Introduction

Source rock evaluation has been an important step in the world of petroleum exploration as it is the first element needed in the system followed by a reservoir, seal and overburden rocks. In applied source rock geochemistry of Peter and Cassa (1994); the source rock is defined as sedimentary rock contains organic matter that has, or may generate petroleum, and this is the main objective of the current study for the Bongaya Formation.

Bongaya Formation details are issued as scarce when compare with Kudat Formation even though they are stratigraphically equivalent (Kudat Formation on the west while Bongaya Formation on the east) due to inaccessibility of the area. Remarkably, Bongaya Formation also correspondent to offshore Malawi Sub-Basin situated to the upper-east side of it which is still undiscovered but shows a possible oil trace based on seismic study (Petronas, 1990). A data set regarding the petroleum potential of this source rock is gathered for future conceivable use and petroleum development site of that area since no petroleum well or exploration was done there. Tongkul (1991) stated that the main lithology in Bongaya Formation consisted of grey sandstones interbedded with carbonaceous shales lie unconformably on top of older formation such as Crocker, Kudat and Chert-Spillite formation. There is also a minor closure of conglomerate beds and limestone facies occurrence (Wilson, 1961). The foraminifera from the formation confirmed its age as Upper Miocene sediments (Wilson, 1961).

This study was aimed to evaluate the coal and shale sediments in the Bongaya Formation, in Pitas area of Sabah (Figure 1), as potential source rocks, particularly relate to organic matter type and richness together with its maturity using geochemical methods.

Figure 1: Location of the study area. Geological map of outcrop of the study area in Sabah. (Geological map redrawn from Fitch, 1960 and Tongkul, 1991).
Samples and Methods

Coals, carbonaceous shale and shales samples were collected from various outcrop of Bongaya Formation in Pitas Sabah. Geochemical analyses conducted in this study include Total Organic Carbon (TOC %), Source Rock Analyzer (SRA), Pyrolysis-Gas Chromatography (Py-GC). Selected eight samples were further subjected to bitumen extraction analysis. The powdered samples were extracted using mixture solvents of dichloromethane (DCM) and methanol in ratio of 93:7 for 72 hours using Soxhlet apparatus to remove free hydrocarbon. The Pyrolysis-Gas Chromatography (Py-GC) analysis was subsequently performed on six extracted, whereby hydrocarbon can be monitor to the function of temperature. Py-GC analysis was conducted using a Frontier Lab Pyrolyser System capable of thermal desorption (40-300 °C) and pyrolysis (600 °C). The device was equipped with an ultra-alloy column type with 30m length fitted with an Agilent GC chromatograph instrument. Identification of peaks based on reference chromatograms was done manually with Agilent ChemStation software and comparison to published data.

The vitrinite reflectance analysis were performed on polished blocks, and were carried out with x50 oil immersion objective under a plane polarized reflected light, using a LEICA DM 6000M microscope and LEICA CTR6000 photometry system equipped with FOSSIL software. A sapphire glass standard with 0.589% reflectance value was used for calibration, and the values reported were arithmetic means of 30 measurements per sample.

Result and Discussion

The analyzed samples show a total organic carbon (TOC) content varied between 0.90 and 63.10 wt%, indicating fair to excellent source rocks. However, the coal and carbonaceous shale samples have relatively higher generation potential than shale samples, with rich organic matter of more than 10 wt% TOC. The amounts of extractable organic matter from bitumen extraction determined the organic richness of source rock. From the bitumen extraction, the analyzed samples of different lithologies (3 coals, 3 carbonaceous shales and 2 shales) have bitumen in the range of 802.07 to 61163.825 ppm, further suggest good to excellent source rock generative potential (Peter and Cassa, 1994).

Figure 2: (a) Plot of Hydrogen Index (HI, mg/g TOC) versus Tmax (˚C) showing quality and thermal maturity of selected samples. (b) Cross plot between Hydrogen Index (HI, mg/g TOC) with TOC (wt. %) showing source rock potential for hydrocarbon generation.

The analyzed samples have hydrogen Index (HI) values from 40.1 to 629.6 mg HC/g TOC, consistent with mainly Type III kerogen and II kerogens as plotted on Van Krevelen diagram of Tmax and HI.
pyrolysis data (Fig. 2a). Most of analyzed coals, carbonaceous shale and shale samples have Type III except two coal samples have Type II, with HI values of greater than 500 mg HC/g TOC to be some Type III and Type II (Fig. 2a). The analyzed coals, carbonaceous shale and shale samples from Miocene Bongaya Formation are considered to be good source rocks for mainly gas with minor oil generation potential (Fig. 2b). Coals in Southeast Asia region was reported to generate liquid hydrocarbon particularly liptinitic rich coal (Cook and Struckweyer, 1986; Wan Hasiah, 1999; Abdullah, 2003). The dominant kerogen Type III and Type-II are further indicated from quantitative results based on an open pyrolysis–gas chromatography analysis (Fig. 3a). In the samples where the HI value is higher than 500 mg HC/g TOC, the Py-GC is dominated by n-alkane/n-alkene doublets extended beyond C30 are indicative for aliphatic-rich, Type II oil-prone, whereas the samples with HI less than 300 mg HC/g TOC have low concentrations of n-alkane/n-alkene doublets extended beyond C26, suggesting contribution of gas-prone source rock (Hakimi, 2018).

**Figure 3**: Quantitative pyrolysis (Py-GC) of selected extracted samples from the Bongaya Formation, showing (a) the characteristics of kerogen based on the relative percentage of three pyrolysate compounds, m-p-xylene, phenol, and n-octene, plotted on the ternary diagram of Eglinton et al. (1990), and (b) the pyrolysate distribution of n-alkene/alkane doublets and aromatic with phenolic compounds.

The thermal maturity of the analyzed samples was measured from both vitrinite reflectance and Tmax value. The analyzed samples have Tmax value from 369.6 to 432 °C, indicating immature source rocks for hydrocarbon generation. This maturation level is in good agreement with vitrinite reflectance ranges between 0.32%Rₒ and 0.43%Rₒ.

**Conclusions**

Organic geochemical investigation, coupled with optical analysis of vitrinite reflectance has been conducted on the coals, carbonaceous shale and shale sediments in the Miocene Bongaya Formation. The results of this study provides a source full data of hydrocarbon generation in Pitas area especially in the petroleum exploration field. The Bongaya sediments in the onshore Pitas Sabah are considered as good source rocks for mainly gas with minor oil generation potential. The maturity indicators such as vitrinite reflectance and pyrolysis Tmax reveal that these sediments are thermally immature and implies that the samples have not been buried deep enough. The deeper sections of the Bongaya Formation at the offshore (Sub-Malawi basin) might have reached a satisfactory maturity level to be considered as potentially effective petroleum source rock.
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References


