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# Eo-Oligocene Oil Shales of the Talawi, Lubuktaruk, and Kiliranjao Areas, West Sumatra: Are they potential source rocks?

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**Abstract** - To anticipate the increasing energy demand, additional data and information covering unconventional fossil fuels such as oil shale must be acquired to promote the usage of alternative energy sources to crude oil. The Talawi and Lubuktaruk regions situated within intra-montane Ombilin Basin, and the Kiliranjao area assumed to be located in a small intra montane Kiliranjao Sub-basin are occupied by Eo-Oligocene sediments of Sangkarewang and Kiliran Formations, respectively. Field activity, geochemical screening techniques, and organic petrographic analysis, supported by SEM mode, are methods used. Most of the oil shale sequence is typically of an organically rich-succession comprising predominantly well-bedded, laminated and fissile, brownish to dark grey organic-rich shales and mudstones. The exinite macerals within oil shale comprise mainly Pediastrum-lamalginite with minor cutinite, resinite, liptodetrinite, sporinite, bituminite, and rare *Botryococcus*-telalginite. Therefore, the oil shale deposits can be described as "lamosites". Minor vitrinite maceral is also recognized. TOC analysis on selected shale samples corresponds to a fair up to excellent category of source rock characterization. The kerogen is suggested to be of mixed Type II and Type I autochthonous materials such as alginite, with minor allochthonous substances. Oil samples collected appear to be positioned within more oil prone rather than gas prone. Thermal maturity of the oil shales tends to show an immature to marginally/early mature stage. By evaluating all the results of geochemical and organic petrological analyses conducted on shale lithologies (shale and mudstone), it can be concluded that the oil shales in those areas are effective source rocks having a favourable potential for generating shale oil or gas to be included as alternative energy resources in the future.

**Keywords:** oil shale, alternative energy, effective source rock, lamosite, oil or gas

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## INTRODUCTION

### Background

Oil shale classified as unconventional fossil fuel resources have a high potential to provide energy and to be developed. Furthermore, as sediments, oil shale having ash content of more than 33 %, contains organic matter yielding oil when destructively distilled (Gavin, 1924). Yen and Chilingarian (1976) stated that oil shale is "composites" of tightly bound organic and inorganic components. The ratio of organics to inorganics rarely exceed ¼. Furthermore, Dyni (2006) stated that oil shale is a fine-grained sedimentary rock containing organic matter yielding substantial amounts of oil and combustible gas upon destructive distillation.

Recently, in the view point of energy resource interest, the generation potential of shale oil from oil shales, particularly as an alternative energy source, has been considered significantly as new energy resources. The oil shale has long been of interest as an indirect resource for fuel (energy) generated by a retorting process and as a possible source rock for hydrocarbon during maturation.

The continuing decline of petroleum supplies, accompanied by increasing costs of petroleum-based products may present opportunities for oil shale to supply some of energy needs. Therefore, to find other alternative energy resources of fossil fuel origin, requires a serious effort for geologists. Most such studies have considered the main source for oil and condensate. Thereby, the oil-shale deposits in Indonesia, which have not been explored intensely, may be expected to be the new fossil energy resources in the future.

As reported in several reports and publications (Suwarna *et al*., 2000, 2001a and b, 2002, and 2006; Kusumahbrata *et al*.,2002, 2003, and 2004; Heryanto *et al*., 2001; Susanto *et al*., 2004; Hermiyanto and Santy, 2008; Widayat *et al*., 2013), oil shale occurs in some parts of Sumatra, including Kiliranjao and Ombilin Basins in West Sumatra (Figure 1). Those oil shales have preliminary been studied, however their potential and quality have not been known well yet. These oil shale beds seem to superimpose the oil, gas, and coal seam basins, and thereby the basin setting is similar to the tectonic configuration of the clastic depositional system.

A general basic information on the presence of oil shales in Sumatra was gained from the geological maps of scale 1:250.000, published by the Geological Research and Development Centre, Bandung. Additional data comprising stratigraphic relationships, sedimentology, and paleontology of the Old Tertiary sediments in Sumatra were extracted from the oil and coal company geological reports.

In general, oil shale from Ombilin and Kiliranjao Basins was deposited in a lacustrine to brackish environments associated with coal depositions. The narrow rock distribution, almost parallel to the direction of Great Sumatra Fault, and bounded by faults, indicates that the oil shale deposits were accumulated within the "syn-rift" basins. Several researches, *i.e*. Suwarna *et al*. (2000 and 2001) show that some prospect areas are occupied by high oil content levels and may have a good prospect to be developed, such as Ombilin and Kiliranjao, West Sumatra.

## Objectives

The information obtained from oil shale analyses is important for having a better understanding on the sediments and organic

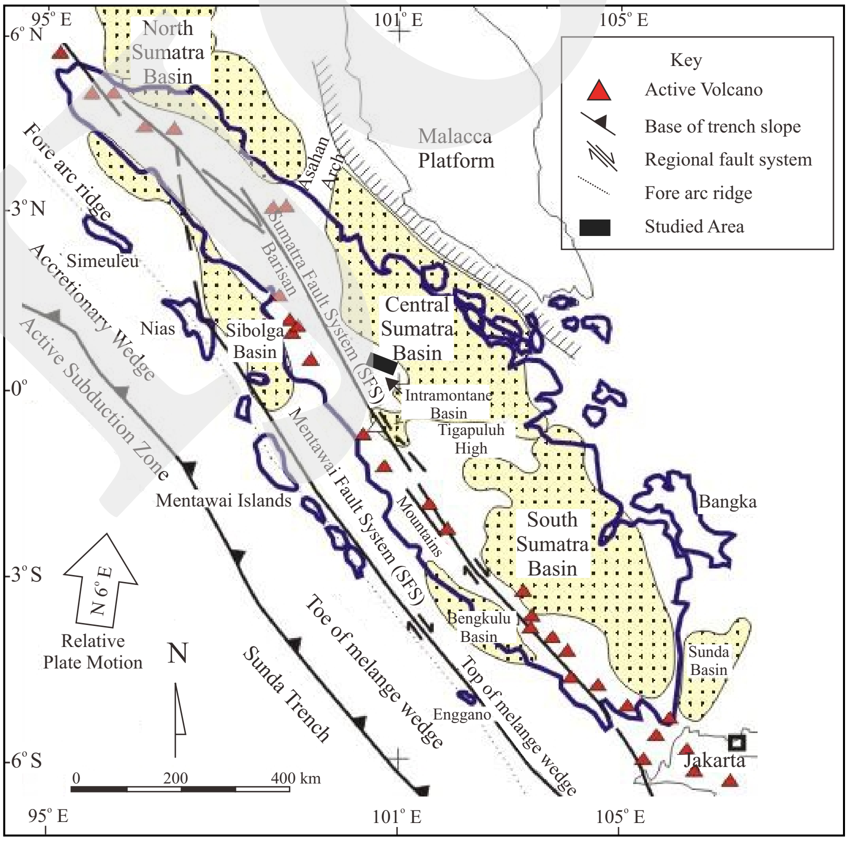

Figure 1. Locality map of the studied area and back-arc basin Sumatra (modified from de Coster, 1974).

matter content, essentially, relating to shale oil (hydrocarbon) potential, within the Eocene-Oligocene sediments in Talawi, Lubuktaruk, and Kiliranjao areas. This paper evaluates and discusses the potential of shale sequence exposed in Talawi, Lubuktaruk, and Kiliranjao areas, West Sumatra, on the basis of lithofacies, organic petrology, Rock-Eval pyrolysis, and SEM analyses. The understanding of studied oil shale characteristics will be useful in selecting an efficient and effective techniques for its resource potential assessment. The paper also informs "potential source rocks" those with sufficient organic content to produce hydrocarbons, whether it is oil-prone or gas-prone category, at generative temperatures, and "effective source rocks" - those potential source rocks which can be shown to have reached generative temperatures.

