

## An assessment of palaeodepositional environment and thermal maturity of Upper Palaeozoic sediments of Peninsular Malaysia by organic geochemical and petrological methods

Amer Mohamed Ibrahim<sup>1</sup> and Wan Hasiah Abdullah<sup>2</sup>

<sup>1</sup>Al-Fateh University, Libya

<sup>2</sup>Department of Geology, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia

**ABSTRACT** Six organic-rich sediments of the Upper Palaeozoic Kuantan Group from East Pahang were analysed by means of organic petrological and geochemical methods. The aim of this study is to assess the type of organic matter, maturity and depositional environments based primarily on biomarker (geochemical fossils) distributions. The gas chromatograms of the saturated hydrocarbon fractions of the Charu and Sagor shales and coaly shales display a smooth high end-member distribution of n-alkanes extending beyond nC<sub>30</sub>. A relatively lower abundance of n-alkanes is displayed by a limestone sample analysed. Most of these samples show evidence of slight biodegradation as suggested by the presence of unresolved complex compounds and the loss of some of the lower molecular weight n-alkanes. The strong predominance of high molecular weight n-alkanes in the shales / coaly shale of the Charu and Sagor formations suggest significant input of higher land plant organic matter into these sediments. The Panching limestone sample is dominated by nC<sub>17</sub> – nC<sub>19</sub> alkanes suggesting significant contributions of algal-derived organic matter. The even n-alkane predominance commonly associated with limestone is apparent within the medium range (nC<sub>14</sub> – nC<sub>19</sub>) of the Panching limestone analysed. The possible presence of a C<sub>21</sub> highly branched isoprenoid is noted in this limestone sample but is not observed in the other samples. The lack of higher land plant-derived organic matter within the Panching limestone sample is evident from the low concentration of higher molecular weight n-alkanes compared to the Charu and Sagor sediments. The presence of significant marine influence in all of the samples studied is suggested by the high abundance of tricyclic terpanes. The 22S/22S+22R C<sub>32</sub> hopane has reached equilibrium, and this is supported by the high maturity level as indicated by the vitrinite reflectance data (1.08 – 1.13%Ro). Although of high maturity, the samples are still within the oil window maturity range, suggesting these samples have not been too severely effected by thermal metamorphism or the active tectonic activities of the Eastern belt of Peninsular Malaysia.

**ABSTRAK** Enam sampel batuan sedimen yang kaya dengan bahan organik berumur Palaeozoik Atas dari Kumpulan Kuantan, Timur Pahang telah dikaji menggunakan kaedah petrologi dan geokimia organik. Tujuan kajian ini adalah untuk menilai jenis bahan organik, kematangan dan persekitaran pengenapan berdasarkan kepada taburan penanda biologi (fossil geokimia). Kromatografi gas hidrokarbon tepu bagi syal Charu dan Sagor menunjukkan taburan sekata bagi alkana biasa ahli hujung yang melebihi nC<sub>30</sub>. Secara relatifnya, sampel batu kapur menunjukkan kehadiran alkana biasa yang kurang. Kebanyakan sampel-sampel ini menunjukkan bukti terdapat sedikit biodegradasi sebagaimana dicadangkan oleh kehadiran sebatian kompleks takterhurai dan oleh kehilangan sebahagian dari alkana biasa yang berat molekul rendah. Dominasi ketara alkana biasa yang mempunyai berat molekul tinggi di dalam syal/syal berarang batu dari Formasi Charu & Sagor mencadangkan sumbangan penting bahan-bahan organik dari tumbuhan daratan peringkat tinggi ke dalam sedimen. Sampel batu kapur Panching didominasi oleh alkana nC<sub>17</sub>-nC<sub>19</sub> yang mencadangkan sumbangan penting adalah dari bahan organik asalan alga. Dominasi alkana biasa bernombor genap yang biasanya dikaitkan dengan batu kapur dapat dilihat dalam julat pertengahan (nC<sub>14</sub>-nC<sub>19</sub>) bagi batu kapur yang dikaji. Kemungkinan kehadiran C<sub>21</sub> isoprenoid dilihat di dalam sampel batu kapur tetapi tidak di lihat di dalam sampel lain. Kekurangan bahan organik dari asalan tumbuhan peringkat tinggi di dalam sampel batu kapur Panching dapat ditafsir dari kepekatan rendah alkana biasa berat molekul tinggi berbanding sedimen Charu dan Sagor. Kehadiran pengaruh marin yang ketara di dalam semua sampel yang dikaji dicadangkan oleh kandungan terpana tricyclik yang tinggi. 22S/22S+22R C<sub>32</sub> hopana telah mencapai keseimbangan dan ini disokong oleh tahap

