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CHARACTERISTIC OF SILICIFIED COAL ON TANJUNG AGUNG SYNCLINE, MUARA ENIM, AND IT'S EFFECT DUE THE MINING INDUSTRY

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Abstract

The presence of silicified coal characterized several coal seam in Muara Enim Formation and become the important issue in coal mining industry. Silicified coal found in the South of Tanjung Agung District, Muara Enim Regency, South Sumatra. The occurence of silica presume related to the volcanic activity during the late miocene along the regression phase that affected the sedimentation process of Muara Enim Formation. Tuffaceous sandstone layer can possibly recognized as the main source of the silica. Aquisition data process done by observing the research area and several previous study. Sampels used were taken from several coal outcrop. Petrography analysis used to explain the characteristic of silicified coal microscopically and used to analyze the possibility of its genesis. The presence of silicified coal characterized the coal seam occur in southern limb of Tanjung Agung Syncline that distinguish it with the coal seam on northern limb. Macroscophically, silicified coal found generally blackish gray color, hard, in the form of lenses and layering and microscophically mostly dominated by crystal quartz in the form of detrital and diagenetic silica. Silicified coal may cause problems in coal mining activity. Particular treatment should be applied during the mining activity because of its hardness.

Keywords: *Silicified coal, silica, Muara Enim Formation.*

1. Introduction

1.1 Background

South Sumatra Basin is one of basin which have many of coal resources. Exploration of coal resources continues to be done mainly on Muara Enim Formation that known as coal bearing formation to increase coal reserves in Indonesia, especially South Sumatra.

The presence of silicified coal characterized several coal seam in Muara Enim Formation and become the important issue in coal mining industry. Silicified coal refers to coal that undergo the silicified process. Silicification process can be interpret as the replacement and/or filling of the plant material by the silica mineral.

1.2 State of the art

Several previous study of silification both on coal and wood that related to the study has conducted by Sigleo (1978, 1979), Stein (1982), Davis et al. (1983), Pujobroto (1997), and Amijaya (2016). Study was conducted to interpret the diagenesis and the main source of silica that take place on the silicification process. Sigleo (1978, 1979) has conducted the research about the geochemistry of silicified wood. The silicified wood commonly occure in, or stratigraphically below, volcanic-rich sediment. The hydrolisis process through the ash which change into clay mineral during the weathering and provide the silica mineral into the meteoric water. Although, the weathering of volcanic tuff may be the important source of silica. On the other side, Murata (1940); Siever and Scott (1963) in Stein (1982) also found that the occurence of the silicified wood in the formations containing volcanic material is the main indicator that the silica present as the result of dissolution of ash and other volcanic debris by the meteoric water.

Davis et al. (1983) provided four mechanism of the silica's origin found in coal: (1) detrital contribution to the peat swamp; (2) biogenic or inorganic authigenic formation during peat's sedimentation; (3) diagenetic alteration and post-depositional of pre-existing minerals; and (4) epiginetic formation. Its origin can be recognize from textural geochemical evidence, grain shape, even the crystal morphology.

Furthermore, Pujobroto (1997) explain the other possibility of silicified coal diagenesis. During the active volcanic activity, the mire that formed was covered by the volcanic ash. The sedimentation process would causes the peat subside and become equivalent to a flat plain and possibly covered by the shallow water and volcanic material. The volcanic material which rich of *silica content were mixed with the peat water. By the hidrogeology process, the silica-rich water percolated down into the the peat layer. The silica-saturated water would be replace the coalifying plant tissue with the suitable condition. Based on Amijaya et al., (2016) on his study explain that the silicification of coal could be started during the early diagenetic coalification stage or even the peat development stage that forming the diagenetic silica by the process of recrystallisation of saturated silica solution.*

Based on some previous study below, writer consider that the study of silicified coal on Tanjung Agung is not done yet, so that, the author initiates to analyze the characteristic of silicified coal on Tanjung Agung District. The objective of the research is to know the characteristics of silicified coal in coal seams and it's association and influence in the mining industry aspects.

The silicified coal that occur in the research area is predicted as the effect of the volcanic material due the pressence of tuffaceous sandstone on the roof of the coal seam. Because of it's characteristics, the occurence of silicified coal is predicted need particular treatment due the mining activity.

