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The Mesozoic Hydrocarbon Source Rock Potential of Singkawang Basin, West Kalimantan

Potensi Batuan Induk Hidrokarbon Mesozoikum dari Cekungan Singkawang, Kalimantan Barat

Suyono and M.H. Hermiyanto Zajuli,

Centre for Geological Survey
Jl.Diponegoro No.57 Bandung, 40122
e-mail : herisayazajuli@gmail.com

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Abstract- The Singkawang Basin is one of Mesozoic Basins in Western Indonesia that located in West Kalimantan. The Mesozoic Singkawang Basin is expected to have potential resources for conventional as well as non-conventional hydrocarbons. Several new concepts of oil and gas exploration may be defined in this basin including volcanic, basement fracture and Mesozoic sedimentary reservoirs. The Singkawang Basin is a basin filled with sedimentary rocks that may have hydrocarbon potential This basin has not been many studied by previous researchers. The aim of this research is to determine the potential of fine grained sedimentary rocks in the Singkawang Basin as the source rock of hydrocarbons. The TOC and Rock-Eval Pyrolysis (REP) analysis results from 69 fine-grained sedimentary rock samples concluded that the Sungaibetung Formation has a rich organic material ranging from 0.95 – 2.84%, while the Banan Formation ranges from 0.42 – 2.41%, the Pedawan Formation ranges from 0.27-2.29%, and the Kayan Formation ranges from 0.41 – 1.82%. The hydrogen index (HI) value of < 150 mg HC/g TOC and S2/S3 ratio value of < 3 indicates that some fine-grained sedimentary rocks of the Mesozoic Singkawang Basin have a tendency as a dry gas producer kerogen type and classified as a lean organic matter. The sedimentary rocks of the Singkawang Basin can be interpreted as gas source rocks that have entered an over mature stage. The Triassic to Oligocene fine -grained sedimentary rock indicates a good organic material. Moreover, the Sungaibetung Formation consists of very good organic material and tend to indicate hydrocarbons source rocks potential.

Keywords: Mesozoic, source rocks, hydrocarbons, West Kalimantan

Abstrak- *Cekungan Singkawang merupakan cekungan berumur Mesozoikum di Indonesia bagian barat yang terletak di Kalimantan Barat. Cekungan Singkawang ini diharapkan mempunyai potensi hidrokarbon konvensional maupun non-konvensional. Terdapat beberapa konsep baru dalam eksplorasi migas, mulai dari batuan vulkanik, basement fracture dan potensi batuan yang berumur Mesozoikum pada cekungan wilayah barat Indonesia. Salah satu cekungan yang berumur Mesozoikum di wilayah barat Indonesia adalah Cekungan Singkawang. Cekungan Singkawang merupakan cekungan yang terisi batuan sedimen, kemungkinan bisa berpotensi sebagai batuan penghasil hidrokarbon. Cekungan ini belum banyak diteliti oleh peneliti sebelumnya. Penelitian ini membahas tentang potensi batuan sedimen berbutir halus yang berpotensi sebagai batuan induk hidrokrabon. Berdasarkan hasil analisis TOC dan Rock-Eval Pyrolisis (REP) terhadap 69 percontoh batuan sedimen berbutir halus, Formasi Sungaibetung memiliki kekayaan material organiknya 0,95 – 2,84%, Formasi Banan berkisar 0,42 – 2,41 %. Formasi Pedawan 0,27 – 2,29%. , Formasi Kayan 0,41 – 1,82%. Nilai Indeks Hidrogen (HI) < 150 mg HC/g TOC dan perbandingan S2/S3 < 3, menunjukkan sebagian besar batuan sedimen berbutir halus di Cekungan Mesozoic Singkawang termasuk ke dalam tipe kerogen yang menghasilkan dry gas dan tergolong ke dalam lean organic. Batuan sedimen di Cekungan Singkawang ditafsirkan sebagai batuan induk yang telah memasuki tahap sangat matang. Batuan sedimen berbutir halus berumur Trias sampai Oligosen mempunyai kekayaan material organik yang baik. Formasi Sungaibetung mengandung kekayaan material organik yang sangat bagus dan mengindikasikan berpotensi sebagai batuan sumber hidrokarbon.*

***Kata kunci** : Mesozoikum, batuan induk, hidrokarbon, Kalimantan Barat*

INTRODUCTION

The Singkawang Basin is bounded by Lupar Fault in the North and Adang Flexure in the South (Arifullah, et al., 2004). Administratively, the basin situated in three regencies, i.e. the Pontianak, Sanggau, and Sambas, West Kalimantan Province (Figure 1).

Mesozoic rocks are not a common target for oil and gas exploration in Indonesia due to their majority formed as basement crystalline rocks. However, there are several oil and gas field Mesozoic rock, i.e. the Northeast Beruk oil field, Suban gas field, Tanjung field, and Gunung Kemala field. The reservoirs for these fields are basement fractured rocks (Hermiyanto and Sodiq, 2017). The Jatibarang field is an example of oil producer in Mesozoic volcanic basins in Northwest Java (Hermiyanto and Sodiq, 2017).

Several discussions of Mesozoic rocks at the Western Indonesia already focused on the petroleum system with the sedimentary rock as the main target. The Singkawang Basin is one of the Mesozoic basins that its Triassic-Cretaceous sediment may be expected to have a potential resource for oil and gas production and as a complete petroleum system, (Hermiyanto and Sodiq, 2017). In contrary, the petroleum system of the Singkawang Basin has not been well-known especially the organic geochemistry characteristics for source rock as well as reservoir, and seal rocks.

The Singkawang Basin may have numerous candidates of petroleum system elements for a non-conventional hydrocarbon resource, such as oil shale, shale gas, or tight sand. The result of this study is expected to answer some existing problems especially the source rock potential.

The Total Organic Carbon (TOC) and Rock–Eval Pyrolysis (REP) analyses represent the organic material content as an indicator of sedimentary rock ability to form hydrocarbons (Table 1). The TOC analysis result is used as a main data of source rocks study to determine whether sedimentary rocks have a capability to produced hydrocarbon or as a non-potential rock.

The type of organic material is affected by the composition of the maceral from sedimentary rocks (Waples, 1985). In general, the kerogen type can be divided into oil and gas expelled by macerals. Kerogen is the portion of naturally occurring organic matter that is non extractable using organic solvents. Kerogen type is grouped into Type I, II, and III. According to Waples (1985), kerogen Type I is mostly derived from algae lacustrine and has a high capacity to produce hydrocarbons. Kerogen Type I is generally composed of maceral liptinite like alginite. Most Type II kerogen can be found in marine sediment deposits under the condition of reduction (backmangrove). This kerogen type has the capacity to form hydrocarbons and a little gas. Kerogen Type II consists of the resinite, cutinite, and sporinite. The Type III kerogen composed by organics high plant material that rich of greasy and waxy elements. This kerogen type generally tends to produce gas. Vitrinite is the dominant maceral of the Type III kerogen. Type IV kerogen is the alteration of kerogen-containing material from various sources and especially under high oxidation condition. However, Type IV kerogen will not produce hydrocarbon. Maceral inertinite is a constituent of Type IV kerogen (Table 2). The abundance of organic material on the shale is not