kematangan tinggi yang di tunjukkan oleh pantulan vitrinit (1.08-1.13%Ro). Walaupun berkematangan tinggi, sampel ini masih di dalam julat jendela minyak, mencadangkan sampel-sampel ini tidak dipengaruhi terlalu hebat oleh metamorfisme terma atau oleh aktiviti tektonik yang aktif di Jalur Timur Semenanjung Malaysia.

(Upper Palaeozoic sediments, biomarker distributions, pristane/phytane ratio, hopane, thermal maturity)

## INTRODUCTION

The Kuantan Group within the Eastern Belt of Peninsula Malaysia is dominated by Carboniferous and Permian clastics and carbonates. Geological investigations of sedimentary rocks in the Kuantan area of Pahang are numerous and include work from the Geological Survey Department of Malaysia, University of Malaya and University Kebangsaan Malaysia. The sedimentary sequence of Pahang contain several rock units. Fitch (1951) named them as Arenaceous and Calcareous series. Alexander (1959) replaced the term Calcareous series by "Kuantan Group". Metcalfe et al (1980) formalised and retained the term Kuantan Group to Charu Formation, Panching Limestone, and Sagor Formation. The Palaeozoic sediments are more intensely folded than the younger strata, having undergone at least two or more periods of deformation (Fateh, 1993). According to Fateh, the present overall structural trend of the country is believed to have been imprinted by the late Triassic Orogeny.

In this paper organic petrological and geochemical parameters are discussed based on six rock samples (three shales, two coaly shales and a limestone) of the Upper Palaeozoic Kuantan Group of East Pahang. Three samples (Ch1, Ch2 and Ch4) are from the Charu Formation, one sample (Pa1) is from Panching Limestone and two samples (Sa2 and Sa4) are from the Sagor Formation. All are outcrop samples collected from three different localities (Figure 1). The aim of this study is to discuss the use of biomarkers (or geochemical fossils) in assessing the type of organic matter, maturity and depositional environments for the sediments under investigation.

## METHODOLOGY

### *Petrology*

Samples for petrographic study were prepared by mounting whole rock fragments of about 2mm

size in epoxy resin and were polished using successively finer grades of silicon carbide papers and alumina powders. Petrographic examination was performed using a Leitz DMRXP photometry microscope in reflected 'white' light and blue light excitation using oil immersion objectives. A photometer was used to measure the reflectance intensity (at 546 nm) by comparison with a glass standard. A total of 25 readings were made to calculate the mean reflectance in oil (%Ro).

### *Geochemistry*

Approximately 120-130g of the powdered samples were Soxhlet extracted using a dichloromethane/methanol mixture (93:7) for 36 hours. The extracts were separated by liquid chromatography into three fractions: aliphatic hydrocarbons, aromatic hydrocarbons, and polar compounds (NSO). The saturated hydrocarbons were analysed by gas chromatography (GC) and gas chromatography - mass spectrometry (GC-MS), monitoring m/z 191 for triterpanes and m/z 217 for steranes. The GC was fitted with a fused silica capillary column (30m, 0.2mm i.d.) and Helium was used as a carrier gas. The oven temperature was held at 50°C to 290°C at 6°C/min with final temperature held for 10 minutes.

## RESULTS AND DISCUSSION

### *Petrology*

Microscopic examination suggests a relatively high contribution of terrestrial material to the total organic content of the rock. The major components of the organic matter are vitrinite, structureless grey particles, and very low reflecting brownish amorphous organic matter. Other recognisable organic matter is generally not abundant. Under blue light excitation, yellow organic fluorescence of bitumen and some amorphous organic matter can be observed (Figures 2 and 3; see also Plate 5.2 of Amer, 1999). The mean vitrinite reflectance (% Ro) for all the samples studied is in the range of 1.08% -

1.13% (Table 2), indicating that these sediments have reached a high level of thermal maturity.

