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Source rock evaluation of the Chia Gara Formation in the Bekhme-1 well, Harir District, Kurdistan Region, Iraq

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Abstract

Rock-Eval pyrolysis technique has been done for 18 cutting rock samples of the Chia Gara Formation (Middle Tithonian-Berriasian) from Bekhme-1 Well on High Folded Zone, Erbil District, Kurdistan Region of Iraq. The range and average of total carbon content (TOC), free Hydrocarbon (S1) are 0.84-2.87, 1.56 wt. % and 0.07-0.94, 0.61 mg HC/g rock respectively; indicating fair to good source rock. The average genetic potential (S1+S2) is 4.12, 4.15, and 4.13 mg HC/g rock for upper, middle, and lower parts, respectively. These values represent moderate potentiality. This study approved that the kerogen is a mixture of type II/III and type III. The combination of production index (range: 0.22-0.15; average:0.15), and T_{max} values (range:438-449°C) illustrate that the stage of maturity for the Chia Gara Formation is early mature. There is no evidence for the oil crossover effect in Bekhme-1 Well because none of the S1/TOC values is greater than one; therefore, it appears that the organic matter just started to enter the oil window.

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Keywords: Chia Gara, rock evaluation, Kerogen, Harir, Iraq

1. Introduction

Kurdistan Region became a host of many international oil companies in the last decade. They have tried to explore new oil or gas field, also upgrade hydrocarbon reserves. By that time, the Kurdistan Region has been subdivided by many areas known as "Block"; which are awarded by specialized oil companies (Fatah et al., 2020). In 2007, the Magyar Olajes Gazipari Nyr (formerly known as MOL Plc), through its subsidiary, Kalegran Limited Company awarded exploration of Akri-Bijeel Block. The Bekhme-1 Well is the second discovery well that was been drilled in this block (Csontos et al., 2011). The Chia Gara Formation, with a thickness of 300 m occurs within the interval 1458-1158 m under the surface. The Bekhme-1 Well is located in the eastern part of the Akri-Bijeel Block in northern Iraq, about 10 km north-west of Harir Town in Erbil Governorate, the capital city of the Kurdistan Region of Iraq. It is situated on latitude 36° 40' 33.05'' North and longitude 44° 17' 47.60'' East (Figure 1).

The study of the organic matter content of the Chia Gara Formation has been investigated by several researchers, for instant: Odisho and Othman (1992) believed that this rock unit might represent a good source rock in the northern part of Iraq. Others e.g. Mohialdeen (2008), Mohialdeen et al.(2013a), Hakimi et al. (2017), Abdula et al. (2017) approved that the organic-rich limestone and shale of the Chia Gara Formation considered a very good to excellent source rock for hydrocarbon generation. The average total organic carbon (TOC wt.%) content for the Chia Gara Formation is 1.5 wt.%, and it contains kerogen types II and III, indicating marine and non-marine organic matter, proposing oil and gas prone sources (Ali, 2018).

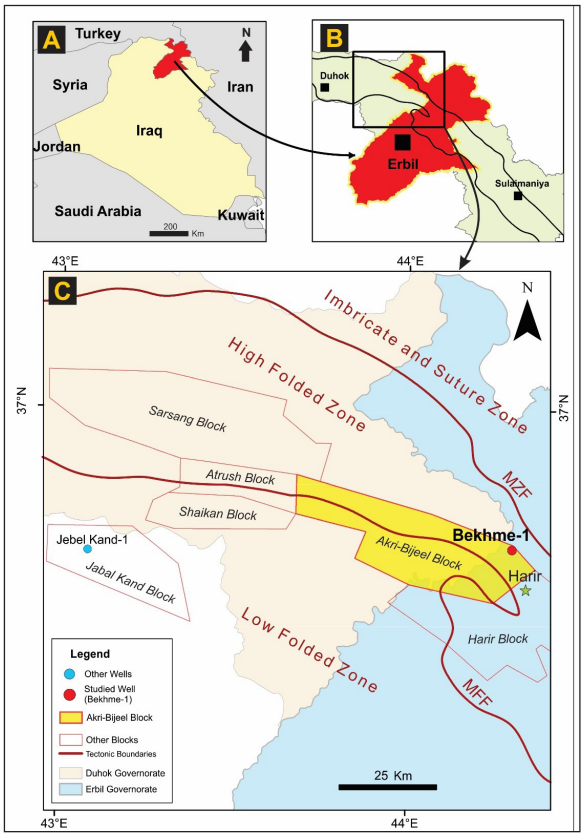

Figure 1. Location map of the studied well. A. The main map of Iraq showing with an indication of Erbil Governorate. B. Close view of Erbil and other cities with an indication of the study area. C. Location map of Bekhme-1 Well within Akri-Bijeel Block with relevant to other surrounding blocks.

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The petroleum system of Jabal Kand Oil Field which is located nearby Akri-Bijeel Field shows that the formations such as the Sargelu and younger, the Chia Gara, are immature and have not generated any oil, depending on vitrinite reflectance (Ro) <0.55% (Abdula, 2017a). Oil-source correlation and biomarker characteristics of oils and oil/bitumen seeps reveal that there is a genetic relationship between these oils and extracted organic matter from the Chia Gara source rock (Mohialdeen et al., 2013b; Al-Jaafary and Hadi, 2015; Edilbi, 2016). The Chia Gara Formation in Atrush, Sarsang, and Shaikhan oilfields can be considered as good to excellent source rock; its TOC content ranges from 1.14-8.50 wt.% with an average of 1.85 wt.%, 3.91 wt.%, and 6.94 wt.% in Atrush-1, Mangesh-1, and Shaikhan-8 wells, respectively (Mamaseni et al., 2019).

