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Organic petrology and Rock-Eval characteristics in selected surficial samples of the Tertiary Formation, South Sumatra Basin

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Abstract

Organic petrologic data of the DOM of Talangakar and Muaraenim Formations show that the organic matter consisting mainly of vitrinite group is essentially composed of telocollinite (1.0 – 70.8 %) and desmocollinite (0.8 – 66.6 %) with minor telinite (0.6 – 9.4 %), detrovitrinite (0.6 – 6.0 %), and corpocollinite (0.6 – 2.0 %). Minor exinite (0.4 – 7.8 %) and inertinite (0.4 – 8.0 %) are also determined. However, mineral matter varies from 0.6 – 99.44 %. Downwards, the increase in vitrinite reflectance (0.33 – 0.48 %) is concomitant with the depth of each formation. Furthermore, based on Rock-eval pyrolysis, TOC value of the Talangakar Formation ranges from 0.09 – 15.38 %, Gumai 0.34 – 0.39 %, Airbenakat 0.32 – 4.82 %, and Muaraenim between 0.08 – 15.22 %. Moreover the PY (Potential Yield) value variation of the Talangakar, Gumai, Airbenakat, and Muaraenim Formations are between 0.04 – 36.61 mg HC/g rock, 0.53 – 0.81 mg HC/g rock, 0.1 – 4.37 mg HC/g rock, and 0.07 – 129.8 mg HC/g rock respectively. Therefore, on the basis of those two parameters, the four formations are included into a gas - oil prone source rock potential. However, the Talangakar and Muaraenim Formations are poor to excellent category, whereas the Air Benakat tends to indicate a poor – fair category and Gumai Formation are only within a poor category. T_{max} value of the Talangakar ranges from 237 – 438^0 C, Gumai 316 – 359^0 C, Airbenakat 398 – 434^0 C with exceptions of 497^0 C and 518^0 C, and Muaraenim Formations 264 – 425^0 C. The Talangakar Formation contains kerogen Type II dan III, with the HI (Hydrogen Index) value varies from 45.16 – 365.43. However two samples show value of 0. The organic content of the Gumai and Air Benakat Formations are included into kerogen type III, with HI value ranges from11.87 – 40.82, and 19 – 114 respectively. Moreover the Muaraenim Formation has two category of kerogen type and HI value, those are type III with the HI value of 1 and kerogen type I with HI value of 821.29. The diagram of T_{max} *vs.* HI shows that the organic thermal maturation of the four formations are included into an immature to mature level.

Keywords: organic petrology, rock-eval pyrolisis, organic matter, South Sumatra Basin

Sari

Analisis petrologi organik Formasi Talangakar dan Muaraenim menunjukkan kandungan utama kelompok maseral vitrinit terdiri atas telokolinit (1,0 – 70,8 %) dan desmokolinit (0,8 – 66,6 %) dengan sedikit telinit (0,6 – 9,4 %), detrovitrinit (0,6 – 6,0 %), dan korpokolinit (0,6 – 2,0 %), serta sedikit eksinit (0,4 – 7,8 %) dan inertinit (0,4 – 8,0 %). Kandungan bahan mineral berkisar dari 0,6 – 99,44 %. Kenaikan nilai reflektan vitrinit (0,33 – 0,48 %) bersesuaian dengan kedalaman setiap formasi. Berdasarkan analisis pirolisis Rock-eval, kisaran nilai kandungan karbon organik total (TOC) serpih Formasi Talangakar 0,09 – 15,38 %, Gumai 0,34 – 0,39 %, Airbenakat 0,32 – 4,82 %, dan Formasi Muaraenim 0,08 – 15,22 %. Potential Yield (kandungan cairan hidrokarbon) serpih Formasi Talangakar berkisar dari 0,04 – 36,61 mg HC/g batuan, Formasi Gumai 0,53 – 0,81 mg HC/g batuan, Formasi Airbenakat 0,1 – 4,37 mg HC/g batuan, dan Formasi Muaraenim 0,07 – 129,8 mg HC/g batuan. Berdasarkan diagram TOC versus Potential Yield keempat formasi tersebut masuk dalam kategori

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gas-oil prone source rock. Selanjutnya, nilai kandungan bahan organik Formasi Talangakar dan Formasi Muaraenim termasuk kategori jelek (poor) sampai baik sekali (excellent). sedangkan Formasi Air Benakat dan Formasi Gumai termasuk kategori jelek (poor) - sedang (fair). Berdasarkan kandungan hidrokarbon (Potential Yield) pada batuan serpihnya, Formasi Talangakar dan Formasi Muaraenim termasuk dalam kategori baik, sedangkan serpih Formasi Airbenakat cenderung termasuk ke dalam kategori kurang baik sampai sedang, dan Formasi Gumai termasuk dalam kategori kurang baik.Formasi Talangakar mempunyai nilai temperatur maksimum (T_{maks}) antara 237 – 438^0 C, Gumai 316 – 359^0 C, Airbenakat 398 – 434^0 C dengan dua kekecualian yakni 497^0 C dan 518^0 C, dan Formasi Muaraenim 264 – 425^0 C. Sementara itu, Formasi Talangakar mempunyai nilai HI (Hydrogen Index) antara 45,16 – 365,43, dengan kandungan kerogen Tipe II dan tipe III; namun dua percontoh mempunyai nilai HI 0. Formasi Gumai memiliki nilai HI 11,87 – 40,82 dengan kandungan kerogen Tipe III, Formasi Airbenakat memiliki nilai HI 19 – 114 dan kandungan kerogen tipe III, dan Formasi Muaraenim memiliki nilai HI 1 dengan kandungan kerogen tipe III serta HI 821,29 dengan kerogen tipe I. Berdasarkan diagram temperatur maksimum (T_{maks}) terhadap nilai indeks hidrogen (HI) bahan organik, kematangan termal keempat formasi tersebut menunjukkan tingkatan belum matang sampai batas awal matang.

***Kata kunci**: petrologi organik, pirolisis rock-eval, bahan organik, Cekungan Sumatra Selatan*

Introduction

The South Sumatra Basin is an important oil producing area in the island of Sumatra. The basin has been exploited more than a hundred years and produced oil and gas around 1.5 million barrel (Pertamina - BPPKA, 1996 in: Ryacudu, 2005), but the new hydrocarbon resources is still found out in this area.

The sedimentological and stratigraphical analysis of the South Sumatra Basin was conducted as a preliminary research. This study expects to get new data and information in the basin area.

Organic petrological determination and Rock-Eval analysis from selected surface samples might support the thermal maturity and source rock potential in the South Sumatra Basin. Furthermore, the focus of the study is to determine level of maturity and maceral types, which both are related to the presence of hydrocarbon in each formation of the South Sumatra Basin.

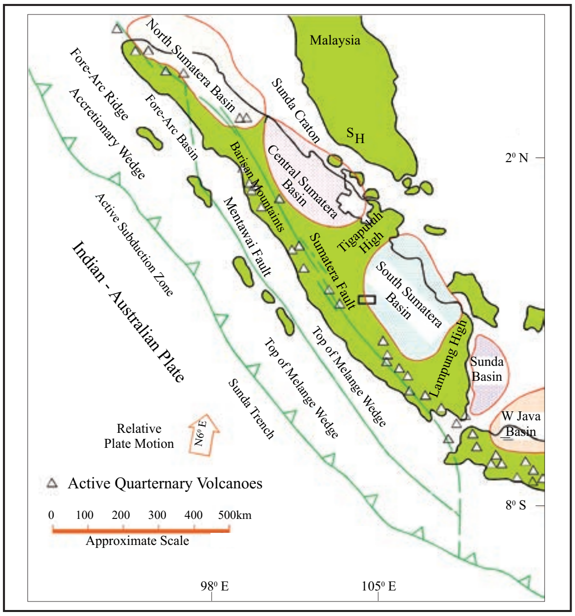

Figure 1. Locality map of the South Sumatra Basin (de Coster, 1974).

