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# The Potential of Ketungau and Silat Shales in Ketungau and Melawi Basins, West Kalimantan: For Oil Shale and Shale Gas Exploration

# *Potensi Serpih Ketungau dan Silat di Cekungan Ketungau dan Melawi, Kalimantan Barat: Untuk Eksplorasi Oil Shale dan Shale Gas*

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**Abstract**

The Ketungau and Melawi Basins, in West Kalimantan, are Tertiary intramontane basins of which the potential for economic conventional oil and gas discoveries have not previously been confirmed. The Ketungau Basin is bordered by the Melawi Basin in the south. Besides non-ideal trapping mechanisms, another major problem in these basins is source rock maturation. Nevertheless, both basins are promising to be explored for oil shale and shale gas energy resources. Therefore, the aim of this paper is to give some perspectives on their source rocks, as an input for the evaluation of the potential of unconventional oil and gas. About twenty samples collected from the Ketungau and Melawi Basins were analyzed using pyrolysis and organic petrographic methods. The results show a poor to good quality of source rock potential. The Ketungau shale, which is the main source rock in the Ketungau Basin, is dominated by type III, immature, and gas prone kerogen. The Silat shale, which is the main source rock in the Melawi Basin, is dominated by type II, immature to early mature, mixed gas, and oil prone kerogen. In the field, Ketungau and Silat Formations have a widespread distribution, and are typically 900 m to 1000 m thick. Both the Ketungau and Silat shales occur within synclinal structures, which have a poor trapping mechanism for conventional oil or gas targets, but are suitable for oil shale and shale gas exploration. This early stage of research clearly shows good potential for the future development of unconventional energy within the Ketungau and Melawi Basins.

**Keywords**: Ketungau and Melawi Basins, oil shale, shale gas, unconventional energy

***Sari***

*Cekungan Ketungau dan Melawi di Kalimantan Barat adalah cekungan antar pegunungan yang secara ekonomis belum cukup terbukti sebagai cekungan berpotensi minyak dan gas untuk dieksplorasi. Di selatan, cekungan ini berbatasan dengan Cekungan Melawi. Selain mekanisme perangkap yang tidak ideal, masalah utama lain pada cekungan-cekungan tersebut adalah kematangan batuan sumber. Namun demikian, kedua cekungan tersebut menjanjikan kehadiran sumber daya energi minyak dan gas serpih. Oleh sebab itu, makalah ini bertujuan untuk memberikan beberapa perspektif sumber batuan di permukaan, sehingga cekungan tersebut dapat ditentukan potensi energi non-konvensionalnya. Sebanyak dua puluh percontoh yang diambil dari Cekungan Ketungau dan Melawi telah dianalisis dengan menggunakan metode petrogafi organik dan pirolisis. Hasilnya memperlihatkan bahwa potensi sumber batuannya "buruk" sampai "baik". Serpih Ketungau yang merupakan batuan sumber utama di Cekungan Ketungau didominasi oleh kerogen type III, tidak matang, dan berpotensi sebagai gas prone. Sementara itu, Serpih Silat yang merupakan batuan sumber utama di Cekungan Melawi, didominasi oleh kerogen tipe II, tidak matang sampai matang awal, dan berpotensi menghasilkan minyak dan gas. Di lapangan, Formasi Ketungau dan Serpih Silat tersebar luas, dan mempunyai ketebalan antara 900 m sampai 1000 m. Kedua formasi terdapat pada suatu struktur sinklin, sehingga sangat buruk sebagai perangkap untuk eksplorasi sumber daya energi konvensional. Sebaliknya struktur tersebut cocok untuk eksplorasi serpih minyak dan serpih gas. Tahap penelitian awal di Cekungan Ketungau dan Melawi jelas memperlihatkan hasil baik, sehingga bisa dikembangkan untuk mendapatkan sumber daya energi non konvensional di masa mendatang.*

***Kata kunci***: *Cekungan Ketungau dan Melawi, serpih minyak, gas serpih, energi nonkonvensional*

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## Introduction

### Background

The Ketungau and Melawi Basins are located in the West Kalimantan region, adjacent to the Malaysian border (Figure 1). The Melawi Basin, in the south is separated from the Ketungau Basin by the Semitau High. Tectonically, the Ketungau and Melawi Basins can be classified as intramontane basins. The Ketungau and Melawi basins are separated from each other by a belt of deep-water rocks and a belt of melange (Boyan Melange; Williams *et al.*, 1984). On the northern margin, the Ketungau Basin is also bounded by the Lubok Antu Melange (Tan, 1982).

Preliminary exploration and assessment of the Ketungau and Melawi Basins were carried out during 1980s and 1990s by several oil companies, including Pertamina and Canadian Occidental Petroleum (Canadian Occidental Petroleum Ltd, 1992). In 1995, Canadian Oxy also ran some seismic lines and drilled some wells, including well Kedukul-1 (Canadian Oxy, 1995). However, no economic discovery was made. The most recent assessment work is conducted by Lemigas Team, and resulted in the Kayan Play Model for Melawi Basin exploration (Lemigas, 2004; Yulihanto *et al.*, 2006).

Recently, in 2009-2010, the Geological Agency carried out field work activities in the Ketungau

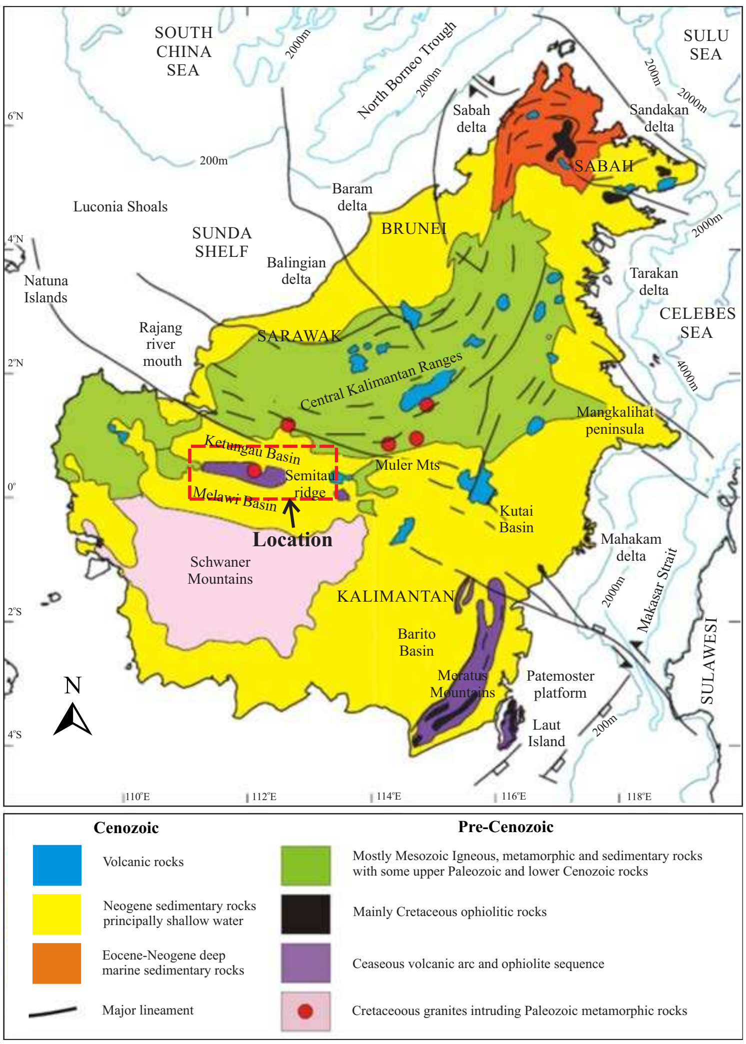


Figure 1. Regional geological pattern of Kalimantan (Halls and Nichols, 2002), showing rock unit distributions, structure and major lineament, and location discussed.