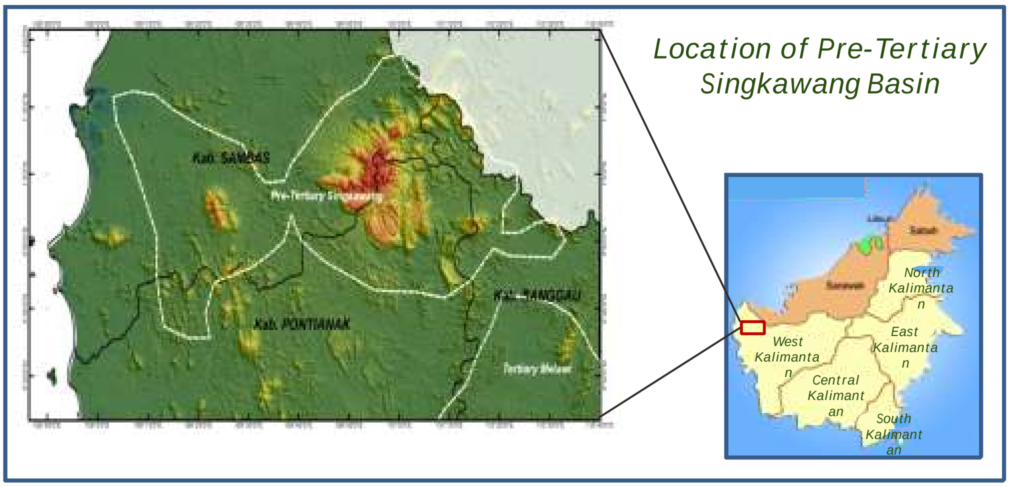


Figure 1. Location of Singkawang Basin located in the Regency of Sambas, Pontianak, and Sanggau

Table1. The results of TOC analysis and rock-eval pyrolisis of Triassic - Oligocene fine sedimentary rocks from Singkawang Basin, West Kalimantan.

No.	Sample ID	Sample Type	General Lithology Description	Formation	Umur (regional)	TOC (%)	S1	S2	S3	PY	Tmax (°C)	PI	PC	HI	OI
								mg/g							
1	FS01E	OC	Shale, lt grey, soft, oxidated, Non Calc	Banan	Jura	1.18	0.02	0.09	0.10	0.11	552	0.18	0.01	8	8
2	FS08D	OC	Shale, lt grey, soft, oxidated, Non Calc	Banan	Jura	0.83	0.04	0.06	0.10	0.10	322	0.40	0.01	7	12
3	FS09A	OC	Shale, lt grey, soft, oxidated, Non Calc	Banan	Jura	0.74	0.02	0.05	0.13	0.07	500	0.29	0.01	7	18
4	FS09I	OC	Siltstone, lt grey, soft, oxidated, Non Calc	Banan	Jura	0.42	0.01	0.04	0.14	0.05	515	0.20	0.00	9	33
5	FS10B	OC	Shale, black, soft, oxidated, Non Calc	Banan	Jura	0.95	0.04	0.06	0.45	0.10	539	0.40	0.01	6	47
6	FS11A	OC	Shale, black, hard, oxidated, Non Calc	Banan	Jura	1.10	0.03	0.07	0.07	0.10	557	0.30	0.01	6	6
7	FS14D	OC	Shale, dk grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.91	0.03	0.17	0.03	0.20	535	0.15	0.02	19	3
8	FS15D	OC	Sandstone, lgt grey, hard, brittle, oxidated, Non Calc	Pedawan	Kapur	0.89	0.02	0.14	0.05	0.16	540	0.13	0.01	16	6
9	FS16B	OC	Claystone, dk grey, soft, oxidated, Non Calc	Pedawan	Kapur	1.09	0.02	0.09	0.03	0.11	556	0.18	0.01	8	3
10	FS17A	OC	Claystone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.53	0.03	0.08	0.06	0.11	555	0.27	0.01	15	11
11	FS17H	OC	Claystone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.39									
12	FS18J	OC	Shale, black, soft, oxidated, Non Calc	Pedawan	Kapur	1.25	0.03	0.16	0.05	0.19	543	0.16	0.02	13	4
13	FS23E	OC	Shale, black, hard, oxidated, Non Calc	Banan	Jura	1.49	0.03	0.09	0.22	0.12	557	0.25	0.01	6	15
14	FS24D	OC	Claystone, brownish grey, hard, oxidated, Non Calc	Banan	Jura	0.70	0.04	0.07	0.58	0.11	529	0.36	0.01	10	82
15	FS26A	OC	Shale, black, soft, oxidated, Non Calc	Banan	Jura	1.88	0.03	0.05	0.16	0.08	558	0.38	0.01	3	9
16	FS27H	OC	Claystone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.54	0.05	0.08	0.03	0.13	532	0.38	0.01	15	6
17	FS28E	OC	Siltstone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.37									
18	FS33B	OC	Siltstone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.57	0.03	0.07	0.05	0.10	546	0.30	0.01	12	9
19	FS35A	OC	Siltstone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	1.18	0.07	0.17	0.14	0.24	541	0.29	0.02	14	12
20	FS36A	OC	Siltstone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	1.01	0.05	0.11	0.07	0.16	550	0.31	0.01	11	7
21	FS36H	OC	Claystone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	1.04	0.04	0.11	0.05	0.15	556	0.27	0.01	11	5
22	FS38	OC	Claystone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.52	0.06	0.09	0.44	0.15	511	0.40	0.01	17	85
23	FS07G	OC	Claystone, brownish grey, soft, oxidated, Non Calc	Banan	Jura	0.63	0.02	0.09	0.11	0.11	518	0.18	0.01	14	17
24	FS03J	OC	Shale, dk grey, soft, Non Calc	Banan	Jura	2.41	0.03	0.06	0.23	0.09	518	0.33	0.01	2	10
25	FS06H	OC	Siltstone, lt grey, soft, oxidated, Non Calc	Banan	Jura	0.96	0.04	0.31	0.03	0.35	478	0.11	0.03	32	3
26	FS06AN	OC	Shale, lt grey, soft, Non Calc	Banan	Jura	1.01	0.06	0.33	0.08	0.39	478	0.15	0.03	33	8
27	MH 01 J	OC	Claystone, dk grey, soft, oxidated, Non Calc	Sungai Betung	Trias-Jura	1.89	0.05	0.08	0.34	0.13	366	0.38	0.01	4	18
28	MH 02 A	OC	Claystone, black, hard, oxidated, Non Calc	Sungai Betung	Trias-Jura	2.20	0.04	0.08	0.12	0.12	558	0.33	0.01	4	5
29	MH 02 E	OC	Claystone, black, hard, oxidated, Non Calc	Sungai Betung	Trias-Jura	2.84	0.05	0.09	0.28	0.14	525	0.36	0.01	3	10
30	MH 04 A	OC	Shale, dk grey, soft, Non Calc	Sungai Betung	Trias-Jura	0.95	0.03	0.09	0.12	0.12	550	0.25	0.01	9	13
31	MH 05 A	OC	Claystone, lgt grey, soft, oxidated, Non Calc	Sungai Betung	Trias-Jura	2.08	0.03	0.09	0.08	0.12	558	0.25	0.01	4	4
32	MH 06 A	OC	Claystone, lgt grey, soft, oxidated, Non Calc	Sungai Betung	Trias-Jura	1.42	0.02	0.09	0.09	0.11	536	0.18	0.01	6	6
33	FS 41 B	OC	Claystone, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.41	0.05	0.12	0.10	0.17	481	0.29	0.01	29	25
34	FS 41 D	OC	Shale, lt grey, soft, Non Calc	Pedawan	Kapur	0.70	0.05	0.34	0.06	0.39	447	0.13	0.03	49	9
35	FS 44B	OC	Shale, grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.31									
36	FS 44 D	OC	Siltstone, grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.25									
37	FS 44 E	OC	Siltstone, lt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.22									
38	FS 44 I	OC	Siltstone, dk grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.73	0.08	0.19	0.08	0.27	449	0.30	0.02	26	11
39	FS 44 L	OC	Siltstone, dk grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.25									
40	FS 44 N	OC	Siltstone, dk grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.33									
41	FS44 S	OC	Shale, lgt grey, soft, weathered, Non Calc	Pedawan	Kapur	0.39									
42	FS 45 A	OC	Shale, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.43	0.04	0.18	0.04	0.22	489	0.18	0.02	42	9
43	FS 45 E	OC	Shale, black, soft, Non Calc	Pedawan	Kapur	0.43	0.03	0.15	0.06	0.18	466	0.17	0.01	35	14
44	FS 47 B	OC	Shale, black, soft, oxidated, Non Calc	Pedawan	Kapur	0.42	0.07	0.08	0.15	0.15	528	0.47	0.01	19	36
45	FS 47 G	OC	Shale, black, soft, oxidated, Non Calc	Pedawan	Kapur	0.36									
46	FS 48 C	OC	Shale, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.57	0.04	0.21	0.09	0.25	456	0.16	0.02	37	16
47	FS 55 B	OC	claystone, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.10									
48	FS 57	OC	Siltstone, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.37									
49	FS 61 D	OC	Siltstone, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.51	0.03	0.13	0.06	0.16	468	0.19	0.01	25	12
50	FS 62 A	OC	claystone, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.33									
51	FS 62 G	OC	claystone, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.27									
52	FS 62 J	OC	Shale, lgt grey, soft, oxidated, Non Calc	Pedawan	Kapur	0.38									
53	FS 63 C	OC	claystone, lgt grey, soft, brittle, oxidated, Non Calc	Pedawan	Kapur	0.42	0.04	0.17	0.07	0.21	491	0.19	0.02	41	17
54	FS 64 B	OC	claystone, lgt grey, soft, brittle, oxidated, Non Calc	Pedawan	Kapur	0.49	0.03	0.12	0.08	0.15	509	0.20	0.01	24	16
55	FS 71 A	OC	Shale, black, soft, oxidated, Non Calc	Pedawan	Kapur	2.29	0.05	0.11	0.33	0.16	405	0.31	0.01	5	14
56	FS 72 C	OC	Shale, black, soft, oxidated, Non Calc	Pedawan	Kapur	0.67	0.03	0.10	0.21	0.13	493	0.23	0.01	15	31
57	FS 73 B	OC	Siltstone, lgt grey, massive, hard, Non Calc	Pedawan	Kapur	1.19	0.06	0.48	0.11	0.54	435	0.11	0.04	40	9
58	FS 77 D	OC	claystone, lgt grey, soft, brittle, oxidated, Non Calc	Pedawan	Kapur	0.72	0.03	0.11	0.18	0.14	541	0.21	0.01	15	25
59	FS 80	OC	Shale, lgt grey, soft, oxidated, Calc	Pedawan	Kapur	0.60	0.06	0.12	0.15	0.18	534	0.33	0.01	20	25
60	FS 82 A	OC	Shale,grey, soft, oxidated, Calc	Pedawan	Kapur	0.31									
61	MH 12 B	OC	Shale, black, soft, oxidated, Calc	Pedawan	Kapur	0.40									
62	MH 12 H	OC	Shale, black, soft, oxidated, Calc	Pedawan	Kapur	0.33									
63	MH 13 B	OC	Shale, black, soft, oxidated, Calc	Pedawan	Kapur	0.38									
64	MH 15 A	OC	Shale, black, soft, oxidated, Non Calc	Pedawan	Kapur	0.31									
65	MH 22	OC	claystone, lgt grey, soft, brittle, oxidated, Non Calc	Kayan	Kapur-Oligo	0.73	0.03	0.16	0.14	0.19	477	0.16	0.02	22	19
66	MH 23 A	OC	Shale, black, soft, oxidated, Non Calc	Kayan	Kapur-Oligo	1.82	0.03	0.08	0.13	0.11	557	0.27	0.01	4	7
67	MH 23 D	OC	claystone, lgt grey, soft, brittle, oxidated, Non Calc	Kayan	Kapur-Oligo	0.41	0.03	0.11	0.50	0.14	433	0.21	0.01	27	122
68	MH 24 A2	OC	Shale, dk grey, soft, brittle, oxidated, Non Calc	Kayan	Kapur-Oligo	1.24	0.02	0.06	0.12	0.08	453	0.25	0.01	5	10
69	MH 25 A	OC	Shale, dk grey, soft, brittle, oxidated, Non Calc	Kayan	Kapur-Oligo	0.80	0.02	0.10	0.28	0.12	357	0.17	0.01	12	35

