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Permian Mengkarang coal facies and environment, based on organic petrology study

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ABSTRACT

The Permian Mengkarang Coal Measures is situated in the middle part of Sumatera Island. Some fresh outcrop samples of the Permian Mengkarang coals have been analyzed both macroscopically and microscopically, to asses their depositional environment. On the basis of organic-petrological analysis, the coal seams show variation in the predominance of some macerals, indicating successions of environmental changes. The dominant maceral group is vitrinite, present in very low to very high values; whilst the minor one is inertinite showing low amount. Environmental information derived from the organic facies study shows that the coals were deposited in wet zone of mire, ranges from wet limnic-telmatic zone to telmatic wet forest swamp under rapid burial condition, due to rapid basin subsidence. The organic facies concept is thus applicable in basin studies context and has potential to become an additional tool for interpretation of depositional environment.

Keywords: Permian Mengkarang Coal Measures, maceral, organic petrology, facies and environment

SARI

Formasi Mengkarang pembawa-batubara yang berumur Perem terletak di Sumatera bagian tengah. Untuk menganalisis lingkungan pengendapannya, sejumlah percontoh batubara dari formasi ini telah dianalisis secara megaskopik dan mikroskopik. Analisis petrologi terhadap batubara tersebut menunjukkan bahwa maseral yang terkandung jumlahnya bervariasi, dan hal ini mengindikasikan adanya variasi perubahan lingkungan. Kelompok maseral vitrinit hadir dominan, dengan kisaran kandungan sangat rendah sampai sangat tinggi, sementara inertinit hanya muncul sedikit. Berdasarkan kajian fasies organik, batubara terendapkan di lingkungan zone basah, yakni kawasan "wet limnic-telmatic" sampai "telmatic wet forest swamp" dalam kondisi penimbunan yang cepat, akibat adanya penurunan cekungan yang cepat. Konsep fasies organik ini dapat diterapkan dalam konteks kajian cekungan, dan merupakan salah satu parameter untuk penafsiran lingkungan pengendapan.

***Kata kunci**: Formasi Mengkarang pembawa-batubara, Perem, maseral, petrologi organik, fasies dan lingkungan*

INTRODUCTION

During 1979–1996, as part of geological mappings of 1:250.000 (Suwarna *et al*., 1992) and 1:100.000 in-scales (Suwarna *et al*., 1998), the region of Mengkarang - Merangin, Bangko Area, was studied. More actual data, leading to a better understanding on stratigraphy and coal geology of the Permian Mengkarang Coal Measures (Formation), were revealed from a stratigraphy and sedimentology research on pre-Tertiary rocks of southern Sumatera, carried out in 1997 (Suwarna and Suminto, 1999).

The aim of the study is to interpret the Mengkarang coal depositional environment. The coal maceral composition obtained is typically based on the coal petrology conducted on several coal hand-samples of selected fresh outcrops and subcrops of a part of sections the Permian Mengkarang Coal Measures.

Geologic field investigations and laboratory techniques were used to achieve the aims of the study. Coal lithotype analysis is the primary megascopic fieldwork activity, supported by stratigraphic observations. Then, collection of the other geologic field data and coal samples for organic petrographic analysis purposes were performed.

Methods and Techniques

In terms of brightness or lithotype, the coals were determined macroscopically. The main coal lithotype, basically, can be divided into bright (vitrinite-rich) and dull (vitrinite-poor) components. Usually, the macroscopic features can predict the microscopic constituents of coals, once a correlation between the two has been established. Moreover, in general, coal type can be determined from the macroscopic and microscopic observations. The appearance or coal lithotype, however, can be changed due to the existence of finely disseminated mineral matter, such as “dull” coals which are rich in vitrinite content. Therefore, significant data are required for a reliable correlation between macroscopic and microscopic determinations.

The laboratory technique, performed in organic petrology mode, is important to have a better understanding of the maceral and mineral matter contents. The Permian Mengkarang coal palaeoenvironmental interpretation can be assumed by considering the data obtained from laboratory analyses supported by the field observation. Interpretations of organic facies are based on semi-quantitative organic petrological examinations of selected polished coal briquettes.

