Research Article

Source Rock Evaluation of the Upper Triassic Baluti Formation in Bekhme-1 and Gulak-1 Wells from Akri-Bijeel Block, Kurdistan-Iraq

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Abstract
This study reports on the petroleum potential of the Upper Triassic Baluti Formation in Bekhme-1 and Gulak-1 Wells from Akri¬-Bijeel Block within the Bekhme Anticline area, North of Erbil City. The area is a part of the Zagros Fold and Thrust Belt, and is locally situated within the High Folded Zone. Typically, the Baluti Formation is composed of gray and green shale calcareous dolomite with intercalations of thinly bedded dolomites, dolomitic limestones, and silicified limestones which in places are brecciated. The geochemical indicators obtained from Rock-Eval pyrolysis of Baluti samples gave Total Organic Carbon content (TOC wt. %) average values of 0.15 and 0.18 wt. % and potential hydrocarbon content (S2) average values of 0.78 mg HC/g rock and 0.58 mg HC/g rock for Bekhme-1 and Gulak-1 respectively, suggesting a source rock of poor potential. The type of organic matter is of mixed type II-III and III kerogens with an average Tmax value of 440 °C for both boreholes, exhibiting early to peak stage of thermal maturity. Considering the results of this study, it is concluded that Baluti Formation in the studied area can not be regarded as a potential source rock for hydrocarbon generation.

Keywords: Baluti, Bekhme, Gulak, Source Rock, Rock-Eval, Akri-Bijeel Block, Kurdistan.

1. Introduction

The study area is located 10 Km northwest of Harir town, and about 100 km north of Erbil city Figure 1. The Bekhme-1 Well was spudded on the top of Bekhme anticline, 5 Km to the north of Gulak-1 Well Figure. 1 (b). Both wells are explorational boreholes drilled down to the Upper Triassic Baluti and Kurra Chine formations (MOL Group Report, 2013). According to the Iraqi tectonic divisions, the Bekhme Anticline is within the High Folded Zone, and regionally within the Zagros Fold and Thrust Belt Figure 1 (Fouad, 2015). The Upper Triassic Baluti Formation outcrops in different localities in North, Northeast, as well as, in many subsurface sections in the Northwest of Iraq (Bellen et al., 1959). The type locality section of the Baluti Formation appears at Gara Anticline, which was described for first time by Wetzel (1950). According to Bellen et al. (1959), its lithotype comprises green shales, calcareous dolomites with intercalations of thinly bedded dolomites, dolomitic limestones, and silicified limestones which in places are brecciated. The age of the Baluti Formation is believed to be Rhaetic (Bellen et al., 1959; Buday, 1980). Other studies (e.g. Hanna, 2007) have suggested a Late Carnian-Norian age. Stratigraphically, the Formation is underlain by the Kurra Chine Formation and overlain by the Sarki Formation (Bellen et al., 1959) Figure 2. The geology of formation is well studied (e.g. Wetzel, 1950; Bolton, 1958; Bellen et al, 1959; Buday, 1980; Al-Juboury & McCann, 2013; Csato et al., 2014; Mustafa, 2015; Shingaly, 2016; Edilbi et al., 2017; Al-Mashaikie, 2017; Asaad & Omer, 2019; Lunn et al., 2019; & Azo et al., 2020).

However, only a few studies have been carried out on the petroleum potential of the formation. Al-Ameri et al. (2009) studied the palynofacies and hydrocarbon generation potential of the Kurra Chine and the lower part of the Baluti Formation, but have not suggested concrete results on Baluti Formation apart from typification of OM. As a source rock, the formation showed only low-fair potential in Atrush-1 and Sheikhan-1B Wells (Akram & Naqishbandi, 2018).

In order to further study the hydrocarbon generation potential of the shale interval within the Baluti Formation and to add more information the possible contribution of the formation to the petroleum systems of Iraqi Kurdistan Region, this study provided more in-depth assessment of the source rock potential of Baluti Formation as geochemically described from rock samples in Bekhme-1 and Gulak-1 from Akri-Bijeel Bock.