1.3 Description of the research area

The research conducted on PT. Sriwijaya Bara Priharum (SBP) Coalfield, located near near the Muara Enim Regency, which is known as "Coal Capital of Indonesia". Stratigraphically the research area composed by Gumai Formation, Airbenakat Formation, Muara Enim Formation, and Kasai Formation. The research area cover the parts of Tanjung Agung districts, Muara Enim regency, South Sumatra province. It is situated at about ±28km from the city of Muara Enim, on the Muara Enim-Baturaja cross road.

1.4 Tectonic framework

The research area is included in the Basin of South Sumatra, which is the Tertiary back arc basin consists of Tertiary sedimentary and basement in the form of metamorphic and igneous rocks Pre-Tertiary (de Coster, 1974). According Pullunggono, et al., (1992) the development of tectonics in southern Sumatra basin divided into three phases.

The first phase done on Jurassic – Cretaceous. On Jurrasic – Cretaceous occurred regime compressed by the movement of the Indian Ocean with the direction WNW-ESE and produce volcanic activity intrusion of granitoid and fault shear dextral (Lematang Fault) intersecting faults trending north (Lenggarannfault and Kikim fault). The second phase, at the end of the Cretaceous – End of Tertiary the Indian plate movement rotates northerly trending extensional regime which forming graben or depression followed by the sedimentation process through the basin. The third phase, during the middle Miocene till now, the plate movement has directed N6ºE that caused the inversion style. The changes in tectonic movement is formed the lineaments and fold with northwest-southeast trend.

1.5 Physiography

Sumatra island is located on the oblique subduction zone between continental and oceanic plate. The oblique subduction causes Sumatra Island physiographically oriented WNW-ESE. van Bemmelen (1949) divided Sumatra into six zones of Physiography: (1) Bukit Barisan Zone; (2) Semangko Zone; (3) Tigapuluh Mountain Zone; (4) Outer arc archipelago zone; (5) Sunda shelf; and (6) Plain and hilly zone, as show on Figure 1.

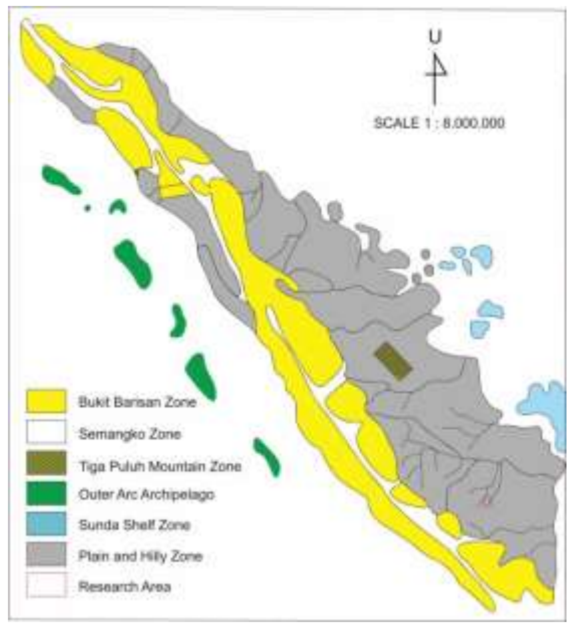

***Figure 1**. Physiography of Sumatra (van Bemmelen, 1949)*

Based on the physiography zone division, the research area is included in the lowland and hilly zone which shown by the gray color in Figure 1. This zone is characterized by the morphology of homocline hills with elevations of 40-200 m above sea level.

1.6 Regional stratigraphy

Heryanto (2006) has divided the South Sumatra basin stratigraphy. Starting from Pre-Tertiary basement rocks that consist of metamorphic, sedimentary and igneous intrusions. Unconformably overlying on the basement is Lahat Formation that was deposited during Eocene-Oligocene composed by sandstone, claystone, mudstone and conglomerate. Then unconformably overlying the Lahat Formation is Talang Akar Formation. The lithologies consist of sandstone and *mudstone with coal intercalation conglomerates Oligocene-Miocene age.*

Then Gumai Formation conformably overlying Talang Akar Formation was deposited on early Miocene-Middle Miocene which composed by shale alternating with fine sandstone, marl, and limestone intercalations. On the Middle Miocene - Late Miocene was conformably deposited Air Benakat Formation composed by claystone alternating with sandstone, intercalation of calcareous conglomerate, and siltstone. Above The Air Benakat Formation, Muara Enim Formation was conformably deposited during the regressive phase on Late Miocene-Pliocene that composed by sandstone, sandy claystone, tuffaceous sandstone and mudstone with coal intercalation.