#### **Total Organic Carbon (TOC)**

The total organic carbon (TOC) data (Table 1) show a distinct variation between the abundance of organic matter present in the shales and coaly shales compared to that in the limestone. The Charu samples possess the highest organic richness with TOC values of between 1.34 and 9.55wt%. The Sagor sample contains a very low TOC (0.26wt%) and the Panching limestone sample possesses only a trace amount of organic matter.

#### **Normal alkane and acyclic isoprenoids**

The distribution of saturated hydrocarbons for samples of the different lithologies analysed are shown in the gas chromatograms of Figure 4. The GC fingerprints of the shales and coaly shales reveal a wide range of n-alkanes with carbon numbers that range from nC<sub>21</sub> to nC<sub>31</sub> or higher. A number of samples show dominant humps comprising unresolved complex hydrocarbon mixtures. The hump starts generally at around nC<sub>22</sub>. The presence of this hump is possibly an indication of biodegradation. The moderate molecular weight n-alkanes (nC<sub>10</sub> – nC<sub>20</sub>) and acyclic isoprenoids, such as pristane and phytane, occur only in low concentrations in all samples. The possible presence of the C<sub>21</sub> highly branched isoprenoid (peak IC<sub>21</sub> in Fig. 4B) is noted in the limestone sample but is not observed in the other samples. The Panching limestone sample (Fig. 4B) is dominated by nC<sub>17</sub> – nC<sub>19</sub> alkanes, perhaps suggesting significant contribution of algal derived organic matter. The even n-alkane predominance commonly associated with limestone is apparent within the medium range (nC<sub>14</sub> – nC<sub>19</sub>) of the Panching limestone analysed. The lack of higher land plant-derived material is suggested by a very low abundance of higher molecular weight n-alkanes (nC<sub>20</sub> to nC<sub>31</sub>). The shale/coaly shale samples display a smooth homologous series within the higher molecular weight range extending beyond nC<sub>30</sub> suggesting significant input of higher land plant organic matter into these sediments. The fingerprint also shows apparent evidence of slight biodegradation (i.e. partial removal of n-alkanes) for most of the samples, and is most apparent around nC<sub>10</sub> to nC<sub>21</sub>. The Panching limestone sample is possibly the most biodegraded as suggested by the highest unresolved hump among the samples studied. The presence of biodegradation could be related

to the mixing of oxygenated waters within these sediments due to prolong surface exposure which is a necessary condition for biodegradation to have taken place.

#### **Pr/Ph ratio**

The isoprenoid alkanes pristane (Pr) and phytane (Ph) are present in all of the samples studied, usually as the most major constituents of the isoprenoid alkanes. Gas chromatogram fingerprints of all the samples show abundant pristane and high pristane/phytane ratios which are characteristic of terrigenous materials. The most common application of these alkanes is to infer the depositional condition and source of the organic materials (Gonzalez-Vila, 1995). The ratio of the pristane to phytane has long been associated with the redox conditions of the depositional environment (Brooks and Smith, 1969; Powell and Mckridy, 1973). These early workers assumed that both pristane and phytane were derived from the phytal side chain of chlorophyll. More recently, it has been shown that pristane can be derived from  $\alpha$ -tocopheral and phytane from bis-phytahyl ethers which occur in archaeobacteria (Philp 1994). According to Cooper (1990), pristane and phytane are derived from the chlorophyll of higher plants, algae and photosynthetic bacteria and from archaeobacteria. The existence of various precursors therefore dictates that the Pr/Ph ratio should be used with care. All of the samples studied here display Pr/Ph ratios greater than 3.0 except for Pa1 (Table 1); The highest ratio occurs in the samples Sa2 and Ch1. The Ch2 and Ch4 samples show Pr/Ph ratios < 4, whilst Ch1, Sa2 and Sa4 samples have Pr/Ph ratios > 4. The Panching limestone has a Pr/Ph ratio equal to 1.8. The high Pr/Ph ratios in the Charu and Sagor samples, and the low Pr/Ph ratio of the Panching limestone, are most likely to be associated with the source of organic matter and less indicative of the extent of the anoxicity/oxicity of the depositional condition.

