Selective mine plan based on coal quality distribution of Batu Ayau formation, Murung Raya-Central Kalimantan

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Abstract. Coal quality, which eventually controlling coal’s behavior during preservation, combustion, and other forms of utilization, are defined by the depositional environment in which the peat was formed. Batu Ayau Formation is a well-known coal-bearing formation of Barito Basin and has been thoroughly explored. The aim of this study, which differs from previous studies, is to figure out the correlation of depositional environment to the coal quality of Batu Ayau Formation and anticipate the less desired coal quality from being mined. The depositional environment is determined through the stratigraphic section compared to Horne model, supported by coal facies determination using Tissue Preservation Index (TPI) vs Gelification Index diagram. Ash and sulphur content (weight %) data from 4 seams are integrated to the lithostratigraphic column. The coal quality distribution is defined from good correlation. The coal-bearing depositional environment of the studied area is transitional – upper delta plain. The ash content is ranging in 5.20-8.64wt% and total sulphur is ranging in 0.34-1.28%. The position of depositional environment that is closer to open marine, which is dipping westward, is preferable in terms of quality. Hence, coal on the center part of the research has preferable coal quality to be mined.

1. Introduction
Coal plays a vital role in electricity generation worldwide, which is unimaginable that modern life can be survived without electricity. Coal-fired power plants currently fuel 38% of global electricity and, in some countries, an even higher percentage [1]. Study of coals in Indonesia mentioned that basically the coals in Kalimantan is better than coals from other sedimentary basins in terms of quality and quantity [2], that becomes the reason Indonesia is one of the country that provides the biggest coal supply into the industry.

Despite the demand on the industry, recognition of peat depositional environments for coal has been a part of modern coal studies since their inception, which is important data to understand the past geological condition, including paleoenvironmental, paleoclimatic and geodynamics [3]. A depositional model of a coal-bearing formation may be one of the useful tools to explain the origin of coal seams [4].

Coal in the research area is within the Batu Ayau Formation from Barito Basin. The research area itself is administratively part of the Murung Raya, Central Kalimantan (figure 1). Batu Ayau Formation is a prolific coal producing formation through Central Kalimantan to East Kalimantan. Several studies have spoken about both the coal and the coal-bearing formation, the coal quality and depositional environment [5-7]. Coal quality, which eventually controlling coal’s behavior during preservation, combustion, and other forms of utilization, is defined by the depositional environment in which the peat was formed [3].
Up until now, there has no study yet that discussed the implication of depositional environment to coal quality in Murung Raya area. Considering that the economic value of coal also rely on its quality, most common are the sulphur and ash content, it is more profitable to have exploration data that can provide the distribution of the coal with preferable quality anticipate the less desired coal quality from being mined. Hence, it becomes the background to conduct this research.

The aim of this research is to define the correlation of coal-bearing formation depositional environment and coal quality within the research area. The result shall provide the information of area that is preferable to continue the mining activity.

2. Method
Lithostratigraphy measurement is conducted on one traverse line shown in figure 2. The measurement also recorded the description of each facies, which are the texture and sedimentary structure. The section included 4 seams studied in this research. The depositional model in this research is referring to [8]. Several observation points (OP) are also necessary to delineate the lithology distribution on the surface.

Petrography analysis is needed to identify the mineral composition from samples of the roof and floor seam at the upper part of this section. A polarization microscope is being used to conduct this analysis, while the rock classification is based on [9].

Maceral-based coal facies interpretation. Maceral analysis data from 60 samples that consist of the representative of 4 different seams is conducted at the lab of PT Marunda Graha Mineral. The maceral composition result is used to calculate the Tissue Preservation Index (TPI) and Gelification Index (GI), where the equation (1) and equation (2), representatively. The result is projected on the TPI vs. GI diagram of [10] to reveal the coal origin.
TPI = \frac{\text{telinite} + \text{telocollinite} + \text{pseudovitrinite} + \text{semifusinite} + \text{fusinite}}{\text{vitrodetritine} + \text{desmocollinite} + \text{inertodetrinite}} \quad (1)

GI = \frac{\text{vitrinite} + \text{macrinite}}{\text{total inertinite}} \quad (2)

Coal bearing Depositional Environment Analysis. In terms of hierarchy of depositional system, the lowest to highest units are facies, facies association and depositional environment. The stacking pattern of facies is visualized in the measured stratigraphy section. This section is compared to depositional environment model of coal-bearing formation by [8].

3. Result

3.1. Lithostratigraphic column of the research area

The corrected total thickness of the measured section is 200 m. There are four lithological units determined from the studied area from the oldest to the youngest strata, which are Carbonaceous Claystone (CC), Tuffaceous Sandstone (TS), Claystone (Cl), and Sandstone (St).

