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UPPERJURASSICSOURCEROCKEVALUATIONANDTHERMALMATURITYEVOLUTIONOFTHENWSABATAYNBASINYEMEN

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Abstract- The Sab'atayn Basin has the greatest oil and gas exploration potential in the Mesozoic basins of Yemen. The quantity and quality of the organic matter of sediments is a core focus of source rocks evaluation in exploration of hydrocarbon. Organic-rich sediments within the Meem (Lower) and Lam (Upper) members from four wells in the NW Sab'atayn basin were analyzed using organic geochemistry and total organic carbon content. The obtained data shows that the total organic carbon content (TOC) values from Meem source rocks are between 0.2 to 1.68 wt% indicating fair to very good source rocks. While the values for the Lam source rocks are between 0.2 to 3.81 wt% indicating excellent source rocks, only two samples have values more than 3 wt% in Kamaran-01 well. The Rock-Eval pyrolysis data reveals that most of the samples are consist of reworked organic matter with no interesting source rocks potential. Most of the studied samples of Meem and Lam source rocks have Tmax less than 440 °C, which place them in immature to marginally mature and in the fringe of main stages of hydrocarbon generation. Based on results of generative potential (GP) of Meem source rocks, it shows that the GP values are less than 2 mg HC/gm rocks are in non-generative rocks. Furthermore, those source rocks with exceptionally high GP values in order of more than 10 mg HC/ g rock may provide an excellent source rock in Dahamr Ali-01 well, if the burial depth is sufficient to build a suitable temperature and pressure. On the other hand Lam source rock is classified as moderate source rocks. Non-generative potential has been reported from Lam source rock in Himyar-01 well where the GP is less than 1 mg HC/g rock. Kerogen type for Lam and Meem source units can be deduced by the cross-plots of pyrolysis parameters, such as HI vs Tmax (modified ven Krevelen diagram) and TOC vs S2 which are probably resulted from deposition of more terrigenous type III organic matters sourced from land. Finally the results of thermal maturation shows that the analyzed Meem source rocks are generally plotted in the mature zone, while the results of Lam source rocks samples show that the source rocks is still immature, marginally mature in Dahamr Ali-01 and Saba-01 wells.

Keywords: upper jurassic source rocks, thermal maturity, hydrocarbon generation potential, sab'atayn basin, yemen.

I. Introduction

Yemen economies are reliant mostly on oil production. The annual petroleum consumption was over 168000 barrel per day in Yemen of 2011 census (Yemeni petroleum exploration & production Authority, (PEPA). The petroleum exploration and production activities have been affected by security issues since 2011, remarkable drop have affect the country economy as well. Worse still, the traditionally large Yemeni oilfields, including Alif, Kharir and Halewah fields are facing a crisis of production reduction. Therefore, resource reassessment must carry out in parts of sedimentary basins previously little explored especially in northwestern part of the petroliferous Sab'atayn basin Fig. 1. The Sab'atayn basin, which conserved Mesozoic succession in its stratigraphy, favored petroleum accumulation because it contains the whole petroleum system element (Source, Reservoirs and Seal rocks). The upper Lam member is the first target of source rock assessment and hydrocarbon exploration because of organic matter richness and greater profic oil prone source rock across Yemen (Brannin et al., 1999; Albaroot et al., 2016). The Lower Meem member made up of argillaceous limestone (Alaug et al., 2011; Al-Areeq, 2011; Al-Azazi, 2010 and Al-Areeq, 2004), consider the second target of source rock assessment. In the past decades, several wells have been drilled in northwestern (NW) part of Sab'atayn basin but unfortunately the results became frustrated. Due to the necessity to increases oil potential we try to re-evaluate this part of the basin by using the available geochemical data from the source rocks. Therefore, it is necessary to evaluate systematically the characteristic of the source rocks and their maturity evaluation within this part of the basin. This evaluation can improve our understanding of Lam and Meem source unit evolution and maturation. The characteristics of source rock evaluation include the kerogen type, organic matter abundance and source rock maturity. The source rocks thermal maturity investigation primarily includes vitrinite reflectance (% Ro) and temperature maximum (Tmax) from the Rock-Eval pyrolysis. The quantity of organic matter is commonly assessed by a measuring *total organic carbon (TOC)* contained in the rocks. Quality is measured by determining the types of *kerogen* contained in the organic matter. Thermal maturity is most often estimated by using *vitrinite reflectance* measurements in addition to data from *pyrolysis* analyses. However, drilling wells and samples are short in the NW part of the basin, because this area has not been subjected to extensive conventional oil and gas targets. Therefore, it is impossible to do any geochemical analysis and difficult to study using

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conventional experimental test methods due to core samples chips scarcity, only data of geochemical analysis can be obtained from (SPT, 1994) reports. Challenges and breakthroughs in recent research in hydrocarbon generation, expulsion, migration and accumulation led to more understanding the whole process of hydrocarbon. Therefore, source rock investigation is of increasing importance because it reduces risk potential and gives a quick insight of concerned area. Along with the development of petroleum geology theory and the wide application of computing technology, quantitative research on the thermal maturity evolution of source rocks in the geological period is of great significance.

