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Stereographic Analysis of Cleat Characteristics in Coal and its Controlling Forces

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Abstract
Cleat analysis plays a crucial role in coal mining, although it is often overlooked. Cleat is related to permeability and porosity, serving as a location for the accumulation of gases. In coal seams, cleats control slope stability and serve as pathways for gas and liquid flow. Therefore, the utilization of cleats in coal mining varies significantly, as it can determine mining patterns and serve as a guide for identifying the presence of Coal Bed Methane (CBM). This research was conducted in the village of Jebak and its surroundings, Muara Tembesi District, Batang Hari Regency, Jambi Province. Stereographic methods were used to identify controlling forces in coal structures based on field measurements of face cleats and butt cleats, resulting in the direction of controlling forces in ridge formation. Based on the results and lithological discussions at the research site, the lithology consists of sandstone interbedded with coal, mudstone, and mudstone with coal and fine sandstone inserts. Stereographic analysis of cleat measurements revealed that the resulting forces were compression forces from the Northeast to the Southwest and from the Southwest to the Southeast, indicating that the origin of the cleat falls into the category of Exogenic Cleat.

1. Introduction

Indonesia boasts one of the world's largest coal reserves, and coal is considered a vital energy source. According to the 2015 World Energy Statistical Review by BP, Indonesia ranks third globally in coal production [1]. Therefore, there is a need for well-executed coal exploration and mining activities, with particular attention to the presence of cleats within coal seams [2]. Cleat refers to natural fractures within coal seams that are open in nature, comprising face cleat and butt cleat [3]. Both types of cleats typically form right angles or near-right angles to each other and are perpendicular to the coal seam surface or have a different orientation relative to the coal seam's position [4]. Face cleat is the primary cleat system, usually dominant with individual planes that are straight and robust, extending over several meters [5]. Butt cleat, on the other hand, is a secondary cleat system, with shorter fractures, sometimes curved, and tending to terminate at face cleat planes (Figure 1) [6].

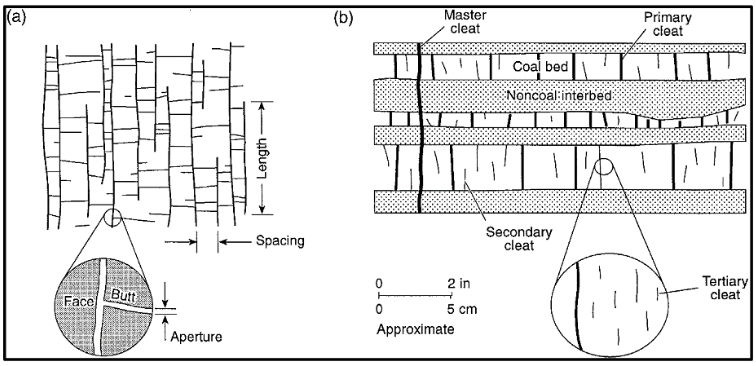


Figure 1. Geometric features of coal cleats. (a) cleat pattern on a horizontal plane (b) cleat pattern based on cross-section [6].