This study aims to report the organic geochemical characteristics and hydrocarbon potentiality of the Chia Gara Formation within the Bekhme-1 Well.

2. Materials and Methods

Eighteen cutting rock samples of the Chia Gara Formation were collected from the Bekhme-1 Well at different depths and different spacing ranges (Table 1). The samples were stored at the Geological Survey Office in Erbil, Kurdistan Region. The collected samples represent the different lithologies of the Chia Gara Formation. These lithologies are common in limestone and shale. The samples have been analyzed at Kurdistan Institution for Strategic Studies and Scientific Research (KISSR) in Sulaymaniyah, Kurdistan Region.

2.1. Rock-Eval pyrolysis

This test is performed for all samples. Initially, the representative cutting samples were cleaned of contaminations and washed with distilled water, then oven-dried at 40 °C for 24 hours. The washed-out samples were crushed to become a powder, then taken about 100 mg of sample to be analyzed by Rock-Eval 6 apparatus. The Rock-Eval test involves the continuous heating of a sample ranging from 100 °C-850 °C in an inert atmosphere (Helium or Nitrogen Gas) (Lafargue et al., 1998). The heating program is: starting from 100 °C, then retain the sample at 300 °C for 3 minutes, and then increased the temperature to 850 °C at a rate of 25 °C/min. The details of this technique and parameters are documented in Behar et al. (2001). The measured parameters include TOC (wt.%), S1 (mg HC/g rock), S2 (mg HC/g rock), and T_{max} (°C) are quoted in Table 1. Additional parameters such as Hydrogen Index (HI=S2/TOC x 100) and Production Index (PI=S1/(S1+S2)) are calculated from these measured values and are also shown in Table 1.

3. Geological Setting

The Mountain Front Flexure (MMF) and Main Zagros Fault (MZF) are considered as the two prominent tectonic features of the Zagros orogenic belt, which separate the Low Folded Zone from the High Folded Zone and the Imbricate Zone (Koshnaw et al., 2017). Bekhme-1 Well situated on the High Folded Zone (Figure 1). Northern Iraq has been affected by several transversal fault systems, which are the Hadar-Bekhme Fault Zone and the Anah-Qalat Dizeh Fault Zone that underwent a sinistral strike-slip movement during the Quaternary (Reif et al., 2012).

Table 1. Rock-Eval pyrolysis data for samples of the Chia Gara Formation in the Bekhme-1 Well in the Kurdistan Region, Iraq (Ali, 2018).

Sample No.	Depth (m)	TOC (wt.%)	S1	S2	T_{max}	HI	PI	GP
1	1158	0.84	0.83	2.92	439	348	0.22	3.75
2	1178	1.05	0.94	3.96	444	377	0.19	4.90
3	1198	1.02	0.65	2.81	441	275	0.19	3.46
4	1218	1.20	0.62	4.51	444	376	0.12	5.13
5	1218	1.28	0.12	2.74	445	214	0.04	2.86
6	1238	1.24	0.63	4.00	439	323	0.14	4.63
7	1258	1.03	0.71	3.40	438	330	0.17	4.11
8	1278	1.03	0.59	2.99	440	290	0.16	3.58
9	1298	1.24	0.66	3.56	439	287	0.16	4.22
10	1318	1.58	0.71	3.59	441	227	0.17	4.30
11	1338	1.90	0.69	3.99	439	210	0.15	4.68
12	1358	1.85	0.65	3.40	440	184	0.16	4.05
13	1378	2.11	0.71	3.79	441	180	0.16	4.50
14	1398	1.71	0.54	3.00	439	175	0.15	3.54
15	1418	1.76	0.58	3.02	439	172	0.16	3.60
16	1438	1.57	0.52	2.55	439	162	0.17	3.07
17	1458	2.87	0.82	5.27	443	184	0.14	6.09
18	1458	2.73	0.07	3.96	449	145	0.02	4.03
	Min.	0.84	0.07	2.55	438	145	0.02	2.86
	Max.	2.87	0.94	5.27	449	377	0.22	6.09
	Average	1.56	0.61	3.53	441	248	0.15	4.14

TOC: Total Organic Carbon (wt.%); S1: Free hydrocarbon (mg HC/gm rock); S2: Generation potential (mg HC/gm rock); T_{max}: Temperature of maximum peak of S2 (C°); HI: Hydrogen Index (100 x S2/TOC); PI: Production Index {S1/(S1+S2)}; GP: Genetic Potential or Petroleum Potential (S1+S2)

From Bijeel Anticline towards Aqra and Bakurman (Figure 2), it is quite common to find steep southerly dips 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 suggests that thrusts underlie the limbs of major folds (Csontos et al., 2012).

The obtainable geological and geophysical data designate that the Akri-Bijeel Block comprises Cenozoic marine and non-marine Cretaceous carbonate and marl strata (Figure 3) that are more than 1.4 Km thick which, in turn, rest conformably on the Jurassic marine sedimentary strata (~0.8 Km thick). 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 designates that some of the cuttings' runs had incomplete or no recovery (Ali, 2018). The Chia Gara Formation (Middle Tithonian-Berriasian) type locality is located at the Chia Gara Anticline, south of Amadia Town in the High Folded Zone of Northern Iraq with a thickness of 232 m (Bellen et al., 1959).