According to Shell (1978), in ideal condition Muara Enim Formation is divided into several members, namely Muara Enim 1 (M1), Muara Enim 2 (M2), Muara Enim 3 (M3), and Muara Enim 4 (M4) (Figure 2). M1 consists of intercalation of sandstone, siltstone, claystone with coal inserts. Coal seam found two layers with thickness ranging from 0.5 m to 1 m. M2 consist of clay, carbonaceous clay, sandstone, siltstone and coal. The coal seam found in M2 member amount to three layers with thickness ranging from 0.3 m to 6.6 m. M3 consist of sandstone, siltstone, claystone, and coal. Coal seam found two layers with thickness between 1.0 m to 8.1 m. M4 consist of sandstone, silt stone, clay stone, and coal. Coal seams on M4 member found two layers with thickness ranging from 1.0 m to 3.7 m.

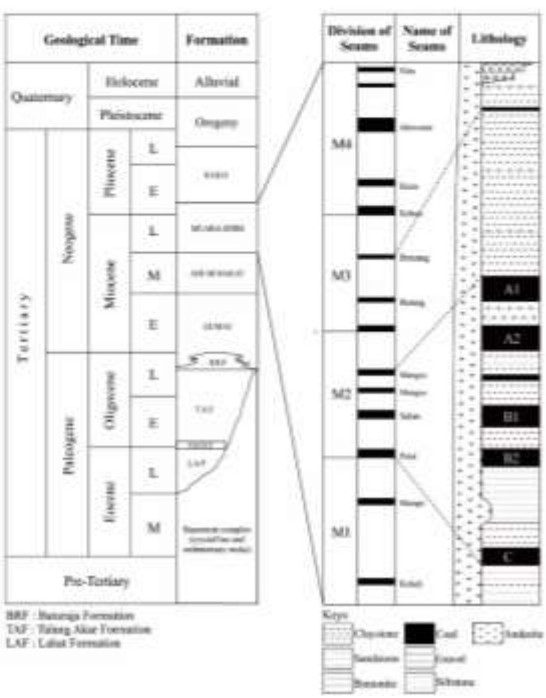

Figure 2. *Stratigraphy of South Sumatra Basin and division of Muara Enim Formation (Sutriyono et al., 2016 modified from Shell, 1978).*

Then Quaternary volcanic activities during Pliocene affect the sedimentary of Sumatra Basin. The intensive volcanic activity provided volcanic material that composed the Kasai Formation. Kasai Formation was conformably deposited above the Muara Enim Formation. Kasai Formation generally consists of tuff, pumice tuff and tuffaceous sandstone.

2. Object and Method

The research conducted using some method that support in completion of the study. Descriptive and observative method used in this study. The methods summarize into three stages below.

(a) Data aquisition, is the early stage of the study to collect primary data and the secondary data that used to support this study. The primary data collected by observing the research area such as rock and coal description, coal geometry measurement, and took some sample of silicified coal. Coal description in this study refers to Kuncoro (2013). While the secondary data collected from some previous paper that related to this study.

(b) Data analysis, is the processing and reviewing stage of the data that obtained and would become the final conclusion. Laboratory analysis has beeen done, petrography analysis used to analyze the mineral contain of the silicified coal.

(c) Syntesize, is the final stage which is the result of analysis was processed to solve the problem in the study.

3. Result and Discussion

Generally coal seam on the north limb and south limb has different characteristic (Table 1). The main difference is the presence of silicified coal. Moreover, The Tanjung Agung syncline may affect the distribution and continuity of coal seam in the research area.