## METHODS, ANALYTICAL PROCEDURES, AND MATERIALS

Various geologic field investigations and laboratory techniques were used, in order to achieve the aims of this study. Primary fieldwork activity includes accurate determinations, observations, and measurements on sedimentology, organic matter characteristics, and detailed stratigraphy of the strata containing oil shales of Sangkarewang and Sawahlunto Formations in the Talawi and Lubuktaruk areas and Kiliran Formation in the Kiliranjao area. Afterwards, collection of field data and samples for geochemical and organic petrographic analyses were carried out.

The samples analyzed are gained from freshest relatively selected representative outcrop and subcrop of shales and mudstones. Rock-Eval pyrolysis was performed on 18 rock samples from layers of oil shales; those are 11 samples fromTalawi, 3 samples from Lubuktaruk, and 4 samples from Kiliranjao. Then, for Retort-Oven analysis mode comprises 34 samples, those are 25 samples from Talawi, 2 samples from Lubuktaruk, and 7 samples represent Kiliranjao area. Furthemore, an organic petrology examination was carried out on 34 oil shale samples, composed of 21 samples representing Talawi, 3 samples from Lubuktaruk, and 10 samples collected from Kiliranjao areas.

The laboratory techniques predominantly deal with hydrocarbon potential and organic matter type content of the shales and mudstones forming the formation. The techniques carried out are petrologic analysis using reflected light and fluorescence microscopy, accompanied by geochemical analysis including TOC content and Rock-Eval Pyrolysis of the organic matter (DOM) and fine-grained clastics (shales and mudstones), which then supported by retorting mode (destructive distillation).

By measuring the quantity, quality, and state of thermal maturity of the contained organic matter, it is possible to understand the origin of hydrocarbon accumulations and potential, and to predict areas most favourable for future exploration. Furthermore, to gain effective source rock information, determination on its organic content and type, and also thermal maturity have been conducted.

### Organic Petrology

Petrologic analysis was focused on maceral determination, especially exinite macerals and vitrinite reflectance. The samples were prepared as polished briquettes or blocks by using Australian Standard procedures (Standards Association of Australia-AS 2061, 1977; and AS 2856, 2000). The polished briquettes were prepared from crushed 1mm-size samples representing each sample, which then mounted in epoxy resin. Maceral composition and characteristics of the samples are gained from semi-quantitative examinations of polished samples. The analysis determines quantitatively the volume of organically derived, microscopically recognizable substances of organic matter, which are defined by their morphology and colour. The methods used for estimating organic carbon abundance, maceral type and composition, and vitrinite reflectance are outlined in Stach *et al.* (1982), Cook and Kantsler 1982), Sappal (1986), Struckmeyer & Felton (1990), Thomas (2002), and Suarez-Ruiz and Crelling (2008).

Optical method used in organic petrology analysis is reflected light method with and without fluorescence mode. The main advantage is to discriminate and locate different types of organic matter and macerals, and to measure their respective rank of evolution. The analysis provides different types of information on the thermal evolution of organic matter, particularly based on vitrinite reflectance measurements. These properties are considered to be indicators for maturation. The analysis based on 500 counts on each sample under reflected white light, was performed microscopically on polished sample sections. Ordinary white reflected light from a tungsten lamp and violet-blue light from a high-pressure mercury lamp to initiate fluorescence were used for illumination. Maceral observation was conducted on a Leitz MPV-2 photomicroscope, in GRDC and Tekmira Laboratories.

Most macerals determined are defined by the International Committee for Coal Geology (ICCP, 1963 and 1971). Hutton (1980) introduced alginite A (telalginite) and B (lamalginite) terms, based on their significant morphological differences between constituents of the alginite.

The organic petrology was accompanied by SEM technique, to provide an excellent information for revealing the type of rocks, organic and bitumen constituents, diagenesis feature and regime, and also the property of rocks, as well as to study concerning rock diagenesis (Wilson and Pittman, 1977; Pittman, 1979). In this study, however, the technique was focused on organic and bitumen constituents, to reveal oil shale characters.

### Organic Geochemical Analysis

Total organic carbon (TOC), Rock-Eval pyrolysis, and also Retort Oven analyses are conducted to analyze organic geochemistry. The Rock-Eval pyrolysis, with its limitations, can be used to characterize the type of organic matter and the general nature of the hydrocarbon product (*eg*. oil *vs*. gas) which will be generated upon thermal maturation (Espitalie *et al*., 1977; Katz (1983).

The quantities of organic matter in oil shale samples were determined based on the total content of organic carbon (TOC) measured by LECO analyzer and on generation potential (GP = S1+S2; free distillable hydrocarbons + generatable hydrocarbons) established by Rock-Eval pyrolysis. Hydrogen index HI (S2/TOC) was used to characterize the kerogen type. A plot of these indices on the van Krevelen diagram shows the type of organic matter present in oil shale samples. Production index S1/(S1+S2) and $T_{max}$ were used to characterize the maturity of kerogen. The analysis was carried out in LEMIGAS Laboratory.

### Retort Oven Analysis

Oil shale heated in the absence of oxygen (destructive distillation) produced shale oil. This heating process is called retorting, and the equipment that is used to do the heating is known as a retort. The rate at which the oil is produced depends upon the temperature at which the shale is retorted. Most references report retorting temperatures as being about 500°C (930°F). The technique was subsequently standardized as the American Society for Testing and Materials Method D-3904-80 (1984). The analysis was conducted in LEMIGAS Laboratory.

## GEOLOGIY

### Geological Setting

Sumatra Island is situated along the south-western edge of the Sunda Shelf, part of the Eurasia Continental Plate, directly adjoining the Indian-Australian Oceanic Plate (Figure 1). Due to the collision between those two plates, an oblique subduction zone is produced, situated along the Sunda Trench, outside the western coast of Sumatra Island (Hamilton, 1979; Curray *et al*., 1979). The subduction taking place led to the presence of magmatic arc such as Barisan Mountains and dextral strike-slip fault parallel to the plate edge, that is called the Sumatra Great Fault System (Fitch, 1972). Moreover, the intra-montane basins were formed, almost parallel in direction to the fault system, that is northwest - southeast direction. Tectonically, the study areas are located at the Back-Arc Zone and Inter-Arc Zone or intra-montane area, underlain by pre-Tertiary rocks, which then is overlain by sediments and volcanics.

