Distribution of Pyrite and Mineral Matter in Coal Seams from Samarinda Area, Lower Kutai Basin, Indonesia

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ABSTRACT
Samples of coal from a stratigraphic section of Balikpapan Formation, near Samarinda, Lower Kutai Basin were studied for their mineralogy and distribution of pyrite using plasma low-temperature ashing plus X-ray diffraction, petrographic examination and SEM analysis. The results show that the inorganic matters of the coal are composed of quartz, clay minerals, calcite, pyrite, chlorite, feldspar and gypsum. Both epigenetic and syngenetic pyrite occurred in this coals and influence of marine conditions is more favored in the lower portion of the studied stratigraphic section. Epigenetic pyrite and minerals might originate from the erosion of Early Tertiary marine sediments of the Central Kalimantan ridge.

KEY WORDS: Lower Kutai Basin / Mineralogy and distribution of pyrite / Samarinda coal

1. INTRODUCTION
Most of the inorganic matter in coal is present as minerals which are dispersed throughout the coal macerals. Individual grains of minerals vary largely in size from less than one micrometer to tens or hundreds of micrometers. Sometimes mineral-rich layers are even thick enough to be visible on the coal surface [1]. Mineral components in the coals were classified in three groups according to their origin [2]: (1) Mineral from the original plants; (2) mineral that formed during the first stage of the coalification process or which was introduced by water and wind into the later coal deposits; and (3) mineral deposited during the second phase of the coalification process, after consolidation of the coal, by ascending or descending solutions in cracks, fissures, or cavities or by alteration of primarily deposited minerals.

The dominant mineral of coals is usually composed of sulfides, clay, carbonates, and quartz and sometimes additional phosphates, heavy minerals, and salts as minor contributions to inorganic matter of coal. In most coals, sulfides are preferentially composed of pyrite and marcasite but pyrite is in general dominating by far [3, 4].

Sulfides can be categorized as either syngenetic (primary), early diagenetic or epigenetic (secondary) in origin. During peatification, syngenetic or early-diagenetic fine-crystalline or fine-concretionary pyrite appears, commonly in the form of framboids. Syngenetic pyrite formed during accumulation of the peat and/or during early (humification) processes, and is usually small in size, and intimately dispersed throughout the coal [5, 6]. This kind of syngentic pyrite in coal is thought mainly to represent sulphide material precipitated by interaction of dissolved iron with H₂S, the H₂S having been produced by bacterial reduction of sulphate ions in the reducing environment of the peat deposit [7, 8]. The sulphate may be introduced from the water filling the swamp itself, or from waters that permeate the peat bed after its deposition. Influxes of fresh water during peat formation, such as around contemporaneous channel-fill deposits, may be associated with lower proportions of pyrite in the mineral matter than areas of the seam in which marine conditions have had a more intense influence [9]. Renton and Bird, 1991 [10] suggest that sulphide precipitation is favoured by high pH (>4.5) in the peat swamp, whereas at lower pH bacterial reduction is suppressed and lesser proportions of sulphide minerals are formed. The water in which the sulphate occurs may be sea water, and the presence of syngenetic pyrite is often taken as an indicator of coal formation under the influence of marine conditions.

Occasionally, the cell walls of plant material have been replaced by pyrite [1]. Falcon and Snyman, 1986 [11] suggest that the accumulation of pyrite in coal might also arise from the aeolian and fluviatile import of iron-rich mineral at the time of peat accumulation followed by in-situ precipitation. Epigenetic pyrite is incorporated in the coal after compaction or partial
consolidation [6] and is generally much larger (coarse grained) and fills cracks, cleats, and cavities [5]. The formation of epigenetic pyrite is dependent primarily on the availability of reduced sulfur, dissolved cation (ferrous iron) and a suitable site for formation i.e., cleat [12, 13 and 14]. Moreover, epigenetic pyrite might be precipitated from water percolating into fractures, cavities and pores present in coal seams long after accumulation of the peat [11].

