

Coal Potential as Source Rock of Hydrocarbon Warukin Formation Based on Coal Macerals Composition, Central Wara, Tabalong, South Kalimantan

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Abstract

The interest of this research: there is oil seepage at the contact between coal seam-A and sandstone facies of Warukin Formation, so it is necessary to study where is the source rock. The correlation between HI and Tmax as result from rock eval pyrolysis shows that the shale of the Warukin Formation is immature while the correlation between HI and OI shows oil prone. The vitrinite (Ro) reflectance of Central Wara coal is between 0.48% up to 0.5% (immature), the content of the vitrinite group is 68.0 - 84.8 (% Vol.), Liptinite 3.0 - 14.0 (% Vol.) and inertinite 0.48 - 25.0 (% Vol.). The high content of liptinite mineral groups (14% Vol.) and the presence of exsudatinite maceral are as an initial indication of bituminization of oil formation when there is a change in reflectance and fluorescence. Therefore, Central Wara coal plays an important role as the source rock of the Warukin Formation, although the maturity level is immature, the presence of exsudatinite maceral is believed to be the source of origin for producing oil, where the organic material comes from terrestrial.

Keywords

Oil Seepage, Coal, Exsudatinite, Bituminization, Source Rock

1. Introduction

The Barito Basin is one of several basins located on the eastern side of Kaliman-

tan. It covers an area of 70,000 square km, extending to South Kalimantan Province in the Barito River area.

Based on the petroleum system study, the source rocks in the Barito Basin are shale, claystone, and coal from Tanjung Formation. Yet according to temporary study there is a possibility that source rock of Barito Basin is shale originating from claystone or shale of Warukin Formation. The main reservoir rock is Tanjung Formation and the secondary reservoir rock is Warukin Formation located in East Tapian, South Warukin and Middle Warukin Field. The cap rock in this area is from shale founded in the Upper Tanjung Formation and shale between Warukin Formation [1].

The hydrocarbon traps are structural traps of fold and combination of fold and thrust fault, another trap is sandstone lenses of stratigraphic traps.

The objective of this study is to determine the hydrocarbon generation system by integrating the coal potential source rocks in the Central Wara, Tabalong, South Kalimantan of the Warukin Formation in Barito Basin on previous and recent coal macerals analysis and pyrolysis rock eval. The interest in this research is discharge of oil seepage at contact between coal seam-A and sandstone facies, so it is needed to study where is the source rock of the oil seepage.

2. Literature Review

Central Wara research location is close to the Tanjung Field located in north east part of Barito Basin, which is one of the largest oil basin in Kalimantan. Geographically in South Kalimantan Province. It is bordered by the core of Sunda Continent in the west which is often known as Sunda Shield that consists of Pre-Tertiary rocks which have been tectonically stable since the Mesozoic era. In the southern part it is separated from the East Java Sea Basin by a relatively stable shelf which is covered by a thin layer of Tertiary sedimentary rock which known as the Barito Shelf. To the East, Barito Basin is separated from Asem-Asem Basin and Sand Basin by Meratus Mountain as a result of young deformation consisting of folds and faults of rocks. Meratus Mountain are interpreted as suture layer (collision zone). The northern part is Pre-Tertiary rocks from Meratus Mountain that widening to the West forms North-South mountain range that separates Barito Basin from Kutai Basin in the north. However, sedimentologically, the boundary between Barito Basin and Kutai Basin is Adang Flexure or Adang Fault [2]; (Figure 1) and cross section of Barito Basin from west to east [2] [3] shows in Figure 2.

The result of the entire tectonic process is the discovery of structural configuration characterized by parallel folds and thrust faults trending southwest - northeast. The fault structure involves bedrock and is increasingly patterned toward the Meratus mountains which are the basis for the tectonic process [3] [4].

Stratigraphically of Barito Basin [2] (Figure 3):

1) Tanjung Formation

Tanjung Formation is divided into Upper Tanjung and Lower Tanjung [2] [5]

[6]. This formation divided into 3 parts based on lithology; Upper Tanjung (calcareous claystone with limestone and coal inserts), Middle Tanjung (sandstone intercalation, siltstone and claystone), and Lower Tanjung (sandstone, conglomerate, with coal inserts) [6].

