Organic geochemistry and thermal maturity of the Madbi Formation, East Shabowah Oilfields, Masila Basin, Yemen

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Abstract — The East Shabowah Oilfields in the Masila Basin are the most productive oilfields in the Republic of Yemen. The Masila Basin contains sediments of Jurassic and younger age. The Madbi Formation, an important regional source rock, is widespread and is encountered in the East Shabowah Oilfields where it consists of two units. The lower unit commonly consists of an argillaceous limestone and a basal sandstone, and forms a good reservoir in some oilfields of the Masila Basin. The upper unit is composed of laminated organic rich shale which is a prolific source rock in the Masila Basin. In this study, organic rich shales were analysed by means of organic petrographic and organic geochemical methods with the objective of evaluating the oil generating potential of the shales. Petrographic analysis was performed to measure vitrinite reflectance (%Ro) in reflected "white light" under oil immersion. Geochemical analyses include determination of total organic carbon (TOC wt%), bitumen extraction, gas chromatography and gas chromatography-mass spectrometry (GC-MS). Based on the results of this study, the rocks were deposited under suboxic conditions in a marine environment. Good source rock potential is suggested by high values of TOC of 2.0 -7.2 wt%, high extractable organic matter content, and hydrocarbon yields exceeding 8,000 ppm. Shale samples are thermally mature for hydrocarbon generation as suggested by %Ro values of 0.65-0.91%.

Keywords: Madbi Formation, biomarker, maturity, Masila Basin, Yemen

INTRODUCTION

The Masila Basin is an important hydrocarbon province and has long been the site of hydrocarbon exploration (Mills, 1992; Csato *et al*., 2001; King *et al*., 2003). However, few studies have been investigated the geochemical characteristics of source rocks or their thermal maturity and the hydrocarbon generation potential is therefore poorly constrained. In this study, organic geochemical and petrological analyses were performed on cuttings samples of organic-rich shales from the Jurassic Madbi Formation in the western central of the Masila Basin (Figure 1). The purpose was to evaluate the shales' organic matter content, thermal maturity, and to interpret their depositional environment.

Petroleum source rocks are rocks that are capable of generating petroleum given the right maturity (Tissot & Welte, 1984). Hunt (1996); Tissot & Welte (1984) discussed the concept and application of organic geochemistry principles in the study of origin, migration, generation, accumulation, and alteration of petroleum. Interpretation of depositional environment and thermal maturity based on biomarker distributions have also been widely applied (Peters and Moldowan, 1993). A biomarker is any compound occurring in the geosphere whose basic carbon skeleton suggests an unambiguous link with a known natural product (Peters & Moldowan, 1993). In this study, the evaluation of petroleum source rock potential, thermal maturity and depositional condition were carried out based on total organic carbon, bitumen extraction, biomarker distribution and vitrinite reflectance data.

GEOLOGICAL BACKGROUND

The Masila Basin, one of Yemen's most prolific basins, is located in the Hadramaut region in East Central Yemen and it attracted the interest of numerous oil companies for the exploration of hydrocarbons. The East Shabowah Oilfields are located onshore and occupy the central west portion of the Masila Basin (Figure 1). The Masila Basin including study area comprises sedimentary rocks ranging from Jurassic to Tertiary in age (Figure 2). The Madbi Formation is Jurassic in age and also the main source rock in the Masila Basin (Mills, 1992). The Madbi Formation is overlain by the Upper Jurassic to Lower Cretaceous shallow-marine carbonates of the Naifa Formation which consists of silty and dolomitic limestones and lime mudstones with wackestones (Beydon *et al.,* 1998). The Madbi, Shuqra and Naifa Formations together make up the Amran Group (Beydon *et al.,* 1998). The Madbi Formation generally is composed of porous grainstone to argillaceous carbonate lime mudstone. The lithofacies of this formation reflect an open marine depositional environment. The Madbi Formation is divided into two members. The lower member is typically an argillaceous limestone with a basal sandstone, and forms good reservoirs in some oilfields of the Masila Basin. The upper member of this formation is composed of laminated, organic rich shales, which are prolific source rock in the basin (Mills, 1992). The shale contains a mixture of type I and II kerogen. These oil prone source rocks were deposited in suboxic marine environment. The organic carbon content (TOC) ranges from 1 to 10 wt% and the hydrogen index values of up to 700 mg HC/g TOC

(SPT, 1994). The oil window was reached in the Cretaceous (PEPA, 2004).

METHODOLOGY

Geochemical and petrographic analyses were performed on a total of ten shale samples from the Madbi Formation were analysed in this study (Tables 1 and 2). All the samples were cuttings collected from boreholes in the Masila Basin (Figure 1).