Remarks :

S_1 : Amount of free hydrocarbon
S_2 : Amount of Hydrocarbon released from kerogen
S_3 : Organic Carbondioxide
TOC : Total Organic Carbon
OC : Outcrops
PY : Amount of Total Hydrocarbons = (S_1+S_2)
PI : Production Index = (S_1/S_1+S_2)
PC : Pyrolysable Carbon
Tmax : Maximum Temperature (°c) at the top of S_2 peak
HI : Hydrogen Index = (S_2/TOC)x 100
OI : Oxygen Index = (S3/TOC) x 100
NDP: No Determination Possible

Table 2. Relation between the TOC values with source rock ability

TOC Value (%)	Ability as a source rocks
<0.5%	Poor ability as a source rocks
0.5% - 1.0%	Limited ability as a source rocks
1.0% - 2.0%	Medium ability as a source rocks
>2.0%	Good ability as a source rocks

source: Waples (1985)

only from a marine environment deposition but also a non-marine, transition, even the lacustrine facies environment (Zou, et al., 2011 in Ju, et al., 2001).

Based on the composition of its chemical elements, i.e., C, H and O, initially the kerogen is distinguished into three main types i.e. kerogen Types I, II, and III (Tissot and Welte, 1984; in Killops and Killops, 2005).

Kerogen type determines the quality of the source rock. The greater the value of hydrogen index (HI) is the better quality of source rock. The following Table 3 defines four types of kerogen according to Law (1999).

Rock Eval Pyrolysis is the analysis of the hydrocarbon component of the parent rock by gradually warming up the sample of the host rock in a non-oxygen state under an inert atmosphere with programmed temperatures. This heating separates the free organic components (bitumen) and the organic components that are still bound in the main rock (kerogen) (Espitalie et al., 1977). Results of Rock-Eval Pyrolysis can be known from the S1, S2, and S3 value in milligrams units. The S1 parameter shows the first existing hydrocarbons in the rocks and the amount of bitumen that can be extracted using solvent.

The second hydrocarbon value shown with S2 indicates the hydrocarbons formed from kerogen in the process of Rock-Eval Pyrolysis due to the decomposition of kerogen by thermal process. The value of the S2 is considered as an important indicator of the kerogen ability in producing hydrocarbons at the moment. S3 is the amount of oxygen content in kerogen. The hydrogen index (HI) and the oxygen index (OI) are indicators in kerogen type categories. Hydrogen index is obtained by dividing the value of the S2 with a TOC, whereas the oxygen index is the result of the TOC/S3 division (Waples, 1985).

