The Tectonic Control on the Formation of Cleats in the Coalbeds of Sajau Formation, Berau Basin, Northeast Kalimantan

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Abstract

Some Pliocene lignite-sub bituminous seams are characterized by the presence of natural discontinuities, so-called cleats. Most often they are opening-mode fractures, consisting of two orthogonal sets (face and butt), both almost perpendicular to the bedding. This paper determines distributions of cleat orientation, spacing, and aperture from the Sajau lignite seams. All observations and measurements were conducted at macroscopic, mesoscopic and microscopic scale. The butt cleats' mean orientations are NE–SW, NW-SE; whereas mean orientation of face cleats NNE-SSW and NE–SE, dipping at a high angle N75°. The angle between strikes of cleat sets is nearly 90°. The spacing of macro face cleats is from 9.52 to 14.46 cm (averaging 11.61 cm) and the spacing of butt cleats is from 2.3 to 11.3 cm (averaging 5.35 cm), and the aperture has a mean 0, 54 cm On the other hand, the mean spacing of microcleats 1.58 mm and aperture measurements of these cleats range from 0.021 to 0.029 mm (averaging 0.026 mm), respectively. The obtained results from outcrop and micro CT Scan Tomography clearly indicate that face cleat orientations NNE–SSW are strictly parallel to the elongation of the main tectonic structures in the study area. Their origin may be explained in at least there was relationship with local tectonic (the maximum principal stress, σ1, was horizontal). The Partial Least Square analysis, of cleat and faults data in this area indicate that a power-law distribution exists between cleats characteristics (spacing, density and aperture) with the distance of faults (R^2 = 0.56). The cleat formation in Sajau Formation was mainly controlled by mechanical in response to tectonic. Based on SEM photography; the origin of cleats in Sajau Formation area endogenic process and tectonic activity which indicated by change the shape of the cleats; from the straight line cleats to curved shape and branching.

***Keywords**: Pliocene, coal, Sajau Formation, cleat, Berau Basin..*

Introduction

In coalbed methane (CBM) exploration and production, the cleats was play an important role. Due to old paradigm that a high rank coal and hard coal was an exploration target in CBM, mostly the cleat study was done in bituminous coal (McCulloch et al., 1974, 1976; Laubach et al., 1992, 1998, Karacan and Okandan, 2000, Solano-Acosta et al., 2007, Moore, 2012, Flores, 2013; Mardon et al., 2014). The successes of developing a CBM obtained from low rank coal (lignite sub- bituminous coal) in various basins in different parts of the world have been well documented. The huge reserves of coalbed methane have been founded, followed by their production in low rank coal; such as in the San Juan Basin, Powder River Basin, and the Uinta Basin Raton Basin in the United States (Ayers, 2002), Surat Basin and Bowen Basin in Australia (Scott et al, 2007) and Ordos Basin in China (Xu, et al., 2012; Songhang et al., 2010). Therefore, research cleat on lignite becomes very important.

The cleat origin is still debatable and controversial; there are two streams associated with the process of cleat formation; namely endogenic and exogenic (Ammosov and Eremin, 1963; McCulloch et al., 1976; Ting, 1977; Laubach et al., 1998; Paul and Chatterjee, 2011). Su et al. (2001), mentioned that a single hypothesis on the cleat formation is probably incorrect.

Berau basin is one of the sedimentary basins in Indonesia that have huge coal reserves. Based on a study by ARI the basin has CBM reserves of about 8, 4 Tcf. However, there are still insufficient studies of fracture/cleats in coals formation. One of the coal bearing formation in Berau basin which have a good prospect for CBM development is Sajau Formation (Figure 1).

The aim of the current study are, firstly cleat attributes such as the orientation, spacing, and aperture of cleats. The variation in spacing and aperture will be discussed in terms of the relatively distance of the lignite seam from the nearest fault. The second goal is the origin of cleat network.

