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GEOLOGIC FACTORS CONTROLLING MINERAL CONTENT IN SELECTED TERTIARY COALS - SOUTHERN KALIMANTAN

Binarko Santoso
R&D Centre for Mineral and Coal Technology
Jalan Jenderal Sudirman 623 Bandung 40211
Ph. 022-6030483, fax. 022-6003373,
e-mail: binarkos@tekmira.esdm.go.id

ABSTRACT

Geologic aspects, particularly geologic history and depositional environment, have a main role in the distribution of mineral matter in association with maceral composition in coal. The Asem-Asem coals include Miocene and Eocene coals, which are associated with clay minerals, quartz, pyrite and carbonate. The average mean mineral content of the Miocene coals (3.9%) is lower than that of the Eocene coals (6.7%). This indicates that the lower content reflects the balance of the subsidence rate and the peat accumulation rate during the Miocene was absolutely different from those during the Eocene. Consequently, this influenced the mineral input to the respective peats. The lower mineral content of the Miocene coals is associated with the bright lithotypes or the vitrinite-rich coals. Otherwise, the higher one of the Eocene coals is associated with dull lithotypes or the vitrinite-poor coals.

Methods applied in this study include optical microscopy (reflected-white light and fluorescence mode), X-ray diffraction and scanning electron microscopy (SEM).

Clay minerals dominated by kaolinite were deposited in a fresh water environment during peat formation. Most of the minerals are syngenetic in origin. However, some of them are considered to be epigenetic (these clays are in fissures). Quartz is mostly syngenetic, although epigenetic quartz is present. Pyrite takes place as grains and a replacement mineral in organic matter. Calcite is mostly epigenetic occurring in fractures and fissures.

Keywords: syngenetic and epigenetic minerals, geologic factors, maceral, Asem-Asem coal

INTRODUCTION

Inorganic constituents of coals include either inherent or adventitious mineral matter (Clymo, 1987). The inherent mineral matter is commonly applied to inorganic constituents that are derived from the original plant material. For the small grain sizes, identification of the mineral matter is mostly only possible by scanning electron microscopy (SEM) with magnification of >800x and chemical analysis rather than optical methods with magnification of approximately 300x, which is for the big grain ones. The adventitious mineral matter is commonly subdivided into primary (syngenetic) and secondary (epigenetic) mineral matter. The syngenetic mineral matter is formed as the peat is being deposited during early coalification. It is commonly of smaller grain size than the epigenetic mineral matter, and is intimately dispersed throughout the coal. By contrast, the epigenetic mineral matter is incorporated into the coal at a later stage, after compaction or partial consolidation. It normally fills fractures, cleats and cavities or pseudomorphs primary minerals.

The origin of particular minerals can be inferred from texture, grain shape, morphology and composition in some samples. In this study, it has been found the association of mineral matter with particular macerals.

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Based on modes of occurrence, mineral matter in the coals in the studied area can be grouped as follows:
- Mineral matter in clay partings, and
- Syngenetic (primary) and epigenetic (secondary) minerals in coal plies.

Mineral matter in clay partings constitutes a significant proportion of the mineral content of the coal. Most of the coal seams have clay partings of varying thickness ranging from a few mm up to 10 cm. The partings occur in any part of the coal seam, but most commonly in the middle or upper parts and only rarely near the base.

Syngenetic and epigenetic minerals in the coal plies are typically finely-divided mineral matter and represent sediment or wind-blown dust that was deposited with the original plant material, inorganic constituents of plants and mineral matter later introduced during coalification by percolating water. Silicate minerals such as quartz and clay minerals are generally syngenetic, whereas carbonates are generally epigenetic.

The aim of this study is mainly to identify and quantify mineral matter in association with macerals according to its geologic factors.

GEOLOGIC SETTING

The origin of the Tertiary basins in association with coal deposits in Kalimantan, particularly those along the east coast of this island is as a result of tectonic activities (Katili, 1989; Witts, 2008). The basins include Tarakan, Kutai, Barito and Asem-Asem, distributing from north to south respectively. They initially developed as a single large depocentre during Early Tertiary, then becoming separated by uplift zones in the later stages of basin development during the Late Miocene orogenic activity (Sikumbang, 1986). They are cratonic and back-arc basins, which are associated with the Tertiary southeast-directed subduction zone in northwest Kalimantan (no longer active), and which developed in the east Kalimantan and the adjacent Makassar Strait.