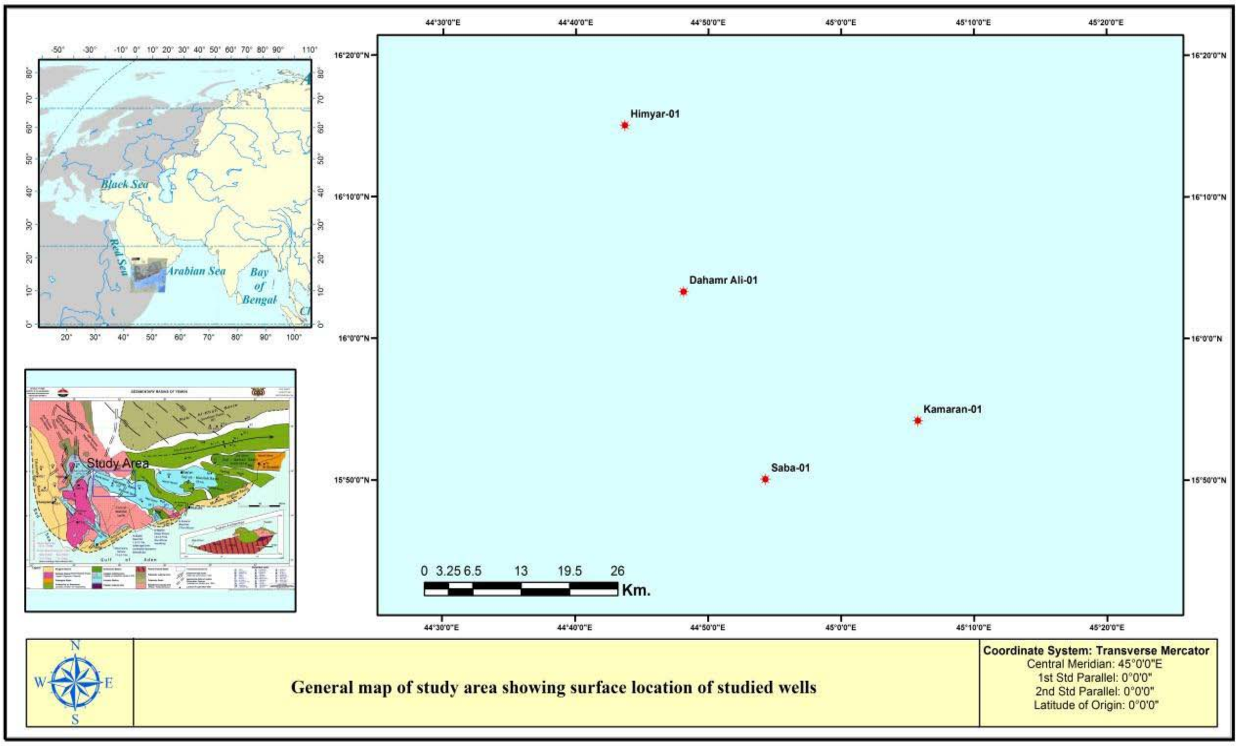

Figure 1: Location map of the studied wells in the NW Sab'atayn Basin, central Yemen.

II. Geological Setting

Yemen, situated at the southern end of the Arabian Peninsula, both are geographically and geologically has the same geological signature between the Arabian and African plate. It is located close to the Tertiary triple junction between the Red Sea, Gulf of Aden and Afar plume. The NW-trending Sab'atayn Basin (also called Marib-Shabwa-Hajar Basin, Marib-Shabwa Basin) is a Mesozoic rift basin in Yemen that follows a deep-seated Proterozoic structural trend (Redfern and Jones, 1995) and oriented NW–SE (Bott et al., 1992; Brannan et al., 1999). Basin formation was a consequence of several extensional phases related to the separation of India from Africa-Arabia (Redfern and Jones, 1995; Ziegler, 2001). The stratigraphic framework of the basin fill according to Beydoun et al. (1998) it varies from marginal to central. The development of Sab'atayn Basin can be subdivided into three tectono-stratigraphic megasequences: (a) a pre-rifting phase (Permian-Oxfordian/Kimmerdgian), (b) a syn-rifting phase (Kimmerdgian-Tithonian) and (c) a post-rifting phase (Early Cretaceous), Permian pre-rift phase not well proved. In the NW part of the basin, syn-rifting phase parts (Kimmeridgian-Tithonian) and post-rifting phase (Early Cretaceous) not encountered at all due to uplift and erosion. Pre-rift deposits are represented by non-marine to shallow-marine clastic rocks (Kuhlan Formation; (Beydoun et al., 1998)) overlain by shallow-marine carbonates (Shuqra Formation). A latest Triassic to Middle Jurassic age is generally accepted for both Formations (see also Al-Wosabi & Wasel, 2011), but Stephenson and Al-Mashaikie (2011) provided evidence for a Late Carboniferous age for the lower part of the Kuhlan Formation. The syn-rift sequence is characterized by horsts and nested fault blocks that were developed during Late Jurassic to Lower Cretaceous time (Redfern and Jones, 1995). During the Late Jurassic commencing in the Kimmeridgian, syn-rift sediments of the Madbi Formation were deposited (Beydoun et al., 1998). The Madbi Formation is composed of porous limestone to argillaceous lime mudstone. This Formation is divided into two members, the lower member (Meem Member) consists of source rock-quality shales, and sandy turbidites in the border of the basin and may form the reservoir rocks in some oilfields of the northwestern Sab'atayn Basin. The Upper Lam Member is mostly composed of laminated organic rich shales and considered to be the most prolific oil-prone source rock in the basin (Brannan et al., 1999 and Csato et al., 2001). During Tithonian time, late stages of the syn- rift phase, ocean circulation in the Sab'atayn Basin became restricted, and an evaporitic succession (Safir Member) with an estimated original thickness of about 731 m was deposited (Albaroot, 2017). Massive halite occurs in the basin center, whereas anhydrite and clastic rocks rare along the basin margins (Seaborne, 1996), or totally absent. Interbedded thin shales within Safir member are rich in organic matter (Brannan et al., 1999). The Sab'atayn Formation is divided into four members named as Safir, Alif, Seen and Yah Member. Yah Member is dominated by fluvio-deltaic sandstone, mudstone and evaporate, followed by Seen Member, which is the second clastic sequence. Alif Member is composed of sandstone with shale, which form main reservoir in Sab'atayn Basin. Safir Member consists predominantly of halite with subordinate anhydrite divisible into several bodies separated by interbedded organic-rich shale and sandstone with minor argillaceous, dolomite and limestone. The interbedded organic rich shales within the Safir Member are considered to be the prolific oil-prone source rock in the Marib-Shabwa Basin within Sab'atayn Formation. The Safir Member constitute an excellent seal to the underling Alif Member reservoir and contain within them some potential good local reservoir seal pairs in the intra evaporate clastics and the evaporates (Beydoun et al., 1998). In the Northwestern part of the Sab'atayn basin during Tithonian time, deposition of late stages of the syn- rift phase clastic and evaporates sedimentations (Sab'atayn Formation) didn't extended and progressively thinned out for causes not well understood.