Table 1. *Characteristic of coal seam on Tanjung Agung District.*

Parameter	***Coal Seam Characteristic***	
	North Limb	***South Limb***
Total of outcrop	*14*	*22*
Thickness (m)	*0,2 – >1*	*0,5 - >2*
Dip (°)	*9-15*	*7-36*
Distribution and continuity	*NNW-SSE*	*NW-SE*
Roof and Floor	*Fine sand, coaly clay, coaly shale, dan shally coal*	*Coarse sand, alluvium deposit*
Silicified coal	*Not present*	*Present*

3.1 Thickness

Coal Seams thickness that obtained from surface geology observation at PT SBP's coal field has a diversity. In the northern area, coal seam thickness ranged from 0.2 to 1 m (including hanging seam) which can be seen in Figure 3. In the center area is not found the coal seam due to the direction of coal seam dip is southwest, it makes the coal seam become deeper and the overburden become thicker.

While in the southern area, coal seam is occur due to the influence of syncline with the thickness ranging from 0.5 - > 2 m (Figure 4). There are trace of scouring of river channel (wash out, post depositional) causing disruption of coal thickness. However, the real thickness of each layer of coal can not be confirmed because of the outcrop conditions on the field that not show an ideal outcop. Many layers of coal that have been eroded by river activity that makes observation more difficult, especially in thickness measurement.

Figure 3. *Coal seam thickness on northern area.*

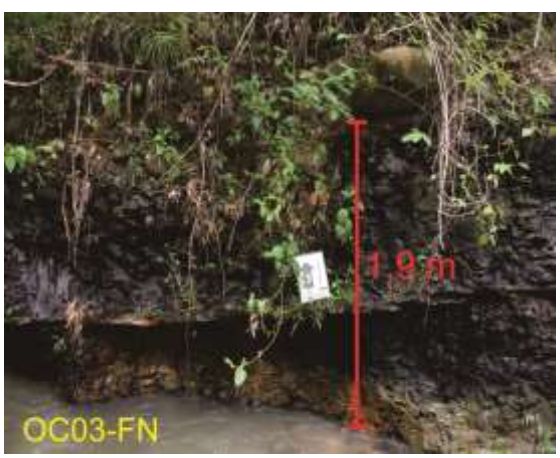

Figure 4. *Coal seam thickness on southern area.*

3.2 Distribution and continuity

Coal seams on nothern area has a spreading pattern with a NNW-SSE trending strike. (Figure 5). However, in the southern area, the distribution pattern is deflected with a NW-SE trending strike. The curved distribution pattern is controlled by the structure of Tanjung Agung Syncline which can recognize from the direction of strike change in the eastern area.

3.3 Dip

Generally, coal seam in coal field PT. SBP has flat – sloping dip. On the northern area, dip of the coal seam ranging from 9º – 15º (Figure 6). While on the southern slope of coal seam ranging from 7º - 36º (Figure 7). The flat-sloping dip will be beneficial because its condition makes the lack of overburden. Minning systems in flat layers are also has the minimum risk of landslides in the pit wall. In the center area the coal seam is not found (Figure 8).

3.4 Roof and Floor

Contact of roof and floor on the northern part are generally with fine grained rocks, ranging from clay to very fine sand (Figure 9). In some places comprising carbonaceous clay, coaly clay, coaly shale, and shally coal are invisible to distinguish with coal. So it needs a careful treatment on stripping process. In southern area also found coal roof with tuffaceous sandstone as found on FN93 outcrop (Figure 10) and alluvium deposits caused by wash out process.

