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GEOCHEMICAL EVALUATION OF ORGANIC MATTER IN JURASSIC SOURCE ROCKS, BEKHME-1 WELL, ERBIL GOVERNORATE, KURDSTAN REGION, IRAQ

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Key words: Source rock, Jurassic, kerogen, Bekhme-1, Kurdistan Region, Iraq

ABSTRACT

Samples from Sarki, Sehkaniyan, Sargelu, Naokelekan, and Chia Gara formations in Bekhme-1 Well, Akri-Bijeel Block about 10 Km northwest of Harir town, Erbil Governorate have been analysed for organic geochemistry. The hydrocarbon potentiality parameters, including type and amount of kerogen and thermal maturity of 34 samples were assessed using Rock-Evalpyrolysis technique. In general, the samples from Sarki and Sehkaniyan formations have production index values of 0.41 – 0.46 (average 0.44) and T_{max} values varying between 437 °C and 453 °C (average 445 °C), suggesting early to late thermal maturity stage, but they are considered as poor source rocks, because the total organic carbon (TOC) content ranges from 0.22 to 0.33 wt.% (average 0.28 wt.%). The samples from Chia Gara, Naokelekan, and Sargelu formations can be considered good source rocks with average TOC content of 1.50, 2.86, 1.44, and 0.63 wt.%, respectively. They contain kerogen types II and III, indicating marine and non-marine organic matter proposing oil and gas prone sources.

تقييم جيوكيميائي للمواد العضويه في صخور العصرالجوراسي المصدريه، بئر بخمة-١ محافظة أربيل، اقليم كردستان، العراق

محمد أحمد علي

المستخلص

تم تحليل جيوكيمياء المواد العضويه في عينات من تكاوين ساركى و سيكانيان و سرگلو، ناوكيليكان وجياگارا من بئر بخمة-1، حوالي 10 كم الى الشمال الغربي من مدينة حرير، محافظة أربيل لتقييمها كصخور مصدرية منتجة للمواد الهيدروكربونية. تضمنت التحليلات نوع ومقدار الكيروجين والنضوج الحراري لأربع وثلاثين عينة بواسطة تقنية (Rock-Eval pyrolysis). بينت النتائج ان العامل الإنتاجي للعينات العائدة لتكوين ساركى يتراوح ما بين 0.41 – 0.46 (المعدل 0.44) وقيمة الحرارة القصوى تتراوح بين 437 م و 453 م (المعدل 445 م)، ولكنها تعتبر صخور مصدرية فقيرة، حيث تراوح أجمالي الكربون العضوي بين 0.22 الى 0.33 بالمئة وزنيا (المعدل 0.28 بالمئة وزنيا). من ناحية أخرى يمكن تصنيف العينات العائدة لتكاوين جياگارا وناوكيليكان، وسرگلو، وسيكانيان على إنها صخورا مصدرية جيدة، حيث أن معدل النسبة المئوية لإجمالي الكربون العضوي وزنيا للتكاوين المذكورة هي 1.50، 2.86، 1.44 و 0.63 على التوالي. تحتوي العينات العائدة لهذه التكوينات على كيروجين من النوع الثاني والثالث مما يدل على مواد عضوية من أصول بحرية وغير بحرية واللتين تدلان على امكانيتهما في أنتاج النفط و الغاز.

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INTRODUCTION

The Akri-Bijeel Block covers an area of 889 Km^2. From a topographic standpoint, the block is divided into a northern part characterized by an E – W trend of mountain series with heights reaching 1,500 m above sea level, and a southern part which is a gentle hilly, plateau-like area, with a height of 500 m above sea level in general (Csontos *et al*., 2011). Abdula *et al*. (2017) used Rock-Eval pyrolysis to examine the petroleum source potential of rock samples from the Bijeel 1 Well, Akri-Bijeel Block in Kurdistan Region of northern Iraq. Their results show that the Sargelu and Sehkaniyan formations contain marine Type IIS kerogen and are potential sources of hydrocarbons. The organic matter is thermally mature with respect to the oil window. In the samples they have studied, carbonates are more organic-rich and more oil-prone than carbonaceous shales and silty mudstones, which appear to be potential sources of natural gas.

The Bekhme-1 Well was drilled as an exploratory/ wild cat. It is located in the southern part of Akri-Bijeel Block in the northern part of Iraq, in the High Folded Zone. Bekhme-1 Well is situated about 10 Km to the north of Harir town, 50 Km north of the regional capital city, Erbil. It lies on latitude 36° 40' 33.05" N and longitude 44° 17' 47.60" E (Fig.1).

As part of an additional effort, we have studied cuttings from the Bekhme-1 exploratory well that was drilled along the northern margin of the Akri-Bijeel Block. Samples from the Jurassic formations were analyzed using Rock-Eval pyrolysis in order to better understand the potential of petroleum source rocks in the block. This paper reports the results of hydrocarbon source rock characterization of Jurassic formations of interest within the Bekhme-1 Well namely, Chia Gara, Naokelekan, Sargelu, Sehkaniyan, and Sarki formations.