and Melawi Basins, which was intended to collect field data, outcrop samples, and sedimentologic and stratigraphy data, as reported by Santy *et al.* (2009), Gumilar *et al.* (2009), Heryanto *et al.* (2009), Santy *et al.* (2010), and Gumilar *et al.* (2010). Observation had been done in the Ketungau Formation, outcropping in Ketungau and Sekalau River, and Silat Formation, outcropping in Silat Rivers and its tributaries in the Melawi Basin (Figure 2). The aim of the study is to assess the probability of petroleum source rock potential for hydrocarbon play in the Ketungau and Melawi Basins. Several samples had been selected for an organic geochemistry analysis.

## General Geological Setting

Tectonic activities in this region were controlled by the movement of Eurasian Plate to the southeast during Cretaceous - Early Tertiary. Pre-Tertiary tectonic activities created uplifting of Semitau Complex and Boyan Melange Complex separating the Ketungau and Melawi Basin (Williams *et al*., 1984). Nevertheless, Halls and Nichols (2002) suggest that the Ketungau and Melawi Basins are not conventional foreland basin formed by loading of thrust sheets, indicated by the absence of thin skinned thrusting in the highly eroded areas.

The pattern of Ketungau-Melawi Basin boundaries follows the direction pattern of NW-SE strike slip zone developing during Eocene-Oligocene (± 30 Ma) at the Sundaland Margin in Kalimantan (Hall, 1996). A 45$^o$ counter clockwise rotation during Late Oligocene to Early Miocene (± 20-10 Ma) resulted in a basin configuration as observed today. The next Neogene tectonic activities caused an E-W trending thrust system (Yulihanto *et al*., 2006), sediment folding, and created Ketungau, Silat, and Melawi synclines, as well as Sintang anticline (Figures 1 and 2).

The base of Ketungau and Melawi Basins is not exposed, though there is a thick succession of lithic arenite sandstone sequence consisting of sandstone, silt, and mudstone. The thick sediment succession is a result of basin subsidence as the response of sedi-

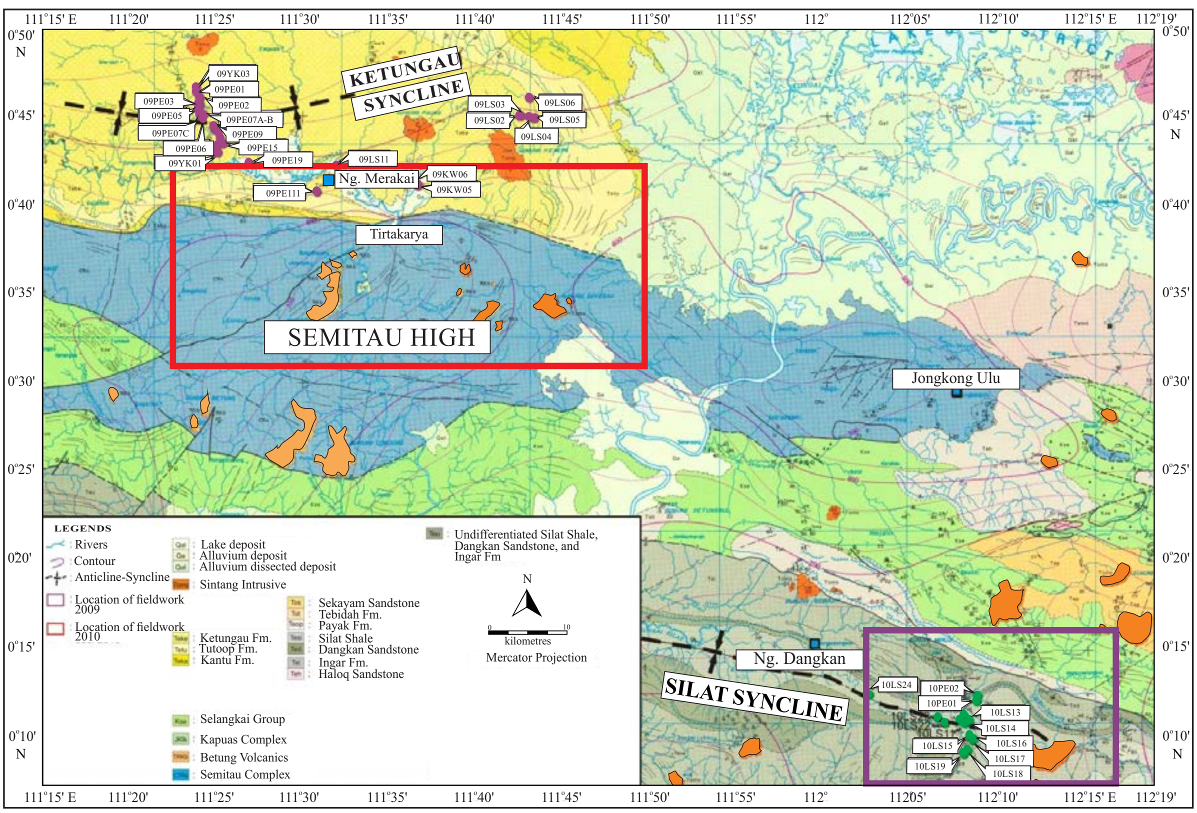


Figure 2. Geological Map of Ketungau-Melawai Basins (Heryanto, 1993 a&b); showing location observations and sample locations during fieldwork conducted in 2009 & 2010.

ment infill in the boundary between a linear zone of granite and schist in the northern part (Semitau High), and the base of continental plate in the southern part (Schwaner Mountain Zone).

Sediment infill in the Ketungau-Melawi basin was dominantly from the eroded rocks of older orogen in the Kalimantan Island. Small part of sediment supply probably also comes from Indochina land (Halls and Nichols, 2002). High rate of clastic detrital sediment supply in this basin had suppressed the productive development of carbonate benthic, therefore no well developed carbonate sediments exist (Smith *et al*., 1990; Halls and Nichols, 2002).

Sedimentary phase of the Ketungau Basin occurred during Eocene until Oligocene, with the deposition of fluvial conglomerate unit gradationally change to be lacustrine and shallow marine sediment unit of Kantu Formation (Figure 3). The Kantu Formation is conformably overlain by a fluvial clastic unit of the Tutoop Formation and a fluvio-marine deposit of the Ketungau Formation (Pieters *et al.*, 1987; Heryanto *et al.*, 1993a&b; Supriyatna *et al.*, 1993).