Geochemistry

Organic geochemical studies included bitumen extraction, gas chromatography (GC), gas chromatography-mass spectrometry (GC-MS) and determination of total organic carbon (TOC). The cuttings samples were pulverized, and then extracted with dichloromethane/methanol mixture (93:7) using a Soxhlet apparatus. The extracts were fractionated into saturated hydrocarbons, aromatic hydrocarbons and polar fractions by column chromatography. Alumina/silica gel (2: 1) columns (30 cm x 0.72 cm) were eluted with light petroleum (100 ml), dichloromethane (100 ml) and methanol (50 ml), respectively. Gas chromatographic separations of the saturated hydrocarbons (including n-alkanes and isoprenoids) were performed on an FID gas chromatography GC equipped with an Hewett Packard 6890 Series; the temperature was programmed from 40 to 300 °C at a rate of 4°C/min and then held for 30 min at 300 °C, was used for GC analysis. GC-MS experiments were performed on a V 5975B inert MSD mass spectrometer with a gas chromatograph attached directly to the ion source (70eV ionization voltage, 100mA filament emission current, 230 ºC interface temperature). The total organic carbon (TOC) content of the samples was determined by using a LECO instrument

Petrology

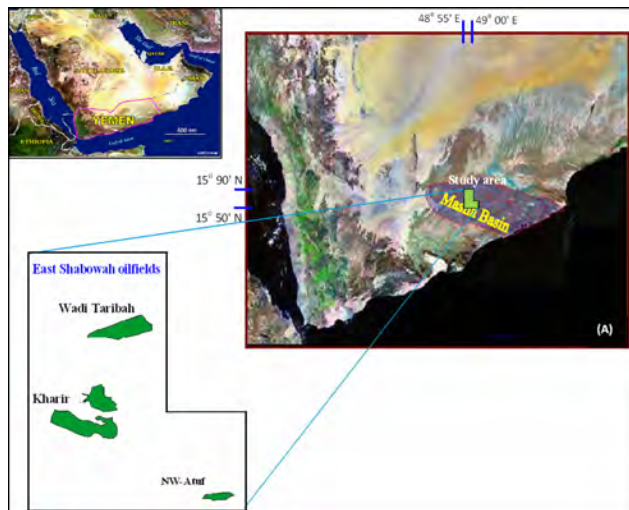Samples for petrographic study were made by mounting whole rock fragments in slow-setting polyester (Serifix) resin together. The samples were allowed to set, then ground flat on a diamond lap and subsequently polished using isopropyl-alcohol lubricated silicon carbide paper of different grades. Finally, the samples were polished to a highly reflecting surface using progressively finer alumina powder (grades 5/20, 3/50 and Gamma). Measurements of mean random vitrinite reflectance (Ro) were carried out with a Leica CTR 6000-M microscope in oil immersion under reflected "white light". TOC, extraction, column chromatography, gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS) analyses were conducted at the Organic Geochemistry Laboratories, University of Malaya.

RESULTS AND DISCUSSION

The total organic matter content, vitrinite reflectance data and biomarker parameters, including n-alkanes and isoprenoids for the studied samples are presented in Tables 1 and 2 and Figures 3 to 6.

Potential Hydrocarbon Generation and Source Rock Richness

The TOC values for the Madbi Formation shales analysed range from 2 to 7.2 wt% (Table 1). The studied samples have "very good" to "excellent" TOC (as defined by Tissot and Welte, 1984). Hydrocarbon yields were very good to excellent (2000 > HC >2400 ppm) (Peters and
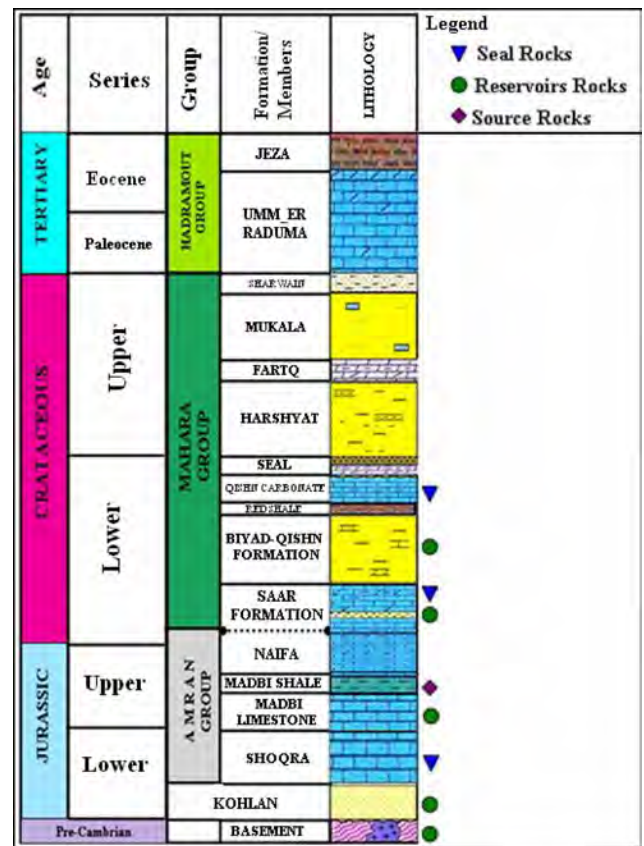

Figure 1: Mosaic of TM Landsat image of Yemen, showing the location of East Shabowah Oilfields.