#### **Carbon Preference Index (CPI)**

The CPI value is influenced both by type of organic matter and by maturity (Tissot and Welte 1984). High CPI values represent an odd over even carbon number preference and occur in response to the chemistry of higher plant surface waxes (an important precursor of waxy components in sedimentary organic matter). Hydrocarbons thought to be derived from a coaly organic matter source contain carbon preference

indices equal to or greater than one. Moldowan *et al.* (1985) concluded that an odd carbon preference is characteristic of oils derived from source rocks deposited in non-marine depositional environments. In contrast, the predominance of an even numbered n-alkane preference is commonly observed in bitumens and oils derived from carbonate evaporite rocks (Palacas *et al.*, 1984). If the total even and odd numbered paraffins are equally abundant the value of the (CPI) will be equal to one as generally observed in high maturity samples (Tissot and Welte, 1984).

In the studied samples the CPI (as defined by Bray and Evans, 1961) ranges from 1.0 to 1.2 (Table 1). The GC fingerprints show a slight odd over even predominance with CPI values of 1.2, 1.1, 1.1 for samples Ch1, Ch2 and Ch4, respectively. Samples Sa1 and Sa4 possess CPI values of 1.0. Sample Pa1 has a CPI value of 1.2. The range of CPI values (1.0 – 1.2) observed in most of the studied samples is believed to represent a residual source influence despite the high thermal maturity of all the samples (exceeding 1.0% Ro, Table 2).

#### **Tricyclic and tetracyclic terpanes**

The tricyclic terpanes are a useful series of biomarkers for differentiating type of organic matter, maturity and depositional environments. Figure 5 shows typical distributions of the tricyclic and tetracyclic terpanes in a selection of samples studied here (peak identifications are given in Table 3). Tricyclic and tetracyclic terpanes are present in high abundance in all of the samples analysed. The C<sub>24</sub> tetracyclic is the major component in most of these samples.

#### **Hopanes**

Hopanes are ubiquitous in geological samples, indicating a widespread bacterial input (Van Dorsselaar *et al.*, 1974; Ensminger *et al.* 1974). The m/z 191 chromatograms for selected samples (Figure 5) show that the distribution of all samples is dominated by the 17 $\alpha$ (H), 21 $\beta$ (H) hopanes series, ranging from C<sub>27</sub> to C<sub>34</sub> or C<sub>35</sub>, with the absence of the C<sub>28</sub> homologue. The C<sub>30</sub> regular hopane is the most predominant member of the series. The extended hopanes, which occur as stereoisomeric pairs, from C<sub>31</sub> to C<sub>35</sub>, display a staircase distribution (i.e. uniformly lower

amounts with increasing molecular weight). The C<sub>31</sub> and higher homologues occur as 22S and 22R epimers.

#### **Ts/Tm**

The ratio of C<sub>27</sub> trisnorhopane (Tm), relative to C<sub>27</sub> trisnorneohopane (Ts), Tm/Ts, was first proposed as a maturity parameter by Seifert and Moldowan (1981). The Ts/Tm ratio can also serve as a facies parameter for related oils (Barkat, *et al.* 1997). Mello *et al.* (1988b) suggested that Ts/Tm values below 1.0 imply a lacustrine, saline, marine evaporite or marine carbonate depositional environment, whereas values above 1.0 indicate lacustrine fresh water or marine deltaic environment. Tm exceeds Ts in all of the samples analysed in this study.

#### **Steranes**

Steranes commonly found in sediments and crude oils are derived via diagenesis from sterols which are widely dispersed in plants and microorganisms; with the C<sub>27</sub> and C<sub>28</sub> sterols most abundant in marine organisms and the C<sub>29</sub> sterols in higher plants (Gonzalez-vila 1995). The C<sub>27</sub>, C<sub>28</sub> and C<sub>29</sub> steranes occur as 20S and 20R epimers. In the studied samples the distribution of the C<sub>27</sub>: C<sub>28</sub>: C<sub>29</sub> steranes shows no obvious preference. The M/Z 217 fragmentograms (traces not shown) display similar sterane distributions for all the studied samples. The steranes are present in lower relative abundance compared to tricyclics, tetracyclics and pentacyclic terpanes. The diasteranes are present only in minor or trace amounts in nearly all the studied samples. The Panching limestone sample (Pa1) shows low concentrations of rearranged steranes or diasteranes relative to regular steranes which could be as indication of an acidic carbonate depositional environment as suggested by Zumberger (1984). Rubinstein *et al.* (1975) proposed that the relative concentrations of the diasteranes reflect the presence of clay minerals and their ability to catalyse sterane rearrangement reactions. Sieskind *et al.* (1979) have shown that diasteranes can form from precursor sterols through the acid – catalytic activity of clay. This possibly suggests the low abundance of diasteranes in the carbonaceous samples studied could be related to limited occurrence of acid – clay catalysed rearrangement of regular steranes.