The studied area is focused in the Asem-Asem Basin, Southern Kalimantan (Darman and Sidi, 2000; **Figure 1**). The basin, which was previously called the Pasir Sub-basin of the larger Kutai and Barito Basins, is separated from the Barito Basin to the west; the Paternoster Platform and the Laut High in the east; and the South Kutai Boundary Fault (the Paternoster High) in the north.

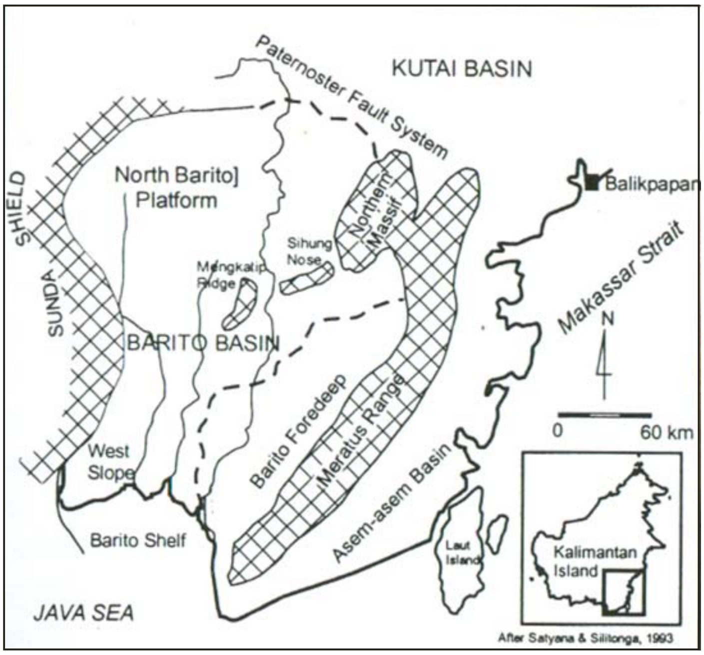

Figure 1. Locality map of the studied area (modified from Darman and Sidi, 2000)

Davis, Noon and Harrington (2007) stated that the Tertiary sedimentation in the Asem-Asem Basin was completed as a single major transgressive-regressive cycle, interrupted only by minor local subcycles and variations. The transgressive nature of the Eocene Tanjung Formation that blankets the basement and has a fairly low relief was deposited in a shallow marine to deltaic environment. It comprises a sequence of coarse clastic rocks interbedded with shale and rare coal beds. The marine influence increased throughout the Oligocene and into Early Miocene time, resulting in deposition of the extensive limestone and marl deposits of the Berai Formation.

The centre of the Asem-Asem Basin subsided rapidly, whereas the continental core (to the west) and the Meratus High (in the east) were uplifted. The strata belong to the Warukin and Dahor Formations, which represent paralic and deltaic sequences, were on the highs.

Orogenic activity in the Plio-Pleistocene resulted in a strong westward movement of the Meratus High, which folded and thrust the basin fill into a series of tight anticlines that were, in part, controlled by basement features (Siregar and Sunaryo, 1980).

PT. Arutmin Indonesia (1986) recognised 3 units in the Tanjung Formation. The oldest unit comprised basal sandstone, pebble conglomerate, beds of massive red claystone and mudstone and coarse-medium grained quartz-lithic sandstone with large scale cross-bedding. The second unit, referred to as the Eocene coal measures, contains coal seams interbedded with laminated sequences of fine-grained sandstone, siltstone and shale. The third unit is a marine Eocene unit of marl, mudstone and clayey sandstone with minor thin limestone beds towards the top.

The overlying Berai Formation (Oligocene-Early Miocene age) consists of a thick sequence of limestone, marl and fine-grained clastic strata. This is a time equivalent unit of the Pamaluan Formation in the Kutai Basin. The Berai Formation includes claystone, marl and thin limestone beds.

The overlaying marine Berai was succeeded by the Warukin Formation (Middle Miocene) that was deposited during a regressive phase of the Tertiary transgressive-regressive cycle. This unit comprises soft, fine-grained clastic rocks with siltstone, sandstone and coal seams up to 40 metres thick. The Dahor Formation (Pliocene-Pleistocene) consists of poorly-consolidated sandstone and minor fine-grained clastic sequences with coal seams. Quaternary deposits include alluvium, estuarine muds and coastal sands.