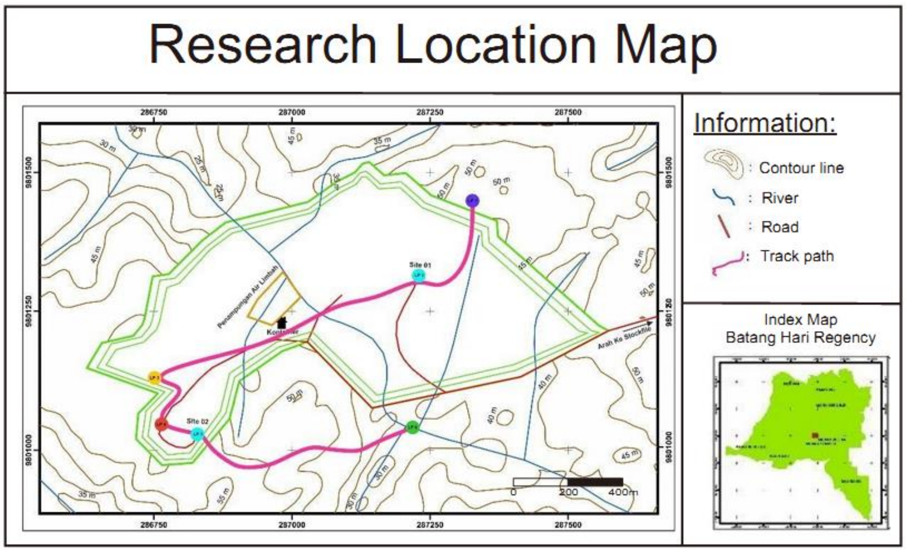


Figure 2. Research Location Map

Cleat has garnered significant attention in the coal mining industry, although quantitative data regarding cleats remain limited [7]. Some available cleat data include orientation, spacing between fractures, fracture width, height, length, interconnectivity between fractures, as well as the relationship between cleats and diagenesis [8]. All of these characteristics are highly crucial in determining coal permeability and porosity, serving as locations for gas accumulation and migration pathways [9]. Fractures within coal seams also influence mining slope stability and function as conduits for the movement of gases and fluids [10]. Similarly, the connection between cleats and sulfur is noteworthy, considering the sulfur content in coal seams is related to coal quality [11]. Genesis cleats can form at different stages during coal formation due to various mechanisms, including the effects of processes such as dehydration or desiccation, devolatilization, deposition mechanisms, coal seam thickness, maceral content, coal lithotype, coal rank, coal deposition environment, thermal contraction, regional tectonics, geological structures, and mining activities [12]. Based on the genetic classification, cleats are divided into endogenic, exogenic, and induced cleats. Endogenic cleats form early in coalification under conditions of internal stress due to dehydration or dewatering and the shrinkage of the coal matrix (organic material) [13]. In relation to the coal's maturity level, their orientation reflects paleo-cleats and is almost always perpendicular to the bedding. They are typically perpendicular to the bedding planes, causing the cleat planes to often divide the coal seam into thin, tabular fragments [14]. Exogenic cleat forms after coalification and is connected by external forces associated with regional stress [15]. These cleats are oriented along the direction of the principal stress and may consist of two sets of fractures that intersect at an angle. Induced cleat is a localized feature resulting from mining activities, involving the transfer of loads into the mine structure or due to blasting effects. Therefore, understanding the characteristics and genesis of cleats becomes crucial. The regional stratigraphy of the research area consists of several rock formations. The Gumai Formation comprises limestone shale with interbedded limestone, marl, and mudstone at the lower part. At the upper part, it consists of alternating sandstone and shale. The thickness of this formation generally varies between 150 m to 2200 m and was deposited in a deep marine environment during the Early Miocene to Middle Miocene [16]. The Muara Enim Formation consists of sandstone, mudstone, mudstone, and coal. The sandstone in this formation can contain glauconite and volcanic debris. The thickness of this formation is 500 to 1000 m, and it has an age range from Late Miocene to Early Pliocene. The coal found in this formation is generally lignite [17]. The research location is in Jebak Village, Muara Tembesi District, Batang Hari Regency, Jambi Province Figure 2.

