Correlation of total sulfur content to the percentage of pyrite content by microscopy in Mallawa formation coal, South Sulawesi Province, Indonesia

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Abstract. The Mallawa Coal Formation in general, has a high sulfur content even though the calorific value is quite high. Deposition environment will affect the sulfur content in coal. This study aims to determine the relationship of sulfur content to the percentage of pyrite mineral content in coal by microscopy. The research method used is field data collection, each using the channel sampling method (ply by ply) in Pujananting Barru Regency and Massenrengpulu Bone regency. Then a proximate and petrographic analysis was carried out to obtain sulfur content, and the percentage of pyrite in coal. The analysis shows that coal in the Pujananting area shows no relationship correlation between total sulfur content in coal and the percentage of pyrite minerals, so it can be concluded that sulfur in Pujananting coal is organic sulfur, which is formed together with the formation of coal starting during the peat process. While Massenrengpulu coal shows a correlation and relationship between the increase in sulfur content and the increase in the percentage of pyrite minerals, it can be concluded that the sulfur content in Massenrengpulu coal is derived from pyritic sulfur, which is strongly influenced by the depositional environment where the coal is formed.

1. Introduction

Coal in the Malawa Formation in South Sulawesi, in general, the calorific value is quite high and meets the requirements for fuel, generally in the range of above two percent, but due to the high content of sulfur and ash, the utilization of coal in South Sulawesi cannot be optimized in factories and user industries coal [1,2]. Coal with high sulfur content is not very preferred. Besides being able to cause air pollution when reacting with oxygen, sulfur can also cause corrosion in processing equipment [3].

The deposition environment of coal, which is influenced by ocean deposits, produces coal with high sulfur content and frambooidal pyrite and euhedral crystals [4]. Coal is composed of two types of minerals, namely Syngenetic Minerals and epigenetic minerals. Syngenetic pyrite is pyrite formed during the beatification process. This type of pyrite is usually in the form of
granules of coal-forming material [4]. While epigenetic pyrite is pyrite formed after the coalification process occurs. This type of pyrite usually fills the stock, fractures and cleats on coal and is usually massive [4]. The formation of epigenetic pyrite is closely related to the cover rock and the frequency of cleats, because dissolved cations (Fe ions) will be carried into the coal by the flow of groundwater through the cleat and then react with reduced sulfur then form pyrite [4]. Mineral precipitation may be in the form of aggregates and usually fill fine cracks in coal, for example, clay minerals or inorganic sulfur elements commonly found in coal mainly derived from secondary pyrite minerals due to seawater reduction [5].

An inorganic form of sulfur is a sulfide, in addition to the usual sulfate also found. Pyrite and marcasite are sulfides that most often appear in coal [1,6]. Peat, which is under the influence of seawater generally contains higher levels of sulfur compared to freshwater peat. Sulphate is a reactant that determines the level of pyritic sulfur quantity and organic sulfur in peat. During paralic coal deposition, the coal seams are affected by seawater transgression, which results in high organic content of pyrite and sulfur, especially in the upper layers. In humic coal, which is rich in sulfur, pyrite in the form of fine grains or fine concretes is usually found in microlitotyopes with high vitrinite content, but this form is also present in sapropel coal. Primary siderite can change shape to pyrite due to the reduction or addition of H₂S-containing solutions [6]. During the process of forming peat, the pyrite is smooth, crystalline smooth, or syngenetic pyrite appears in a framboidal form. A broad framboidal surface compared to a single crystal causes higher levels of reaction with oxygen so that it can cause a dangerous fire (self-combustion) [6].

The composition of coal is almost the same as the chemical composition of plant tissue, both of which contain the main elements consisting of elements C, H, O, N, S, P. The percentage of these elements can be known by ultimate analysis on coal. Sulfur has joined the coal deposition system since the coal is still in the form of peat deposits. Peat contains all forms of sulfur obtained in coal, including pyritic, sulfuric, and organic sulfur. The sulfur content found in peat can predict the quantity of sulfur in coal. In the reflection light, pyrite looks very bright to yellowish. The Diagram of the formation of sulfur in coal [7] can be seen in Figure 1.