METHODS

Three analytical methods were employed to identify and quantify mineral matter in the samples as follows:

- Optical microscopy both reflected white and fluorescence mode was used to identify and point count the mineral matter in coal samples.
- X-ray diffraction techniques were used to identify the minerals in clay partings and shaly coals.
- Scanning electron microscopy (SEM) was used to observe the small grain size and the morphological and textural features of the minerals.

Optical methods are very useful for describing the types and occurrence of mineral matter in coals. Information can be gathered on various mineral types and mineral-maceral association. The normal point count method was used to determine the mineral abundances. Minerals were identified by properties such as morphology, reflectance and anisotropy. The mineral under the point of the cross hair was examined under reflected white light and fluorescence mode as some minerals (carbonate and some clay minerals) fluoresce with reasonably distinctive colours and intensities. Mineral content is expressed as the percentage by volume of the whole rock. In this study, three main minerals were identified:

- silicates (clay minerals and quartz).
- sulphides (predominantly pyrite).
- carbonates (mainly calcite).

In SEM techniques, both secondary electron (SE) and backscattered electron (BS) images were employed. The BS mode is the most useful procedure for identifying minerals in the coal as the response of the beam to density is more accurate. The SE mode is the best to determine relief or morphology of either macerals or mineral matter in coals. Mineral matter shows the brighter phase, followed by inertinite, vitrinite and liptinite.

RESULTS

Coal measures sequences in the Asem-Asem Basin occur in the Eocene Tanjung Formation and in the Miocene-Pliocene Warukin Formation. The coal-bearing sequences, which have a total thickness of approximately 615 metres (PT. Arutmin Indonesia, 1986), consist predominantly of shale, mudstone, sandstone and limestone. The thickness of the seams ranges from 4 m to 9 m with an average of 5.9 m. dips vary from 5º to 15º at outcrop. Koesoemadinata *et al.* (1978) stated that the Eocene coals in the Tanjung Formation were formed in intramontane basins as were other Palaeogene coals in Indonesian basins. Additionally, Panggabean (1991) suggested that those coals were deposited in low-lying back swamps adjacent to a meandering river system (for the lower seam) and in low-lying swamps and marshes associated with filled interdistributary bay sequences in a lower delta plain setting (for the upper seam). The Miocene-Pliocene coals of the Warukin Formation range from 1 m to 40 m. These coals were probably deposited as raised swamps (Koesoemadinata *et al.*, 1978). Exposures of the Miocene coals cropping out along the Asem-Asem River indicate that it is a clean coal with only a few dirt bands, and thus supporting a raised swamp for peat development.

Economic Miocene coal deposits in the Tanjung area in the Warukin Formation that is a sequence of 400-450 m thick comprising sandstone, siltstone, claystone and coal. Up to 11 seams have been identified with the thickness of 2-10 m and dips of 30º towards the west. Thin Eocene seams, typically <1 m thick, are also present in this area. Examination of hand specimens shows that the coals are composed mainly of bright banded and bright lithotypes. Thick bright lithotype is normally interbedded finely-striated bands of bright banded lithotype. Dull lithotype is not common in any of the coals. The maceral and mineral matter data for each of the 34 coal samples analysed are listed in **Table 1**. In general, organic petrological examination of the coals shows that all samples contain dominantly vitrinite, sparse to major liptinite, rare inertinite and sparse to major mineral matter.