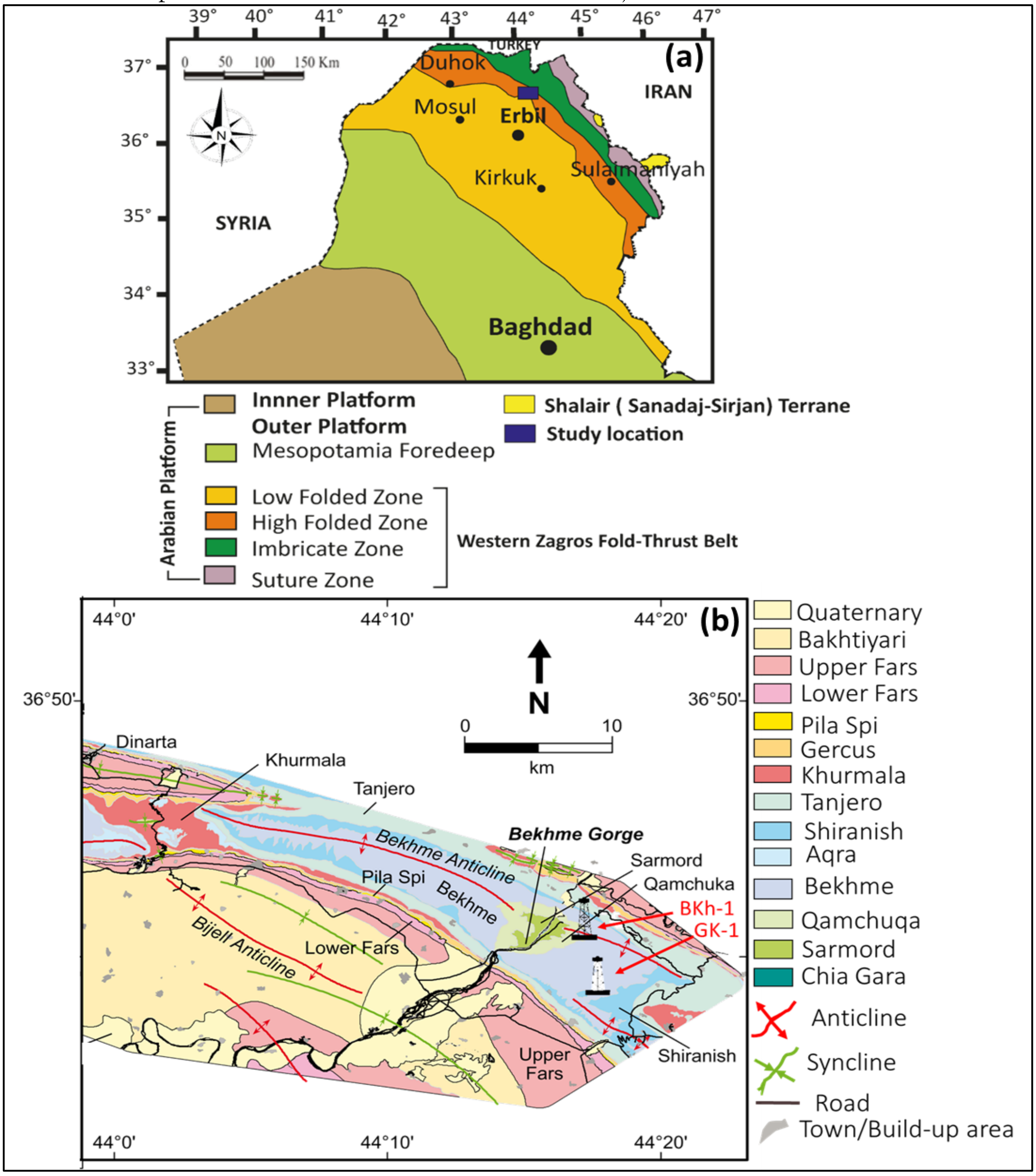

Figure 1. (a) Location of the study area and tectonic map of the Iraqi Kurdistan (After Fouad, 2015), (b) Geological map of the area and locations of the studied wells (After Csontos et al., 2012).

2. Geological Setting

In the Late Permian the Neo-Tethys opened which was associated with drifting away of one or more narrow blocks from the northeastern margin of the Gonadawna. During the Early Triassic, the Neo-Tethys progressively widened on the north and east margins of the Arabian Plate, and a break-up unconformity created in the passive margin (Jassim & Goff, 2006). In the Mid-Late Triassic, renewed rifting took place within the passive margin which caused forming a broad and restricted intra-shelf basin in the Mesopotamian. This restricted intra-shelf basin was separated from open ocean by a narrow rift with alkali basalts and a ridge of thinned continental crust (Jassim et al., 2006). Megasequence

AP6 which is known as the Late Permian-Liassic Megasequence comprises three second order sequences: the Late Permian-Mid Triassic, Late Triassic, and Early Jurassic sequences. The most widespread Triassic sequence in the Arabian Peninsula was the Late Triassic Sequence. In Iraq, it is represented by inner shelf carbonates and clastics of the Mulussa and Zor Hauran formations in the Stable Shelf, and inner shelf carbonates, evaporites and restricted lagoonal environment of the Kurra Chine and Baluti formations in the Foothill and High Folded Zones (Jassim et al., 2006). The depositional environments setting of the Baluti and Sarki formations (Upper Triassic- Lower Jurassic) in northern Iraq are mostly similar to those from the western part of Iraq. The same depositional setting of Triassic – Jurassic succession is recorded from adjacent regions, which represent the southern margins of Tethys and around the northern and western margins of Tethys (Al-Juboury & McCann, 2013). The Baluti Formation can be found in all locations that Kurra Chine Formation is found. The formation is not identified in the Mesozoic succession exposed in the western region long the Wadi Hauran. Thus the Zor Hauran Formation tentatively can be considered as equivalent of the Baluti at western of Iraq. The Baluti Formation has a number of the lateral equivalents within the region. The most correlatable formation in Syria to the Baluti Formation may be the Mulussa-E Formation (Lunn et al., 2019). The Minjur Formation (Upper Triassic-Lower Jurassic) in Kuwait and Saudi Arabia might.be tentatively correlated to the Baluti Formation. Within the Iranian part of the Zagros there is not a distinctive rock unit of the Late Triassic age or a clear equivalent to the Baluti Formation. The Dashtak Formation in Iran is a possible lateral equivalent formations to the Baluti Formation (Lunn et al., 2019).