Petrographic analysis required for the study was focused on maceral determination. The samples were prepared as polished briquettes by using Australian Standard procedures (Australian Standards 2061 and 2856, 1986). The polished briquettes were prepared from crushed 1 mm-size samples representing each sample, which then mounted in epoxy resin.

Maceral composition of the coals is gained from semi-quantitative organic petrological examinations of polished coal briquettes. The analysis determines quantitatively the volume of organically derived, microscopically recognizable substances of coal, which are defined by their morphology and colour. The methods used for estimation of organic matter abundance and maceral composition are outlined in Cook & Kantsler (1982), Sappal (1986), and Struckmeyer & Felton (1990).

The analysis based on 500 counts on each sample (including mineral matter) under reflected white light, was performed microscopically on polished briquette sections. Ordinary white reflected light from a tungsten lamp and violet-blue light from a high-pressure mercury lamp to initiate fluorescence were used for illumination. Maceral observation was carried out on a Leitz MPV-2 photomicroscope.

Most macerals determined are defined by the International Committee for Coal Petrology (I.C.C.P., 1963 and 1971). Brown *et al.* (1964) introduced vitrinite-A and B terms used as convenient ones to separate the structured vitrinite macerals from the unstructured or degraded vitrinites. Macerals telinite, telocollinite, and in-situ corpocollinite are included into vitrinite-A sub-group; whereas vitrinite-B includes desmocollinite, gelocollinite, and detrital corpocollinite.

Geographical and Geological Settings

The study area, geographically bounded by latitudes 2°07’ - 2°13’ S and longitudes 102°08’ - 102°12’ E (Figure 1), is located along and around the Mengkarang and Merangin Rivers. It falls, administratively, under the Merangin Regency of the Jambi Province.

Geologically, the study area is occupied by the Permian sediments and volcanics intruded by the Triassic-Jurassic granitic rocks (Figure 1). Quaternary sediments are also present in the area. The Permian rocks comprising the Mengkarang, Telukwang, and Palepat Formations, interfinger one to another (Suwarna *et al*., 1998). The Mengkarang Coal Measures, having thickness up to 1,000 m, tend to be distributed in WNW - ESE direction (Figure 1). The presence of *Cathaysian* flora and brachiopod with fusulinid contents, supported by the evidence that the coal measures are intruded by the Triassic granite, indicates an Early to Middle Permian age.

The Merangin and Mengkarang Rivers are occupied by a major structural element trending WNW-ESE nearly parallel to the strike of the rock (Figure 1). The southernmost fault, presumed to be a suturing (tectonic) contact, is present as a geological contact between the Mengkarang Formation and northern portion of the Peneta Formation of the Asai - Rawas Group. The formation is low to moderately deformed, shown by the presence of bedding which is still well-preserved.

Petrography of Coal

Organic constituents of coal in coal petrography are described in terms of lithotypes and macerals, according to the International Classification of Coal (ICCP, 1963 and 1971; 1975). The petrographic determination of the Mengkarang coals is established on ten fresh outcrop and subcrop samples of Mn05A1, Mn05A2, Mn05B1, Mn05B2, Mn06-1, Mn06-2, Mn08-1, Mn08-2, Mn09-1, and Mn09-2.

Detailed discussion on the petrographic data related to the interpretation of coal depositional environment is gained mainly from maceral analysis, presented as follows:

Lithotypes

The coal was logged in terms of general lithotypes. Detailed macroscopic examination of the coal samples from the Mengkarang Coal Measures displays that on the basis of Diessel's terminology (1965); the coals are finely-thick banded to massive and are composed of bright to banded types with minor dull one.

Macerals

Maceral composition of the Permian Mengkarang coals identified in reflected light and fluorescence modes is discussed within the paper. The coals analyzed were collected from the Merangin and Mengkarang River areas, where the fresh outcrops and subcrops are situated.

