CHAPTER 7: DISCUSSION

Chapter 7

Discussion

7.1 Liptinite Content and Maturation

Liptinites originate from relatively hydrogen-rich plant materials such as sporopollenin, cutin, subrin, resins, waxes, balsams, latex, fats and oils as well as from bacterial degradation products derived from proteins, cellulose and other carbohydrates. In contrast to humic materials, liptinites contain comparatively large amounts of aliphatic constituents. A large fraction of liptinite derives from plant lipids (fatty substances), which can be subdivided on the basis of their behavior in organic solvents into a soluble fat-wax group and an insoluble, highly polymerized, suberin-cutin group (Taylor et al., 1998). During the peatification and diagenesis of brown coal, the liptinite precursors are relatively stable (in contrast to those of vitrinite). They don't undergo humification and gelification.

The boundary between the sub-bituminous coal stages (0.5 % Ro) has been described as the first coalification jump of liptinites (Teichmuller, 1974). There begins a distinct change in the properties of lipid constituents in this stage. This change coincides with petroleum formation in oil source rocks. In coals, constituents which are typical of petroleum are formed through decarboxylation and reduction processes.

In Labuan sediments, the Tg. Punei unit, Richardson Point unit, Temiang unit, East Kiamsam Sandstone Tg. Batu unit samples have passed the first coalification jump, as they possess a vitrinite reflectance more than 0.56%. The Layang Layangan units and

Bethune Head samples are close to this boundary with a vitrinite reflectance ranging from 0.48 to 0.52% and 0.44% for Bethune head.

A second coalification jump in liptinites, which coincides with the breakdown of the large hydrocarbons in petroleum (i.e. Conversion into gaseous hydrocarbons), takes place within the medium-volatile bituminous coal stage, corresponding to 1.2-1.5% vitrinite reflectance. In the present study, no sample has reached this jump, the highest maturity observed in Labuan sediments being 0.80% in Tg. Punei.

However, sedimentary rocks on Labuan contain oil prone organic matter. The Layang Layangan units show abundance in liptinitic macerals compared other. The relatively lower abundance of the liptinitic macerals in other units may be due to oil generation and expulsion from these macerals at an early maturation stage.

7.2 Evidence of Liquid Hydrocarbon Generation from Coal Macerals

Microscopic examination of samples from Labuan show a number of features which may indicate that these sediments have actively generated liquid hydrocarbons. Liptinites are hydrogen rich macerals that have potential to generate liquid hydrocarbons during coalification. The most common liptinite macerals observed were resinite, suberinite, sporinite and bituminite. Observed petrographic features indicative of hydrocarbon generation from liptinites include: occurrence of fluorinite, secondary macerals such as exsudatinite and micrinite, oil haze and framboidal pyrite associated with liptinite macerals.

7.2.1 Occurrence of Exsudatinite and Bitumen

Teichmuller (1974) recognised and separated exsudatinite from resinite. She described it as a secondary liptinite maceral produced by sweating of lipid rich liptinites and vitrinite during coalfication at the sub bituminous / bituminous coal rank boundary. It has been described as a product indicating the onset of the bituminisation process related closely to the genesis of liquid hydrocarbon. It is, therefore, characterised as expelled hydrocarbon. Exsudatinite is found in Labuan within samples from Layang Layangan units as veins generated from suberinite (Plate 6.9) or filling the voids of sclerotinite (Plate 6.5 & 6.12). Exusdatinite was observed also in the sample from Temiang unit exudates from bituminite maceral (Plate 7.1). Exusdatinite probably represents the heavy portion of hydrocarbons which have migrated only a short distance from the liptinitie source (Teichmuller, 1974). In samples where exsudatinite is relatively abundant, it induces cracking of vitrinite and even causes brecciation (Wan Hasiah, 1999a).

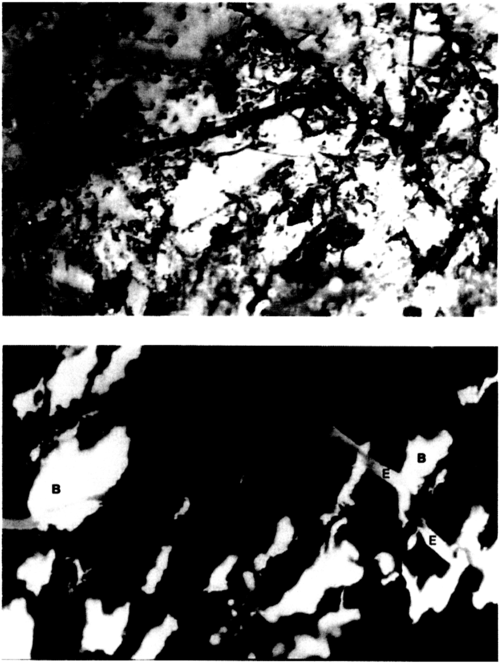


Plate 7.1 Exsudatinite (E) is exuding from bituminite (B) (under reflected light (top) and bottom: under blue light excitation (bottom), field width 0.21mm). (sample: Lab 39)

Exsudatinite is virtually absent in the Temburong Formation. This is probably due to either the high maturity or to a matrix rich in mineral matter which absorbs exsudatinite.

Bitumen is found in shale samples and shaly material from all units (Plate 6.7 & 6.8).

7.2.2 Occurrence of Fluorinite

Fluorinite is a maceral of the liptinite group which displays strong yellow to greenish-yellow fluorescence, under blue light excitation, in brown and low rank bituminous coals (Stach et al., 1982).