## Interpretation of the thermal maturity, source and depositional environment

### *Thermal maturity*

Maturation of organic matter in sediments is a chemical change in which temperature acts during burial of sediments, causing many changes in the original organic matter. Many varied parameters have been suggested and used as possible indicators of organic maturity such as mean vitrinite reflectance % Ro, amount of extractable soluble organic matters, n-alkane preference index (CPI), and pentacyclic triterpane isomer ratios (Douglas and Williams, 1981).

The geochemical maturity parameters of the studied samples are presented in Tables 1 and 2. The mean vitrinite reflectance (%Ro) for all the studied samples is in the range of 1.08% - 1.13%, indicating that these sediments have reached a high level of thermal maturity (late oil window range).

It is well established that the carbon preference index (CPI) values are influenced by the type of organic matter and by the degree of maturity. Higher CPI values > 1.5 always refer to relatively immature samples, low CPI values do not necessarily mean higher maturity, they can also mean a lack of higher n-alkanes originating from terrestrial input (Tissot and Welte, 1984). Bray and Evans (1961) quantified the odd/even preference in n-alkane distributions by defining a carbon preference index (CPI) and they found this value higher in immature sediments but near unity, or just below, in crude oils.

The slight odd-even predominance of n-alkane in these samples (CPI<sub>25-33</sub>: 1.0-1.2, Table 1) is consistent with their maturity range. The decrease in CPI values being an indication of the increase in thermal maturity, although no correlation is observed with vitrinite reflectance data. However, despite the high maturity, it is believed that the influence of type of organic matter, which is mostly of terrestrial origin, is still responsible for the range of observed CPI values.

Extracts from samples of the Charu, Sagor and Panching limestone formations have a predominance of Tm. In addition they have high relative abundance of C<sub>29</sub>Ts (18 $\alpha$ (H)-30-norneohopane) and low relative abundance of C<sub>30</sub> moretane and the C<sub>31</sub>-C<sub>35</sub> extended hopanes. The

lower moretane concentration and elevated concentration of the Ts series reflect the higher maturity of these sediments.

The 22S/22S+22R ratio for C<sub>32</sub> hopane in all the samples studied is about 0.60 (i.e. in the range of 0.56-0.59, Table 2). The 22S/22S+22R ratio has an equilibrium value of 0.60 which corresponds to the onset of hydrocarbon generation (Mackenzie 1984). The isomerisation ratio of the C<sub>29</sub> steranes, as shown by the epimer ratio of 20S/20S+20R, ranges from 0.5 to 0.6, typical of equilibrium values, thus supporting the vitrinite reflectance data.

This high maturity suggests the sediments have been buried to considerable depth, prior to being uplifted to their present position. Although of high maturity, the samples are still within the oil-window range (towards the end of it), suggesting these samples have not been too severely effected by thermal metamorphism or the active tectonic activities of the Eastern Belt of Peninsular Malaysia.

### *Source/type of organic matter*

The gas chromatograms of the saturated hydrocarbons for all the selected samples in this study display smooth homologous series of n-alkane extending beyond n-C<sub>31</sub>, with a low odd/even predominance and with a high relative concentration of long chain n-alkanes. The waxy appearance of these samples suggests a significant contribution of organic matter input of land plant origin.

A relatively lower abundance of n-alkanes is displayed by the Panching limestone sample. This sample is dominated by nC<sub>17</sub>-nC<sub>19</sub> alkanes suggesting significant contributions of algal derived organic matter. The lack of higher land plant derived organic matter within the Panching limestone sample is apparent from the low concentration of higher molecular weight n-alkanes compared to the Charu and Sagor sediments.

No distinct variation has been observed for the Ts/Tm ratios (Table 2). Among the samples studied here, this ratio may not be indicative of source input but, more likely, are strongly influenced by the high thermal maturity attained by all of these samples.