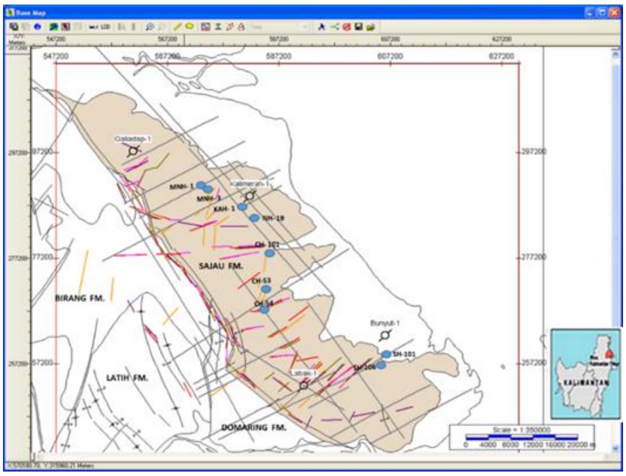

Figure 1. The geological map of Tanjungredeb Sheet and samples location in Berau Basin

Geological Setting

The Berau Basin encompasses a wide variety of faults, structural elements and trends. Tectonics of the basin was initiated by extension and subsidence during the Middle to Late Eocene formed wrench faults and resulted in the formation of major NW-SE oriented arches and has stopped by the end of Early Miocene. Two deep-seated NE-SW sinistral Mangkalihat and Maratua. Were influenced the structural trends in Berau Basin. These faults play an important role not only in the arrangement of NW-SE, NNW-SSE fold; but also in cleats direction. The main stress (σ1) of cleats in Berau basin is NW-SE (Figure 2).

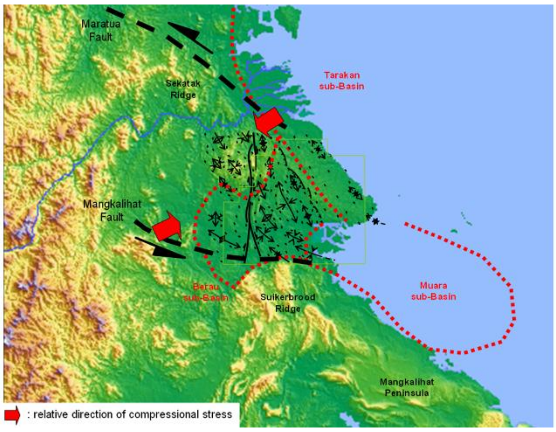

Figure 2. The tectonic setting in Berau basin with two deep-seated faults (Salahuddin et al., 2011)

Stratigraphically, Berau Basin was consists into Pre-Tertiary, Tertiary, and Quartenary deposits (Figure 3). The oldest age rocks of Tertiary period is Danau Formation, consist of strong tectonics rocks and metamorf with highly significance thickness in the age of Permian-Carbon or Jurassic Cretaceous.

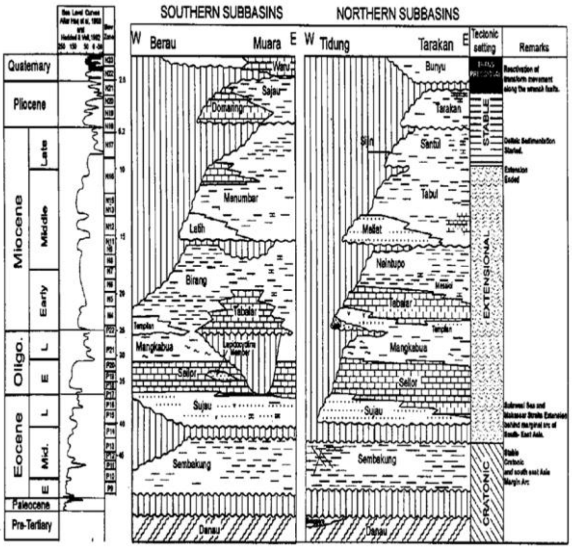

Figure 3. Stratigraphy of Berau basin and surrounding area (Achmad and Samuel, 1984)