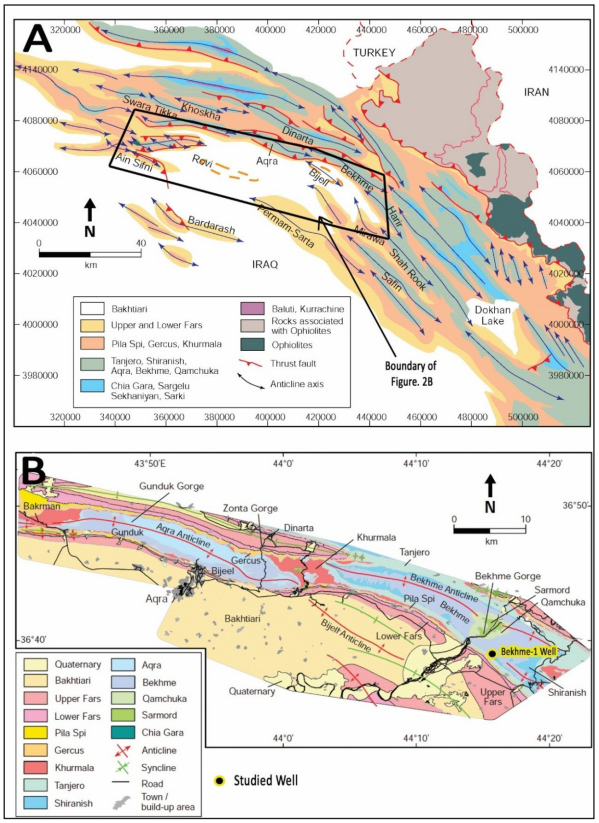

Figure 2. A. Schematic geologic map of Northern part of Iraq showing generalized geologic formations and trends of anticline axes (after Csontos et al., 2012). B. Detailed geological map of the area with an indication of the studied well, the map showing the two main anticlines to the north that correspond to the Aqra (western) and the Bekhme (eastern) (after Csontos et al., 2012).

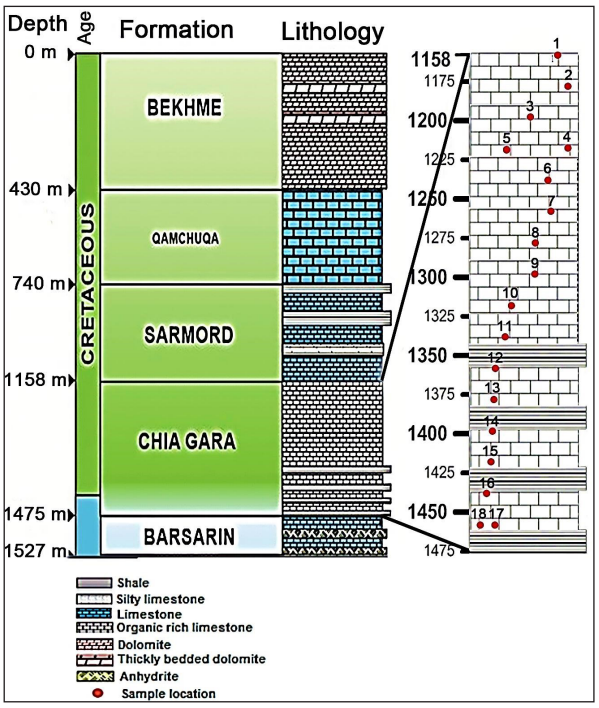

Figure 3. Stratigraphic column of Bekhme-1 Well showing the summary of well lithology with measured depth and sample locations (Ali, 2018).

The stratigraphic sequence of the Chia Gara Formation in Bekhme Gorge and Rowanduz area is characterized by intercalation of dark grey thin to thickly bedded limestone with black fissile shale (Al-Qayim and Saadalla, 1992).

The depositional environment of the Chia Gara Formation was supposed to be the beginning of the toe of the slope to the deep open marine environment (Bellen et al., 1959; Buday, 1980; Edilbi, 2010). The study of clay minerals showed that rocks of the Chia Gara mainly consist of kaolinite and illite in different proportions, which indicates deposition during a transgressive episode of sea level (TST) (Edilbi and Sherwani, 2019). Leanza (1996) correlated the lithological facies of the Chia Gara Formation with Vaca Muerta Formation in the Argentine Andes. Many horizons of both formations were found to be consisting of dark brown marly shales comprising several big-sized ("Phacoids") calcareous concretions all of them were deposited in a highly bituminous environment, signifying a primary short-term depositional control on their formation (Howarth, 1992; Leanza, 1996). This might characterize an extremely bituminous worldwide occurrence worth being considered as a high-resolution chemical-stratigraphic event (Kauffman, 1988).

4. Results and Discussion

4.1. Total organic carbon

Generally, the Total Organic Carbon (TOC wt.%) in a rock sample; describes the quantity of organic carbon within a rock unit, including both kerogen and bitumen. This parameter is used for measuring the quantity, but not the quality of organic carbon in the rock sample (Hunt, 1996; Peters et al., 2005). However, a sufficient amount of TOC increases the sediment chance to be a good source rock concerning the type of initial input of the organic matter and degree of maturity (Tissot and Welte, 1984; Peters and Cassa, 1994). To produce oil, the carbon has to be connected to hydrogen in a source rock (Demaison and Moore, 1980; Peters, 1986; Dembicki Jr, 2009). In Barker's (1996) opinion, the 1.0 wt.% TOC is the lower limit for a productive source rock as it would never yield enough oil to trigger primary migration from a source rock of less than 1.0 wt.% (Figure 4).