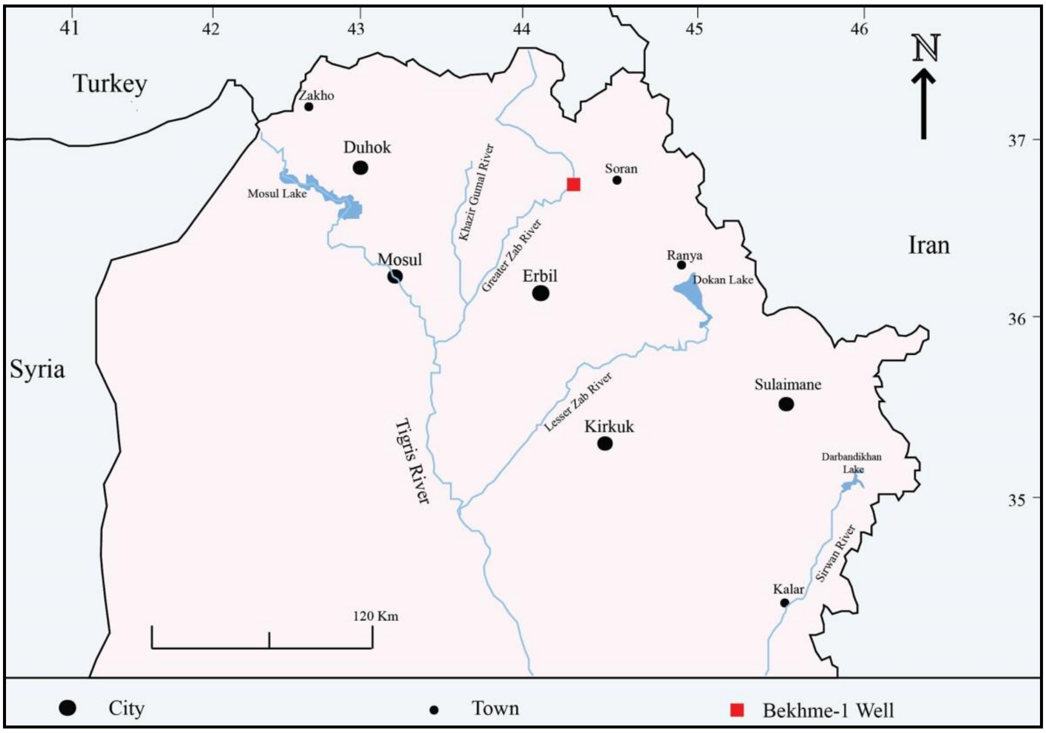

Fig.1: Location map showing the studied well

GEOLOGICAL SETTING

Iraq forms the northeastern part of the Arabian Plate and the stratigraphy of the country is strongly affected by its structural position within the main geostructural units of the Middle East region. Akri-Bijeel area is located in the NNE of Iraq at the boundary between the Arabian part of the African Platform (Nubian-Arabian) and the Asian branches of the Alpine Tectonic Belt (Al-Jouboury, 2009). From Bijeel anticline towards Akri and Bakrman (Fig.2) it is quite common to find steep southerly dipping strata in the Mesozoic section on the southern limb of the anticline. A lot of thrust exposures were found at the southern limbs, and one at the northern limb, which suggest that thrusts underlie the limbs of these major folds (Csontos *et al*., 2012; Abdula *et al*., 2017).

The available geological and geophysical data (Fig.2) indicate that the Akri-Bijeel Block includes Cenozoic marine and non-marine Cretaceous carbonate and marl strata that are more than 1.4 Km thick which, in turn, rest conformably on the Jurassic marine sedimentary strata (~0.8 Km thick) (Fig.3). The Bekhme-1 well reached a total depth of 4560 m in hard formations and it was sampled from about 1158 to 2290 m with a generally good recovery, but the well-log history indicates that some of the cutting runs had incomplete or no recovery.

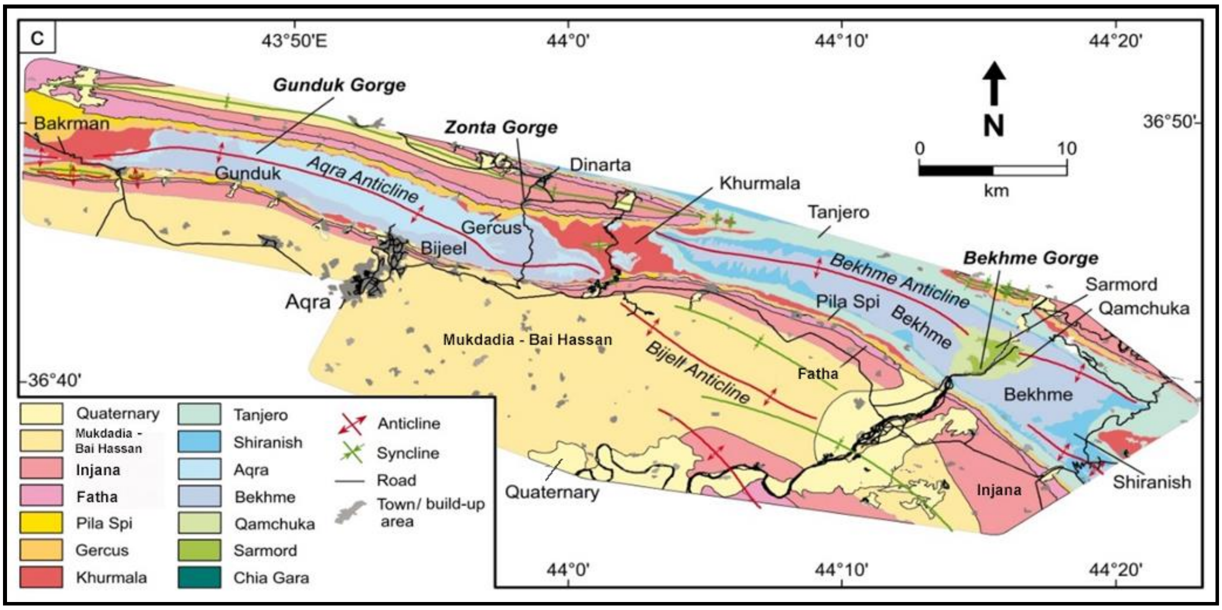

Fig.2: Detailed geological map of the area. The two major anticlines displaying Mesozoic formations in the north correspond to the Akri (western) and the Bekhme (Eastern) anticlines (modified from Csontos *et al*., 2012)