Fluorinite was observed in samples from the Layang Layangan units (Plate 6.11) having a vitrinite reflectance of about 0.49%. Teichmuller (1974) regarded fluorinate to be primarily derived from essential plant oils because of its shape and size and close association with cutinite in leaf-derived tissue. Such association can be observed in sample Lab 7 (Plate. 6.5)

However, some occurrences of fluorinite may represent high pour-point oils trapped within coal (Cook and Struckmeyer, 1986)

7.2.3 Occurrence of Micrinite

Micrinite is regarded as a secondary maceral appearing first in the bituminous stage and is a biproduct of oil generation from liptinites by disproportionation reactions (Cook and Struckmeyer, 1986; Stach et al., 1982; Teichmuller, 1974). Micrinite has been described in bituminous and higher rank coals. However, Wan Hasiah (1997) reported the appearance of micrinite in coals of lower rank, suggesting that oil generation occurs in a wider rank than that of the oil generation window of Cook and

Struckmeyer, 1986). Micrinite often shows a distinctive original morphology where the cell substance has been converted to very small and highly reflecting particles. Chemical analyses of micrinite often show high hydrogen content (Taylor et al., 1998). The main origin of micrinite is probably from various liptinite macerals. In Labuan, micrinite is found in samples having relatively high maturity (Plates 6.1 & 6.2). These rocks have vitrinite reflectance between 0.56% and 0.80%. Micrinite is a maceral that forms in the early stage of coalification. Like exsudatinite, it is a secondary maceral and apparently the product of the first coalification jump of liptinite, which lies in the ``critical`` stage of high volatile bituminous C und B coals (Teichmuller, 1974).

7.2.4 Oil Haze and Globules

Observed oil haze represents ``free`` hydrocarbons expelled by liptinite macerals. Under blue light excitation, the fluorescing oil haze can hide the shape of the liptinite macerals (Plate 7.2). Plate 7.3 shows the substance which is considered to be oil generated from coaly macerals. The oily materials are closely related with framboidal pyrite which is used as possible evidence for oil generation from coal.

7.2.5 Occurrence of Framboidal Pyrite

Framboidal pyrite occurs in association with the macerals suberinite, exsudatinite (Wan Hasiah, 2001), and bituminite (Wan Hasiah, 2001, Graham, et al, 1995). However, Wan Hasiah (2001) regarded the association of framboidal pyrite with these macerals as an indicator for oil generation.

Several samples from Labuan show association of framboidal pyrite with liptinitic macerals and oil expulsion (Plate 6.10). In Plate 7.4 an association of oil globule is observed with pyrite veinlets as well as with framboidal pyrite.

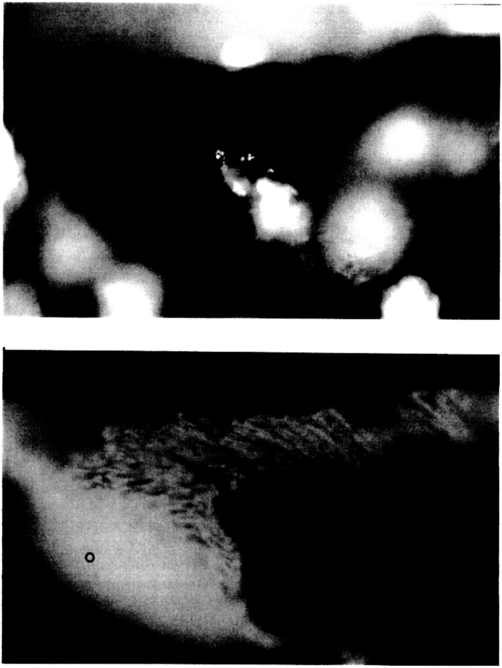


Plate 7.2: Oil haze (O) from structured liptinite macerals (L) in sample Lab 4 (under normal light (top) and under blue light excitation (bottom), field width 0.21mm).

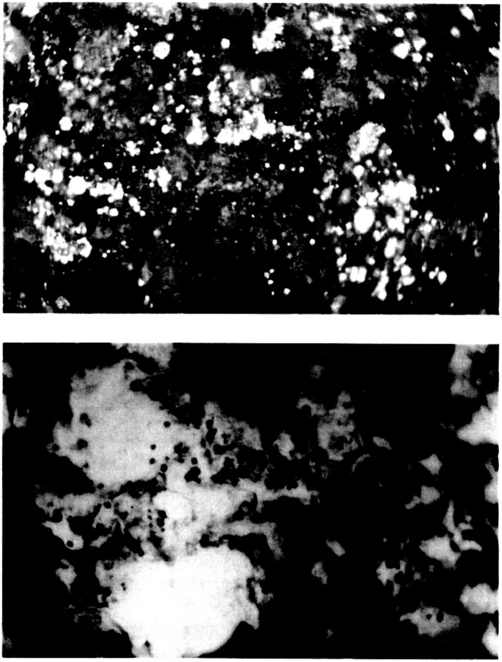


Plate 7.3: Framboidal pyrite associated with a considerable liquid hydrocarbon (under normal light (top) bottom: under blue light Excitation (bottom), field width 0.21mm). Sample Lab 2 from Layang Layangan unit II

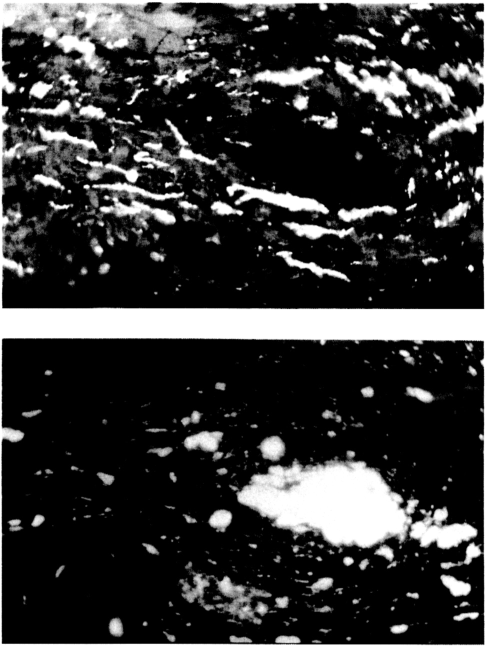


Plate 7.4: Elongated pyrite (the white bodies in the above image) associated with liptinitic macerals and hydrocarbon generated in the form of globules (under reflected light (top) and under blue light excitation (bottom), field width 0.21mm).