Many previous investigations [8, 10, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28 and 29] have described the characteristics, type, morphology, genesis, and distribution of pyrite in coal seams from different deposits. The present investigation deals with pyrite and mineral occurrences in the Middle Miocene coal seams from Samarinda area, Lower Kutai Basin, Indonesia. The primary purpose of the study is to identify the types of pyrite and factors affecting their appearance and it's relation with paleoenvironmental conditions during deposition of the coals.

2. REGIONAL GEOLOGY AND COALS OF THE KUTAI BASIN

The Kutai Basin is the largest Tertiary basin in Western Indonesia. The Early Paleogene rifting along the margins of Sundaland, which is a back arc setting of the Indian Ocean plate, resulted a number of shallow basins [30, 31]. Friederich et al., 1999 [32] have worked out, in detail, on the coal bearing sequences of Indonesia. Eastern Kalimantan is one of the major coal basins in Indonesia having economic coal deposits [33] where the thickest coal seams are attributed to High stand System Tracts (HST) and Transgressive System tracts (TST) owing to the optimum preservation potential. According to Longley, 1997 [34], three major episodes of peat formation took place within Tertiary of Indonesia. The first episode took place during Early to Middle Eocene. This resulted in the rifting in Java, Kalimantan and Sulawesi. The second episode began in the Late Oligocene in Sumatra and Java. This episode was associated with thermal subsidence and transgression. The third episode occurred during global high stand of Middle Miocene and extended by Late Miocene to Pleistocene times over the whole region. This episode is marked by the development of major prograding deltas all along their margins. This can be seen in Kutai Basin in the Southeast Kalimantan (Fig. 1).

Coal rank in the Kutai basin is low to moderate, ranging from lignite to high-volatile bituminous, the latter described as bright and lustrous. Vitrinite reflectance of shallow coal from coal mining areas is typically 0.45 to 0.63% [35]. This is higher than other Indonesian coal basins. Ash content is favorably low and the coal is high in volatile matter content; these factors usually promote good cleating and may enhance permeability [35]. In the study area in Samarinda, identified reserves of high-volatile bituminous and sub bituminous coals from Loa Kulu and Loa Haur are 35 million tons, but these reserves

EXPLANATION

- **Qa**: Alluvium
- **Tpbk**: Kampung Baru Formation
- **Tmbb**: Mulukalapan Formation
- **Tmbb**: Pulau Balang Formation
- **Anticline and Syncline**
- **Thrust Fault**
- **Fault**
- **River**
- **Road**

Figure 1 Location and geological map of the studied stratigraphic section.
are in scattered small areas. In the Badak Syncline there are 428 million tons of reserves in 14 seams, mostly of sub-bituminous rank coal [36].

3. MATERIALS AND METHODS

Eighteen coal samples were collected from all coal bearing interval of the surface exposures and represents all seams from the base to the top of the section. From each exposed locations, about 2kg of coal samples were collected. They were crushed, to reduce in quantity to prepare composite samples. These samples were then subjected to petrographic analyses. The samples were crushed to ~20 mesh size and were embedded in a plastic mold (diameter 3 cm) using epoxy resin as an embedding medium. After hardening, the samples were ground, flat and polished for petrographic analysis. The sample preparation and microscopic examination generally followed the procedures described by Taylor et al., 1998 [1]. For coal mineralogy, selected four samples were used for plasma low-temperature ashing plus X-ray diffraction analyses using a Rigaku RINT 2100. A scanning electron microscope (SEM) was used to study the appearance of different type of pyrite in the coal seams. All analyses were done at the Earth Resources Engineering Department, Kyushu University, Japan.

4. RESULTS AND DISCUSSIONS

4.1 XRD

Owing to the difficulty of identifying minerals in raw coal due to the matrix effect, Low Temperature Ash (LTA) was produced from selected four seams (seam 1, seam 4, seam 6 and seam 9) for XRD analysis. The temperature for low-temperature ashing was lower than 200 °C. Semi-quantitative information was derived from the rough comparison of measured relative intensities of the XRD diffraction peaks for the identified minerals.