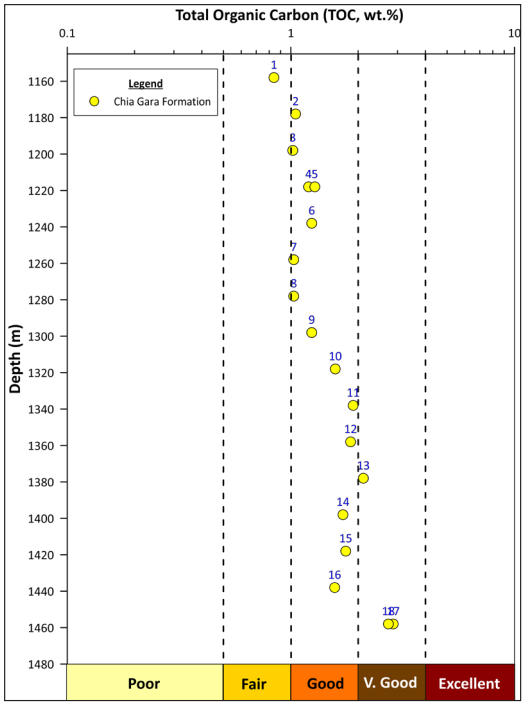

Figure 4. TOC wt.% versus depth indicates that the lower part is richer than the upper part.

To ensure the contamination effect upon the TOC, all the samples have been plotted on the cross plot of TOC versus S1 (Figure 5) dependingly, it's clear that all the samples are clean and not contaminated by drilling fluid.

Rock-Eval data for samples in the Bekhme-1 Well show that TOC wt.% values range from 0.84 wt.% to 2.87 wt.% with an average of 1.56 wt.% (Table 1) (Ali, 2018). This range represents a good to very good source rock at the lower part and a good source rock at the middle and upper parts (Figure 4) depending on the assumptions described by Peters (1986) and Peters and Cassa (1994).

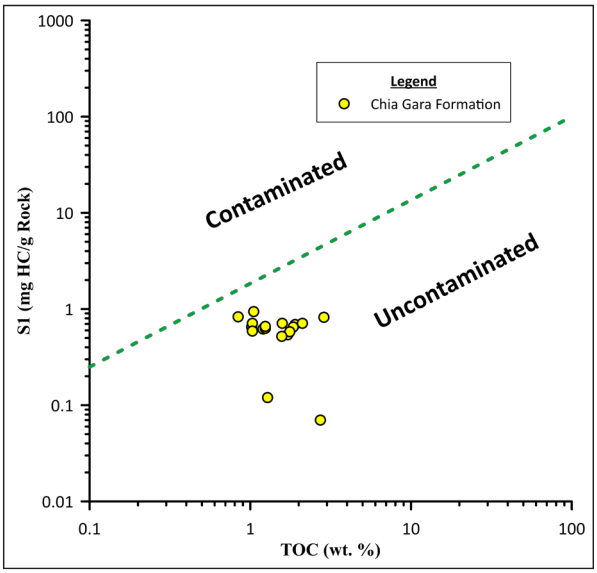

Figure 5. Cross plot of TOC wt.% versus S1 shows that all the samples are uncontaminated by drilling fluid (Osli et al., 2019).

4.2. Genetic potential

A genetic potential includes the total amount of free hydrocarbon already formed from kerogen (S1) and the amount of hydrocarbon left (S2) that has not been yet converted. Mathematically, this could be expressed as S1+S2 (mg HC/g rock) (Tissot and Welte, 1984). Genetic potential is not a measure of hydrocarbon character although it can be used to determine the consistency of prospective organic matter (Pitman et al., 1987).

Depending on Rock-Eval data, the analyzed samples of Chia Gara Formation contain S1 ranges from 0.07 to 0.94 and S2 ranges from 2.55 to 5.27 mg HC/g rock. Consequently, the genetic potential (GP) ranges from 2.86 to 6.09 with an average of 4.14 mg HC/g rock (Table 1). The average genetic potential values are 4.12, 4.15, and 4.13 for upper, middle, and lower parts, respectively. These genetic potential values are almost the same and indicate a fair to good potentiality (Figure 6).

4.3. Hydrogen index

The quality of organic matter depends on the amount of hydrogen that exists. For petroleum to be generated, the carbon needs to be associated with hydrogen in a source rock (Dembicki Jr, 2009). The HI values fluctuate back and forth (Table 1) due to the organic matter's hydrogen content, but generally, the lower part of the Chia Gara Formation contains a low amount of HI content (Figure 7).

A low-hydrogen organic matter commonly has a high T_{max}, and a high-hydrogen organic matter has a low T_{max} (Hunt, 1996). The hydrogen index values are lower in the deeper horizons which may indicate that hydrocarbon started to generate hydrocarbon within the lower horizon, but it is not initiated in the upper horizons yet (Figure 7). As a consequence of generating hydrocarbon, the amount of hydrogen decreases (Hunt, 1996).

The oil crossover effect appears when S1/TOC is more than 1, but none of the values is greater than one; therefore, it appears that the organic matter just started to enter the oil window (Figure 8).

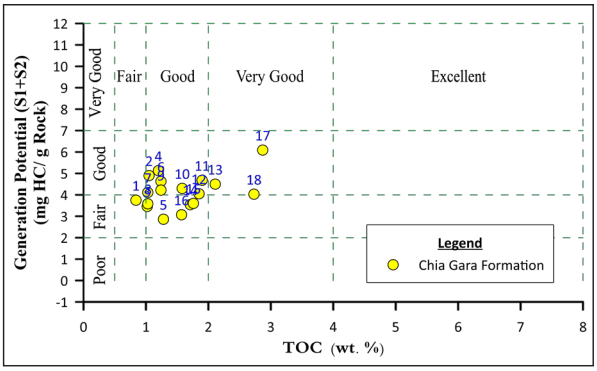

Figure 6. Cross plot of TOC wt.% versus Generation Potential (GP) shows the fair to good potentiality (Alaug et al., 2014).