Figure 2: Lithostratigraphic column of Masila Basin including East Shabowah oilfields, Yemen (modified after Total Oil Company, 1999).

Table 1: Extractable organic matter data and n-alkane and isoprenoids ratios of selected shale samples.

Samples	Litho-logy	TOC (%wt)	EOM (ppm of whole rocks)				EOM (mg EOM/gTOC)				n-alkane maximum	CPI	Pr/Ph	Pr/C$_{17}$	Ph/C$_{18}$
			Total extr	Aliph.	Arom.	Total HC	Total extr	Aliph.	Arom.	Total HC					
SK 1308	Shale	3.43	4964.4	1276.7	1911.3	3188.0	144.7	37.2	55.7	92.9	nC15	1.00	1.97	1.39	0.83
SK 2105	Shale	3.23	5240.5	1216.5	1614.3	2830.8	162.2	37.7	50.0	87.7	nC16	1.01	1.87	1.58	0.83
SK 1304	Shale	1.94	5760.4	466.5	1288.3	1754.8	296.9	24.0	66.4	90.4	nC14, nC15	0.98	1.64	1.38	0.79
SK 1278	Shale	3.34	4329.7	740.9	1234.9	1975.8	129.6	22.2	37.0	59.2	nC14	1.01	2.26	1.23	0.63
SK 11916	Shale	7.19	8009.7	1624.3	2308.9	3933.2	111.4	22.6	32.1	54.7	nC14	0.98	2.05	1.68	0.83
SK 2164	Shale	2.14	2885.5	634.8	1174.6	1809.4	134.8	29.7	54.9	84.6	nC19	0.99	1.84	1.40	0.78
SK 3083	Shale	3.78	4163.9	435	1605.4	2040.4	110.2	11.5	42.5	54.0	nC15	1.08	2.25	1.34	0.69
SK 12713	Shale	3.89	5457.1	1057.2	2122.2	3179.4	140.3	27.2	54.6	81.8	nC13	1.04	2.09	1.26	0.68
SK 2162	Shale	3.89	5325.4	781.1	1535.5	2316.6	136.9	20.1	39.5	59.6	nC15	1.03	2.38	1.47	0.79
SK 12717	Shale	6.16	8918.7	1412.9	4000.5	5413.4	144.8	22.9	65.0	87.9	nC14	1.02	2.17	1.57	0.73

Table 2: Biomarkers parameters calculated from m/z 191 and m/z 217 mass chromatograms and vitrinite reflectance (%Ro) data.

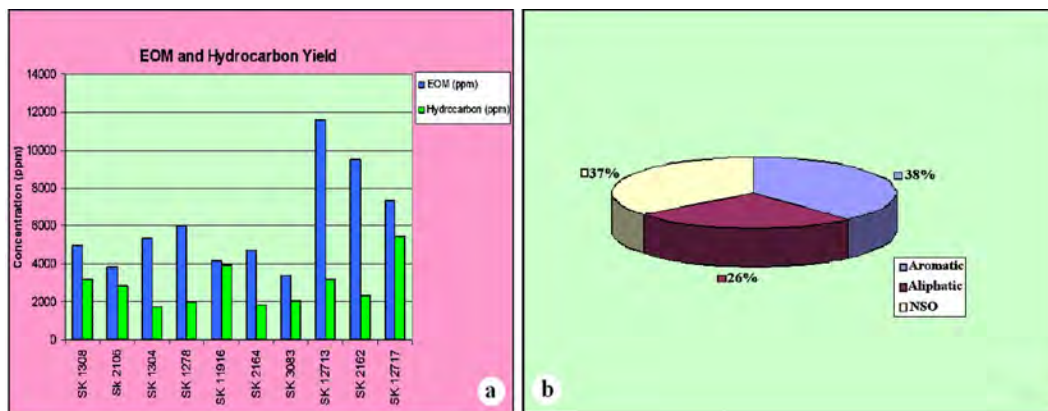| Samples	litho-logy	Triterpanes and terpanes (m/z191)					Steranes and diasteranes (m/z217)						Steranes/hopanes	%Ro
		22S/(22S+22R)	Ts/Tm	C$_{29}$Hop/C$_{30}$Hop	C$_{24}$Tri/C$_{29}$Hop	Moret/Hope	20S/(20S+20R)	αββ/(αββ+ααα)	C$_{27}$,C$_{28}$,C$_{29}$ Regular steranes			C$_{29}$/C$_{27}$	Diaste-ranes/Steranes	
SK 1308	Shale	0.60	0.46	0.43	1.60	0.15	0.45	0.44	37.1	18.9	44.0	1.19	0.72	1.0	0.74
SK 2105	Shale	0.63	0.54	0.39	2.00	0.13	0.49	0.56	38.8	18.8	42.4	1.10	1.08	0.6	0.88
SK 1304	Shale	0.61	0.48	0.37	1.80	0.15	0.46	0.53	35.3	20.0	44.7	1.27	1.09	0.6	0.80
SK 1278	Shale	0.61	0.45	0.44	1.90	0.14	0.46	0.46	35.5	19.4	45.1	1.27	0.87	0.9	nd
SK 11916	Shale	0.59	0.43	0.44	2.10	0.15	0.48	0.48	35.9	19.0	45.1	1.25	0.70	1.0	0.81
SK 2164	Shale	0.60	0.50	0.43	1.60	0.12	0.46	0.54	34.1	19.3	46.6	1.37	0.96	0.7	0.80
SK 3083	Shale	0.58	0.45	0.40	1.80	0.14	0.46	0.53	35.4	20.2	44.4	1.26	0.97	0.8	0.80
SK 12713	Shale	0.61	0.44	0.37	1.80	0.13	0.45	0.51	37.6	17.8	44.6	1.18	0.97	0.7	0.77
SK 2162	Shale	0.58	0.48	0.38	2.10	0.12	0.49	0.52	38.3	20.6	41.1	1.07	0.91	0.8	0.79
SK 12717	Shale	0.60	0.42	0.41	1.70	0.14	0.49	0.53	39.3	17.6	43.1	1.10	0.90	0.7	0.78