METHODOLOGY

Thirty four samples were collected from the Bekhme-1 Well at different depths and different spacing ranges. The samples were stored at the Geological Survey Office in Erbil, Kurdistan, Region. The collected samples represent the different lithologies of the Chia Gara, Naokelekan, Sargelu, Sehkaniyan, and Sarki formations which are commonly composed of limestone and shale (Fig.3). Detailed information on the laboratory procedures of Rock-Eval pyrolysis, as well as guidelines for interpreting the results of these analyses, can be found in publications by Peters (1986) and Peters and Cassa (1994). The analyses were conducted at Kurdistan Institution for Strategic Studies and Scientific Research (KISSR), in Sulaymaniyah Governorate, Kurdistan Region. Thirty four representative samples were analyzed by Rock

Eval pyrolysis. The measured parameters included S1 (mg HC/g rock), S2 (mg HC/g rock), T_{max} (°C), and TOC (wt.%) (Table 1). Additional parameters, such as Hydrogen Index (HI = S2/TOC*100), Production Index {PI = S1/ (S1+S2)}, and vitrinite reflectance, are calculated from these measured values (Table 1).

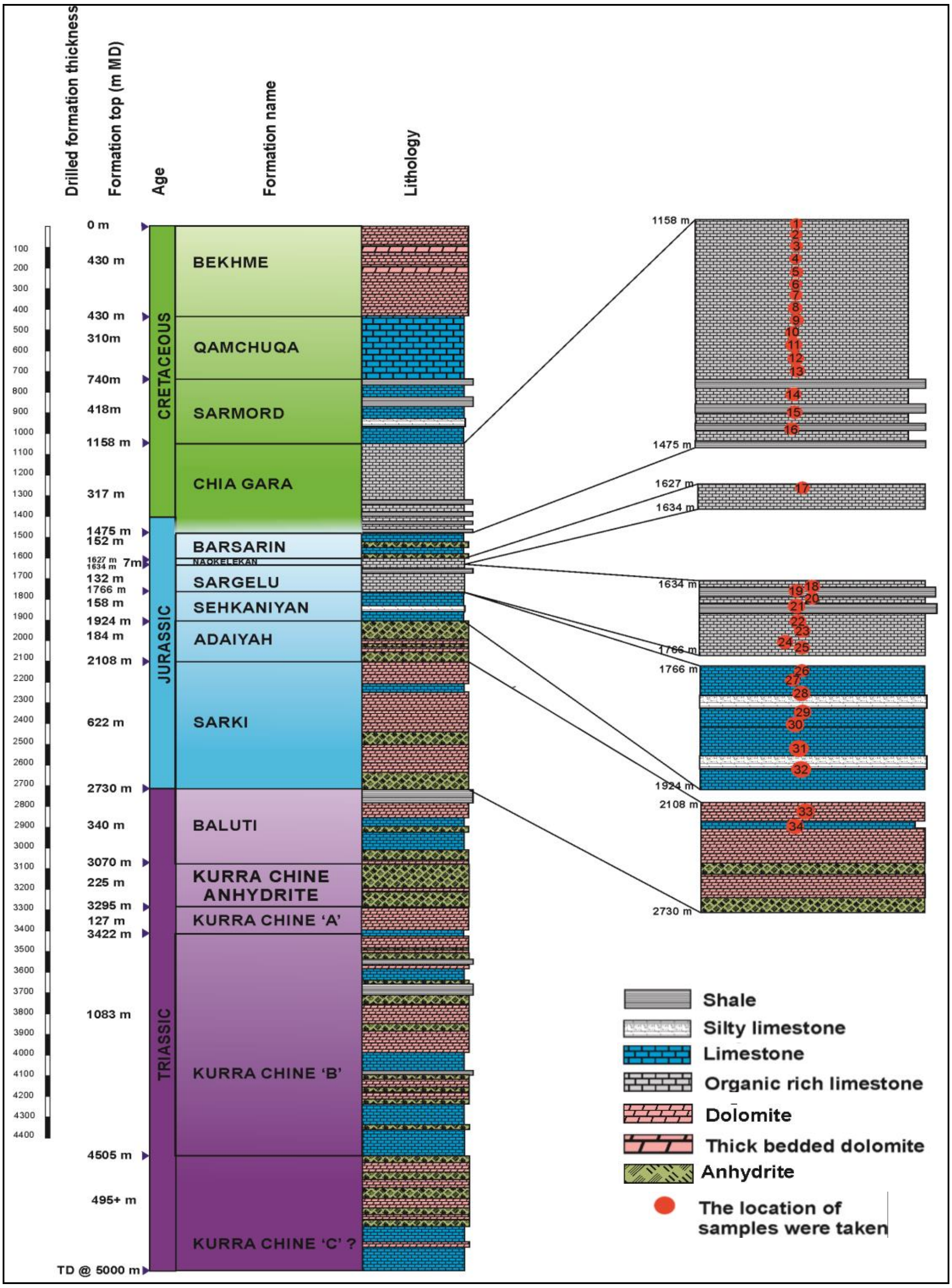

Fig.3: Stratigraphic column of well Bekhme-1 showing general well lithology with measured depth