4.4. Kerogen type

Kerogen type determination in source rock is the initial task because different types of organic matter have different potentialities for hydrocarbon generation (Tissot and Welte, 1978; 1984). The cross plot of TOC wt.% versus S2 (Figure 9) points out the kerogen types II/III and III (Dahl et al., 2004; Allen et al., 2008) which indicates mixed oil-gas prone and gas-prone (Figure 9). The plot of HI vs. T_{max} also points out the existence of types II/III and III kerogens (Hunt, 1996) (Figure 10). The HI values of these samples range between 145 and 377 mg HC/g TOC (Table 1), which also suggests mixed oil-gas-prone and terrestrial gas-prone (Tissot and Welte, 1984; Peters and Cassa, 1994). The quality of organic matter increases from the lower part to the upper part according to their HI values (Figure 7). The organic matters belong to Type III (HI average 172 mg HC/g TOC), mixed Type II and III (average 254 mg HC/g TOC), and Type II (HI average 319 mg HC/g TOC) for lower, middle, and upper parts, respectively (Tissot and Welte, 1984; Peters and Cassa, 1994).

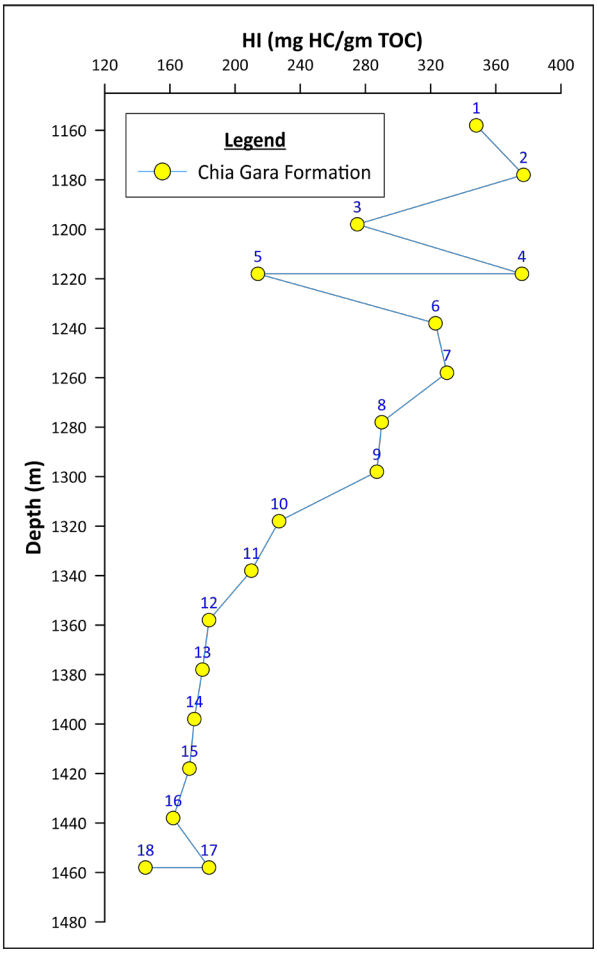

Figure 7. Hydrogen index versus depth shows that hydrogen index values within the lower part (deeper) are lower than the upper part (shallower).

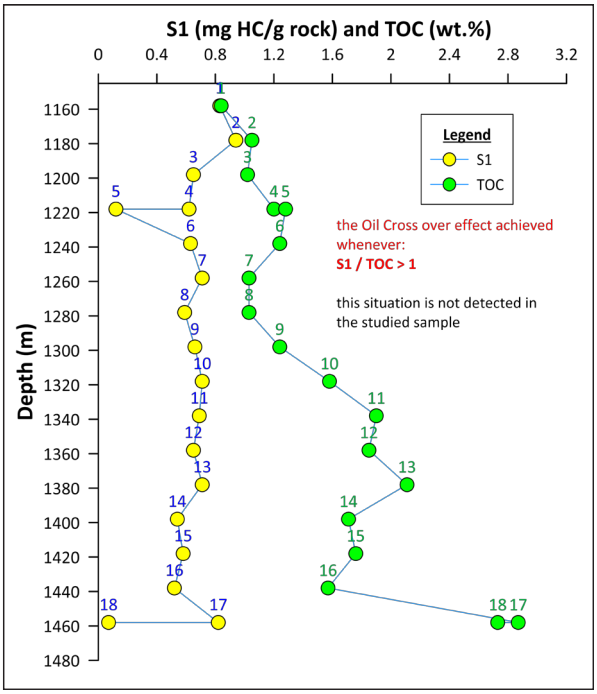

Figure 8. S1 (mg HC/g rock) and TOC (wt.%) versus depth displays that S1/TOC values are less than 1.

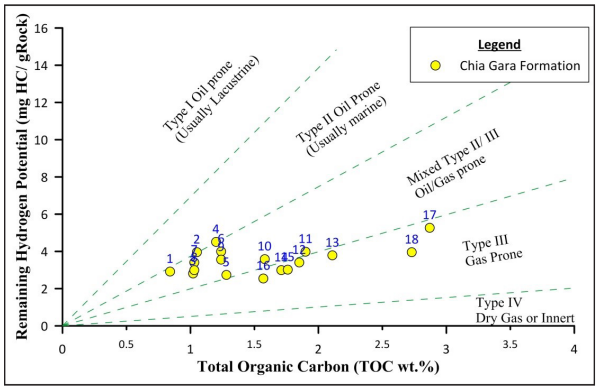

Figure 9. Total Organic Carbon (TOC) vs. S2 diagram of kerogen types shows that the Chia Gara Formation samples lie in the field of type II/III and III kerogens (modified from Dahl et al., 2004; Allen et al., 2008).