Figure 9. *Coal seam's floor contact with claystone.*

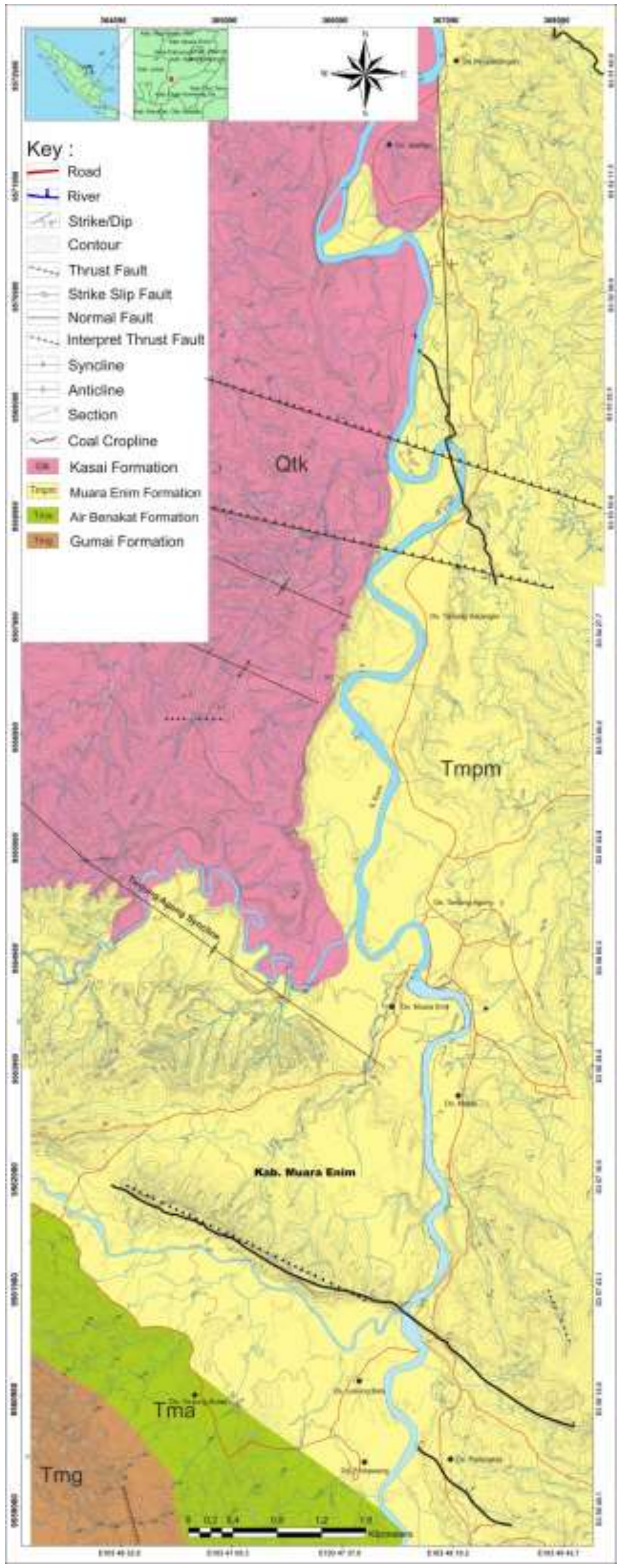

Figure 5. *Geological map of the research area.*

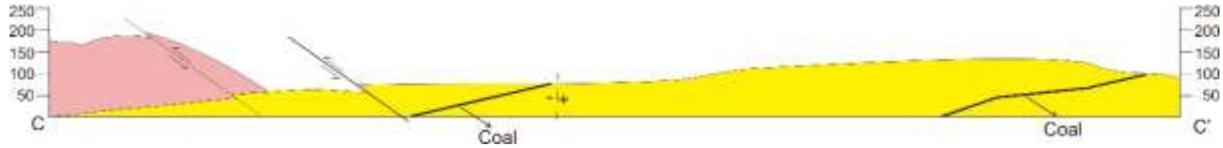

***Figure. 6**. Section C-C', northern of research area.*

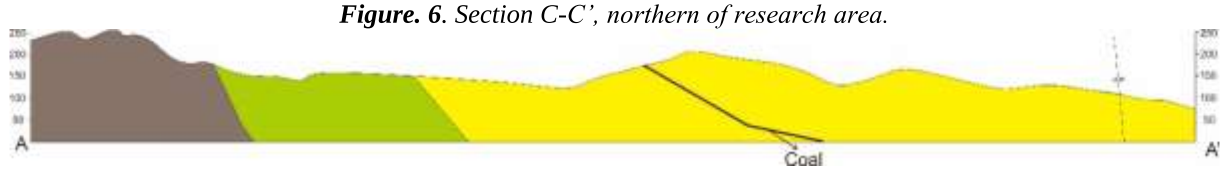

***Figure. 7.** Section A-A', southern of research area.*

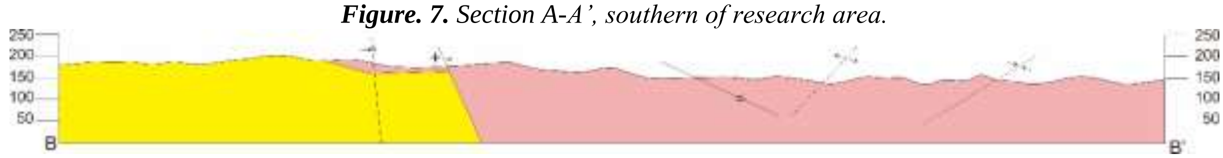

***Figure 8.** Section B-B', center of research area.*

***Figure 10.** Coal seam's roof contact with tuffaceous sandstone.*

3.5 Characteristic of silicified coal

The presence of silicified coal is one of the characteristic of the coal seam that formed in Muara Enim Formation. Silicified coal becomes an important issue in the coal mining world. Silicified coal found on seven coal outcrop on Tanjung Agung (Table 2).

Macroscopically, silicified coal observed on the field is mostly blackish gray, hard, and heavy. The silicified coal's thickness ranging between 8 - 35 cm, some has quartz vein (Figure 