Aquino Neto et al. (1983) suggested a microbial origin for both tricyclic and tetracyclic terpanes series. Philp and Gilbert (1986) on the other hand associated high abundance of C<sub>24</sub> tetracyclic with high input of terrestrially derived organic matter. The high abundance of C<sub>24</sub> tetracyclic terpanes in the studied samples could therefore be associated with either higher land-plant, algae, or microbial sources. The Charu, Panching and Sagor sample extracts generally display high concentration of C<sub>23</sub> tricyclic terpanes, and therefore have relatively high C<sub>23</sub> tricyclic terpane/C<sub>30</sub> hopane ratios. The presence of tricyclic terpanes in sediment extracts and oils has been associated with the presence of marine influence by workers such as Aquino Neto et al. (1983) and Mello et al. (1988a), and therefore supports the marine depositional setting of these formations as proposed by workers such as Metcalfe *et al.* (1980).

The Pr/Ph ratios in most of the studied samples (except for the limestone) are within the range of 3-9 (Table 1) which seem to be diagnostic of an oxidizing peat swamp depositional environment (Lijmbach, 1975). The Pr/Ph ratios in this investigation can be taken as evidence for the origin of the organic matter in situ. According to Jennings and Lee (1985), outcrops near Chukai, Gambang and Panching, contain carbonaceous beds with a Stigmairian rooted zone, which suggests non marine swamps. The high Pr/Ph and Pr/nC<sub>17</sub> ratios in the Charu and Sagor samples compared to the Panching limestone sample are most likely to be associated with the source of the organic matter (further discussed in the following section).

Based on the above discussed parameters, although differences between the lithologies within a particular formation could not be made, distinction can be made between the dominant type of organic matter that is present in the shale and coaly shale compared to the limestone. It can be said that the Charu and Sagor formations seem to have received substantial amounts of land-derived organic matter that has been transported into a marine depositional setting, whilst the Panching limestone is dominated by algal-derived organic matter and lacks higher plant material as suggested by low Pr/Ph ratio.

#### **Depositional environment**

High Pr/Ph ratios have generally been inferred to indicate that the organic matter has undergone

some degree of oxidation and decarboxylation of the phytol side-chain of chlorophyll which leads to the formation of pristane. Under reducing conditions, phytane is more likely to be produced through hydrogenation and dehydration of phytol (Brooks *et al.*, 1969). Organic matter derived predominantly from terrestrial plants would therefore be expected to show a high Pr/Ph ratio, however, organic matter derived predominantly from aquatic photosynthetic organisms, such as algae, could also have a high Pr/Ph ratio if the water column were relatively well oxygenated (Clayton, 1993).

Marine or open water sedimentation with high bacterial activity yields only relatively small amounts of pristane and phytane as a result gives low Pr/Ph (<2.0) and Pr/nC<sub>17</sub> (<1.0) ratios, whereas in peat swamp environments, with low aerobic bacterial activity, most of the phytol are converted to pristane with only small amounts of phytane. Thus, oils from source rocks deposited under peat swamp conditions will have a high Pr/Ph (>3.0) and Pr/nC<sub>17</sub> (>1.0) ratios (Didyk et al., 1978, Lijmbach, 1975). This is observed for all of the Sagor and Charu samples analysed. Although the Pr/Ph ratio values in the sample studied is most likely source influenced, the low values of Pr/Ph (< 2) in the Panching Limestone (Pa1) sample also suggests an aquatic depositional environment under reducing bottom conditions. This is in agreement with the depositional environments postulated by workers such as Metcalfe, *et al.* (1980) who postulated the Charu Formation as sediments deposited in a shallow marine near shore environment, the Panching Limestone formed in a warm shallow marine reefal environment, and the Sagor formation was deposited in a relatively shallow marine environment. The low Ts/Tm ratios (<1.0; Table 2) support such aqueous depositional conditions.

The relative abundance of the C<sub>31</sub>-C<sub>34</sub> extended hopanes compared to the C<sub>30</sub> hopane and C<sub>29</sub> norhopane have been proposed to be typically associated with carbonate sedimentary environments (Palacas *et al.*, 1984). However, a relatively high concentration of extended hopanes and C<sub>29</sub>-norhopanes was found in the rock extracts of the Charu and Sagor formations, although the extracted samples were actually black shales and coaly shales, not carbonates. Enhanced concentrations of extended hopanes have been proposed to reflect a more anoxic

nature of a depositional environment (Moldowan, 1988) which is probably the situation with the Charu and Sagor organic rich sediments studied.