Stratigraphic succession in the early development of the Melawi Basin has a similar characteristic and lithologic distribution with the Ketungau Basin. Those formations were deposited above the Pre-Tertiary basal sediments of Selangkai Formation (Figure 3; Heryanto *et al.*,1993a&b). The Haloq Formation, the oldest sediments deposited in the basin, is regarded as an equivalence of Lower Ketungau. This formation consists of fluvial quartz sandstone and conglomeratic unit, deposited during Upper Eocene. The Ingar Formation unconformably overlying the Haloq Formation, consists of alternating mudstone, silt, and fine sandstone of lacustrine deposit. The Dangkan Formation, which is considered to be equivalent to the Tutoop sandstone, was deposited unconformably over the Ingar Formation. It is followed by the Silat Shale, regarded to be equivalent to the Ketungau Formation, that was deposited during Oligocene. When the sediment deposition in the Ketungau Basin had terminated, the deposition in the Melawi Basin still occurred where fluvial units of the Payak, Tebidah, and Sekayam Formations were deposited (Pieters *et al.*, 1987, Pieters *et al.*, 1993)

### Description of Ketungau and Silat Formations

As a whole packet, the Ketungau Formation is 900 m thick, consisting of claystone, shale, silt, fine sandstone, and thin bedded coal in the upper part (Figure 4a). Claystone layers usually contain silt or fine sand concretions and mollusk fossils of Gastropods and Bivalves. Ichnofossils of *Planolites*, *Thalassinoides*, and *Ophiomorpha* were sometimes found in some layers (Figure 5). Sandstone is usually micaceous and contains framboidal pyrite as an indication of marine influence (Stach *et al.*, 1982; Diessel, 1992). Shale layers are flaky, rich in organic matters, and contain mollusk fossils of Gastropods and Bivalves, of which some of them are in juvenile forms. The depositional environment of this formation is fluvio-marine, with the interval of shallow marine sediments appearing periodically (Heryanto *et al.*,1993a&b).

The Silat Formation consists of 1000 thick sediments, dominated by black carbonaceous mudstone, shale, slaty shale, minor dark coloured siltstone, fine- to medium-grained sandstone, and occasionally thin layer of coal (Figures 4b and 6). In several spots, there are also rich layers of Gastropod, Pelecypod, and plant remains. The depositional environment of Silat shale is fluvio-marine to open marine (Pieters *et al.*, 1987, Heryanto *et al.*, 1993a & b).

## Methods

Field studies were carried out in 2009 (Santy *et al.*, 2009; Gumilar *et al.*, 2009, and Suyono *et al.*, 2009) within the Ketungau Basin, including the collection samples of the Ketungau Formation at the Ketungau and Sekalau Rivers and their tributaries (Figure 2). In 2010, the fieldwork (Santy *et al.*, 2010, Gumilar *et al.*, 2010) was continued within the Melawi Basin, including the collection of samples of the Silat Formation at the Silat River and its tributaries (Figure 2).

Several samples were carefully selected for the laboratory analysis, including eighteen samples of organic fine sediments for petroleum geochemistry analysis. Rock-Eval Pyrolysis and Gas Chromatography-Mass Spectometry (GC-MS) were carried out at Lemigas. Eight samples from the Ketungau Formation and ten samples from the Silat Formation were picked up for Rock-Eval Pyrolysis (Table 1) to test their total organic carbon (TOC), maximum temperature at the top of S2 peak ($^{o}$C, $T_{max}$), the amount of free hydrocarbon (S1), the amount of hydrocar-

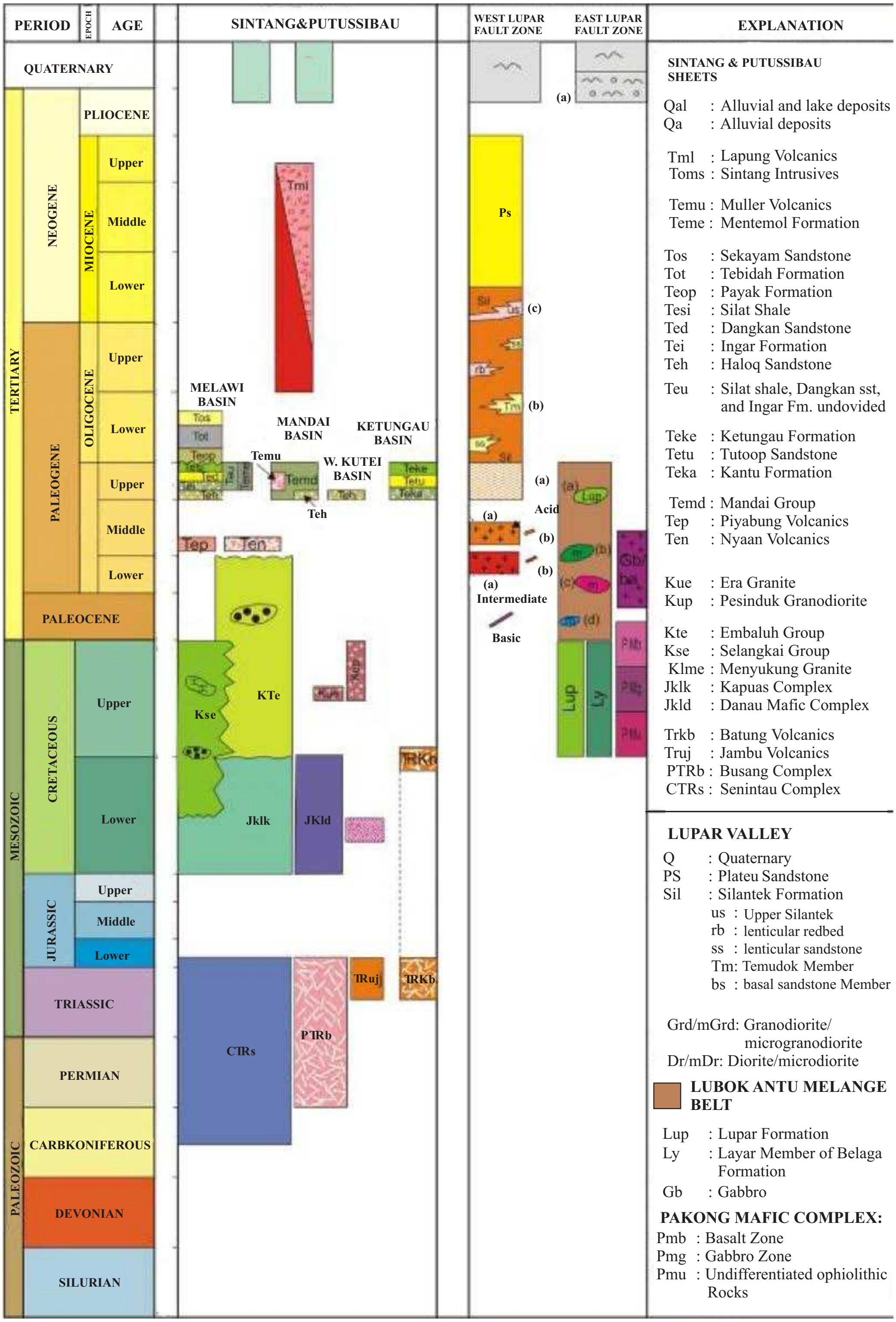


Figure 3. Stratigraphic comparison between Ketungau Basin and Melawi Basin, and Lupar-Serawak Valley (Tan, 1979; Heryanto *et al.* 1993 a&b).

