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Petrographic features of oil-prone coals from the Brunei-Muara District, Negara Brunei Darussalam

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Abstract: Petrological investigation of a number of coal samples from the Brunei-Muara District reveals the presence of oil-generative features commonly observed in oil-prone coals. These features include the occurrence of exsudatinite, oil globules, oil haze and changes in fluorescence intensity; all of which were observed to be associated with the maceral suberinite and bitumens in the samples studied. These liptinitic constituents, which are commonly associated with liptodetrinite, are regarded as the most oil-prone components in the coals of the Brunei-Muara District. Exsudatinite is developed by fracturing of the vitrinite following generation of fluid hydrocarbons. This leads to expulsion of hydrocarbons under sufficient pressure to cause the fractures to develop and form exsudatinite crack network. This occurs at a relatively low thermal maturity level of 0.42 to 0.49%R_o. These coals are characterised by a high abundance of liptodetrinite, inertodetrinite and vitrodetrinite occurring within a desmocollinite (or collodetrinite) matrix, and occasional mineral matter. The presence of a high abundance of hydrogen-rich liptodetrinite and its association with collodetrinite further enhances the oil-generative and expulsive features possessed by these coals. In these coals, liptodetrinite seems to be mostly derived from the breakdown of the suberinite-phlobaphinite framework, primarily by fragmentation of suberinite. This breakdown is associated with liquid hydrocarbon generation. The generation of liquid hydrocarbons by the liptodetrinite maceral, however, was not observed at this low thermal maturity and is likely to occur later at a relatively higher maturation level.

INTRODUCTION

During recent years, the idea of coal as a potential source rock for oil has gained increasing support. Hunt (1996) expressed no doubt that hydrogen-rich coal and terrestrial kerogen can generate economic quantities of liquid petroleum. The distribution of oil fields derived from coals are, however, geographically restricted: Southeast Asia and Australia being the locations of most published examples (Cook and Struckmeyer, 1986; Robinson, 1987; Khorasani, 1987; Horsfield *et al.*, 1988; Powell and Boreham, 1994; Todd *et al.*, 1997). Although geochemical oil and gas typing suggest that land plant organic material is the source of most of the liquid petroleum around the Northwest Borneo region (Schreurs, 1996; Todd *et al.*, 1997), no discrete, rich source rock layers of mappable extent have been identified in Brunei (Ramli Hitam and Scherer, 1993). The core and outcrop samples studied by the latter authors revealed good quality source rock material in the form of lenses and thin layers, a few centimeters thick, deposited within fluvial, lagoonal and in open marine shelf environments.

The samples studied here are from the Middle Miocene Belait Formation from Brunei-Muara District. This formation was deposited in a lower flood plain under tidal influence (Tate, 1976; Yap, 1996). In this preliminary study, a number of coal samples are analysed by organic petrological methods, the aim being to identify microscopic features that are commonly considered to indicate liquid hydrocarbon generation from coal. The samples studied were outcrop samples collected along Jalan Sungai Akar and at Tanjung Batu as shown in Figure 1. The coals mostly occur as thin beds of several centimeters thick within a sequence dominated by sandstone and mudstone. The coal seam at Tanjung Batu is, however, very thick (at least 3 m).

METHOD OF STUDY

Coal samples were crushed to 2–3 mm size and mounted in a slow-setting resin. The blocks were polished using successively finer grades of silicon carbide papers and alumina powders using water as a lubricant. Microscopical examination was carried out principally in oil immersion under normal reflected 'white' light and 'blue' light excitation using a BP 420–490 excitation filters and a RKP 510 dichromatic mirror. Random reflectance measurements in oil on vitrinite (%R_0) were carried out in plane-polarised, reflected 'white' light and the data were acquired using a Windows-based programme.

RESULTS AND DISCUSSION

A brief petrographic description of the coals is given below and photomicrographs relevant to the present study are shown in Figures 2 to 9.

