8  | MH02K       | 426| NDA     | II   | 20 | NS29G     | 773| A       | I    |
| 9  | MH02L       | 656| NDA     | I    | 21 | NS29I     | 646| A       | I    |
| 10 | MH02M       | 569| NDA     | II   | 22 | NS29K     | 745| NDA     | I    |
| 11 | MH02N       | 736| A       | I    | 23 | NS29M     | 676| A       | I    |
| 12 | MH02O       | 1522| NDA | I   | 24 | NS29N     | 347| A       | I    |

* Dominant maceral: A=Alginite; L=Liptinite; NDA=No data available

4.3. Source maturity

Maturity parameters used in this study are pyrolysis Tmax and vitrinite reflectance (Ro). Data with regards to the parameters are shown in table 3. Tmax data seem to be more reliable than the Ro. This is because HI values for the sediments are relatively high. The high values of HI strongly indicate that the sediments contain mainly Type I and/or II kerogen. Such sediments generally comprise a little or even no vitrinite maceral. In the absence of vitrinite, the Ro values measured are often suppressed that may indicate values lower than those of the regional trend. The suppressed Ro values must be corrected. In this study, Ro correction was done by using Subroto’s method [6]. After correction, the corrected Ro values become more proportional. The outcrop sediments analysed are apparently immature to just mature; only a few samples are relatively mature.

**Table 3.** Maturity parameter data for the sediment samples.

| No | Sample code | Tmax (°C) | Ro (%) | Corrected Ro (%)* | No | Sample code | Tmax (°C) | Ro (%) | Corrected Ro (%)* |
|----|-------------|----------|--------|-------------------|----|-------------|----------|--------|-------------------|
| 1  | MH02C       | 435      | NDA    | NDA               | 18 | NS29B      | 438      | 0.33   | 0.49              |
| 2  | MH02D       | 437      | NDA    | NDA               | 19 | NS29C      | 433      | 0.28   | 0.38              |
| 3  | MH02E       | 431      | NDA    | NDA               | 20 | NS29G      | 446      | 0.26   | 0.27              |
| 4  | MH02G       | 435      | 0.21   | 0.21              | 21 | NS29I      | 434      | 0.3    | 0.44              |
| 5  | MH02H       | 431      | NDA    | NDA               | 22 | NS29K      | 441      | NDA    | NDA               |
| 6  | MH02I       | 434      | 0.21   | 0.21              | 23 | NS29M      | 438      | 0.43   | 0.65              |
| 7  | MH02J       | 435      | 0.45   | 0.61              | 24 | NS29N      | 437      | 0.36   | 0.56              |
| 8  | MH02K       | 429      | NDA    | NDA               | 25 | NS29Q      | 439      | NDA    | NDA               |
| 9  | MH02L       | 433      | NDA    | NDA               | 26 | NS29P      | 435      | 0.42   | 0.66              |
| 10 | MH02M       | 436      | NDA    | NDA               | 27 | NS29Q1     | 435      | NDA    | NDA               |
| 11 | MH02N       | 434      | 0.33   | 0.55              | 28 | NS29Q2     | 438      | 0.27   | 0.31              |
| 12 | MH02O       | 437      | NDA    | NDA               | 29 | NS30A      | 432      | 0.33   | 0.5               |
| 13 | MH02P       | 433      | NDA    | NDA               | 30 | ES13C      | 443      | 0.32   | 0.39              |
| 14 | MH02Q       | 432      | NDA    | NDA               | 31 | ES14A      | 433      | 0.31   | 0.44              |
| 15 | MH02R       | 433      | NDA    | NDA               | 32 | ES15C      | 431      | 0.43   | 0.68              |
| 16 | MH02S       | 431      | 0.27   | 0.32              | 33 | ES16B      | 430      | 0.3    | 0.39              |
| 17 | NS 29A      | 439      | 0.33   | 0.51              | 34 | ES18A      | 442      | 0.33   | 0.51              |

*Corrected Ro using method proposed by Subroto [6]; NDA=No data available
4.4. Depositional environment

One of the uses of biomarker is for depositional environment and origin of the organic matter. The biomarkers used for such purposes in this study are normal alkanes, isoprenoids, steranes, and hopanes. Of the fourteen samples analysed using GC technique, twelve of them show good results, whereas out of the sixteen samples introduced to the GC-MS apparatus, only six of them give good analysis data. Figures 4 and 5 reveal depositional environment as well as the origin of the organic matter contained in the sediment samples by using normal alkanes, isoprenoids, and steranes biomarkers. Based on the assessments, it is apparent that the sediments contain mixture of terrigenous materials and some algal component, deposited in lacustrine area with suboxic to highly oxidizing terrestrial condition.

