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Organic petrological characteristics of limnic and paralic coals of Sarawak

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Abstract: An organic petrological study was performed on Tertiary coals from the Merit-Pila and the Mukah-Balingian coalfields of Sarawak. The main objective of this study was to determine the petrological characteristics of these coals in relation to their environment of deposition. The coals analysed were deposited in two distinct depositional settings. The Mukah-Balingian coals were deposited under paralic conditions of a lower coastal plain setting whilst the Merit-Pila coals were deposited inland under limnic condition of a lacustrine setting. Differentiation of these depositional settings are based on the presence of diagnostic macerals, such as alginite, and on cross plots of gelification index (GI) versus tissue preservation index (TPI). While both sets of coals possess TPI values < 1, the paralic origin coals generally possess GI values > 10 whilst limnic coals possess GI values < 10.

Abstrak: Suatu kajian petrologi organik dilakukan ke atas arang batu Tertiar dari Merit-Pila dan Mukah-Balingian, Sarawak. Objektif utama kajian ini ialah untuk menentukan ciri-ciri petrologi arang batu ini yang berkaitan dengan persekitaran pengenapan mereka. Arang batu yang dikaji telah dienapkan di dalam dua persekitaran pengenapan yang berbeza. Arang batu Mukah-Balingian dienapkan di bawah keadaan paralik di kawasan dataran pantai bawah sementara arang batu Merit-Pila dienapkan di kawasan daratan pendalaman di bawah keadaan limnik persekitaran lakustrin. Perbedaan di antara persekitaran pengenapan ini adalah berdasarkan kepada kehadiran maseral-maseral diagnostik seperti alginit, dan berdasarkan plot indeks gelifikasi (GI) lawan indeks pengawetan tisu (TPI). Sementara kedua-dua set arang batu ini mempunyai nilai TPI < 1, arang batu asalan paralik biasanya mempunyai nilai GI > 10 sementara arang batu limnik mempunyai nilai GI < 10.

INTRODUCTION

Limnic coals originate in topogenous peatlands without any hydrological connection to the sea. Such conditions occur in inland areas such as in intermontane terrain. Rift valley grabens offer preferable depositional sites for limnic coals, of which ancient examples include the Upper Rhine Graben, Germany and the Rundle oil shale in Queensland, Australia (Diessel, 1992). In these examples the lacustrine conditions prevailed in the basin for much of the time interval during which the deposit was formed. The Merit-Pila coals of Sarawak were deposited in an inland half-graben setting (Liaw *et al.*, 1987). Although an oil shale sequence is not observed within the Merit-Pila area, its presence should not be discounted. In Malaysia, the occurrence of coal-related oil shale lacustrine sequences of inland intermontane setting have been documented at Batu Arang, Selangor (Wan Hasiah and Abolins, 1998).

In contrast, paralic conditions of deposition occur where the peat swamp is hydrologically connected to the sea. It does not necessarily imply a physical contact of peat with sea water but merely indicates a hydrological link. As such, although lower coastal plain environments are commonly paralic, some upper delta plain settings can be as paralic as the lower delta plain (Diessel, 1992). Tertiary coal deposits along the NW Borneo coast are widely reported as being deposited under brackish-water influence (Wolfenden, 1960; Tate, 1976; Morley, 2000) and are known to be oil-prone (Todd *et al.*, 1997; Mazlan and Abolins, 1999).

PETROLOGICAL CHARACTERISATION

In this petrological study, the coals were examined in normal 'white' light and blue light excitation using a Leitz reflected light microscope. Whole rock samples were mounted in resin mixture and polished using silicon carbide papers followed by successively finer grades of alumina powder. The prepared polished blocks were examined under the microscope using an oil immersion objective. Maceral analysis (a 1,000 point count) was performed on seven samples from Mukah-Balingian and four samples from Merit-Pila.

Coal Macerals as Palaeoenvironment Indicators

Macerals are the microscopically recognisable constituents of coal, the differentiation of which is based on morphology, structure and reflectance. Coal macerals are the result of depositional conditions in the peat bog and post-depositional coalification processes. Recognition of macerals, microlithotypes (associations of macerals identified petrographically) and mineral matter content can help in developing an understanding of the depositional environment of coal-bearing sequences.

Macerals are generally derived from specific plants or parts of plants, but some may be the result of physical and chemical degradation of source materials within the environment of deposition. According to Teichmüller (1982), coal deposits can either be autochthonous (i.e. formed beneath the plant cover from which they are derived), allochthonous (i.e. plant attritus transported a considerable distance away and deposited in another sedimentary environment) or hypautochthonous (i.e. plant matter transported from its immediate source but accumulated within the same sedimentary environment). This distinction needs to be recognized and understood when using macerals as palaeoenvironmental indicators. The Mukah-Balingian coals analysed in this study are autochthonous deposits whilst those from Merit-Pila are hypautochthonous deposits.