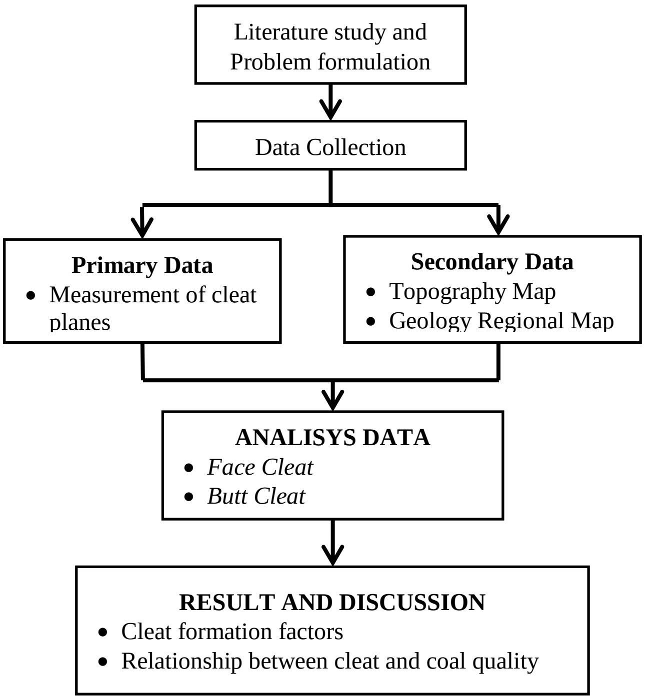
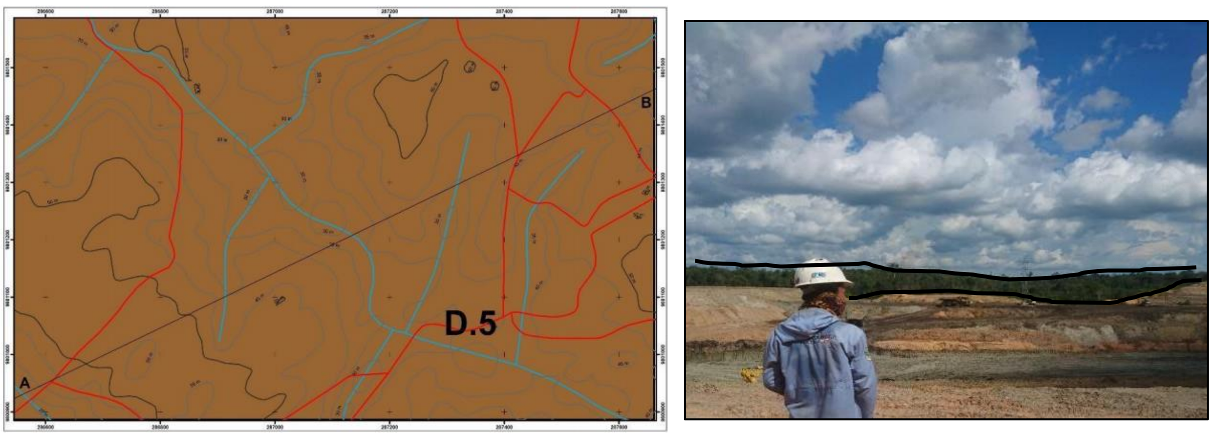


Figure 3. Research flowchart

2. Methodology

This research was conducted in several stages as shown in Figure 3. The first stage involved a literature study related to the research area, including data on the regional geological map, stratigraphy, and journals. The data collection stage was carried out through field observations. Field observations were conducted to examine the rock structures, lithology of the surrounding area, cleat forms, cleat orientations, and data on rock discontinuities to determine the characteristics of the cleat. The data obtained from measuring the cleat planes in the coal layers were processed using the Stereographic method to determine the direction of the controlling forces on the cleat. Stereographic projection is one of the methods used to efficiently represent geometric descriptions to depict the angular relationships between lines and a plane directly. In the analysis of stereographic projection, geological structural elements are depicted and confined within the surface of a sphere. A projection plane will form a primitive circle, and the projection of the structural orientation of the plane horizontally (Dip = 0°) will reveal the inclination of a tilted plane on the Wulff net and Schmidt net. 0° (zero) lies on the primitive circle, and 90° is located at the center of the circle. The final stage involved drawing conclusions based on the completion of all the previous stages and aligning them with the researcher's expectations



(a) (b)

Figure 4 (a). Geomorphology map reserach area, (b). Geomorphological features of Denudational Flatland (D.5)

3. Result and Discussion

Geological study area, the geomorphology of the research area is classified into geomorphological units based on the landforms present in this region.

There is one classification unit of Denudational geomorphological unit, as shown in Figure 4. Based on the descriptive aspects of geomorphological units in the research area, it falls under the Flatland (D5) geomorphological unit, covering 100% of the entire research area. This area consists of coal, sandstone, and clay lithologies, with the highest point at an elevation of 50 meters above sea level (masl) and the lowest point at 25 masl. The slope in this area ranges from 0 to 70, and it exhibits stages of erosion ranging from young to mature. The land use in this area is utilized for Coal Mining and Plantation purposes.