Maceral and mineral matter analyses in the coal were conducted to establish the maceral types and distribution. Results of the proportions of maceral and mineral matter in the individual coals are presented in Table 1, whilst Table 2 shows the ratio of specific maceral combinations (measure of petrographic indices of TPI-Tissue Preservation Index and GI-Gelification Index) of the Mengkarang Formation.

The data presented in Table 1 indicate that the Mengkarang coals, predominantly, have consistently high proportions of vitrinite, with minor low amounts;

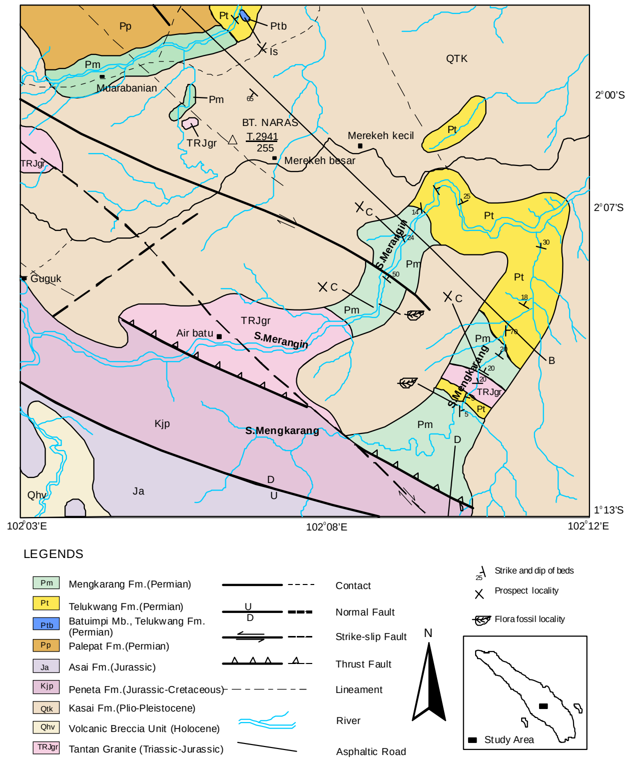

FIGURE 1. GEOLOGICAL (SUWARNA *ET AL.*, 1992 & 1998) AND LOCALITY MAP OF THE STUDY AREA.

a low inertinite constituent; and dominant high mineral matter content, with minor low to medium ones.

A remarkable regular maceral and mineral matter contents of the coals studied is recognized. "Brightness" in coal is attributable to structured vitrinites, whilst "dullness" is due to the relatively high content of non-structured vitrinite and/or mineral matter.

Vitrinite Group

The vitrinite content is, six samples (Mn05A1, Mn05A2, Mn08-1, Mn08-2, Mn09-1, and Mn09-2), high varying from 77.4 to 93.0%, whilst four samples (Mn05 B1, Mn05 B2, Mn06-1, and Mn06-2) show low amounts of 10.8 and 25.4% (Table 1). Within samples of Mn05A2, Mn08-1, Mn08-2, Mn09-1, and Mn09-2, telovitrinite (vitrinite A) predominates vitrinite group; whilst the sample Mn 05A1 is occupied by a relatively quite similar vitrinite A (telovitrinite) and vitrinite B (detrovitrinite and gelovitrinite). However, samples of Mn05 B1, Mn05 B2, Mn06-1, and Mn06-2, are dominated by vitrinite B, with minor vitrinite A.