Figure 3: (a) histogram showing quantity of extractable organic matter (EOM) and hydrocarbon yield and (b) pie chart displaying average percentage of aliphatic, aromatic and NSO fractions in studied samples.
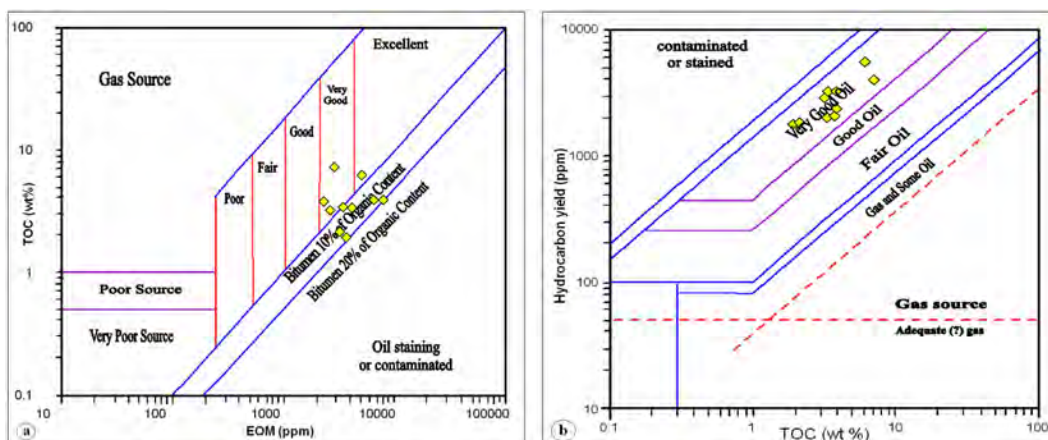

Figure 4: (a) TOC versus EOM cross-plot, showing source potential rating and (b) source-rock richness cross-plot (modified after Othman, 2003) for the studied organic-rich shale

Cassa, 1994) (Table 1 and Figure 3). Hydrocarbon generation potential in a source rock also can be estimated from an extractable organic matter EOM (ppm) versus TOC (wt%) crossplot. Figure 4(a) cross-plot shows that the analysed samples have a very good to excellent source rock potential. Another source rock richness rating is obtained from a TOC (wt%) versus hydrocarbon yields (ppm) crossplot, based on which (Figure 4(b)) the sequence seems to be a good oil source confirming the earlier inferences.

Biomarkers Distribution

n-alkane and isoprenoids

Gas chromatograms of the aliphatic fractions of all shale samples analysed display abundant n-alkanes, particularly of low to medium molecular weight. Normal alkanes in the range n-C_{12} to n-C_{16} are the dominant peaks in the saturated gas chromatograms (Figures 5 and 6). Acyclic isoprenoids are abundant in samples, with pristane being the dominant peak in all saturated gas chromatograms. Pristane concentration is always higher than n-C_{17} and phytane concentration is always lower than n-C_{18}, thus giving high pristane/ n-C_{17} ratios of 1.2-1.7. The Pr/Ph ratios of samples from Madbi Formation are 1.6-2.4 (Table 2). CPI index is calculated based on the formula proposed by Peters and Moldowan (1993), that is $(2(C_{23}+C_{25}+C_{27}+C_{29})/[C_{22}+2(C_{24}+C_{26}+C_{28})+C_{30}])$ with ranging from 0.99 to 1.06.

Triterpanes and steranes

In this study, sterane and triterpane distributions of the bitumen were determined for shale samples of the Madbi Formation (Figures 5 and 6). Peak identification on m/z 191 and m/z 217 chromatograms are given in Appendix C. In addition, various biomarker parameters were computed using the triterpane and sterane distributions recorded on m/z 191 and m/z 217 mass chromatograms, respectively.