Coal Rank

All of the coals studied are of low thermal maturity, ranging in rank from sub-bituminous C to sub-bituminous B possessing mean vitrinite reflectance of 0.42% to 0.49%. The thermal maturity range in which oil generation from petroleum source rocks is very dependent upon kerogen composition but will generally occur is between 0.5 to about 1.3%R_0 (Tissot and Welte, 1984). With relation to oil generation from coals, however, some workers (e.g. Khorasani, 1987; Zhao *et al.*, 1990; Khorasani and Michelsen, 1991; Wan Hasiah, 1997a, 1997b) suggested an early phase of hydrocarbon generation from coals at vitrinite reflectance of less than 0.5%R_0. The Brunei coals studied here also appear to generate liquid hydrocarbons at similarly low thermal maturity levels.

Coal Type

Most of the coals studied are relatively massive in hand specimen and in this property resemble cannels and canneloid coals. Petrographic examination suggests these coals are possibly of a hypautochthonous origin consisting mostly of attrital constituents such as liptodetrinite, inertodetrinite and vitrodetrinite, set within a predominantly desmocollinite (or collodetrinite, ICCP, 1998) groundmass associated with some mineral matter (Fig. 2). Some of these coals could be classified as carbargillite where they contain a significant amount of mineral matter. The assemblage of vitrinite macerals and the presence of fungal tissue are indicative of degraded forest litter. Suberinite is a common constituent of these coals, constituting about 10–15% by volume of the whole rock. Liptodetrinite occurs in greater abundance (15–20%). Exsudatinite/bitumens and terpene resinite generally occur in minor amount (5–10%). Isolated, thin coal horizons, however, occur which comprise of the clarite microlithotype