TABLE 1. PETROGRAPHIC ANALYSIS DATA OF THE MENGKARANG COAL

No.	Sample No. (*Coal*)	Telovitrinite %	Detrovitrinite %	Gelovitrinite %	**Vitrinite** %	Fusinite %	Semifusinite %	Micrinite %	Sclerotinite %	Inertodetrinite %	**Inertinite** %
1	Mn 05 A1	41.8	49.8	0.4	93.0	0.4	-	-	0.2	1.8	3.0
2	Mn 05 A2	64.2	23.4	0.6	88.2	2.4	0.8	0.2	-	1.0	4.4
3	Mn 05 B1	4.2	20.4	0.8	25.4	1.2	0.6	0.4	0.2	1.2	3.6
4	Mn 05 B2	0.8	10.0	-	10.8	0.6	1.0	-	0.2	0.4	2.2
5	Mn 06-1	6.2	23.4	0.6	30.2	1.0	0.6	-	0.2	1.4	3.2
6	Mn 06-2	2.8	11.4	0.2	14.4	0.8	0.4	-	0.2	1.0	2.4
7	Mn 08-1	50.6	26.8	0.2	77.6	0.6	0.2	0.2	-	1.4	2.4
8	Mn 08-2	48.4	29.0	-	77.4	1.4	0.8	-	0.2	0.2	2.6
9	Mn 09-1	50.8	27.0	0.4	78.2	0.6	0.4	0.2	0.2	1.0	2.4
10	Mn 09-2	51.2	26.4	0.2	77.8	0.8	0.6	-	0.2	1.2	2.8

Remarks: - absent

TABLE 2. TISSUE PRESERVATION INDEX (TPI) AND GELIFICATION INDEX (GI) OF THE MENGKARANG COALS USED AS DEPOSITIONAL ENVIRONMENT PARAMETERS

No.	Sample No.	TPI	GI
1	Mn 05 A1	0.81	38.75
2	Mn 05 A2	2.63	21.00
3	Mn 05 B1	0.26	8.06
4	Mn 05 B2	0.23	4.91
5	Mn 06-1	0.31	9.44
6	Mn 06-2	0.32	6.00
7	Mn 08-1	1.83	35.36
8	Mn 08-2	1.72	29.76
9	Mn 09-1	1.82	32.58
10	Mn 09-2	1.89	27.78

A reasonable degree of preservation of decayed plant material present is indicated by the high vitrinite content in most of the coal samples. The vitrinite could be used as a measure of petrographic indices (Table 2) to interpret a peat depositional environment.

Inertinite Group

The inertinite macerals almost do not exceed 4.0%, except the sample Mn05A2 having amount of 4.4% (Table 1). The inertinite maceral group identified comprises fusinite, inertodetrinite, semifusinite, sclerotinite, and micrinite. In interpreting the coal-precursor palaeoenvironment, the inertinite maceral group could be also used as a measure of petrographic indices (Table 2).

DISCUSSIONS

Coal Facies Analysis

A 'habitat in which organic material, especially peat is accumulated' is termed as a 'mire' ('moor') (McCabe, 1987; Moore, 1987 and 1989). The 'topogenic' or 'low moors' are environments of the peat or coal formation, generally slowly sinking depressions, where mineral input is nil or very small, and in which the groundwater table can keep abreast of peat formation. However, 'ombrogeneous mires' or 'high moors' including 'raised bogs' and 'blanket bogs', which may form above the groundwater table, are only present in areas of very high rainfall.

Diessel (1982, 1986, and 1992), Harvey and Dillon (1985), and Cohen *et al*. (1987), who have independently investigated the application of macerals in coal facies analysis, created a new trend of coal facies studies based on organic matter petrology. Basically, the macerals comprise three main groups; those are vitrinite, inertinite, and exinite. Vitrinite maceral group is derived mainly from humified "woody" plant remains; whereas inertinite represents oxidized and degraded plant remains, has the same origin as vitrinite.

On the basis of maceral grouping mentioned above, discussion of coal facies analysis is performed. Diagnostic macerals as palaeoenvironmental indicators are compared to the remaining macerals. Telinite, telocollinite, semifusinite, fusinite, inertodetrinite, alginite, and sporinite are used as facies diagnostic macerals. Telinite and telocollinite, formed in a relatively high moisture conditions, are derived from partially gelified woody tissues. On the other hand, the structured inertinite (semifusinite and fusinite) were derived from woody vegetation, but under relatively dry oxidizing conditions. However, inertodetrinite, also having the same origin as semifusinite and fusinite, is originated from the disintegration of structured inertinites.

