Organic geochemical characteristics and depositional setting of Tertiary organic-rich sediments from onshore Penyu Basin, Malaysia

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Summary

Due to the poor knowledge of the organic facies characteristics of the eastern Chenor Pahang has made it remain an untapped potential in the Penyu Basin. Therefore, detailed geochemical and petrographic characterization of the Tertiary organic facies of the eastern Chenor area of the Penyu Basin was carried out to characterized its organic matter (OM) source input. Towards achieving the goal, this study focuses on determination of organic matters richness, type and origin as related to their paleoenvironmental conditions of the carbonaceous mudstone and shale using organic petrography combined with organic and inorganic geochemistry. The sedimentary succession is characterized by fine to coarse grained sandstone occurring in association with carbonaceous mudstone and shale in a predominantly fining upward sequence within a lacustrine environment. These facies are generally enriched in organic matter as indicated by the TOC results, hydrocarbon yield (S2) and extractable organic matter (EOM), suggesting significant hydrocarbon generation potential for the area.

Introduction

Asian region, especially Malaysia, has a number of petroleum-bearing sedimentary basins commonly associated with coal, carbonaceous mudstone and oil shale strata (Wan Hasiah and Abolins, 1998; Wan Hasiah et al., 2012). Most often, shales are source rocks of conventional petroleum resources, while coals are known sources of unconventional resources such as coal bed methane (CBM) even though it can generate conventional liquid hydrocarbons. The obvious but inevitable decline in conventional petroleum across the globe necessitated exploration of unconventional energy sources (e.g. carbonaceous mudstone, oil shale, shale gas, tight sand, coal bed methane and fractured basement). Malaysia is not an exception, within offshore Peninsular Malaysian basin (e.g. Penyu and Malay Basins), organic-rich sedimentary facies (mudstones, shale and coal) are known to act as petroleum source rocks (Wan Hasiah and Abolins, 1998).

Previous studies indicate Tertiary age for this section based on palynomorph assemblage of the eastern Chenor sediments (Mustaffa Kamal., 2012). However, integration of organic petrography and detail geochemical characterization of these Tertiary sediments to unraveled its hydrocarbon source potential is missing in literature. This will definitely give insight into an untapped potential in Penyu Basin. Thus, in this study, carbonaceous mudstones, shales and sandstones in eastern Chenor, Pahang have been investigated using organic and inorganic geochemical and petrological methods to interpret the organic matter origin/type and
preservation, paleodepositional environment, paleoclimatic condition and tectonic setting of the area.

**Theory and/or Method**

Whole rock samples of carbonaceous mudstones, shales and sandstones were crushed to fine powder and analyzed using Weatherford source rock analyzer (SRA) TOC/TPH (equivalent of Rock-Eval-6 equipment) to determine the source rock richness (S1 and S2) and thermal maturity (Tmax). Thereafter, about 100 mg of the samples were subjected to total organic carbon (TOC) analysis using a multi N/C 3100 analyzer. This provides information about the quantity of organic matter present in the samples. The SRA and TOC results were used in calculating other parameters (Table 1) such as hydrogen index (HI) and production index (PI) as described by Peters and Cassa, (1994).

Representative samples were analyzed using a PerkinElmer 2400 Series II CHNS/O Analyzer to determine the concentrations of carbon (C), hydrogen (H), nitrogen (N), sulfur (TS) and oxygen (O). From the result of the CHNS/O analysis, atomic ratios of H/C, O/C and S/C were calculated.

Bitumen extraction was carried out using Soxhlet procedure. About 10 g of each samples were pulverized to less than 75 microns' grain size and treated with mixture of dichloromethane (CH2Cl2) and methanol (CH3OH) (93:7) for 72 hours in a Soxhlet apparatus. Thereafter, extractable organic matters (EOM) were separated into saturated hydrocarbon, aromatic hydrocarbon and NSO-compound fractions by liquid chromatography. Fractions of saturated hydrocarbons were analyzed by Agilent gas chromatography—Mass Spectrometry (GC-MS) 5975B mode at an ionization energy of 70 eV, 100 mA filament emission current and a source temperature of 230 °C.

**Examples**

Biomarkers signatures [ n-alkanes >n-C25, high C29/C30 17α (H) hopane ratios of 1.10–3.3 & high C29 steranes (49.0–71.3%)] and chemical compositions [low total sulfur and V/(V+Ni)] suggest a predominantly terrestrial source input with a minor contribution from aquatic microorganism as also indicated by alginite. Integration of biomarkers studies with bulk geochemical and petrographic analysis reveal that the analyzed samples were deposited in a fresh water lacustrine environment, under suboxic bottom water conditions. This is consistence with observation based Sr/Br, V/Ni and Pr/Ph ratios. Stratified fresh water column with suboxic bottom water conditions contribute to OM preservation in the mudstone and shale samples. Moreover, high bioproductivity in combination with better OM preservation favoured more oil associated kerogen type I and II (algae) enrichment in the mudstone and shale facies. Also, the high organic matter content in the shale may be related to fine-grained matrix and the associated semi-arid climate in the area. Based on hydrogen-to-carbon (H/C) versus oxygen-to-carbon (O/C) ratios, the organic matter type of the analyzed samples is shown to be of Types I and II kerogen. This is supported by the high hydrogen index of >300 mg HC/g TOC as well as presence of abundant liptinitic materials such as fluorescing bitumen, alginite, sporinite, resinite, liptodetrite and amorphous organic matter.
Conclusions

Tertiary mudstone, shale and sandstone from the Penyu Basin were analyzed using organic geochemical and organic petrological methods to determine the origin, type and preservation conditions of organic matter in relation to paleodepositional environment. The following are the conclusions:

1. The sedimentary succession is characterized by fine to coarse grained sandstone occurring in association with carbonaceous mudstone and shale in a predominantly fining upward sequence within a lacustrine environment. These facies are generally enriched in organic matter especially the carbonaceous mudstone and shale as evident from the high TOC contents (>3 wt. %) as well as hydrocarbon yield (S2) and (EOM). This suggest significant hydrocarbon generation potential for the area.

2. Geochemical studies show that analyzed samples are composed of mixed source input of predominantly terrigenous organic matter with minor amount of aquatic algae and microorganisms influence deposited in a freshwater lacustrine environment. This is evident from high concentration of C29 compared to other steranes and minor amounts of structured alginite and structureless (amorphous) as observed under the microscope.

3. Analyzed organic facies from the eastern Chenor area comprises of mainly oil-proned Type I and II kerogens. This is obvious from high HI (>300 mg HC/g TOC), atomic H/C (>1.5) and organic petrographic observation showing high concentration of liptinite macerals.

4. Based on biomarker assemblage and the trace elements (Sr, Ba, V, Ni, U & Cr) compositions as well as their ratios, the major controlling factors for OM preservation during the deposition is the presence of a stratified water column with fresh and suboxic bottom water conditions within the studied area.

5. The n-alkane distribution patterns, reasonable concentrations of the phosphorus (P), relatively higher C27+29/C29 steranes, and low hopanoids/steroids ratios within the samples, provide evidence for enhanced nutrient supply leading to increased biological productivity within the photic zone of the water columns.

6. The high organic matter content in the mudstone and shales samples can also be related to fine-grained matrix and prevailing warm to semi-arid climate in the area.

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