The sedimentary succession in the Berau Basin can be grouped into 5 major cycles of sedimentation (Achmad, Z. and Samuel, L., 1984); cycle 1 (Late Eocene – Oligocene), cycle 2 (Early Miocene –

Middle Miocene), cycle 3 (Middle Miocene – Late Miocene), cycle 4 (Pliocene) and cycle 5 (Quartenary). The tectonics and relative sea level changes were influence the lithological variation. The oldest sedimentary cycle is a syn-rift volcanic bearing siliciclastic-rich unit of the Middle to Upper Eocene which called Sekatak Group consisting of Sembakung Formation and the unconformable overlying Sujau and Malio Formations. This group were deposited unconformable overlies pre-rift, Triassic to Cretaceous Sundaland basement rocks, also underlies the post-rift unconformity below the younger group sediments. The youngest which called Simenggaris Group is divided into five lithostratigraphic units, Meliat/Latih (oldest), Tabul/Domaring, Tarakan/ Sajau, and Bunyu (youngest) Formation.

The outcrops of Sajau coal measures in Tanah Kuning, Mangkupadi in northern part and in the Kasai, Batu-Batu area southern part of the basin typically consist of siliciclastic rocks and coals. This formation consisting claystone, shale, sandstone, conglomerates with interlaminated coal, also containing molluscs, quartzite, and mica. The lithological structure which can be found are cross and parallel lamination. The coal thickness in this formation is 0.5 – 6 m, black and brownish yellow. The sedimentation process begin on the fluvial and deltaic system over Pliocene – Pleistocene period which conformably overlying Waru Formation.

Methods and data

The research methods based on field study and laboratory measurements. During field research; cleats were measured (spacing, aperture, orientation) and classified. From the oriented core samples from coal exploration; the mesocleat was identified by CT scan method and the microcleat was determined by SEM technique. The relationship between cleat attributes and the nearest fault distance were analyzed by Partial Least Square (PLS) method.

Definition and Classification

The cleats is defined a fracture set which have an angle between strikes of cleats sets nearly 90^0. In this paper we use basic division of cleat into face cleat and butt cleats (Nelson, 1983; Laubach et al., 1998).

The term of cleats orientation is apply of strike and dip angle. The cleats spacing is the distance between two cleats which measured perpendicular to the cleats.

Result

Cleats Characterization

The outcrop cleat characterization were taken in ten locations from three coalmine site; e.g. three measurement in Kasai Block, four in Mangkupadi Block and three in Tanah Kuning. The cleat outcrops were near the fault zones and folds, some were close to the fault. (Figure 4)

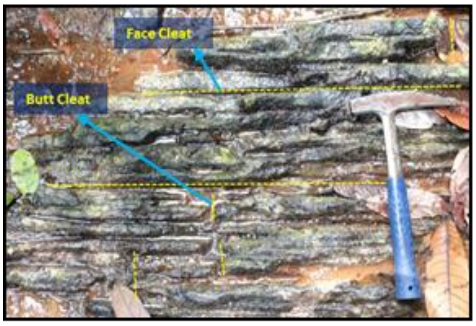

Figure 4. Photographs showing well developed face and but cleats in the Kasai opencast mine (Location: C1)

The measurements of strike/dip of cleats in Kasai Block were taken in C2, C3 and C4; which were located near the E-W faults zone. The orientation of face cleat was N 243^0 E – N 252^0 E and butt cleat was N 62^0 E – 337^0 E. The orientation of face cleat in Mangkupadi Block were measured in C5, C6, C7 and C8 which influenced by NW-SE fault direction; has shown the orientation of face cleat at N 243^0 E and N 246^0 E and butt cleat at N 327^0 E – N 330^0E. In Tanah Kuning Block the cleat orientation were measured near the NW-SE fault zone in location of C9, C10 and C11; the strike/dip of face cleat were at N 242^0 E and butt cleat at N 326^0 E (Table 1).