### Talawi and Lubuktaruk Areas (Ombilin Basin)

The geologic setting and history of the Ombilin Basin has been described in several previous publications (Silitonga and Kastowo, 1975; Cameron *et al*., 1981; Koning, 1985, Noeradi *et al.,* 2005). An area of approximately 25 km by 60 km, trending parallel to the Sumatera axis, is present as the exposed portion of the Ombilin Basin. The basin developed in an intramontane setting as a result of the subduction of the Indian-Australian Plate beneath the Southeast Asian Plate, during the Late Cretaceous - Early Tertiary. It is a graben-like, pull-apart basin formed as a series of fault-bounded troughs (Koning, 1985). Predominantly, these troughs were filled with Tertiary terrestrial clastics, those are lacustrine and fluvial sediments, which overlies a complex of pre-Tertiary basement. Deposition of the Tertiary sedimentary units was tectonically controlled, and each rock unit is separated along their lower and upper contacts by a well-defined conformity with local depositional hiatus.

The principal source of the shale oil is the lacustrine - brackish sediments of Eocene - Early Oligocene Sangkarewang Formation, deposited in a subsiding basin under tropical conditions. In the deeper part of the basin, the rock unit comprises mainly calcareous shale and marl, brown to black, parallel laminated to very fissile; containing plant, fish, and bird-track fossils, as well as pyrite. Intercalations of calcareous quartz and feldspathic sandstone, graded-bedded, fining upwards, with slump structure locally. Calcareous characteristic of the rock is due to the abundance of limestone debris and bicarbonate-rich river water during the deposition of the sediments. Stratigraphically, the Sangkarewang Formation rests unconformably on the Pre-Tertiary rocks, and is conformably overlain by the Sawahlunto Coal-Measures.

### Kiliranjao Area (Kiliranjao Sub-basin)

The Kiliranjao Sub-basin, situated approximately 60 km to the east of the Ombilin Basin, is filled with siliciclastic-dominated sediments of the Kiliran Formation. Sedimentation of the rock unit, was tectonically controlled, and it developed in a periodically growing pre-Tertiary half-graben subbasin. The sedimentary sequence containing oil shale seams, was deposited in a lacustrine to marginal facies. Impressions of woody organic detritus (leaves, twigs, and barks) up to several centimetres in size are common to occur on bedding-plane surfaces within the siltstones.

The study area is situated probably within the westernmost part of the Central Sumatera Basin, one of the Indonesian important oil producing back-arc basins. However, it is interpreted to be an isolated small intra-montane basin, present as a nearly southeast-northwestward elongate form.

The oldest rock in the study area present as a basement of the sub basin is the Permo - Carboniferous Kuantan Group. The sub-basin is filled with Early Tertiary (Oligocene) siliciclastic-dominated sediments of Kiliran Formation and Quaternary Alluvium deposits. Sedimentation of the Tertiary sedimentary unit was tectonically controlled. The Kiliran Formation, generally, comprises a sequence of graben fill sediments, containing variegated shales and mudstones, sandstones, conglomerates, and coals. Predominantly, micro-laminated to massive slightly calcareous organic-rich, brown to light grey mudstone forms the unit. Evidence of bioturbation occurs, and bottom conditions are presumed to have been anoxic. The association of frequent freshwater mollusc fossils such as Paludina sp., Brotia sp., and Thiara sp. (Aswan *et al*., 2009) and *Botryococcus* algae contents (Suwarna *et al,* 2000 and 2001), indicates a lacustrine setting. Furthermore, the presence of lamalginite and telalginite sub-macerals (Figure 2), preserved assemblages of spores, and framboidal pyrite (Figure 3), suggest a freshwater with minor marine incursion environment occurred.

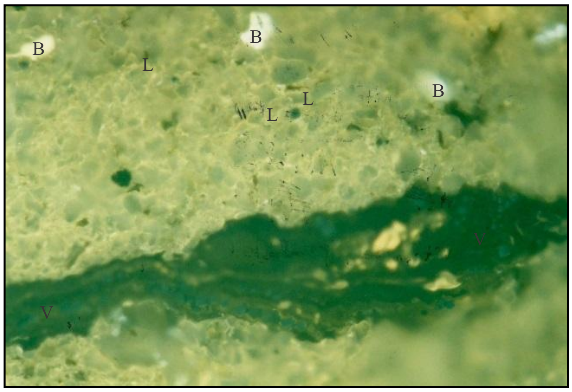

Figure 2. Photomicrograph of lamalginite (L, pale yellow subparallel lamellar bodies), telalginite (B, pale yellow oval bodies), and vitrinite (V, dark big sub-elongate body) interlayered in Kiliran shale (Fuorescence mode).

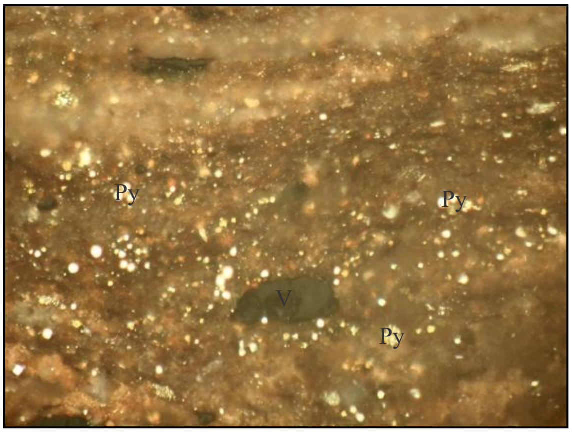

Figure 3. Photomicrograph of framboidal pyrite assemblage (Py; small rounded yellow bodies) and vitrinite maceral (V) in Kiliran oil shale (reflected light mode).

## RESULTS AND DISCUSSION

### Organic Geochemical Analysis

The TOC content of the selected samples of Talawi and Lubuktaruk areas ranges from 1.10 to 8.12 % (Table 1) with 3.18 % in average. The highest TOC content occurs in spongy mudstone (8.12 %) located in Lubuktaruk (NS 12B), followed by flaky mudstone of NS.11C (4.73 %) occurring in Sipang River. On the other hand, the lowest TOC content (1.10 %) occurs on shaly mudstone of HR.0 I E situated in Setangkai area.

The analysis indicates that, based on Rad classification (1984) and Tissot and Welte (1984), the shales and mudstones of Talawi and Lubuktaruk (NS.08A, -10A, -11C, -19A, ES.07A, SB.08B, and NS.12B) areas have excellent hydrocarbon potential that are able to generate a significant amount of oil (Figure 4) with TOC values varies from 2.23 % to 8.12 % (> 2.0 %), pyrolysis yields (PY) between 15.97 and 67.72 mg HC/g rock (mainly more than 20.0 mg HC/g rock), $T_{max}$ of 440° - 447° C, hydrogen indices (HI) in 595 - 829 range, and PI of 0.01 - 0.03. Therefore, the oil shales can be categorised as oil-to gas prone source-rocks (Figure 4), their kerogen contained is mainly included into Type I, with thermal maturity of early mature close to late immature level (Figure 5).