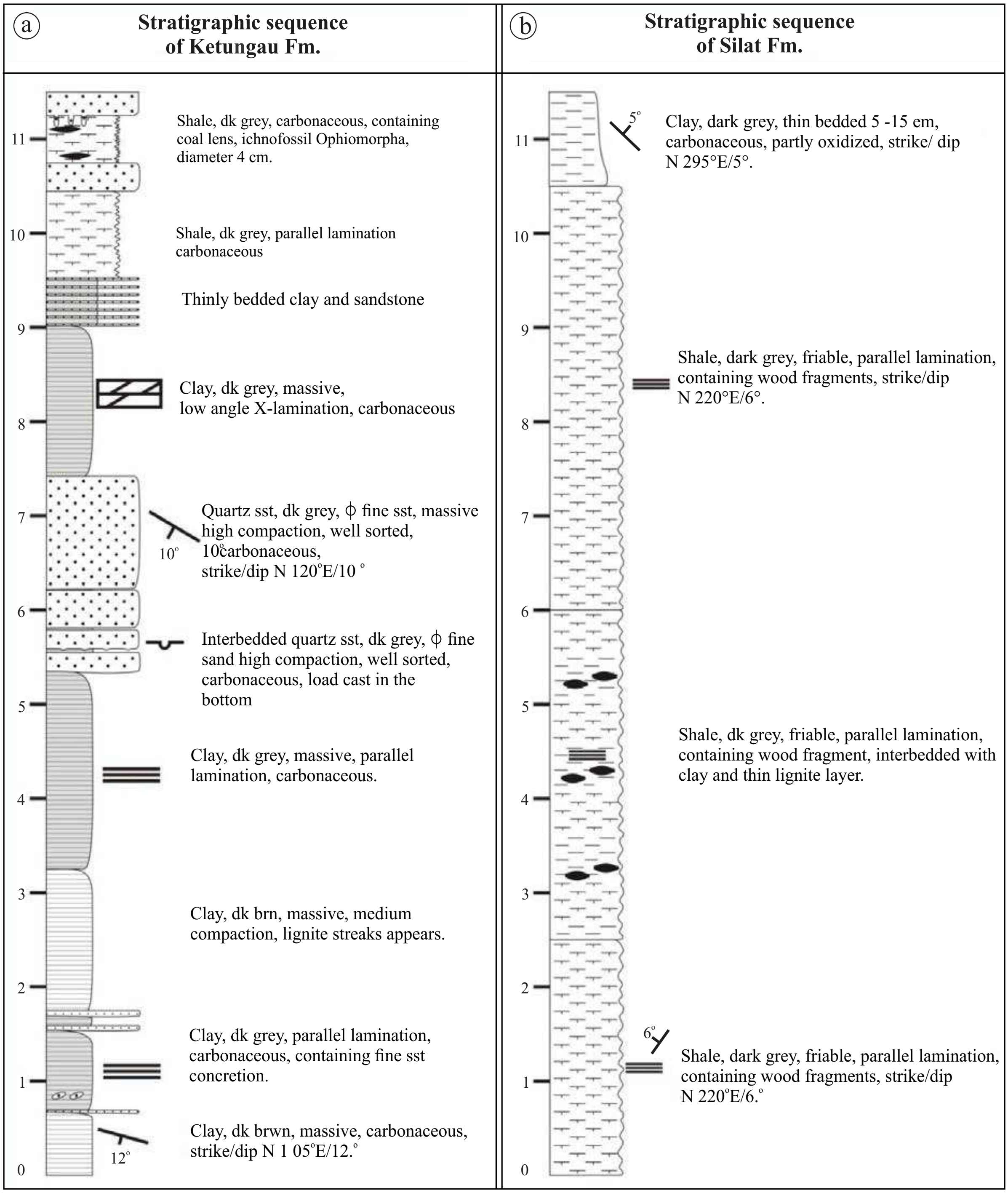


Figure 4. Stratigraphic sequence of Ketungau and Silat Formations. a. Ketungau stratigraphic sequence is taken from location 09LS02, Temiang Hill. b. Silat stratigraphic sequence is taken from location 10LS17, Pengga River.

Figure 5. Thick layer of Ketungau Shale contains fine sand concretions and *Ophiomorpha* ichnofossil. Location of the outcrop is at point 09PE10,Sekalau River (see Figure 2 for the position on the map).

Figure 6. Carbonaceous shale of Silat Formation, outcropping at point 10LS17, Sengkuang Teribuk (see Figure 2 for the position on the map).

bon released from kerogen (S2), and the amount of organic carbon dioxide (S3). Whereas, totally eight samples were taken for GC-MS analysis (Table 2). The analysis were conducted for biomarker purposes in order to determine the origin of organic matter and the maturity level of the source rocks following the method recommended by Bordenave (1993). The analysis includes derivation values of n-alkanes, steranes, isoprenoids, and triterpanes.

Total hydrocarbon volume is calculated through the formula suggested by Waples (1985), as follows :

Volume of HC = (k) x (TOC) x (HI)x(f)

Total HC volume = (HC volume/cubic mile) x (cubic mile of source rock)

Total oil can be generated = (Expulsion effi ciency) x (Total HC volume)

Where :

k = 0,7 (constant value for shale)

TOC = Total Organic Carbon (in wt%)

HI = Hydrogen Indeks (mg HC/ gr TOC)

*f* = value of fractional conversion for HC maturity

Maturity is expressed as a fraction f between 0 (completely immature) and 1 (fully mature). Sluijk and Nederlof (1984, in Waples 1985) suggested a relationship between reflectance vitrinite values (Ro) and fractional conversion (f) of every types of kerogen, as shown in Figure 7.

## Source Rock Evaluation

### Origin of Organic Matter

The origin of organic matter is determined from the content of normal alkanes, isoprenoids, triterpanes, and steranes in every samples analyzed. Biomarker analysis was conducted from two samples of the Ketungau Formation and six samples of the Silat Formation (Table 2).

Waples (1985) explains isoprenoid as a good indicator of depositional environment. High ratio of pr/ph (with CPI < 1) usually marks oxidizing environment (Bordenave (1993). Peters and Moldowan (1993) mention that the presence of oleanane and gammacerane can be used to differentiate terrestrial high plant origin over hypersaline condition. While the application of sterane hase been used by Huang and Meinschein (1979, in Waples and Machihara, 1991), and Bordenave (1993) to determine the depositional environment. The relative amount of $C_{27}$-$C_{29}$ in sterol is related to a specific range of depositional environment. Therefore, the content of sterane in the sediments will be useful in determining the origin of organic matter.

