**IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)\
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)**

Vol.20, No.2, 2024 ***p 23 – 37***

SOURCE ROCK EVALUATION AND HYDROCARBON GENERATION POTENTIAL OF THE CRETACEOUS (DOKAN AND GULNERI) FORMATIONS IN BAI HASSAN-13 WELL SECTION, KURDISTAN, NORTH OF IRAQ

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Type of the Paper: Article
Received: 20/ 09/ 2022
Accepted: 18/ 01/ 2023
Available online: November 06, 2024

Keywords: Dokan; Gulneri; Bai Hassan; pyrolysis; palynofacies.

ABSTRACT

Eleven cutting rock samples from both Dokan and Gulneri formations (Cretaceous) in one subsurface section of Bai Hassan-13 (BH-13) well in northern Iraq were studied by using two techniques for hydrocarbon generation potentiality. The geochemical technique included Rock-Eval Pyrolysis analysis, The optical technique was achieved by studying palynological slides. The rock-Eval pyrolysis results showed that Dokan Formation has total organic carbon (TOC) wt.% ranging between 1.16 % and 2.3 % (good to very good), Gulneri Formation has a high TOC of 1.34 % and 4.64 % (good to excellent) quantity of organic matter. About the quality of organic matter, both Dokan and Gulneri formations are composed of kerogen types I and II. The organic matter of the Dokan Formation is not indigenous (migrated), one sample of the Gulneri Formation is indigenous the other one is located on the slanted line separating the Indigenous from non-indigenous organic matter. The organic matter within the two formations are thermally immature source rock, Therefore, they cannot generate oil and gas.

The palynological study revealed that amorphous organic matter is the predominant organic matter component in both formations with more than 89%, whereas phytoclasts and palynomorphs comprised only a few percentages. There is no great variation in the percentages of the mentioned organic matter components, except a slight increase in the percentage of phytoclasts and palynomorphs in the lower part of the Dokan Formation, therefore one primary palynofacies type can be recognized, and divided into two secondary palynofacies. Through plotting Tyson's Amorphous, phytoclasts, and palynomorphs (APP) diagram, it is clear that the two formations are deposited in a distal suboxic to anoxic basin.

1. INTRODUCTION

Bai Hassan Oilfield is located in the Northeastern part of Iraq within the Foothills Zone of the Unstable Shelf Zone with an NW – SE trend; it is one of several elongated, asymmetrical, doubly plunging anticlines (Dunnington, 1958; Zeynalov et al., 2016). The field was discovered in 1953 by the Iraqi Oil Company (IPC) and came into production in 1960 (Baban, 2008). The structure is 34 Km long and 3.8 Km wide and consists of a longitudinal, sinusoidal anticline. It is composed of two domes, Kithka, and Dauod Domes previously separated by a narrow saddle

called the Shahal saddle, Kithka dome is bigger and higher structurally by 335m than the Dauod dome (Buday, 1980; Buday & Jassim, 1987; Zeynalov et al., 2016) (Figure 1).