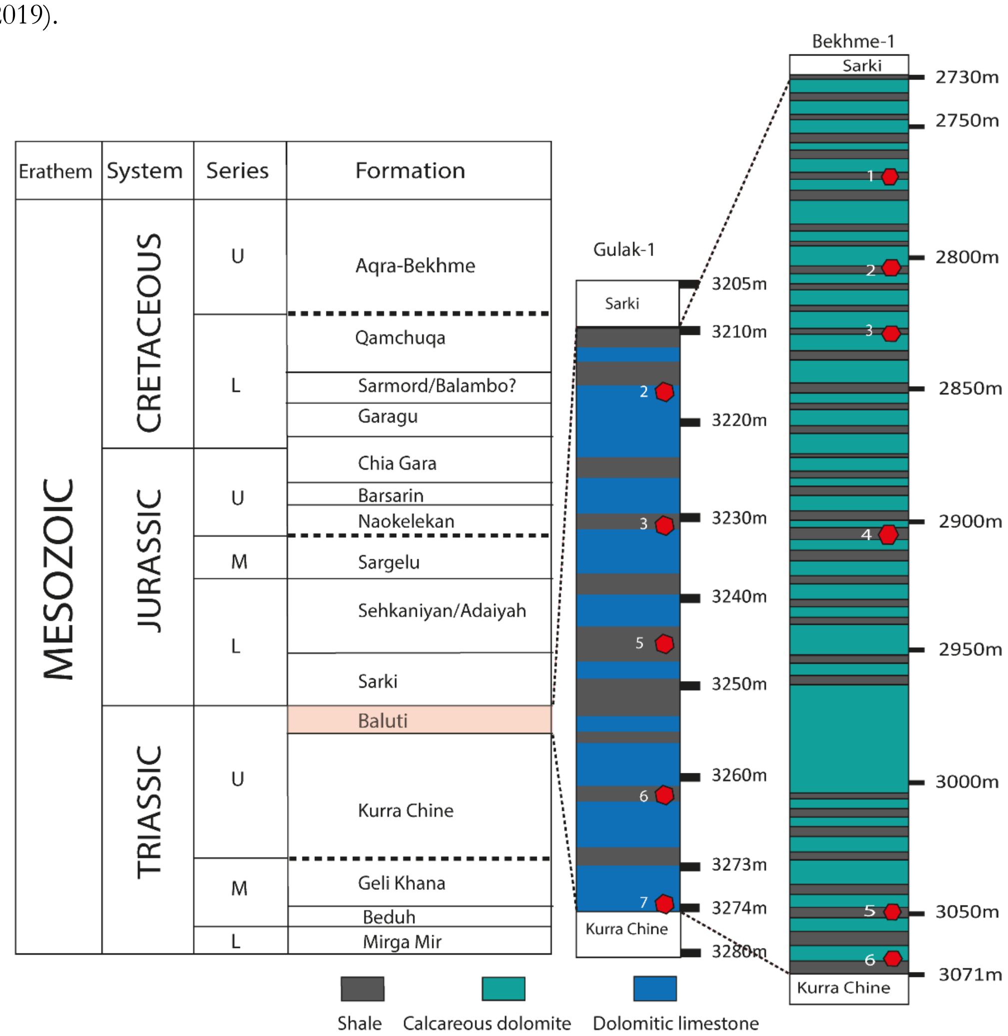

Figure 2. Litho-stratigraphic position of Baluti Formation in Boreholes Gulak-1 and Bekhme-1 of the study area.

3. Materials and Method

Rock-Eval pyrolysis was carried out for eleven borehole cuttings samples at the Scientific Research Center (SRC) in Soran University. Prior to pyrolysis, the samples were cleaned, crushed and powdered, and then approximately 100 mg of each sample were in a crucible for pyrolysis. When Rock-Eval apparatus was calibrated with main standards, the samples were run for pyrolysis. In this study, the following parameters were used for source rock potential of the pyrolyzed samples; TOC (Total Organic Carbon, wt. %.), S1 (Volatile hydrocarbon (HC) content, mg HC/ g rock), S2 (remaining HC generation potential, mg HC/ g rock), S3 (Carbon dioxide content, mg HC/ g rock), HI (hydrogen index = S2 × 100/ TOC, mg HC/g TOC), OI (oxygen index = S3 × 100/ TOC, mg CO2/g TOC), PI (production index = S1 / (S1+ S2).