The good potential category is characterized by TOC value between 1.10 - 2.03 % (<2.0), and pyrolysis yields (PY) varying from 2.18 - 7.91 mg HC/g rock. This category is represented by samples ES.01A, HR.01E, NS.01B, NS.07A, NS.12E10, and DS.28A of Talawi region and sample NS.12A collected from Lubuktaruk. $T_{max}$ values of this category vary from 438° to 453°C, with HI (hydrogen indices) between 335 - 707 range. Those oil shales are situated in oil-prone level (Figure 4), and their kerogen is included into Types II with lesser extent of Type I (Figure

Table 1. Rock-Eval Pyrolysis Data of the Talawi, Lubuktaruk, and Kiliranjao Areas

| No | Location | Sample Code | Lithology | TOC (%) | S1 | S2 | PY | PI | $T_{max}$ (°C) | HI |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | kg/t | | | | |
| 1 | Ombilin | HR. 01 E | Mdst., shaly | 1.10 | 0.13 | 2.18 | 2.31 | 0.06 | 453 | 198 |
| 2 | | NS. 01 B | Mdst., dk.gy-blk. | 1.63 | 0.22 | 3.29 | 3.51 | 0.06 | 446 | 202 |
| 3 | | NS. 07 A | Mdst., brn.-dk.gy. | 1.61 | 0.07 | 7.84 | 7.91 | 0.01 | 438 | 487 |
| 4 | | NS. 08 A | Mdst., dk.gy. | 4.41 | 0.38 | 26.24 | 26.62 | 0.01 | 440 | 595 |
| 5 | | NS. 10 A | Mdst., dk.gy. | 4.05 | 0.68 | 26.44 | 27.12 | 0.03 | 447 | 653 |
| 6 | | NS. 11 C | Siltstone, shaly | 4.73 | 0.82 | 35.15 | 35.97 | 0.03 | 440 | 743 |
| 7 | | NS 19 A | Mdst., calc., gy. | 2.23 | 0.21 | 15.76 | 15.97 | 0.01 | 441 | 707 |
| 8 | | ES. 07 A | Mudstone | 4.51 | 0.42 | 34.42 | 34.84 | 0.01 | 446 | 763 |
| 9 | | SB. 08 B | Siltstone, dk.gy. | 2.45 | 0.11 | 16.68 | 16.79 | 0.01 | 441 | 681 |
| 10 | | DS. 07 A | Mdst, dk.gy. | 2.03 | 0.04 | 6.81 | 6.85 | 0.01 | 439 | 335 |
| 11 | | ES. 01 A | Mdst., dk.gy. | 1.03 | 0.06 | 2.12 | 2.18 | 0.03 | 438 | 206 |
| 12 | | DS. 34 A | Siltstone, dk.gy. | 0.18 | 0.01 | 0.02 | 0.03 | 0.50 | ND | 11 |
| 13 | Lubuktaruk Area | NS. 12 A | Shale, lt.gy. | 1.22 | 0.15 | 2.52 | 2.67 | 0.06 | 439 | 207 |
| 14 | | NS. 12 B | Mdst., spongy | 8.12 | 0.44 | 67.28 | 67.72 | 0.01 | 441 | 829 |
| 15 | | NS 12 E 10 | Mdst., spongy | 1.34 | 0.23 | 3.33 | 3.56 | 0.06 | 443 | 249 |
| 16 | Kiliranjao Area | NS. 13 C | Mdst,. Spongy | 7.23 | 0.65 | 62.5 | 63.15 | 0.01 | 432 | 864 |
| 17 | | NS. 13 E | Mdst., spongy | 9.03 | 1.68 | 78.04 | 79.72 | 0.03 | 432 | 864 |
| 18 | | NS. 14 G | Mdst. | 5.94 | 0.37 | 30.63 | 31.00 | 0.01 | 431 | 516 |
| 19 | | NS. 15 A | Siltstone | 3.00 | 0.14 | 14.52 | 14.66 | 0.01 | 432 | 484 |

Explanation:

TOC : Total Organic Carbon
S1 : Amount of free HC
PI : production index = S1/S1+S2
Mdst : mudstone
blk : black

S3 : Organic carbon dioxides
PY : Amount of total HC = S1+S2
dk : dark
brn : brown

$T_{max}$ : maximum temperature (°C) at top of S2 peak
HI : hydrogen index (S2/TOC) X 100
S2 : Amount of HC released from kerogen
gy : gray
calc : calcareous

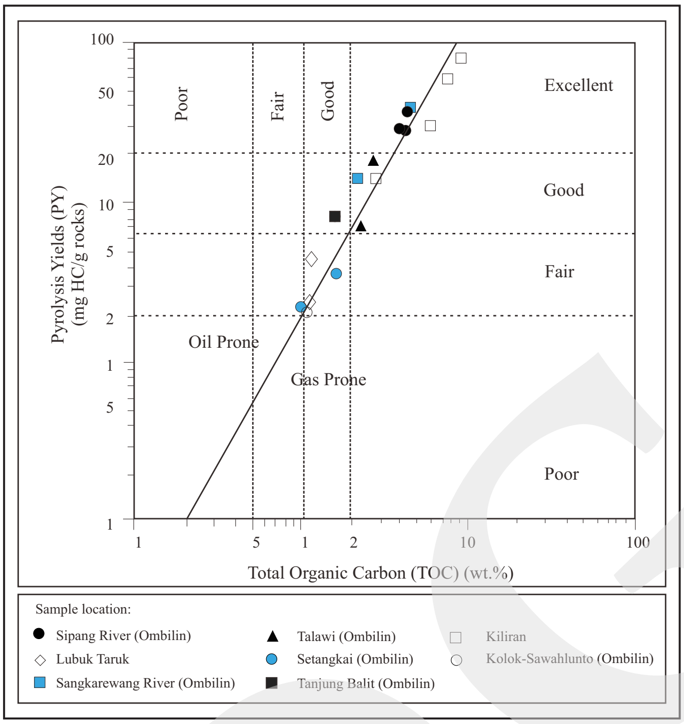

Figure 4. Diagram of TOC *versus* Pyrolysis Yields (PY) showing the richness and hydrocarbon potential of the Talawi (including Sipang River, Sangkarewang River, Setangkai, Tanjungbalit, and Kolok-Sawahlunto), Lubuktaruk, and Kiliranjao oil shales.