According to Waples (1985), HI of < 150 mg HC/g TOC indicates the absence of a fat number that produces oil and is grouped as type III and IV kerogen that will only generate a little amount of gas. HI values over 150 mg HC/g TOC shows the increase of fats rich material amount which derived from the mainland (cutinite, resinite, liptinite) or sea algae material and lacustrine algae (alginate). HI between 150 mg HC/g TOC and 300 mg HC/g TOC contains more Type III than Type II kerogen, which has causing the medium ability to produce oil. HI value of > 300 mg HC/g TOC indicates that the source rock is composed by Type II maceral which tends to produce liquid hydrocarbons. Whilst, the HI value of less than 600 indicates to be derived from Type I and II kerogens that capable of producing excellent liquid hydrocarbons. Peters and Cassa (1994) divides the hydrogen index into five grades. HI < 50 mg HC/g TOC indicates non producting hydrocarbons including kerogen Type IV. HI between 50 – 200 mg HC/g TOC are generally has capable of gas producing and grouped as kerogen Type III (Table 4). HI values between 200 – 300 mg HC/g TOC in type II/IIIb kerogen have the ability to produce oil and gas, HI value of 300 – 600 mg HC/g TOC generally produce oils and

Table 3. TOC content classification.

Potential (Quantity)	Ability as a source rocks
Poor	<0.5
Fair	0.5 - 1.0
Good	1 - 2
Very Good	2-4
Excellent	>4

source: Peters and Cassa (1985)

Table 4. Type of kerogen, maceral content, and origin of organic material.

Maseral	Kerogen Type	Origin of Organic Material
Alginit	I	Freshawater algae
Liptinit	II	Pollen, spores
Kutinit	II	Wax Coating plants
Resinit	II	Resin plants
Liptinit	II	Fatplants, sea algae
Vitrinit	III	High plant material (wood, cellulose)
Inertinit	IV	Charcoal, re-arranged material that oxidezed

source: Waples (1985)

is included in type II kerogen, while 600 mg HC/g TOC > HI can be classified into Type I kerogen which indicate of oil production.

Stratigraphic Research Area

The Singkawang basin is originally part of Sundaland (BPPKA Pertamina, 1997; Figure 2). The research areas have been mapped into the 1:250,000 scales of Singkawang Sheet (Suwarna and Langford, 1993), Sanggau Sheet (Supriatna, et al, 1993), and Sambas Sheet (Rusmana and Pieters, 1993).

Several candidates of stratigraphic formations (Sungaibetung and Pedawan Formatian) are expected to be potential of petroleum system in the Singkawang Basin:

Kayan Sandstone

The sandstone consists of quartz to feldspathic sandstone, shale, siltstone with minor conglomerate, coal, and locally silicified wood. The Kayan sandstone was deposited in Late Cretaceous to Late Eocene.

Pedawan Formation

The Pedawan Formation consists of shale, carbonaceous mudstone, siltstone, and sandstone with locally calcareous, limestone, fossiliferous tuff. This formation was deposited in Cretaceous.

Brandung Formation

The Brandung Formation is composed by calcareous mudstone that interbedded with mudstone, slatty shale, and fossiliferous fine grained sandstone. This formation was deposited during Late Jurrasic.

Bengkayang Group

The Bengkayang group consists of two formations:

- The Sungaibetung Formation: consists of mudstone interbedded with silstone and fine to medium pale grey – black sandstones. This formation was conformably deposited above the Banan Formation in the Early Jurassic.
- The Banan Formation: composed by sandstones and slight conglomerates at the top, sandstone and shale in the middle, sandstones and sandstones intercalation with tuff in the bottom. This formation was deposited in Late Triassic.

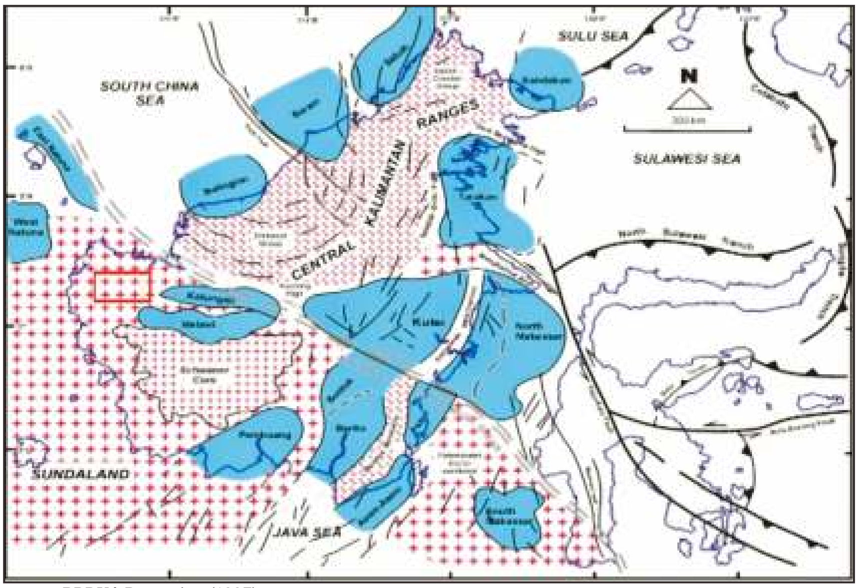
Seminis Formation

This formation is composed by slate, phylite, and meta-sandstone that deposited in Carboniferous-Permian.

Geological Structure and Tectonics

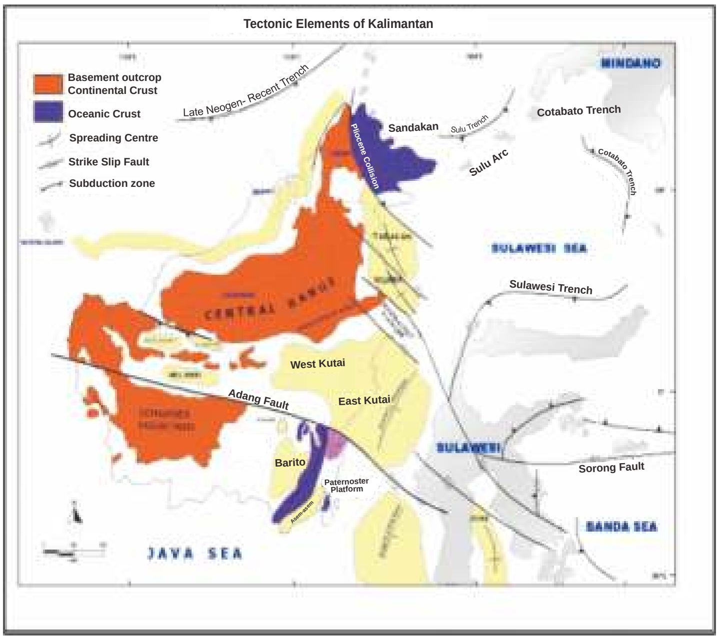
According to Arifullah, et al (2004), Kalimantan is crossed by several northwest-southeast horizontal sinistral fault structures i.e. Adang-Lupar, Tinjar, and Palu-Koro Faults, and a NW-SE geological structure (Figure 3).

Satyana, et al (2000) suggested that Singkawang areas are potentially prospective Mesozoic section. The Singkawang Basin is suggested to be the result of magmatic arc subduction between Proto-South China Sea plate (Figure 4), and the northern part of the Sunda



source: BPPKA Pertamina (1997)

Figure 2. Research area (red block) situated as a part of Sundaland.



source: Arifullah, et al (2004)

Figure 3. Tectonic elements of Kalimantan.