4. Results and Discussion

4.1. Source rock quantity

The results of the Rock-Eval pyrolysis for analyzed samples are shown in Table 1. The Total Organic Carbon (TOC %) is quantitative parameter that is pointed out to the weight percentage of organic carbon in the rock, in other words it is a measurement of the organic matter richness of a sample (Tissot & Welte, 1984; Peters, 1986; Peters & Cassa, 1994). Peters and Cassa (1994) suggested the values of TOC less than 0.5 can be regarded as a poor quantity, the TOC % values between 0.5 and 1.0% indicate a fair source rock potential, the values between 1.0 to 2.0%, reflecting a good source rock potential, and TOC % values of 2- 4.0%, displaying a very good source rock potential, and the values more than 4.0%, revealing excellent source rock. The data present TOC content of sediments of the Baluti Formation varies from 0.08 % to 0.33 %. Organic richness of analyzed samples tends to be categorized as poor source rock potential. S1 parameter is the total amount of free hydrocarbons, in mg/g of rock, that is volatilized out of the rock at a moderate temperature without cracking the kerogen at the first stage of pyrolysis (Maky & Ramadan, 2008). It is normally increased with depth. If the value of S1 is more than 1 mg/g, it may be indicative of an oil show (Pimmel & Claypool, 2001). It should be considered that the contamination of samples by drilling fluids and mud can give an abnormally high value for S1 (Tissot & Welte, 1984). A plot of TOC (wt. %) versus S1 is widely used to distinguish between indigenous (uncontaminated) and non-indigenous (contaminated) (Hun, 1996; Rabbani & Kamali, 2005). The plot of S1 (mg HC/ g rock) against TOC (wt. %) shows that all (except one) samples were below the inclined line, indicating the presence of indigenous hydrocarbons Figure 3. Peters (1986) suggested the S1 values less than 0.5 are classified as a poor source rock potential. As shown in Table 1 the S1 values of the analyzed samples range from 0.09 to 0.32 mg HC/g rock. The S1 data show that all samples are believed to be poor source rock potential for hydrocarbon generation in studied wells.

Table 1. The results of Rock-Eval parameters for analyzed samples from the Baluti Formation in studied wells. Note: Due to very low values of TOC and S2, the highlighted values of the T_{max} are considered as unreliable data (Peters & Cassa, 1994, English et al., 2015).

Sample	TOC	S1	S2	S3	S2/S3	T_{max}(°C)	HI	OI	PI
BKh1	0.28	0.22	1.45	0.76	1.9	441	518	271	0.13
BKh2	0.08	0.09	0.41	0.24	1.7	426	512	300	0.18
BKh3	0.19	0.25	1.06	0.65	1.6	429	558	342	0.19
BKh4	0.11	0.13	0.50	0.27	1.9	423	455	245	0.21
BKh5	0.12	0.18	0.62	0.47	1.3	427	517	392	0.23
BKh6	0.12	0.31	0.65	0.25	2.6	423	542	208	0.32
Average	**0.15**	**0.2**	**0.78**	**0.44**	**1.83**	**428**	**517**	**293**	**0.21**
GK-2	0.24	0.25	0.85	0.85	0.5	434	354	354	0.23
GK-3	0.10	0.11	0.36	0.45	0.8	422	360	450	0.23
GK-5	0.13	0.16	0.63	0.43	5.3	423	485	331	0.20
GK-6	0.33	0.32	0.82	0.78	7.8	444	248	236	0.28
GK-7	0.12	0.10	0.26	0.30	3.1	384	217	250	0.28
Average	**0.18**	**0.19**	**0.58**	**0.56**	**3.11**	**421***	**333**	**324**	**0.24**

Abbreviations: TOC – Total Organic Carbon, wt. %., S1 – Volatile hydrocarbon (HC) content, mg HC/ g rock. S2 – remaining HC generation potential, mg HC/ g rock., S3 – Carbon dioxide content, mg HC/ g rock., HI – Hydrogen Index = S2 × 100/ TOC, mg HC/g TOC., OI – Oxygen Index = S3 × 100/ TOC, mg CO2/g TOC., PI – Production Index = S1 / (S1+ S2). * In this study, the average value of T_{max} is not considered as reliable value for interpretation.

The parameter S2 is the thermally generated (cracked) hydrocarbons, in mg/g of rock, from kerogen during pyrolysis (Peters, 1986). Based on Peters, (1986), Ibrahimbas and Riediger (2004) and Dembicki (2017), the S2 value less than 2.5 mg HC/g rock is categorized as poor source rock. S2 values be from 2.5 to 5 mg HC/g rock show fair source rock potential. The sample that contains S2 from 5.0 to 10 mg/g is referred to a good source rock, and sample with more than 10 mg HC/g rock display very good source rock. The S2 values in this study for analyzed samples are ranging from 0.26 mg HC/g rock to 1.45 mg HC/g rock. Based on the above criteria, the data show poor source rock potential.