Facies diagnostic macerals for palaeoenvironmental interpretation include macerals of the vitrinite and inertinite groups and a number of those within the liptinite group, such as alginite, cutinite and suberinite. Each of these is briefly discussed below.

Vitrinite

Vitrinite generally originate from trunks, branches, stems, leaves and roots of higher land-plants. Telinite and telocollinite, both varieties of vitrinite, are mainly derived from incomplete gelification of xylem and cortex tissues and therefore their presence commonly indicates a palaeoenvironment involving wood-producing plants under moist conditions (Diessel, 1982). Desmocollinite, or structureless vitrinite, is thought to originate from thoroughly decomposed and gelified attritus of various source materials, the main contributors being leaves, grasses, shrubs and reed-like plants.

Inertinite

Most inertinites originate from plant tissues which may have been totally oxidised to form fusinite or partly charred to form semifusinite, thus suggesting dry conditions during the formation of such components. Fusinite found in discrete layers or lenses is generally thought to be derived from charcoal produced during fires which burned through the swamp during dry periods whilst the absence of fusinite suggests a consistently high water-table level (Teichmüller, 1982). However, fusinite present in an environment may not be autochthonous as it may have been a result of wind/water transportation. Because of this, fusinite and alginite may be found in the same sample. According to Diessel (1982), inertodetrinite, although initially formed in a relatively dry forest moor, is more likely to be redeposited in a sub-aqueous environment as a result of transportation.

Alginite

The presence of alginite in coals, even in trace amount, indicates either a limnic (sub-aquatic) or a lacustrine environment of deposition as water is required for algal growth. *Botryococcus* is an example of an alga indicative of a fresh-water environment of deposition.

Cutinite

Cutinite precursors are mainly leaf cuticles. Cutinite is often associated with wood-derived vitrinite and therefore is commonly preserved in forest-moor deposits. Cuticles also originate from leaves of non-woody plants and they too can be widely dispersed by wind and water. Certain sub-aquatic coals contain a high abundance of cutinite, but it is uncommon in some coals (Teichmüller *et al.*, 1998). Therefore cutinite should be used as a palaeoenvironment indicator with caution.

Suberinite

Suberinite originates from suberin-impregnated cell walls of cork in bark tissues, or other parts, of woody and herbaceous plants. It is predominantly known from Tertiary coals and a few Mesozoic coals. *Rhizophora sp.* of mangrove swamps, in particular, contains abundant suberinitic and the associated phlobaphinitic cell fillings (Teichmüller, 1982).

RESULTS AND DISCUSSION

Maceral Assemblages of Merit-Pila and Mukah-Balingian Coals

The maceral assemblages of the Merit-Pila and the Mukah-Balingian coals analysed in this study are shown in Table 1. Vitrinite is the most dominant maceral in the Mukah-Balingian coals. However, in the Merit-Pila coals the liptinite is more dominant than vitrinite in two of the samples analysed, whilst in the other two samples vitrinite is more dominant. Inertinite content is low to fairly common (about 2–9% by volume) in both sets of samples. Micrinite occurs in close association with mineral matter in the Merit-Pila coals. The finely granular micrinite and clay minerals are grouped together because of the difficulty of their distinction even at high magnification. A high abundance of micrinite that is intimately associated with mineral matter is a common feature observed in sub-aquatic coals (e.g. Abdullah *et al.*, 1988). Teichmüller *et al.*, (1998) regarded the close association between micrinite and alginite as characteristic of sapropelic (or sub-aquatic) coals. The presence of the diagnostic maceral alginite (Fig. 1), supports the interpretation of a sub-aquatic environment for the Merit-Pila coals. The common occurrence of the maceral suberinite (Fig. 1) suggests a proximity to forests for this lacustrine setting — suberinite, as well as cutinite, resinite and sporinite, being transported into the lake.

The Mukah-Balingian coals are dominated by vitrinite and also contain a high abundance of liptinite macerals. Phlobaphinite (a type of collinite) is very common and occurs in close association with suberinite. A high abundance of phlobaphinitic constituents associated with suberinite are known to be common coal constituents to

Table 1. Maceral analysis of Mukah-Balingian and Merit-Pila coals.