The stratigraphy of the research area shown in Figure 5 consists of lithological units arranged in chronological order from the oldest to the youngest. It comprises a unit of gray clay with interbedded layers of blackish-gray coal and fine-grained sandstone with a brownish-gray color and fine texture. This lithological unit can be compared to the Air Benakat Formation, which dates back to the Middle to Late Miocene. The clay and coal units are distinguished by their gray color and fine texture for clay and a blackish-gray color and massive texture for coal. These units can be compared to the clay and coal units of the Muara Enim Formation, which dates back to the Late Miocene. The sandstone unit interbeds with clay and has a brownish-gray color and a fine and brittle texture. This unit can be compared to the sandstone unit of the Kasai Formation, which dates back to the Pliocene. The geological structures that have developed in the research area include left-lateral strike-slip faults (sinistral faults), and there are fracture structures (cleats) within the coal layers, indicating the presence of cleat structures.

The factors that cause the formation of cleat in the coal layers in the research area fall under the category of "Exogenic Cleat" genesis. In this case, the cleat in the coal layers forms due to the influence of geological structures that play a role in the research area. It is important to note that cleats in coal often form in Bituminous Coal. The cleats in the coal layers create two sets of fracture lines forming an angle, as shown in Figure 6. There are two types of cleat formations: "Face Cleat," which forms vertical lines, and "But Cleat," which forms horizontal lines. These cleat formations are influenced by the geological structures present in the research area.