Moreover, the S2 in conjunction with TOC for quantification of source rock show that all samples are plotted in the field of poor quantity Figure 4 (a).

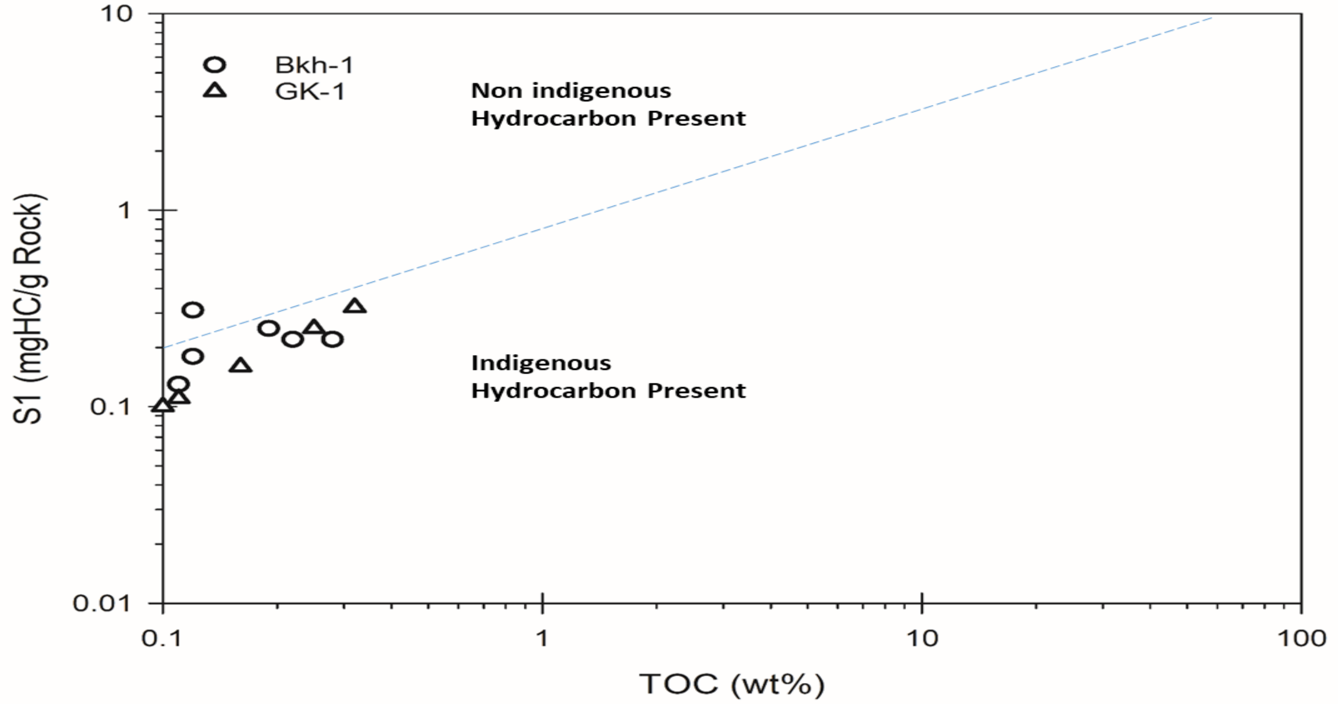

Figure 3. Plot of S1 vs. TOC%, in which migrated or contaminating hydrocarbons can be distinguished from indigenous hydrocarbons (Hunt, 1996; Rabbani & Kamali, 2005).