Maceral Group	Maceral	Mukah-Balingian							Merit-Pila			
		1	2	3	4	5	6	7	1	2	3	4
	Telocollinite	15	12	17	2	37	7	2	20	2	18	3
	Desmocollinite	39	46	38	45	46	38	55	32	28	22	27
Vitrinite		***54***	***58***	***55***	***47***	***83***	***45***	***57***	***52***	***30***	***40***	***30***
	Fusinite	3	1	2	3	2	7	1	0	0	0	0
	Semifusinite	0	1	2	1	0	0	0	2	0	4	2
	Inertodetrinite	0	0	0	0	0	0	0	4	4	1	4
	Sclerotinite	tr	tr	tr	1	0	1	2	3	0	2	2
Inertinite		***3***	***2***	***4***	***5***	***2***	***8***	***3***	***9***	***4***	***7***	***8***
	Alginite	0	0	0	0	0	0	0	1	3	1	3
	Cutinite	2	2	1	5	tr	1	4	9	8	15	14
	Liptodetrinite	21	21	11	19	5	20	16	5	8	7	11
	Resinite*	6	3	12	5	7	16	10	2	4	2	1
	Sporinite	0	0	2	2	0	0	0	3	17	3	7
	Suberinite	5	6	6	5	tr	3	2	11	6	5	12
Liptinite		***34***	***32***	***32***	***36***	***12***	***40***	***32***	***31***	***46***	***33***	***48***
	Mineral Matter + micrinite**	9	8	9	12	3	7	8	8	20	20	14
	Total	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***
	GI	18.0	29.0	13.8	11.8	41.5	6.4	57.0	8.7	7.5	8.0	5.0
	TPI	0.46	0.30	0.55	0.13	0.85	0.37	0.05	0.63	0.08	0.96	0.16

* Including lipid resinite, dammar & exsudatinite if present
** For Mukah-Balingian samples this is mineral matter only

Figure 1. Alginite (bottom and top corners), suberinite (centre and centre left) and finely liptodetrinite associated with clay minerals and micrinite in Merit-Pila coal; blue light excitation, field width = 0.25 mm.

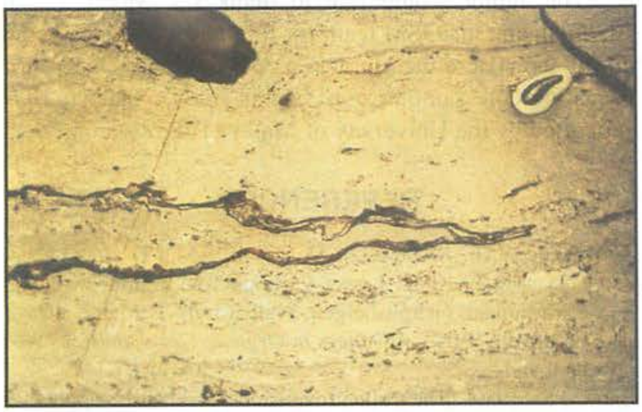

Figure 2. Resinite (top left) and cutinite (centre) in structureless vitrinite (desmocollinite) associated with finely detrital liptinitic constituents (liptodetrinite) in Mukah-Balingian coal; 'white' light, field width = 0.25 mm.

have originated from *Rhizophora sp.* (Teichmüller, 1982). The mineral matter content is rather high in the Mukah-Balingian coals analysed. This mineral matter is not observed to be associated with micrinite but is commonly associated with pyrite. Liptodetrinite is generally very common in the Mukah-Balingian coals. This finely detrital liptinitic constituent originates from other liptinite components. When in high abundance, liptodetrinite is considered to be indicative of wet conditions of deposition (Teichmüller *et al.*, 1998). Alginite is not present in all of the Mukah-Balingian coals analysed here. The common occurrence of the macerals suberinite and resinite (Fig. 2) again suggest that forested land, of cork- and resin-bearing trees, occur within or nearby these areas of wet condition of deposition, identified here as a lower delta plain setting (see GI versus TPI plots of Fig. 3).

Depositional Environment based on GI versus TPI plots

The paleoenvironment interpretation based on GI (Gelification Index) versus TPI (Tissue Preservation Index) was initially proposed by Diessel (1986) and modified after other workers (e.g. Kalkreuth and Leckie,1989). Figure 3 shows the GI versus TPI plots that has been modified based on the current work. The GI and TPI formulation used in this study is as follows:

GI = Vitrinite/(semifusinite + fusinite + inertodetrinite)
TPI = (telocollinite + semifusinite + fusinite)/ (Desmocollinite + inertodetrinite)

Wet conditions of peat formation are indicated by a high gelification index. High GI values can either be attributed to a high content of wood-derived, structured vitrinite (telinite + telocollinite) which will then result in a high TPI, or a high content of structureless vitrinite (mainly desmocollinite) resulting in a low TPI. According to Diessel (1986), a high degree of gelification based on structureless vitrinite, the presence of cutinite and the lack of any wood-derived macerals suggest such coals have formed from soft-tissued herbaceous or reed-like plants in a marsh environment of a lower delta-plain setting. Relatively higher TPI is expected for coals of a forest-swamp environment since intermittent dry conditions in an upper delta-plain setting would give rise to an increased proportion of semifusinite and fusinite.