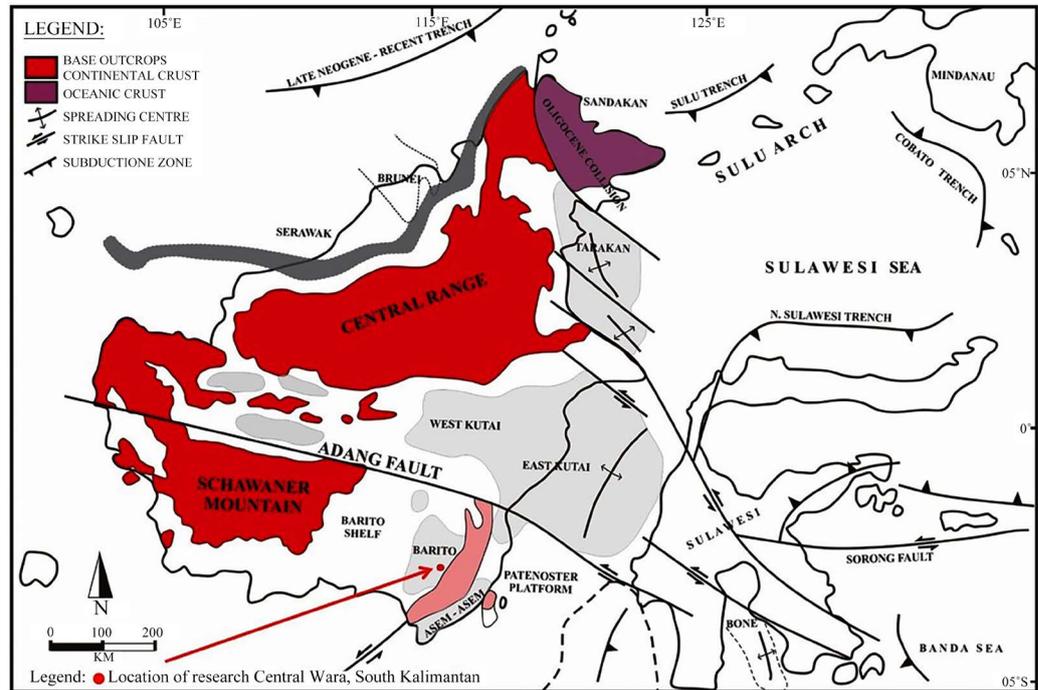


Figure 1. Position of barito basin (Kusuma, 1989) [2].

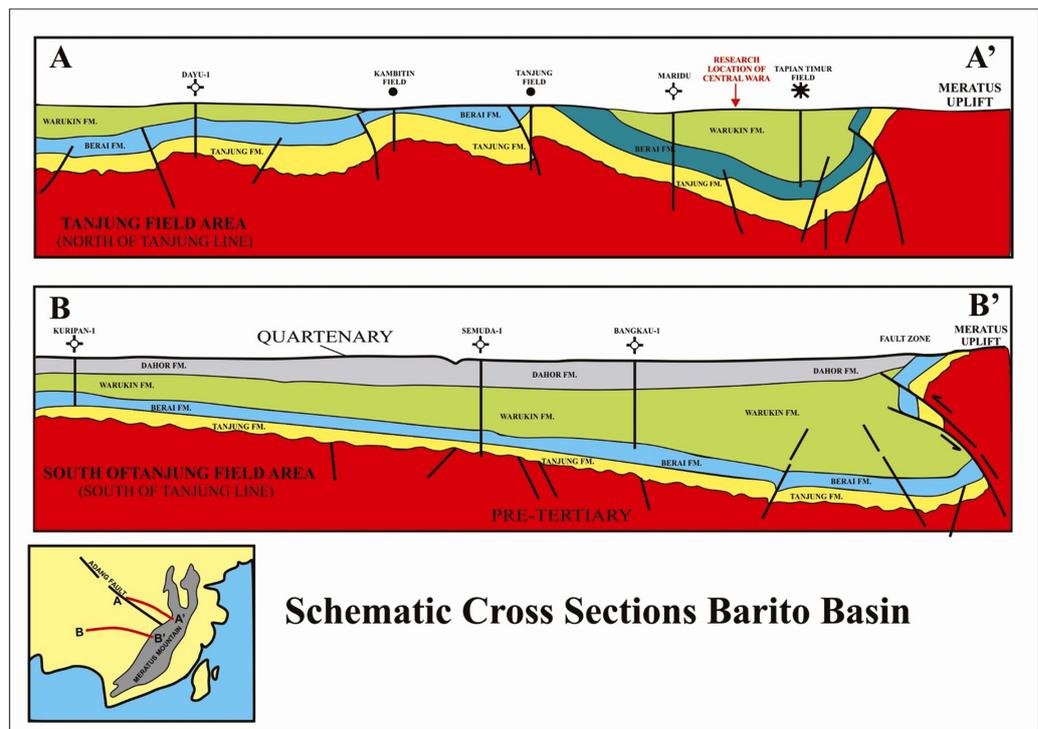


Figure 2. Cross section of barito basin (Kusuma, 1989; Satyan., 1994) [2] [3].