11) and amber fragment. The quartz vein colour is shiny white and fill the fracture in the silicified coal. Silicified coal found in the form of lenses and layering (Figure 12),

***Table 2.** Characteristics of silicified coal*

Outcrop	*Characteristics*			
	Lenses	***Layering***	***Quartz Vein***	***Sample***
OC01-FN	✓	×	×	×
OC03-FN	×	✓	×	✓
OC15-FN	✓	✓	×	×
FF1	✓	✓	×	✓
FN20	×	✓	✓	✓
FN93	✓	✓	✓	✓

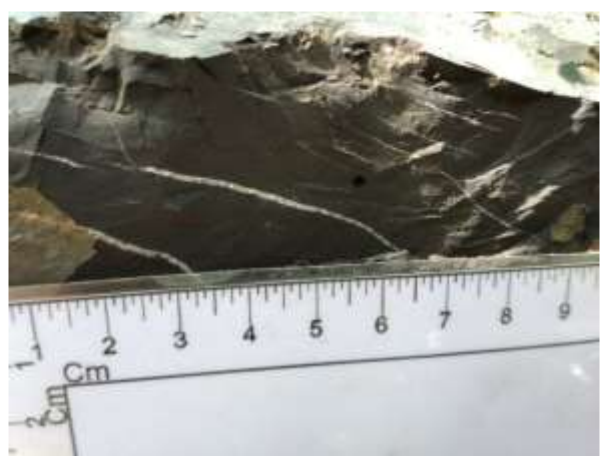

***Figure 11.** Quartz vein on silicified coal.*

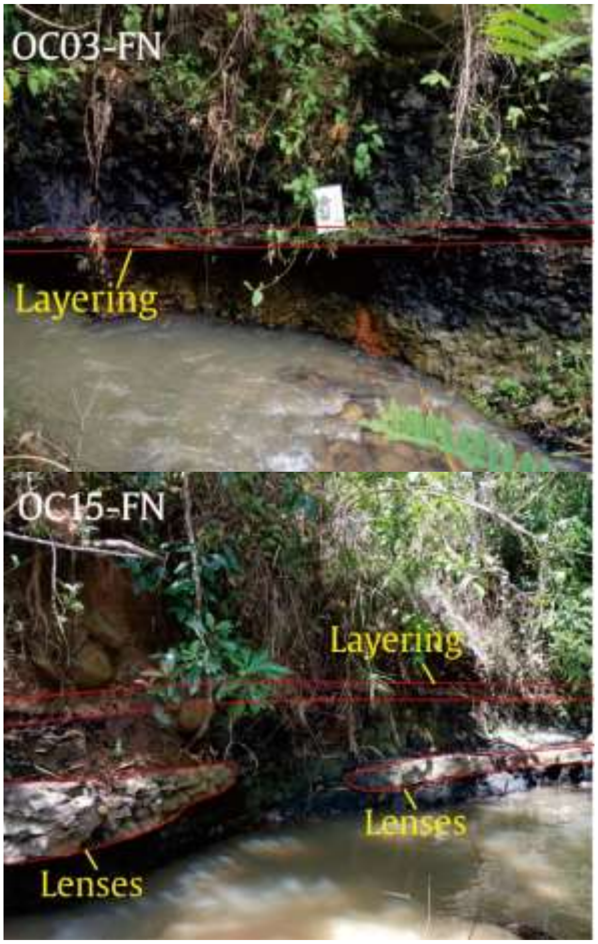

Figure 12. *Lenses and layering of silicified coal.*

In some places, the wood structure still visible and it is quite similar to petrified wood as show in the Figure 13. The silicified wood structure indicates that the plant material possibly has been silicified before completely becoming peat. The silicified coal with remaint wood structure may indicate some parts of plant material are formerly silicified before the peatification stage of coal forming process.