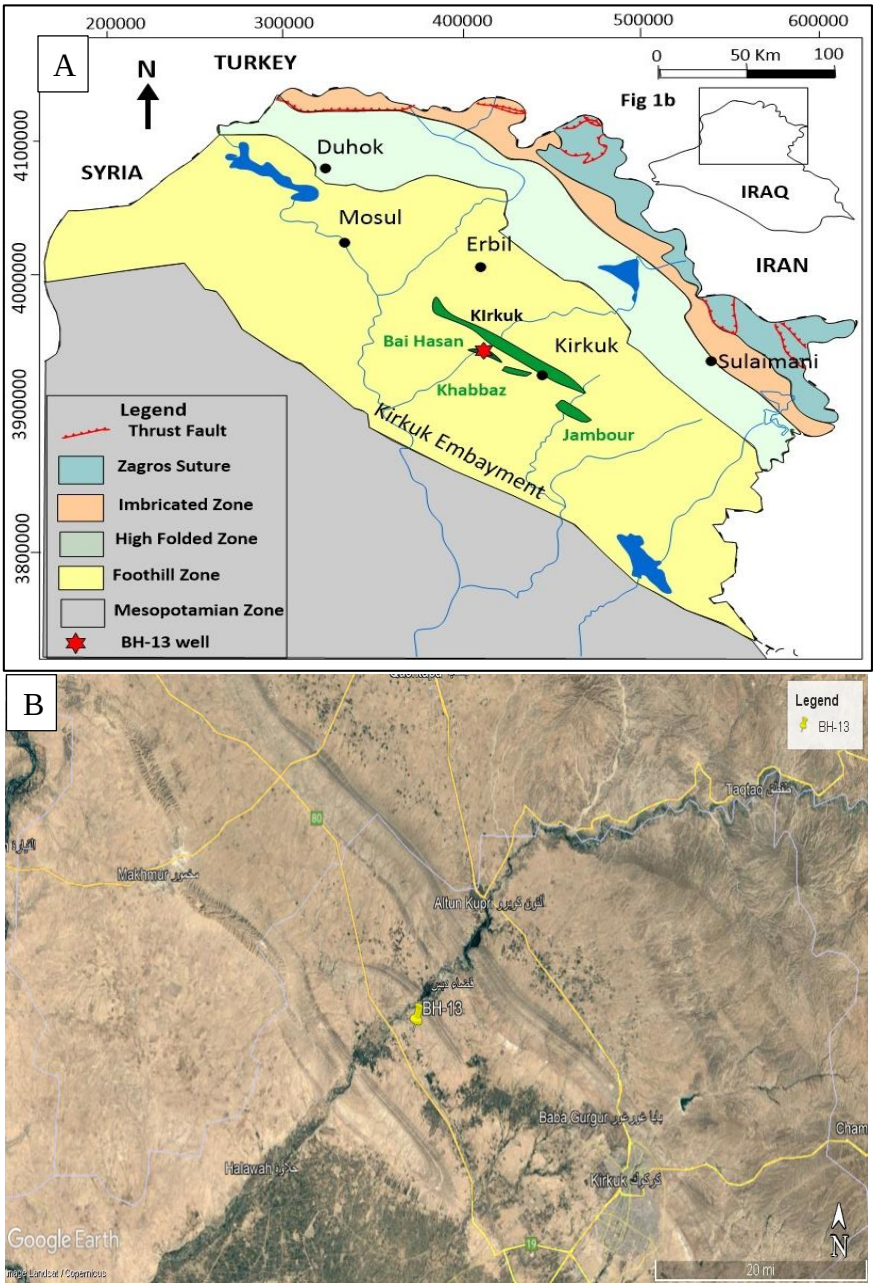

Figure 1: BH-13 well section, Northern Iraq **A)** Location map and **B)** Google Earth satellite image.

Few studies were done on the Dokan and Gulneri formations concerning palynology, organic geochemistry, and hydrocarbon potentiality, such as (Sarraj, 2006) studied the two formations in three wells (Khabaz-12, Jambour-50, and Taq Taq-1) and Dokan outcrop section. (Baban & Sarraj, 2007) studied the two formations in three wells (Khabaz-12, Jambour-50, and Taq Taq-1). (Sarraj, 2017) studied the Dokan and Gulneri formations in Kirkuk-130 well. In an extension of the previous studies, this study represents comprehensive studies of Dokan and Gulneri formations in the BH-13 well section. The aims of this study encompass the evaluation of both formations from a hydrocarbon potentiality point of view, besides the study of

palynofacies and paleo-depositional environment to confirm their contribution to generating accumulated oil in the BH-13 well section. The target was achieved through the geochemical and optical studies of eight samples from the Dokan Formation, and three samples from the Gulneri Formation.

The study section is located at depth intervals between the depths 5227.5 feet (1593.2 m) and 5374 feet (1638 m) with UTM coordinates 442 686.22 E and 3929 449.78 N (Figure 1).

2. MATERIALS AND RESEARCH METHODS

Eleven rock samples of a total of 44.8 m thickness in well BH-13 were selected to be studied optically and analytically.

Eleven palynological slides were prepared depending on the standard method (Barss & Williams, 1974). The crushed samples are placed in flasks to which HCl (10%) is added to remove the carbonates. Then concentrated HCl (37%) is added. After pouring off the acid, distilled water was added and washed with distilled water five times. Then HF acid (52%) is added to the flask to remove the silicates and left for about 3-4 days. After that, the acid was poured off and distilled water was added and washed five times until it was neutral. The kerogen residues are sieved with 10 μm nylon mesh, mounted by cell size on the cover slip and sticker on the slide by a small amount of Canada balsam. The prepared slides were studied under a polarizing Leitz microscope type to identify different organic matter components and determine palynofacies types.

Six samples from the aforementioned formations were subjected to Rock-Eval Pyrolysis by using Rock-Eval 6 in the Kurdistan Institution for Strategic Studies and Scientific Research, Sulaimani/ Iraq. The samples were cleaned from impurities and washed with distilled water. Then kept in the oven for 24 hours to dry at a temperature of 40° C. Then crushed and ground to be homogeneous powder for analysis by Rock-Eval 6. The pyrolysis was performed with about 70 mg of crushed samples, which were heated to 600° C in a helium atmosphere. The oven was held at 300 °C for 3 minutes and then increased at a rate of 25° C/min. The parameters measured were S1, S2, S3, TOC %, and T_{max}, other parameters such as HI, OI, PI, and Genetic potential are calculated for the samples.