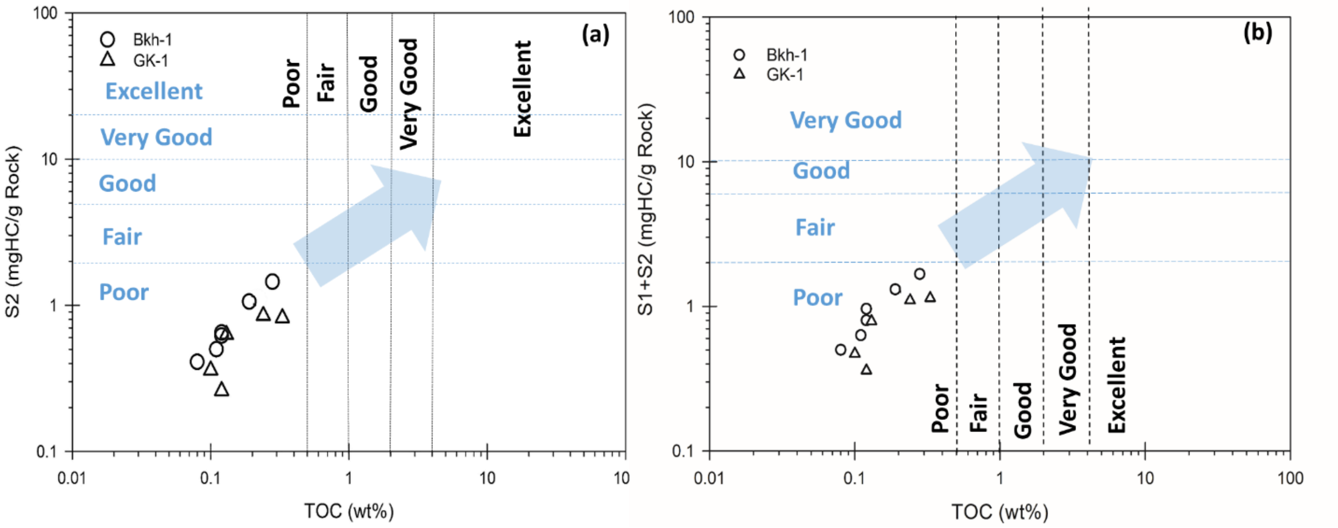

Figure 4. (a) Cross plot of Total Organic Carbon (TOC, wt.%) vs. S2 (mg HC/g Rock) for analyzed samples of the Baluti Formation (After Dembicki, 2017), and (b) Cross plot of S1 + S2 versus TOC (wt.%), showing production potential of the analyzed samples (After Ghori, 2002).

The Generation Potential or Genetic Potential (GP) of a source rock can be appraised via summation of the S1 and S2 pyrolysis data (Peters, 1986; Bordenave, 1993; Akande et al., 2005). Hydrocarbon generation potential of a source rock will be highly dependent on the type and abundance of organic matter and thermal maturity (Tissot & Welte., 1984; Dembicki., 2009). The value of GP less than 2.0 mg/g is classified as poor generative potential, the values between 2.0-6.0 mg/g are considered as fair, and the value more than 6.0 mg/g shows good generative potential (Tissot & Welte, 1984). The plot of TOC (wt. %) against Genetic Potential (PG) is also widely used to determine petroleum generating potential. As shown in Figure 4 (b), the Baluti Formation in studied wells has poor generation potential.

4.2 Source Rock Quality

The S2/S3 ratio is referred to the amount of hydrocarbons, which can be generated from a rock relative to the amount of organic CO2 pyrolysis (Peters & Cassa, 1994). As shown in Table 2 the type III kerogen contains a lower value of S2/S3 than type I and II kerogens because type III kerogen originally derived from higher plant (terrestrial) that possess substantially more oxygen than the other types (Peters & Cassa, 1994; Nunez & Baceta,1994). On the base of the attained results, the type III kerogen is suggested for the organic matter of the Baluti Formation Tables 1 and 2.

Table 2. Types of kerogen, referring to the values of HI and S2/S3 (Peters & Cassa, 1994).

HI	S2/S3	Kerogen type
<50	<1.0	IV
50-200	1.0-5.0	III
200-300	5.0-10	II, III
300-600	10-15	II
>600	>15	I

The Hydrogen Index (HI = S2/TOC × 100) is a measurement of hydrogen richness in kerogen (Dembicki, 2009) and has a direct relationship to elemental hydrogen to carbon ratios (Hunt, 1996). The Hydrogen Index is widely used to define kerogen type and the approximate level of maturation (Tissot & Welte, 1984; Ibrahimbas & Riediger, 2004; Peters et al., 2005). The HI values ranging from 217-558 mgHC/gTOC, suggest the prevalence of mixed type II-III kerogens. However, owing to very low values of TOC and S2 these values may be unreliable (Peters & Cassa, 1994; English et al., 2015). The Hydrogen Index in conjunction with Oxygen Index (OI= S3/TOC x 100) are also commonly used to determine the type of kerogen. As shown in Figure 5, the kerogen type for organic matter of the Baluti Formation in studied wells is probably mixed type II-III kerogen. As mentioned earlier, due to unreliable HI, the more likely kerogen type can be of type III that refers to terrestrial environment where OM is derived from higher plants Tables 1 and 2.