### CONCLUSIONS

The results from this investigation of selected Upper Palaeozoic Kuantan Group carbonaceous sediments using organic petrology and organic geochemistry show that the application of vitrinite reflectance data, CPI values, and measurement of the stereoisometric ratios (22S/22S+22R and 20S/20S+20R) of the extended hopane and steranes, indicate the sediments studied have reached a relatively high level of maturity (late oil window maturity).

Features such as high Pr/Ph ratio (> 3.0) and high Pr/nC<sub>17</sub> (> 1.0), strong predominance of high molecular weight n-alkane, low concentration of steranes, and high C<sub>24</sub> tetra/C<sub>23</sub> tricyclic ratio indicate that the Charu and Sagor samples contain higher plant material but were most probably deposited under relatively anoxic conditions of shallow marine environment.

The Panching limestone sample is dominated by nC<sub>17</sub> – nC<sub>19</sub> alkanes suggesting significant contribution of algal derived organic matter and lacks higher plant material. The high abundance of C<sub>24</sub> tetraacyclic terpanes could be associated with either higher land-plant, alga, or a microbial source. The Pr/Ph and Pr/nC<sub>17</sub> ratios show distinct differences between the Panching limestone and the shales of the Charu and Sagor formations, reflecting dissimilarities in depositional environment conditions.

The distribution of tetracyclic, tricyclic and pentacyclic terpanes show little variation between the studied samples, suggesting that all the biomarker extracts were derived from the same organic matter type that were subsequently reworked/alterd by bacterial activity within the marine sediments. The presence of significant marine influence is suggested by the high abundance of tricyclic terpanes in all the samples studied.

The differences in depositional setting/conditions and resulting organic geochemical facies between the formations are further manifested by the relative abundance of the land derived macerals as observed petrographically.

Although of high maturity, the samples are still within the oil window maturity range, suggesting these samples have not been too severely effected by thermal metamorphism or the active tectonic activities of the Eastern belt of Peninsular Malaysia.

**Acknowledgements** Thanks are due to Prof Madya Dr. Azhar Hj. Hussin for field supervision, Prof. B.R.T. Simoneit for tentative identification of a C<sub>21</sub> highly branched isoprenoid, the University of Malaya Kuala Lumpur for the financial support and providing research facilities, and to the Libyan General Secretarial of Education for providing the research grant. The authors are very grateful to Mr. Peter Abolins and Assoc. Prof. Dr. Lee Chaï Peng who reviewed the paper.

**Table 1.** Total organic carbon (TOC) and geochemical parameters from gas chromatograms of saturated hydrocarbon fraction.