Figure 4. A cross plot Pr/nC17 vs. Ph/nC18 showing depositional environment and origin of the organic matter contained in the sediments. Pr: pristane; Ph: phytane.

Figure 5. Ternary diagram of Huang and Meinschein [7] revealing depositional environment for the organic matter in the sediments.

4.5. Petrographical assessment

Identification of alginite has been used to define the type of oil shale. Based on morphology of its cell, alginite may be divided into two maceral types, i.e. telalginite and lamalginite [8]. Telalginite is alginite which has unicellular with thick wall, showing strong fluorescence in the low maturity with unique characteristic on its outer structure. Telalginite has two sources, i.e. from marine or lacustrine. Lacustrine telalginite is mainly originated from Botryococcus braunii while marine telalginite from Gloeocapsomorpha prisca, Tasmanites, and Foerstia. Lamalginite is alginite which is from planktonic algae or small benthos that is also unicellular but having thin wall. In the immature stage, this alginite shows weak to medium strong fluorescence. Its lamella structure is visible under the perpendicular section across the stratum. Lamalginite could also be divided into two on the basis of its origin, i.e. marine and lacustrine. Lacustrine lamalginite might be originated from Pediastrum, Septodinium, and Cleistosphaeridium. Furthermore, lacustrine lamalginite could also be differed into two types, i.e. Rundle (discrete) and Green River (layered). The two different lamalginites may be used to differentiate type of lamosite shales. Lamosite Rundle type could be deposited in the fresh water lake up to brackish water, whereas the Green River type in the more saline water. On the other hand, marine lamalginite might be derived from organisms such as marine dinoflagellata and acritarch.

Figure 6 shows comparison among the three lamosite types: Green River, Rundle, and the one from this work. It is apparent, that the one from this study is very similar with that of Rundle type, showing no continuity (not layered). This Rundle type lamosite is predominated by lamalginite that were derived from Pediastrum which is lacustrine typed lamalginite. Furthermore, beside lamalginite, telalginite was also observed in the sediment samples, but in much smaller concentration. The telalginite organisms found are those interpreted to derive from Botryococcus braunii. Botryococcus braunii is organism that has been originated from lacustrine environment. In general, on the basis of the type of the alginite, the oil shale in the study area might have been deposited in a fresh water up to brackish lacustrine environment.
In their work [9], they have concluded that lacustrine organic facies could also be determined through a combination of TOC, HI, visual kerogen, pyrolysis products, and biomarkers. Using these tools, lacustrine organic facies could be divided into three organic facies, i.e. terrestrial algae, algae, and hypersaline algae. Terrestrial algae organic facies may have an association with the fluvial-lacustrine facies which indicates a particular lacustrine type, namely overfilled lake basin. Algae organic facies is associated with fluctuation profoundal facies from specific type of balanced fill basin, and hypersaline algae organic facies with evaporative facies of underfilled lake basin. The data observed in the sediment samples studied seem to agree with algae organic facies in the balanced fill basin type.

To conclude, the formation is very interesting to be the target for hydrocarbon exploration in the near future. One thing that should be confirmed is brittleness of the shale. This phenomenon is not covered within this study.

**Figure 6.** Comparison of the feature of Green River (left) and Rundle (middle) types against the lamalginit character from samples collected during this study (right). It is apparent that lamalginite type of the samples in this study is similar with that of Rundle. It should be noted that the left and middle pictures were taken from [8].

**5. Conclusions**

Oil shale in the study area contains good to excellent organic matter, mainly Type I-II (oil prone), and from just mature to relatively mature. The shale seems to consist of a mixture between algal and some higher plant materials. It contains the Rundle typed lamosite, indicating *Pediastrum* organisms predominant deposited in a fresh water to brackish lacustrine environment, more specifically, the formation was derived from algae organic facies in the balance fill basin type. The Kelesa Formation is very promising to be the source rock for shale oil in the area.

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