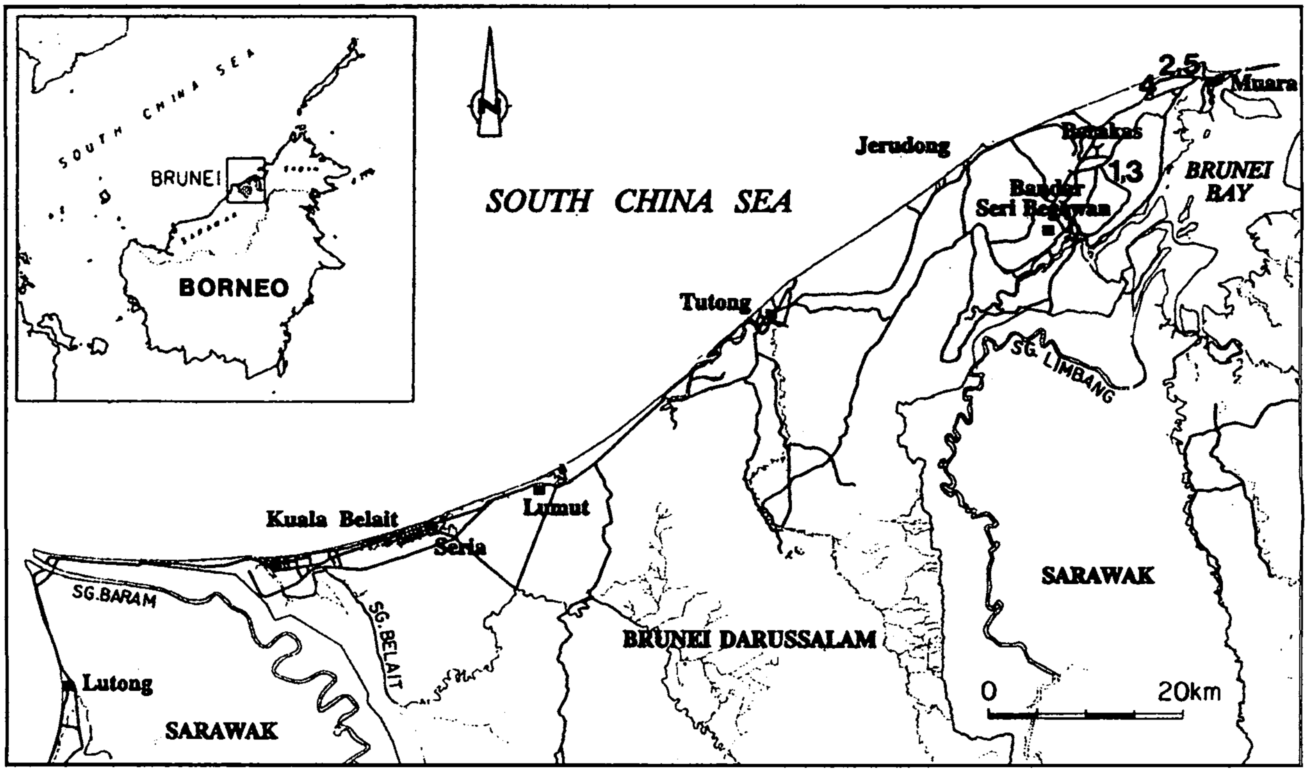

Figure 1. Location of the study area. Numbers indicate sample locations: 1 and 3 at Jalan Sungai Akar and 2, 4 and 5 at Tanjong Batu.

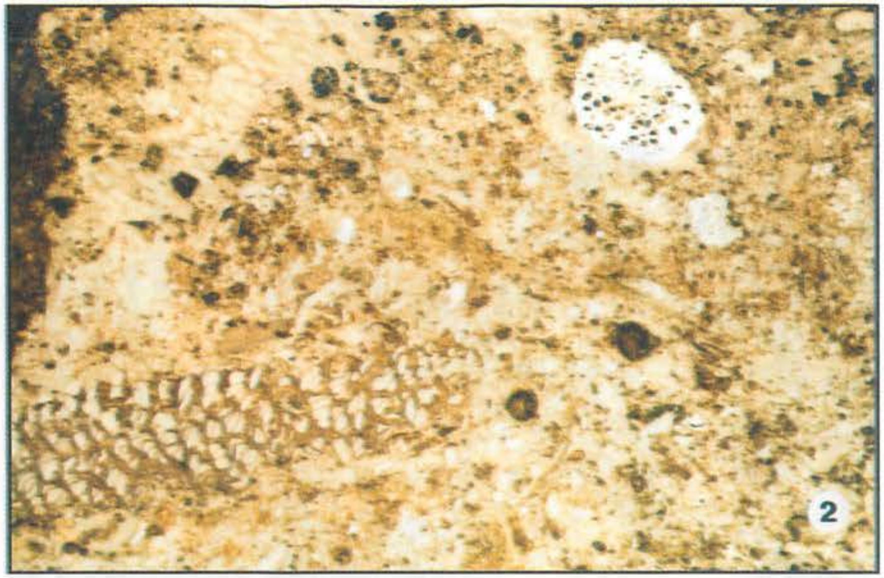

Figure 2. Fine-grained attrital constituents consisting of liptinite macerals (mostly liptodetrinite and some sporinite), collodetrinite and mineral matter mixed with coarser grains of vitrodetrinite (of possible phlobaphinitic origin), inertodetrinite, sclerotinite and some telovitrinite (top left of the field): reflected white light; field width = 0.65 mm.