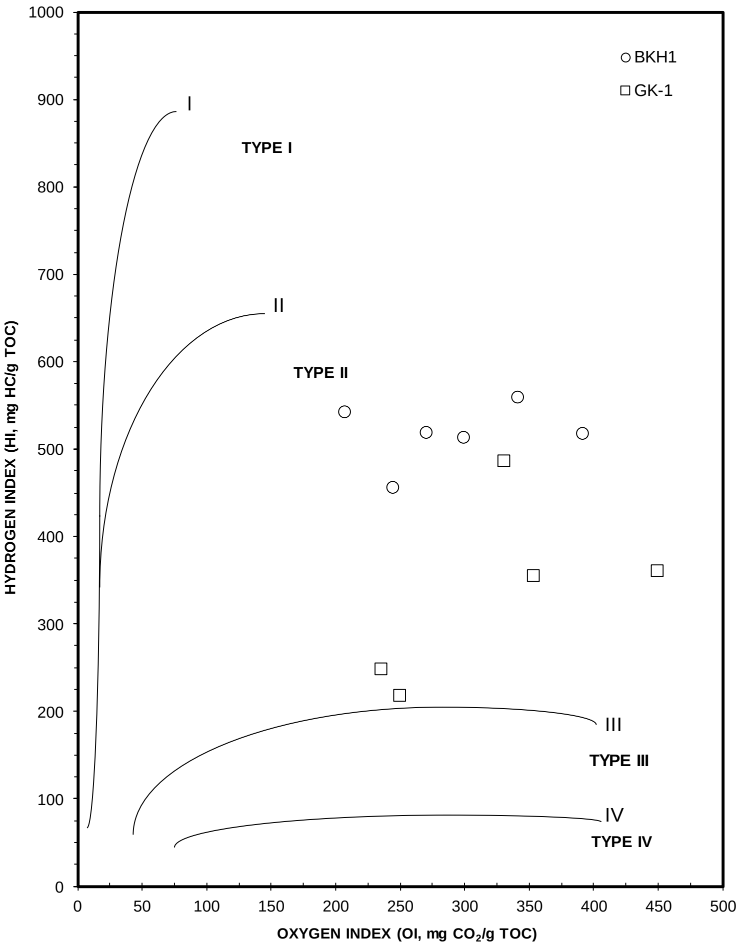

Figure 5. Plot of HI versus OI, showing kerogen type of studied samples.

4.3. Thermal Maturity

In addition to organic matter richness and good quality, a source rock cannot be considered as a potential source rock unless it is thermally mature (Law, 1999). One of the most applied parameters to find out the thermal maturity of OM is T_{max} . T_{max} is the temperature at which the maximum amount of hydrocarbon can be generated during pyrolysis, indicating the level of maturity of the organic matter in the rock (Tissot & Welte, 1984). Hydrocarbons produced by pyrolysis is related to the amount of hydrogen in the sample and to its level of maturation because the more mature sample contains a lower amount of hydrogen, thus the highest amount of energy is needed to liberate hydrocarbon (Baiyegunhi et al., 2020). In Rock-Eval pyrolysis, the T_{max} values less than 435°C show immature organic matter, the values between 435 – 455°C display mature organic matter. The T_{max} values between 455 – 470°C show high mature organic matter, and the values greater than 470°C indicate Wet Gas or the over mature zone (Peters & Cassa, 1994).

The T_{max} values of the pyrolyzed samples range from 384°C to 444°C, indicating immature to early mature stage of thermal maturity. Plotting Hydrogen Index versus T_{max} also shows that most of analyzed samples are located in the immature field except three samples, which are in the early and peak mature zone (oil window) Figure 6. Production Index (PI = S1/S1 + S2]) is the amount of hydrocarbon which has been produced relative to the total amount of total hydrocarbons which a sample is able to produce (Nunez-Betelu & Baceta, 1994). This parameter is used to characterize the evolution level of the organic matter. An increase in production index value can be noted with increasing the depth thus a high PI values may indicate high level of maturation, vice versa for lower (PI) values (Tissot & Welte, 1984; Peters, 1986). The values of production index of the Baluti Formation in the studied wells range between 0.13 to 0.32 Table 2. As shown in cross plot of T_{max} versus PI in Figure 7, most of the samples are plotted in the field of immature (stained or contaminated) to oil window (intensive generation, and expulsion). It should be taken into consideration that owing to very low values of TOC and S2, the T_{max} for the most samples (except three samples) are considered as unreliable for deducing a precise thermal maturity (Peters & Cassa, 1994; English et al., 2015). Based on the previous study on the Jurassic Naokelekan source rock in Gulak-1 Well, the organic matter of the Naokelekan Formation has thermally reached peak-late oil window (Abdula, 2018). Therefore, the Baluti Formation in study area is also expected to be thermally mature and in the oil window at least.