Geological Setting

The geological setting of the South Sumatra Basin has been described in several published and unpublished reports. According to De Coster (1974), the basin is located in the southern part of Sumatra Island, which is regarded as a back-arc basin bounded by the Barisan Mountains in the southwest and by the pre-Tertiary Sunda Shelf to the northeast (Figure 1). The study area is situated within the geological maps presented by Gafoer *et al.* (1993) and Suwarna *et al.* (1992, 1998).

Regional Stratigraphy

The study area is occupied by the Lahat, Talang Akar, Baturaja, Gumai, Air Benakat, Muaraenim, and Kasai Formations, ended by a Quartenary sequence of alluvial deposits (Suwarna *et al*., 1992). The stratigraphic succession of the formations is presented in Figure 2.

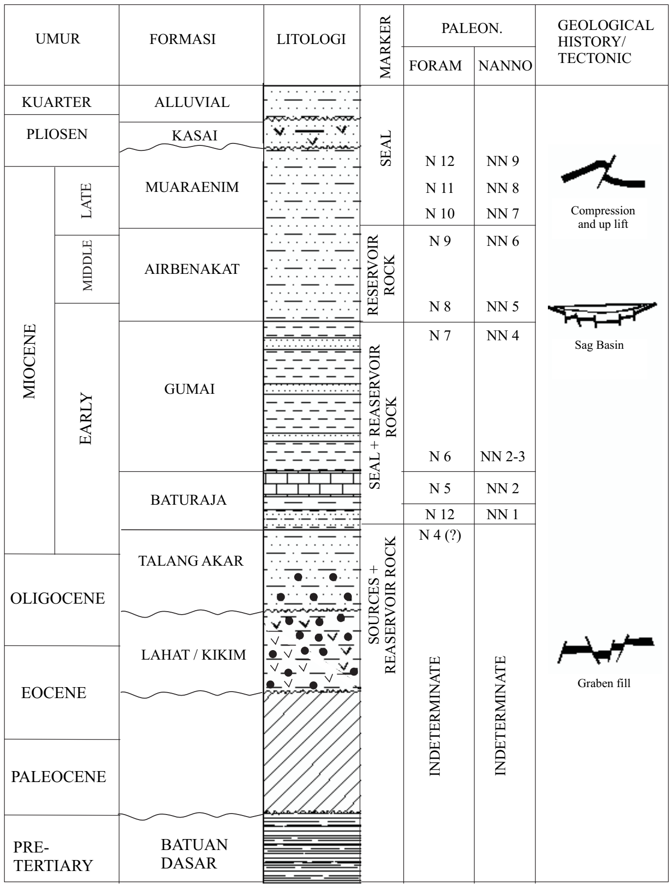

Figure 2. The stratigraphy of rock successions in the South Sumatra Basin (modified from Tarazona *et al*.,1999; in Hermiyanto *et al*., 2006).

Basement of the South Sumatra Basin is pre-Tertiary rocks, comprising various igneous and low grade meta-sediments. The basement is overlain unconformably by the Eocene - Oligocene Lahat (Kikim) Formation consisting of purple green and red brown tuff, tuffaceous clays, andesite, breccia, and conglomerate.

In turns, the Lahat Formation is unconformably overlain by the Oligocene - Miocene Talangakar Formation, composed of medium- to coarse-grained sandstones and coal seams in the lower part; and calcareous grey shale and sandstone with coal seams in the upper part. Thickness of the Talangakar Formation is approximately up to 900 m. Locally, the Talangakar Formation deposited in a terrestrial to paralic environment, rests unconformably on top of the pre-Tertiary basement. Then, the Talangakar Formation is conformably overlain by the shallow marine calcareous shale and limestone of the Baturaja Formation.

Moreover, the Baturaja Formation conformably underlies with the Gumai Formation composed of marl, claystone, shale, and silty shale, with occasionally thin limestone and sandstone intercalations. The Gumai sediments was deposited in a deeper open marine environment. In turns, the Gumai Formation is conformably overlain by the littoral to shallow marine Airbenakat Formation comprising sandy and marly claystone, with intercalations of glauconitic sometimes calcareous sandstone. The deposition of Talangakar up to Airbenakat Formations occurred during Oligo - Miocene time.

The Late Miocene - Pliocene Muaraenim Formation, conformably overlying the Airbenakat Formation, is divided into Member a (interstratified sandstone and brownish claystone with principal coal seams) and Member b (greennish blue claystone with numerous ligniteous coal seams) deposited in a brackish environment (Suwarna *et al*., 1992).

The youngest unit is the Kasai Formation, consisting of gravel, tuffaceous sands and clays, volcanic concretion, pumice, and tuff. The formation conformably to unconformably overlies the Mio-Pliocene Muaraenim Formation. The deposition of the Kasai Formation coincided with a volcanic and magmatic activity occurring in the area. This activity formed some igneous intrusives intruding the coal measures such as in the Bukit Asam coalfields.

Methods of Study

Achieving the aims of the study, specific geologic field investigations and laboratory techniques were carried out. Futhermore, the study focused on the stratigraphic analysis of each formation, with measured section method using geological compass and GPS. Eventually, each formation was selected for a representative section, which was supported by collecting rock samples for laboratory analysis purposes, such as organic petrology, Rock-Eval pyrolysis, and SEM mode.

Petrographic analysis was performed on 73 polished briquettes of rock sample for vitrinite reflectances and 19 samples for maceral analysis. Maceral analysis were performed using a point counting technique, firstly in white light and again using ultraviolet/blue irradiation to produce visible autofluorescence of the contained exinite. The analysis was carried out in the Tekmira and Geological Agency Laboratories.

Rock-eval pyrolysis performed in the Lemigas Laboratories, was conducted on each sample for two replicates of each sample following standard procedures. Parameters determined include total organic carbon (TOC), T_{max}, and S_1, S_2, S_3 values.

Moreover, the SEM analysis was conducted to study the mineral and organic composition of each sample, especially leading to a diagnosis level.

Analysis Results

Organic Petrology

A complete organic petrology result from 19 rock samples, representing the Talangakar (2 coal and 6 DOM samples), Air Benakat (1 coal and 3 DOM samples), and Muaraenim (7 coal samples) Formations is presented in Table 1.

The Talangakar coal is characterized by the presence of vitrinite maceral group ranges from (74.8 – 93.0 %), mainly composed of desmocolinite (36.6 – 58.6 %), telocolinite (13.6 – 54.6 %), telinite (0.6 – 2 %), and corpocollinite (0.6 – 1.2 %). Exinite maceral group (1.0 – 2.0 %), predominantly made up of resinite (0.4 – 1.2 %), with sporinite (0.4 – 0.6 %) and liptodetrinite (0.4 %) is also determined. Inertinite group (1.2 – 2.6 %) is essentially composed of sclerotinite about 2.2 % and semifusinite (0.4 – 1.2 %).

Dispersed Organic Matter (DOM) of the formation is dominated by the presence of vitrinite (0.6 – 3.0 %) comprising detrovitrinite (0.6 – 1.2 %) and desmocollinite (0.8 %). Exinite recognized is resinite (0.4 %), whilst inertinite (0.8 %) consists of sclerotinite (0.4 – 0.8 %) and semifusinite (0.4 %). The mean vitrinite reflectance value of the formation varies from 0.33 – 0.44 %.

The organic matter of the Air Benakat Formation is composed mainly of vitrinite maceral group of 0.8 – 79.4 %. It is dominated by desmocollinite (0 – 38.0 %) and telocollinite of 0 – 35.4 %. A small amount of inertinite (0 – 1.2 %) comprising sclerotinite (0 – 0.8 %). and inertodetrinite (0 – 0.6 %) is also recognized. The mean vitrinite reflectance value ranges between 0.36 – 0.48 %.