III. Methology

Source rock evaluation within the study area depends on the determination of organic matter content, which is usually expressed as total organic carbon (TOC). The hydrocarbon potentiality depends on the type and quantity of organic matter (kerogen) preserved in the petroleum source rock, thermal maturity and finally the generation potential of kerogen. The geochemical data such as total organic carbon (TOC), Rock-eval pyrolysis data, and vitrinite reflectance are presented and discussed for the proposed Upper Jurassic rock units in Northwestern part of Sab'atayn Basin (Dahamr Ali-01, Himyar-01, Kamaran-01 and Saba-01 wells). TOC determination and Rock-Eval pyrolysis analysis were performed on 100 mg crushed whole rock samples, heated to 600° C in a helium atmosphere, using a Rock-Eval II unit with a total organic carbon module. The Rock-Eval pyrolysis data provide information on the quantity, quality and maturity of organic matter contained within the Lam and Meem rock units (Table 1). A total of 148 rock samples were collected from shales of the Lam and Meem Members in the studied wells. Initially, the studied shale samples were cleaned of contaminants from drilling mud additives by washing the samples with water several times until no mud was visible on their surface. Parameters measured include Total organic carbon (TOC), free hydrocarbons (S1) in the rock, remaining hydrocarbon generative potential, mgHC/g rock (S2), and temperature of maximum pyrolysis yield (Tmax). Hydrogen (HI), production yield (PY), and production (PI) indexes were mathematically calculated (Table 1). The temperature at which the maximum generation of the products of pyrolysis occurs was used to calculate the following:

OI, oxygen index [OI = (S3/TOC) x 100)]

HI, hydrogen index [HI = (S2/TOC) x 100].

Plot of HI versus OI can be used to deduce the type of organic matter present in the source rock.

PI, production index [PI = S1 / S1+S2)

Hydrogen richness in the kerogen = S2/S3

Genetic potential of the source rock = S1+S2

Details on the Rock-Eval method and parameters as well as a summary of interpretive guidelines for Rock-Eval data are available in (Espitalie et al. (1977), Peters (1986), Peters and Cassa (1994), and Snowdon et al. (1998).

IV. Results & Discussions

The capability of any prospective reservoir depends on an effective source rock. Petroleum geochemistry is proving its value in helping petroleum geologists to evaluate source rocks and quantify the elements and processes that control the generation of oil and gas. Geochemistry is also an important tool for reducing uncertainty inherent in exploration and production of frontier basins. This section will explore basic geochemical methods used to evaluate new prospects.

a) *Quality and quantity of organic matter*

The impact of quality and quantity of the organic matter (TOC) in the sediments are very important for hydrocarbon generation. The quality term of organic matter is refer to whether the source rock organic matter is oil prone or gas prone, since different types of organic matter have different hydrocarbon generating potential or quality. However, the amount of organic matter in source rocks is the results of a wide variety of environmental influences. Tissot and Welte (1984), Peters and Cassa (1994) and Peters (1986) presented a scale for the assessment of source rocks potentiality, based on the TOC weight % and Rock–Eval

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pyrolysis data, such as S_1 and S_2. The obtained data in (Table 1) show that the total organic carbon content (TOC) values for the Meem source rocks are between 0.2 and 1.68 wt% indicating fair to good source rocks. While the values for the Lam source rocks are between 0.2 and 2.93 wt% indicating fair to excellent source rocks only two samples have values more than 3 wt% in Kamaran-01 well. These conclusions are confirmed by the plots of total organic carbon (TOC wt%) versus remaining hydrocarbon (S2 mgHC/g rock) Fig. 2A. The total organic carbon is mostly very poor in studied wells. The Rock-Eval pyrolysis data in (Table 1) reveal that most of the samples consist of reworked organic matter with no interesting source rocks potential. On the other hand, the plot of Tmax versus production index (PI) Fig. 2B provides an indication of source rock maturity and hydrocarbon genesis. Thermal maturity is influenced by source rock organic matter type and the presence of excess free hydrocarbon together with the other factors like mineral matter, content, depth of burial and age (Tissot and Welte, 1984). The degree of thermal evolution of the sedimentary organic matter was deduced from Tmax (°C) Production Index (PI) and Vitrinite Reflectance (% Ro). The increase of maturity level of organic matter corresponds to an increase in Tmax. This phenomenon is related to the nature of chemical reactions that occur through thermal cracking. The weaker bonds breakup in the early stages while, the stronger bonds survive until higher temperatures in the late stages (Whelan and Thompson, 1993). Combining and finding relations between the essential Rock-Eval parameter, Tmax, and calculated Rock-Eval parameter, PI, is a valuable method for indicating the maturity of organic matter. The following relations between Tmax and PI are observed:

1. *Immature organic* matter has Tmax and PI values less than 430 °C and 0.10, respectively;
2. *Mature organic* matter has a range of 0.1 – 04 PI. At the top of oil window, Tmax and PI reach 460°C and 0.4, respectively;
3. *Mature organic* matter within the wet gas-zone has PI values greater than 0.4; and
4. *Post-mature* organic matter usually has a high PI value and may reach 1.0 by the end of the dry-gas zone (Peters K.E. (1986), Peters and Cassa, (1994), and Bacon, et al, (2000).