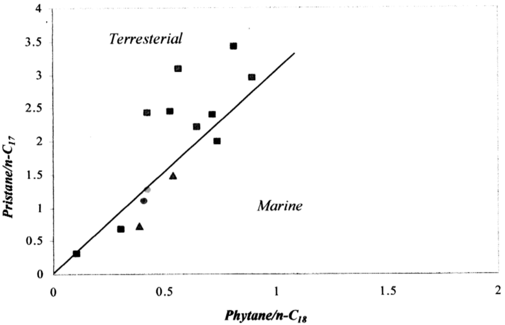
7.3 Organic matter input and depositional environments

Organic matter derived from biological precursors is a constituent of most sedimentary rocks. Its amount in recent sediments is known to be controlled by a variety of biological, physical and chemical factors such as bioproductivity, transport from the site of plant growth to the site of deposition and oxygen content of water at the sediment/water interface. It is generally assumed that the same factors also influenced the concentration of organic matter in older sediments, including petroleum source rocks (Taylor et al., 1998).

The nature of the coal forming environment is related by Horne et al. (1978) to the autocyclity of the clastic environment in which the coal is inter-bedded. Coal lithofacies and geochemical analysis can provide important indications regarding to the nature of the depositional environment. Paleenvironment in this study area can vary between deep marine to delta complex, therefore a very complex system of depositional environments can build up over time. These variations in environment are supported by biomarker analysis (using GC MS) of sample extracts. Pr/Ph ratios measured on these sediments are in the range of 1.59 to 4.57. Pr/Ph ratios can be used to estimate the redox potential of an environment.

Labuan sediments were therefore deposited in a terrestrial suboxic to oxic environment.

Figure 7.1 represents a plot of pristane/C_{17} Vs phytane/C_{18}. On such a diagram, samples of similar origin tend to plot linearly along a ray whose angle with the abscissa is a function of organic matter type. A low angle is characteristic of algal organic matter, whereas a high angle is typical of terrestrial origin (Connan and Cassou, 1980).



Black square = Tg. Punei unit, blue triangle = Tg. Batu unit, blue circle = Temiang unit, green circle = East Kiamsam Sandstone, red square = Richardson Point unit and blue square = Layang Layangan units.

Figure 7.1: Isoprenoid/normal alkane ratios (after Connan and Cassou, 1980; Mukhopadyay, et al, 1997) showing the position of Labuan sediments.

The plot of pristane/n-C_{17} Vs phytane/C_{18} on the Shanmugam chart also show that organic matter within Labuan Sediments is terrestrial in origin deposited under an oxidizing condition (Figure 7.2). This is in agreement with the geological data. Both of the figures 7.1 &7.2 show also, in part, a function of maturity with more mature samples tending to plot closer to the origin.

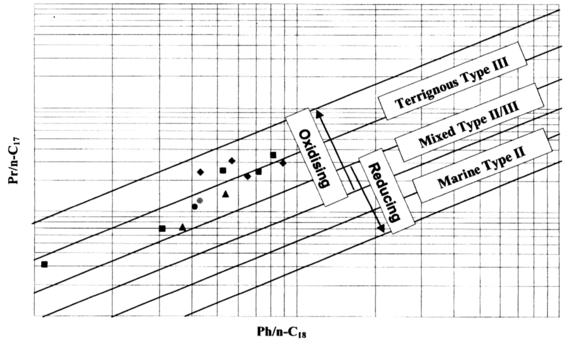
Oleanane is detected in all samples as one peak representing α- and β-oleanane. Oleanane is considered as a Cretaceous or younger higher plant marker (Ekweozer et al. 1987). However, Murray et al. (1997) have related the abundance of oleanane to the changing the aromatic oleanoids (in plant matter) to oleanane in early diagenetic conditions in marine or evaporate conditions.

7.3.1. Tg. Punei unit

The high abundance of low molecular weight n-alkanes, compared to high molecular weight, suggest low contribution of terrigenous organic matter, which can be supported by low n-C_{31}/n-C_{17} ratios. The nC_{31} indicates higher plant inputs and n-C_{17} show contribution of algae (Hunt, 1995; Tissot and Welte, 1984). The low Pr/n-C_{17} and Ph/n-C_{18} ratios (031-0.68 and 0.11-0.31, respectively) have been reported to suggest deposition in a deep marine environment, which generally possesses relatively lower amounts of acyclic isoprenoids compared to n-alkanes (Wan Hasiah, 1999b).

7.3.2. Richardson Point unit

The samples from this unit are characterized by an abundance of both low and high molecular weight n-alkanes, which suggests plant input. Pristane/Phytane ratios, all greater than 2, are suggesting that waters were not anoxinic at the time of deposition



Black square = Tg. Punei unit, blue triangle = Tg. Batu unit, blue circle = Temiang unit, green circle = East Kiamsam Sandstone, red square = Richardson Point unit and blue square = Belait Formation

Figure 7.2: Plot of Pristane/n-C_{17} Vs Phytane/n C_{18} showing terrestrial source of hydrocarbon (Modified after Shanmugan, 1985).