In the crossplot of Figure 3, "mangrove" replaces "marsh" facies of Diessel (1986) and Kalkreuth and Leckie (1989). This modification is considered necessary in order to better represents a tropical setting and tropical floral input. Coals of NW Borneo have been reported to possess organic geochemical characteristics suggestive of a mangrove origin (e.g. Brown, 1989; Wan Hasiah, 2001). This is supported by the observation that most seams are thin, rarely exceeding 1 m, with common occurrence of pyrite. Such features are known to be typical of marine-influenced lower delta plain coals (e.g. Diessel, 1986). Although Mukah-Balingian coals are dominated by the structureless form of vitrinite (desmocollinite), it should be noted that structured vitrinites (telocollinite) are also very common in most of these coals suggesting a significant contribution from woody components. In the GI versus TPI plots of this study, the mangrove coals generally possess GI > 10 (except for sample 6) and TPI < 1. The low GI of less than 10 for sample 6 is possibly indicative of a low water table during the deposition of the peat that formed this particular coal compared to the rest of the Mukah-Balingian samples. All of the lacustrine coals of Merit-Pila possess GI values < 10 and TPI values < 1.

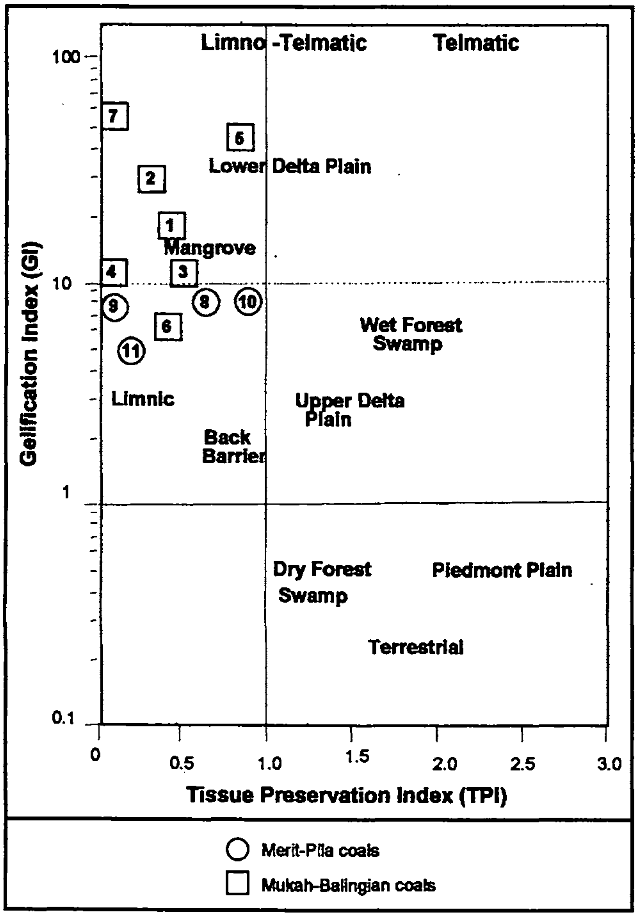

Figure 3. GI versus TPI crossplot.

The low TPI for both sets of environments studied are due to the high abundance of unstructured vitrinite which is indicative of deposition under wet conditions and this is in agreement with the occurrence of diagnostic macerals such as alginite in the Merit-Pila coals and liptodetrinite in Mukah-Balingian coals.

CONCLUDING REMARKS

The limnic and paralic coals of Sarawak can be clearly distinguished based on their respective GI values and the occurrence of certain diagnostic liptinitic macerals. Low TPI values in both sets of samples suggest both environments studied were wet. The Mukah-Balingian coals of paralic origin generally possess GI values > 10 whilst those from Merit-Pila of limnic setting possess GI values < 10. The TPI values of both sets of coals are < 1 which is indicative of wet conditions of deposition. Coals of the paralic setting studied here are believed to be of mangrove origin. This is apparent from their high abundance of phlobaphinitic constituents associated with suberinite, which are known to be common constituents originated from *Rhizophora sp.* Coals of the lacustrine setting are characterized by the presence of *Botryococcus sp.* algae, although the alga occurs in low relative abundance. The presence of significant amounts of suberinitic and phlobaphinitic constituents within the lacustrine-derived coals suggests that cork-derived vegetation precursors are proximal to the lacustrine environment. The setting is presumably a low montane terrain.

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