Table 1. Petrographic data of the coals

No.	V (%)	I (%)	L (%)	CL+Q	MM			Rvmax (%)
					CA	PY	Tot	
1	80.7	2.4	12.3	4.2	0.2	0.2	4.6	0.28-0.39
2	94.1	1.6	0.8	3.4	-	0.1	3.5	0.29-0.43
3	77.7	1.8	11.3	8.6	-	0.6	9.2	0.29-0.40
4	89.9	2.1	3.6	4.2	0.2	-	4.4	0.31-0.41
5	75.8	7	11.9	5.3	-	-	5.3	0.30-0.40
6	91.8	1.2	3.4	3.6	-	-	3.6	0.29-0.36
7	92.1	4.9	1.9	1.1	-	-	1.1	0.30-0.44
8	90.7	2.4	2	4.3	0.2	0.4	4.9	0.25-0.39
9	81.9	8.3	7.5	2.3	-	-	2.3	0.28-0.45
10	83.4	0.8	9.7	5.9	-	0.2	6.1	0.31-0.41
11	75.9	6.6	15.2	2.3	-	-	2.3	0.32-0.42
12	78.3	0.9	15	5.8	-	-	5.8	0.26-0.35
13	44.9	2.7	6.7	45.7	-	-	45.7	0.31-0.42
14	80.4	0.7	12.2	6.7	-	-	6.7	0.28-0.39
15	85	3.2	7	4.8	-	-	4.8	0.31-0.41
16	69.3	9.9	17.3	3.5	-	-	3.5	0.30-0.42
17	82.5	3.9	11.1	2.2	0.1	0.2	2.5	0.32-0.39
18	86.7	3.8	6.1	3.4	-	-	3.4	0.31-0.39
19	76.2	9.5	10.6	3.7	-	-	3.7	0.31-0.44
20	65.5	4.1	10.3	16.1	-	4	20.1	0.33-0.41
21	94.2	1.9	1.2	2.5	-	0.2	2.7	0.30-0.39
22	74.8	3.5	19.6	1.6	-	0.5	2.1	0.30-0.40
23	75.5	2.5	19.3	2.5	-	0.2	2.7	0.29-0.40

Table 1. Petrographic data of the coals (continued)

No.	V (%)	I (%)	L (%)	CL+Q	MM			Rvmax (%)
					CA	PY	Tot	
24	93.7	1.3	3.2	1.8	-	-	1.8	0.30-0.40
25	86.4	1.5	10.7	1.4	-	-	1.4	0.35-0.44
26	78.7	1.4	17.5	2.2	-	0.2	2.4	0.38-0.46
27	86.3	1.9	10.4	1.4	-	-	1.4	0.30-0.38
28	85.3	7.6	4.2	2.5	0.2	0.2	2.9	0.31-0.40
29	63.5	3.5	30.9	1.9	-	0.2	2.1	0.29-0.43
30	92.4	0.2	4	2.8	0.2	0.4	3.4	0.32-0.42
31	85.1	1.6	12.2	1.1	-	-	1.1	0.32-0.43
32	76.1	4.1	17.4	2.2	-	0.2	2.4	0.30-0.41
33	75.3	4.2	17.7	2.6	-	0.2	2.8	0.32-0.40
34	81.3	3.2	14	0.8	-	0.7	1.5	0.34-0.44

Notes : V-vitrinite; I-inertinite; L-liptinite; MM-mineral matter; CL-clay; Q-quartz; CA-carbonate; PY-pyrite; Tot-total

Petrographically, the Miocene Asem-Asem coals are composed mainly of vitrinite with substantial liptinite and inertinite. Mineral matter, mainly clay minerals (**Figure 2a** and **2b**), quartz, pyrite (**Figures 3a** and **3b**) and carbonate (**Figures 4a** and **4b**), is sparse to major.

As for the Miocene coals, Eocene coals are typically rich in vitrinite with abundant liptinite. Inertinite constitutes only a minor component of the coals. Mineral matter (mainly clay minerals, quartz and pyrite) is present substantial amounts in the coals. Mean maximum vitrinite reflectance values (Rvmax) for both Miocene and Eocene coals are between 0.25% and 0.46% with average of 0.36%. These values indicate brown coal to subbituminous rank.

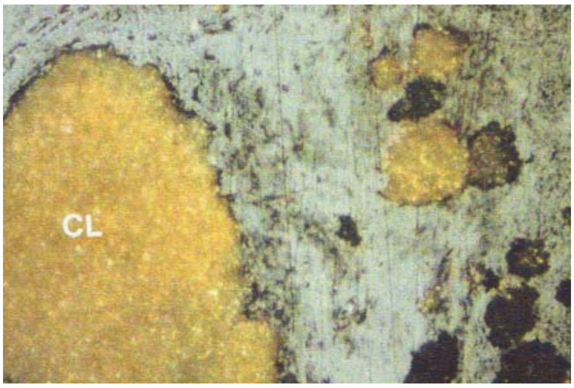

Figure 2a. Disseminated lenses of clay minerals (yellow, CL) in vitrinite (grey). Rvmax=0.42%, field width 0.32 mm, reflected white light