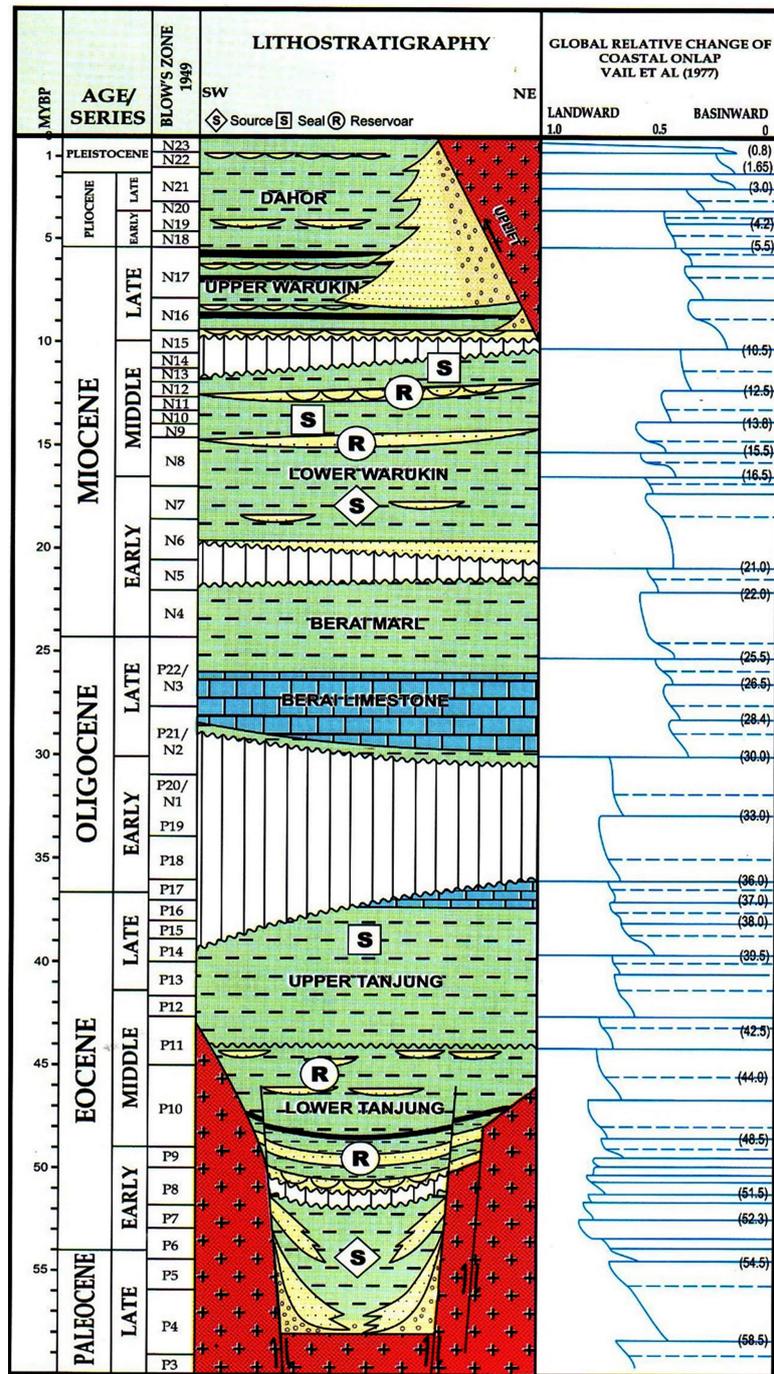


Figure 3. Regional tectonostratigraphy of barito basin (Kusuma, 1989) [2].

2) Berai Formation

The Berai Formation is divided into Upper Berai, Middle Berai and Lower Berai [6] [7]. This division is generally based on differences in lithology. Upper Berai lithology composes of limestone intercalation, claystone and marls, Middle Berai is massive limestone, reefal or skeletal, and Lower Berai is an intercalation of limestone with marls [6].

3) Warukin Formation

Experts divide Warukin Formation into Lower Warukin and Upper Warukin [4] [5] [6]. Warukin Formation divided based on lithology characteristics into Lower Warukin (intersection of sandstone and claystone, with calcareous claystone and thin limestone insert), Middle Warukin (intersection of sandstone, clay and coal layers), and Upper Warukin (at the top is an alternation of thick coal with clay and alternating thin layers of sandstone and claystone with thin coal) [6].

4) Dahor Formation

The boundary between Dahor and Warukin is unconformity between Middle Miocene and Late Miocene [4] [5] [6], in contrast [2] [3]. using the top of the coal seams as a boundary. Satyana, A., *et al.*, 1994 [3] explain on the stratigraphic diagram the presence of unconformity between the Late Miocene and Pliocene. Dahor Formation is composed of conglomerate lithology, thick sandstones, siltstone and claystone with lumps of older rock fragments.

Barito Basin covers 70,000 km² containing Tertiary sedimentary rocks consisting of clastic rocks deposited transgressively from Tanjung Formation (Paleocene-Eocene), carbonate rock sequences from Berai Formation (Oligocene-Early Miocene), and sediment characteristics of the delta sequence of Warukin Formation and Dahor Formation (Miocene-Pliocene) [4]. Tectonically, sedimentation in Barito Basin is a complete succession of the transgression and regression cycles with effect of rising and falling sea levels over time.