The maceral composition of Muaraenim coal consists of vitrinite group up to 98.6 % in amount, with telocollinite (1.0 – 70.8 %), desmocollinite (23.4 – 66.6 %), corpocollinite (0 – 2 %), and telinite (0.6 – 9.4 %). The inertinite group (0.4 – 8 %) is essentially composed of sclerotinite (0 – 5.2 %), semifusinite (0 – 3 %), inertodetrinite (0 – 1.0 %), and fusinite (0 – 0.4 %). The exinite group (0.4 – 7 %) includes resinite (0 – 4 %), sporinite (0 – 1.4 %), cutinite (0 – 0.6 %), alginite (0 – 1.6 %), and liptodetrinite (0 – 1.4 %). The mean vitrinite reflectance value of the Muaraenim coal varies between 0.42 – 0.45 %.

The mineral matter of DOM of Talangakar Formation is composed of clay 88.4 – 98.6 % with two exceptions of 1.6 % and 19 % in the coal, carbonate 0 – 1.2 %, pyrite 0 – 3 % with one value of 12.0 %. Mineral matter group of the Air Benakat DOM varies from 89.4 % to 99.2 % with one value of 19.4 % from coal sample. The mineral matter of Air Benakat

Table 1. Organic Petrology Results of 19 Rock Samples from selected Sites in the South Sumatra Basin

NO	SAMPLES	Lithology	MACERAL (%)																	MINERAL (%)				Rv (%)			Formation
			Tl	TC	Dv	Dsm	Crp	V	Sp	Cu	Re	Alg	Lipt	E	F	Sf	Sc	Intr	I	Cly	Crb	Py	MM	Min	Max	Mean	
1	06 MH 36 B	Coal	0.6	54.6	0.0	36.6	1.2	93.00	0.4	0.0	1.2	0.0	0.4	2.0	0.0	0.4	2.2	0.0	2.6	1.6	0.4	0.4	2.4	0.38	0.420	0.40	Talangakar
2	06 NS 03 D	Coal	2.0	13.6	0.0	58.6	0.6	74.80	0.6	0.0	0.4	0.0	0.0	1.0	0.0	1.2	0.0	0.0	1.2	19.0	1.2	3.0	23.0	0.38	0.500	0.44	Talangakar
3	07 RL 13B	Shale	0.0	0.0	1.2	0.0	0.0	1.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.4	0.2	0.0	98.8	0.40	0.440	0.42	Talangakar
4	07 AP 03 B	Siltstone	0.0	0.0	0.8	0.0	0.0	0.80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	98.6	0.0	0.0	99.2	0.32	0.400	0.37	Talangakar
5	07 AP 03 D1	Claystone	0.0	0.6	1.2	0.8	0.0	2.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.8	88.4	0.8	0.8	96.6	0.36	0.400	0.38	Talangakar
6	07 AP 03 D2	Claystone	0.0	1.4	0.8	0.8	0.0	3.00	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.4	0.4	0.0	0.8	90.0	1.0	0.6	95.8	0.40	0.440	0.42	Talangakar
7	07 AP 06	Claystone	0.0	0.0	0.8	0.0	0.0	0.80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.0	0.4	2.0	99.2	0.32	0.460	0.33	Talangakar
8	06 WG 09 C	Siltstone	0.0	0.0	0.6	0.0	0.0	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.8	0.8	12.0	99.4	0.38	0.440	0.39	Talangakar
9	06 MH 08 A	Siltstone	0.0	0.0	0.8	0.0	0.0	0.80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.0	2.4	2.2	99.2	0.32	0.380	0.36	Air Benakat
10	06 MH 08 B	Claystone	0.0	2.8	2.4	4.8	0.0	10.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	83.4	0.8	11.0	89.4	0.42	0.460	0.44	Air Benakat
11	06 MH 08 C	Siltstone	0.0	0.0	1.6	1.0	0.0	2.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	89.6	0.6	0.2	97.0	0.38	0.420	0.40	Air Benakat
12	06 MH 09 C	Coal	0.0	35.4	6.0	38.0	0.0	79.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.4	1.2	14.0	3.4	0.8	19.4	0.46	0.500	0.48	Air Benakat
13	06 AP 01 C	Coal	1.2	70.8	0.0	24.6	2.0	98.60	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.4	0.0	0.4	0.2	0.6	0.38	0.480	0.44	Muaraenim
14	06 NS 01 B	Coal	2.6	1.0	0.0	49.4	0.0	53.00	1.4	0.0	2.2	0.4	0.0	4.0	0.0	0.0	3.4	0.6	4.0	30.0	5.6	3.0	39.0	0.38	0.440	0.43	Muaraenim
15	06 NS 01 D	Coal	0.6	16.4	0.0	66.6	1.2	84.80	0.0	0.2	1.8	0.4	0.0	2.4	0.0	0.0	2.4	0.0	2.4	6.6	0.8	3.0	10.0	0.38	0.446	0.44	Muaraenim
16	06 NS 02 A	Coal	0.6	59.0	0.0	23.4	1.2	84.20	1.4	0.0	4.0	1.6	0.0	7.0	0.4	2.0	5.2	0.4	8.0	0.8	0.0	0.0	0.8	0.40	0.480	0.45	Muaraenim
17	06 AP 05 C	Coal	0.6	55.8	0.0	28.2	0.6	85.20	1.2	0.6	1.6	0.0	1.4	4.8	0.0	0.0	5.0	1.0	6.0	1.6	0.8	1.6	4.0	0.36	0.440	0.42	Muaraenim
18	06 MH 06	Coal	9.4	57.6	0.0	24.0	1.0	91.40	0.4	0.6	1.4	0.0	0.4	2.8	0.0	1.6	3.6	0.0	5.2	0.4	0.2	0.0	0.6	0.40	0.430	0.42	Muaraenim
19	06 AP 11A	Coal	0.6	6.4	0.0	44.4	0.6	52.00	0.4	0.0	1.0	0.0	0.0	1.4	0.0	3.0	0.0	0.4	3.4	39.0	1.6	3.0	43.0	0.38	0.460	0.43	Muaraenim

Tl	:	Telinite	Sp	:	Sporinite	F	:	Fusinite	Cly	:	Clay	Rv	:	Vitrinite reflectance
TC	:	Telocollinite	Cu	:	Cutinite	Sf	:	Semifusinite	Crb	:	Carbonate	Min	:	Minimum
Dv	:	Detrovitrinite	Re	:	Resinite	Sc	:	Sclerotinite	Py	:	Pyrite	Max	:	Maximum
Dsm	:	Desmocollinite	Alg	:	Alginite	Intr	:	Inertodetrinite	MM	:	Mineral Matter			
Crp	:	Corpocollinite	Lipt	:	Liptodetrinite	I	:	Inertinite						
V	:	Vitrinite	E	:	Exinite									

DOM is dominated by clay mineral (83.4 – 95.0 %) with one value of 14.0 % from coal sample, carbonate (0.6 – 2.4 %), and pyrite (0.2 – 11.0 %). Whilst, the Muaraenim coal is characterized by the presence of mineral matter group up to 43.0 % incomprising clay (0 – 39 %), carbonate (0 – 5.6 %), and pyrite (0 – 3 %).

Moreover, additional vitrinite reflectance analysis was also conducted in 73 sedimentary rock samples, and its result is depicted in Table 2. Generally, the increase in vitrinite reflectance of Kikim, and Gumai Formations are concomitant with the depth of each formation shown in Figure 3. The maximum vitrinite reflectance value (Rv) of sedimentary rocks of the Kikim Formation varies from 0.38 – 0.48 %, with the mean reflectance value ranges from 0.35 % to 0.39 %; the Talangakar Formation ranges from 0.36 – 0.5 %, with Rv (mean of reflectance value) varies between 0.33 – 0.46 %. Rv mean value of the Baturaja Formation 0.43 %; Gumai Formation between 0.35 and 0.42 %; Airbenakat Formation from 0.33 – 0.55 %, and Muaraenim Formation ranges from 0.34 – 0.45 %. Based on the vitrinite reflectance (Rv) of six formations having values < 0.55 % tends to indicate an immature zone (Kantsler, 1978; Cook, 1982).