3.1.1. Carbonaceous claystone. The Carbonaceous Claystone unit is 18 m thick, predominantly consists of claystone and coal seam 1 (total thickness is 5 m, including claystone as parting). There are also sandstone and siltstone. The seam floor is siltstone which is interpreted as a product of interdistributary bay, whilst the roof is claystone (figure 4) from the lowest strata of crevasse splay, based on the pattern of coarsening upward pattern (figure 3). On the upper part of this unit is the sandstone of a channel facies association, with cross bedding sedimentary structure. The CC unit is most likely the end of the transgressive phase.

![Basemap of research area, showing traverse line and well correlation sections with west-east orientation.](image)
3.1.2. Tuffaceous sandstone. The Tuffaceous Sandstone unit is 63 m thick, mainly composed of sandstone (figure a) with tuff materials (figure 5b). It is identified from the stratigraphic column, repetitive fining upward stacking pattern from sandstone to claystone (figure 3). Cross bedding and ripple lamination are found in the sandstones but mostly are showing normal graded bedding sedimentary structure. The sandstone is interpreted as the product of channel sediment, which vertically is still separated by the claystone of flood plains. The stacking pattern is also an indication where the accommodation space is relatively high, despite the end of the transgressive phase, compare to the sediment supply, which may cause meandering channels. The coal is only formed on the bottom of this unit, named seam 3. The roof seam is sandstone of channel facies. Thus non-organic material is expected to be abundant on the upper part of seam 3.

3.1.3. Claystone. The Claystone unit is 63 m thick, predominantly consist of claystone, with interbedded sandstones (0.5 m thick), as shown in figure 6. It is most likely that the Cl unit is deposited in a more tidal influenced environment that formed the lenticular bedding. Seam 2 is 1.8 m thick at the lower part of this unit, with claystone partings. The seam floor is claystone, while the roof is siltstone (figure 3).

Figure 3. Lithostratigraphic column measured within the research area. The lowermost strata begin with the Carbonaceous Claystone (CC), overlaid by Tuffaceous Sandstone (TS), continued by Claystone (Cl), and the uppermost strata are Sandstone (St).
Figure 4. Outcrop of Carbonaceous Claystone at OP 14 showing the siltstone on the floor and claystone at the roof of seam 4.

Figure 5. Sandstone of Tuffaceous Sandstone Unit outcrop at OP 12 (a) and the petrographic view of the sample showing fragments of reworked volcanic material (clasts of plagioclase G-J:6-9; feldspar D-E:9-10) (b).

Figure 6. Outcrop of claystone from Claystone Unit at OP 7.
Figure 7. Outcrop of thick sandstone of Sandstone Unit at OP 3 (a), and the petrographic view of the sample showing abundant quartz mineral (b).

3.1.4. Sandstone. The sandstone unit is 83.5 m thick, mainly composed of sandstone as shown in figure 7 (thickness ranging from 2 m up to 8 m), with interbedded claystone and carbonaceous claystone. The sandstone mostly shows normal graded bedding (figure 3). As the interval goes upward, there were also found cross bedding and lenticular bedding, and siderite in the form of concretions. The St unit obviously indicated much limited accommodation compare to the high rate sediment supply. The environment is also influenced by tidal waves that caused the form of lenticular bedding. The dominant influx of seawater was most likely contributed to siderite into the sandstones.

3.2. Maceral analysis and quality parameter
The observed macerals of the vitrinite group are telocolinite, desmocollinite and corpogelinite, which also the predominant maceral from all seams. The identified maceral from liptinite group are resinite, alginite (from seam 1 and seam 4, figure 8a,b) and suberinite (from seam 4). The inertinite group in the samples are semifusinite (absent in seam 1) and sclerotinite. The maceral list is provided in Table 1.

The mire condition that formed these coals was described based on the maceral composition. The four seams are projected in TPI vs GI crossplot in figure 9. Basically, the coals have relatively high TPI and GI. The mire is within the wetland area that has high net primary productivity. This condition is also supported by the teematic hydrologic regime that is more suitable in preserving the vitrinite. The presence of alginite is most likely due to the contribution of seawater influx into the mire, which is also the reason for pyrite formed in the seam.

The quality parameter obtained from the proximate analysis is listed in Table 2. The average ash content is ranging from 5.20-7.76 weight%, where the highest percentage is from seam 4 and the lowest is from seam 1. the average total sulphur is ranging from 0.34-1.28 weight%.

| Table 1. Maceral and mineral matter composition of seams in research area (in %) |
|-----------------|-----------------|--------|--------|--------|--------|
| Maceral Group and Mineral Matter | Submaceral | Maceral | Seam 1 | Seam 2 | Seam 3 | Seam 4 |
| Vitrinite | Telovitrinite | Telocolinite | 35.6 | 54.6 | 48.6 | 53.4 |
| | Detrovitrinite | Desmocollinite | 52.0 | 28.4 | 28.2 | 30.0 |
| | Gelovitrinite | Corpogelinite | 1.0 | - | - | - |
| Liptinite | Resinite | - | 2.0 | 1.6 | 2.6 | 1.6 |
| | Alginite | - | 0.4 | - | - | 0.4 |
| | Suberinite | - | - | - | - | 0.4 |
| Inertinite | Teloalgininertinite | Semifusinite | - | 2.2 | 1.6 | 4.0 |
| | Gelatinertinite | Sclerotinite | 5.4 | 11.6 | 17.4 | 9.0 |
| | - | Macrinite | - | - | 0.6 | - |
| Pyrite | - | - | 3.6 | 1.2 | 1.0 | 1.2 |
Figure 8. (a) Feature of macerals in seam 1 sample and (b) macerals in seam 4, where alginit were presence from both samples.