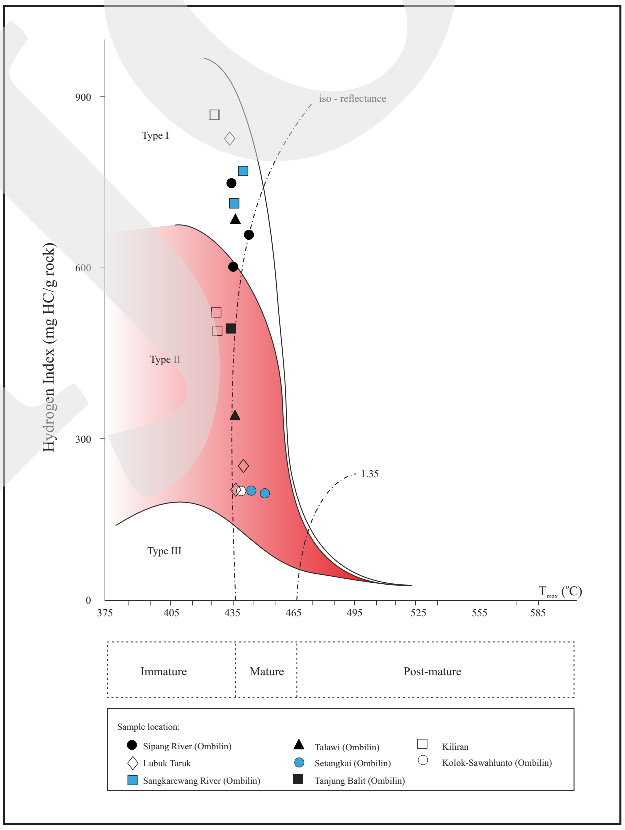

Figure 5. Hydrogen Index (HI) *versus* $T_{max}$ diagram, showing kerogen type of oil shale of the Talawi (including Sipang River, Sangkarewang River, Setangkai, Tanjungbalit, and Kolok-Sawahlunto); and Lubuktaruk areas, and also Kiliranjao region.

5). Moreover, their PI dominated by 0.01 values, tends to indicate a thermally immature level that means it has not reached oil generation maturity. However, on the basis of other $T_{max}$ and PI values (HR.01E and NS.01B), the samples tend to indicate an early mature stage. Thereby, the thermal maturity is of immature to early mature stage.

In addition, Widayat *et al*. (2013) who studied oil shale in Ombilin Basin, where Talawi area is situated, indicate that their samples contain TOC between 3.55 - 5.87%, pyrolysis yield (PY) varying from 27.47 - 42.79 mg HC/g rock, $T_{max}$ value between 435 - 439$^{o}$C, PI of 0.06 - 0.13, and HI ranging between 497.4 - 752.7 range. These characteristics tend to show that the samples are included into a good potential category, and situated in oil-prone level. Moreover, their thermal maturity can be classified as late mature to early mature stage, also supported by the PI value. The kerogen content is suggested to be Type I. The Widayat's result is concommittant with the author's study.

Retort-Oven analysis indicates that the oil content of the 25 analyzed samples of Talawi, predominantly varies from 3.0 to 97.0 l/t with averages 25.8 l/t (Table 2). The highest oil content occurs in sample NS.11A (97.0 1/t), whereas, the lowest oil content in NS.10G (3.0 1/t); both occur in Sipang River of Talawi area. Sixteen of twenty five samples represent a good to excellent level of hydrocarbon potential (oil content > 18.00 1/t). This condition is dominated by thirteen samples, that have average oil content of 37.35 1/t. However, in Lubuktaruk, the oil produced varies from 5 - 10 l/t.

Furthermore, in the Kiliranjao area, Rock-Eval pyrolysis (Table 1) and Retort-Oven analysis (Table 2) reveal that the four selected representative oil shale (mudstone and siltstone) samples (NS.13C, NS.13E, NS 14G, and NS.15A) show characteristics as described follows. The TOC values range between 3.00 - 9.03 % , pyrolysis yields (PY) between 14.66 - 79.72 mg HC/g rock, $T_{max}$ varies from 431° - 432° C, and hydrogen index (HI) of 484 - 864 range. Based on this data, thereby, the oil shale of this area is classified as an excellent potential level, included into Type I and II kerogens (Figure 5), and is dominated by oil-prone potential level (Figure 4) which can generate a significant amount of oil. Thermal maturity of the samples falls onto an immature stage (Figure 5). Thermal maturity of the rock samples is consistent, that the rocks are included into a late immature level and have not reached oil generation maturity (Figure 5). This condition is supported by the the dominant hydrocarbon potential index (PI) = ~ 0.01 (Table 1).

Table 2. Retort-Oven Analysis Data of the Talawi, Lubuktaruk, and Kiliranjao Areas

| No. | Sample Code | Location | Oil Content (l/t) | Water Content (l/t) |
|---|---|---|---|---|
| 1 | NS. 01 B | Ombilin Area | 8.0 | 104.0 |
| 2 | NS. 02 B | | 5.0 | 62.0 |
| 3 | NS. 04 D | | 5.0 | 50.0 |
| 4 | HR. 01 E | | 10.0 | 70.0 |
| 5 | HR. 03 A | | 10.0 | 78.0 |
| 6 | NS. 06 A | | 0.0 | 78.0 |
| 7 | NS. 07 A | | 18.0 | 172.0 |
| 8 | NS. 08 A | | 41.0 | 96.0 |
| 9 | NS. 08 D | | 36.0 | 132.0 |
| 10 | NS. 08 G | | 61.0 | 92.0 |
| 11 | NS. 08 J | | 28.0 | 72.0 |
| 12 | NS. 08 L | | 42.0 | 42.0 |
| 13 | NS. 10 A | | 18.0 | 20.0 |
| 14 | NS. 10 D | | 41.0 | 60.0 |
| 15 | NS. 10 G | | 3.0 | 68.0 |
| 16 | NS. 11 A | | 97.0 | 44.0 |
| 17 | NS. 11 E | | 36.0 | 92.0 |
| 18 | NS. 11 -I | | 44.0 | 62.0 |
| 19 | ES. 06 C | | 18.0 | 72.0 |
| 20 | ES. 06 D | | 22.0 | 44.0 |
| 21 | ES. 07 A | | 36.0 | 100.0 |
| 22 | NS. 18 A | | 13.0 | 118.0 |
| 23 | NS. 19 A | | 20.0 | 98.0 |
| 24 | NS. 05 A | | 18.0 | 200.0 |
| 25 | DS. 34 A | | 6.4 | 44.0 |
| 26 | NS. 12 A | Lubuktaruk Area | 10.0 | 96.0 |
| 27 | NS. 12 E 10 | | 5.0 | 70.0 |
| 28 | NS. 13 C | Kiliranjao Area | 50.0 | 92.0 |
| 29 | NS. 13 E | | 78.0 | 232.0 |
| 30 | NS. 14 A | | 24.0 | 192.0 |
| 31 | NS. 14G | | 28.0 | 396.0 |
| 32 | NS. I4 I | | 22.0 | 162.0 |
| 33 | NS. 15 A | | 24.0 | 28.0 |
| 34 | NS. 15 E | | 22.0 | 38.0 |

The excellent potential level of the Kiliranjao oil shale coincides with the Carnell *et al.*, (2013) study. They stated that the dark brown, faintly laminated, highly organic-rich shale, with predominant algal matter, contains TOC varying from 2.58 - 16.3% and HI of 424 - 743. On the basis of that condition, it can be interpreted that the shale is an excellent quality oil- prone source rock, with kerogen Type I-II.