Table 1: Rock-Eval pyrolysis data of samples selected from the Jurassic formations in well Bekhme-1

	Formation	depth (m)	TOC (wt.%)	S1 (mg HC/g TOC)	S2 (mg HC/g TOC)	HI (mg HC/g TOC)	Tmax (°C)	GP (mg HC/g TOC)	PI	PCI (mg HC/g TOC)	S1/TOC	Ro %
1	Chia Gara	1158	0.84	0.83	2.92	348	439	3.75	0.22	3.11	0.99	0.74
2	Chia Gara	1178	1.05	0.94	3.96	377	444	4.90	0.19	4.07	0.90	0.83
3	Chia Gara	1198	1.02	0.65	2.81	275	441	3.46	0.19	2.87	0.64	0.78
4	Chia Gara	1218	1.20	0.62	4.51	376	444	5.13	0.12	4.26	0.52	0.83
5	Chia Gara	1238	1.24	0.63	4.00	323	439	4.63	0.14	3.84	0.51	0.74
6	Chia Gara	1258	1.03	0.71	3.40	330	438	4.11	0.17	3.41	0.69	0.72
7	Chia Gara	1278	1.03	0.59	2.99	290	440	3.58	0.16	2.97	0.57	0.76
8	Chia Gara	1298	1.24	0.66	3.56	287	439	4.22	0.16	3.5	0.53	0.74
9	Chia Gara	1318	1.58	0.71	3.59	227	441	4.30	0.17	3.57	0.45	0.78
10	Chia Gara	1338	1.90	0.69	3.99	210	439	4.68	0.15	3.88	0.36	0.74
11	Chia Gara	1358	1.85	0.65	3.40	184	440	4.05	0.16	3.36	0.35	0.76
12	Chia Gara	1378	2.11	0.71	3.79	180	441	4.50	0.16	3.74	0.34	0.78
13	Chia Gara	1398	1.71	0.54	3.00	175	439	3.54	0.15	2.94	0.32	0.74
14	Chia Gara	1418	1.76	0.58	3.02	172	439	3.60	0.16	2.99	0.33	0.74
15	Chia Gara	1438	1.57	0.52	2.55	162	439	3.07	0.17	2.55	0.33	0.74
16	Chia Gara	1458	2.87	0.82	5.27	184	443	6.09	0.14	5.05	0.29	0.81
17	Naokelekan	1627	2.68	1.04	4.93	184	446	5.97	0.17	4.96	0.39	0.87
18	Sargelu	1647	1.52	0.66	2.42	159	448	3.08	0.21	2.56	0.43	0.90
19	Sargelu	1648	1.74	0.65	3.30	190	454	3.95	0.17	3.28	0.37	1.01
20	Sargelu	1651	0.81	0.02	2.69	332	444	2.71	0.01	2.25	0.02	0.83
21	Sargelu	1667	2.07	0.77	3.20	155	450	3.97	0.19	3.3	0.37	0.94
22	Sargelu	1687	1.42	0.59	2.00	141	450	2.59	0.23	2.15	0.42	0.94
23	Sargelu	1707	1.67	0.53	2.88	172	447	3.41	0.15	2.83	0.32	0.89
24	Sargelu	1727	1.22	0.37	2.00	164	445	2.37	0.16	1.97	0.30	0.85
25	Sargelu	1747	1.03	0.34	1.62	157	441	1.96	0.17	1.63	0.33	0.78
26	Sehkaniyan	1767	1.76	0.46	2.24	127	449	2.70	0.17	2.24	0.26	0.92
27	Sehkaniyan	1787	0.68	0.22	0.73	107	446	0.95	0.23	0.79	0.32	0.87
28	Sehkaniyan	1807	0.54	0.15	0.47	87	440	0.62	0.25	0.51	0.28	0.76
29	Sehkaniyan	1827	0.51	0.21	0.50	98	441	0.71	0.30	0.59	0.41	0.78
30	Sehkaniyan	1847	0.29	0.12	0.16	55	439	0.28	0.42	0.23	0.41	0.74
31	Sehkaniyan	1887	0.22	1.16	0.12	55	440	1.28	0.57	1.06	5.27	0.76
32	Sehkaniyan	1907	0.42	0.36	0.35	83	461	0.71	0.51	0.59	0.86	1.14
33	Sarki	2280	0.22	0.13	0.16	73	437	0.29	0.46	0.24	0.59	0.71
34	Sarki	2290	0.33	0.17	0.23	70	453	0.40	0.41	0.33	0.52	0.99

RESULTS AND DISCUSSION

- **Sample Screening**

Pyrolysis technique is used to assess the hydrocarbon potentiality and the likely hydrocarbon products or source type. All measured parameters of sample number 20, which belongs to the Sargelu Formation at depth of 1651 m, were rejected because of contamination (Hunt, 1996) (Fig.4). The T_{max} and HI values of samples number 30 – 34 were also rejected because TOC wt.% of these samples is less than 0.5 wt.% (Peters and Cassa, 1994; Bacon *et al*., 2000).