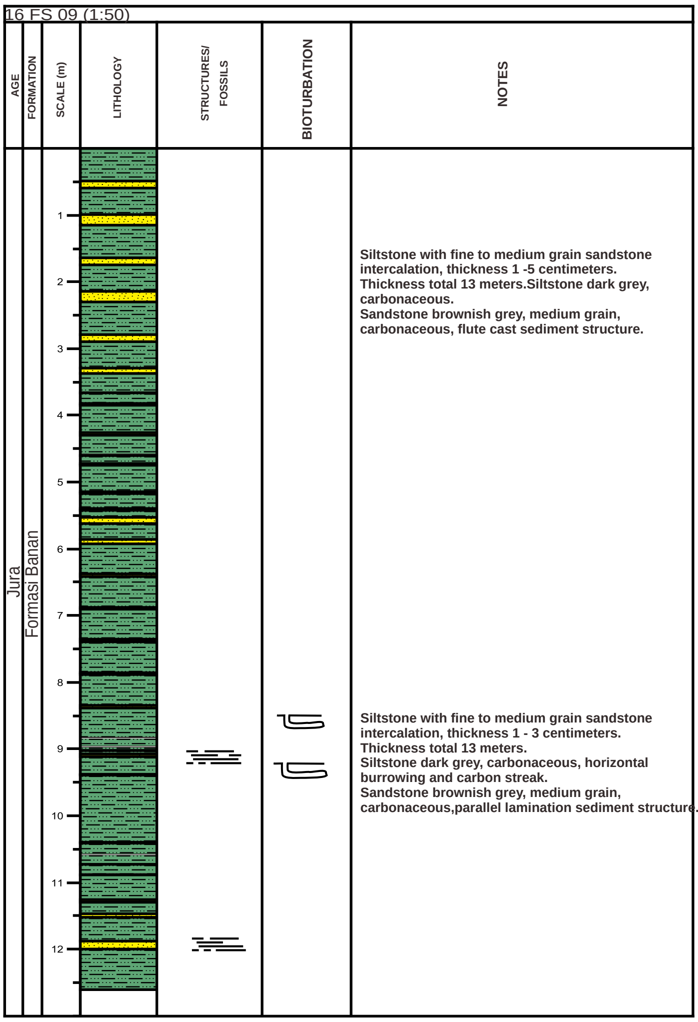


Figure 4. Stratigraphic sections of Middle Banan Formation.

Shelf that has tilted to the south during Early Cretaceous (Suwarna et al, 1993). Evidence of the subduction is convinced by the presence of a Cretaceous mélange in the north, i.e. Serabang Complex in Sambas Sheet (Rusmana and Pieters, 1993).

Furthermore, subduction activity in Eocene – Early Oligocene was due to the occurrence of the extension forming at the South China Sea (Metcalfe, 2010). This process caused the movement of the Luconia continent blocks southwards in resulting subduction. Therefore, the Eocene – Early Oligocene magmatic arc distributing from Sintang to Kelian can be seen along the Central Kalimantan. In the Middle Oligocene, the subduction developed into a collision. Intrusion activity by magmatic arc occured during Late Oligocene into Middle Miocene. Therefore, a young magmatic arc can be traced from Sintang, Masuparia, Kelian, Muyup, Muarawahau, upto Sesayap. The magmatic activity is related to the relict of the subducted plate during Eocene (William, et al, 1984).

The youngest intrusion such as the Sintang intrusion rock shows the northeast – southwest extension structure (Metcalfe, 2011). Fractures within the Sintang intrusion are generally northwest – north orientations, in which some places found mineralized quartz veins with copper and gold deposits. Moreover, magmatic arc was found in Sibu-Rajang zone in Middle Miocene–Pliocene. This magmatic arc was predicted to have been influenced by a subduction in the Palawan trench. Magmatic arc was also found in Sulu Sea in Late Miocene – Pleistocene extending to the Dent Peninsula and associated with the Sulu trench subduction (Hall and Breitfeld, 2017).

METHODOLOGY

Data obtained from field survey consist of data records of each observation location, stratigraphic measurements, and rock sampling for laboratory analysis. Rocks sampling consist of 69 fine grain sedimentary rock samples from Sungaibetung (6 samples), Banan (13 samples), Pedawan (45 samples), and Kayan (5 samples) Formation. Samples were obtained in 2016 in the Pre -Tertiary Singkawang Basin, west Kalimantan that was located in Ledo, Simpang Ledo-Sambas, Seluas and Balai Karangan. In this area the Pedawan Formation has the widest distribution compared to the Sungaibetung, Banan, and Kayan Formation. Shale of Pedawan Formation is the target of this research.

Laboratory Analysis

Laboratory analysis used in this study is the geochemical organics analysis (TOC and Rock-Eval pyrolysis (REP). This analysis used to verify the organic content, source rock quality, maturity, hydrocarbon characteristics for source rock potential. Among these techniques, Rock-Eval pyrolysis has been widely used in the industry as a standard method in petroleum exploration (Lafargue, et al, 1996). This technique consists in the temperature programmed heating of a small amount of rock (100 mg) in an inert atmosphere (Helium or Nitrogen) so as to determine: the quantity of free hydrocarbons present in the sample (S1 peak) and the amounts of hydrocarbons and oxygen containing compounds (CO_2) that are produced during the thermal cracking of the insoluble organic matter (kerogen) in the rock (S2 and S3 peaks respectively peak). Furthermore, the Total Organic Carbon (TOC) content of the rock is determined by oxidation under air, in a second oven, of the residual organic carbon after pyrolysis (S4 peak; Lafargue, et al, 1996). In this study did not use organic petrology data (vitrinite reflectance).

RESULT

In the research area, the Banan Formation composed by sandstones and slight conglomerates at the top, sandstone and shale in the middle, sandstones and sandstones intercalation with tuff in the bottom. Banan Formation consist of shale dominantly (Figure 4). The Mudstone of Sungaibetung Formation are the most dominant rocks found in the study area. The Pedawan Formation consist of shale, sandstone, siltstone, and alternating of shale and lamination sandstone (Figure 5). The lower part comprising of alternating of sandstone and shale, upper part consits of sandstone dominantly. The Kayan Formation consist of dominantly of metasandstone.

Organic Material

The TOC value of less than 0.5% indicates as a non-potential hydrocarbon source rock due to its ability to produce hydrocarbons in a non-sufficient amount and causing no expulsive occurrence (Waples, 1985). According Table 5, indicators to determine whether the sedimentary rock has the potential as a source rock.

The TOC value between 0.5-1% indicate that the sedimentary rock has no ability as an effective source rock, but producing small amounts of hydrocarbons expulsion. The TOC value of 1.0%-2.0% indicates a