In well Dahamr Ali-01, most of the samples of Meem source rocks especially in the lower part have Tmax more than 445 °C and PI of 0.34 – 0.73. This indicate that the lower part in mature stage, while the upper part are in early mature and immature stages. Most of the samples are non-indegenous hydrocarbon except for few samples which fall within the hydrocarbon generation zone. Most of the samples in Himyar-01, Kamaran-01 and Saba-01 wells have Tmax less than 445 °C, accordingly ranging from immature to early mature stage. Some samples have elevated Tmax more than 445 °C making them peak mature. Samples from aforesaid wells except four samples from Kamaran-01 well are in main stages of hydrocarbon generation. The reset samples are non-indigenous hydrocarbons (Fig. 3). Most of the samples from the Lam source rocks in Dahamr Ali-01, Himyar-01, Kamaran-01 and Saba-01 wells are have Tmax less than 435 °C, accordingly plotted in immature zone.

b) Generating potentialities

The generating potential of source rocks is used to evaluate their capacity for hydrocarbon generation and can be determined by using the results of pyrolysis analysis. Tissot and Welte, (1984) proposed a genetic potential (GP = S1 + S2) for the classification of source rocks. According to their classification scheme, rocks having GP of less than 2 mg HC/g rock correspond to gas-prone rocks or non-generative ones, rocks with GP between 2 and 6 mg HC/g rock are moderate source rocks, and those with GP greater than 6 mg HC/g rock are good source rocks. Based on the above criteria, the Meem source rocks with a GP of less than 2 are non-generative rocks. Furthermore those source rocks with exceptionally high GP values in order of more than 10 mg HC/g rock may provide either an excellent source rock in Dahamr Ali-01 well, if the burial depth is sufficient to build temperature and pressure. On the other hand Lam source rock is classified as moderate source rocks. Non-generative potential has been reported for Lam source rock in Himyar-01 well where the GP is less than 1 mg HC/g rock Fig. 3. It is worthy to mention that both of the source rocks are located in shallow depth in the study area even more exposed on the surface for some wells location.

c) Genetic type of organic matter

The initial genetic type of organic matter of a particular source rock is essential for the prediction of oil and gas potential. Waples, (1985) used the hydrogen index values (HI) to differentiate between the types of organic matter. Hydrogen indices <150 mg/g indicate a potential source for generating gas (mainly type III kerogen). Hydrogen indices between 150 and 300 mg/g contain more type III kerogen than type II and therefore are capable of generating mixed gas and oil but mainly gas. Kerogen with hydrogen indices >300 mg/g contains a substantial amount of type II macerals and thus are considered to have good source potential for generating oil and minor gas. Kerogen with hydrogen indices >600 mg/g usually consists of nearly type I or type II kerogen; they have excellent potential to generate oil. Kerogen type for Lam and Meem source units can be deduced by the cross-plots of pyrolysis parameters, such as HI vs Tmax (modified ven Krevelen diagram, Fig. 4 and TOC vs S2 (Fig. 2A) which are probably resulted from deposition of more terrigenous type III organic matters sourced from land. Type III kerogen is composed of terrestrial organic material that is lacking in fatty or waxy components. Cellulose and lignin are major contributors. Type III kerogen have much lower hydrocarbon-generative capacities than do Type II kerogen and, unless they have small inclusions of Type II material, are normally considered to generate mainly gas. Majority of study area is dominated by type III kerogen, which is attributed to terrestrial environment where land derived organic matter is prevailed. This type of kerogen is characterized by small amount of Hydrogen is present; However this type of kerogen can generate gas only.

d) Thermal Maturation

Thermal maturity is the extent of heat-driven reactions that alter the composition of organic matter. The concentration and distribution of hydrocarbons contained in a particular source depend on both the type of the organic matter and its degree of thermal alteration (Longford et al, 1990). In the present paper, the thermal maturity level of the source rocks of Meem and Lam members has been determined by the study of the geochemical parameters as Rock–Eval temperature pyrolysis ''Tmax'', Hydrogen index ''HI' Fig. 4. Combining and finding relations between the essential Rock-Eval parameter, Tmax, and calculated Rock-Eval parameter, HI, is a valuable method for indicating the thermal maturity of organic matter. Based on pyrolysis data kerogen classification diagrams were constructed using the HI versus Tmax plot as carried out by previous workers (Espitalie et al, 1985) which is used to determine the kerogen type and maturity Fig. 4. The results show that the analysed Meem source rocks are generally plotted in the mature zone of type III kerogen. Some samples in Dahamr Ali-01 well are upgraded to marginally mature zone. In addition Kamaran-01 well ranges from mature to post mature zone. The wide variation in maturity level of Meem source rocks attributed to overburden rocks and depth. Results of Lam source rocks samples show that the source rocks are still immature. Marginally mature in Dahamr Ali-01 and Saba-01 wells. These results have led to classify the Meem member as fully mature source rocks, while the Lam member is immature source rocks in the study area, because the structural setting shows the deepening of Meem member and shallowing of Lam member.

V. Conclusion

Upper Jurassic source rocks in the NW Sab'atayn Basin central Yemen have been investigated. The main conclusions of the study are, Upper Jurassic source rocks consider the main source rocks in the study area. Deposition of the Meem and Lam source rocks succession did not result in a renewal of generation processes. As evident from kerogen type present in studied wells we can clearly argued this kerogen derived from land derived organic matter. The Rock-Eval pyrolysis data is reveal that most of the samples consist of reworked organic matter with no interesting source rocks potential. Organic rich source rock with poor to good potential to generate oil and gas is present in the Upper Jurassic Meem and Lam Members. Good to fair source rocks of Meem and Lam Members is located in study area. Results of TOC for the studied wells show that the quantity of source rocks are fair to good, some samples are graded to excellent. Most of the studied samples of Meem and Lam source rocks have Tmax less than 440 °C, which place them in immature to marginally mature. Majority of samples in main stages of hydrocarbon generation Based on generative potential of Meem source rocks, it shows non-generative rocks. Kerogen type for Lam and Meem source units is dominated by type III organic matters sourced from land.