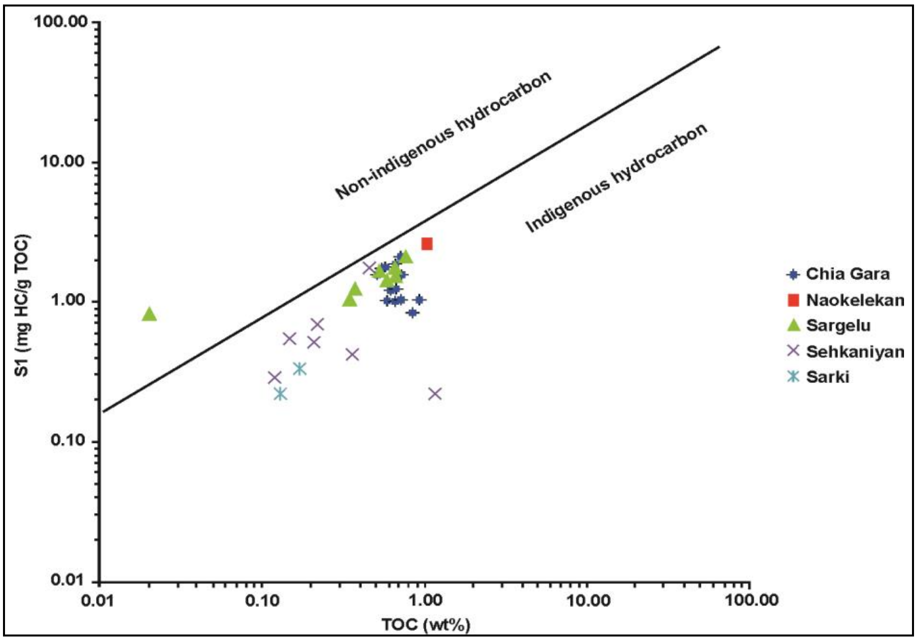

Fig.4: Total organic carbon (TOC) versus S1 for the identification of hydrocarbons migration in the samples of the Jurassic formations in Bekhme-1 Well (Hunt, 1996)

- **Quantity and type of organic matter**

The TOC content of the sediments can be considered as a straight expression of kerogen and bitumen abundance. The TOC ranges in the samples of Sargelu Formation from 0.81 wt.% to 2.07 wt.%, averaging 1.44 wt.%. The TOC wt.% ranges 0.84 – 2.87 (average 1.50); 0.22 – 1.76 (average 0.63) and 0.22 – 0.33 (average 0.28) in the samples of Chia Gara, Sehkaniyan, and Sarki formations, respectively and TOC wt.% is 2.86 in Naokelekan Formation (Table 1). According to Peters and Cassa, (1994), the sediments from the Sargelu, Chia Gara, and Naokelekan formations can be rated as having fair to very good hydrocarbon potential. The Sehkaniyan Formation has poor to fair hydrocarbon potentiality and Sarki Formation has poor hydrocarbon potential (Table 1 and Fig.5).

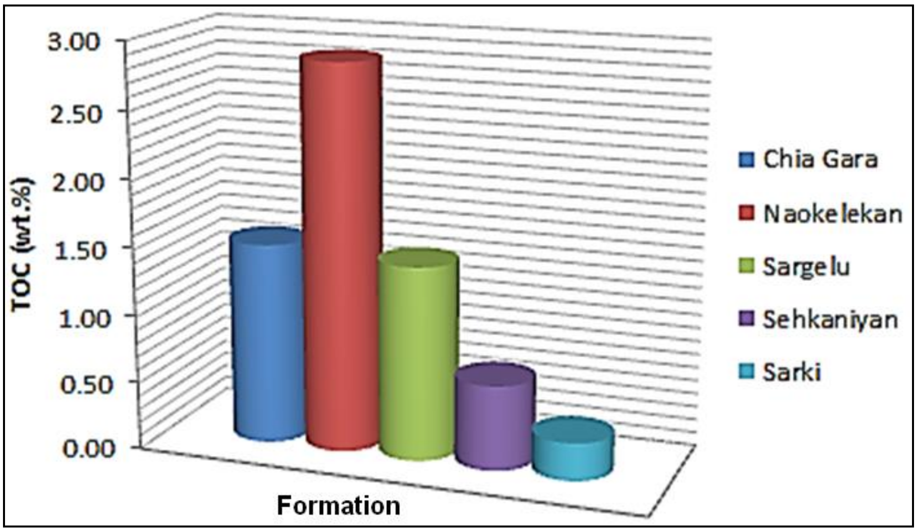

Fig.5: Histogram showing the mean distribution of total organic carbon of the Jurassic formations in Bekhme-1 Well

The type of organic matter must be recognized and determined because different types of organic matter have different hydrocarbon generation potential and products (Brooks, 1981; Tissot and Welte, 1984; Tyson, 1995). Most of the samples from the Jurassic formations are located in the field of kerogen types II and III (Figs.6 and 7). These kerogen types suggest common terrestrial and marine depositional environments. The cross plot of HI versus T_{max} indicates dominance of kerogen Type II and types II/III in all formations (Fig.6). The S2 versus TOC indicates that most samples represent types II and III. The Pyrolyzable Carbon Index (PCI) represents the extreme amount of hydrocarbon a sample is capable of generating during the analysis. Mathematically, it can be expressed as PCI = 0.83 X (S1 + S2). The PCI can be used to evaluate the kerogen type and its hydrocarbon potential. The PCI values of ≥75 indicates type I; 40 – 50 represents type II and <15 indicates type III (Reed and Ewan, 1986; Shaaban *et al*., 2006). Thus all samples are Type III.