In general, sedimentation begins with the rifting process occurring in the Late Cretaceous to Paleocene where in low topographical areas in the Pre-Tertiary bedrock, transgression slowly during the Middle Eocene deposit the oldest Tertiary sedimentary rocks named Tanjung Formation which consists of sandstones, shale, conglomerates and thin layers of coal that is deposited in fluvial to deltaic environments with the affect of ocean on the younger layers.

During the Oligocene to Early Miocene, Barito Basin was very stable in a shallow marine environment. This condition is very good for depositing limestone from Berai Formation characterized by shelf facies with few reefs growing locally on the elevation extending on the eastern edge of the Pasternoster shelf to the Sundaland craton in the west and the southern part of the Pasternoster heights to the south towards Java Sea.

At the late of the Miocene the uplift resulted in the subsidence of the Meratus block which resulted in the isolation of Barito Basin against the open ocean in the east. The rapid subsidence accompanied by uplift in the western part caused a process of erosion of the shield. This erosion process produces the materials needed to deposit the thick layers of the transitional deposits of Warukin and Dahor Formation into the basin. Orogenesis in the Plio-Pliocene resulted in a strong westward movement of the Meratus block, folding and faulting the sedimentary rocks within the basin, forming a series of tight folding likely controlled by the geometry of the bed rock (Figure 4).

Microscopically, the organic materials that form coal are called maceral, ana-

logous to the minerals in rock. This term was originally introduced by Stopes, 1935 [7] to denote the smallest material that makes up coal which can only be observed under a microscope reflection. Maceral in coal can be grouped into 3 main groups, namely the vitrinite, liptinite and inertinite groups. This grouping is based on morphological shape, size, relief, internal structure, chemical composition, color of reflection, intensity of reflection and degree of coalification [7].

In this study, the division starts from the maceral group (group), the maceral subgroup and the maceral type which refers to the Australian Standard: AS2856 (1986) (Table 1). The advantage of this Australian Standard system is that the distribution of the mass composition applies to all coal rank, both hard coal and brown coal, and this system is quite simple. Meanwhile, other standard systems are usually distinguished between hard coal and brown coal.

Vitrinite basically derived from cellulose ($C_6H_{10}O_5$) and cell wall of lignin in plants. Some of the macerals in the vitrinite group come from tannins impregnated on the cell wall or as fillers of cell cavities. Protein and lipide also the forming material of Vitrinite (such as Huminite). This macerals can be recognized from its high aromatic fraction and is rich in oxygen. Vitrinite are generally the major constituents of coal (>50%). Through refraction microscopy, the vitrinite group shows a reddish brown to dark color, depending on the level of coal rank, the higher the rank of the coal the darker the maceral color.

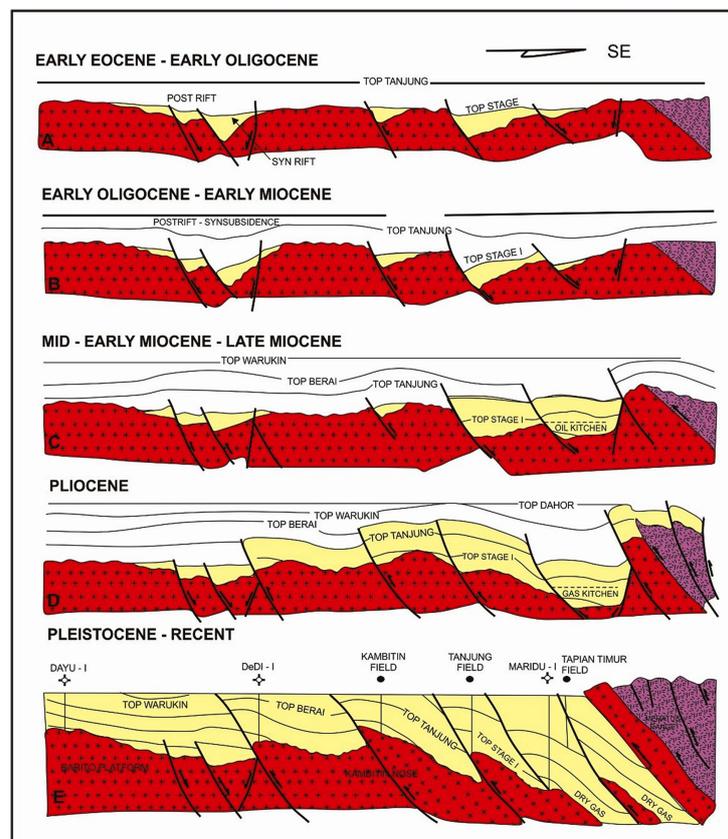


Figure 4. Tectonic evolution of the Barito basin (Satyana, 1994) [3].