Biomarker analysis for all Ketungau samples show pr/ph ratio > 1, indicating an oxic marine condition (Table 2). Plotting of $C_{27}$-$C_{29}$ distribution (Figure 8) also resulted in the similar depositional environment. However the presence of oleanane in all samples (ranging from 0.04 - 0.06;Table 2) suggests input of terrestrial high plants (Moldowan *et al.*, 1985; Peters and Moldowan, 1993). Therefore the environment suitable for these conditions is an

Table 1. TOC and Pyrolysis Rock Eval Data of Ketungau and Silat Formations

| No | Formation | Sample No. | Sample Tipe | Analized Lithology | TOC (%) | S1 | S2 | S3 | PY | S2/S3 | PI | PC | $T_{max}$ (°C) | HI | OI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | mg/g | | | | | | | | | |
| 1 | Ketungau | 09 LS 02 A | OC | Shale, dkgy, Hd | 0.64 | 0.40 | 0.13 | 0.07 | 0.53 | 1.86 | 0.75 | 0.04 | 360** | 20 | 11 |
| 2 | | 09 LS 03 B | OC | Shale, v dkgy, sl hd, slickensided (slighty meta) | 4.70 | 0.15 | 0.00 | 2.23 | 0.15 | 0.00 | 1.00 | 0.01 | 412** | 0 | 47 |
| 3 | | 09 LS 05 A | OC | Shale, v dkgy, sl hd, slickensided (slighty meta) | 4.72 | 0.09 | 0.00 | 0.20 | 0.09 | 0.00 | 1.00 | 0.01 | 247** | 0 | 4 |
| 4 | | 09 LS 05 B | OC | Shale, v dkgy, hd, slighty meta | 0.86 | 0.06 | 0.00 | 0.15 | 0.06 | 0.00 | 1.00 | 0.00 | 246** | 0 | 18 |
| 5 | | 09 LS 11 D | OC | Shale, brn dkgy | 2.79 | 0.37 | 4.48 | 0.49 | 4.85 | 9.14 | 0.08 | 0.40 | 424 | 160 | 18 |
| 6 | | 09 PE 18 A | OC | Shale, v dkgy/blk | 10.53 | 0.18 | 7.52 | 2.43 | 7.70 | 3.09 | 0.02 | 0.64 | 415 | 71 | 23 |
| 7 | | 09 PE 18 C | OC | coal, blk, vitreos | 50.63 | 1.32 | 66.86 | 5.66 | 68.18 | 11.81 | 0.02 | 5.66 | 412 | 132 | 11 |
| 8 | | 09 YK 09 | OC | claystone, gy-med dkgy | 0.74 | 0.05 | 0.42 | 0.16 | 0.47 | 2.63 | 0.11 | 0.04 | 427 | 57 | 22 |
| 9 | Silat | 10 LS 13 | OC | Sh, v dkgy | 0.75 | 0.39 | 0.02 | 0.33 | 0.41 | 0.06 | 0.95 | 0.03 | 433 | 3 | 44 |
| 10 | | 10 LS 17 A | OC | Sh, v dkgy | 0.52 | 0.08 | 0.03 | 0.37 | 0.11 | 0.08 | 0.73 | 0.01 | 273 | 6 | 71 |
| 11 | | 10 LS 17 B | OC | Sh, v dkgy | 0.62 | 0.04 | 0.00 | 0.19 | 0.04 | 0.00 | 1.00 | 0.00 | 246 | 0 | 31 |
| 12 | | 10 LS 17 C | OC | Sh, v dkgy | 0.71 | 0.11 | 0.00 | 0.16 | 0.11 | 0.00 | 1.00 | 0.01 | 273 | 0 | 23 |
| 13 | | 10 LS 20 A | OC | Sh, v dkgy | - | - | - | - | - | - | - | - | - | - | - |
| 14 | | 10 LS 20 B | OC | Sh, v dkgy, calc | 0.80 | 0.95 | 1.40 | 0.24 | 2.35 | 5.83 | 0.40 | 0.20 | 439 | 174 | 30 |
| 15 | | 10 LS 22 A | OC | Sh, v dkgy, black | 1.21 | 1.51 | 3.06 | 0.22 | 4.57 | 13.91 | 0.33 | 0.38 | 442 | 252 | 18 |
| 16 | | 10 LS 22 B | OC | Sh, dkbrown-dkgy | - | - | - | - | - | - | - | - | - | - | - |
| 17 | | 10 LS 23 A | OC | Sh, v.dkgy.black | 1.37 | 1.12 | 3.98 | 0.17 | 0.17 | 23.41 | 0.22 | 0.42 | 445 | 290 | 12 |
| 18 | | 10 LS 23 B | OC | Sh, v.dkgy.black | 1.72 | 1.36 | 4.67 | 0.21 | 0.21 | 22.24 | 0.23 | 0.50 | 443 | 272 | 12 |

Table 2. GC-MS Data of Ketungau and Silat Formations

| No | Formation | Sample No. | Sample Type | Analized Lithology | EOM (ppm) | TOC | Sat. | Arc. | NSO | Pr/Ph | Pr/$nC_{17}$ | Pr/$nC_{13}$ | CPI | Sterane | | | Triterpane | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (% weight) | | | | | | | | C27 | C28 | C29 | OI | Gammm |
| 1 | Ketungau | 09 LS 02 D | OC | sh, v.dkgy | 111.59 | - | 44.44 | 3.7 | 51.86 | 1.24 | 0.94 | 0.19 | 0.98 | 43 | 24 | 33 | 0.04 | - |
| 2 | | 09 LS 05 A | OC | sh, v.dkgy | 1.015.90 | - | 31.9 | 4.76 | 63.34 | 3.65 | 0.6 | 0.29 | 1.05 | 48 | 24 | 29 | 0.06 | - |
| 3 | Silat | 10 LS 13 | OC | sh, v.dkgy | 178 | 0.75 | 19.44 | 16.66 | 63.9 | - | - | - | - | 49 | 23 | 27 | 0.13 | - |
| 4 | | 10 LS 17 B | OC | sh, v.dkgy | 71 | 0.62 | 13.79 | 13.79 | 72.42 | - | - | - | - | 52 | 22 | 26 | 0.22 | - |
| 5 | | 10 LS 17 C | OC | sh, v.dkgy | 102 | 0.71 | 10.25 | 5.13 | 84.62 | - | - | - | - | 62 | 20 | 18 | 0.11 | - |
| 6 | | 10 LS 22 A | OC | sh, v.dkgy | 3066 | 1.21 | 69.1 | 8.97 | 21.93 | - | - | - | - | 51 | 23 | 25 | 0.17 | - |
| 7 | | 10 LS 23 A | OC | sh, v.dkgy | 2926 | 1.37 | 63.65 | 12.14 | 24.21 | - | - | - | - | 49 | 21 | 29 | 0.03 | - |
| 8 | | 10 LS 23 B | OC | sh, v.dkgy | 3386 | 1.72 | 56.61 | 13.46 | 29.93 | - | - | - | - | 49 | 22 | 29 | 0.02 | - |

Remarks:

| | | | | | |
|---|---|---|---|---|---|
| EOM | : gram bitumen/gram sample x$10^6$ (ppm) | Pr | : Pristane | BDG | : Biodegraded |
| Sat | : Saturated fraction | Ph | : Phytane | OC | : Outcrop |
| Aro | : Aromatic fraction | n-$C_{17}$ | : Normal alkane | OI | : Oleanane |
| NSO | : Polar fraction | CPI | : Carbon Preference Index | CPI | : $(C_{25}+C_{27}+C_{29}+C_{31})^{/2*}(C_{25}+C_{28}+C_{30})$ |

open marine with the influence of fluvial channel as a terrestrial input that can be deposited.

While plotting of $C_{27}$-$C_{29}$ distribution for Silat shales (Figure 8) shows an open marine or deep lacustrine environment. High amount of $C_{27}$ indicates source from marine phytoplankton, whereas large amount of $C_{29}$ indicates contribution from terrestrial input. Sample 10LS17C has the highest content of $C_{27}$ sterane (ratio of $\alpha\beta\beta C_{27}$ is 62; Table 2), refering to a deeper marine environment. Nevertheless, olenane appears in all Silat samples (ranging from 0.02 - 0.22; Table 2), indicating the presence of terrestrial input in the environment.