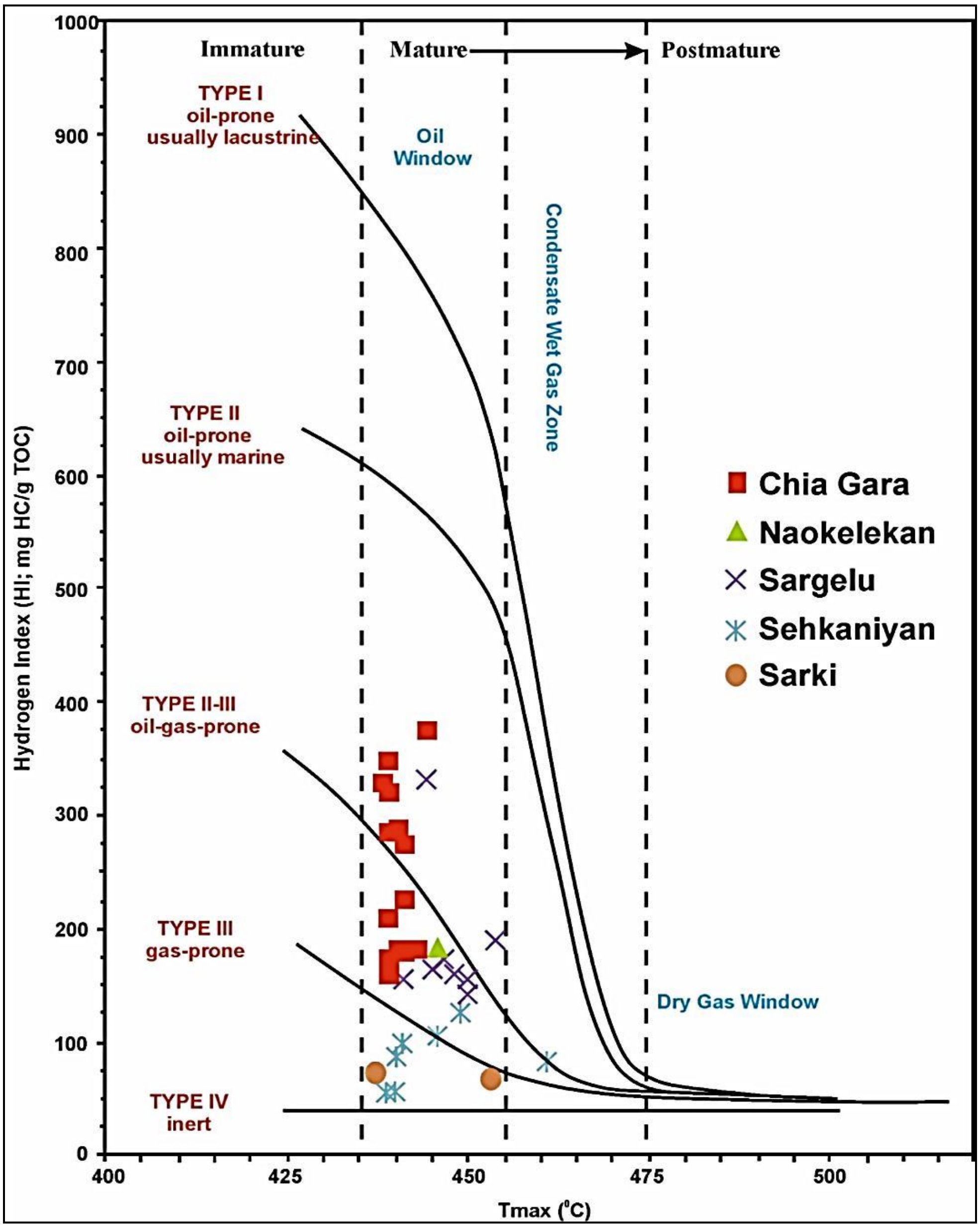

Fig.6: Hydrogen index (mg HC/g TOC) versus T_{max} (°C) plot for Jurassic formations' samples in Bekhme-1 Well (Espitalié *et al*., 1985)

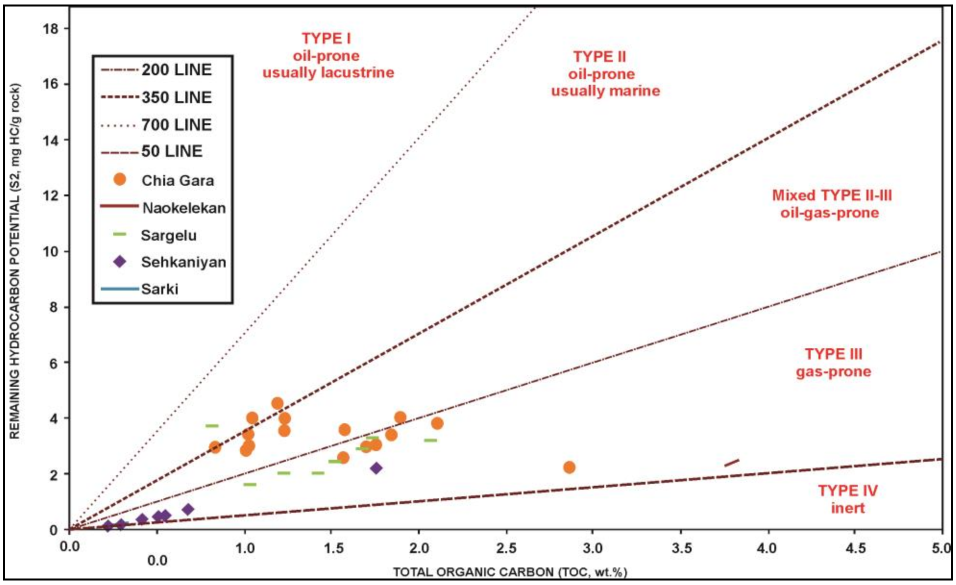

Fig.7: Plot of total organic carbon weight percent (wt.%) versus Rock-Eval pyrolysis S2 shows the kerogen type of the Jurassic formations in Bekhme-1 (modified from Dahl *et al*., 2004; Allen *et al*., 2008)