Organic Maturation

Twenty five samples were collected from the Sarolangun, Muara Bungo, Jambi, and Palembang areas for Rock-Eval pyrolysis analysis (Table 3). The analysis shows that, the total organic carbon (TOC) content of shales of the Talangakar, Gumai, Airbenakat, and Muarenim Formations varies from 0.08 – 15.38 %. The highest TOC content (15.38 %) is contained within the Talangakar Formation (06AP314D2), that crops out in the Banyuasin area.

Table 3 depicts that the Talangakar shale has a potential yield from 0.04 – 36.61 mg HC/g rock; the Gumai shale is between 0.53 and 0.81 mg HC/g rock; the Airbenakat Formation varies from 0.1 – 4.37 mg HC/g rock, whilst the Muaraenim Formation has a potential yield of 0.07 – 129.8 mg HC/g rock. Based on these potential yields, the Talangakar and Muaraenim Formations are included into a poor – excellent category, whilst the Air Benakat Formation tends to indicate to be poor – fair category; however the poor one dominates. Moreover, the Gumai Formation shows a poor

Table 2. Result of Vitrinite Reflectance from selected surfacial Coal Samples of the Tertiary Formation, South Sumatra Basin

NO	Samples code	Rv-max	Rv-min	Rv-mean	Formation
1.	06 NS 132 A	0.46	0.40	0.44	Muaraenim
2.	06 NS 136 A	0.44	0.36	0.41	Muaraenim
3.	06 NS 138 A	0.38	0.36	0.36	Muaraenim
4.	06 NS 204 B	0.38	0.32	0.35	Muaraenim
5.	06 NS 204 A	0.40	0.30	0.35	Muaraenim
6.	06 NS 203 A	0.42	0.38	0.40	Muaraenim
7.	06 NS 202 A	0.44	0.36	0.40	Muaraenim
8.	06 AP 01 C	0.48	0.38	0.44	Muaraenim
9.	06 NS 01 B	0.44	0.38	0.43	Muaraenim
10.	06 NS 01 D	0.45	0.38	0.44	Muaraenim
11.	06 NS 02 A	0.48	0.40	0.45	Muaraenim
12.	06 AP 05 C	0.44	0.36	0.42	Muaraenim
13.	06 MH 06	0.43	0.40	0.42	Muaraenim
14.	06 AP 11A	0.46	0.38	0.43	Muaraenim
15.	06 NS 201 C	0.40	0.30	0.34	Muaraenim
16.	06 NS 201 B	0.44	0.36	0.41	Muaraenim
17.	06 NS 201 A	0.40	0.36	0.40	Muaraenim
18.	06 AP 307 A	0.46	0.36	0.41	Air Benakat
19.	06 MH 02	0.56	0.48	0.55	Air Benakat
20.	06 NS 120 A	0.36	0.30	0.33	Air Benakat
21.	06 NS 120 B	0.42	0.36	0.39	Air Benakat
22.	06 MH 08 A	0.38	0.32	0.36	Air Benakat
23.	06 MH 08 B	0.46	0.42	0.44	Air Benakat
24.	06 MH 08 C	0.42	0.38	0.40	Air Benakat
25.	06 MH 09 C	0.50	0.46	0.48	Air Benakat
26.	06 NS 120 C	0.40	0.32	0.35	Air Benakat
27.	06 NS 212 A	0.44	0.38	0.42	Air Benakat
28.	06 NS 211 A	0.46	0.34	0.40	Air Benakat
29.	06 NS 210 B	0.48	0.36	0.42	Air Benakat
30.	06 MH 50 A	0.38	0.32	0.35	Gumai
31.	06 NS 205 A	0.40	0.32	0.36	Gumai
32.	06 NS 206 A	0.44	0.38	0.42	Gumai
33.	06 NS 208 A	0.38	0.32	0.35	Gumai
34.	06 TH 220 A	0.42	0.36	0.39	Gumai
35.	06 WG 39	0.46	0.36	0.40	Gumai
36.	06 WG 48	0.44	0.32	0.38	Gumai
37.	06 TH 213 A	0.46	0.38	0.43	Baturaja
38.	06 AP 314 E1	0.46	0.42	0.44	Talang Akar
39.	06 AP 314 D2	0.46	0.42	0.42	Talang Akar
40.	06 AP 314 D1	0.46	0.40	0.44	Talang Akar
41.	06 AP 312 A	0.42	0.34	0.37	Talang Akar
42.	06 AP 311 A	0.40	0.34	0.37	Talang Akar
43.	06 LS 03 B	0.46	0.34	0.40	Talang Akar
44.	06 MH 23	0.38	0.32	0.36	Talang Akar
45.	06 MH 29	0.36	0.32	0.34	Talang Akar
46.	06 MH 15 B	0.42	0.34	0.37	Talang Akar
47.	06 MH 30 A	0.48	0.36	0.44	Talang Akar
48.	06 NS 01	0.48	0.42	0.45	Talang Akar
49.	06 NS 02 A	0.48	0.42	0.46	Talang Akar
50.	06 NS 03 A	0.48	0.38	0.42	Talang Akar
51.	06 NS 04 A	0.46	0.36	0.43	Talang Akar
52.	06 NS 06 B	0.38	0.32	0.35	Talang Akar
53	06 NS 07A	0.42	0.36	0.39	Talang Akar
54	06 MH 36 B	0.42	0.38	0.40	Talang Akar
55	06 NS 03 D	0.5	0.38	0.44	Talang Akar
56	07 RL 13B	0.44	0.40	0.42	Talang Akar
57	07 AP 03 B	0.40	0.32	0.37	Talang Akar
58	07 AP 03 D1	0.40	0.36	0.38	Talang Akar
59	07 AP 03 D2	0.44	0.40	0.42	Talang Akar
60	07 AP 06	0.46	0.32	0.33	Talang Akar
61	06 WG 09 C	0.44	0.38	0.39	Talang Akar
62	06 NS 07 H	0.46	0.38	0.42	Talang Akar
63	06 NS 07 K	0.36	0.34	0.36	Talang Akar
64	06 TH 205 C	0.42	0.36	0.40	Talang Akar
65	06 TH 204 B	0.46	0.36	0.42	Talang Akar
66	06 TH 202 A	0.44	0.32	0.38	Talang Akar
68	06 WG 51	0.40	0.34	0.37	Talang Akar
69	06 LS 08 A	0.38	0.32	0.35	Kikim
70	06 LS 08 C	0.38	0.34	0.36	Kikim
71	06 WG 106 B	0.40	0.34	0.37	Kikim
72	06 WG 106 C	0.42	0.36	0.38	Kikim
73	06 WG 120 A	0.48	0.32	0.39	Kikim