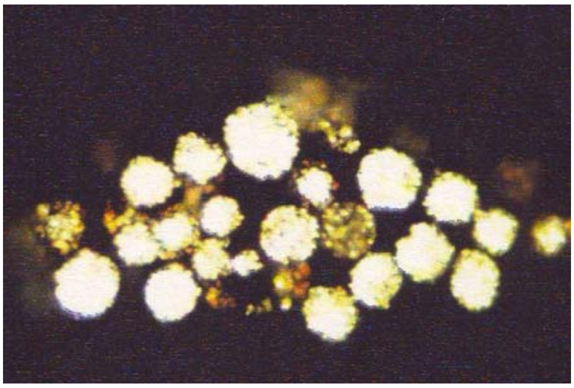

Figure 2b. Layers and lenses of clay minerals (black, CL) in vitrinite. Rvmax=0.63%, field width 0.36 mm, reflected white light

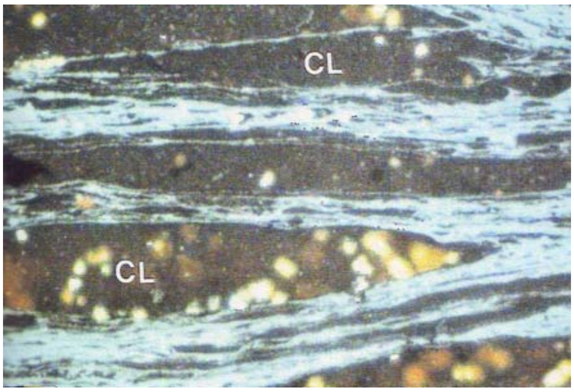

Figure 3a. Framboidal pyrite. Rvmax=0.47%, field width 0.20 mm, fluorescence mode

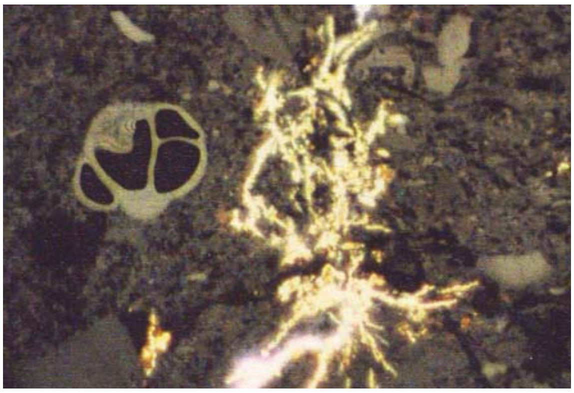

Figure 3b. Veins of pyrite in vitrinite. Rvmax=0.51%, field width 0.15 mm, reflected white light

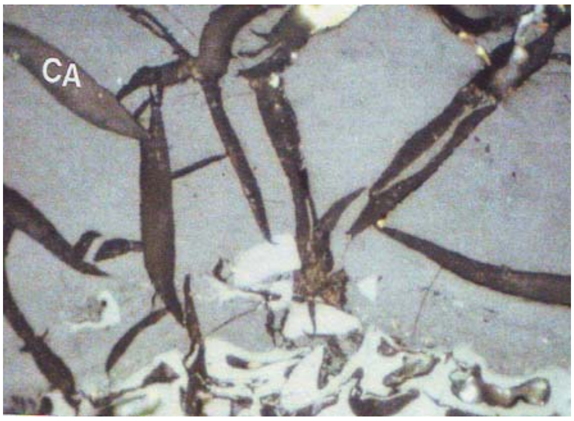

Figure 4a. Carbonate (black, CA) infilling fractures in vitrinite (grey). Rvmax=0.64%, field width 0.26 mm, reflected white light

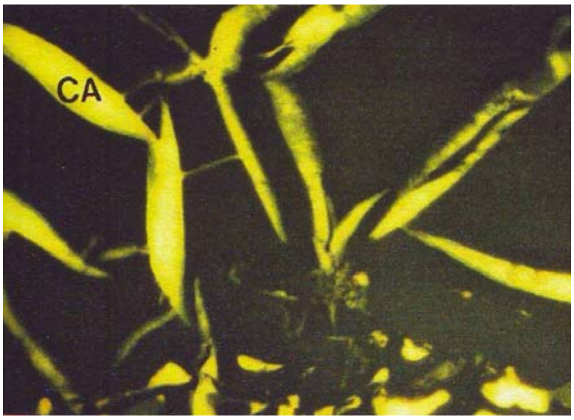

Figure 4b. As for Figure 4a, but in fluorescence mode

DISCUSSION

The distribution of mineral matter in coal depends on its geologic history and the environment of the peat mires. These factors as the surrounding geologic setting and the nature of the ground water are a great influence on the proportion of mineral matter added to a peat swamp.