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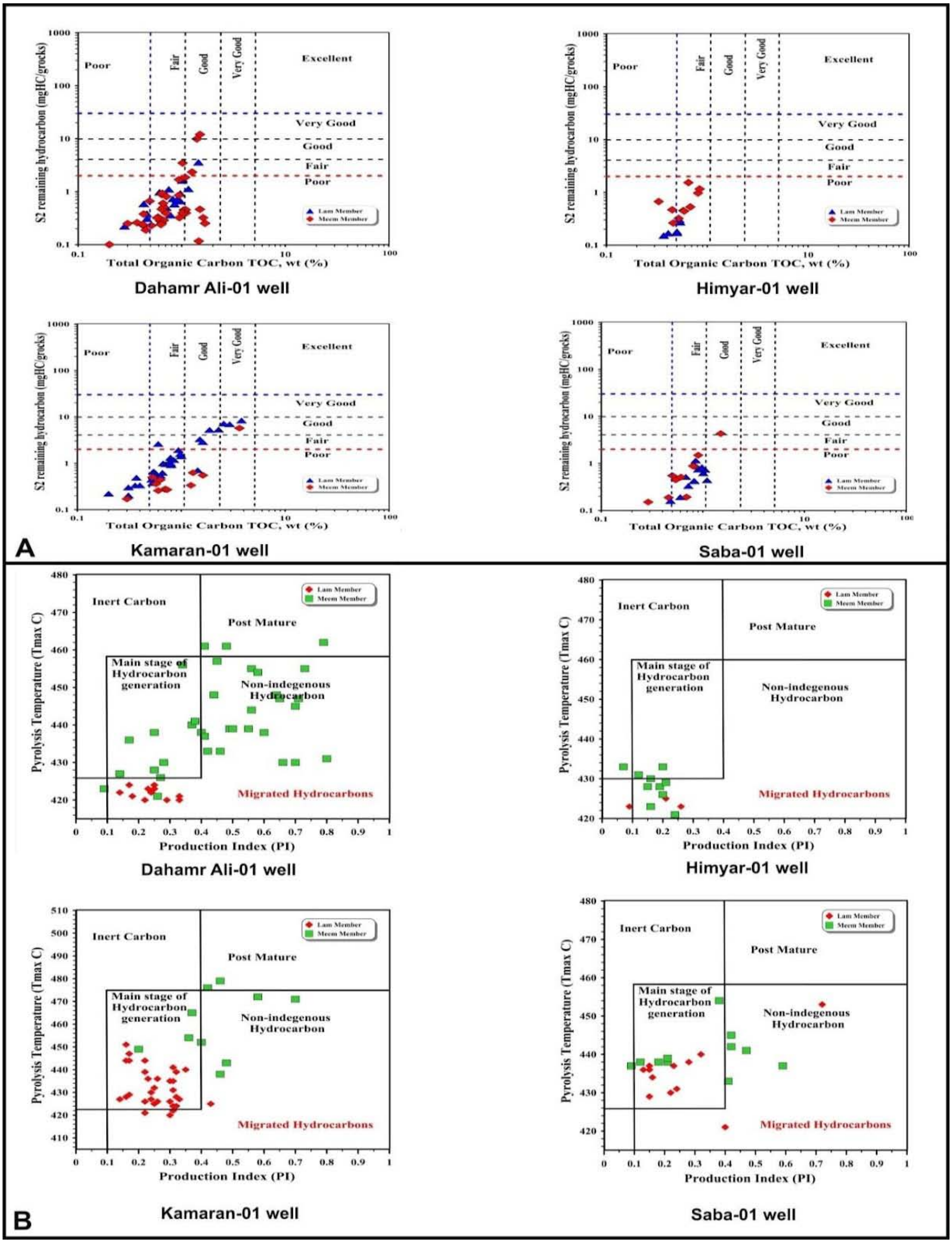

Figure 2: Quality and quantity of organic matter of Meem and Lam source rocks, NW Sab'atayn basin, Yemen.