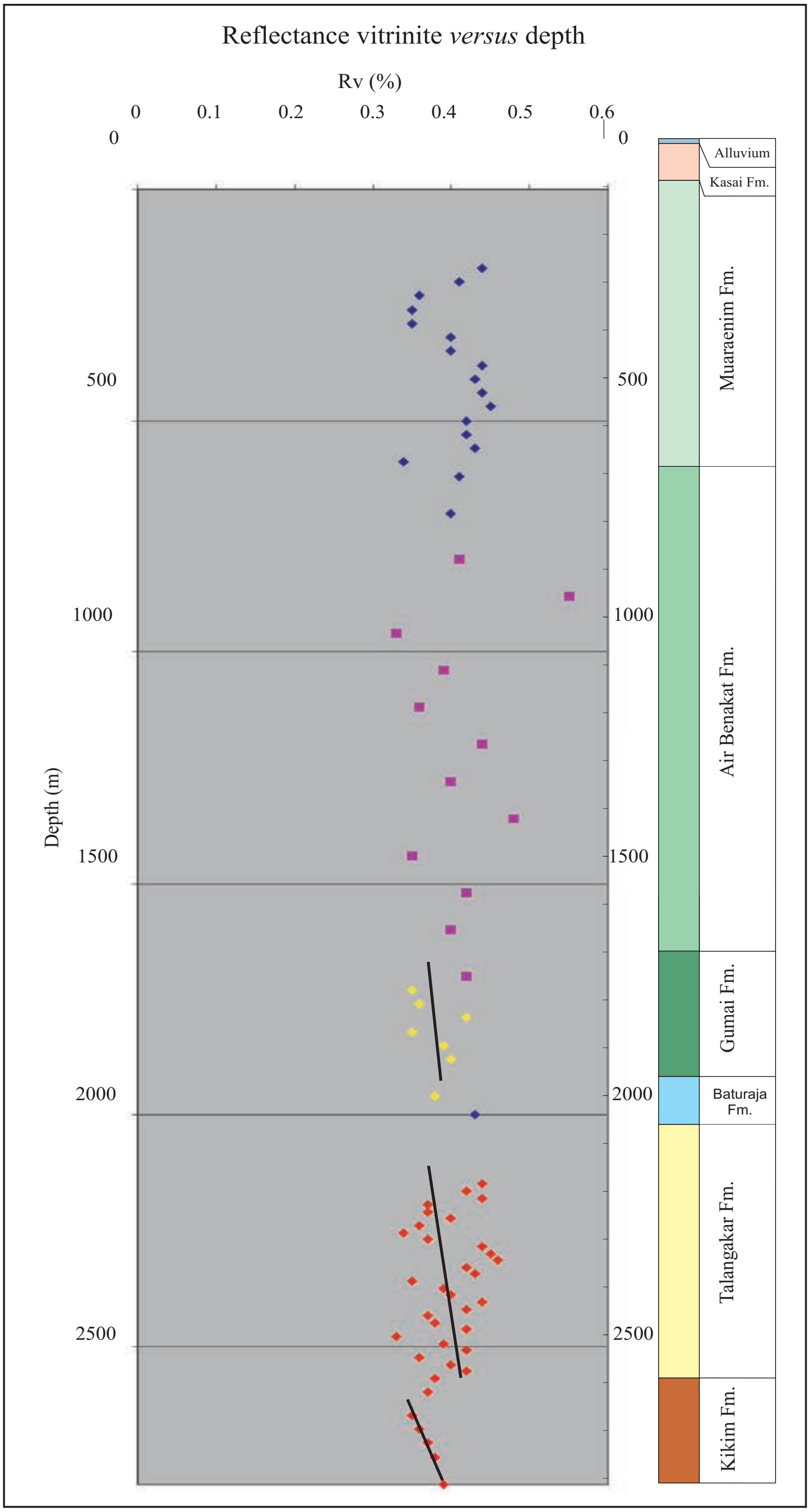

Figure 3. Diagram showing a general increase in vitrinite reflectances concomitant with the depth of each formation.

Table 3. Total Organic Carbon (TOC) dan Rock-Eval Pyrolisis Analysis Results of selected surface Samples of the Tertiary Formation, South Sumatra Basin

No	Sample No.	Lithology	Formation	TOC %	S_1 (mg / g)	S_2 (mg / g)	S_3 (mg / g)	PY (mg / g)	S_2/S_3	PI	PC	T_{max} °C	HI	OI
1.	06 AP01A	Clst. dkgy. sltst. lam	Talangakar	2.99	0.34	1.58	1.15	1.92	1.37	0.18	0.16	422	53	38
2.	06 AP 314 D1	Coaly shale	Talangakar	3.01	0.26	3.16	1.37	3.42	2.31	0.08	0.28	411	105.02	45.53
3.	06 AP 314 D2	Coaly shale	Talangakar	15.38	0.94	35.67	11.08	36.61	3.22	0.03	3.04	427	231.92	72.04
4.	06 MH 15B	Sh. gy. non calc. lam	Talangakar	1.30	0.09	0.81	0.43	0.90	1.88	0.10	0.07	432	61	33
5.	06 MH 28	Clst. dkgy. calc	Talangakar	1.41	0.19	2.91	0.16	3.10	18.19	0.06	0.26	433	206	11
6.	06 NS 07 C	Clst	Talangakar	0.76	0.11	0.35	0.08	0.46	4.38	0.24	0.04	438	45.16	10.32
7.	06 NS 07 H	Shaly Coal	Talangakar	4.05	1.53	14.80	0.52	16.33	28.46	0.09	1.36	437	365.43	12.84
8.	07 RL 13B	Sh brngy	Talangakar	0.93	1.06	0.89	0.31	1.95	2.87	0.54	0.16	438	96	33
9.	07 AP 03 B	Sltst/Vf.Sst.whtgy-gy	Talangakar	0.16	0.20	0.11	0.05	0.31	2.20	0.65	0.03	371	71	32
10.	07 AP 03 D1	Clst.dkgy-dkgy/bik.sl.hd	Talangakar	0.48	0.04	0.00	0.82	0.04	0.00	1.00	0.00	313	0	172
11.	07 AP 03 D2	Clst.dkgy.slty	Talangakar	0.66	0.05	0.00	0.52	0.05	0.00	1.00	0.00	237	0	79
12.	07 AP 06	Clst.yell.lt.gy-lt.gy.wht.oxidized	Talangakar	0.09	0.10	0.03	0.12	0.13	0.25	0.77	0.01	320	35	141
13.	06 NS 205 A	Siltst	Gumai	0.39	0.65	0.16	0.30	0.81	0.53	0.80	0.07	359	40.82	76.53
14.	06 NS 206 A	Siltst	Gumai	0.34	0.49	0.04	0.26	0.53	0.15	0.92	0.04	316	11.87	77.15
15.	06 NS 120 A	Siltst	Air Benakat	0.88	0.20	0.54	0.31	0.74	1.74	0.27	0.06	430	61.16	35.11
16.	06 NS 120 B	Siltst	Air Benakat	0.39	0.02	0.08	1.41	0.10	0.06	0.20	0.01	518	20.62	363.40
17.	06 NS 120 C	Siltst	Air Benakat	0.33	0.05	0.07	0.15	0.12	0.47	0.42	0.01	427	21.02	45.05
18.	06 MH 08 B	Clst.dkgy	Air Benakat	4.82	0.41	1.87	0.55	2.28	3.40	0.18	0.19	497	39	11
19.	06 MH 09 B	Clst.yellowish lt brn	Air Benakat	0.32	0.13	0.06	0.24	0.19	0.25	0.68	0.02	398	19	76
20.	06 MH 09 D	Sh.dkgy/bik	Air Benakat	3.27	0.65	3.72	0.10	4.37	37.20	0.15	0.36	434	114	3
21.	06 IR 01	Clst. dkgy. calc	Air Benakat	0.83	0.07	0.51	0.20	0.58	2.55	0.12	0.05	421	61	24
22.	06 NS 136 A	Coal	Muaraenim	15.22	4.80	125.00	9.40	129.80	13.30	0.04	10.77	425	821.29	61.76
23.	06 MH 06 A	Clst.dkgy.sl.hd	Muaraenim	0.76	0.06	0.01	0.16	0.07	0.06	0.86	0.01	264	1	21
24.	06 MH 07 A	Clst.ltgy.wht.oxidized	Muaraenim	0.08	0.05	0.04	0.05	0.09	0.80	0.56	0.01	284	48	60
25	06 RNK 01 B	Coaly shale	Muaraenim	14.21	5.12	42.65	0.33	47.77	129.24	0.11	3.96	404	300	2

TOC : Total Organic Carbon

S_1 : Amount of free Hydrocarbon

S_2 : Amount of Hydrocarbon released from kerogen

S_3 : Organic Carbon Dioxides

PY : Amount of Total Hydrocarbons = S_1+S_2

PI : Production Index = S_1/ S_1+S_2

PC : Pyrolysable Carbon

T_{max} : Maximum Temperature (°C) at the top of S_2 peak

HI : Hydrogen Index = (S_2/TOC) x 100

OI : Oxygen Index

category. Plotting on the TOC *versus* Potential Yield diagram, the Talangakar, Gumai, Airbenakat, and Muaraenim Formations are suggested to be a gas-oil prone source rock (Figure 4).