3. GEOLOGICAL SETTING

The Dokan and Gulneri formations belong to the Late Tithonian- Early Turonian Megasequence (AP8). This Megasequence is thickest in the Foothill Zone and in the Tigris Subzone, and absent over part of Mosul High (Jassim and Buday, 2006) (Figure 2).

In the Upper Triassic- Early Upper Cretaceous, the depositional basin in Iraq has undergone an open phase toward NNE–SSW in which most of the Cretaceous sediments accumulated on the north edge of the Arabian Plate (NOC, 1993; Shahab et al., 2022).

The sedimentary basin in the Early Cretaceous had started converging due to the collision of both the Arabian and Eurasian Plates, besides the Zagros Main Fault and continuing convergence till the Late Paleocene another phase of compressional movement occurred which led to the form of the Low Folded Zone in Iraq including the structure of Bai-Hassan Oilfield (NOC, 1993; Shahab et al., 2022).

The Middle Turonian to Lower Campanian succession in Iraq is comprised of homogenous carbonate sediments with a lack of sandstone and evaporates, including Balambo, Dokan, Gulneri, and Kometan formations in Kurdistan (Rashid et al., 2015; Sadooni, 2004).

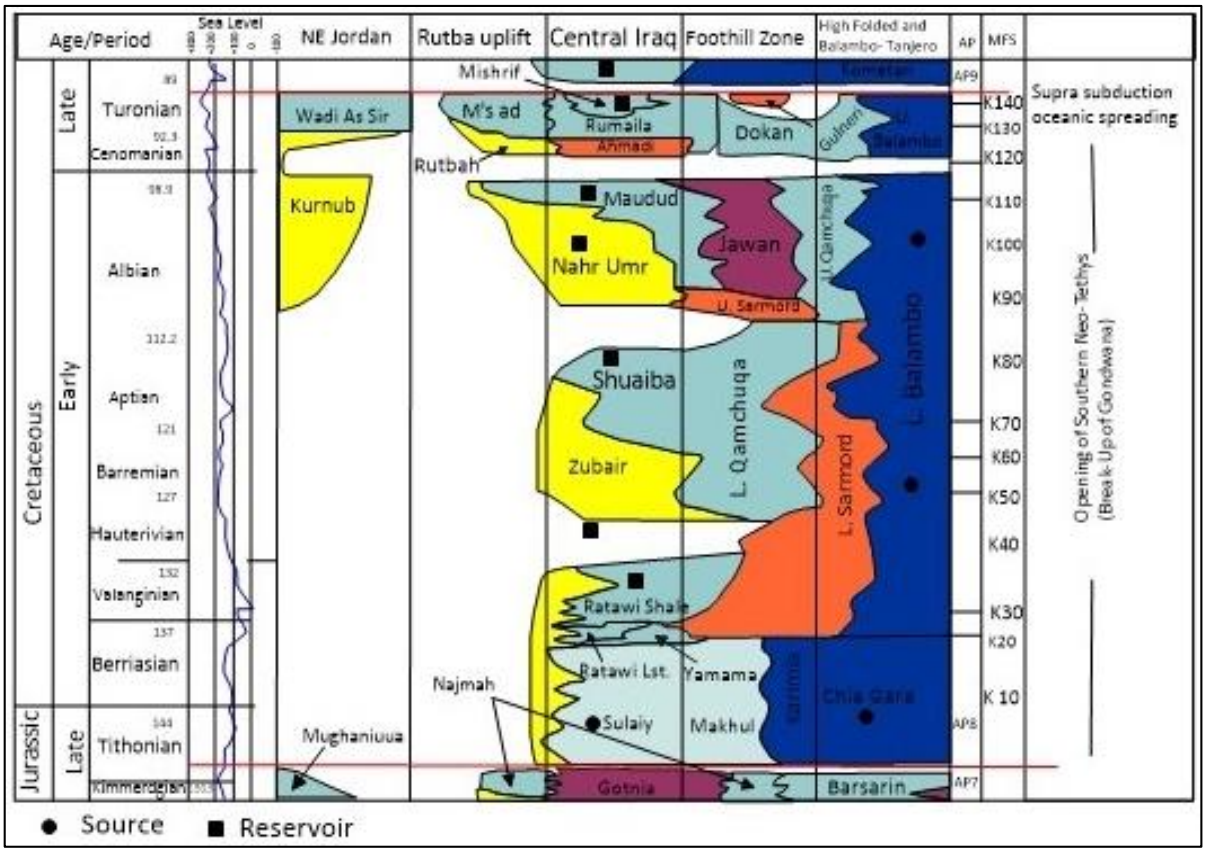

Figure 2: Stratigraphic correlation for the formations of Megasequence AP8 (after Jassim & Buday, 2006)