Additionally, Widayat *et al.* (2013) who analyzed the oil shale samples from Kiliran (Kiliranjao) area, show the result as follows. TOC content of the samples gained varies from 2.10 - 10.94%, pyrolysis yield (PY) of 6.08 - 66.72 mg HC/g rock, HI ranging between 285.3 and 754.9, $T_{max}$ from 423 - 435°C, and PI of 0.01 - 0.02. These values tend to indicate that the oil shale of Kiliranjao can be classified as an excellent potential level, included into Type I and II kerogen, with thermal maturity level falls onto an immature class. Oil-prone potential level is suggested to dominate.

On the basis of Retort-Oven analysis, the oil content of the samples analyzed in Kiliranjao region ranges between 22.0 and 78.0 l/t.The highest oil content showing excellent level of oil potential occurs in sample NS.13B, whereas two samples (NS 14i and NS.15E have a similar lowest oil content.

### Organic Petrologic Analysis

Organic petrology result presented in Table 3 shows the maceral composition of DOM and its mineral matter content of the Talawi, Lubuktaruk, and Kiliranjao areas.

Table 3. Maceral and Mineral Matter Composition and Vitrinite Reflectance of the Talawi, Lubuktaruk, and Kiliranjao Oil Shale (Suwarna *et al*., 2000 and 2001; Iqbal, 2014)

| No | Sample Code | Lithology | Area/ Basin | E (%) | | | | | | | V (%) | Rv (%) | Py (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lam | Tel | Cut | Sp | Lpt | Res | Bitu | | | |
| 1 | HR.03B | Shaly Coal | Ombilin | 1.0 | - | - | - | - | - | - | 42.0 | 0.22 | 0.3 |
| 2 | HR.01E | Siltstone | | 0.1 | - | - | - | - | - | - | 0.1 | 0.23 | 4.0 |
| 3 | NS.01B | Siltstone | | 0.1 | - | - | - | - | - | - | 0.2 | 0.27 | 0.3 |
| 4 | NS.03A | Siltstone | | - | - | - | - | - | - | - | 0.3 | 0.24 | 0.2 |
| 5 | NS.05A | Siltstone | | 2.0 | 0.1 | 2.9 | 0.3 | 0.2 | 0.2 | - | 1.0 | 0.28 | 1.0 |
| 6 | NS.05E | Sandstone | | 0.1 | - | - | - | - | - | - | 0.2 | 0.38 | 0.1 |
| 7 | NS.05G | Siltstone | | 2.5 | - | - | - | - | - | - | 1.2 | 0.37 | 0.3 |
| 8 | NS.05J | Claystone | | 1.0 | - | - | - | - | - | - | 0.1 | 0.21 | 5.0 |
| 9 | NS.06A | Siltstone | | 25.0 | - | - | - | - | - | - | 0.1 | 0.25 | 4.8 |
| 10 | NS.07A | Siltstone | | 5.0 | - | - | - | 0.2 | - | - | 2.0 | 0.22 | 5.2 |
| 11 | NS.08A | Sandstone | | - | - | - | - | 0.1 | - | - | 0.1 | 0.32 | 0.1 |
| 12 | NS.08G | Claystone | | 55.0 | - | - | - | 1.0 | - | 0.1 | - | - | 6.0 |
| 13 | NS.08L | Claystone | | >55.0 | - | - | - | - | - | - | 0.1 | 0.19 | 5.8 |
| 14 | NS.10A | Claystone | | 43.0 | - | - | - | 2.0 | - | - | 0.1 | 0.19 | 6.6 |
| 15 | NS.10G | Siltstone | | 0.6 | - | - | - | - | - | - | 1.0 | 0.24 | 1.0 |
| 16 | NS.11A | Siltstone | | 19.5 | - | - | - | 0.5 | - | 0.1 | 4.0 | 0.17 | 5.2 |
| 17 | NS.12A | Claystone | | 2.5 | - | - | - | 0.1 | - | - | - | - | 0.8 |
| 18 | NS.12B | Claystone | | 27.5 | - | - | - | 2.5 | - | - | 0.1 | 0.22 | 5.2 |
| 19 | NS.12E | Shaly Coal | | - | - | 1.0 | 1.0 | - | - | - | 42.0 | 0.36 | 15.0 |
| 20 | NS.18A | Siltstone | | 1.4 | - | - | - | 0.1 | - | - | 0.3 | 0.20 | 4.8 |
| 21 | NS.19B | Siltstone | | 29.9 | - | - | - | 1.0 | - | 0.1 | 0.2 | 0.19 | 4.6 |
| 22 | RH.02A | Siltstone | | - | - | - | - | 0.1 | - | - | 0.2 | 0.40 | 0.8 |
| 23 | RH.02K | Siltstone | | - | - | - | - | - | - | - | 0.2 | 0.37 | 0.2 |
| 24 | RH.02P | Siltstone | | 0.4 | - | - | - | - | - | - | 0.2 | 0.25 | 0.3 |
| 25 | NS.13C | Siltstone | Kiliran | 0.3 | - | - | - | - | - | - | 4.2 | 0.25 | 0.2 |
| 26 | NS.13E | Siltstone | | 5.0 | - | - | - | - | - | - | 0.1 | 0.20 | 1.0 |
| 27 | NS.14A | Siltstone | | 1.0 | - | - | - | - | - | - | 0.2 | 0.21 | 1.1 |
| 28 | NS.14G | Siltstone | | 1.5 | - | - | - | - | - | - | 0.2 | 0.25 | 0.3 |
| 29 | NS.14i | Shaly Coal | | 0.1 | - | 0.1 | - | - | - | - | 38.0 | 0.40 | 1.0 |
| 30 | NS.15A | Siltstone | | 29.3 | - | - | - | 0.7 | - | - | 3.2 | 0.23 | 5.2 |
| 31 | NS.15B | Siltstone | | 3.4 | - | - | - | 0.1 | - | - | 0.3 | 0.20 | 0.9 |
| 32 | NS.15E | Siltstone | | 7.0 | 0.1 | - | - | - | - | - | 4.0 | 0.25 | 5.2 |
| 33 | IQ 13 | Claystone | | 10.0 | 0.2 | - | - | 0.1 | - | - | 2.0 | 0.20 | 5.2 |
| 34 | IQ 18 | Claystone | | 3.0 | 0.1 | - | - | 0.1 | - | 0.1 | 0.2 | 0.23 | 4.8 |

Explanation:

E : Exinite
Lam : Lamalginite
Tel : Telalginite
Cut : Cutinite
Sp : Sporinite
Lpt : Liptodetrinite
Re : Resinite
Bitu : Bituminite
V : Vitrinite
Rv : Vitrinite reflectance
Py : Framboidal pyrite

In Talawi and Lubuktaruk areas, petrographically, the maceral composition of oil shales determined on twenty one and three selected samples, respectively (Table 3) is dominated by exinite group (0.1 - 55.0 %) comprising lamalginite of 0.1 - 55.0 %, with minor *Botryococcus*-telalginite (0.1 %), cutinite (1.0 - 2.9%), resinite (0.2%), liptodetrinite (0.1 - 2.5%), sporinite (0.3 - 1.0%), and bituminite (0.1%). Minor amounts of vitrinite macerals of 0.2 - 2.0 % are also recognized. Mineral matter present are mainly pyrite of framboidal type (0.2 - 15.0%) and clay minerals. The mean vitrinite reflectance varies from 0.17 - 0.40 %.