The sterane chromatograms (m/z 217) for source rock samples in this study are shown in Figures 5 and 6 common way to distinguish different source rocks or organic facies of different facies of the same source rock (Peters and Moldowan, 1993) is through the use of C_{27}-C_{28}-C_{29} sterane ternary plot. C_{27}-C_{28}-C_{29} steranes were measured from the m/z 217 chromatograms (Figures 5 and 6), and results are given in Table 2. As shown in Table 2, the distributions of C_{27}-C_{28}-C_{29} for all shale samples are very similar ($C_{27}>C_{28}>C_{29}$). The C_{29}/C_{27} sterane and diasterane/sterane ratios are also calculated for the studied shale samples (Table 2). Calculated ratios for two different sterane thermal maturity parameters were conducted in this study: the C_{29} 20S/(20S+20R) and the C_{29} αββ(αββ+ααα) ratios (Peters & Moldowan, 1993) (Table 2). The significance of these parameters will be discussed in the organic maturation and depositional environment sections.

The m/z 191 mass chromatograms of the aliphatic hydrocarbon fractions show high relative abundance of pentacyclic triterpanes with low relative abundance of tricyclic terpanes (Figs. 5 and 6). The relative abundance

of the C_{29} hopane is generally half, or less than that of the C_{30} hopane. Tm is more abundant than Ts thus $T_s/(T_s+T_m)$ ratios of less than 1. The moretane/hopane ratio is 0.12-0.15. The C_{35} homohopanes are observed in all of the studied samples, indicating that the source rock was deposited in at least suboxic conditions, and the concentrations of C_{35} homohopane are in all samples indicate that the depositional environment was not strongly anoxic (suboxic; Figure 5 and 6).

Maturity of Organic Matter

Thermal maturity describes the impact of heat and time during burial of sediments. This thermal exposure converts kerogen into petroleum. Several data types and parameters have been used to evaluate the level of organic maturity; these include vitrinite reflectance data (%Ro), carbon preference index (CPI), pentacyclic triterpanes and regular sterane isomerisation ratios (Peters and Moldowan, 1993).

Vitrinite reflectance

Vitrinite reflectance (% Ro) is widely accepted by exploration geologists as a technique for measuring the thermal maturity of sedimentary rock. Vitrinite reflectance is the most widely used indicator for thermal stress, because it extends over a longer maturity range than other indicators, and a skilled organic petrologist can process a large number of analyses in a relatively short time. Vitrinite maturation is not affected significantly by pressure, only by temperature (Hunt, 1996). Vitrinite reflectance values between 0.5% and 1.3% suggest samples are within the oil generation window, while values less than 0.5% are considered thermally immature. Vitrinite reflectance greater than 1.3% indicates gas window maturity (Tissot & Welte, 1984). The mean vitrinite reflectance values of the studied samples are shown in Table 2, and the range of 0.65 to 0.91%. The samples are thermally mature for hydrocarbon generation.

Biomarker parameters

Carbon preference index (CPI) values that are significantly higher (i.e. odd preference) or lower (i.e. even preference) than 1.0 suggest a sample is thermally immature (Peters & Moldowan, 1993). The CPI values are, however, affected by type of organic matter as well as the degree of maturity (Tissot and Welte, 1984). Using Peters & Moldowan (1993) formula, CPI values of the samples range from 0.99 to 1.06. This indicates that these extracted samples are fully mature.