The results indicate (Table 1 and Fig 3) the predominance of quartz, clay group minerals (kaolinite, Hydargillite, Illite), calcite, pyrite, chlorite, feldspar and gypsum. Regional data indicates that the majority of clay minerals are probably the alteration products of volcanic materials. It can be said that, Kaolinite group clays are the products of either hydrothermal or volcanic glass alteration from andesitic rocks by neutral-acidic lake water. Quartz minerals may be of detrital origin.

4.2 Characteristics and type of pyrite

According to the microscopic appearance of Samarinda coal samples, the types of pyrite can be divided into framboidal, euhedral, massive, anhedral and epigenetic pyrite in cleats/fractures.

4.2.1 Framboidal pyrite

Framboidal forms of pyrite are categorized as syngenetic [20]. Some authors proposed that the type of this pyrite originates from pyritization of sulfur bacteria

Table 1 Types of minerals in LTA of selected coal seams from the Samarinda area.

<table>
<thead>
<tr>
<th>SeamNo</th>
<th>Quartz</th>
<th>Clay Group</th>
<th>Calcite</th>
<th>Pyrite</th>
<th>Gypsum</th>
<th>Chlorite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seam 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Seam 4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seam 6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Seam 9</td>
<td>X</td>
<td></td>
<td></td>
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</tbody>
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[5, 8, 12, 25, 26 and 37]. Kortenski and Kostova, 1996 [25] also proposed the possibility of pyritization of other kinds of bacteria which might have coexisted along with the sulfur metabolizing bacteria and supported the decomposition and assimilation of the plant tissue. Moreover, it has been suggested that framboidal pyrite might be generated from mineral solutions in inorganic material [17, 18, 25]. Other theories, Wilkin and Barnes, 1997 [38] suggested for the formation of framboidal pyrite is in first step the activity of biogenic processes i.e., pyritic fossilization of bacterial colonies, and in a second step further growing of framboidal pyrite by organic processes, based on laboratory syntheses over a wide range of thermal conditions. Bacterial framboidal pyrite preserves the independence of the separate globules even when they form aggregates [5, 8 and 25]. During peatification, syngenetic or early-diagenetic fine-crystalline or fine-concretionary pyrite appears, commonly in the form of framboids. Coal samples of Seam 5, Seam 6, Seam 9 and Seam10 contain bacterial framboidal pyrite in high abundance. In most of the framboidal pyrite globules the crystals are densely intergrown and consist of some aggregates as previously described by Skripchenko and Berberian, 1989 [27]; in Kortenski and Kostova, 1996 [25]. Most of bacterial framboidal pyrite appears as single bodies or solitary and sometimes as aggregates (Fig 2a and 2b).

4.2.2. Euhedral pyrite

Euhedral pyrite is recognizable as well shaped pyrite crystals [25] Querol et al., 1989 [8] described euhedral pyrite in the coal samples from Maestrazgo Basin, northeastern Spain. Kortenski and Kostova, 1996 [25] observed this type of pyrite in the coal samples from Bulgaria and divided euhedral pyrite into isolated and clustered varieties and isolated anhedral crystals and aggregates of euhedral crystals. Most of the euhedral pyrite is syngenetic and is generated during deposition of peat and/or during early humification. In general, the crystals of euhedral pyrite are small in size.
and intimately dispersed throughout the coal [5, 6, 20, 21 and 28]. Isolated euhedral pyrite was found only in small amounts in sample from Seam 1, Seam 2 and Seam 6 (Fig. 2f). Clustered euhedral pyrite could not be detected in all analyzed samples.