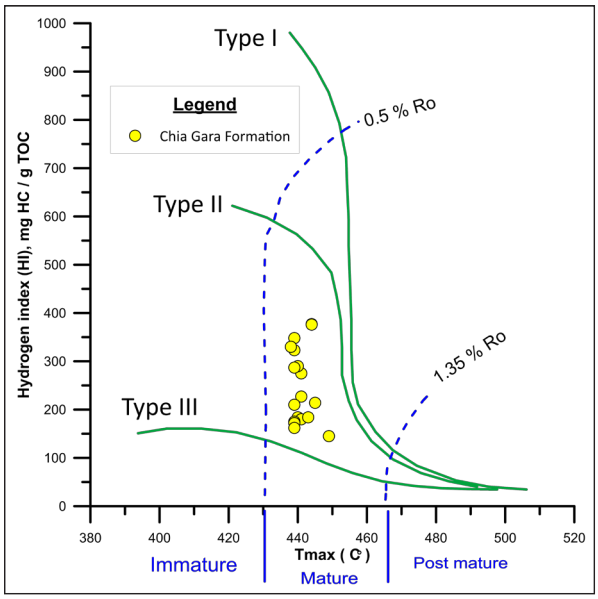

Figure 10. T_{max} vs. HI kerogen shows that the samples are types III and a mixture of II and III and they lie in the mature field (Hunt,1996).

4.5. Maturity

Rock-Eval T_{max} (°C) is the temperature at which the S2 (mg HC/g rock) peak during pyrolysis reaches its maximum amount of hydrocarbon production (Espitalié et al., 1984). Tissot and Welte (1984) and Hunt (1996) recognized factors that affect T_{max} values such as type of organic matter, contamination, and the mineral matrix. Tissot et al. (1987) proposed that T_{max} is a strong maturation predictor between 420 °C and 460 °C in Type II kerogen and between 400 °C and 600 °C in Type III terrestrially derived kerogen.

The T_{max} values range between 438 and 449 °C with an average of 441 °C. This range is within early mature for Type III kerogen (Peters and Cassa, 1994; Bacon et al., 2000). The production index values range between 0.02 and 0.22 with an average of 0.15. These values when combined with T_{max} values indicate an early mature stage (Peters and Cassa, 1994).

T_{max} vs. PI plot shows the Chia Gara Formation samples are located in the early mature zone and started to enter the oil window zone (Figure 11). The same situation is also approved when samples are plotted in the cross plot of T_{max}

versus HI (Figure 10).

The study of Chia Gara Formation by Edilbi (2010) and Abdula (2017a) approved that the maturity increase from the west (Banik: T_{max} values range between 438 and 441 °C with an average of 440 °C) toward the east (Barsarin: T_{max} values range between 449 and 486 °C with an average of 463 °C) of their study area. Increasing maturity toward the east of the studied well may be related to the higher burial that the formation has experienced as documented by Edilbi's (2010) isopach map and consequently experienced higher temperature and pressure. According to Abdula (2017b), the current borehole temperature is 85.8 °C at 4060.2 m below the ground level, but palaeotemperature could be higher. The 1D basin modelling of the Bekhme-1 Well displays that the Chia Gara Formation reached a maximum depth of 2700 m around 75 Ma (Figure 12).

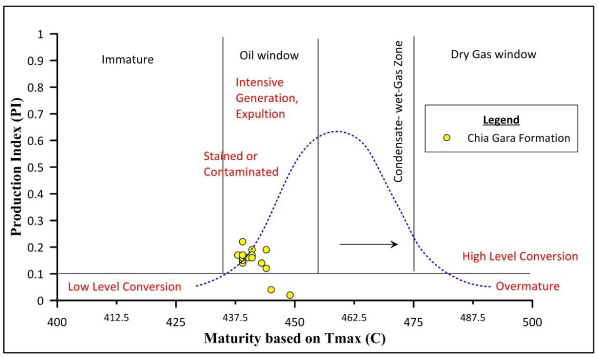

Figure 11. T_{max} vs. Production Index (PI) diagram of the Chia Gara Formation (adapted from Atta-Peters et al., 2015).

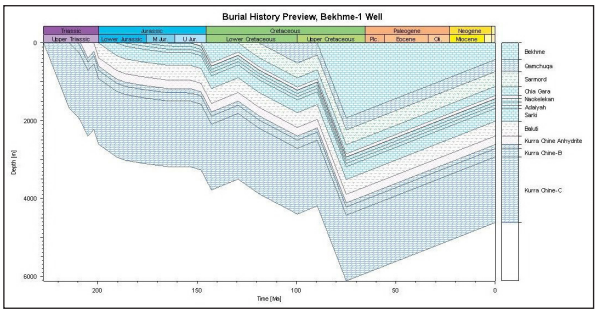

Figure 12. Thermal, burial and subsidence history curves at Bekhme-1 Well (Abdula et al., 2020).

5. Conclusions

The Chia Gara Formation in Bekhme-1 Well can be considered as a fair to good source rock in the lower part and a good source rock in the middle and upper parts, where the average of TOC content is 1.55 wt.%. The organic matter content belongs to kerogen types II/III and III. The average genetic potential (S1 + S2) value is 4.12, 4.15, and 4.13 mg HC/g rock for upper, middle, and lower parts, respectively. These values indicate a moderate potentiality. The maturity level based on the production index values (0.02-0.22)and T_{max} values (average of 441 °C) indicate an early mature stage. There is no evidence for the oil crossover effect for the analyzed samples because none of the S1/TOC values is greater than one; therefore, it appears that the organic matter just started to enter the oil window.