(Didyk, et al., 1978). The Carbon Preference Index (CPI) values are between 1.20 and 1.32 (odd number predominance). Usually, a marked odd predominance is associated with terrestrial organic matter (Tissot and Welte, 1984). N-C_{31}/n-C_{17} ratios are between 1.65 and 2.26, generally greater than 1, suggesting terrestrial input compared to marine input. Pr/n-C_{17} is variable between 2.38 and 3.44. Didyk, et al., (1978) suggested that high Pr/n-C_{17} ratio (> 1) may indicate that terrigenous plants play a major role in depositional environments. However, Wan Hasiah (1999b) reported the high Pr/n-C_{17} ratio associated with sediments of shallow marine environments. The waxy appearance of these samples from Richardson Point unit suggests significant input of higher land plant organic matter in the sediments.

7.3.3 East Kiamsam sandstone and Temiang unit

East Kiamsam sandstone and the Temiang unit show similarity in all parameters, which may indicate the same depositional environments. The distribution of n-alkanes is characterized by a dominance of lower carbon number compounds with odd over even preference. Their n-C_{31} over n-C_{17} ratios are < 1, indicating less higher plant input. The high Pr/Ph ratios of between 2.70 and 2.97 indicate that the pristane and phytane for these units came from a similar source. The high ratios of Pr/n-C_{17} may suggest deposition in shallow marine environment.

7.3.4 Tg. Batu unit

This unit shows a n-alkane distribution similar to the East Kiamsam Sandstone and Setap Shale with high CPI values (1.25-1.37) and high Pr/Ph ratio (1.59-2.72), indicating terrestrial organic matter input. Low n-C_{31} / n-C_{17}, and low Pr/n-C_{17} (0.72) for cross bedded sandstone and high for overlying shale, suggesting a shallow marine setting for the sandstone and more open marine for shale.

Plot of pristane/n-C_{17} versus phytane/n-C_{18} (Figure 7.2), shows a terrestrial source of organic matter for these rocks deposited under oxidizing conditions.

7.3.5 Layang Layangan unit I

The n-alkanes contained in the samples of this unit are dominantly high carbon number with a high odd over even carbon preference. The n-alkane maximums appear generally at C_{31}, indicative of terrestrial material input (Tissot and Welte, 1984; Hunt, 1996). The nC_{31}/nC_{17} ratios are very high in measured samples (>3). Pr/Ph ratios are variable from 2.38 to 7.27 and Pr/nC_{17} in measured samples are 2.95-3.09, suggesting an oxic depositional environment according to Didyk (1978) and dysearobic (intermediate between aerobic and anaerobic) condition according to Khorasani (1987)

7.4.6 Layang Layangan unit II

The low abundance of n-alkanes made the measurements of these samples difficult. However the high CPI value, high Pr/Ph ratios and nC_{31}/nC_{17} ratios, suggest a higher plant input deposited under an oxic to dysearobic condition deposition similar to Layang Layangan unit I.

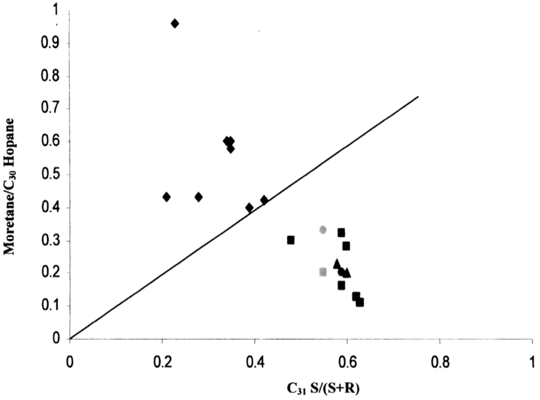
7.4 Thermal Maturity

Maturation of organic matter in sediments is a chemical change in which heat and pressure act during burial of sediments, causing many changes in the original organic matter of the sediments. Many varied parameters have been suggested and used as possible indicators of organic matter maturation such as mean vitrinite reflectance (%R), amount of extractable soluble organic matter, n-alkane preference index (CPI), and pentacyclic triterpane isomer ratios (Douglas and Williams, 1981). The geochemical parameters of the studied samples are presented in Tables 6.1 and 6.2.

Vitrinite Reflectance (VR) is the most commonly used organic maturation parameter (e.g. Hunt, 1995). The thermal maturity of samples studied shows a wide range, i.e. ranging from 0.44% to 0.80% Ro. In Figure 7.1 the isoprenoid/n-alkane ratios are also, in part, a function of maturity with more mature samples tending to plot closer to the origin. Figure 7.3 is a plot of C_{31} S/(S + R) hopane Vs Moretane/C_{30} hopane and shows variations in maturity within the Labuan sediments.

The vitrinite reflectance of the Tg. Punei ranges from 0.68 – 0.80% Ro, showing moderate maturity. Biomarker data reveals this unit has a CPI value of about 1.09. A CPI value close to 1 indicates complete maturation for terrigenous samples (Simoneit, 1978).

The hopane isomeration at C-22, the 22S / (22S+22R) parameter is probably the most widely applied biomarker maturity parameters and records the relative abundance of the more thermally stable 22S isomer (e.g. Peters and Moldowan, 1993; Kolaczkowska et al., 1990) compared to the biologically-derived 22R stereochemistry.



Black square = Tg. Punei unit, blue triangle = Tg. Batu unit, blue circle = Temiang unit, green circle = East Kiamsam Sandstone, red square = Richardson Point unit, blue square = Layang Layangan units and green square = Bethune Head unit.