The abundance of vitrinite in the coal indicates that the coal originated in a wet forest swamp environment (Teichmüller and Teichmüller, 1982; Bustin *et al*., 1983), mainly from arborescent vegetation (Rimmer and Davis, 1988). A greater degree of degradation of woody tissue, mainly influenced by the type of vegetation, depth of water, pH, bacterial activity, and temperature of peat (Teichmüller and Teichmüller, 1982; Stout and Spackman, 1989; Shearer and Moore, 1994) or mixed environmental conditions across the peat swamp (Marchioni and Kalkreuth, 1991) may be resulted in the high content of degraded vitrinite.

An environmental model, based on the ratio of specific maceral combinations, was demonstrated by Diessel (1986). On the basis of Tissue Preservation Index (**TPI**) and Gelification Index (**GI**), the ratio can be used to determine particular peat-forming environments. The ratio is formulated as follows:

GI = (Vitrinite + Macrinite) / (Semifusinite + Fusinite + Inertodetrinite)

TPI= (Vitrinite A + Semifusinite + Fusinite) / (Vitrinite B + Macrinite + Inertodetrinite).

High GI (>5) and TPI (>1) values indicate a wet condition of peat formation, whereas low GI (<5) and TPI (<1) show a dry condition (Diessel, 1986 and 1992). Thereby, GI plays an important role in representing influence of groundwater, whereas the type of plant input is indicated by the TPI value. Moreover, Lamberson *et al.* (1991) explained that the high GI and TPI values in which the content of vitrinite > inertinite and structured vitrinite > degraded vitrinite occurred in wet forest swamp of telmatic zone with rapid burial. However, the high GI and low-moderate TPI values are due to microbial attack conducted on coal precursor that was deposited in limited influx-clastic marsh (Figure 2). The coal existing is characterized by vitrinite > inertinite, and degraded vitrinite > structured vitrinite.

In the case for coal seams low in GI and TPI values, the coal was deposited in open-marsh where a desiccation activity and "severe oxidation restricted to the formation of telinite and telocollinite, under conditions of falling water table, and even disintegration of structured inertinite to form in-situ inertodetrinite, commonly coupled with an increase in inherent ash.

Furthermore, coals deposited in wet forest swamp of upper delta plain and fluvial environments are rich in vitrinites (wet forest swamp), but also in clastic clay minerals. Generally, coals rich in vitrinite are thought to have been deposited in wet and more anoxic environments. Fluvial environment lead to coals rich in vitrinite and also rich in mineral matter, predominantly clays.

The GI - TPI combination can predict a degradation level of woody tissue structure of plant remnants. Due to the limited aerobic degradation process of cell structure, the inertinite content is very low. This condition is shown by the high GI and low TPI (Lamberson *et al*., 1991).

Palaeoenvironmental Analyses

To interpret the depositional environment of coal-precursor, petrographic indices, calculated from the diagnostic maceral compositions are used as parameters. The petrographic indices are gelification index (GI) and tissue preservation index (TPI). A depositional environment model proposed by Diessel (1986 and 1992) is used in the study.

Table 2 displays the calculated petrographic indices used in the palaeoenvironmental interpretation. The TPI values, occupying a compositional zone around 1.72–2.63 (Mn05A2, MN08-1, Mn08-2, Mn09-1, and Mn09-2), indicate that relatively well-preserved plant tissues are present in the coal. However, another five samples (Mn05A1, Mn05B1, Mn05B2, Mn06-1, and Mn06-2) show poor- to moderate-preserved plant tissues, represented by the low TPI values of 0.23–0.81. The GI, representing by value of 4.91–38.75, indicates that the coals have a low oxidation degree which is compensated by high gelification process (Lamberson *et al*., 1991). It means that the coal depositional environment is used to be wet or subaqueous.