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References

Abdula, R.A. (2017a). Petroleum system modeling of Jabal Kand Oil Field, Northern Iraq. ZANCO Journal of Pure and Applied Sciences 29(2): 88–95.

Abdula, R.A. (2017b). Geothermal gradients in Iraqi Kurdistan deduced from bottom hole temperatures. Egyptian Journal of Petroleum 26: 601–608.

Abdula, R.A., Hassan, H.Y., Martin, M. (2020). Petroleum system modeling of Akri-Bijeel Oil Field, northern Iraq: Insights from 1D Basin Modeling. UKH Journal of Science and Engineering 4(2): 166–177.

Abdula, R.A., Ali, M.A., Ahmed, M.M., Hamad, H.R. (2017). Rock-Eval pyrolysis results from the Bijeel-1 Well, Kurdistan Region, Iraq. ZANCO Journal of Pure and Applied Sciences 29(3): 29–38.

Alaug, A.S., Mahmoud, M.S., Deaf, A.S., Al-Ameri, T.K. (2014). Palynofacies, organic geochemical analyses and hydrocarbon potential of some Upper Jurassic-Lower Cretaceous rocks, the Sabatayn-1 Well, Central Yemen. Arabian Journal of Geosciences 7(6): 2515–2530.

Ali, M. (2018). Geochemical evaluation of organic matter in Jurassic source rocks, Bekhme-1 Well, Erbil Governorate, Kurdistan Region, Iraq. Iraqi Bulletin of Geology and Mining 14(2): 49–59.

Al-Jaafary, A.S. and Hadi, A. (2015). Hydrocarbon potential, thermal maturation of the Jurassic sequences, and the genetic implication for the oil seep in North Thrust Zone, North Iraq. Arabian Journal of Geosciences 8(10): 8089–8105.

Allen, T.L., Fraser, T.A., Osadetz, K.G. (2008). Rock-Eval/TOC data for 18 wells, PeelPlateau and Plain, Yukon Territory (65º 50' to 67º 00' N; 133º 45' to 135º 15' W). Yukon Geological Survey, Open-File 2008-1, 14 p. plus spreadsheet(s):http://ygsftp.gov.yk.ca/publications/openfile/2008/of2008_1.pdf, accessed 2/8/2010.

Al-Qayim, B. and Saadallah, A. (1992). Petrology of Jurassic Chia Gara Formation, Northern Iraq. Journal of the Geological Society of Iraq 25 (2): 162–181.

Atta-Peters, D., Achaegakwo, C.A., Garrey, P. (2015). Palynofacies, organic geochemical analyses and hydrocarbon potential of the Takoradi 11-1 Well, Saltpond Basin, Ghana. Petroleum and Coal 57(5): 478–499.

Bacon, C.A., Calver, C.R., Boreham, C.J., Leaman, D.E., Morrison, K.C., Revill, A.T., Volkman, J.K. (2000). The petroleum potential of onshore Tasmania-a review. Geological Survey Bulletin 71. Mineral Resources Tasmania.

Barker, C. (1996). Thermal modeling of petroleum generation: theory and applications. New York, Amsterdam; Elsevier. 1st edition, 45: 1–512.

Behar, F., Beaumont, V., Penteado, H.L. De B. (2001). Rock-Eval 6 technology: Performances and developments. Oil and Gas Science and Technology Rev. IFP 56(2): 111-134.

Bellen, R.C. Van, Dunnington, H.V., Wetzel, R., Morton, D. (1959). Lexique Stratigraphique International. 3, Asie, Fascicule 10a Iraq, Paris.

Buday, T. (1980). The Regional Geology of Iraq: Stratigraphy and Paleogeography. Dar Al-Kutub Publishing House, University of Mosul, Mosul.

Csontos, L., Pocsai, T., Sasvari, A., and Koncz, I. (2011). Geology and petroleum systems of Akri-Bijeel Block, Kurdistan region of Iraq. MOL Scientific Magazine 2011 (1): 16–23.

Csontos, L., Sasvári, A. Pocsai, T., Kósa, L., Salae, A.T., and Ali, A. (2012). Structural evolution of the Northwestern Zagros, Kurdistan Region, Iraq—Implications on oil migration. GeoArabia 17(2): 81–116.

Dahl, B., Bojesen-Koefoed, J.A., Holm, A., Justwan, H., Rasmussen, E., Thomsen, E. (2004). A new approach to interpreting Rock-Eval S2 and TOC data for kerogen quality assessment. Organic Geochemistry 35: 1461–1477.

Demaison, G.J. and Moore, G. (1980). Anoxic environments and oil source bed genesis. AAPG Bulletin 64(8): 1179–1209.

Dembicki Jr, H. (2009). Three common source rock evaluation errors made by geologists during prospect or play appraisals. AAPG Bulletin 93(3): 341–356.

Edilbi, A.N.F. and Sherwani, G.H. (2019). Petrography and source rock potential of Chia Gara Formation (Late Jurassic–Early Cretaceous) in Northern Iraq and Kurdistan Region. Journal of Petroleum Exploration and Production Technology 9: 1801–1818.

Edilbi, A.N.F. (2016). The role of the Baluti Formation within Triassic Petroleum Systems in Kurdistan; Akre-Bijeel Block, Gara and Ora anticlines: An organic geochemical and basin modeling approach. PhD thesis, University of Aberdeen.