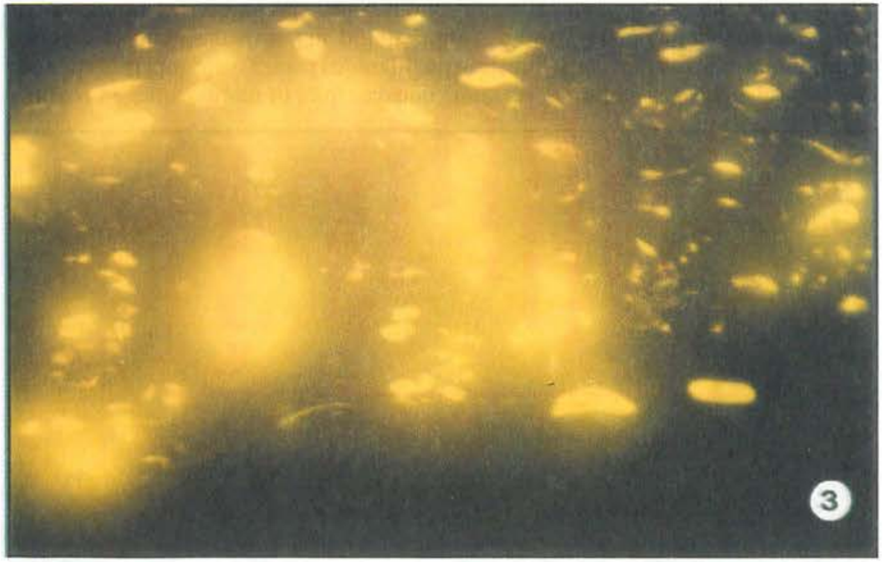

Figure 3. Volatilization of hydrocarbons in the form of oil haze (representing oil cut) from exsudatinite in cell lumens of telinite: blue light excitation; field width = 0.20 mm.

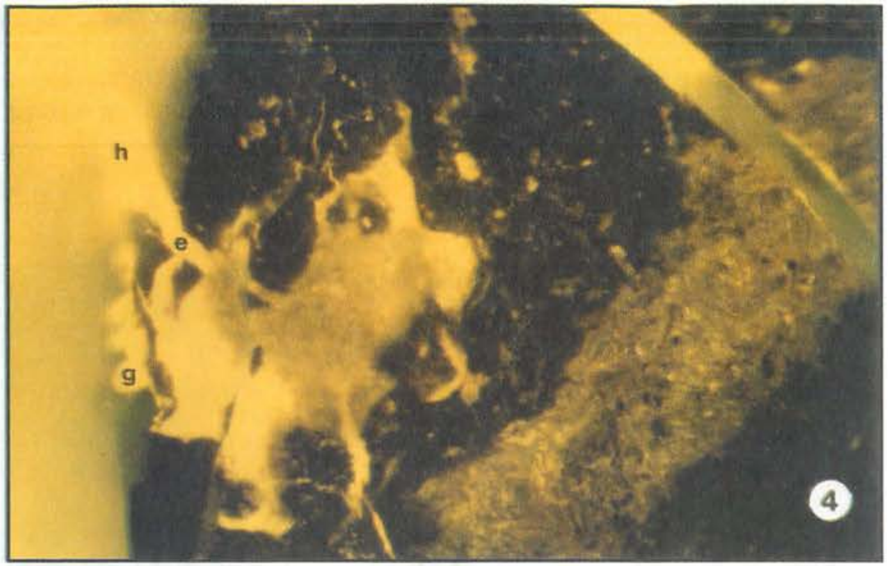

Figure 4. Generation of liquid hydrocarbons in the form of exsudatinite (e), oil globules (g) and oil haze (h) from bitumen. Note that bitumen, which originally fluoresces dull brown, increases its fluorescence intensity to bright yellow as a consequence of hydrocarbon generation: blue light excitation; field width = 0.26 mm.