## Organic Richness

For the purpose of assessing the source rock potential of the Ketungau and Silat shales, a diagram of crossplott between TOC (in wt %) and total generation potential (PY, in mg HC/g rocks) was made. The ranges of potential values used in the cross-plot are based on the classification suggested by Tissot and Welte (1984), Waples (1985), Peters (1986), and Bor-

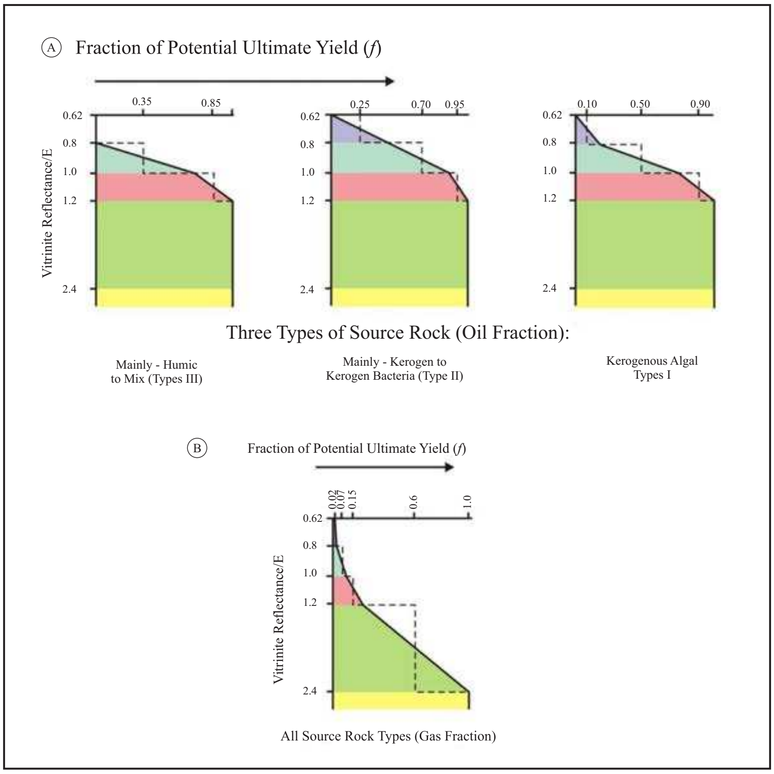


Figure 7. Curves showing the relationship between Ro values and fractional conversion (f) of every types of kerogen (Sluijk and Nederlof, 1984; in Waples, 1985).

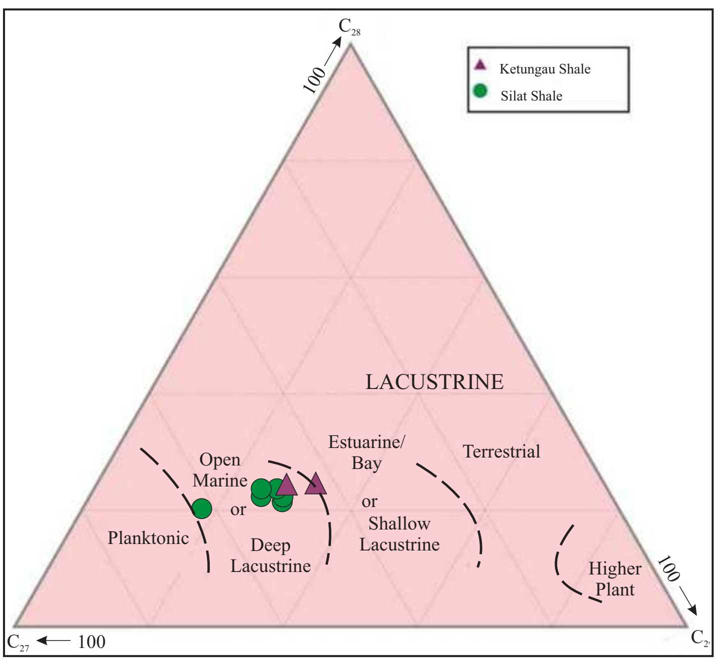


Figure 8. Triangular diagram shows the correlation between depositional environment and sterol composition in organism (Huang and Meinschein 1979, in Waples and Machihara, 1991.

denave (1993). The result of the cross-plot in Figure 9a shows that four samples from the Silat Formation and five samples from the Ketungau Formation are categorized as poor source rocks (TOC 0.52 - 4.72 wt %; PY 0.04 - 0.53 mg HC/g rock). One sample taken from a Ketungau coal layer (09PE 18C) shows an excellent source type (TOC 50.63 wt% and PY 68.18 mg HC/g rock).

Good source rock potentials (TOC 1.72 - 10.53 wt%; PY 6.03 - 7.70 mg HC/ g rock) are shown by one sample from the Ketungau shale (09PE 18A) and one sample from the Silat Shale (10LS 23B). While, three samples from the Silat shale (10LS20B, 10LS22A, and 10LS23A) and one sample from the Ketungau shale (09LS11D) are considered as fair source rocks (TOC 0.80 - 2.79 wt%; PY 2.35 - 5.10 mg HC/ g rock). A cross-plot between TOC *versus* Hydrogen Index (HI) was also made for a comparison (Figure 9b).

**Kerogen Type and Maturity Indicator**

The crossplot between Hydrogen Index and $T_{max}$ (Figure 10) shows that all samples from the Ketungau Formation are kerogen type III, derived from mixed marine algae and terrestrial plant, and tend to be more gas prone (Waples, 1985). While only one sample from the Silat Formation (10LS13) is identified as type III kerogen. Four samples from the Silat Formation are type II kerogen, derived dominantly from marine algae, and tend to be more oil prone.

Maturity indicator from pyrolisis temperature ($T_{max}$) identifying five samples of the Ketungau Formation are immature ($T_{max}$ < 435 $^{o}$C). Whereas, four samples from the Silat Formation have reached maturity level, and only one sample (10LS13) is still immature.

Maturity indicator from biomarker analysis was taken for a comparison. Waples and Machihara (1991) mention that maturity indicator from kerogen and biomarker analyses is different. Kerogen has an immobile characteristic, therefore the maturity indicator from kerogen is similar to the rock or sediment maturity when it is found. While biomarker from bitumen fraction has a mobile characteristic in rock or sediments, so the maturity identification from biomarker can only be done for indigeneous bitumen.