Table 1. Distribution of coal maceral composition (AS 2856).

GROUP MACERAL	SUB GROUP MACERAL	MACERAL
Vitrinite	Telovitrinite	Textinite
		Texto-ulminite
		Eu-ulminite
		Tellocollinite
	Detrovitrinite	Attrinite
		Densinite
		Desmocollinite
	Gelovitrinite	Corpogelinite
		Porigelinite
		Eugelinite
Liptinite		Sporinite
		Cutinite
		Resinite
		Liptodetrinite
		Alginite
		Suberinite
		Flourinite
		Exsudatinite
		Bituminite
		Inertinite
Semifusinite		
Sclerotinite		
Detroinertinite	Inertodetrinite	
	Micrinite	
Geloinertinite	Macrinite	

By the observation of the reflection microscope, the vitrinite group macerals showed brighter reflective colors, ranging from dark gray to light gray depending on the coal rank, the higher the rank of coal the brighter the color of the reflection produced. Based on the morphology, the vitrinite group macerals is divided into subgroup macerals and macerals (**Table 1**).

Liptinite group maceral originated from plant organs (algae, spores, spore box, outer shell (cuticle), plant sap (resin) and pollen. The liptinite group has the most hydrogen content and the least carbon content when compared to other maceral groups. Under the microscope the reflection shows the reflection is gray to dark, has low reflectivity and high fluorescence [7]. Liptinite comes from plant organs (algae, spores, spore boxes, cuticles and resin), which are relatively high in aliphatic bonds so it contains high hydrogen [8] or it can be secondary, occurs during the ignition process of bitumen. The optical properties (low ref-

lectivity and high fluorescence) of Liptinite ranging from peat and coal at low rank to sub-bituminous coals are relatively stable [9].

Based on the morphology and source of origin, the liptinite group can be distinguished such as: sporinite, cutinite, suberinite, resinite, liptodetrinite, exsudatinitite, fluorinite, alginite, and bituminite (**Table 1**).

The inertinite group macerals are originated from burnt plants (charcoal) and some are thought to be due to oxidation processes from other macerals or decarboxylation processes caused by fungi or bacteria (biochemical processes). With this process, the inertinite group has a relatively high oxygen content, low hydrogen content, and higher O/C ratio than the vitrinite and liptinite group macerals.

The inertinite group macerals has the highest reflectance value among other maceral groups. Under a reflection microscope, inertinite shows a gray to greenish gray color, but in ultraviolet light it does not show fluorescence. Based on the internal structure, level of preservation and intensity of combustion, the inertinite group was divided into several macerals, called fusinite, semifusinite, sclerotinite, micrinite, inertodetrinite and macrinite (**Table 1**).

Coal contains various forms of organic elements over a range of chemical compositions, and these variations in chemical composition can be combined to determine the geological history of what type HC was produced. coal as the source of origin for gas Hydrocarbon and liquid HC (oil), especially for kerogen and or maceral [10].

Kerogen is a typical classification of hydrocarbons for types I to IV based on chemical composition [10]. Chemically, kerogen is basically classified in the proportions of C, H and O. Petrographically (microscopically), kerogen is directly related to the origin of organic material that has been deposited in sedimentary rocks and the products of mechanical, biological and thermal alteration. In this way, each kerogen type can be characterized using the coal mineral terminology.

3. Methodology

This research was conducted in the coal mining in Central Wara, Tabalong, South Kalimantan area and its surroundings. The research methods carried out in the field are coal observation and sampling data from outcrop direct.. The main target of coal seam is Seam A Central Wara in Warukin Formation (**Figure 5** and **Figure 6**).

The method for taking coal samples is carried out directly in the outcrop of coal mine walls at seam-A by the ply by ply method, based on the appearance of the lithotype macroscopically. Then each sample is reduced in size, and a composite is then divided into two for archives and laboratory analysis.

Microscopic analysis of coal identifies mineral composition, minerals and vitrinite reflectance values. Coal samples taken from the outcrop of mining wall then prepared for polishing incisions. In sample preparation several tools and materials are needed such as:



Figure 5. Coal sampling from Seam-A central wara.



Figure 6. Oil seepage at the contact Coal Seam-A and sandstone facies.

- 1) Coal samples;
- 2) Resin powder (transoptic powder);
- 3) Pounder Tool;
- 4) Sizes 16, 20 and 65 mesh sizes;
- 5) Print polished briquette, heaters, thermometers, and presses;
- 6) Grinder-polisher;
- 7) Silicon carbide sizes 800 and 1000 mesh and alumina oxide size 0.3; 0.05; and 0.01 microns;
- 8) Glass preparations and night candles.

Coal samples obtained from the drill core are reduced by coning and quartering to obtain the appropriate number of samples for analysis needs. Next, the coal samples were crushed manually and sifted using 16 mesh and 20 mesh sieves, the coal grain size fraction -16 mesh $+20$ mesh obtained was used for coal petrographic analysis.