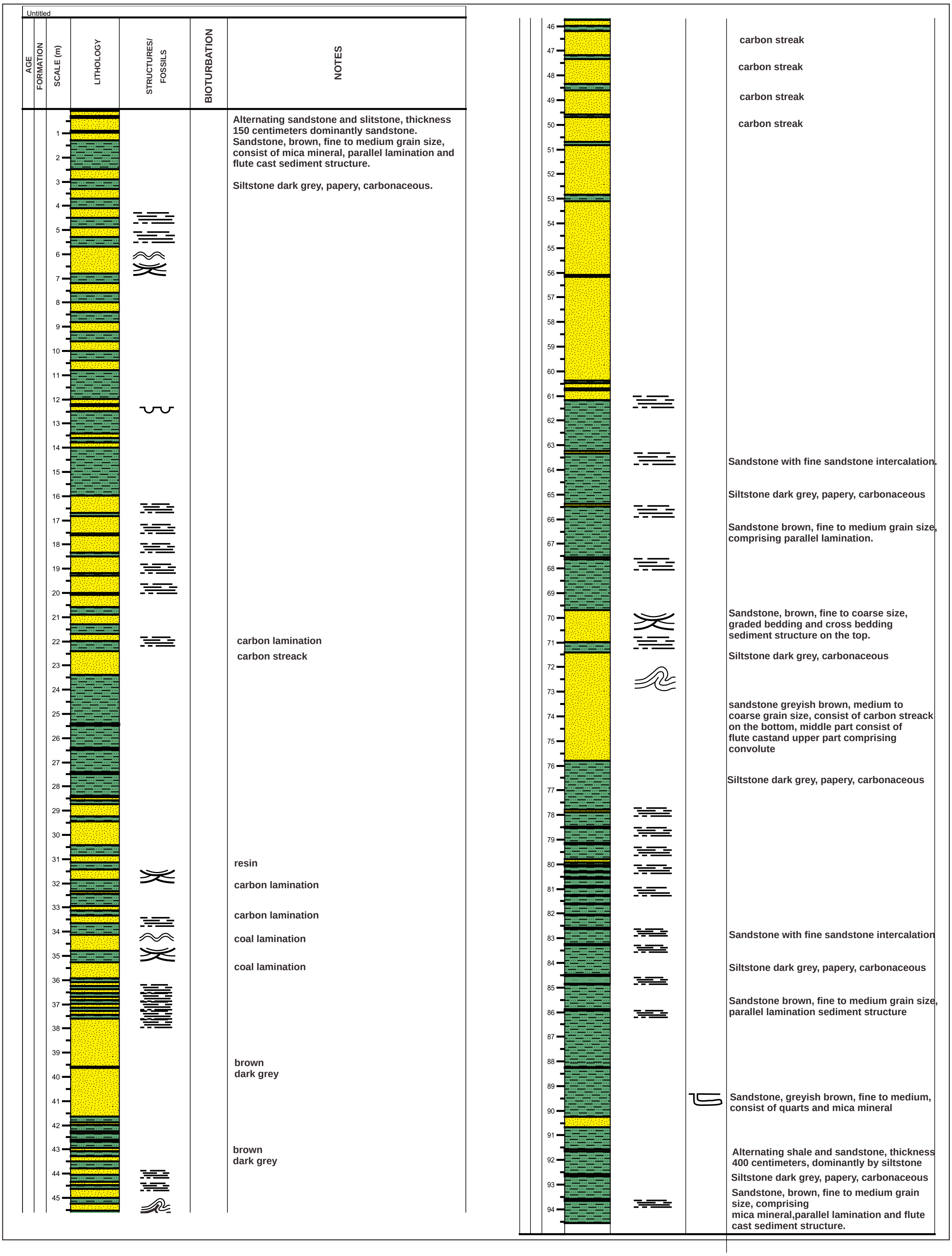


Figure 5. Stratigraphic column of Pedawan Formation in Ledo area.

Table 5. The four basic types of kerogen according to Law (1999)

Kerogen Type	Type Hydrocarbon Producer	Type of the Deposition Environment
I	Oil - producing	Lake
II	Oil and gas producers	Sea
III	Gas generator	Land
IV	Does not produce any	Land

sumber: Waples (1985)

Table 6. Geochemical kerogen type parameters and resulting product

Kerogen Type	Hydrogen Index (mg HC/g TOC)	S2/S3	Atom H/C	Main Products
I	> 600	> 15	> 1.5	Oil
II	300 - 600	10 - 15	1.2 - 1.5	Oil
II/IIIb	200 - 300	5 - 10	1.0 - 1.2	Oil and Gas
III	50 - 200	1 - 5	0.7 - 1.0	Gas
IV	< 50	< 1	< 0.7	No Hydrocarbon Production

sumber: Peters and Cassa (1994)

deposition at oxidation and reduction associated with a transitional environment. Subsequently, the TOC above 2.0% indicates that the sedimentary rock is associated with high level reduction environment resulted as a potentially good source rock. Eventually, Peter and Cassa (1994) classify the TOC value into five categories as shown in Table 6.

According to Rad (1984), the TOC value of < 0.5% is classsified as low organic material abundance, the TOC value of 0.5 – 1% as medium organic material abundance, the value of 1-2% as a good organic material abundance, and the value of > 2 %is as a very good organic material abundance.

Based on the TOC and REP result on 69 samples (Table 1), can be concluded that the fine sedimentary rock of The Sungaibetung Formation has a rich organic material from 0.95 – 2.84 %, which is grouped as a medium until very good category source rock.

Afterwards, the fine sedimentary rock of the Banan Formation has an organic material abundance of 0.42 – 2.41% which is classified as a poor to very good category and tends to have capacity as a good source rock (Waples, 1985). The Cretaceous sedimentary rock of the Pedawan Formation has a TOC value between 0.27 – 2.29 % which is also classified as poor to very good category of organic richness and has a good ability to produce hydrocarbons.The fine-grained sedimentary rock of the Kayan Formation has TOC value range from 0.41 – 1.82 % which has the tendency to become poor to good source rock quality (Waples,1985).

The TOC analysis resume from all samples shows that several formations have variation potential of hydrocarbon source rock. The Pedawan Formation shows several samples that are classified as poor quality, while other samples are classified as very good. Based on the litology associate, the Pedawan Formation was deposited in the deltaic environment. Sediment supply is very dynamic. That process can be caused an effect on organic richness.

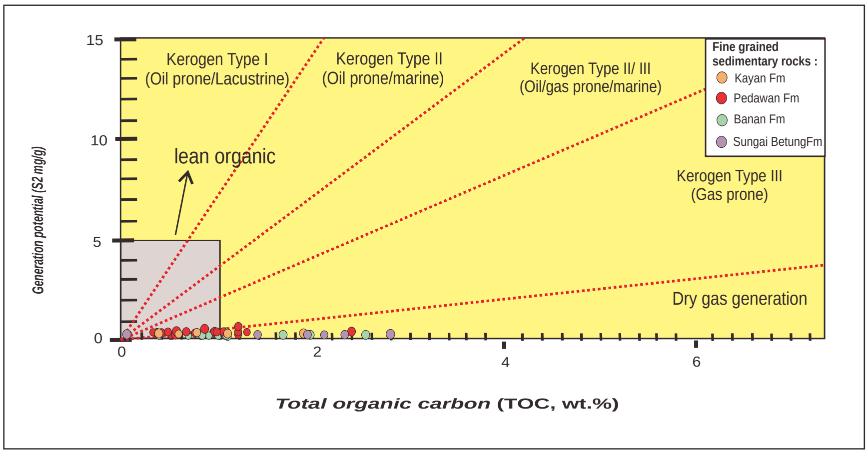
The sedimentary rocks of the Kayan Formation have abundance a poor to good organic material. Based on the analysis result from all samples, it is concluded that there is a possibility that the Triassic - Oligocene fine sedimentary are having good abundance of organic material for hydrocarbons source rock. The Sungaibetung Formation is a rock unit containing abundance of organic material which indicates as an excellent hydrocarbons source rocks.

Type of Organic Material

The TOC and the REP analysis results (Table 4) can be concluded that all samples have the hydrogen Index (HI) < 150 mg HC/g TOC and S2/S3 ratio values is minor (dominant < 3). Based on diagram of TOC versus S2 (modified from Jarvie, 2008) fine-grained sedimentary rocks in this areas indicates most of fine sedimentary rocks in the Mesozoic Singkawang Basin have a tendency to be classified as dry gas producer and contain poor organic matter (Figure 6). The sedimentary rocks of Singkawang Basin tend to indicate kerogen type III. From the fact that some samples have generated dry gas, it could also be interpreted that samples of the Singkawang Basin have entered an over mature stage.