The presence of sulfur content, both inorganic and inorganic forms in the atmosphere are triggered by the presence of rainwater, resulting in acidic water formation. This acidic water can damage buildings, plants, and other biotas [3].

This study is to determine the extent of the relationship between total sulfur content in coal and the percentage of pyrite minerals by microscopy in coal.

Figure 1. Diagram of formation of sulfur in coal [7].
2. **Research Methods**

The research method carried out in this study is multilevel, in which data is obtained in the field and followed by laboratory analysis, then interpreted to achieve a synthesis. Research data was taken directly from the field on coal from the Mallawa Formation in Barru and Bone Region (Figure 2). Field data from coal outcrops include General appearance of coal, position of coal seams, and sampling of coal of approximately 2 kg for laboratory purposes and for backup samples. Collecting coal samples using the channel ply sampling method, which is systematic sampling, starting at the bottom, middle and upper layers in a direction perpendicular to the coal seam. Samples from the field were then analyzed in the laboratory in the form of (with) ultimate analysis and petrographic analysis.

![Figure 2. Topographic Map of Bone-Barru Region.](image)

Petrographic analysis aims to collect data from 500 observation points per sample regarding the microscopic appearance of pyrite minerals, knowing the percentage of volume, and the forms of pyrite under a microscope. The ultimate analysis aims to obtain data on the total sulfur content in each coal sample analyzed. Then connect the value of total sulfur content and the percentage of pyrite using Linear regression diagrams to find out the influence or relationship between the two variables.

3. **Discussion**

The results of the analysis of total sulfur content in coal in the Pujananting District of Barru Regency and Massenrengplu Region of Bone Regency, from each of the three samples, analyzed showed a total sulfur content that varied. In the Pujananting area, the total sulfur content in the lower coal seam (P.01) is 2.64%, the middle layer (P.02) is 2.22%, and the upper layer (P03) is 0.99%. Whereas in Massenrengplu in the lower coal seam (M.01) is 4.53%, the middle layer (M.02) is 3.10%, and in the upper coal layer (M.03) is 2.95%.

The results of microscopy analysis on the Pujananting Region coal showed the percentage of pyrite volume at the bottom layer (P.01) 4.60%, middle layer (P.02) 15.40%, and an upper layer (P03) of 7.80%. Whereas in the Massenrengplu region coal layer, the percentage of pyrite volume in the lower layer (M.01) is 7.80%, middle layer (M.02) 3.80%, and in the upper layer (M.03) 7.40%. Table 1 shows the percentage of total sulfur content and the percentage of pyrite volume of Pujananting coal and Massenrengplu coal. The results of the analysis in both
locations can be seen in Table 1.

**Table 1.** Percentage of total sulfur content and pyrite volume in Pujananting and Massenrengpulu coal.

| Sampling locations | Samples     | Total sulfur content (%) | Volume of pyrite (%) |
|--------------------|-------------|--------------------------|----------------------|
| Pujananting        | P.01 (lower)| 2.64                     | 4.60                 |
|                    | P.02 (middle)| 2.22                     | 15.40                |
|                    | P.03 (upper) | 0.99                     | 7.80                 |
| Massenrengpulu     | M.01 ((lower)| 4.53                     | 7.80                 |
|                    | M.02 (middle) | 3.10                     | 3.80                 |
|                    | M.03 (upper)  | 2.95                     | 7.40                 |

![Figure 3](image)

**Figure 3.** Graph of the relationship between total sulfur and pyrite content in Pujananting coal in Barru Regency.

The graph of the linear equation shown in Figure 3 illustrates that the increase in total sulfur content in coal is not followed by an increase in the percentage of pyrite in the coal. This shows that the total sulfur content in Pujananting coal is not affected by the percentage of pyrite volume. This is possible if the total sulfur content in Pujannanting coal comes from organic sulfur, which in its formation is formed s ingenetically, together with coal formation since the peat process.