However, the mean vitrinite reflectance is dominated by 0.19 - 0.25 %. Weakly fluorescent matrix (groundmass) is evident in most fine-grained samples, indicating the presence of hydrogen-rich organic matter (Robert, 1981; Bustin *et al.*, 1985).

Moreover, the diagenesis stage of the Talawi and Lubuktaruk oil shale is presented in Table 4. SEM analysis shown in Table 4, reveals that the shales of both Talawi and Lubuktaruk areas are characterized by compact dense presence of smectite, illite, with kaolinite. It indicates a mesodiagenesis to early mesodiagenesis level which can be correlated to vitrinite reflectance of <4%.

Furthermore, alginite present in the oil shale samples is predominantly "lamalginite" (Table 3), of a yellow to orange fluorescence colour (Figure 6a). Therefore, the oil shale deposits can be termed as "lamosites", although a very rare of probably *Botryococcus* telalginite also occurs.

In Kiliranjao area, macerals occurring (Table 3) as DOM (Figures 2 and 6b) within the eight oil shale samples are predominated by exinite (liptinite) group comprising lamalginite (0.1 - 29.3%), followed by liptodetrinite (0.1 - 0.7%), *Botryococcus*-telalginite (0.1 - 0.2%), cutinite of 0.1%, and bituminite of 0.1%. Sparse to abundant vitrinite maceral is also determined of 0.2 to 4.0%, with one sample ( NS.14i) shows value of 38.0 %. Some macerals present (Table 4), can also be identified by Scanning Electron Microscopy (SEM) such as Pediastrum-lamalginite (Figure 7), *Botryococcus*-telalginite (Figure 8), and vitrinite. The dominant range of mean vitrinite reflectance ($Rv_{max}$) is situated between 0.20 % and 0.25 %. Weakly fluorescent matrix (groundmass) is evident in most fine-grained samples, indicating the presence of hydrogen-rich organic matter (Robert, 1981; Bustin *et al.*, 1985). Some framboidal pyrites (0.2 - 5.2 %) commonly occur (Figure 3). The mean vitrinite reflectance ($Rv_{max}$) varying from 0.20 - 0.25%, is situated within the diagenesis level, also tends to indicate an immature stage.

SEM analysis shown in Table 4, reveals that the representative shale of Kiliranjao area is characterized by compaction and the presence of

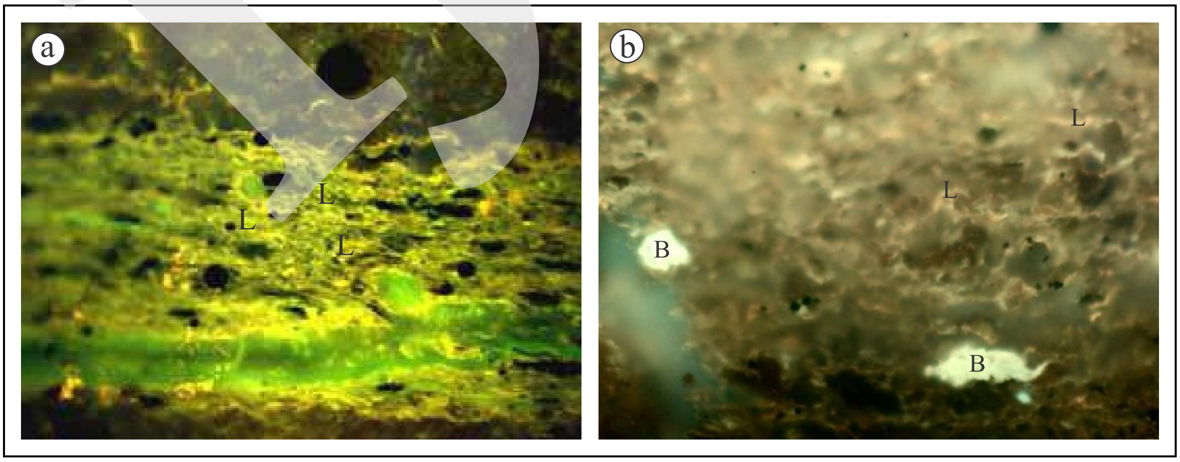

Figure 6. (a). Photomicrograph of lamalginite set (L; yellow parallel lamellar bodies) in oil shale sample of the Sangkarewang Formation, Ombilin area (Fluorescence mode). (Source Fatimah, 2009). (b). Photomicrograph of lamalginite (L; pale yellow lamelar form) and (?)*Botryococcus*-telalginite (B; pale yellow subrounded form) set in oil shale of Kiliran Formation (Fluorescence mode).

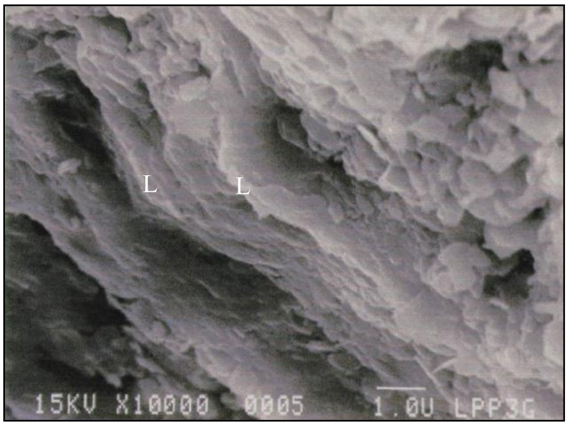

Figure 7. SEM photomicrograph of shale showing organic matter of lamalginite (L), typically *Pediastrum* (Suwarna *et al*., 2000).

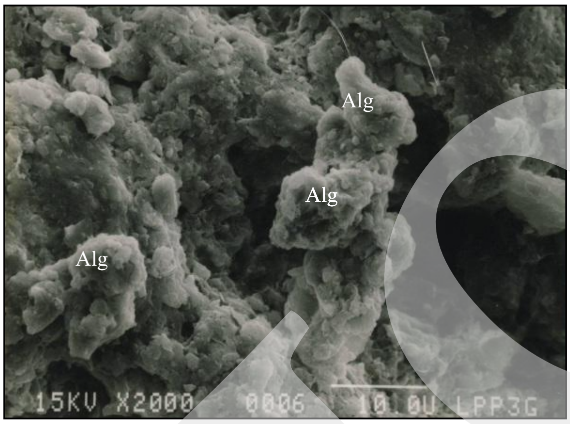

Figure 8. SEM photomicrograph of organic matter of typical alginite (?*Botryococcus*/Alg) and some drop oil (bitumen) within disordered kaolinite of Kiliranjao oil shale (Suwarna *et al*., 2000).

smectite-illite with rare kaolinite. It is interpreted probably to have been buried of more than 1000 m deep, which then to indicate a mesodiagenesis stage which can be correlated with vitrinite reflectance of <0.4%.