Table 1. The macrocleat orientation from Sajau Coal

Location	Face cleat			Butt cleat		
Kasai	SP	AP	Strike	SP	AP	Strike
	(cm)	(cm)	(N^0E)	(cm)	(cm)	(N^0E)
C2	9.5	0.8	243	2.5	0.1	337
C3	14.2	0.6	243	8.5	0.2	335
Mangkupadi						
C4	11.4	0.8	62	11.3	0.1	162
C5	14.5	0.5	70	4.3	0.2	133
C6	8.7	0.6	328	6.2	0.2	58
C7	8.2	0.6	246	8.2	0.1	118
Tanah Kuning						
C8	12.4	0.4	318	2.4	0.2	48
C9	13.2	0.5	324	3.6	0.1	56
C10	10.4	0.2	74	2.4	0.1	174
C11	12..1	0.4	65	3.2	0.2	65
Average	11.46	0.54		5.35	0.15	

SP: Cleat spacing; AP: Cleat aperture.

The integrated study of field measurement and CT scan tomography have done for analyzed the microcleat (Figure. 5).

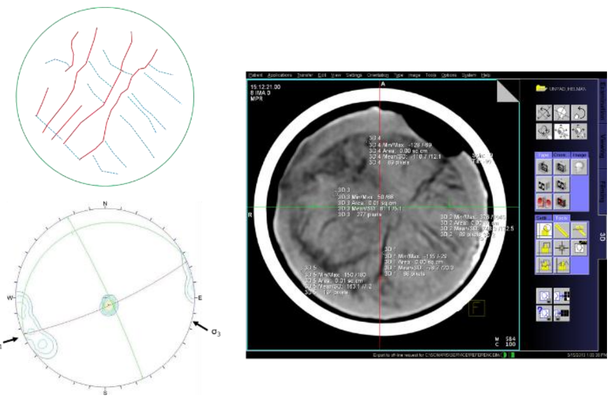

Figure 5. The slice image of SH-101A (Z-axis direction); illustrating the CT cleat image (right)) , cleat interpretation and orientation (upper left) and Schmidt lower hemisphere equal projection net of cleats orientation (lower left)

The figure showing that σ1 has NE-SW direction. There are two cleat orientations has have been identified i.e. NNE-SSW direction (face cleat, red color), and NW-SE direction (butt cleat, blue color). The cleats with NW-SW direction were are abutting in the NE-SW cleats (Hamdani, A.H., 2015). Tectonically, the structural geology in Berau Basin were is influenced by deep-seated NE- SW sinistral Mangkalihat and Maratua (Salahuddin, 2011). These faults play an important role not only in the arrangement of NW-SE, NNW-SSE fold; but also in cleats direction. The main stress (σ1) of cleats in Berau basin is NW-SE (see figure 6). Based on the reconstruction of the structural elements; the relative compression stress of structural geology (fold, fault) also approximately has an approximately NE-SW direction too (Figure. 5). Therefore, the compressional stress (σ1) of fold, faults and cleats have a similar direction.

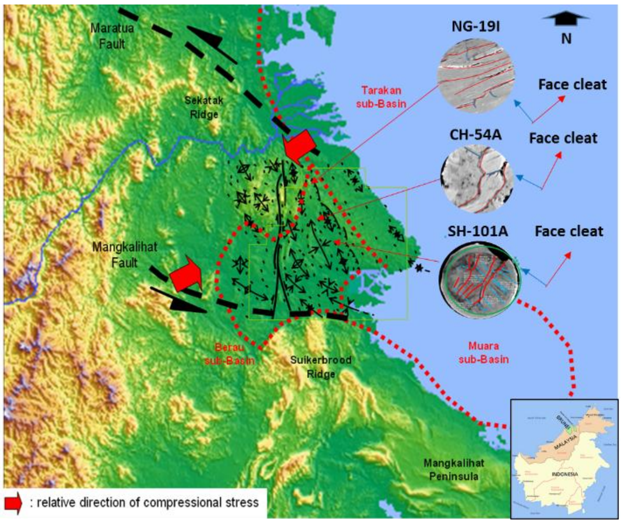

Figure 6. Structural geology (folds, faults and cleats) arrangements in Berau Basin and CT scan image of representative coal samples