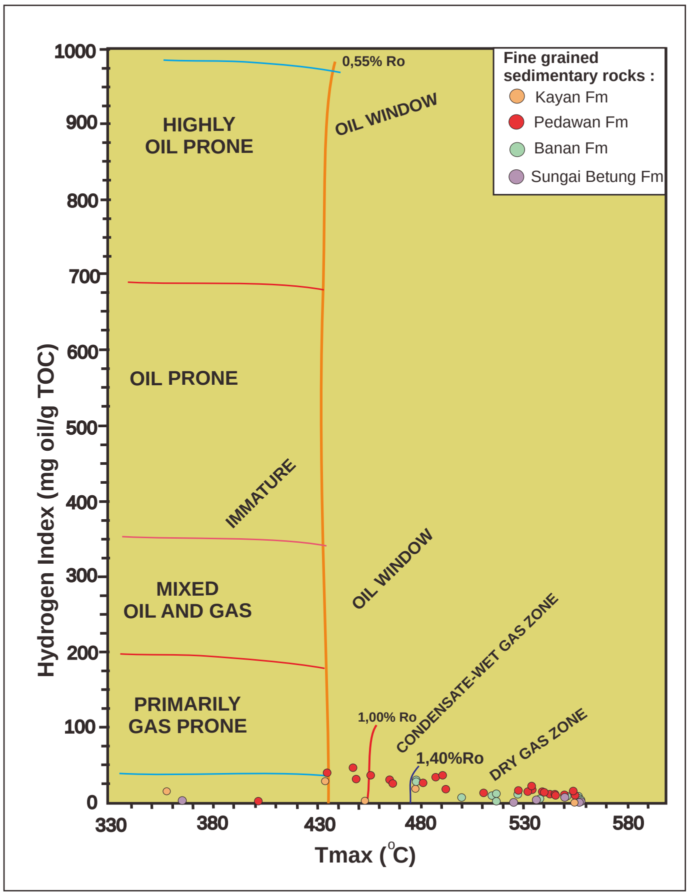
Maturity

According to Waples and Machihara (1991), the fundamental maturity differential of the source rocks is obtained from the analysis of kerogen, while the nature of biomarkers is not moving (immobile), thus maturity is equal to a rock or sediment deposited. Otherwise, biomarkers of bitumen fractions can move in the rocks



source: modified form Jarvie (2008)

Figure 6. Diagram of TOC versus S2 shows the type of kerogen on the sedimentary rocks in the Singkawang Basin.



source: modified form Jarvie (2008)

Figure 7. T_{Max} versus HI diagram shows the fine sedimentary rocks sample in Singkawang Basin as a part of gas prone zone.

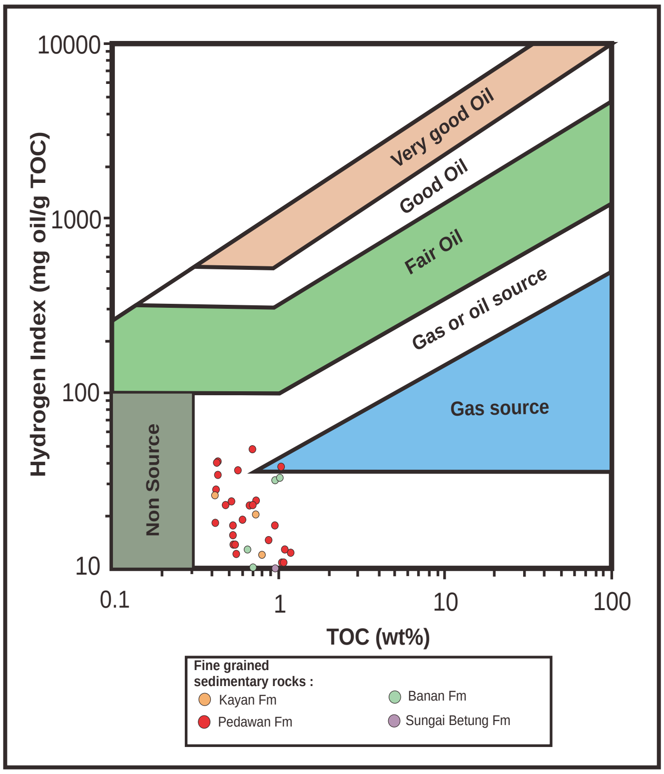
and sediments. The TOC and REP analysis results and Tmax vs HI diagrams (Jarvie, et.al., 2008) of 69 samples (Figure 7) represent the fine sedimentary rocks of the Singkawang Basin has entered an immature to over mature stage.

According Waples (1985) based on thermal maturity level of source rock (Tmax), mature level has value >435^{0}C. Based on the REP analysis, The soft sedimentary from the Sungaibetung Formation has a Tmax value between 525 – 558 ^{o}C, the Banan Formation 478 – 558 o C, Pedawan Formation 405 – 556 ^{o}C, and Kayan 357 – 557^{o}C. Maturity of the sedimentary rock of the Sungaibetung Formation tend to indicate overmature level, the Banan Formation included in mature to overmature categories. The Pedawan and Kayan Formation have a thermal maturity tend to immature to overmature categories.

DISCUSSION

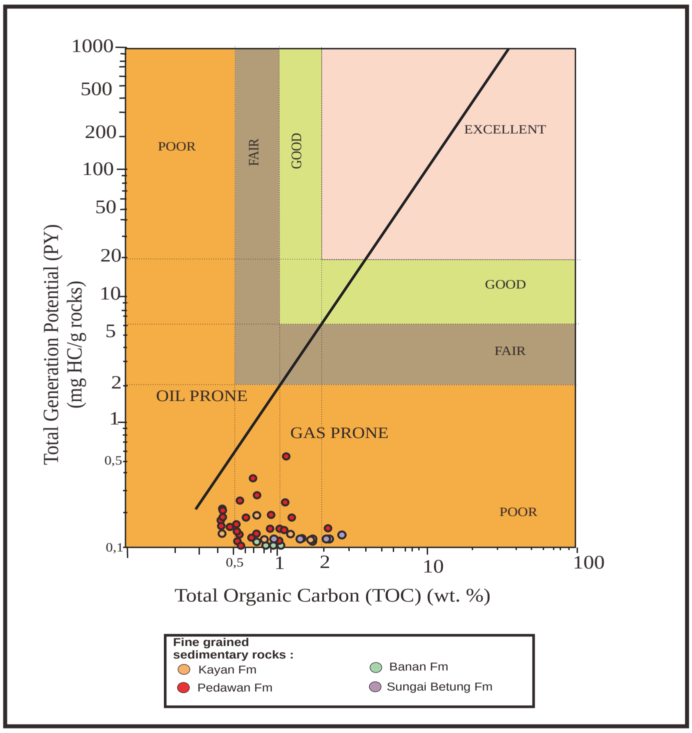
Source rocks potential can be evidently found as a fine-grained sedimentary rock that exists in the area of Ledo, Simpang Ledo-Sambas, and Seluas area as well as the Balai Karangan. Therefore, it can be concluded that the fine sedimentary rock of all formations has a favourable organic material abundance as a source rock candidate. However, of the four fine grained-sedimentary rock formations, the Sungaibetung Formation has the best potential in organic material abundance.