The high GI and TPI values occurring in the Mengkarang coals (Table 2) indicate a development in a wet area, that is a marsh or lake swamp environment under anoxic conditions; whereas, high GI with variated TPI values show that the depositional environment of the coals was marsh to fen under limnotelmatic to telmatic conditions. The coal having high GI should contain plenty of vitrinite, with minor content of fusinite, semifusinite, and inertodetrinite. Vitrinite formation would be well developed if the peat (coal precursor) was always in a wet condition (Diessel, 1986; Cohen *et al*., 1987; Teichmüller, 1989); Lamberson *et al*.,1991, and Calder *et al*., 1991). There-

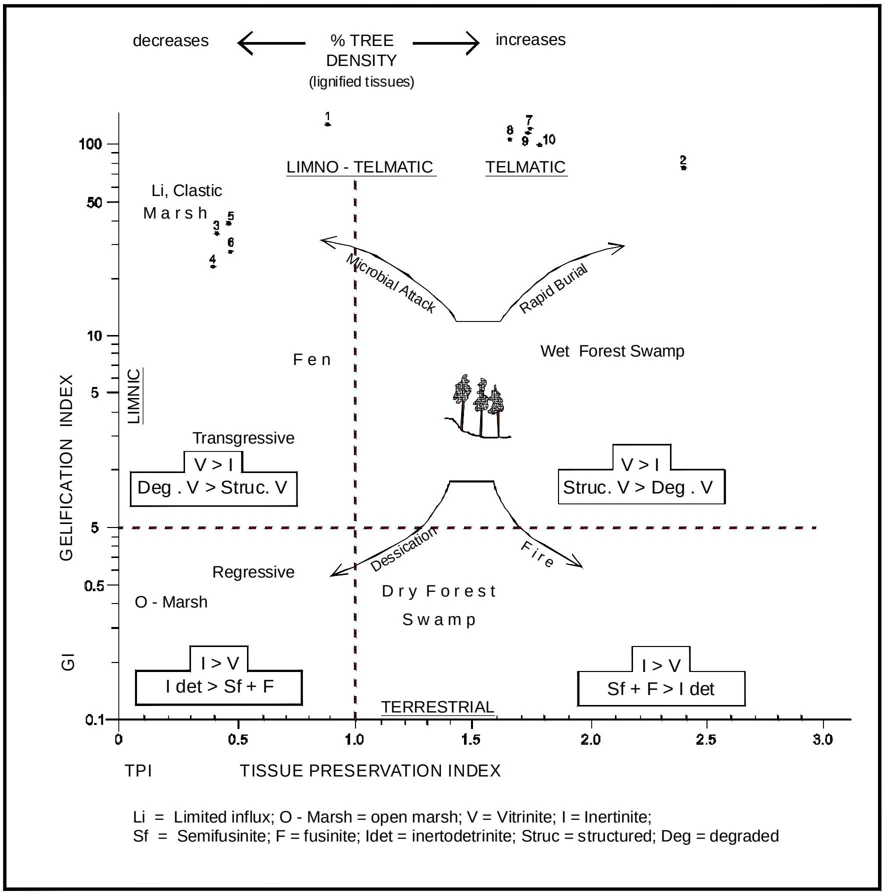

Figure 2. Coal depositional environment of the Mengkarang Coal Measures (based on Diessel's diagram, 1992).

fore, the coals studied are used to be deposited in wet zone of mire, evidenced by the high GI value.

To prevailing moor during deposition of coal precursor, using the TPI and GI values (Diessel, 1986; Lamberson *et al*., 1991; Diessel, 1992) are illustrated in Figure 2. This TPI-GI diagram, where all coal samples are located within wet area, shows that an almost stable wet phase occurred. An evidence of a stable marsh phase is displayed by samples Mn05B1, Mn06-1, and Mn06-2 which are located close together on the diagram (Figure 2). On the other hand, another four coal samples, Mn08-1, Mn08-2, Mn09-1, and Mn09-2, on the diagram also plotted close together, indicate a stable telmatic wet forest swamp.

Five coal samples (Mn08-2, Mn09-1, Mn08-1, Mn09-2, and Mn05A2) fall within telmatic of forest swamp with a rapid burial condition. However, the other five coals (Mn05B2, Mn05B1, Mn06-1, Mn06-2, and Mn05A1) occupy a limnic environment with limited influx-clastic marsh setting under a microbial attack condition. These conditions represent a relatively permanently flooded area having occurred during the Permian Mengkarang coal deposition.