Figure 7.3: Plot C_{31} S/(S + R) Vs Moretane/C_{30} Hopane, showing variations in maturity within Labuan sediments.

These ratios of 0.62 to 0.63 for C_{31} and for C_{32} from 0.57 to 0.59, indicating that this unit has entered oil window range.

Ts / (Ts+Tm) ratios range from 0.32 to 0.41. This parameter is used for maturity assessment, although there is a variation with source of organic matter (Seifert and Moldowan, 1978). In the Labuan samples the source of organic matter affects these ratios and, therefore, this parameter can't be used for measuring the maturation of this unit.

The moretane / C_{30} hopane ratios are low in all samples and range from 0.11 to 0.13. Moretanes are much less stable than hopanes, and thus decrease in concentration more rapidly with increasing maturity. All or most of the moretane loss occurs at very low maturities. Moretanes/hopane ratios, like 22S/ (22S+22R) ratios for extended hopanes are mainly useful as a qualitative indicator of maturity (Grantham, 1986). This ratios is variable from about 0.8 in immature bitumens to values of less than 0.15 in mature source rocks and oils to minimum of 0.05 (Mackenzie et al., 1980; Seifert and Moldowan, 1980)

The oleanane index (oleanane/C_{30} hopane) for these sample ranges from 0.89 to 1.33. . The oleanane index tends to increase by destruction of hopanes. High maturity oils show a higher oleanane index than original organic matter in immature or low-maturity-level source rocks (Alberdi and Lopez, 2001).

Since this unit was deposited in marine environment and the organic matter is of terrestrial origin, the occurrence of oleanane may due to the change of aromatic oleanoids (decrease with increase of oleanane) which can be obtained by contact of seawater with plant matter (Murray et al., 1997).

In contrast to Tg Punei unit, the East Kiamsam sandstone, Temiang unit and so-called Richardson Point unit are of moderate maturities, but less than the Tg. Punei unit (see above). These units show vitrinite reflectance ranging from 0.56 to 0.58% Ro. Moretane/C_{30} hopane are between 0.16 – 0.33, are low but more than Tg. Punei. The high maturation is also reflected in a high degree of conversion of the biologically produced 22R to 22S for C_{31} and C_{32} homohopanes. The ratios 22S/ (22S+22R) for C_{31} range from 0.59 to 0.60 and from 0.55 to 0.66 for C_{32} for these units.

In contrast to the East Kiamsam sandstone, Temiang unit and Richardson Point units, the vitrinite reflectances of Layang Layangan units and Bethune Head range from 0.52% Ro at base of Layang Layangan I to 0.44% Ro for Bethune Head, indicating low maturity. CPI values range from 1.20 to 1.72, which also reflect low maturity. In relation to hopanes, the low degree of thermal maturity is reflected in a low degree of conversion of the biologically produced 22R form for C_{31} –C_{33} 17α (H) hopanes (homohopanes) to their 22*S* epimer. The ratios 22S / (22*R* + 22*S*) of Layang Layangan units for C_{31} range from 0.28 to 0.42 and from 0.18 to 0.42 for the C_{32} homologue. These ratios for the upper part of Belait Formation range from 0.21 to 0.34 for C_{31} and from 0.25 to 0.38 for C_{32}.

There are relatively large amounts of moretane, which is thermally less stable than C_{30} hopane in Layang Layangan units. The ratios of moretane/C_{30} hopanes range from 0.42 to 0.96 for Layang Layangan unit I and from 0.43 to 0.60 for Layang Layangan unit II. These high values of moretane/C_{30} hopane ratios are an indicator of the low thermal maturity of the organic matter (Mackenzie et al., 1980; Seirfert and Moldowan, 1980)

The high abundance of Tm compared to Ts is reflected in Ts/ (Ts+Tm) ratios, which range from 0.17 to 0.47 for both Layang Layangan unit I and the Layang layangan unit II, and may indicate low maturity. However, these ratios must be taken with considerable care as an indicator of thermal maturity, as it depends to a considerable degree on the conditions of sedimentation and the character of the sources of organic matter (Seifert and Moldowan, 1978).

Similar to East Kiamsam Sandstone (above), the vitrinite reflectance for Tg. Batu unit (Belait Formation in previous work) is moderate (0.60% Ro) and high compared to Layang Layangan units which is less than 0.52%. The moretane/C_{30} hopane ratios range from 0.20 to 0.23. The 22S/ (22S+22R) for C_{31} and C_{32} hopane are 0.58-0.60 and 0.58-0.62 for C_{31} and C_{32}, respectively.

7.5 Relationship between geochemical parameters and stratigraphy

The stratigrapy of Labuan Island was studied by many workers but so far there is no clear division for this sequence. For example, Wilson (1964) divided it as three formations consisting of Temburong formation, Setap Shale and Belait Formation. Lee (1977) divided these formations to small units to show the facies changes. Mazlan (1994) and (1997) studied the western part of the island and grouped the Layang Layangan unit I of Lee (1977), which forms the lower part of the Belait Formation, beneath the prominent conglomerate strike ridge from Tg. Layang Layangan, with the Temburong Formation. Tongkul (2001) divided this sequence into Setap Shale and Belait formation. Clearly, there remains some confusion over the stratigraphy of Labuan.

None of the earlier authors tried to study the sequence in relation to organic geochemical parameters. In this part of the current study, geochemical parameters will be used to make with comparison previous studies.