The TOC versus hydrogen index diagram represents that the fine grained sedimentary rocks from four formations are categorized into gas source zone which indicate as a gas producer source rock (Figure 8). Diagram of TOC versus HI (El Nady et al., 2015) indicates a potential fine sedimentary rock that is included into gas source zone. TOC versus PY and TOC versus S2 diagram indicate that fine sedimentary rock from four formations belongs to gas zone with having a



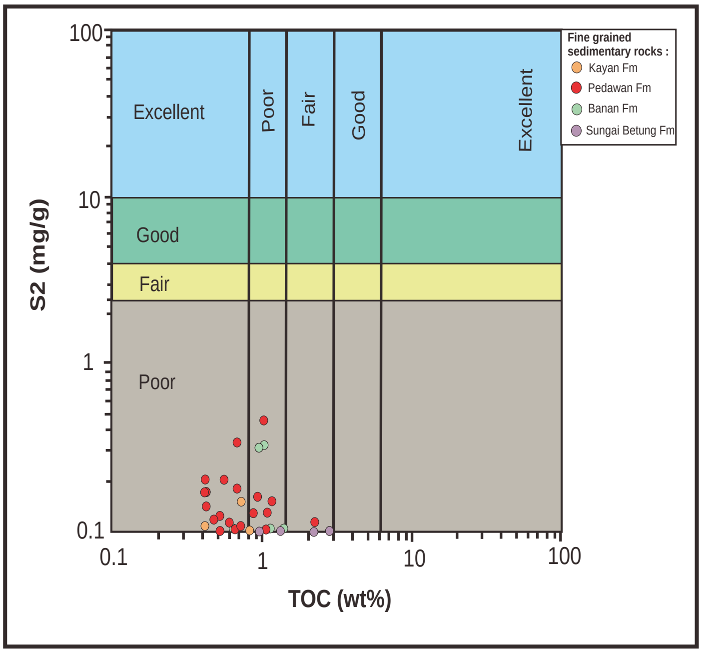
source: modified form El Nady.et al (2015)

Figure 8. Diagram of TOC versus HI indicating potential fine sedimentary rock that is included into gas source zone.



source: van Krevelen (1997)

Figure 9. Diagram of TOC versus PY showed potential as a producer of hydrocarbons.



source: modified form El Nady.et al (2015)

Figure 10. TOC versus S2 which shows the quality of fine sedimentary rock as the hydrocarbon source rocks.

poor to medium quality source rock (Figures 9 and 10). Sedimentary rocks of the Pedawan and Sungaibetung Formation have a better potential source rock than any other sedimentary rocks in the Banan and Kayan Formations. In general, the black shale of the Sungaibetung Formation has source rock potential.

CONCLUSIONS

The fine-grained sedimentary rocks from four formations have significant hydrocarbon potential as source rocks based on the laboratory analysis, interpretation, and evaluation from physical appearance. Furthermore, the fine-grained sediment of the Sungaibetung Formation has more potential as source rock than the Banan, Pedawan, and Kayan Formations. Thus, fine-grained sediment formation in Singkawang Basin is confirmed as more of gas rather than oil resources.

Finally, for the future research topic, different method i.e. geophysic method, absolute dating, and isotope analysis need to be carried out in order to correlate the stratigraphy of each formation and tectonics event of the studied area.

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REFERENCES

Arifullah, E., Bachtiar,A., Juhaeni, 2004. Ichnological Characteristics in The Modern Mahakam Delta, East Kalimantan. *The 33rd Annual Convention and Exhibition Indonesian Association of Geologist (IAGI)*, Bandung.

BPPKA, Pertamina, 1997. Indonesia Basin Summary (unpublish report)

El Nady, M.M., Ramadan. F.S., Mahmoud, M., Hammad, and Lotfy, N.M., 2015. Evaluation of Organic Matters, Hydrocarbon Potential and Thermal Maturity of Source Rocks Based on Geochemical and Statistical Methods: Case Study of Source Rocks in Ras Gharib Oilfield, Central Gulf of Suez, Egypt. *Egyptian Journal of Petroleum* 24: 203–211.

Espitalie, J., Laporte, J.L., Madec, M., Marquis, F., Leplat, P. And Paulet, J. 1977. Méthode Rapide De Caractérisation Des Roches Mères, De Leur Potentiel Pétrolier Et De Leur Degré D'évolution. *Rev. Inst. Fr. Petr*.32: 23-45.

Hall, R., and Breitfeld., H. T., 2017. Nature and demise of the Proto-South China Sea. *Bulletin of the Geological Society of Malaysia*, 63: P 61 – 76.

Hermiyanto, M.H and Sodiq F. 2017. Mineralogy and Rock-Eval Characteristic of Mesozoic Fine Grained Sedimentary Rock from Pedawan Formation : Implication for Shale Hydrocarbon Potential. *Proceedings Joint Convention Malang : HAGI – IAGI – IAFMI- IATMI.*

Hunt. J.M., (1996).: *Petroleum Geochemistry and Geology*, 2nd edition, New York, W.H. Freeman and Company, 273 – 351.

Jarvie, D, 2008. *Geochemical Characteristis of The Devonian Woodford Shale*. Worldwide Geochemistry, LLC.

Ju YW., Wang, G., Bu, H., Li, Q., Yan, Z., 2014, China Organic Rich Shale Geologic Features and Special Shale Gas Production Issues, *Journal of Rock Mechanics and Geotechnical Engineering* 6: 196-207.

Killops, S., and Killops, V., 2005, *Introduction to Organic Geochemistry, Second Edition*, Blackwell Science Ltd, a Blackwell Publishing company

Lafargue, E. J. Espitalié, F. Marquis And D. Pillot, 1996. Rock-Eval 6 Applications In Hydrocarbon Exploration, Production And In Soil Contamination Studies In *Revue De L'institut Français Du Pétrole*, 53 (4): 421 - 437.

Law, C. A., 1999. Evaluating Source Rocks. *AAPG Special Volumes. Volume Treatise of Petroleum Geology/Handbook of Petroleum Geology: Exploring for Oil and Gas Traps*, P. 3-1 - 3-34.

Metcalfe I, 2011. Tectonic framework and Phanerozoic evolution of Sundaland. Gondwana Research 19, p 3–21.

Peters and Cassa., 1994. Applied Source Rock Geochemistry. in Magoon, L.B, and W.G Dow, eds, 1994, *The*

Petroleum system- from source to trip AAPG memoir 60: P. 93-119.

Rad, F.K., 1984. Quick Look Source Rock Evaluation by Pyrolysis Technique. *Proceedings 13th Annual Convention Indonesian Petroleum Association*, h.113-124.

Rusmana, E., and Pieters, P.E., 1993. *Geological Map of the Sambas/Siluas Sheet, Kalimantan*. Badan Geologi, Bandung.

Satyana, A.H., 2000, Kalimantan, An Outline of The Geology of Indonesia, *Indonesian Association of Geologists*, p.69-89.

Supriatna, S., Margono, U., Sutrisno, Pieters, P.E., and Langford, R.P., 1993. *Geological Map of the Sanggau Sheet, Kalimantan.* Badan Geologi, Bandung.

Suwarna, N., and Langford R.P., 1993. *Geological Map of the Singkawang Sheet, Kalimantan*. Badan Geologi, Bandung.

Waples. D. W., 1985. *Geochemistry in Petroleum Exploration*. Brown and Ruth Laboratories Inc, Denver Colorado. 33 p.

Waples, D.W., and Machihara, T., 1991. Biomarkers for geologists - a practical guide to the application of steranes and triterpanes in petroleum geology, American Association of Petroleum Geologists Methods in Exploration Series 9. *The American Association of Petroleum Geologists*, Oklahoma: USA.

Williams, P. R., Supriatna, S. Trail, D. S. Heryanto, R. 1984. Tertiary Basins of West Kalimantan, Associated Igneous Activity and Structural Setting. *13th Annual Convention Proceedings* 1:151-160.