- **Thermal Maturity**

The maturity level of the oil window depends on the type of organic matter (Bacon *et al*., 2000). It encompasses a vitrinite reflectance (Ro) range from 0.55 to 1.00% (Sweeney and Burnham, 1990) and temperature, at maximum rate of hydrocarbon generation during S2 evolution (T_{max}), from 435 to 470 °C. The production index (PI) parameter is another measure of maturity, with values ranging from 0.15 to 0.40, normally associated with oil generation. The level of thermal maturity can roughly be estimated from the HI versus T_{max} plot (Fig.6). The figure shows that the majority of the samples are thermally mature, where pyrolysis T_{max} ranges from 422 – 431 °C and PI is ≥ 0.15. The high PI indicates that the organic matters are within oil window, but this does not conform to the low T_{max} values. Figure 8 shows that all samples are mature and Figure 9 shows that the HI values are decreasing with increasing maturity.

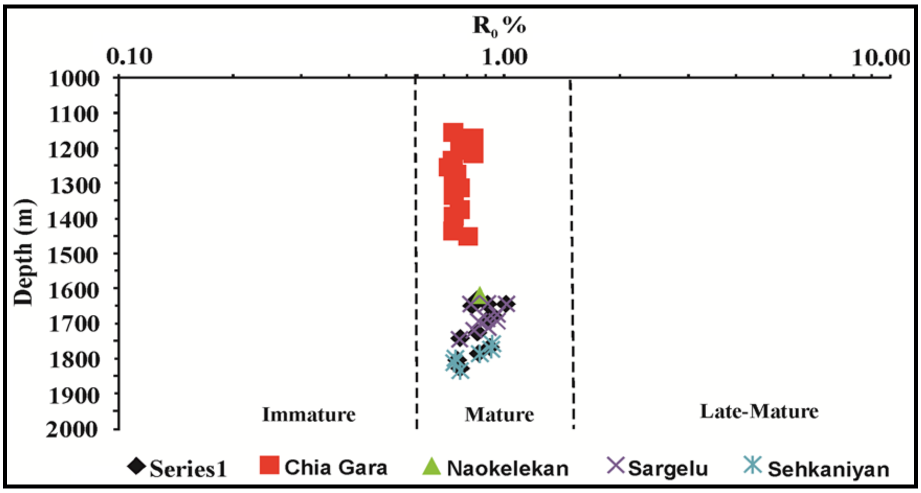

Fig.8: Vitrinite reflectance (Ro%) versus depth (m) of the Jurassic samples in well Bekhme-1. Ro (calculated) = (0.018) x (T_{max}) −7.16 (Jarvie *et al*., 2001)

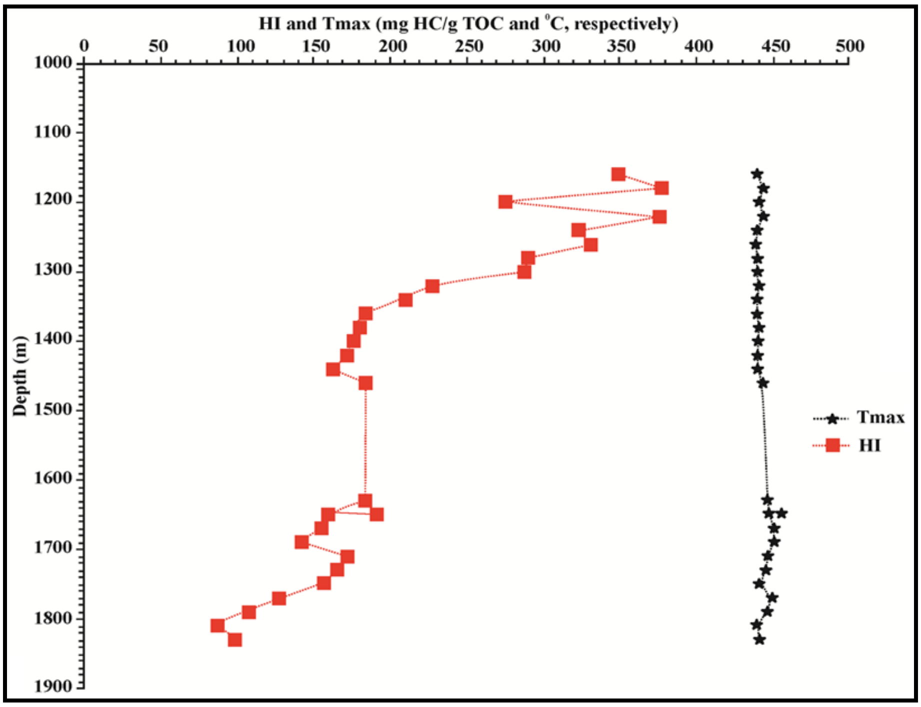

Fig.9: HI (mg HC/g TOC) and T_{max} (°C) versus depth (m) of Jurassic samples in well Bekhme-1. The plot shows a decrease of HI values with increasing depth