The maximum temperature (T_{max}) data indicate that the Talangakar Formation is characterized by the value varying from 237 – 438°C, Gumai Formation from 316 – 359°C, Airbenakat Formation from 398 – 434°C with two expections of 497°C and 518°C, and Muaraenim Formation between 264 – 425°C. Moreover, based on Hydrogen Index (HI), organic matter from the Talangakar Formation having HI from 0 – 365.43 indicate a Type II and III kerogen. The Gumai Formation that has HI from 11.87 – 40.82 contains type III kerogen, Airbenakat Formation characterized by HI value of 19 – 114 contains type III kerogen, and the Muaraenim Formation with HI of 1 – 300 indicates a type

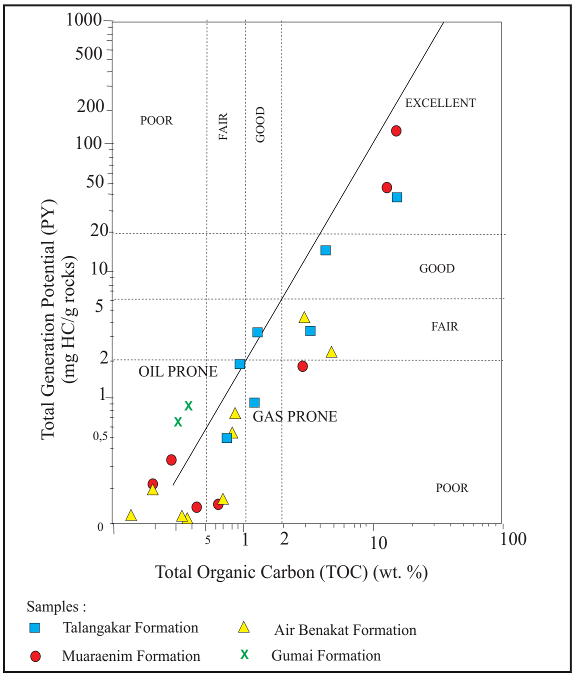

Figure 4. TOC *versus* Pyrolysis Yield (PY) diagram showing the hydrocarbon potential in research areas.

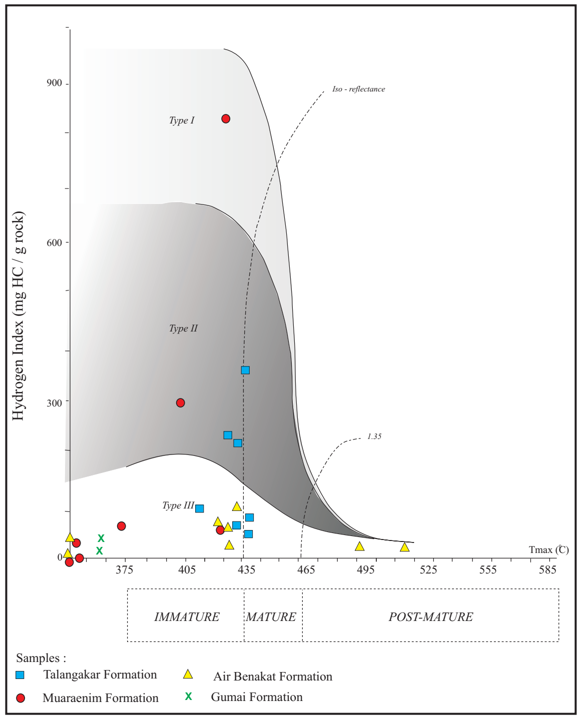

Figure 5. Hydrogen Index (HI) *versus* T_{max} diagram, showing kerogen type and maturity level of sedimentary rocks from the research areas.

II and III kerogen content, whilst its HI of 821.29 indicates type I kerogen (Figure 5). According to Waples (1985), type I kerogen which are limited to anoxic lakes and to a few unusual marine environments is derived principally from lacustrine algae. This type has high generative capacities for liquid hydrocarbon. Type II kerogen arises from several different sources, including marine algae, pollen and spores, leaf waxes, and fossil resin, and also include contributions from bacterial-cell lipids. Most type II kerogen is found in marine sediments deposited under reducing conditions. They all have great capacities to generate liquid hydrocarbons and a little gas. Type III kerogen is composed of terrestrial organic materials that are lacking in fatty or waxy components. Cellulose and lignin are major contributors. This type is normally considered to generate mainly gas.

The maximum temperature (T_{max}) *versus* Hydrogen Index (HI) diagram (Figure 5) shows that thermal maturity of the organic matter from the four formations tends to occur between an immature to early mature zone with two exception sample of post mature zone from the Air Benakat Formation. These two samples are located around an intrusion area, so that samples increased up to post mature. The result shows the presence of a different hidrocarbon potential from bottom to top of the formations.

Scanning Electron Microscope (SEM) Analysis

Fourteen samples analyzed by the SEM method have recorded in digital microphotographs, including the EDX result of all objects that observed clearly and brightly. Ten samples of the Talangakar Formation are represented by samples 06 AP 07, 06 AP 10, 06 AP 12, 06 NS 01A, 06 NS 01B, 06 NS 01D, 06 NS 02A, 06 NS 03A, 06 NS 03B and 06 NS 03D3; whilst four samples (06 AP 01B, 06 AP 01B, 06 AP 02, dan 06 AP 05C) represent the Muaraenim Formation.

The Talangakar Formation consists of quartz sandstone (06 AP 07), calcareous shally claystone (06 AP 10 dan 06 AP 12), coal (06 NS 01A, 06 NS 01B, 06 NS 01D and 06 NS 02A), lithic sandstone (06 NS 03A), tuffaceous claystone (06 NS 03B), and shally coal (06 NS 03D3). Quartz sandstone is generally predominated by quartz (75 %) with minor feldspar (5 %), and clay matrix (20 %). Calcareous shaly claystone comprises predominantly illite-smectite (75 %), quartz (10 %), planktonic material (5 %) coated by smectite, ferry oxide, and rutile (Figure 6). Coal consists of telocollinite, inertinite (semifusinite), micrinite, desmocollinite, corpocollinite, liptinite (resinite), kaolinite clay, and oil droplet (Figure 7). Lithic sandstone comprises fragments of quartz (70 %), feldspar (10 %), lithic (5 %), and illite-smectite clay (10 %) and smectite (5 %) matrix. Tuffaceous clay consists of kaolinite clay (75 %), plagioclase (15 %), and quartz (5 %); Shaly coal predominantly consists of vitrodetrinite (65 %) with kaolinite clay (30 %), ferry oxide (2.5 %), and pyrite (2.5 %) (Figure 8). Diagenesis characters of the Talangakar Formation are identified by the presence of authigenic clays, such as kaolinite and illite-smectite. Thus, the rocks examined have mostly been realm by diagenesis processes of Early Mesodiagenesis regimes. Most of the Talangakar Formation have been buried at more than 1500 - 2000 m in depth.