Figure 13. *Wood structure on silicified coal.*

Petrography analysis have been done to recognize the composition of the silicified coal. The petrography analysis uses four sampel that taken on four different coal outcrop (Table 2). Based on the microscopic observation, the silicified coal contain mostly dominated by crystal quartz, euhedral-subhedral in general (Figure 14).

The silica found in two different form and characteristics, detrital and diagenetic silica. The diagenetic silica formed as the result of the high temperature during the early coalification stage of coal forming. High temperature causes the silica become saturated and then undergo recrystalized, some of it observed in the form of vein and asimetry, give the impression of replacement.

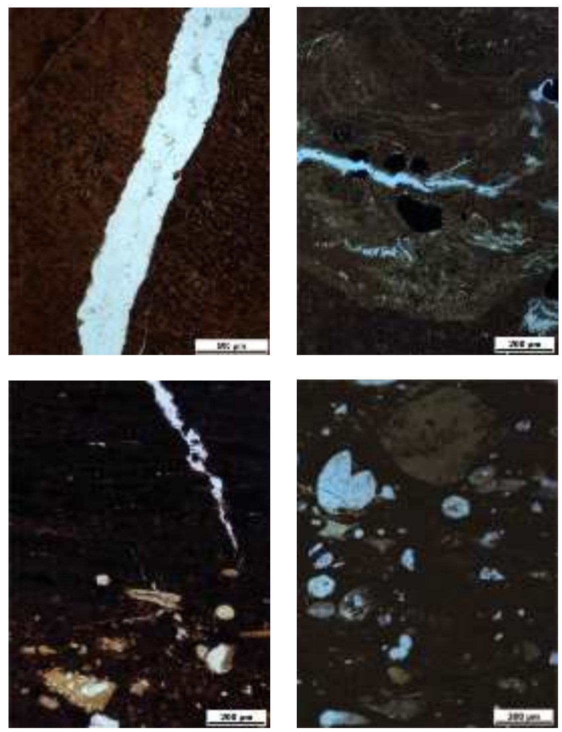

***Figure 14**. Thin section of silicified coal.*

The presence of silica presume related to the volcanic activity during the late miocene along the regression phase that affected the sedimentation process of Muara Enim Formation. The silica rich content volcanic material covered the peat during the peatification process, as the tuffaceous sandstone found in the roof of coal on FN93 outcrop. The tuffaceous sandstone layer can possibly recognized as the main source of the silica. This statement is supported by the Murata (1940) and Buurman (1975) on Sigleo (1979) previous study obtain that the common occurence of petrified wood is on, or stratigraphically, below sediment of volcanic. In case of silicified coal, during the early coalification stage, the temperature and pressure increase causes the leaching of the primary *silica in the tuffaceous sandstone then infil and/or replace the plant cell.*

On the research area, silicified coal found on the south of PT SBP coalfield. In coal mining world, silicified coal also known as batupack. The presence of silicified coal may cause problems in coal mining activity. Particular treatment should be applied during the mining activity. Because of its hardness, silicified coal may become inhibitor for the bucket wheel excavator to peeled it and may increase the cost production. Beside that, silicified coal may affect the coal quality as silicified coal contain high silica.

4. Conclusion

Silicified coal observed on the field is mostly blackish gray, hard, in the form of lenses and layering, contain mostly dominated by crystal quartz in the form of detrital and diagenetic silica. As the author presume that the diagenetic silica formed as the result of the high temperature during the early coalification stage of coal forming related to the tuffaceous sandstone on the roof of coal seam. Tuffaceeous sandstone confirmed that there was volcanic activity during the forming of Muara Enim Formation.

Because of its hardness, silicified coal may become inhibitor for the bucket wheel excavator to peeled and need particular treatment that can increase the cost production. Further research need to be done especially the geochemistry analysis due the coal with the presence of silicified coal to provide the effect as silicified coal contain high silica.

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