3.3. Coal-bearing formation depositional environment

The term formation here is equivalent to the lithology units explained in the previous section. Based on the lithostratigraphic column and the quantitative TPI and GI calculation, the coal-bearing unit was deposited within the marginal environment. More specific, referring to the depositional model [8], the depositional took place at the transitional to upper delta plain. As the depositional model is assessed based on several parameters, the most distinct characteristic is that there is no sandstone sequences thickness greater than 50 feet, with common fine grain sediment sequences of 5 to 25 feet thick. The strata show common ripple lamination, which also considered as a parameter of transitional to upper delta plain.

The lithostratigraphic column shows repeated channel facies deposits, that vertically is still separated by claystones, which is the product of a meandering channel system [11]. Feature of lenticular and flaser sedimentary structure that was both identified from the lithostratigraphic column has become strong evidence of change in flow direction due to frequent change of relative sea level, most likely influenced by tidal waves. Thus, the meandering channel is formed in a marginal environment rather than a fluvial system in the land (terrestrial).

The occurrence of siderite concretion is another evidence of marine water incursion into the research area, which later support the interpretation of upper delta plain environment [12]. Even though overall, the depositional environment of the coal-bearing unit took place in marginal area, the appearance of siderite concretion has also become the characteristic that distinguished the lower strata (Carbonaceous Claystone, Claystone and Tuffaceous Sandstone Unit), which consist seam 2, 3 and 4, is still dominant in terrestrial influence, and the upper strata (especially the Sandstone Unit), which bears seam 1 is more into marine influenced.

Table 2. Coal quality parameter, Tissue Preservation Index and Gelification Index list

| Seam    | Average ash content (weight%) adb | Average total Sulphur (weight%) adb | TPI  | GI   |
|---------|----------------------------------|-----------------------------------|------|------|
| Seam 1  | 5.20                             | 0.34                              | 2.21 | 6.41 |
| Seam 2  | 6.76                             | 0.43                              | 2.40 | 6.48 |
| Seam 3  | 8.64                             | 1.14                              | 2.45 | 4.07 |
| Seam 4  | 7.76                             | 1.28                              | 0.78 | 16.40|
Figure 9. The TPI vs GI crossplot of seams in research area shows that the organic source is accumulated in a wetland area.

3.4. Coal quality distribution
In this research, the quality parameter that is discussed due to its percentage variation is ash content and total sulphur. Both average ash content and total sulphur decreased from the seam at the lower strata towards the seam at the upper strata. The average ash content is 7.76% from seam 4, and the percentage increases until the number reached 5.20% from seam 1. The same goes for average total sulphur, where seam 4 has 1.28% at the lower strata and decreased until 0.34% from seam 1 at the upper strata.

Figure 10. Well correlation of dip section (west-east orientation) on the northern part of research area.
The explanation of the quality within each seam is actually coincide to the shifting of coal-bearing unit depositional environment condition. The seam at the lower strata is a product of lithology unit that is deposited in a more fluvial influenced upper delta plain. The fluvial system is the biggest carrier of sediment particles that was transported from the land, which most likely contributed more non-organic sediment into the mire [10], this later recorded as the ash content in coal. On the other hand, seam at the upper strata (seam 1) was accumulated in a more marine influence transitional delta plain. The marine influence has limited the influx of sediment from the fluvial system into the mire. Hence, relatively lower ash content in seam 1 compared to seam from the lower strata.

Well correlation is conducted to visualize the subsurface coal distribution. Considering that seam 1 has the most suitable quality composition as the preferable coal to be exploited, the targeted area will be focusing on the distribution of Sandstone Unit and seam 1 itself. The subsurface section, both on the north section (figure 10) and south section (figure 11), shows the dip direction is heading westward. It can be concluded that, if there is no fault or fold involved, seam 1 is distributed in a north-south direction. This information is valuable to the mining company to make the decision in designing a future mine plan.

4. Conclusion
Seam 1 has the lowest ash content (5.20%) and sulphur content (0.34%). Sandstone Unit, which is the coal-bearing unit of seam 1, must be the main mine prospect in terms of a preferable coal quality within the research area, without considering the thickness or volume. The distribution of the Sandstone Unit is at the center part of the research area, which means that the mine is recommended to focus the mine production activity within this area. Up until this research is completed, the pit is only moving westward. In terms of expanding the mine area, the research suggested moving in a north-south direction, following the distribution of Sandstone Unit that bears the coal with the most preferable quality.

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