7.5.1 Temburong Formation

The Tg. Punei unit (Proximal turbidite unit of Lee (1977)) mapped by Wilson (1964) as part of the Crocker Formation, is exposed along the south western extremity of the Kiamsam Peninsula, extending from the Shell Oil Terminal to Tg, Punei. Tongkul (2001) considered it as part of Setap Shale. The geochemistry study for this unit indicates open marine depositional environments with low input of terrestrial organic matter. This observation is reflected in the normal alkane distribution, Low pristane/normal-C_{17} and normal-C_{31}/C_{17} ratios. The pristane/phytane less ratio is than 3. The thermal maturity parameters show that these rocks are the oldest rocks in Labuan. The vitrinite reflectance is 0.68 to 0.80%, where even the 0.68 % Ro reading may be low because of oil staining in this sample. The CPI value and hopane isomerations at C-22 of extended hopane support the relative high thermal maturity, therefore they support the deepest burial in units studied in Labuan Island.

7.5.2 Setap Shale

In this study, based on geochemical data and vitrinite reflectance, Setap Shale may be present in Labuan Island. Tongkul (2001) reported that Setap Shale made up the core of Labuan Island, indicating therefore that the Setap Shale is the oldest rocks in the Island.

The current study supports that Setap Shale makes up the core of the Labuan anticline. Since the depositional environments of the Labuan sediments are open marine, shallow marine and delta, this sometimes made the differentiations difficult, especially with the high deformation which these sediments underwent. The Belait Formation differs between delta complexes, tidal flat to shallow marine; Setap Shale are shallow marine to deep marine; Temburong Formation is deep marine. To date none of the previous workers have made a detailed correlation between Labuan sediments since Wilson, 1964 and Lee, 1977.

As is known Labuan Island is an anticline (Wilson, 1964; Lee, 1977, Mazlan, 1994 & 1997; Tongkul, 2001). Therefore the interpretation of Labuan stratigraphy should be explained based on a typical anticline structure, which suggests the older rocks are in the core and the youngest in the flanks.

7.5.2.1 Richardson Point unit

The Richardson Point unit, or distal turbidite unit of Lee (1977) is part of Temburong Formation, is quite an extensive unit on Labuan making up large areas of the older core rocks forming the Labuan anticline; in particular, large portions of Kiamsam Peninsula and also most of the southern part of the Rancha Rancha Peninsula. This unit, included by Wilson (1964) in the Temburong Formation based on the comparatively similar lithology of these rocks, mapped as the Kiamsam series by Heybroek and Crews (1954), to the Temburong Formation on the mainland of Borneo. Tongkul (2001) placed it in Setap Shale, based in sedimentary features.

Based on geochemical data and vitrinite reflectance, the current study supports Tongkul's interpretation. The alkane distributions of the samples of this unit show some differences from the Tg. Punei unit (Temburong Formation). While the Samples of Temburong Formation show deep marine influence with less terrestrial organic matter, this unit shows, shallower environments than Temburong Formation with large amount of terrestrial organic matter.

The pristane/phytane ratios are more than 3 for this unit while for the Temburong Formation they are lower than 3. This perhaps suggests more oxidizing conditions for the Richardson Point unit. The ratios of n-C_{31}/n-C_{17} are more than 1; while for the Temburong Formation they are lower than 1. The CPI value ranges from 1.20 to 1.32, suggesting lower maturity than the Temburong Formation (CPI of 1.09). The lower maturity of this unit is supported by vitrinite reflectance which is 0.56% while for Temburong Formation R_0 ranges from 0.68 to 0.80% Ro. The occurrence of this unit, and the Tg. Punei unit at the same topographic level, may be explained by the fault located in south west Labuan Island (Lee, 1977 & Tongkul, 2001).

This fault raised the Temburong Formation to the same level with the Setap Shale.

Based on the parameters used in this study, Sample Lab 41 (outcrop near to Jalan Rancha Rancha), shows some similarity to the Richardson Point unit (Figure 7.4). Sample Lab 41 also shows some lithological similarity to that unit. The TIC of Lab 41 shows abundant high normal alkanes similar to those seen into Richardson Point unit. The Ratio of n-C_{31}/n-C_{17} indicates large amounts of terrestrial organic matter can be supported by high pristane/phytane and high pristane/n-C_{17} ratios. CPI value of 1.06 suggests moderate maturity. The moderate maturity is supported by vitrinite reflectance (Ro 0.56%). The moretane/C_{30} hopane and the isomerisation ratios at C-22 of C_{31} and C_{32} hopane support the moderate maturity. The moretane/C_{30} hopane ratio is quite low (0.30) while 22S/ (22R+22S) ratios are 0.48 for C_{31} and 0.61 for C_{32}. The low reading in C_{31} hopane may be due to coelution with other compound as noted by Farrimond et al., (1998).

7.5.2.2 Kiamsam Sandstone

East Kiamsam Sandstone is the informal unit of Lee (1977) which crops out at Tg. Kiamsam. Wilson (1964) mapped it as part of Temburong Formation (Tg. Punei unit), while Lee (1977) separated them due to contrast in rocks type.

The current study supports the contrast between Kiamsam Sandstone and Tg. Punei unit, therefore supporting the observation of Tongkul (2001) who mapped it within the Setap Shale. The TIC for the Tg. Punei unit and East Kiamsam sandstone show marine influence and both of them have n-C_{31}/n-C_{17} ratios less than 1. Even though there is similarity in normal alkane distribution and n-C_{31}/n-C_{17} ratio, the East Kiamsam sandstone shows more terrestrial organic matter than the Tg. Punei unit, these ratios may suggest a shallower environment than Tg. Punei unit.

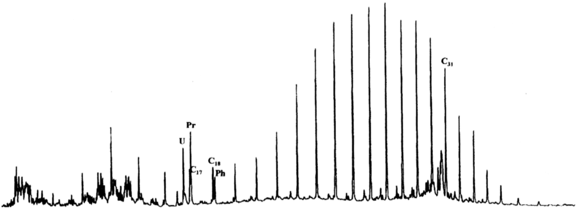


Figure 7.4: TIC of alkane in sample Lab 41 show abundance of high molecular weight.