The $T_s/(T_s+T_m)$ ratio (sometimes calculated as T_s/T_m) can be used for maturity assessment (Farrimond *et al.*, 1996) and increases with organic maturity but also may be influenced by source lithology (Seifert & Moldowan, 1978; Moldowan *et al.,* 1986). Generally, most samples possess T_s less than T_m and hence values of $T_s/(T_s+T_m)$ are less than 1 (Table 2). Another widely used biomarker maturity parameter is the (22S/(22S+22R) homohopane ratio (Ensminger, 1977). C_{31} or C_{32} 22S/22S+22R homohopane ratios increase from zero to about 0.6 at equilibrium (Seifert
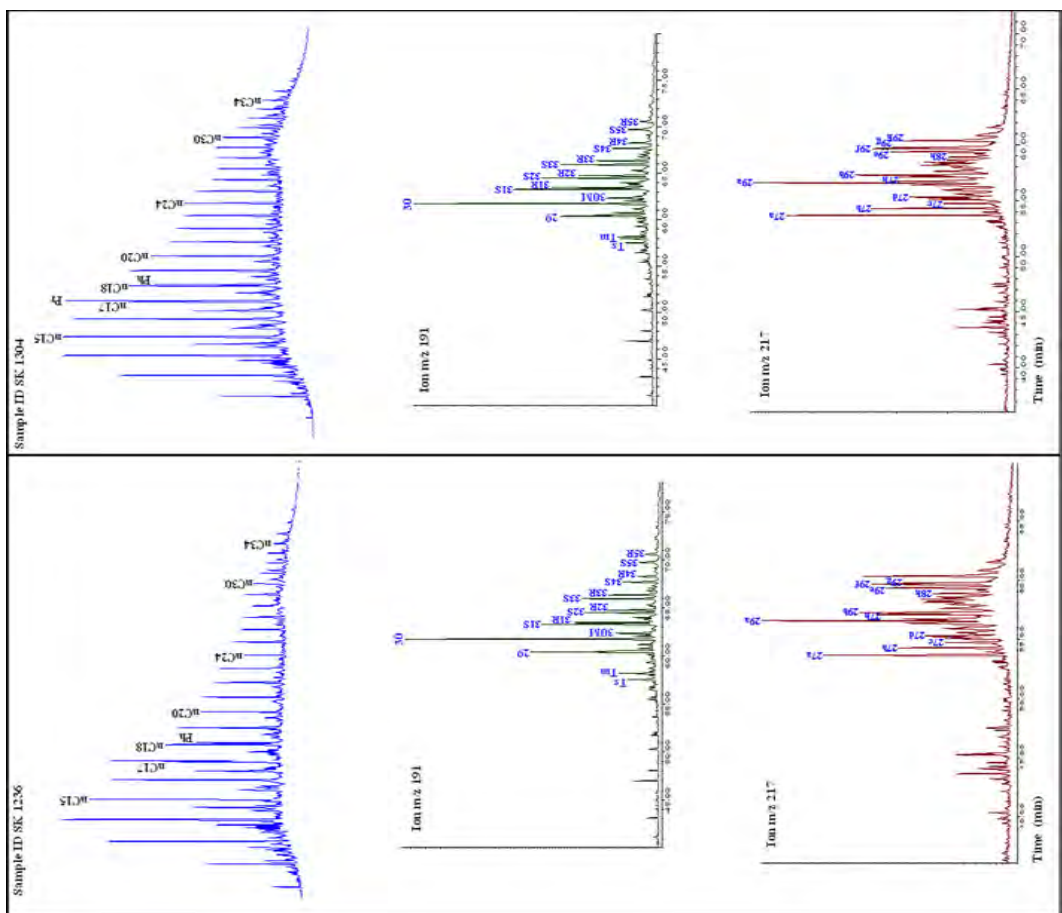
Figure 6: Gas chromatograms and mass fragmentograms (m/z 191 and 217) of the saturate fraction of samples SK 1236 and SK 1304.
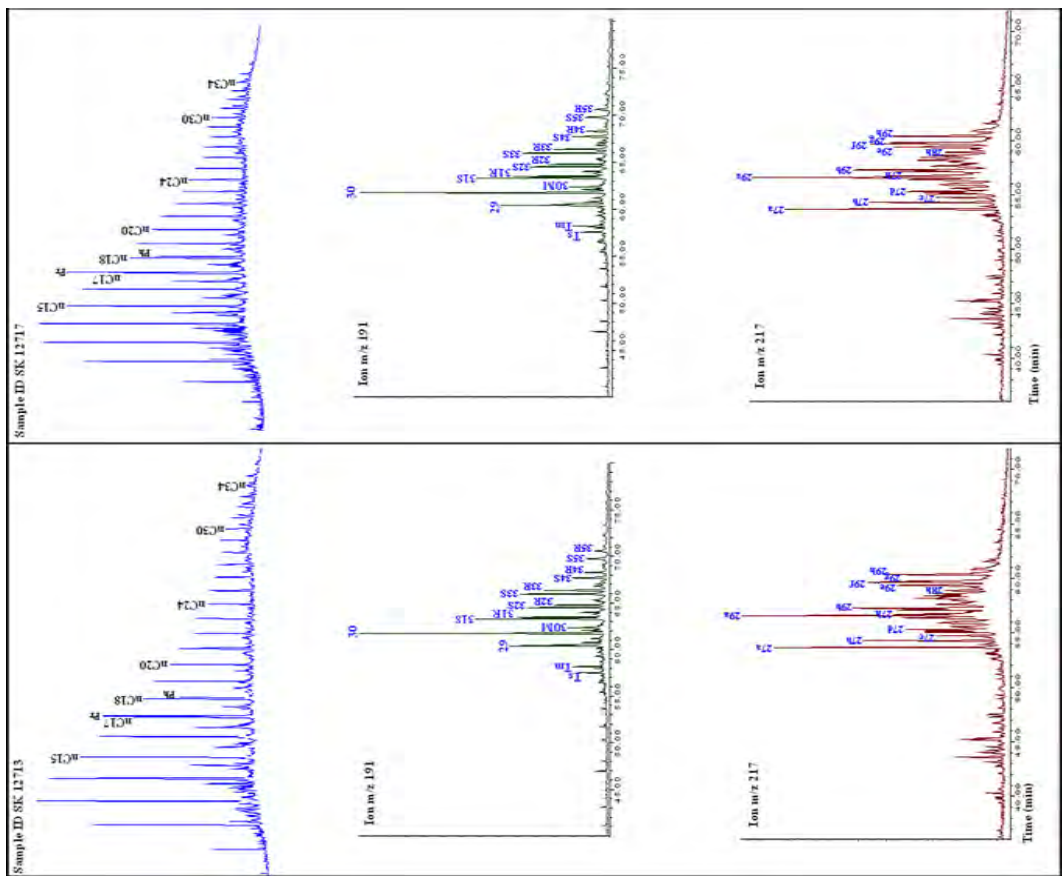

Figure 5: Gas chromatograms and mass fragmentograms (m/z 191 and 217) of the saturate fraction of samples SK 12713 and SK 12717.