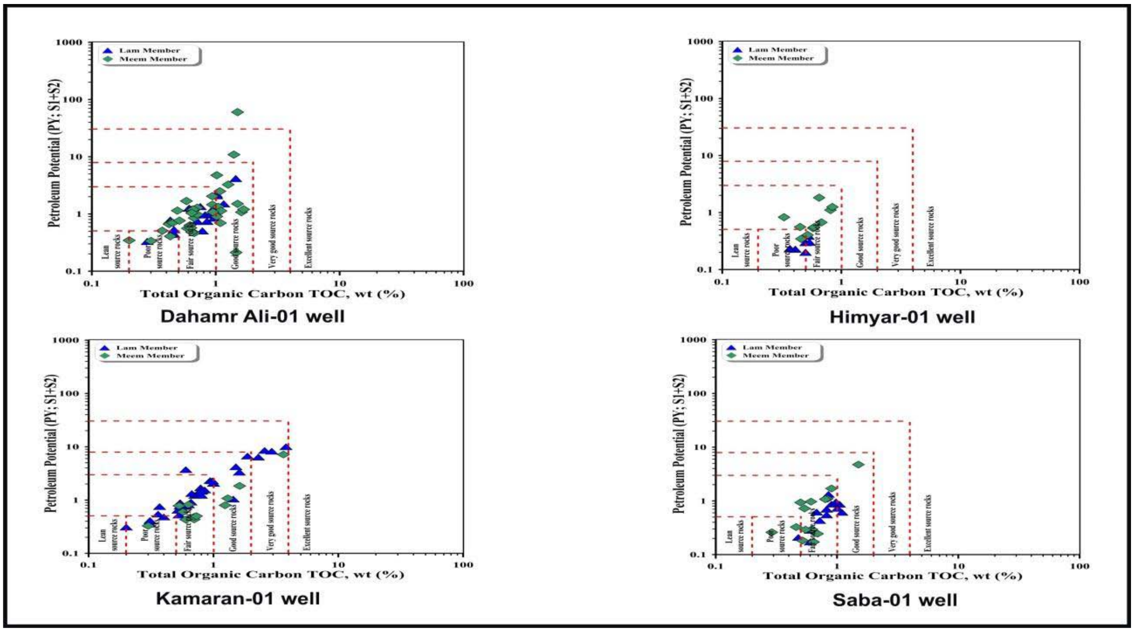

Figure 3: Generating potentialities of Meem and Lam source rocks, NW Sab'atayn basin, Yemen.

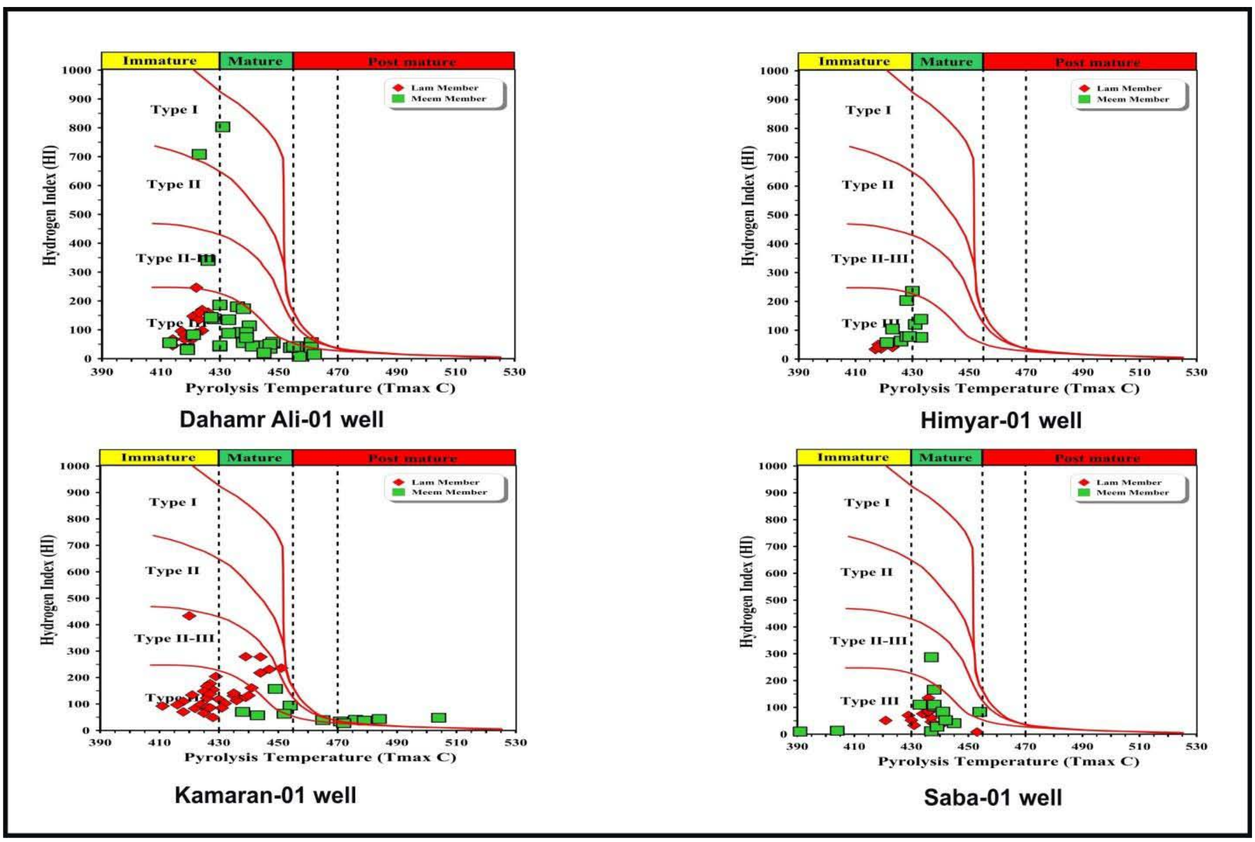

Figure 4: Kerogen type and Thermal maturation of Meem and Lam source rocks, NW Sab'atayn Basin, Yemen.

Table 1: Rock–Eval pyrolysis data for Lam and Meem source rocks in the studied wells.