The Muaraenim Formation is made up of quartz sandstone (06 AP 01B dan 06 AP 02), calcareous claystone (06 AP 01B), and coal (06 AP 05C). Quartz sandstone consists of quartz (85 %), feldspar (5 %), and matrix of chlorite, kaolinite, and illite (10 %) (Figure 9). Calcareous claystone is composed of predominantly illite-smectite clay (70 %), benthic and planktonic foraminifera (20 %), and silica (10 %) (Figure 10). Coal is predominated by the presence of

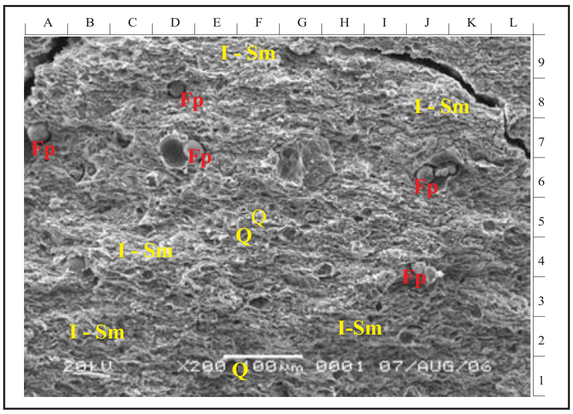

Figure 6. Photomicrograph of illite-smectite (I-Sm), quartz (Q) and planktonic material (Fp), coated by smectite, Fe-oxide, and rutile forming calcareous shaly claystone. Sample 06 AP 12.

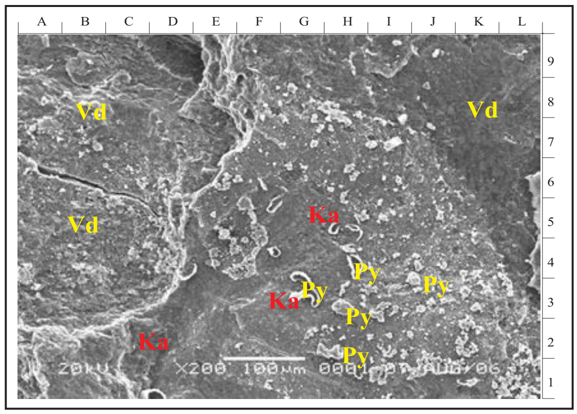

Figure 8. Photomicrograph of shaly coal, consisting of vitrodetrinite (Vd), kaolinite (Ka), and pyrite (Py). Sample 06 NS 03D3.

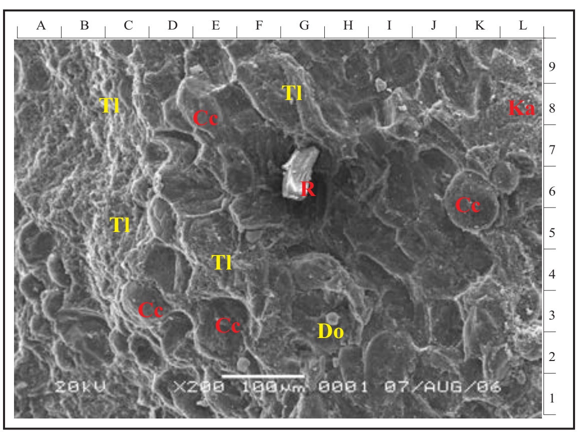

Figure 7. Photomicrograph of coal comprising telocollinite (Tl), corpocollinite (Cc), resinite (R), kaolinite (Ka), and oil drop (Do). Sample 06 NS 01B.

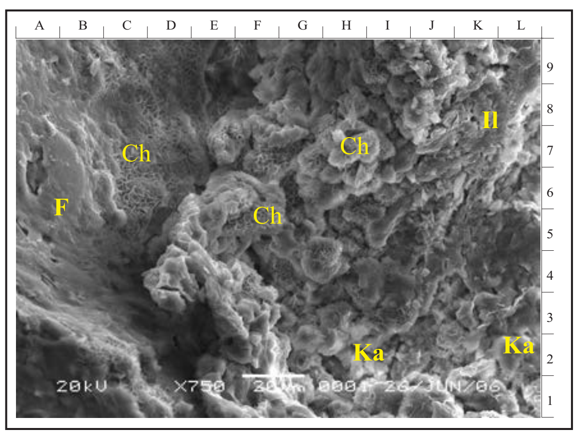

Figure 9. Photomicrograph of quartz, feldspar (F), kaolinite (Ka), illite (Il), and chlorite (Ch) forming quartz sandstone. Sample 06 AP 01B.

vitrinite (95 %), exinite (3 %), oil droplet, inertinite (<1 %), and kaolinite clay (<2 %) (Figure 11). Diagenesis characters shown by the presence of kaolinite and illite - smectite, tend to indicate that the Muaraenim Formation has undergone an Early Mesodiagenesis, that have been buried more than 1500 – 2000 m deep.

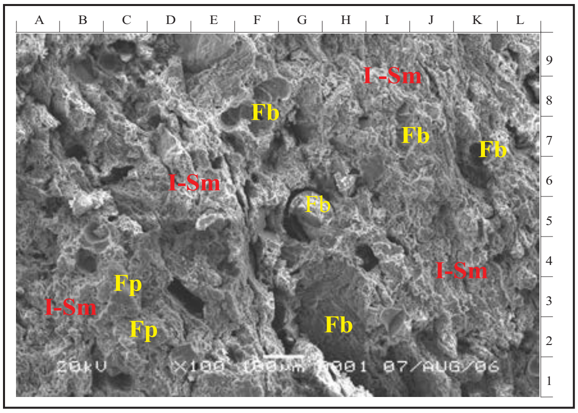

Figure 10. Photomicrograph of calcareous claystone made up of illite-smectite (I-Sm), benthic (Fb) and planktonic (Fp) foraminifera, and silica. Sample 06 AP 02.

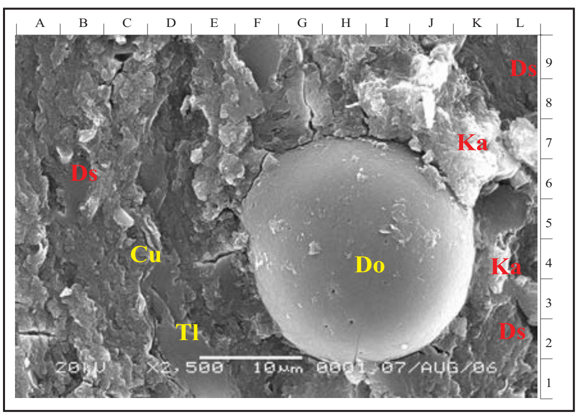

Figure 11. Photomicrograph of coal comprising desmocollinite (Ds), telocollinite (Tl), cutinite (Cu), kaolinite (Ka), and oil droplet (Do). Sample 06 AP 05C.

Discussions

The Talangakar coal comprising predominant vitrinite maceral group (74.8 – 93.0 %) in a similar amount of desmocollinite and telocollinite, with minor resinite and sporinite, leads to an interpretation that the depositional environment of coal was a wet swamp area varies from a telmatic to limnotelmatic zone. Moreover, the Air Benakat and Muaraenim Formations showing a predominant vitrinite maceral group content, tends to indicate a similar depositional environment as the Talangakar Formations.

Pyrite mineral found abundantly in two samples of the Talangakar (06 WG 09 C) and Airberakat Formations (06 MU 08 B) is suggested that a reducing condition and also a marine incursion took place during sedimentation processes of both formations.