& Moldowan, 1986) during maturation. Values in the range 0.50 to 0.54 have barely entered oil generation, whereas ratios from 0.57 up to 0.62 indicate that the oil window has been reached. Most extracted here display values of C_{32} 22S/22S+22R from 0.58 to 0.63 which suggest that these samples are thermally mature and that the oil window has been reached. 20S/(20S+20R) and $\beta\beta/(\beta\beta+\alpha\alpha)$ C_{29} sterane ratios suggest a similar interpretation, as do the moretane/ hopane ratios (Table 2). Most of the source rock samples yielded values that are approaching to the end point for 20S/(20S+20R) and $\beta\beta/(\beta\beta+\alpha\alpha)$ C_{29} sterane parameters, suggesting they are thermally mature and that the oil window has been reached. The ratio of moretane to their corresponding hopanes decreases with increasing thermal maturity, from about 0.8 in immature sediments to about 0.15-0.05 in mature source rocks and oils (Mackenzie *et al.,* 1980; Seifert and Moldowan, 1980). Most samples have moretane/hopane ratios in the range from 0.12-0.15, which suggests the shale samples are thermally mature.

Organic Matter Input and Depositional Environment

Biomarker distributions may provide information about organic facies and depositional environment (Waples and Machihara, 1991; Hunt, 1996; Peters *et al.,* 2005). Using the organic geochemical analyses data, depositional environment conditions for the shale samples can be evaluated. In this study, organic facies and depositional environments were examined with the use of sterane and triterpane distributions recorded using m/z 217 and m/z 191 mass chromatograms (Volkman & Maxwell, 1986) and parameters calculated from these distributions (Table 2).

Pristane/Phytane (Pr/Ph) ratio can be used as an indicator of redox conditions in ancient sediments (Didyk *et al.,* 1978). Values above 3.0 are considered to indicate terrestrial organic matter input under oxic conditions, low values (<0.6) indicate anoxic conditions and values between 1.0 and 3.0 suggest intermediate conditions (Powell, 1988; Amane and Hideki, 1997; Basant *et al.,* 2005). Sarmiento and Rangel (2004) suggested that Pr/Ph ratios (1.7 to 2.4) in oil indicate a largely argillaceous source rock with some minor carbonate, deposited in a suboxic marine environment, and lower values (less than 1.7) indicate source rocks deposited in a more calcareous anoxic marine environment. Pristane/ Phytane ratio for the studied samples here displays values in range from 1.64 to 2.38 which suggest that these samples are deposited under a suboxic conditions. In addition, in cases of C_{31} and C_{32} dominancy, a low C_{35} homohopane indicates a suboxic environment (Hunt, 1996; Murray & Boreham, 1992).

The relative abundances of C_{27}-C_{28}-C_{29} steranes are calculated and indicate the distributions of C_{27}-C_{28}-C_{29} steranes for all samples are very similar (Table 2). The C_{29}/ C_{27} steranes ratios for the studied shale samples approach unity and C_{28} sterane is in lower quantity in comparison to C_{27}, and C_{29} which suggest that these samples contain marine algae (Waples & Machihara, 1991). In addition, the

sterane/hopane ratio is relatively high in marine organic matter, with values generally approaching to unity (Tissot & Welte, 1984). On the basis of these data, the shale samples under investigation are believed to have been deposited in a suboxic marine environment.

CONCLUSIONS

The combined organic geochemical and organic petrographic approach used here has been able to evaluate the maturity and source rock potential for oil generation. Madbi Formation shales possess very good source rock potential for oil generation as supported by high values of TOC and high values of extractable organic matter and hydrocarbon yield. Overall evaluation of the maturity data implies that the Madbi shale is mature. Vitrinite reflectance data show that the Madbi Formation are thermally mature. This is supported by biomarker parameters such as CPI, C_{32} 22S/22S+22R homohopane ratios, 20S/(20S+20R) and $\beta\beta/(\beta\beta+\alpha\alpha)$ C_{29} sterane ratios and moretane/hopane ratios. Based on biomarker ratios such as Pr/Ph, C_{29}/C_{27} steranes, and sterane/hopane ratios the sediments are considered to have been deposited under suboxic conditions in a marine environment.