The contrast in environments is reflected in high ratios of pristane/phytane and pristane/n-C_{17}. The pristane/phytane ratio is 2.93 for East Kiamsam sandstone and 2.20 -2.75 for Tg. Punei unit. Pristane/n-C_{17} are 1.26 and from 0.31 to 0.68 for East Kiamsam sandstone and proximal turbidite, respectively.

In terms of thermal maturity, the Tg. Punei unit is more thermally mature than East Kiamsam sandstone. Vitrinite reflectance ranges from 0.68 to 0.80% for Tg. Punei unit and 0.58% for East Kiamsam Sandstone. The contrast in thermal maturity also is reflected in moretane/C_{30} hopane ratios and homohopane isomeration at C-22. Moretane /C_{30} hopane ratio of East Kiamsam Sandstone is 0.33 while for Tg. Punei unit is from 0.11 to 0.13. The homohopane isomeration at C-22 of Kiamsam sandstone is 0.55 and 0.57 for C_{31} and C_{32}, respectively, while for Tg. Punei unit is from 0.62 to 0.63 of C_{31} and from 0.57 to 0.59 of C_{32}.

7.5.2.3 Tg. Batu unit

The Tg. Batu unit is located at the east part of Labuan Island. As shown in Heybroek's map (Wilson, 1964) and Lee (1977) the eastern part is mainly Belait formation even though Wilson (1964) noted an occurrence of Setap shale near to Tg. Batu. Correlation between the western part and eastern part of Labuan Island remains unclear (Mazlan, 1994). In this study, Samples from Tg. Batu, which is located in south of the eastern part of the island, were studied geochemically to determine the thermal maturity, type of organic matter and conditions of deposition, then compared with the Belait Formation in the western part. In the samples studied, there are significant variations between these rocks. In terms of organic matter which can be seen clearly by eye, the eastern part (Tg. Batu unit) is very lean, while the Belait on the west side is rich in organic material including coal. Based on GC-MS analysis, the TIC of Tg. Batu unit is uni modal and shows more marine influence than western part, which is reflected in the normal-alkane distribution, n-C_{31}/n-C_{17} ratios (0.53 - 0.71) and pristane/n-C_{17} (0.72 - 1.48). The ratio of C_{29} norhopane/C_{30} hopane of Tg. Batu is low compared to western part. Based on vitrinite reflectance, these rocks show moderate maturity of 0.60% Ro therefore the current study suggests grouping Tg. Batu unit within Setap Shale (Figure7). Other evidence supporting this observation is similarity of this unit to the Kiamsam Sandstone. Both of them show similarity in thermal maturity and type of organic matter. Sample Lab 41 (see above), located in the eastern part of Labuan anticline and was interpreted as belonging to Setap Shale in this study, may support t the occurrence of Setap Shale in south eastern part of Labuan Island as claimed by Wilson (1964) who reported that, Setap Shale is existing near to Tg. Batu.

7.5.3 Belait Formation

7.5.3.1 Layang Layangan units

The correlation of Belait Formation is carried out on Layang Layangan I which is located under prominent strike ridge from Tg. Layang Layangan to Tg. Kubong, and Layang Layangan unit II and Tg. Kubong which make up the prominent strike ridge. The environments of Layang Layangan unit I (lower Belait Formation of Lee (1977) and Tongkul (2001) differ between delta slope to tidal flat, while for Layan Layangan unit II is a fluvial deposit (Wilson, 1964; Lee, 1977; Mazlan, 1994, 1997; Tongkul, 2001).

Mazlan, (1997) grouped the Layang Layangan unit I of Lee (1977), which forms the lower part of Belait Formation with Temburong Formation. Tongkul (2001) regrouped it within Belait formation. According to Lee (1977) the Layang Layangan unit I possibly lies conformably on Setap Shale and the contact could be transitional.

This study supports that the Layang Layangan unit I should be grouped within the Belait Formation as Wilson (1964), Lee (1977) and Tongkul (2001) suggested.

All the vitrinite reflectance measurements of samples from Layang Layangan units suggest that the organic matter within these sediment, are thermally immature. The vitrinite reflectances are from 0.52 %Ro at base of Layang Layangan unit I to 0.48 %Ro for the Layang Layangan unit II. The vitrinite measurements were carried out on indigenous macerals and carefully excluded reworked material.

The GC-MS analyses for samples of this formation from different locations agree with vitrinite reflectance observations.

Based on Geochemical data and vitrinite reflectance, all the samples studied are immature with lower maturity observed in the upper part compared to the lower one. The vitrinite reflectance measurements may suggest that the uncomfortable contact between the lower part and upper part of Belait Formation reflects only facies changes vertically within a delta complex. The %Ro for the Layang Layangan unit I ranges from 0.52% to 0.49 %, while for the fluvial unit (Layang Layangan unit I) is 0.48 R%.

The TIC distribution of samples studied from this units show a relatively low abundance of normal alkanes compared to samples from the Temburong Formation and Setap Shale, even though there are two samples from fluvial deposits collected from different locations (Tg. Layang Layangan and Tg. Kubong) which show slight biodegradation (Figure 6.5). The TIC distributions reflect the low abundance of normal alkane for these units, but they are more abundant for samples from the Layang Layangan unit I compared to unit II. The TIC also shows a high abundance of high molecular weight, terrestrial organic matter which could be supported by high ratios of pristane/phytane (1.63-7.5) (Peters and Moldowan, 1993), high n-C_{31}/n-C_{17} (Hunt, 1996) and high pristane/n-C_{17} (2.43 – 3.09 (Didyk, 1978).