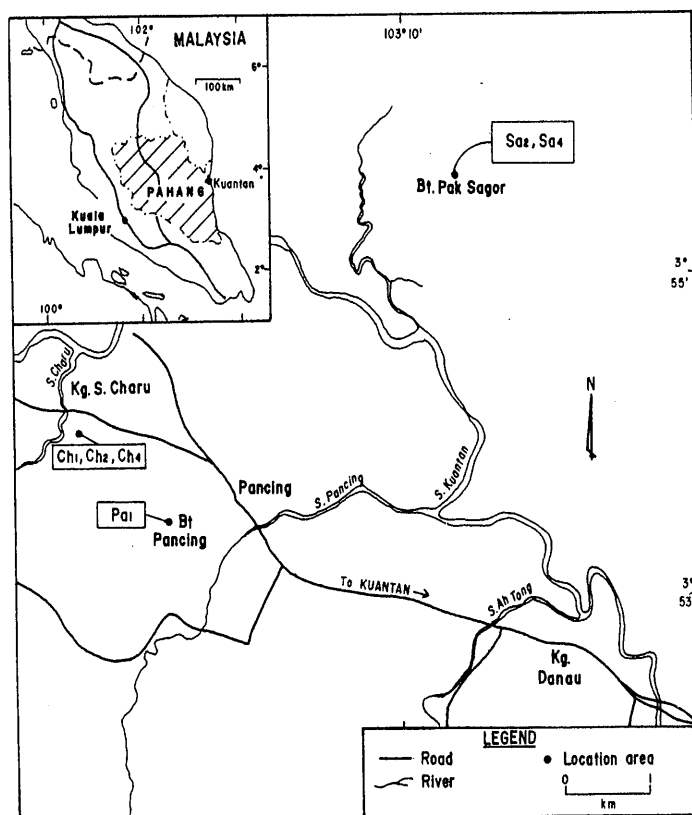
Formation	Age	Sample No.	Lithology	TOC (wt%)	n-alkane max	Pr/Ph	Pr/nC <sub>17</sub>	Ph/nC <sub>18</sub>	NC <sub>27</sub> /nC <sub>17</sub>	CPI
Sagor	Carboniferous	Sa2	Shale/Mudst	n.d.	C <sub>27</sub>	9.0	8.0	0.23	24.8	1.0
Sagor	Carboniferous	Sa4	Shale	0.26	C <sub>27</sub>	6.5	8.0	0.23	39.7	1.0
Panching	Carboniferous	Pa1	Limestone	Trace	C <sub>18</sub>	1.8	0.2	0.20	0.85	1.2
Charu	Carboniferous	Ch1	Shale	1.34	C <sub>28</sub>	9.0	18.0	0.17	32.0	1.2
Charu	Carboniferous	Ch2	Coaly shale	4.76	C <sub>27</sub>	3.5	1.1	0.38	7.6	1.1
Charu	Carboniferous	Ch4	Coaly shale	9.55	C <sub>27</sub>	3.6	2.4	0.28	28.8	1.1

**Table 2.** Biomarker parameters and vitrinite reflectance data (%Ro) for selected rock extracts.

Formation	Age	Sample No.	Lithology	T <sub>s</sub> /T <sub>m</sub>	C <sub>23</sub> Tri/ C <sub>30</sub> Hop	C <sub>24</sub> Tetra/ C <sub>30</sub> Hop	C <sub>32</sub> Hopane 22S/22S+22 R	C <sub>29</sub> Sterane 20S/20S+20R	%Ro
Sagor	Carboniferous	Sa2	Shale/Mudst	0.8	0.6	1.6	0.56	0.6	1.10
Panching	Carboniferous	Pa1	Limestone	0.9	0.4	1.2	0.57	0.6	1.08
Charu	Carboniferous	Ch1	Shale	0.8	0.3	0.5	0.56	0.6	1.13
Charu	Carboniferous	Ch4	Coaly shale	0.9	0.8	2.3	0.59	0.6	1.13

**Table 3.** Peak assignments in the m/z 191 mass fragmentograms.

C <sub>23</sub> tri	tricyclic terpane
C <sub>24</sub> tri	tricyclic terpane
C <sub>25</sub> tri	tricyclic terpane
C <sub>24</sub> tetra	tetracyclic terpane
C <sub>27</sub> Tm	17 $\square$ (H)-22,29,30-trisnorhopane
C <sub>27</sub> Ts	18 $\square$ (H)-22,29,30-trisnorneohopane
C <sub>29</sub>	17 $\square$ (H), 21 $\square$ (H) norhopane
C <sub>29</sub> Ts	18 $\square$ (H)-30-norhopane
C <sub>30</sub>	17 $\square$ (H), 21 $\square$ (H) hopane
C <sub>30</sub> *m	17 $\square$ (H), 21 $\square$ (H) moretane
C <sub>31</sub> S	17 $\square$ (H), 21 $\square$ (H)22S homohopane
C <sub>31</sub> R	17 $\square$ (H), 21 $\square$ (H)22R homohopane
C <sub>32</sub> S	17 $\square$ (H), 21 $\square$ (H)22S bishomohopane
C <sub>32</sub> R	17 $\square$ (H), 21 $\square$ (H)22R bishomohopane
C <sub>33</sub> S	17 $\square$ (H), 21 $\square$ (H)22S trishomohopane
C <sub>33</sub> R	17 $\square$ (H), 21 $\square$ (H)22R trishomohopane
C <sub>34</sub> S	17 $\square$ (H), 21 $\square$ (H)22S tetrakishomohopane
C <sub>34</sub> R	17 $\square$ (H), 21 $\square$ (H)22R tetrakishomohopane



**Figure 1.** The location of study areas.