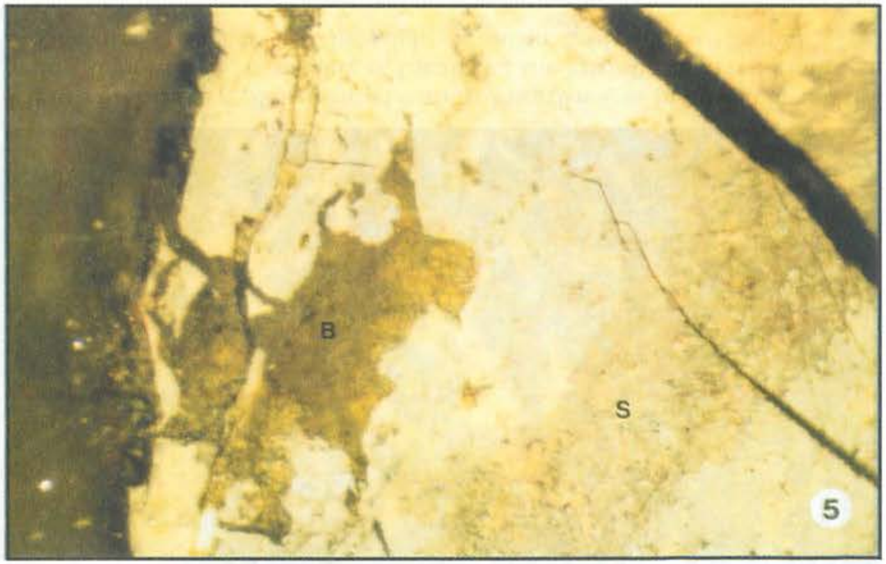

Figure 5. Same view as above under reflected white light. The hydrocarbons generated appear as bluish and reddish stains on bitumen (B) and suberinite (S).

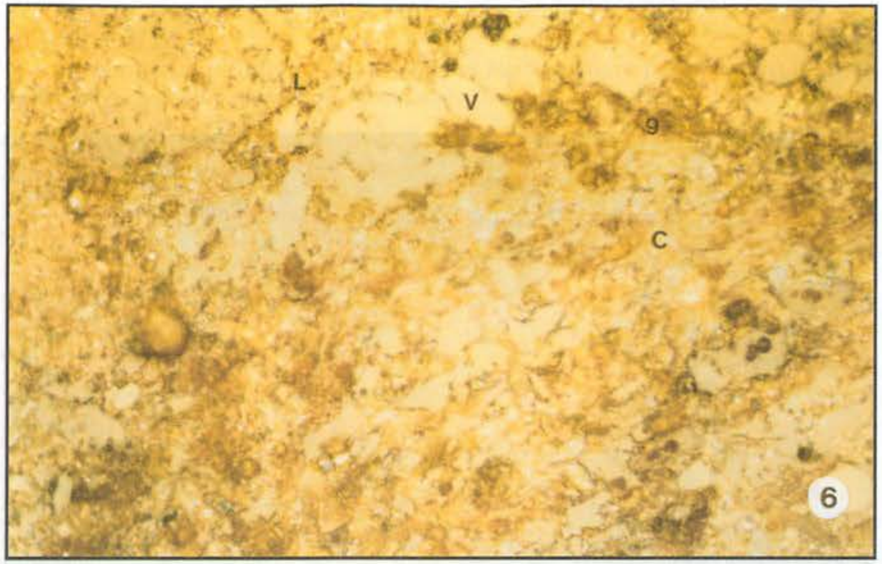

Figure 6. Subsequent to hydrocarbon generation, indicated by the presence of brownish oil globules (g) and colourful oil staining, the suberinite-phlobaphinite framework disintegrates. The phlobaphinite mainly forms collodetrinite (C) and vitrodetrinite (V) while suberinite forms liptodetrinite (L) and oil globules (g): reflected white light; field width = 0.26 mm.