The coal fraction size -16 mesh +20 mesh is then mixed with resin powder (transoptic powder) with a ratio of 1:1. The mixture is then put into the mold and heated to 200°C. After the temperature reaches 200°C the heater is turned off and the mold is pressured to 2000 psi. Briquette can be removed after the temperature reaches room temperature. The next stage is briquette polishing which starts with cutting using a polishing tool (grinder-polisher) then smoothed with silicon carbide size of 800 mesh and 1000 mesh above the glass surface. Next polished using alumina oxide measuring 0.3 microns, 0.05 microns, and finally measuring 0.01 microns on silk or silk cloth. The resulting polishing incision is placed on the preparatory glass with the night candle holder then leveling.

Observation of polishing incisions is done using a reflectance microscope both qualitatively and quantitatively to determine the mineral content and minerals in coal. Microscopic research using reflected light with 200 times magnification with observation of 500 points.

The analysis process was carried out at the Coal Petrographic Laboratory, TekMIRA Research Center, Bandung. Coal Mining Classification uses Australian standards (AS 2856, 1986) and the microscope used is Microscope Spectrophotometer Polarization with Fluorescence, type: MPM 100, brand: Zeiss.

Organic carbon content (wt%) is measured using LECO CS-344 carbon/sulfur analyzer. Previously, the analysis of powdered coal samples was mixed with dilute hydrochloric acid (10%) to remove carbonates. The samples were washed three times with distilled water and dried for 1 hour at 105°C. For sample element analysis, coal is mixed with iron flakes and a tungsten accelerator is burned in an oxygen atmosphere at a temperature of 1370°C. The combustion product causes moisture and dust to disappear, while the solid portion of CO₂ gas is measured by infrared detector. The organic carbon content was used to determine the extract yield (mg extract/g TOC).

Pyrolysis rock eval method used to approach the actual hydrocarbon formation event in nature which occurs at low temperatures but with a very long geological time [11]. The method used is rock eval with the parameters used are S1, S2, S3, maximum temperature (Tmax), Hydrogen Index (HI) and Oxygen Index (OI).

4. Result and Discussion

The results of the pyrolysis analysis of rock eval samples of Central Wara coal and coaly shale are shown in **Table 2**. The Tmax of Central Wara Seam-A coal varies between 376°C - 413°C, HI values are between 155 - 238 mg HC/g TOC and OI values between 51 - 73 mg HC/g TOC.

The result of depiction of the Hydrogen Index value against the Tmax value indicates that the maturity of the Central Wara Seam-A coal is immature (**Figure 7**). Stated that the description of HI value against Tmax for 3 samples of humic coal is generally in kerogen type III (Gas Prone) and 1 sample of coaly shale is in kerogen type II (Oil Prone) [11]. However, the depiction can also be between

type II and III kerogens, because generally the way coal responds is not the same as the organic matter in type III kerogen. Likewise, Based on the results study of pyrolysis rock eval from several coal basins, it shows that most of the HI depictions of Tmax are between kerogen types II and III [12]. This condition applies to Central Wara Seam-A coal, that the results of HI depiction of Tmax are in kerogen type III (Figure 7), while the results of depicting HI to OI are included in kerogen between types II and III (Figure 8). Tmaks (<435°C), the maturity level of the source rock is still immature, so for Central Wara Seam-A coal with Tmax values ranging from 396°C - 410°C [11], the maturity level is immature (Table 2).

Based on the lower OI value compared to HI, this supports the fact that reduced oxygen is a character for low rank coal coalification [13]. Thus, it is consistent between the vitrinite reflectance (Rv) value, the Tmax value and the depiction of the Hydrogen Index value against Tmax, that the maturity level of the Central Wara Seam-A coal is immature.