ACKNOWLEDGEMENTS

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Appendix A
Abbreviations used in Table 1

TOC	Total Organic carbon (%wt)
EOM	Extractable Organic Matter
Total Extr	Total Extract
Aliph.	Aliphatic
Arom.	Aromatic
HC	Hydrocarbons
CPI	Carbon Preference Index $= (2(C_{23}+C_{25}+C_{27}+C_{29})/[C_{22}+2(C_{24}+C_{26}+C_{28})+C_{30}])$
Pr/Ph	Pristane/Phytane
Pr/C_{17}	Pristane/n-C_{17}
Ph/C_{18}	Phytane/n-C_{18}

Appendix B
Abbreviations used in Table 2.

22S/(22R+22S)	$C_{32}17\alpha(H),21\beta(H)22S/(C_{32}17\alpha(H),21\beta(H)22R+C_{32}17\alpha(H),21\beta(H)22S)$
T_s/T_m	$18\alpha(H),22,29,30$-trisnorneohopane/$17\alpha(H),22,29,30$-trisnorhopane
$C_{29}hop/C_{30}hop$	$C_{29}17\alpha(H),21\beta(H)$-norhopane/$C_{30}17\alpha(H),21\beta(H)$-hopane
20S/(20S+20R)	$C_{29}5\alpha(H), 14\alpha(H), 17\alpha(H)20S/(C_{29}5\alpha(H), 14\alpha(H), 17\alpha(H)20(S+R)$
Diasteranes/steranes	$C_{29}13\beta(H), 17\alpha(H) 20 (R+S)$ diasteranes/$C_{29} \alpha\alpha\alpha+ \alpha\beta\beta20(R+S)$ steranes
$\alpha\beta\beta/(\alpha\beta\beta+ \alpha\alpha\alpha)$	{$5\alpha(H), 14\beta(H), 17\beta(H)(20R+20S) C_{29}$ steranes}/{$5\alpha(H), 14\beta(H), 17\beta(H)(20R+20S)+ 5\alpha(H), 14\alpha(H), 17\alpha(H)(20R+20S) C_{29}$ steranes}
C_{27},C_{28},C_{29} steranes abundance	$C_{27}5\alpha(H), 14\alpha(H), 17\alpha(H)20R, C_{28}5\alpha(H), 14\alpha(H), 17\alpha(H)20R, C_{29}5\alpha(H), 14\alpha(H), 17\alpha(H)20R$ steranes
C_{29}/C_{27}	$C_{29}5\alpha(H), 14\alpha(H), 17\alpha(H)20R$ steranes/ $C_{27}5\alpha(H), 14\alpha(H), 17\alpha(H)20R$ steranes
Steranes/hopanes	Relative abundance of steranes in m/z 217/ relative abundance of hopanes in m/z 191
%Ro	Present reflectance of vitrinite in oil

Appendix C

Peak assignments for alkane hydrocarbons in the gas chromatograms of aliphatic fractions: (I) in the m/z 191 mass chromatograms and (II) in the m/z 217 mass chromatograms.

	Compound	Abbreviation
(I) peak No.		
T_s	18α(H),22,29,30-trisnorneohopane	T_s
T_m	17α(H),22,29,30-trisnorhopane	T_m
29	17α(H),21β(H)-norhopane	C_{29} hop
30	17α(H),21β(H)-hopane	hopane
3M	17 β(H),21α (H)-moretane	C_{30}Mor
31S	17α(H),21β(H)-homohopane (22S)	C_{31}(22S)
31R	17α(H),21β(H)-homohopane (22R)	C_{31}(22R)
32S	17α(H),21β(H)-homohopane (22S)	C_{32}(22S)
32R	17α(H),21β(H)-homohopane (22R)	C_{32}(22R)
33S	17α(H),21β(H)-homohopane (22S)	C_{33}(22S)
33R	17α(H),21β(H)-homohopane (22R)	C_{33}(22R)
34S	17α(H),21β(H)-homohopane (22S)	C_{34}(22S)
34R	17α(H),21β(H)-homohopane (22R)	C_{34}(22R)
35S	17α(H),21β(H)-homohopane (22S)	C_{35}(22S)
35R	17α(H),21β(H)-homohopane (22R)	C_{35}(22R)
(II) the numbers on the chromatograms correspond to the carbon number of the molecules, and the letters identify the stereochemistry		
a	13β(H), 17α(H)-diasteranes 20S	diasteranes
b	13β(H), 17α(H)-diasteranes 20R	diasteranes
c	13α(H), 17β(H)-diasteranes 20S	diasteranes
d	13α(H), 17β(H)-diasteranes 20R	diasteranes
e	5α(H), 14α(H), 17α(H)-steranes 20S	ααα20S
f	5α(H), 14β(H), 17β(H)-steranes 20R	αββ20R
g	5α(H), 14β(H), 17β(H)-steranes 20S	αββ20S
h	5α(H), 14α(H), 17α(H)-steranes 20R	ααα20S
i	5β(H), 14α(H), 17α(H)-steranes	βαα