On the basis of Cook *et al*. (1981), Hutton (1987) and Hutton *et al*. (1988) terminologies, due to the organic matter comprises predominantly algae of typical lamalginite, along with a very minor amount of probable *Botryococcus* telalginite, the shales and mudstones of Talawi, Lubuktaruk, and Kiliranjao areas can be classified as lamosites of Rundle-type. Hutton (1987) indicated that the Rundle-type oil shales were derived mainly from green algae deposited in a fresh to brackish lacustrine condition. Thereby, the Talawi, Lubuktaruk, and Kiliranjao oil shales were deposited in a fresh to brackish lacustrine environment. This condition is also supported by the presence of low to high content of framboidal pyrite showing a marine incursion.

Summarizing the three studied areas, the kerogen contained in oil shales is included into Type II and Type I in an almost similar amount (Figure 5). The oil shales contain both autochthonous and allochthonous organic material. The autochthonous materials consist of Type I kerogen, alginite, and exsudatinite, whilst the allochthonous type comprises Type II kerogen, sporinite, cutinite, resinite, and vitrinite, of floral/humic origin. By using a combination of TOC, PY, and HI values, in accordance with Rad's parameter (1984) the oil shales of the three areas studied falls on fair to excellent category, oil-prone with minor gas-oil prone potential, predominantly situated within a thermally immature level. Based on Espitalie *et al*. (1977) and Peters (1986) statements, the pyrolysis yield of >10 mg HC/g rock, occuring in Talawi, Lubuktaruk, and Kiliranjao oil shales, tends to indicate that they are classified as a very good or excellent source-rock potential, which also can be classified as an 'effective source-rock'. It is suggested that those oil shales can be defined as organic-rich substances containing significant amounts of oil- to gas-prone kerogen which can produce oil upon heating. Moreover, Tissot and Welte (1984) stated that oil shale containing organic matter typically > 5%, can be defined as alternative sources for fossil fuels. It is also supported by Peters' observation (1986 and 1989), that rocks with HI>300 mg HC/g TOC will produce oil. Additionally, the thermal maturity of the samples, in general, is included into immature stage, with some samples showing an early mature stage.

Most vitrinite reflectance value ranging between 0.19 % to 0.28 %., shows that these values fall beyond the "oil birth" line occupying the non-onset oil zone. However, sample NS.14i has a slightly higher reflectance indicating that it is close to the oil "birth" line, although still within the non-onset oil area.

The majority of PI values of the samples that are less than 0.1 (Table 1), indicate that the

Table 4. SEM Characteristics of Some Selected Oil Shales of the Sangkarewang and Kiliran Formations (Suwarna *et al*., 2000 and 2001)

| Sample Number | Lithology | Clay Mineral | "Fossil Fuel" Emelent | Diagenesis Character | Diagenesis Regime | Remaks |
|---|---|---|---|---|---|---|
| NS. 06 A 1 Tg. Balit | Claystone / mudstone | Mixed kaolinite and smectite. | Abundant alginite of typically "*Pediastrum*". | Compact, dense, the presence of clay minerals (kaolinite, smectite) and micropores among clay minerals. | Late Eodiagenesis to Early Mesodiagenesis. | Had been buried of not more than 1000 m deep. |
| NS. 08 A S. Sipang | Shale | Smectite, minor illite and kaolinite. | Alginite of typically *Pediastrum* (lamalginite). | Compaction, the presence of clay minerals (smectite, and minor illite and kaolinite). | Eodiagenesis - Early Mesodiagenesis. | Probably had been buried of less than 1000 m deep. |
| NS. 08 L S. Sipang | Mudstone | Smectite-illite, and kaolinite. | Alginite (lamalginite) | Compaction and dense the presence of smectite-illite, and kaolinite. | Early Mesodiagenesis. | Had been buried of less than 1000 m deep. |
| NS. 12 A Bt. Porogadang) | Shale | Smectite-illite. | Alginite of "*Pediastrum*" type (lamalginite). | Compact and dense, directed clay minerals, and the presence of smectite and illite. | Early Mesodiagenesis. | Had been buried of more than 1000 m deep. |
| NS. 12 E 4 (Bt. Porogadang) | Sandstone, fine-grained | Smectite, illite, and minor kaolinite. | Many vitrinite and liptinite as sporanite. | Compaction and the presence of clay minerals (smectite-illite). | Late Eodiagenesis to Early Mesodiagenesis. | Had been buried of more than 1000 m deep. |
| NS. 18 A S. Sangkarewang | Sandstone | Kaolinite and smectite-illite. | Rare to absent. | Compaction, the presence of clay minerals (smectite-illite and kaolinite). | Late Eodiagenesis to Early Mesodiagenesis. | Probably had been buried of not more 1000 m deep. |
| RH. 02 A Padang-ganting) | Shale | Smectite-illite, and a little kaolinite. | Abundant lamalginite, typically "*Pediastrum*". | Compact, dense, the presence of clay minerals (smectite-illite), and micropores among them. | Late Eodiagenesis to Early Mesodiagenesis. | Probably had been buried of not more 1000 m deep. |
| HR. 01 E Setangkai (Atar) | Claystone / mudstone. | Kaolinite. | Rare lamalginite. | Compaction and the presence of kaolinite. | Late Eodiagenesis to Early Mesodiagenesis. | Probably had been buried of not more than 1000 m deep. |
| NS. 13 C Kunangan | Shale | Smectite-illite, rare kaolinite. | Abundant lamalginite, typically "Pediastrum". | Compaction and the presence of smectite-illite. | Mesodiagenesis. | Probably had been buried of more than 1000 m deep. |

Talawi, Lubuktaruk, and Kiliranjao oil shales are situated within an immature stage. Overall, the vitrinite reflectance agrees with the $T_{max}$ and PI values, and also diagenesis stage of clay minerals showing Eo-Mesodiagenetic level. This condition is in accordance with Foscolos *et al*.'s chart (1976), that due to their $Rv_{max}$ values of <0.4 %, the oil shales had undergone an eodiagenetic process.

## Conclusion

Oil shales from Talawi, Lubuktaruk, and Kiliranjao areas show an excellent to fair hydrocarbon potential level, with kerogen contained is included into Type I and II. They can be categorized as oil-prone source-rock, with thermal maturity significantly varies from an immature to early mature level, dominated by immature stage.

The low values of vitrinite reflectance tend to indicate that they are dominantly situated beyond the "oil birth" line occupying the non-onset oil zone. The maceral composition of oil shales in the studied areas is dominated by exinite group mainly Pediastrum-lamalginite along with a lesser extent of *Botryococcus*-telalginite, liptodetrinite, sporinite, cutinite, resinite, and bituminite. Mineral matter present, besides clay, is mainly framboidal pyrite.

The oil shales dominated by "lamosites" of Rundle-type, are classified as an excellent to very good source-rock potential, which then can be classified as an 'effective source-rock' of hydrocarbon.

Depositional environment of the oil shales were fresh to brackish lacustrine zones.

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