The appearance of pyrite by microscopy on Pujannating coal in several observation samples shows isolated subhedral pyrite forms. This type of pyrite is believed to form during the beatification process. This reinforces the availability of sulfur in coal, not because of the influence of pyrite minerals from its depositional environment. In this coal sample, no bacterial framboidal pyrite or inorganic framboidal pyrite was found.
3.1. Massenrengpulu coal

The total sulfur content in the Massenrengpulu coal Bone District shows results in the lower coal seam (sample M.01) below 4.53%, in the middle (M.02) 3.10% and in the upper layer (M.03) 2.95%. In microscopy, the percentage of pyrite minerals in the lower coal seam (M.01) is 7.8%, in the middle layer (M.02) 3.8%, and in the upper layer (M.03) of 7.4%.

The graph of the linear equation between the total sulfur content in coal and the percentage of pyrite minerals is intended to determine the relationship between the two variables (Figure 5). The results shown in the graph of the linear equation resulting from the plot of total sulfur content and the percentage of pyrite in Massenrengpulu coal show a positive relationship between the two variables, with a value of $R^2 = 0.2542$. An increase in the percentage of pyrite as an independent variable, followed by an increase in the amount of total sulfur content as a dependent variable. This shows that the higher the percentage of pyrite in Massenrengpulu coal, the greater the total sulfur content in coal. Thus it can be concluded that the total sulfur content in Massenrengpulu coal is strongly influenced by its pyritic mineral content. Or in other words, it can also be concluded that the total sulfur content in Massenrengpulu coal comes from pyrite minerals or is pyritic sulfur.

Microscopically, observing the percentage of pyrite shows the presence of pyrite minerals in the form of framboidal pyrite and massive pyrite. Divided framboidal pyrite into two parts, namely inorganic framboidal and framboidal bacteria [8]. Both types of pyrite are distinguished from the shape of the crystal. Framboidal inorganic pyrite is homogeneous crystalline pyrite, often appearing in concentric, symmetrical, intergrowth forms following the crystalline core. Framboidal pyrite bacteria are believed to form together with the formation of coal seams. The term framboidal has been widely used in various writings. But there is another term used for this type, namely "cauliflower" type pyrite [9]. Many researchers assume that framboidal pyrite is a pyrite product of bacteria, but on the other hand, there are researchers who think that pyrite is formed from a mineral solution. The framboidal pyrite found in microscopic observations on Massenrengpulu coal is inorganic framboidal pyrite. Likewise, with the presence of massive pyrite minerals found in coal seams, it can be concluded that the sulfur content in Massenrengpulu coal is due to the influence of pyritic sulfur, which is influenced by the coal depositional environment at the time of formation so that the increase in the volume of sulfur.

Figure 4. Appearance of subhedral pyrite microscopy (a,b,c,d), with a magnification of 500x.
will be followed by an increase in sulfur content in coal. The presence of pyrite minerals in coal is strongly influenced by the depositional environment. The Mallawa Coal Formation is formed in the back-barrier area in limnic-marsh environmental conditions, with the development of depositional facies from peat swamps being low moor to high moor, in eutrophic to mesotrophy-oligotrophic conditions [10].

![Graph of the relationship between the total sulfur content and the percentage pyrite of Massenrengpulu coal using a graph of linear equations.](image)

**Figure 5.** Graph of the relationship between the total sulfur content and the percentage pyrite of Massenrengpulu coal using a graph of linear equations.

![Microscopic appearance of framboidal pyrite (a, b) and massive pyrite (c, d), with a magnification of 500x.](image)

**Figure 6.** Microscopic appearance of framboidal pyrite (a, b) and massive pyrite (c, d), with a magnification of 500x.

4. **Conclusion**
Coal in the Pujananting area shows no correlation between the total sulfur content in coal and the percentage of pyrite, so it can be concluded that the total sulfur in Pujananting coal is organic sulfur, which is formed together with the formation of coal starting at the time of the
peat process. Coal in the Massenrengpulu area shows a correlation and correlation between the increase in total sulfur content and the increase in pyrite percentage, so it can be concluded that the total sulfur content in Massenrengpulu coal is derived from pyritic sulfur, which is strongly influenced by the depositional environment where the coal is formed.

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