Wells Name	Members	Depth (m)	TOC "wt%"	S1	S2	S1+S2	Tmax	HI	PI
Dahamr Ali-01	Lam Member	203.7	1.01	0.60	1.62	2.21	426	160	0.27
		323.2	1.16	0.38	1.13	1.50	424	97	0.25
		405.5	0.78	0.15	0.36	0.51	414	46	0.29
		484.8	0.97	0.19	0.66	0.85	420	68	0.22
		594.5	0.82	0.23	0.73	0.96	422	89	0.24
		640.2	0.85	0.16	0.58	0.74	418	68	0.22
		703.7	0.71	0.24	0.50	0.74	421	70	0.33
		722.6	1.45	0.58	3.57	4.15	422	246	0.14
		731.7	1.02	0.35	1.72	2.08	424	169	0.17
		798.8	0.9	0.29	0.70	0.99	420	78	0.29
		817.1	0.97	0.36	0.92	1.28	417	95	0.28
		881.1	0.46	0.13	0.31	0.44	414	67	0.3
		981.7	0.75	0.24	1.10	1.34	421	147	0.18
		1073.2	0.46	0.15	0.38	0.53	418	83	0.28
		1201.2	0.43	0.19	0.58	0.78	423	136	0.25
		1320.1	0.61	0.29	0.97	1.26	423	159	0.23
		1356.7	0.28	0.11	0.22	0.33	420	79	0.33
		1420.7	0.3	0.09	0.25	0.34	421	83	0.26
	Meem Member	1457.3	0.64	0.29	0.88	1.18	428	138	0.25
		1459.7	0.65	0.15	0.93	1.08	427	143	0.14
		1530.5	1.5	48.18	12.05	60.23	431	803	0.8
		1535.4	1.4	0.98	9.91	10.89	423	708	0.09
		1539.6	1.02	1.28	3.47	4.75	426	340	0.27
		1622.0	0.94	0.35	1.69	2.04	436	180	0.17
		1723.2	1.26	0.91	2.34	3.26	430	186	0.28
		1759.1	0.71	0.48	0.81	1.28	440	114	0.37
		1832.3	1.08	0.62	1.87	2.49	438	173	0.25
		1841.5	0.49	0.48	0.66	1.14	433	135	0.42
		1914.6	0.67	0.34	0.51	0.85	438	76	0.4
		1987.8	0.37	0.25	0.26	0.51	439	70	0.49
		2020.1	0.94	0.59	0.86	1.45	437	91	0.41
		2051.8	0.66	0.60	0.60	1.20	439	91	0.5
		2088.4	0.43	0.32	0.38	0.70	433	88	0.46
		2152.4	1.05	0.88	0.45	1.33	430	43	0.66
		2243.9	1.1	0.74	0.40	1.13	447	36	0.65

		2298.8	0.71	0.59	0.39	0.98	438	55	0.6
		2344.5	0.62	0.36	0.28	0.63	444	45	0.56
		2426.8	0.67	0.18	0.29	0.46	441	43	0.38
		2445.1	0.43	0.18	0.23	0.41	448	53	0.44
		2545.7	1.09	0.24	0.46	0.69	456	42	0.34
		2591.5	1.02	0.51	0.40	0.90	455	39	0.56
		2618.9	0.42	0.43	0.24	0.67	448	57	0.64
		2637.2	1.46	0.10	0.12	0.21	457	8	0.45
		2710.4	0.2	0.24	0.10	0.34	447	50	0.71
		2774.4	0.59	0.23	0.33	0.56	461	56	0.41
		2893.3	0.64	0.23	0.25	0.48	461	39	0.48
		3176.8	0.63	0.33	0.24	0.57	454	38	0.58
		3213.4	0.45	0.51	0.19	0.70	455	42	0.73
		3295.7	0.58	1.36	0.32	1.68	413	55	0.81
		3359.8	0.95	0.75	0.32	1.08	419	34	0.7
		3423.8	0.51	0.54	0.23	0.77	430	45	0.7
		3469.5	0.64	0.57	0.47	1.04	439	73	0.55
		3564.0	1.61	0.75	0.32	1.07	445	20	0.7
		3631.1	1.5	1.04	0.47	1.50	419	31	0.69
		3640.2	1.68	0.95	0.25	1.20	462	15	0.79
Himyer-01	Lam Member	91.5	0.50	0.03	0.27	0.297	423	54	0.09
		100.6	0.50	0.03	0.17	0.2	417	34	0.15
		295.7	0.50	0.02	0.18	0.2	419	36	0.1
		353.7	0.54	0.03	0.27	0.3	418	50	0.1
		362.8	0.41	0.06	0.17	0.227	423	41	0.26
		445.1	0.37	0.08	0.15	0.233	418	41	0.35
		454.3	0.37	0.08	0.15	0.23	418	41	0.34
		570.1	0.53	0.08	0.3	0.382	425	57	0.21
	Meem Member	628.0	0.52	0.08	0.32	0.403	426	62	0.2
		658.5	0.58	0.08	0.45	0.532	428	78	0.15
		686.0	0.45	0.09	0.47	0.557	423	104	0.16
		731.7	0.81	0.13	0.97	1.105	431	120	0.12
		750.0	0.84	0.09	1.16	1.246	433	138	0.07
		777.4	0.33	0.16	0.67	0.827	428	203	0.19
		817.0	0.59	0.11	0.44	0.553	433	75	0.2
		823.2	0.65	0.29	1.53	1.818	430	235	0.16
		828.0	0.46	0.08	0.26	0.345	421	57	0.24