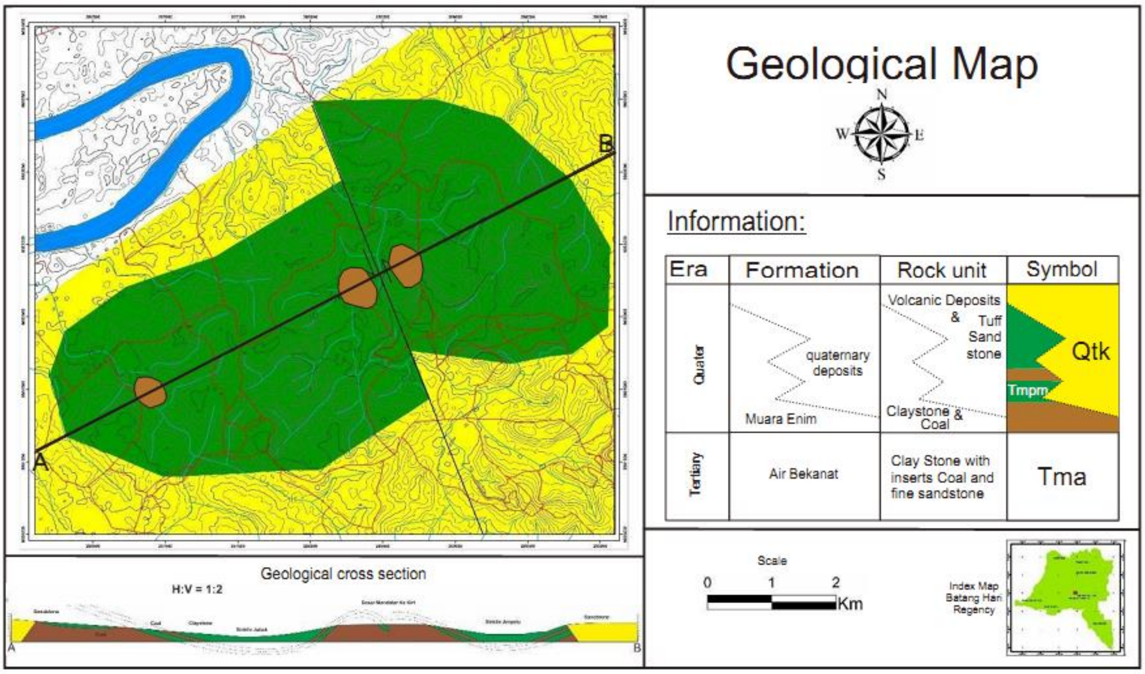


Figure 5. Geology map research area

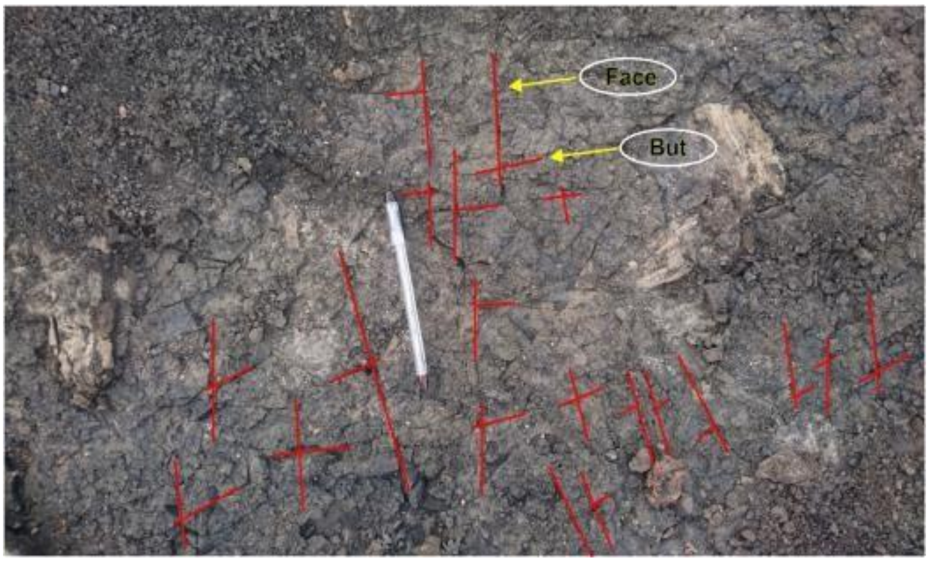
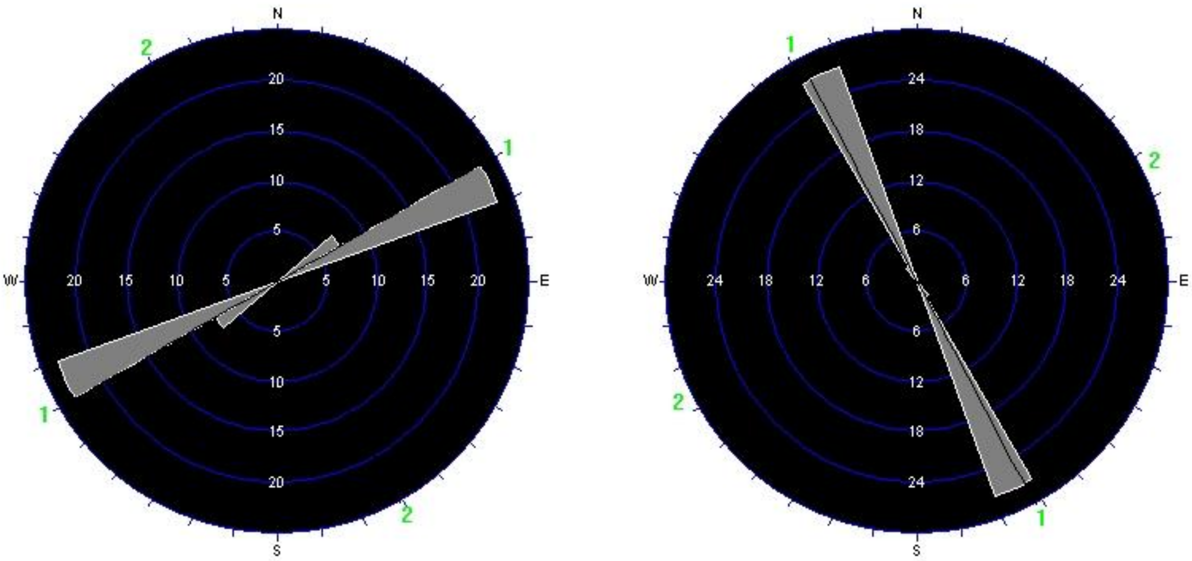


Figure 6. *Face Cleat* and *But Cleat* in research area

Based on the data measurements of face cleat and but cleat, and the analysis using the stereographic method to determine the direction of the forces occurring in the coal layers in the research area, as shown in Figure 7, the following observations can be made:

(a) Face Cleat Analysis:
The stress direction resulting from the face cleat measurements is N 60° E. This indicates that the stress force is generated from the Northeast direction towards the Southwest (Figure 6(a)).