Somewhat more frequent clastic influx may have been deposited during peat accumulation, resulted in a favoured preservation of vitrinite precursor as indicated by a relatively wide TPI plot varying within 0.23 to 2.63 intervals (Kalkreuth *et al*., 1991). A substantial degree of transportation process took place in the coal precursor marsh prior to final deposition of peat as indicated by the low value of TPI (Mn05A1, Mn05B1, Mn05B2, Mn06-1, and Mn06-2) (Kalkreuth and Leckie, 1989). It also reflects a predominant occurrence of shrubs and grass in coal precursor environment.

The low GI value of samples Mn05B1, Mn05B2, Mn06-1, and Mn06-2, still situated in a wet environment area, indicates that the coals developed within wet forest swamp and wet marsh depositional environments. The high GI values (samples Mn05A1, Mn05A2, Mn08-1, Mn08-2, Mn09-1, and Mn09-2), coinciding with the high vitrinite and low inertinite contents, indicate the wettest condition of the coal precursor environment, also representing a low level of aerobic decomposition with a rapid organic matter accumulation and burial (Lamberson *et al*., 1991).

The coal samples of Mn05B1, Mn05B2, Mn06-1, and Mn06-2, containing high mineral matter content were possible to develop in a marsh environment. A combination of desmocollinite (and gelovitrinite), and a little of telocollinite content, shows that the coal was originated from soft tissues of shrubs within a marsh environment.

In the case of TPI < 1, vitrinite will usually be associated with desmocollinite. Therefore, coals having TPI < 1 and GI > 1, represented by coal samples of Mn05A1, Mn05B1, Mn05B2, Mn06-1, and Mn06-2, indicate coal depositional environment of a marsh zone with limited input of clastics (Figure 2). Moreover, the values of TPI < 1 and GI > 1 are due to microbial attack conducted on coal precursor. Vitrinite > inertinite, and degraded vitrinite > structured vitrinite characterize the coal existing. These high GI and low TPI values, as well as high amounts of pyrite and another mineral matter, present in brackish coals, partly as marsh peat, are due to marine transgressions.

Based on GI and TPI value variation, three samples of the Mengkarang coals accumulated in marsh peatland from weakly to relatively strong decomposed shrub and grass tissues, under condition of microbial attack within moderate subsidence in limnic- to limno-telmatic setting, with a relatively high detrital input. However, the other three coal samples were deposited in a forested swamp (peatland) from weakly to relatively strong decomposed woody tissues, under condition of moderate to rapid subsidence in telmatic zone. These conditions are also characterized by rapid burial, and mild to strong humification with strong gelification of plant tissues, occurring in the coal mire.

In summary, based on organic facies gained from the maceral analysis, which then is supported by associated sediment characteristics, the depositional environment of the Mengkarang coal is postulated to range from wet limnic- to limno-telmatic, limited-clastic influx marsh, with microbial attack activity, to telmatic wet forest swamp under rapid burial condition.

Conclusions

The coal seams of the Permian Mengkarang Coal Measures are mainly characterized by high contents of vitrinite (77.4%-93.0%), with minor low ones (10.8% and 25.4%); whilst inertinite is present in a low quantity. However, a predominant high quantity mineral matter occurs, comprising predominant clay minerals, with low values of pyrite and carbonates.

A high amount of vitrinite, supported by low amount of inertinite, is indicative of the absence of severe oxidation/dehydration during accumulation of the peat.

A mixed moist forest swamp and reed moor facies, assumed for these coals, are consistent with the result of GI and TPI characteristics.

Organic facies, gained from the maceral analysis, tend to show that the depositional environment of the Mengkarang coal ranges from wet limnic-telmatic zone, in limited-clastic influx marsh, with microbial attack activity, to telmatic wet forest swamp under rapid burial condition.

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