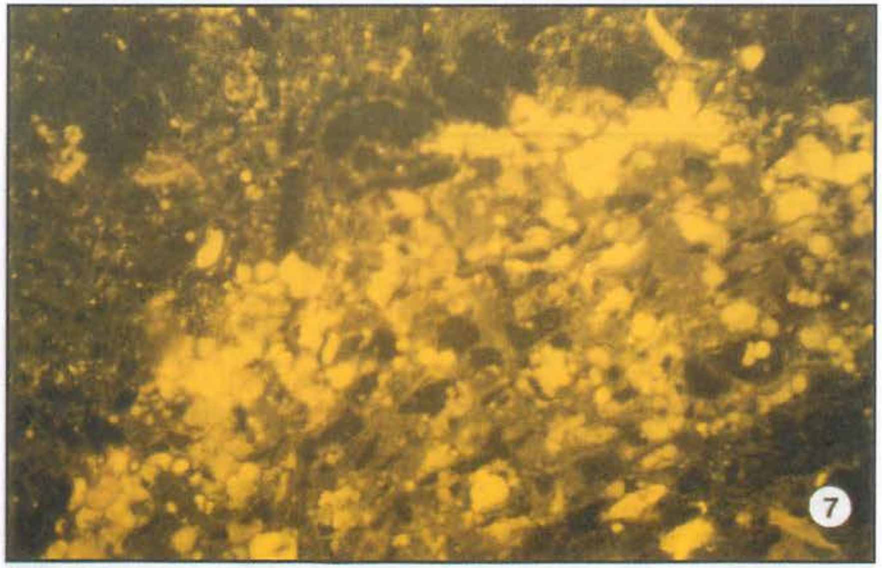

Figure 7. Same view as above under blue light excitation. Widespread occurrence of bright yellow to greenish yellow fluorescing oil globules and liptodetrinite (whereby the distinction between these two components is arbitrarily based on size, in which the latter is smaller), and dull yellow fluorescing collodetrinite. The structureless form and the dull fluorescence of the collodetrinite maceral suggest some affinities to the maceral bituminite.

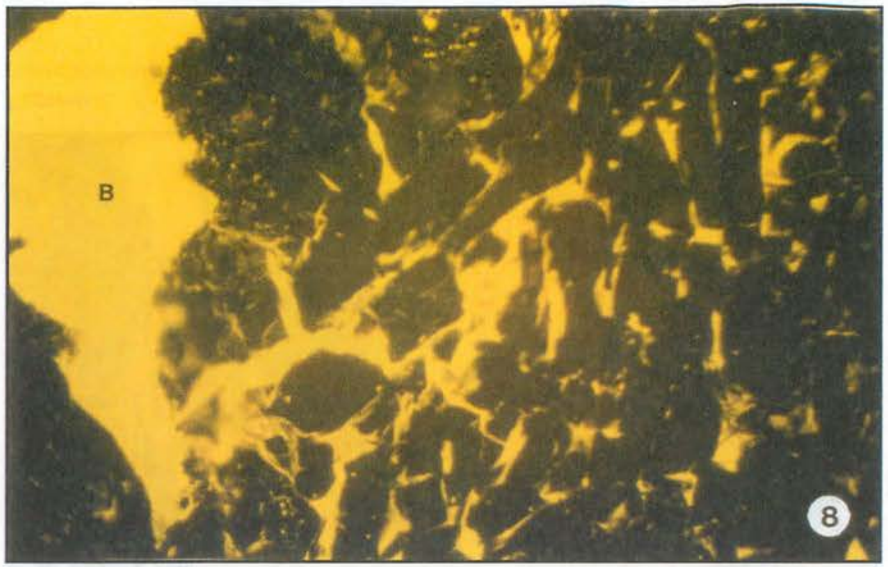

Figure 8. Bitumen (B) saturated with hydrocarbons, as indicated by intense yellow fluorescence, is capable of fracturing the vitrinite matrix forming an exsudatinite crack network: blue light excitation; field width = 0.26 mm.