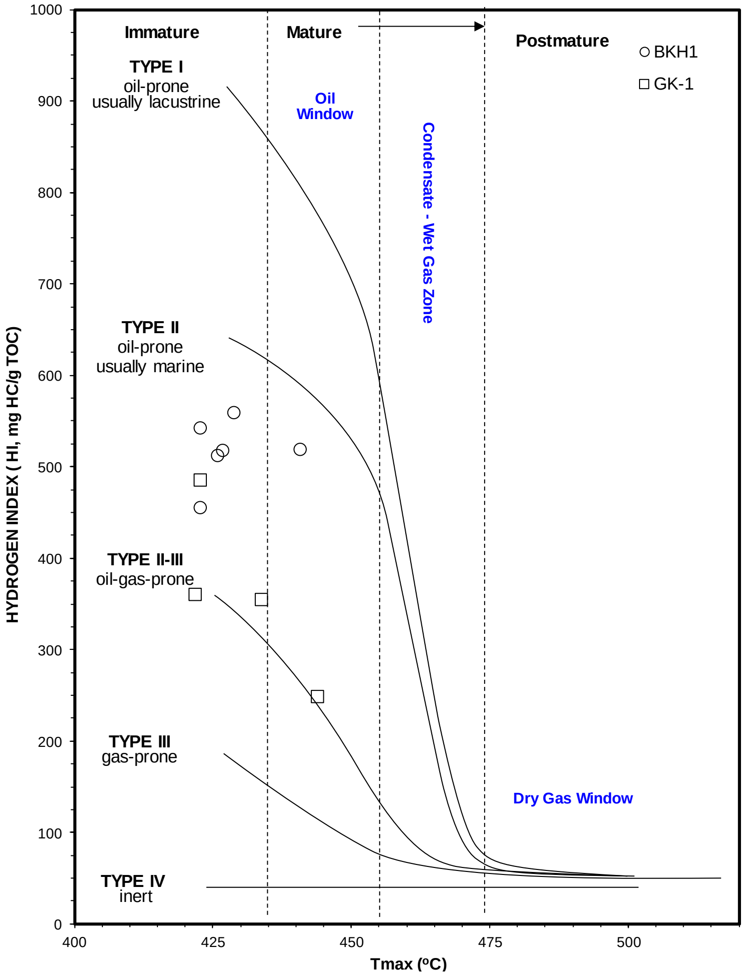

Figure 6. Plot of HI versus T_{max}, showing maturity of studied samples.

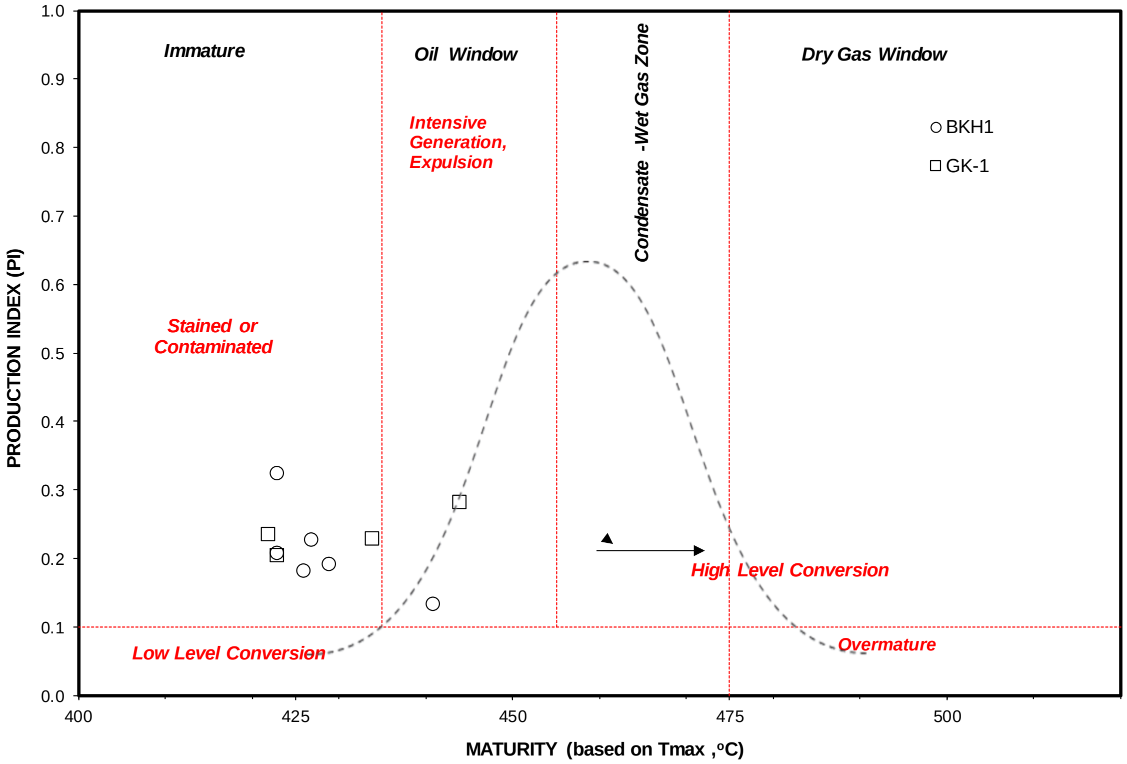

Figure 7. Plot of PI versus T_{max}, showing maturity of studied samples of the Baluti Formation.

4. Conclusions

The examined samples of the Baluti Formation from Bekhme-1 and Gulak -1 Wells contain unsatisfying amounts of total organic carbon, and the values of S1, S2, and genetic potential (PG) reveal that the formation has no potential to be considered as a source rock. The mixed type II-III and III kerogens are suggested for the organic matter of the formation which is considered to be mainly gas-prone. Regardless of unreliable T_{max} values, the formation is possibly mature and reached oil window.

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