Triterpane paramaters, $C_{30}$ moretane/hopane, $C_{27}$-trisnorhopane 17α(H)-22,29-30 (Tm), and $C_{27}$-trisnorneohopane 18α(H)-22,29-30 (Ts) have been used as the biomarker maturity parameter (Figure 11). Two samples from the Ketungau Formation (09LS02D and 09LS 05A) indicate an immature to

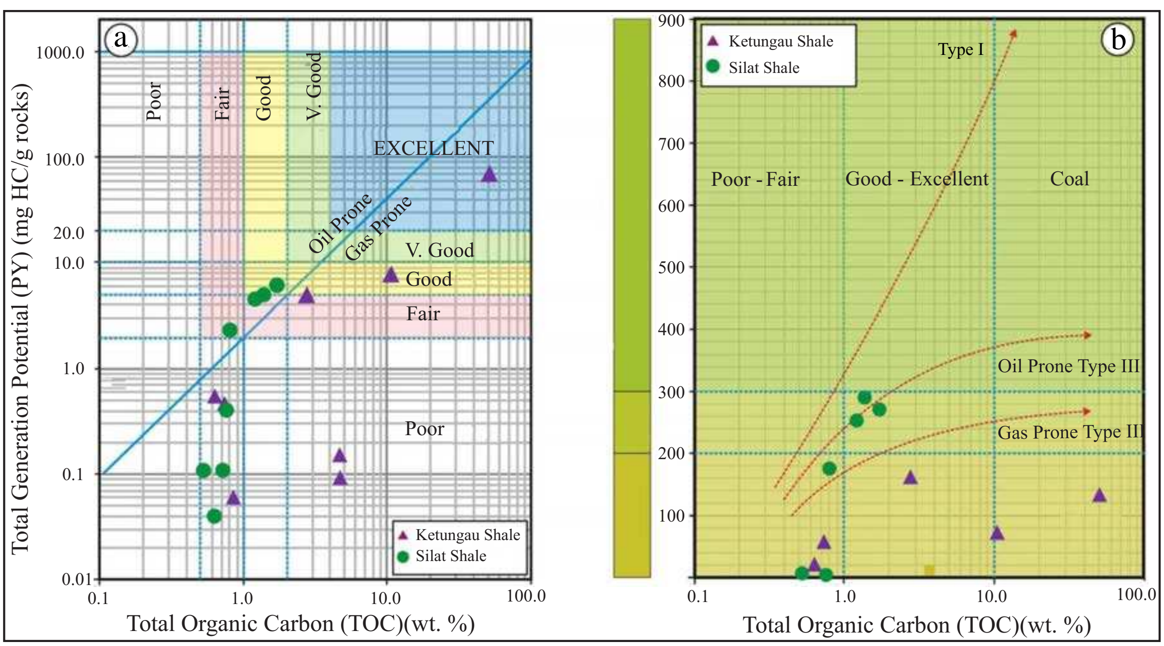


Figure 9. a). Diagram TOC *vs* PY shows source rock potential of the Ketungau and Silat Formations b). Diagram TOC *vs* HI shows slightly different values of source rock potential compared to TOC *vs* PY crossplot.

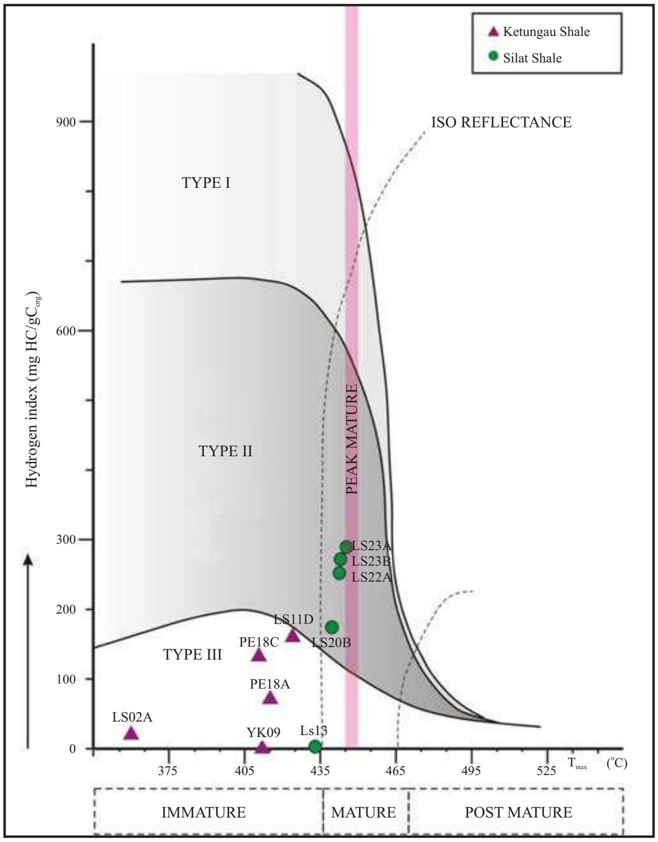


Figure 10. Crossplot between hydrogen index and $T_{max}$ shows most of the Ketungau samples are immature, in the contrary most of the Silat shales have reached a mature condition.

early mature level. While one sample of the Silat Formation (10LS17C) shows peak mature level, and two samples (10LS23A and 10LS23B) have reached a late mature level.

## Oil Shale/Shale Gas Potential

So far, several main key parameters for oil shale to be economically produced according to Tissot and Welte (1984) are: 1) composition of organic matter, 2) TOC content and Oil Yield, and 3) density and type of kerogen. The kerogen in oil shale can be converted to oil through the chemical process of pyrolysis. During pyrolysis the oil shale was heated to ca500°C in the absence of air and the kerogen was converted to oil and separated out. The process is called "retorting" (Tissot and Welte, 1984). Thus, much more abundant organic matter within the shale and the higher TOC content and Oil Yield, are better, so that more oil could be generated during pyrolysis.

While, key parameters for potential shale gas are slightly more complicated, that include: 1) Reservoir thickness, 2) thermal maturity, 3) TOC content, 4) high gas in place, and 5) adsorbed gas capacity, and fracability or friability ( Jarvie, *et al.*, 2007; Ross and Bustin, 2008). Cipolla *et al*. (2009) mentions that typical shale gas reservoirs exhibit a net thickness of 50 to 600 ft (equivalent to 15 to 185 m), porosity of 2-8%, TOC content of 1-14%, and are found at depth ranging from 1,000 to 13,000 ft (equivalent to 300 to 4000 m).

Unlike in conventional oil and gas exploration, migration and trapping mechanism are not important factors, since the oil shale and shale gas explorations are conducted within the layer that was previously called as source rock or/ and cap rock. Therefore, the distribution of the Ketungau and Silat Formations within syncline structures will not become a major problem for potential exploration. In fact, it is

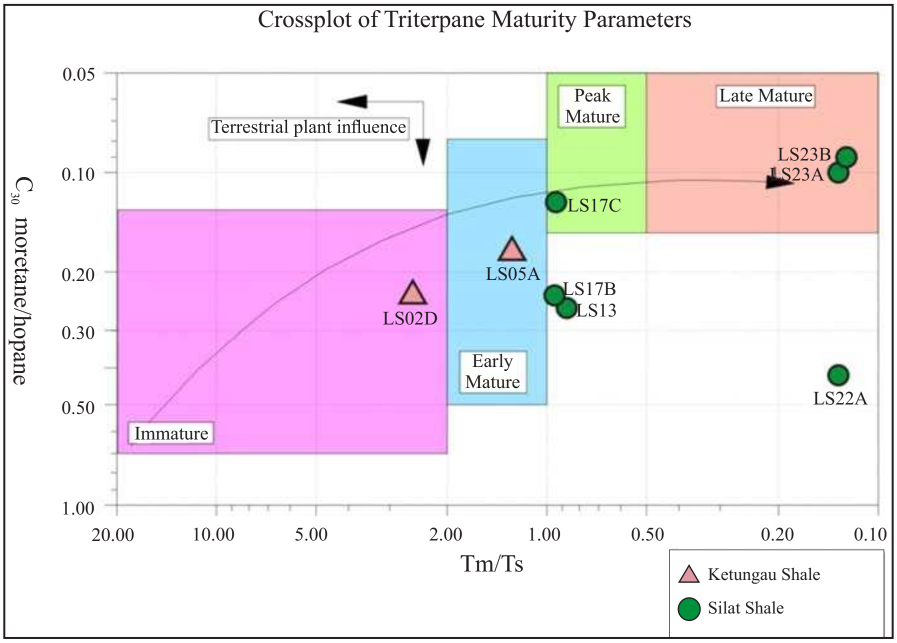


Figure 11. Triterpane maturity parameter shows different result of maturity indication for samples of Ketungau and Silat Formation

just suitable for the common structure of shale gas reservoir (Bowker, 2007).