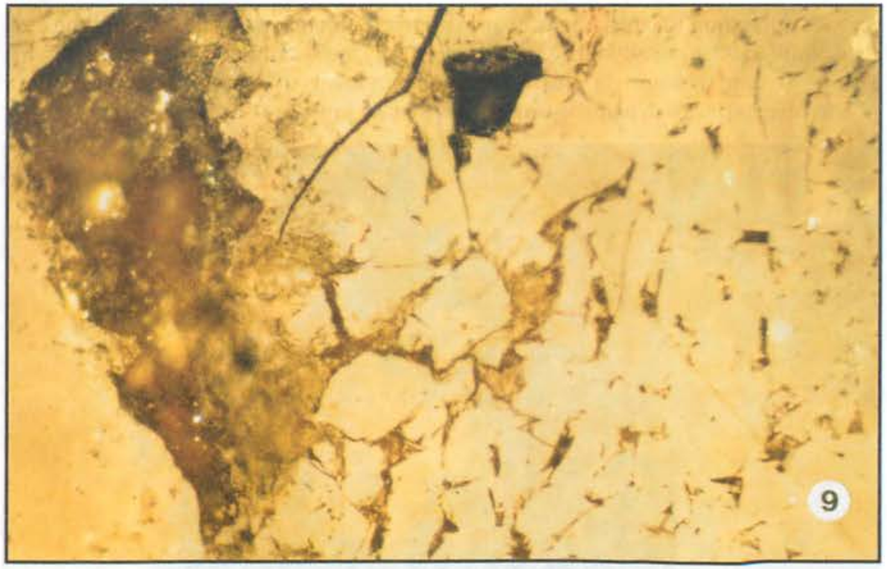

Figure 9. Same view as above under reflected white light showing exsudatinite pervading the telovitrinite coal fabric and causing it to fractured.

consisting of approximately 50% vitrinite and 50% terpene resinite. The overall liptinite content in these coals is generally between 25 to 50%.

The types of macerals present in the Brunei-Muara coals are very similar to those of the Bintulu coals from Sarawak (Wan Hasiah, 1997b), although their relative proportions may differ significantly. However, the occurrence of the maceral bituminite, as described by Teichmuller (1982), could not be identified with confidence in the Muara coals. It is observed that the maceral suberinite is more common in the Muara coals than in the Bintulu coals. This could be attributed to a slightly higher maturity level of the Bintulu coals (0.45–72%R_0) compared to the Muara coals whereby the maceral suberinite is known to disappear with increasing maturity (Khorasani and Michelsen, 1991; Wan Hasiah, 1997b).

Oil-Generative and Expulsive Features

A number of microscopic features that may be indicative of coal as an active generator of liquid hydrocarbons have been previously described by Cook and Struckmeyer (1986). These include the occurrence of exsudatinite and oil globules which indicate that oil-generation and mobilisation has occurred within the coal, while the occurrence of oil haze (or oil cut) represents the presence of free 'oil'. These features are most apparent when observed under blue light excitation (Figs. 3, 4, 7 and 8). Changes in fluorescence intensity are also considered as important petrographic features indicating oil generation from coal. Fluorescence intensity is observed to increase at the onset of liquid hydrocarbon generation and fade away once most of the hydrogen-rich components have been expelled towards the end of the generation phase (Wan Hasiah, 1997b).

In the Muara coals, oil-generative features most commonly observed under blue light excitation are oil haze and oil globules (Figs. 3, 4 and 7). When observed under normal reflected white light, the oil globules appear as greenish or brownish vesicles and are seen to be commonly associated with reddish-blue oil staining (Figs. 5 and 6). Oil haze, however, could not be easily detected under normal white light. The generation of liquid hydrocarbons in the form of oil globules can be intense when associated with the macerals suberinite and phlobaphinite. This process of hydrocarbon generation caused the disintegration of the suberinite-phlobaphinite framework (Fig. 6). This gives rise to fragmented phlobaphinite (forming collodetrinite and vitrodetrinite) and liptodetrinite. Collodetrinite seems to have affinities to bituminite when observed under blue light excitation as suggested by its structureless form and a dull fluorescence (Fig. 7). The generation of liquid hydrocarbons by liptodetrinite, however, could not be ascertained at this low thermal maturity and is likely to occur later at a relatively higher maturity level.