Edilbi, A.N. (2010). Stratigraphy and petroleum potential of Chia Gara Formation (Tithonian- Berriasian) in selected sections in North Iraq. Master thesis, Salahaddin University.

Espitalié, J., Marquis, F., Barsony, I. (1984). Geochemical logging. In Voorhees, K.J. (ed.), Analytical pyrolysis: techniques and application. London, Butterworths, pp. 276–304.

Fatah, S.S., Salih, D.A., Kalaitzidis, S., Mohialdeen, I.M., Khanaqa, P.A. (2020). Organic geochemical and petrographical characteristics of the lower part of Sarmord Formation, M-2 Well, Miran Oil Field, Kurdistan, NE Iraq: Implications for hydrocarbon generation potential and thermal maturation. Journal of Zankoy Sulaimani 22 (1), pp. 39-58.

Hakimi, M.H., Mohialdeen, I.M.J., Al-Ahmed, A.A., El-Nady, M.M. (2017). Thermal modeling and hydrocarbon generation of the Late Jurassic-Early Cretaceous Chia Gara source rock in the Iraqi Kurdistan region, northern Zagros Fold Belt. Egyptian Journal of Petroleum **27(4). DOI:** 10.1016/j.ejpe.2017.10.007.

Howarth, M.K. (1992). Tithonian and Berriasian ammonites from the Chia Gara Formation in northern Iraq. Paleontology 35(3): 597–655.

Hunt, J.M. (1996). Petroleum geochemistry and geology. Second edition, New York, W. H. Freeman, and Company.

Kauffman, E.G. (1988). Concepts and methods of high-resolution event stratigraphy. Annual Review of Earth and Planetary Sciences 16: 605-654.

Koshnaw, R.I., Horton, B. K., Stockli, D. F., Barber, D. E., Tamar-Agha, M. Y., Kendall, J.J. (2017). Neogene shortening and exhumation of the Zagros fold-thrust belt and foreland basin in the Kurdistan region of northern Iraq. Tectonophysics 694: 332-355.

Lafargue, E., Marquis, F., Pillot, D. (1998). Rock-Eval 6 applications in hydrocarbon exploration, production and in soil contamination studies. Revue De L'institut Français Du Pétrole (IFP) 53(4): 421–437.

Leanza, H.A. (1996). The Tithonian ammonite genus *Chigaroceras* Howarth (1992) as a bioevent marker between Iraq and Argentina. GeoResearch Forum 1(1996): 451-458.

Mamaseni, W.J., Naqshabandi, S.F., Al-Jaboury, F.Kh. (2019). Hydrocarbon Generation Potential of Chia Gara Formation in Three Selected Wells, Northern Iraq. Open Geosciences, 11(1): 77-88.

Mohialdeen, I.M.J., Hakimi, M.H., Al-Beyati, F.M. (2013a). Geochemical and petrographic characterization of late Jurassic-early Cretaceous Chia Gara Formation in Northern Iraq: Palaeoenvironment and oil-generation potential. Marine and Petroleum Geology 43: 166–177.

Mohialdeen, I.M.J., Hakimi M.H., Al-Beyati, F.M. (2013b). Biomarker characteristics of certain crude oils and the oil-source rock correlation for the Kurdistan oilfields, Northern Iraq. Arabian Journal of Geosciences 8(1) DOI: 10.1007/s12517-013-1228-3.

Mohialdeen, I.M.J. (2008). Source rock appraisal and oil/source correlation for the Chia Gara Formation, Kurdistan-north Iraq. PhD dissertation, University of Sulaimani, Iraq.

Odisho, K.Y. and Othman, R.S. (1992). Preliminary geochemical evaluation of hydrocarbon source rocks in the northern part of Iraq. Iraqi Geological Journal 25: 136–153.

Osli, L.N, Shalaby, M.R., Islam, M.A. (2019). Hydrocarbon generation modeling and source rock characterization of the Cretaceous-Paleocene Taratu Formation, Great South Basin, New Zealand. Journal of Petroleum Exploration and Production Technology 9(1): 125–139.

Peters, K.E. (1986). Guidelines for evaluating petroleum source rock using programmed pyrolysis. AAPG Bulletin 70(3): 318–329.

Peters, K.E. and Cassa, M.R.(1994). Applied source rock geochemistry. Chapter 5, In Magoon, L.B. and Dow, W.G. (Eds.), The petroleum system—from source to trap. AAPG Memoir 60: 93–120.

Peters, K.E., Walters, C.C. and Moldowan, J.M. (2005). The biomarker Guide (2nd ed.) 1-2, United Kingdom, Cambridge University Press.

Pitman, J.K., Franczyk, K.J., Andres, D.E. (1987). Marine and non-marine gas-bearing rocks in Upper Cretaceous Blackhawk and Nelson formations, eastern Uinta Basin, Utah-sedimentology, diagenesis, and source rock potential. AAPG Bulletin 71(1): 76–94.

Reif, D., Decker, K., Grasemann, B., Peresson, H. (2012). Fracture patterns in the Zagros fold-and-thrust belt, Kurdistan Region, Iraq. Tectonophysics 576–577: 46–62.

Tissot, B.P., Pelet, R., Ungerer, P.H. (1987). Thermal history basins, maturation indices and kinetics of oil and gas generation. AAPG Bulletin 71: 1445–1466.

Tissot, B.P. and Welte, D.H. (1984). Petroleum formation and occurrence—A new approach to oil and gas exploration. 2ndedition: Springer Verlag, Berlin.