Table 2. The mesocleat attributed from Sajau Coal

Location	Face cleat			Butt cleat	
Kasai	DF	FC	DFC	SP	AP
	(m)	(N/cm)		(mm)	(mm)
SH-101	306	4.77	12	1.43	0.0248
SH-106	302	5.25	12	1.50	0.0273
Mangkupadi					
CH-102	1176	2.58	7	1.82	0.0219
CH-34	70	8.78	5	1.10	0.0291
CH-54	180	7.54	6	1.15	0.0289
CH-53	250	7.2	4	1.18	0.0291
Tanah Kuning					
MNH-1	4280	3.91	7	1.80	0.0257
MNH-2	4390	3.08	5	1.60	0.0258
KAH-1	1064	3.12	5	1.55	0.0228
NH-15	760	6.31	6	1.24	0.0280

DF: Distance of fault (m); FC: cleats frequency (N/cm); DFC: cleat cross cutting density; SP: cleat spacing (mm); AP: cleat aperture (mm)

The Partial Least Square analysis, of cleat and faults data in this area indicate that a power-law distribution exists between cleats characteristics (spacing, density and aperture) with the distance of faults (R^2 = 0.56).

By the SEM techniques of coal samples should be identified that there is a possibility of an endogenous process (matrix swelling) and exogenous (tectonic) are working together in the presence of distributing coal cleats. The structural deformation in the study area consists of cataclastic deformation; which is relatively weak tectonic has been found in coal from CH-102, CH-122.; while the type of stronger tectonic deformation type; such as brittle deformation and wrinkle deformation was occurred relatively near the core zone fault structure.

The endogenic cleats as a result of the swelling matrix, fracture dilatation and compacting that occurs in coal cause a reduction in the volume of water; it will form a cleat with a thin line shape that looks intersection between the face cleat and butt cleat as shown in Figure 7 A; whereas cataclastic deformation is characterized by the presence of two or more intersection between cleats or with other micro fracture (Figure 7B). With the increasing intensity of the tectonic deformation in the coal cleat formed will form early intensive will change its shape can cause the curved cleat (curvature shape) or secondary cleats formed concentrated around the main cleats (Figure 7 C) and is referred to as brittle deformation.

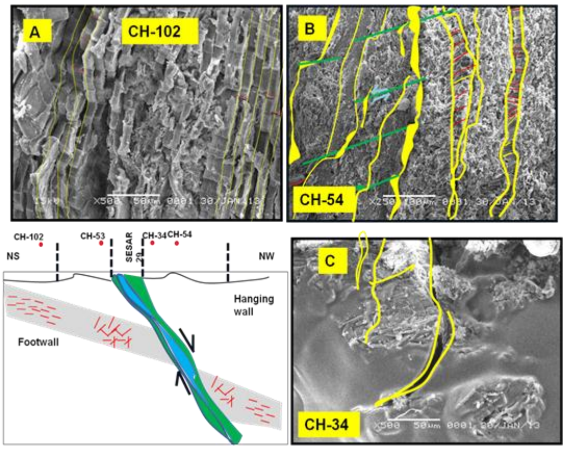

Figure 7. The type of coal cleat deformation in Sajau Coal based on SEM investigation

The pararelism of cleats orientation with other structural type (fault and fold); it clear that the tectonic was influenced in the cleat formation in Sajau Formation at Berau basin.

Acknowledgments

The authors were deeply grateful to Dean of the Faculty of Geological Engineering for the technical and financial supporting to conduct this research.

Conclusion

- Two sets of cleat system; face and butt cleat were identified macroscoscopically in Berau basin. These cleat sets are perpendicular to each other, and face cleat directions are NE–SW and butt cleat NW–SE, respectively. The angle between two cleats is nearly to 90°.
- The cleat formation in Sajau Formation was mainly controlled by mechanical in response to tectonic; both regional or locally.

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