(b) But Cleat Analysis:
The stress direction resulting from the but cleat measurements is N 152° E. This indicates that the stress force is generated from the Southeast direction towards the Northwest (Figure 7 (b)). In summary, the face cleat and but cleat analyses reveal two different stress directions affecting the coal layers in the research area: N 60° E for face cleat and N 152° E for but cleat. These stress directions suggest the presence of distinct forces influencing the structural characteristics of the coal layers in the study region.



(a) (b)

Figure 7. (a). Analisys Face Cleat, (b). Analisys But Cleat

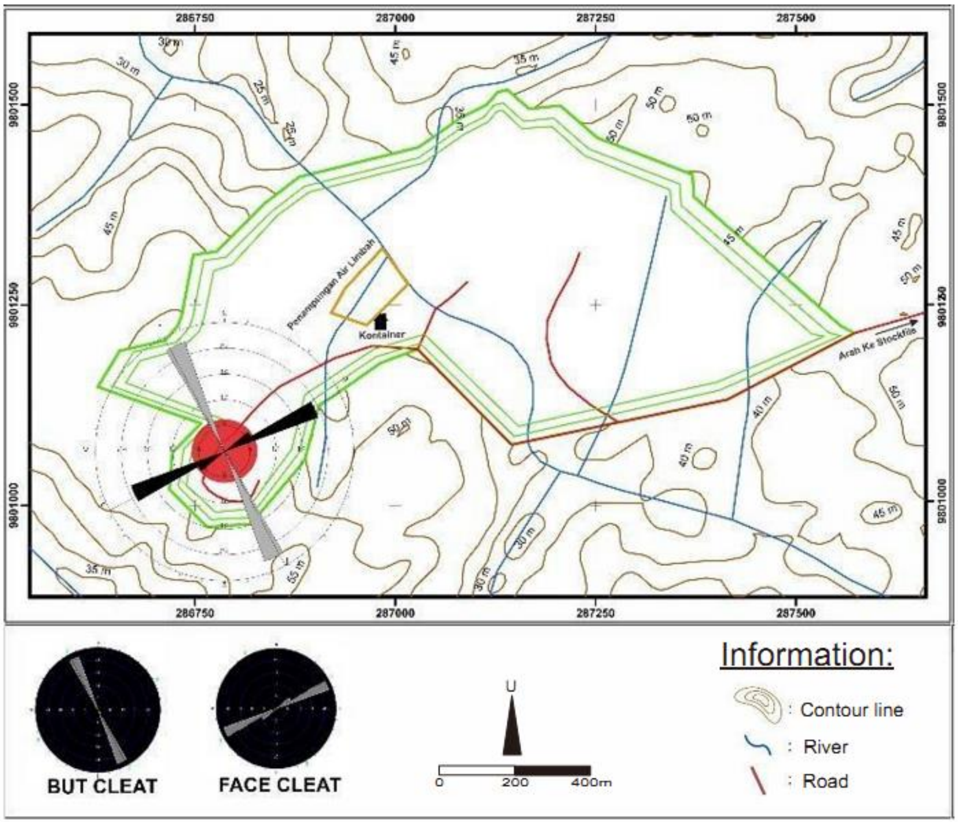


Figure 8. Map of Stress Direction Based on Analysis of Cleat Measurement Data

From the measurements of face cleat and butt cleat, it can be observed that the controlling forces on the coal structure originate from the Northeast - Southwest and Southeast - Northwest directions, as determined using the Stereographic Method, as shown in Figure 8. The relationship between cleat and coal quality has a significant impact. Coal with cleats tends to be filled with clastic material, leading to increased content of Mineral Matter, Volatile Matter, and Ash. As a result, the calorific value of the coal decreases. Therefore, the more cleats present in the coal layers, the lower the calorific value of the coal will be.

4. Conclusion

Based on the analysis and discussion, the following conclusions can be drawn. The formation of cleat in the research area is influenced by the geological structures present, which falls under the process of exogenic cleat formation. The relationship between cleat and coal quality has a significant impact because each cleat fracture tends to be filled with clastic material, leading to increased content of Mineral Matter, Volatile Matter, and Ash in the coal. As a result, the calorific value of the coal decreases. There are two types of cleat, namely Face Cleat and But Cleat, forming vertical and horizontal angles. The data measurements of Face Cleat and But Cleat revealed the stress direction controlling the coal structure, which is from the Northeast to Southwest and Southeast to Northwest.

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