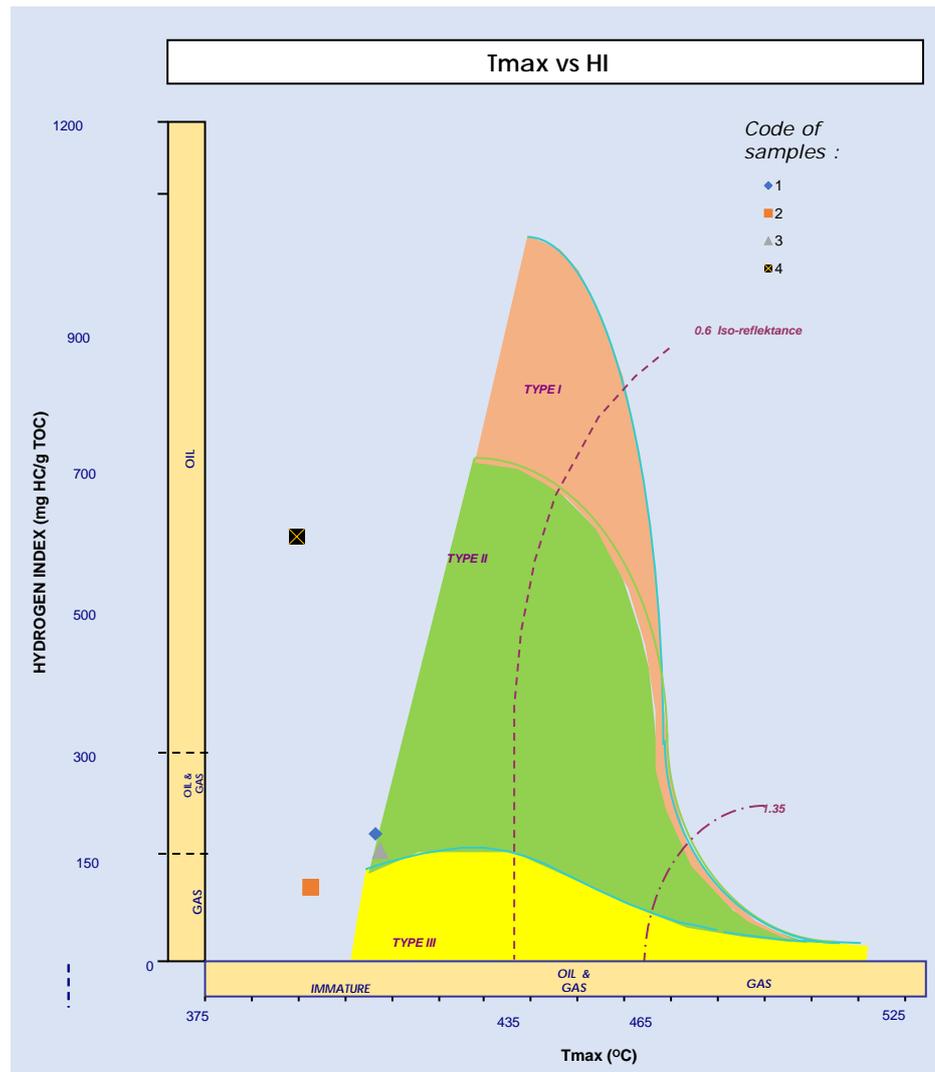


Figure 7. HI vs Tmax graphic.

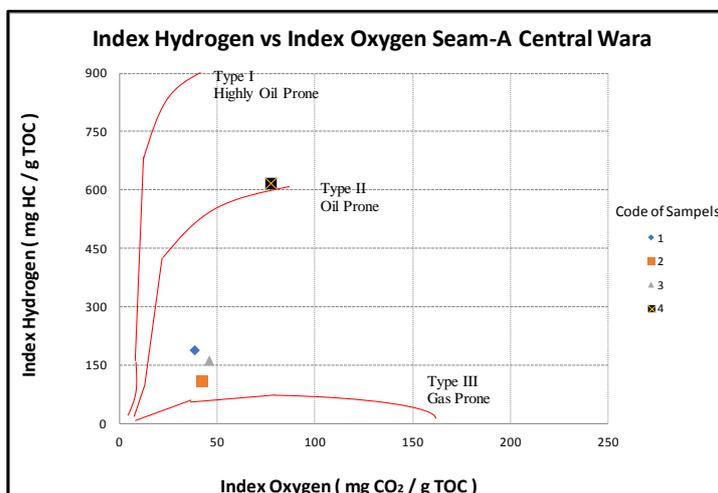


Figure 8. Plot HI vs OI.

Table 2. Pyrolysis rock eval analysis result.

Sample	Formation	Lithology	TOC (wt%)	S1	S2	Potential Yield S1 + S2 (mg/g)	OPI S1/(S1 + S2)	HI	OI	Tmax	Ro
1	Warukin	Coal	43.8	1.95	82.31	84.26	0.02	187.922374	38.3789954	410	0.45
2	Warukin	Coal	38.84	2.18	43.09	45.27	0.05	110.942327	42.0442842	396	0.47
3	Warukin	Coal	46.16	2.75	75.58	78.33	0.04	163.734835	46.0138648	411	0.47
4	Warukin	Coaly Shale	9.84	11.79	60.62	72.41	0.16	616.056911	77.4390244	393	0.46

Coal contains various forms of organic elements covering a range of chemical compositions, and these variations in chemical composition can be combined by determining the geological history of what type of HC was produced. Coal as the source of origin of HC gas and liquid HC (oil), especially kerogen and maceral [10].