The triterpanes (m/z 191) of Layang Layangan units show differences in distribution between Temburong Formation and Setap shale. In contrast to Temburong and Setap Shale samples, C_{29} norhopane is the most dominant compound in all samples. The dominance of C_{29} hopane is reflected in the high ratios of C_{29} hopane/C_{30}, which are generally more than 1 (Table 6.2). High ratios of C_{29}/C_{30} hopane have been reported from sediments believed to be from terrestrial source rocks including coal (Brooks, 1986).

However, oils and sediments from organic rich carbonates and evaporates have also been shown to possess high concentrations of the C_{29} hopane (Zumberge, 1984; Connan et al., 1986; Price et al., 1987). Wan Hasiah (1994) noticed the C_{29}/C_{30} hopane ratios are high in forest-swamp coals and regards the ratio as a terrestrial marker and noted that it is also maturity dependant. In this study, ratio could also be maturity-dependant whereby samples of low thermal maturity (Belait Formation) possess relatively higher C_{29}/C_{30} hopane ratios compared to those of higher thermal maturity (Temburong Formation and Setap Shale).

The ratios of 22S/ (22S+22R) for C_{31} 17α (H), 21β (H)-hopanes are between 0.42 to 0.23 for Layang Layangan unit I and from 0.34 to 0.21 for the fluvial deposits. The moretane/C_{30} ratios are high, ranging from 0.42 to 0.96 for Layang Layangan unit I and from 0.43 to 0.60 for fluvial deposits. 22S/ (22S+22R) for C_{31} and moretane/C_{30} hopane ratios suggest low maturity and therefore support the vitrinite reflectance data.

7.5.3.2 Bethune Head unit

This unit clearly represents upper part of the Belait Formation (Lee, 1977; Mazlan, 1994). One sample (Lab 17) from this unit was selected for this study. The vitrinite reflectance of sample Lab 17 is 0.44% R_o, which shows the lowest maturity in Labuan sediments. The maturity for extracted organic matter didn't support this low maturity (Figure 7.5).

This sample has ratio about 0.55 for both C_{31} and C_{32} at C-22 of homohopane isomeration. The homohopane isomeration ratios are used to estimate the thermal maturity of extracted organic matter and oil (Peters and Moldowan, 1993; Farrimond et al., 1998). The sample also shows the oleanane to C_{30} hopane about of 1.36 which may suggest high maturation (Alberdi and Lopez, 2000). The low ratio of moretane/C_{30} hopane may also support high maturity. Therefore, the hydrocarbon within this sample is interpreted as migrated hydrocarbon.

7.5.4 Proposed Stratigraphic Division

Based on the organic geochemical parameters and petrological data obtained in this study a revised stratigraphic division is proposed here. This is as show in Table 7.1.

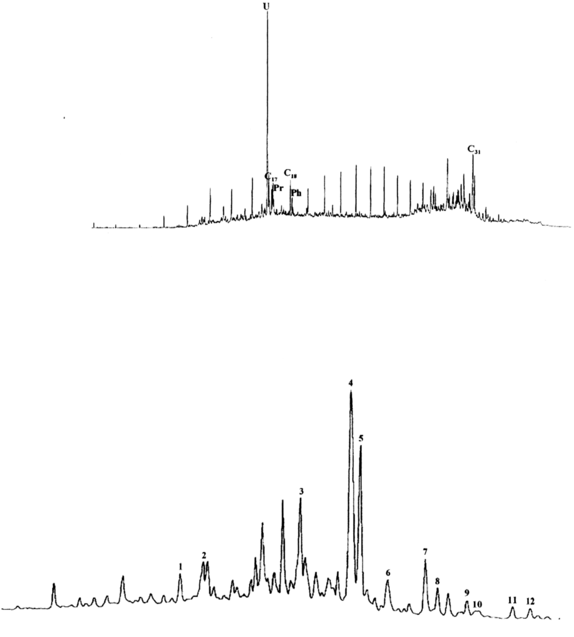


Figure 7.5: Normal-alkanes, isoprenoids (top) and triterpanes (m/z 191) distributions (bottom) in Bethune head unit.

<table>
<tr><th>Stratigraphy units used in this study</th><th>Division of this study</th><th>Ro%</th><th>Pr/Ph</th><th>CPI</th><th>Moretane/ C_{30} Hopane</th><th>C_{31} S/(S+R)</th></tr>
<tr><td>Bethune Head unit</td><td rowspan="3">Belait Formation</td><td rowspan="3">0.44-0.52</td><td rowspan="3">1.63-7.50</td><td rowspan="3">1.42-2.33</td><td rowspan="3">0.42-0.96</td><td rowspan="3">0.21-0.42</td></tr>
<tr><td>Layang Layangan unit II</td></tr>
<tr><td>Layang Layangan unit I</td></tr>
<tr><td>Tg. Batu unit</td><td rowspan="4">Setap Shale</td><td rowspan="4">0.56-0.60</td><td rowspan="4">1.57-4.57</td><td rowspan="4">1.06-1.37</td><td rowspan="4">0.16-0.33</td><td rowspan="4">0.55-0.60</td></tr>
<tr><td>Temiang unit</td></tr>
<tr><td>East Kiamsam Sandston unit</td></tr>
<tr><td>Richardson Point unit</td></tr>
<tr><td>Tg. Punei unit</td><td>Temburong Formation</td><td>0.68-0.80</td><td>2.20-2.75</td><td>1.09</td><td>0.11-0.13</td><td>0.68-0.80</td></tr>
</table>

Table 7.1: division of Labuan sediments according to geochemical parameters used in this study