Based on Rock-Eval pyrolysis, TOC value of the Talangakar Formation varies from 0.09 – 15.38 %, Gumai 0.34 – 0.39 %, Airbenakat 0.32 – 4.82 %, and Muaraenim between 0.08 – 15.22 %. Moreover the PY (potential yield) value variation of the Talangakar, Gumai, Airbenakat, and Muaraenim Formations are between 0.04 – 36.61 mg HC/g rock, 0.53 – 0.81 mg HC/g rock, 0.1 – 4.37 mg HC/g rock, and 0.07 – 129.8 mg HC/g rock, respectively. Therefore, on the basis of those two parameters (TOC and PY), the four formations are included into a gas – oil prone source rock potential (Figure 4). The Talangakar and Muaraenim Formations are poor to excellent category, whereas the Air Benakat tends to indicate a poor - fair category, whilst the Gumai Formation are only within a poor category (Figure 4). The possibility of oil occurrence is also supported by the presence of oil droplet (Figure 7 & 11).

Furthermore, T_{max} value of the Talangakar, Gumai, Air Benakat, and Muaraenim Formations ranges from 237 – 518^{0}C. The HI (hydrogen index) values of the four formations are mostly between 0 – 365.43, with one value of 821.29. By plotting the value of those T_{max} and HI on the diagram of T_{max} *vs.* HI (Figure 5), the organic thermal maturation of the four formations are included into an immature to mature category. The Talangakar Formation contains kerogen type II and III; Gumai and Air Benakat Formations are characterized by kerogen type III content, whilst the Muaraenim Formation tends to contain kerogen type I and III.

Based on the organic petrology, the Talangakar, Air Benakat, and Muaraenim coals are dominated by vitrinite maceral group that indicate kerogen type III, whilst kerogen type II of the Talangakar is shown by the presence of low vitrinite maceral. Furthermore, the Muaraenim Formation also tends to contain kerogen type I. This condition is supported by presence of the alginite showing value from 0.4 – 1.6 % (06 NS 01 B, 06 NS 01 D, and 06 NS 02 A).

Diagenesis characters of the Talangakar and Muaraenim Formations are identified by the presence of authigenic clays, such as kaolinite and illite-smectite. Thus, the rocks examined have mostly been realm by a diagenesis process of Early Mesodiagenesis regimes, which tends to indicate that both formations have been buried at depth of 1500 – 2000 m.

The maximum vitrinite reflectance of organic matter contained within the Kikim Formation varies from 0.38 – 0.48 %, Talangakar Formation ranges between 0.36 – 0.5 %, Baturaja Formation is 0.46 %, Gumai Formation from 0.38 to 0.46 %, Air Benakat Formation 0.36 – 0.56 %, and the Muaraenim Formation from 0.38 – 0.48 %. By plotting those maximum vitrinite reflectance values on the Kantsler Diagram (Figure 12), the maximum temperature of organic matter of the six formations vary from 40^0 to 65^0 C. Therefore, it is suggested that the burial depth of those four formations ranges from 1000 – 1850 m.

Based on the maximum vitrinite reflectance pattern (Figure 3), the Kikim and Talangakar Formations boundary tends to suggest to be a reverse fault. Therefore, the Kikim Formation is overlain unconformably by the Talangakar Formation.

By plotting the vitrinite reflectance range of each formation on the Kanstler *et al.* diagram (Figure 12), the maximum paleo-temperature of the Kikim Formation varies from 39^0 – 55^0 C. It shows a burial history from 950 – 1350 m in depth. The Talangakar Formation occuring from 38^0 to 58^0 C tends to suggest a burial depth of 900 – 1500 m. Then, paleo-temperature 58^0 C of the Baturaja Formation shows a burial history taking place from 1500 m in depth, whilst T_{max} temperature of the Gumai Formation ranging from 40^0 to 58^0 C shows a burial history from 1000 – 1500 m deep. Moreover, the Air Benakat Formation having maximum paleo-temperature from 38^0 to 65^0 C suggests a burial history from 900 – 1850 m in depth. Furthermore, the maximum paleo-temperature of Muaraenim Formation varying from 39^0 to 55^0 C tends to indicate a burial history within 900 – 1350 m deep. Therefore, it can be summarized that the burial depth of those

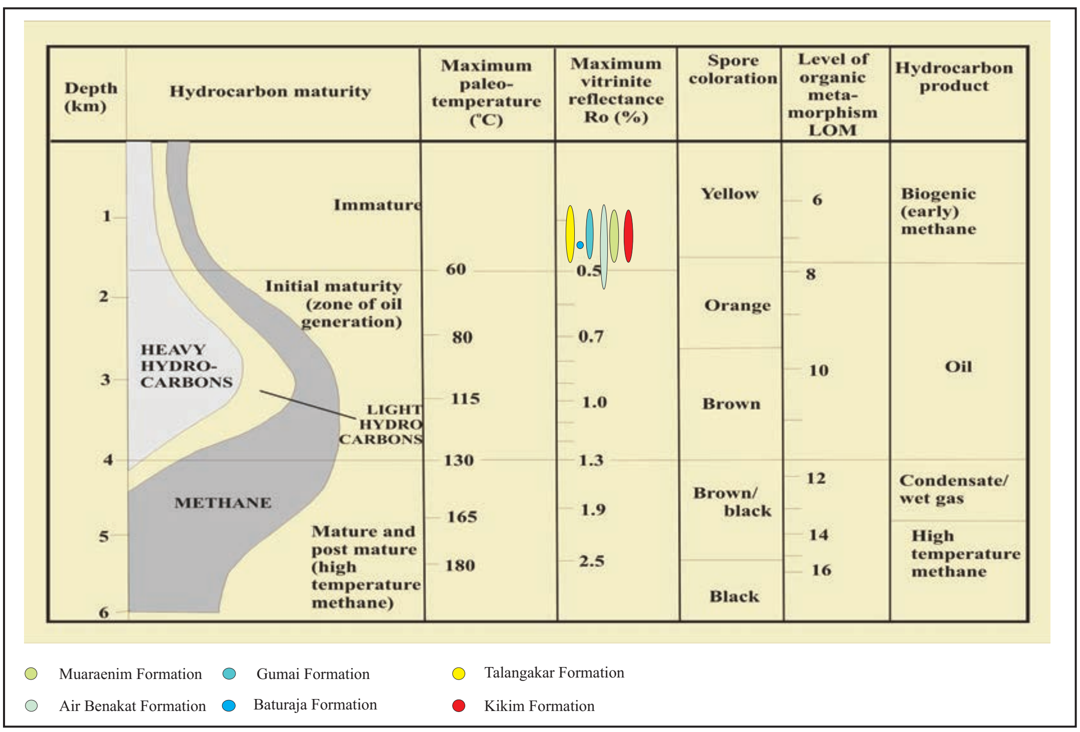

Figure 12. General correlation of organic maturity index from selected surface samples of the Tertiary Formation, South Sumatra Basin plotted on the Kantsler Diagram (Kantsler *et al.*, 1978).

four formations is situated between 1000 – 1850 m (Figure 12). This interpretation almost similar to the SEM results, that indicate a burial depth of 1500 – 2000 m.

Conclusions

The Talangakar and Muaraenim organic matter are predominated by vitrinite group, essentially composed of telinite and desmocollinite, rare to sparse inertinite, with minor exinite and mineral matter.

Based on Rock-Eval pyrolysis, the four formations are included into a gas - oil prone source rock potential. The Talangakar and Muaraenim Formations are poor to excellent category, whereas the Air Benakat and Gumai Formations are only within a poor category. The Talangakar and Muaraenim Formations tend to exist as an oil and gas source rock. On the other hand, the Gumai and Air Benakat Formations are only present as gas sources. The kerogen contained in the Talangakar Formation is type II and III; the Gumai and Air Benakat Formations is type III, while type I and III are recognized within the Muaraenim Formations. The organic matter of four formations were derived from terrestrial to marine organic sources.

The diagenesis regime of the four formations is Early Mesodiagenesis level, suggesting that the formations have been buried at depth of 1000 – 2000 m.

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