Kerogen type II (sample number 4) shows it is rich in lipids, its characteristic is Sapropelic Organic Matter, and can be widely recognized with the highest amount. Microscopically it contains Alginite maceral (for example coal A-1). Based on microscopic observations of the blue light (fluorescence) kerogen type II ranges from white-yellow to shine depending on the composition of origin and thermal maturation. Kerogen of this type consists of a large range of maceral, including the liptinite group. Macerals that can be recognized through its biological structure include sporinite, cutinite, and suberinite. Cannel coal is rich in composition with type II kerogen. Many types of Amorphous Organic Matter can also become known as type II kerogen, including resinite, suberinite, flourinite, bituminite and exsudatinite. Bituminite is particularly common in shale oils and is commonly referred to as matrix bituminite where it forms in the fluorescent base mass in fine-grained sedimentary rocks.

Kerogen type III (Sample numbers 1, 2 and 3) are characteristic of the Organic Humic Matter. It has an H-C ratio of less than 1.00 and an O-C ratio of a wide

range from 0.05 to 0.40. This type of kerogen has the opposite strength to the type I and type II kerogen because of type III kerogen is dominated by the Aromatic group structure, Heteroatomic Ketones and Carboxylic Acid and contains a relatively minor proportion of Aliphatic and Alicyclic compounds. Contrary to type II, Kerogen type III is known as High Prone Gas. Kerogen type III is typically non-fluorescent, although this appears weak brown fluorescence and a suppressed reflectant in samples where the content is high [10]. Kerogen type III is the product of woody plant tissue and thus covers the full range of vitrinite maceral, including huminite, telinite and collinite. Semifusinite, partially oxidized from the remains of wood tissue, can also include type III kerogen.

Kerogen or coal maceral as a hydrocarbon occurs during coalification, namely significant changes in both mechanics and chemistry during stockpiling, and these changes are driven by compaction, biological activity and kinetic thermal. These 3 factors are very complex relationships and can be fully effective with the tectonic and depositional history of a sedimentary basin. The generation of hydrocarbons can perhaps be considered to be mostly more effective in the framework during the coalification process. During the coalification process, there are critical changes in the chemical composition of hydrocarbons, especially the characteristic O-C and H-C ratios [14].

Liptinite macerals content between 3.0% - 14.0% Vol (Table 3) which is relatively abundant in Seam-A Central Wara coal consisting of sporinite, alginite, resinite, cutinite, suberinite, fluorinite and exsudatinite (Figure 9) being kerogen types I and II as an oil-forming, generally derived from humic coal, while vitrinite is a major constituent the dominant form of coal seam, is likely the product of woody plant tissue that has fulfilled as an oil-forming material from the water column or surrounding sediment in its original depositional environment [7]



Figure 9. Exsudatinite maceral appearance microscopics of Coal Seam-A Central Wara as precursor of oil forming.

and the result of bacterial degradation can help increase the hydrogen content of some organic materials wooden. Perhydrous vitrinite is also more strongly associated with coal and shale which is rich in the type of oil-forming organic elements (oil prone). Therefore, the high hydrogen content and the suppression of the reflectance of the perhydrous vitrinite may be explained by the sorption of hydrocarbon oil that has been generated from kerogen types and other macerals in liptinite such as flourinite as a residue to produce hydrocarbon solutions, thus coal has the potential to regenerate oil in large volumes [10].

The immature level of coal maturity indicates that the coal is still in the gelification stage, where during coalification there is vitrinitization accompanied by the formation of liquid bitumen (oil). This clue is seen in the presence of fluorinite alginite sporinite alteration result which is rich in hydrogen content (high Hydrogen Index) to oil forming.

In general, the type of tertiary coal plant in the tropics is an angiosperm containing coniferous rich in resine, latex, oil and fat as a source of resinite [9]. Resinite has a tendency to form exsudatinitite at the beginning of the coalification process [9]. The resins appear as cell fillers in telocollinite or isolated on the base mass of vitrinite. The round, opal or irregular shapes of resinite show large variations in reflectivity and fluorescence.

Exsudatinitite maceral in Central Wara Coal, Warukin Formation is a secondary maceral in the Liptinite maceral group and formed during the coalification process (initial bituminization) from Liptinite (flourinite) and Perhydrous Vitrinite [10] to oil forming. Exsudatinitite achieves a higher reflectivity than vitrinite reflectivity in the early coking coal stage. Many meta-exsudatinitites are known for their high anisotropy. In general, Liptinite reflectance and fluorescence change at the oil window stage. Exsudatinitite can be observed by fluorescent light. Exsudatinitite fills in the fractures, bedding areas, burrows, cells empty of fusinite and sclerotinitite [10]. The chemical composition of exsudatinitite is thought to be asphaltene [10]. Therefore the presence of exsudatinitite maceral as an initial indication of bitumenization of oil formation when there is a change in reflectance and fluorescence.

5. Conclusion

The presence of exsudatinitite maceral in the coal of Central Wara Warukin Formation proves that:

- The coal had bituminization, tended to form kerogen type II (oil prone) and as a precursor to oil forming.
- Coal in Central Wara is source rock of Warukin Formation, South Kalimantan.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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