The average mean mineral matter content of Eocene coals (average of 6.7%) is higher than that of the Miocene coals (average of 3.9%). The low mineral matter in some of the Miocene coals indicates that the balance between the rate of subsidence and the rate of accumulation of peat during the Miocene age was significantly different from those during the Eocene age, and this phenomenon influenced the mineral input to the respective peats.

Clay minerals and quartz (silicates) are the most common mineral components in the coals, although a small proportion of coals contain relatively high proportion of pyrite and calcite. Clay minerals, quartz, pyrite and carbonates show a preferential association with vitrinite as it is the most susceptible maceral for replacement (Stach *et al.,* 1982). Kaolinite is the dominant clay mineral in clay partings in the seams, although sericite, illite, montmorillonite and halloysite are also present. The kaolinite in Tertiary brown coals is detrital or allochthonous origin as well derived from pre-diagenetic transformation of K-rich clay minerals in the original peat swamp (Miller and Given, 1978).

Pyrite, particularly framboidal pyrite, is most abundant in coal seams, which are directly overlain by marine strata (Lyons, Whelan and Dulong, 1989). For this reason, pyrite is thought to develop mainly in areas where a marine or brackish environment transgressed the swamp shortly after peat accumulation. However, this is not the mode of pyrite formation in most of the coals, because there is no evidence of a marine succession directly above the coal seams. It is postulated that vitrinite formed where the water table and pH of peat environments were high and Eh was low. Otherwise, inertinite precursors formed where the water table was lower and the Eh was higher.

Vitrinite-rich coals generally have lower mineral contents than vitrinite-poor ones. Furthermore, the data suggest a wide range of mineral abundances for the high-vitrinite coals. Correspondingly, inertinite-rich coals have higher mineral contents compared to inertinite-poor ones.

Depositional conditions influence both lithotype and mineral composition of coals. The Miocene coals contain fewer clay partings than the Eocene coals and tend to be characterised by bright lithotypes with abundant vitrinite and low mineral contents. This is interpreted as indicating variations in subsidence rates with rapid burial of plant material encouraging preservation of the organic matter and producing coals rich in vitrinite with fewer clay partings.

CONCLUSION AND SUGGESTION

Conclusion

The Asem-Asem vitrinite-rich coals that show bright lithotypes contain lower mineral contents. Otherwise, the vitrinite-poor coals indicate higher mineral contents. Accordingly, the inertinite-rich coals have higher mineral contents as compared to inertinite-poor coals. The Miocene coals contain fewer clay partings than the Eocene coals, and are characterised by bright lithotypes with major vitrinite. This is an indication of variations in subsidence rates and rapid burial of plant materials causing vitrinite-rich coals with lower clay mineral contents. In addition, the low mineral content is a function of the environment of deposition of the peat.

The Asem-Asem coals contain predominantly clay minerals, quartz, pyrite and carbonate. These mineral contents are much higher in the Eocene coals rather than in the Miocene coals.

The presence of kaolinite in the coals indicates a freshwater environment during peat formation. Only a small proportion of the clay minerals are considered to be epigenetic in origin in which these clays are in veins.

Quartz, the second most abundant mineral, is mostly syngenetic, although epigenetic quartz is present. Detrital quartz was introduced into the peat mire as overbank deposits from streams or by wind action.

Pyrite occurs mostly as grains, framboids, massive nodules, veins and a replacement mineral in organic matter. Calcite is mostly epigenetic, occurring in fractures and fissures.

Suggestion

From a utilisation viewpoint, the most important feature of the coals is the relatively low mineral contents, especially pyrite, which suggests that the coals will have a ready market both for domestic use and for export, when production is increased in the prospective future.

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