4.2.3 Massive pyrite

Massive pyrite is usually found as cleat-/cell- fillings, cementing or coating frambooids, euhedral or detrital minerals [8]. Massive pyrite has also been found as a replacement of organic matter in different macerals [8]. Many authors denoted pyrite grains with irregular shapes and different sizes by the term massive pyrite [20, 25, 29 and 39]. Renton and Bird, 1991 [10] described this type of pyrite as irregular. Massive pyrite was found in most coal samples from Seam 1 to Seam 10. The homogeneous massive pyrite was generally porous and not compact, which is due to the inclusion of relict organic matter and clay minerals during the crystallization processes (Figs.2d and 2e).

4.2.4 Anhedral pyrite

Anhedral pyrite corresponds to pyrite forms whose shape depends on the shape of the plant debris in which they were deposited. The anhedral pyrite was divided into two types, the replacement anhedral pyrite and the infilling anhedral pyrite [25, 29], which are of late syngenetic and epigenetic origin, respectively. The anhedral pyrite in the sample from Samarinda coals was found in small amounts. Replacement anhedral pyrite was deposited in the lumens of funginite maceral (Figs.2j, 2k and 2l). The replacement anhedral pyrite was a result of mineralization of cell wall and described to originate from replacement of plant material or massive pyrite replacement of organic matter [8, 25 and 29].

4.2.5 Epigenetic pyrite in cleats and fractures

The term epigenetic pyrite in cleats and fractures is used for pyrite deposited in fractures or cleats which determine the path of solutions penetrating a coal seam. There are two types of epigenetic pyrite in cleat and fracture: infilling and replacing epigenetic pyrite. The infilling epigenetic pyrite in cleat and fracture has again been divided in two types: fracture and cleat filling [5, 8 and 25]. Epigenetic pyrite in cleats and fractures is observed in Seam 1, Seam 2, Seam 4, Seam 5, Seam 7, Seam 9 and Seam 10 (Figs.2g and 2h).

5. CONCLUSION

The predominance of mineral matter in the coals of Samarinda area is quartz, clay group minerals (kaolinite, hydargillite, illite), calcite, pyrite and feldspar and gypsum. Both epigenetic and syngenetic pyrite occurred in the Samarinda coals and their types can be classified as syngenetic bacterial framboidal pyrite, syngenetic euhedral pyrite, epigenetic massive pyrite and epigenetic pyrite in cleats and fractures. Syngenetic pyrite in this coal formed during accumulation of the peat or during early humification processes and sulphide minerals are precipitated by interaction of dissolved iron with H₂S. Since the coal seams from lower portion of the studied stratigraphic section contains higher proportion of syngenetic pyrite than the upper part, it can be said that sulphide precipitation and influence of marine conditions is more favored in the lower portion than the upper portion of the studied stratigraphic section. Epigenetic pyrite might be deposited by the aeolian and fluviatile import of iron-rich mineral and percolating water into fractures, cavities and pores within the coal seam long after initial accumulation of the peat. In case of the epigenetic pyrite and mineral content of Samarinda coals, they might originate from the erosion of Early Tertiary marine sediments of the Central Kalimantan Ridge, delivering sufficient iron and sulphate for pyrite formation under subaqueous conditions.

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REFERENCES


Figure 2 Representative photomicrographs of different types of pyrite (py) in the Samarinda coal (a) preservation of framboidal pyrite aggregates showing the independence nature of separate globules under microscope (b) the same view under SEM (c) close up view of framboidal pyrite under SEM (d) massive pyrite under oil immersion (e) massive pyrite under SEM (f) euhedral pyrite under oil immersion (g) replacing epigenetic pyrite in cleats/fractures (h) replacing epigenetic pyrite under SEM (i) massive pyrite under oil immersion (j) replacement anhedral pyrite deposited in the lumens of funginite maceral (k) the same view under SEM (l) close up view of replacement anhedral pyrite deposited in the lumens of funginite maceral.

Figure 3 Typical XRD profile of LTA from (a) seam 1, (b) seam 4, (c) seam 6 and (d) seam 9 reveals the predominance of quartz and clay minerals.