**Assessment for Ketungau Formation**

The Ketungau Formation is distributed within Ketungau syncline, on an area of about 2216 km2 (equivalent to 855.7 square miles), and the average thickness is 900 m (Santy *et al.* 2009 and Santy *et al.* 2010). The potential thickness to be accounted for the resources of oil and gas for the Ketungau Formation is estimated to be 10 % of the total thickness, which is 90 m (Sutjipto, 1992). Maturity becomes a big issue for Ketungau source rock, since most samples from this formation were identified to be immature. However, in order to show the possibility of potential oil shale and shale gas exploration, the volume of oil and gas that can be generated from this source rock will be estimated. TOC and HI calculation from sample 09LS11D has been used for this estimation (TOC 2.79 wt %; HI 160 mg HC/g rock; Table 1).

The Ketungau source rocks mostly consist of kerogen type III that can commonly generate about 20% oil and 80% gas as suggested by Waples (1985). However, because in oil shale exploration all fine organic rich sediment fraction can be converted into liquid oil through pyrolysis, probably the amount of organic carbon capable of generating oil is thus 100% of the 2.79% of TOC.

Calculating the volume of oil generated, the relationship between f and Ro for humic to mix kerogen (type III) is used in this study as shown in Figure 7, which is 0.35 for the f value. Using the formula suggested by Waples (1985), then the volume of oil that can be generated from Ketungau source rock is :

*k*)(TOC)(HI)(*f*) = (0.7) x (2.79) x (160) x (0.35)
= 109.368 million barrels oil/cubic mile of source rock

Volume of sediment = area x thickness = 2216 km$^2$ x 0.09 km = 199.44 km$^3$
= 47.84 cubic mile

Total oil volume = (oil volume/ cubic mile) x (cubic miles of souce rock)
= 109.368 x 47.84
= 5,232.2 million barrels

As the result, the total oil that can be converted from the Ketungau source rock is 5,232.2 million barrels.

The volume of gas generated is calculated in the similar way, except that f for gas generation it is determined to be 0.07 from the curves of Ro vs f for gas fraction (Figure 7). TOC value is calculated

80% of the 2.79% of TOC, or 2.23% (the amount of gas generated from type III kerogen). Constant k is multiplied by 6 (six) to obtain the volume of gas in billion of standard cubic feet per cubic mile of source rock. While, the effective thickness for shale gas layer is estimated 90 m.

The volume of gas that can be generated from the Ketungau source rock is :

= (0.7) x (6) x (2.23) x (160) x (0.07)

= 104.8992 billion cubic feet gas per cubic mile of source rock

Volume of sediments = area x thickness = 2216 $km^2$ x 0.09 km = 199.44 $km^3$ = 47.848 cubic mile

Total gas volume = (gas volume/ cubic mile) x (cubic miles of souce rock)= 104.8992 x 47.848= 5019.2 billion cubic feet gas (BCF)

Then, the total gas that can be produced from the Ketungau shale layer is about 5019.2 BCF.

**Assessment for Silat Formation**

The Silat Formation is distributed within Silat Syncline, on an area of about 715.4 $km^2$ (equivalent to 276.2 square miles), and 1000 m thick on the average (Heryanto *et al.*, 1993b; Suyono *et al.*, 2009; Santy *et al.*, 2010). Similarly, the potential thickness to be accounted for the resources of oil and gas for the Silat Shale is estimated to be 10 % of the total thickness, which is 100 m (Sutjipto, 1992). Maturity calculation for the Silat shale shows that almost all samples analyzed have reach mature levels. TOC and HI calculation from sample 10LS23C has been used for this estimation (TOC 1.72 wt %; HI 272 mg HC/g rock; Table 1).

Calculating the volume of oil generated, the relationship between f and Ro for humic to mix kerogen (type II) has been applied here as shown in Figure 7, which is 0.5 for the f value. Then, the volume of oil can be generated from Silat shale is:

(k)(TOC)(HI)(f) = (0.7) x (1.72) x (272) x (0.5)
= 163.744 million barrels oil/ cubic mile of source rock

Volume of sediment = area x thickness = 715.4 $km^2$ x 0.1 km = 71.54 $km^3$
= 17.16 cubic mile

Total oil volume = (oil volume/ cubic mile) x (cubic miles of souce rock)
= 147.56 x 17.16 = 2,532.6 mil lion barrels

Therefore, the total oil that can be converted from Silat shale is around 2,532.6 million barrels.

The Silat shale source rock mostly consists of kerogen type II that can commonly generate about 90% oil and 10% gas (Waples, 1985). However, most shale gas play in the world comes from type II kerogen instead (Ross and Bustin, 2008; Cipolla *et al*., 2009). In order to get an illustration about gas potential from the Silat shale, 80% of gas generation from 1.72% of TOC, or 1.55% is used in this calculation. The value of constant k is multiplied by 6 to get the volume of gas in billion of standard cubic feet per cubic mile of source rock. While, the effective thickness for shale gas layer is 100 m.

Then, the total gas that can be generated from Silat shale is:

= (0.7)(6)(1.4)(272)(0.07)

= 111.9552 billion cubic feet gas per cubic mile of source rock

Volume of sediment = area x thickness = 715.4 $km^2$ x 0.1 km = 71.54 $km^3$
= 17.16334 cubic mile

Total gas volume = (gas volume/ cubic mile) x (cubic miles of souce rock)
= 111.9552 x 17.16334 = 1,921.525 billion cubic feet

Then, the total gas that can be produced from Silat shale layer is about 1,921.525 BCF or 1.92 TCF.

## Conclusions

The Ketungau and Silat Formations surely have good potential for unconventional oil shale or/and shale gas exploration. Apart of both formations having great sediment thickness, the composition of organic matter, TOC content and Oil Yield, density and type of kerogen are all important factors in oil shale and shale gas to be economically explored. The Ketungau shale mostly consist of kerogen type III, while the Silat shale consists of kerogen type II.

A total volume of oil which can be generated from oil shale production from the Ketungau Formation is about 5,232.2 million barrels, and the total gas that can be generated from the shale gas layer is about 5019.2 BCF. While, the total oil that can be generated from the Silat Shale is 2,532.6 million barrels, and total gas can be generated is 1.92 TCF. However, source rock maturity in the Ketungau

Formation is variated, and is mostly still in immature level. This condition can surely decrease the potential of the Ketungau source rock to produce oil and gas. On the contrary, the Silat shale can become a very good source rock, since the maturity distribution in this formation is spreading more evenly, mostly reaching a mature level.

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