		887.2	0.7	0.14	0.53	0.671	429	78	0.21
Kamaran-01	Lam Member	920.50	1.61	0.46	2.85	3.314	427	177	0.14
		938.78	0.36	0.21	0.33	0.543	411	92	0.39
		975.36	0.53	0.15	0.37	0.523	418	70	0.29
		993.65	0.66	0.29	0.62	0.912	424	94	0.32
		1011.94	0.4	0.15	0.33	0.481	422	83	0.31
		1030.22	0.2	0.09	0.22	0.31	418	110	0.29
		1085.09	0.31	0.15	0.2	0.354	425	65	0.43
		1131.08	0.71	0.27	0.95	1.22	421	134	0.22
		1176.53	0.54	0.24	0.53	0.767	424	98	0.31
		1222.25	0.31	0.11	0.3	0.412	416	97	0.27
		1277.11	0.81	0.24	1.25	1.485	428	154	0.16
		1295.40	0.94	0.39	1.92	2.31	429	204	0.17
		1331.98	0.54	0.23	0.66	0.89	426	122	0.26
		1350.26	0.79	0.37	1.32	1.691	426	167	0.22
		1368.55	0.67	0.33	0.99	1.322	425	148	0.25
		1408.18	0.6	1.11	2.6	3.711	420	433	0.3
		1426.46	0.55	0.2	0.65	0.854	430	118	0.24
		1481.33	0.57	0.19	0.58	0.775	432	102	0.25
		1548.38	0.75	0.29	0.96	1.247	436	128	0.23
		1600.20	0.6	0.23	0.53	0.754	426	88	0.3
		1645.92	0.63	0.27	0.54	0.809	427	86	0.33
		1691.64	0.52	0.2	0.44	0.641	431	85	0.31
		1773.94	0.85	0.37	1.17	1.543	427	138	0.24
		1828.80	0.8	0.32	0.9	1.222	436	113	0.26
		1901.95	0.78	0.44	1.02	1.46	435	131	0.3
		2002.54	1	0.63	1.41	2.043	435	141	0.31
		2066.54	0.98	0.71	1.58	2.287	441	161	0.31
		2075.69	1.87	1.47	5.22	6.689	439	279	0.22
		2139.70	0.79	0.46	0.99	1.452	439	125	0.32
		2148.84	2.57	1.36	7.14	8.505	444	278	0.16
		2157.98	1.51	0.92	3.28	4.201	444	217	0.22
		2167.13	2.29	1.08	5.29	6.373	447	231	0.17
		2176.27	2.93	1.32	6.91	8.232	451	236	0.16
		2194.56	0.37	0.26	0.49	0.751	440	132	0.35
		2258.57	1.44	0.33	0.71	1.038	428	49	0.32
		2267.71	3.81	1.7	8.31	10.01	444	218	0.17
		2276.86	3.64	1.43	5.71	7.144	449	157	0.2

		2322.58	0.63	0.38	0.44	0.817	438	70	0.46
		2404.87	0.3	0.16	0.17	0.329	443	57	0.48
		2450.59	0.53	0.28	0.5	0.778	454	94	0.36
		2505.46	0.57	0.24	0.36	0.599	452	63	0.4
		2587.75	0.7	0.16	0.27	0.433	465	39	0.37
	Meem Member	2660.90	0.7	0.2	0.28	0.483	476	40	0.42
		2752.34	0.6	0.17	0.26	0.43	484	43	0.4
		2843.78	0.73	0.23	0.27	0.5	479	37	0.46
		2907.79	1.62	1.29	0.55	1.836	471	34	0.7
		2926.08	1.24	0.46	0.33	0.797	472	27	0.58
		2944.37	1.3	0.45	0.62	1.076	504	48	0.42
		48.768	0.82	0.28	0.42	0.697	421	51	0.4
		67.056	1.05	0.13	0.74	0.865	429	70	0.15
		112.776	0.82	0.12	0.43	0.547	430	52	0.22
		149.352	0.48	0.05	0.16	0.208	431	33	0.24
		204.216	0.72	0.1	0.33	0.43	437	46	0.23
		240.792	0.6	0.09	0.19	0.282	440	32	0.32
	Lam Member	286.512	0.68	0.1	0.52	0.615	434	76	0.16
		329.184	1.01	0.11	0.62	0.725	437	61	0.15
		356.616	0.9	0.13	0.74	0.868	436	82	0.15
		396.24	0.98	0.12	0.83	0.957	436	85	0.13
		423.672	1.1	0.17	0.44	0.611	438	40	0.28
		460.248	0.6	0.12	0.05	0.171	453	8	0.72
Saba-01		496.824	0.85	0.17	1.15	1.319	436	135	0.13
		524.256	0.5	0.38	0.55	0.932	433	110	0.41
		560.832	0.9	0.2	1.49	1.698	438	166	0.12
		579.12	1.5	0.43	4.31	4.731	437	287	0.09
		624.84	0.83	0.23	0.86	1.093	438	104	0.21
		707.136	0.8	0.19	0.88	1.073	438	110	0.18
		743.712	0.61	0.45	0.51	0.967	441	84	0.47
	Meem Member	780.288	0.64	0.1	0.07	0.172	437	11	0.59
		816.864	0.69	0.05	0.19	0.245	439	28	0.21
		853.44	0.62	0.23	0.06	0.295	450	10	0.79
		885.672	0.52	0.12	0.07	0.183	404	13	0.63
		917.448	0.55	0.19	0.1	0.291	430	18	0.66
		944.88	0.46	0.14	0.19	0.325	445	41	0.42
		981.456	0.29	0.11	0.15	0.26	442	52	0.42
		1018.032	0.54	0.27	0.45	0.723	454	83	0.38

Table 2: Guidelines for interpreting source rock quantity, quality and maturation, and commonly used Rock-Eval parameters.

Quantity	TOC (wt%)	S1 (mg HC/g Rock)	S2 (mg HC/g Rock)
Poor	< 0.5	< 0.5	< 2.5
Fair	0.5-1	0.5-1	2.5 - 5
Good	1 - 2	1 - 2	5 - 10
Very Good	2 - 4	2 - 4	10 - 20
Excellent	> 4	> 4	> 20
Quality	**HI (mg HC/g Rock)**	**S2/S3**	**Kerogen Type**
None	< 50	< 1	IV
Gas	50 - 200	1-5	III
Gas and Oil	200- 300	5-10	II/III
Oil	300 - 600	10-15	II
Oil	> 600	> 15	I
Maturation	**Ro (%)**	**Tmax (°C)**	**TAI**
Immature	0.2 - 0.6	< 435	1.5 - 2.6
Early Mature	0.6 - 0.65	435 - 445	2.6 - 2.7
Peak Mature	0.65 - 0.9	445- 450	2.7 - 2.9
Late Mature	0.9 - 1.35	450 - 470	2.9 - 3.3
Post Mature	> 1.35	> 470	> 3.3

Source: (Espitalié et al., 1984) and (Peters, 1986).