Changes in the fluorescence intensity with hydrocarbon generation can be observed distinctly in the maceral exsudatinite and bitumen (Fig. 4). The term bitumen used here refers to the oil-prone amorphous liptinitic constituents that readily generate liquid hydrocarbons at low thermal maturity. The exsudatinite/bitumen shows a dull brown fluorescence under blue light excitation where it is not expelling liquid hydrocarbon. Upon the onset of liquid hydrocarbon generation, either in the form of exsudatinite veins, oil globules, or oil haze, its fluorescence intensity increases to bright yellow. These features were also observed within Tertiary coals from the Bintulu area, Sarawak (Wan Hasiah, 1997b). Pyrolysis gas chromatograms of liptinite-rich coals from Bintulu, Sarawak, contain high amount of n-alkane/alkene doublets and aromatic hydrocarbons (Wan Hasiah, 1999).

A further interesting microscopic feature that is observed in both the Bintulu and Muara coals is the development of a network of fissures filled with exsudatinite which seems to play a significant role in hydrocarbon expulsion (i.e. primary migration) as well as in hydrocarbon generation. Upon reaching its saturation threshold, as indicated by the intense fluorescence of the bitumen mass (Fig. 8), the generated hydrocarbons pervade the coal fabric (as can be observed from the slight fluorescence in the coal fabric) and cause the vitrinite particles to fracture (Fig. 9). Such fractures appear to have been generated by pressure exerted by the exsudatinite itself or by related fluids as suggested by Daulay and Cook (1988). Horsfield *et al.* (1988) speculated that the generated material that pervades the coal fabric deactivates adsorptive sites. This subsequently facilitates the expulsion of oil from the precursor maceral. Stout (1994), on the other hand, emphasized the physical association between macerals (i.e. microlithotype composition) to be an important factor in oil expulsion from coals. Mukhopadhyay *et al.* (1991) and Stout (1994) suggested the association of the macerals liptodetrinite/humodetrinite not only provides the appropriate type of oil proneness but also offers a greater porosity and permeability for oil expulsion. It is similarly postulated here that such an association may well be an important expulsion mechanism within the coals studied based on the presence of a high abundance of liptodetrinite and collodetrinite that were mostly derived from the break-down of the suberinite-phlobaphinite framework. At low rank, collodetrinite has been described to possess a slightly porous surface (ICCP, 1998). It is intuitively obvious that the nature of the coal fabric could govern the mechanism of expulsion. In sapropelic type coals or in coals dominated by detrovitrinite fabric, the association of the macerals liptodetrinite/collodetrinite would be more efficient while in structured coal fabric (telinite/telocollinite or collotelinite, ICCP, 1998) the formation of an exsudatinite crack network would seem more efficient as expulsion mechanism within coaly petroleum source rocks.

CONCLUSIONS

Petrographically, the Muara coals possess the characteristics of oil-prone coals. The coals contain a high abundance of hydrogen-rich macerals such as suberinite and liptodetrinite. These macerals are regarded here as the most oil-prone macerals of the Muara coals. Suberinite displays oil-generative features that suggest liquid hydrocarbon generation is taking place at a relatively low thermal maturity level of 0.42 to 0.49%R_0. Liptodetrinite and collodetrinite seem to be mostly derived from the breakdown of the suberinite-phlobaphinite association and mostly get incorporated into the coal fabric. Liptodetrinite is likely to generate liquid hydrocarbons at a slightly later maturity stage than suberinite. The association between liptodetrinite and collodetrinite could also provide a porous and permeable fabric for oil expulsion within coaly source rocks. In structured coal fabric, within low-rank coals, the formation of an exsudatinite crack network could offer an efficient expulsion mechanism for primary migration of liquid hydrocarbons.

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