- **Hydrocarbon Migration**

The high S1 values could be normal, which indicate potential source rocks, or anomalous, resulting from mixing with migrated oil, or coming from drilling additives (Peters and Cassa, 1994). When S1 is high and the TOC is low, non-indigenous hydrocarbons can be identified (Hunt, 1996). Figure 4 separates migrated from non-migrated hydrocarbons for the samples from Chia Gara, Naokelekan, Sargelu, Sehkaniyan, and Sarki formations in the studied samples. The dividing line on the plot is where S1/TOC = 1.5. Values belonging to non-indigenous hydrocarbons appear above this line while indigenous hydrocarbon values emerge below it (Hunt, 1996).Thus all the samples analyzed indicate indigenous hydrocarbons present except sample number 20 which belongs to Sargelu Formation (Fig.4).

- **Oil or Gas Prone**

The mixed-prone Sargelu source rock intervals are characterized by intermediate to high potential to generate oil and gas as indicated by their hydrogen indices (pyrolysis S2 yields 1.62 – 3.30 mg HC/g rock; and HI ranges from 141 to 332 with an average of 184 mg HC/g TOC). The Chia Gara and Naokelekan formations are characterized by having the capacity for oil and gas generation. The oil and gas-prone source rocks have potential to generate oil and gas as indicated by their hydrogen indices (average pyrolysis S2 yields 3.55 and 4.93 mg HC/g rock; HI 256 and 184 mg HC/g TOC, for Chia Gara and Naokelekan formations, respectively) (Figs.7 and 9).

The Sehkaniyan and Sarki formations are characterized by having the capacity for gas generation. The gas-prone source rocks have potential to generate gas due to their low S2 and HI. The Sehkaniyan and Sarki formations have average S2 values of 0.65 and 0.20 mg HC/g TOC and average HI values of 87 and 70 mg HC/g TOC, respectively. Thus, all samples are gas and mixture of oil and gas prone (Table 1). According to Peters (1986), Peters and Cassa (1994), and Bacon *et al*. (2000), in their definition of maturity level based on T_{max} and PI, the

Jurassic succession is both mature and immature in Bekhme-1 Well (Fig.10), but these findings conflicts with Ro% values which indicate mature samples (Fig.8). The discrepancy can be linked to the presence of Type III kerogen in a high percentage.

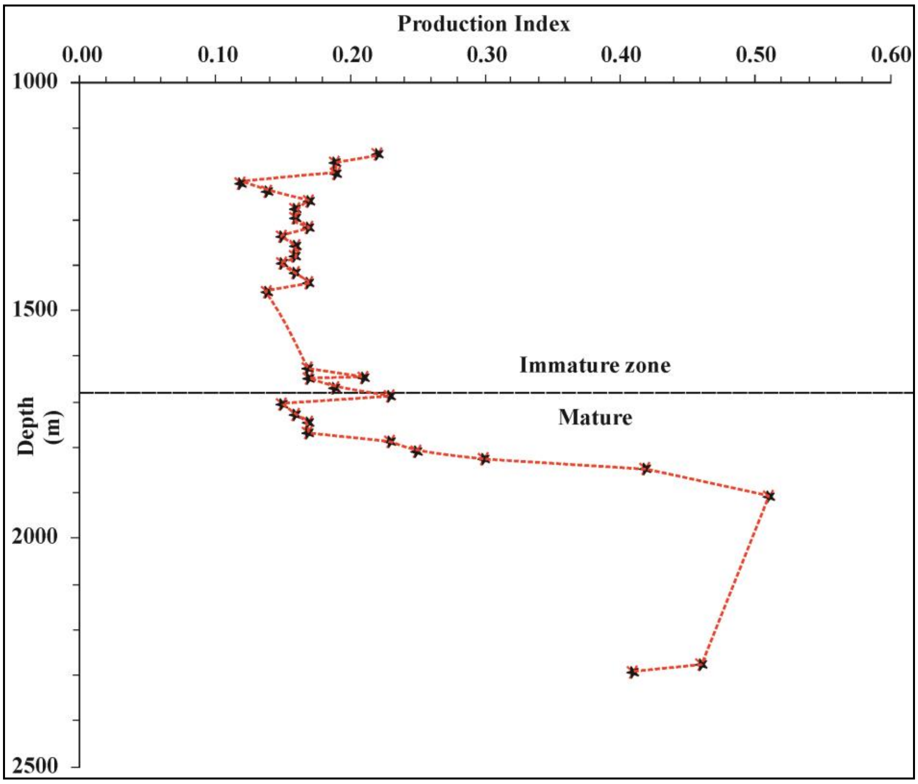

Fig.10: Production index versus depth in a Bekhme-1 Well. The discontinuous black line indicates the boundary between the mature zone and the immature zone (adapted from Huc and Hunt, 1980)

CONCLUSIONS

Most of the samples analyzed from the Lower and Middle Jurassic formation have kerogen types II and III and are in early mature to mature stage of thermal maturity. They can be considered as good source rocks, where the average of TOC content is 1.27 wt.%. The organic matter in the studied formations is within oil and gas window according to their high production index values (0.01 – 0.57 with an average of 0.22). This high production index, accompanied with T_{max} (437 – 461 with an average of 443 °C), suggests the presence of Type III kerogen.

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