3.1. Dokan Formation

This formation was first described by Lancaster Jones in 1957 in Dokan Dam, Sulaimani, northeast Iraq, it is composed of light grey or white, white-weathering oligosteginal limestone, locally rubbly, with glauconitic coatings of constituent pebble-like masse (Van Bellen et al., 1959). It is thickness in the type section is about 4 m, in Khabbaz well (Kz-12) 21 m, Jambour well (Ja-50) 70 m, Taq Taq well (Tq-1) 2 m, Kirkuk well (K-130) 10.5 m, in this study it's thickness is about 38 m thickness.

3.2. Gulneri Formation

It was first described by Lancaster Jones in 1957 in Dokan Dam, Sulaimani, northeast Iraq, lithologically it is composed of black, bituminous, finely laminated calcareous shale with some glauconitic and cellophane in the lower part. In the type section, its thickness is about 1.1 – 1.2 m (Van Bellen et al., 1959), in the Kz-12 well 10 m, in Ja-50 well 11 m, Tq-1 8 m, K-130 well 9.5 m. In this study, it is about 6.8 m in thickness.

4. RESULTS AND DISCUSSION

4.1. Rock-Eval Pyrolysis

The data obtained from Rock-Eval Pyrolysis analysis are S1, S2, S3, T_{max}, and TOC, as well as HI, OI, PI, PP, or GP as shown in Table 1.

4.1.1. Organic carbon richness

The amount of organic carbon present in a source rock is expressed as TOC (wt.%), and it is used as an indicator of the source rock richness concerning how much hydrocarbon the sediment may generate (Dembicki, 2017). By combining TOC and S2, you can get an idea of how much organic matter is present and how much hydrogen is associated with it (Dembicki Jr, 2009). In this study, the Dokan Formation possesses good to very good organic matter richness with TOC values ranging from 1.16% to 2.3% and good to excellent generation potential with S2 value range from 7.28 mg HC/g rock to 14.42 mg HC/g rock; Whereas Gulneri Formation considered as good to excellent organic matter richness with TOC values ranging from 1.31 % to 4.64 %. Furthermore, the Gulneri Formation is characterized by good to very good generative potential with S2 values of 6.5 mg HC/g rock to 31.76 mg HC/g rock (Table 1, and Figure 3).

Table 1: Rock-Eval pyrolysis results for the Dokan and Gulneri formations in the BH-13 well section.

Formation	Sample NO.	Depth (m)	TOC (%)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	Tmax (°C)	HI (mg HC/g TOC)	OI mg CO2/g TOC)	PI	S2/S3	GP (S1+S2) (mg HC/g rock)	S1/ TOC
Gulneri	1	1594.1	1.31	2.01	6.5	1.04	425	485	78	0.24	6.25	8.51	1.53
	3	1598.6	4.64	4.59	31.76	0.78	422	684	17	0.13	40.71	36.35	0.98
Dokan	4	1603.2	1.86	5.39	12.09	0.27	424	650	15	0.31	44.77	17.48	2.89
	6	1612.3	2.3	6.35	14.42	0.27	417	627	12	0.31	53.40	20.77	2.76
	8	1629.1	1.64	3.2	9.36	0.33	423	571	20	0.26	28.36	12.56	1.95
	`11	1636.7	1.16	2.32	7.28	0.33	423	628	28	0.24	22.06	9.6	2.0

TOC: total organic carbon (weight percentage of the whole rock); **S1:** low hydrocarbon yield and values are mg hydrocarbon/g rock; **S2:** residual petroleum potential (mg HC/g rock); **S3:** Organic CO2-kerogen derived (mg CO2/g rock; **T_{max}:** temperature at which maximum emission of high temperature (S2) hydrocarbons occurs; **HI:** hydrogen index (mg HC/g TOC); **OI:** oxygen index (mg CO2/g TOC); **PI:** production index = S1/S1+ S2); **GP:** Genetic potential = (S1+S2) (mg HC/g rock).

Table 2: Geochemical parameters describing Kerogen type (Quality) and the Character of expelled products (Peters & Cassa, 1994).

Kerogen type	HI (mg HC/G TOC)	S2/S3	Atomic H/C	Main expelled product at peak maturity
I	> 600	> 15	> 1.5	Oil
II	300 – 600	10 – 15	1.2 – 1.5	Oil
II/III	200 – 300	5 – 10	1 – 1.2	Mixed oil and gas
III	50 – 200	1 – 5	0.7 – 1.0	Gas
IV	< 50	< 1	< 0.7	None

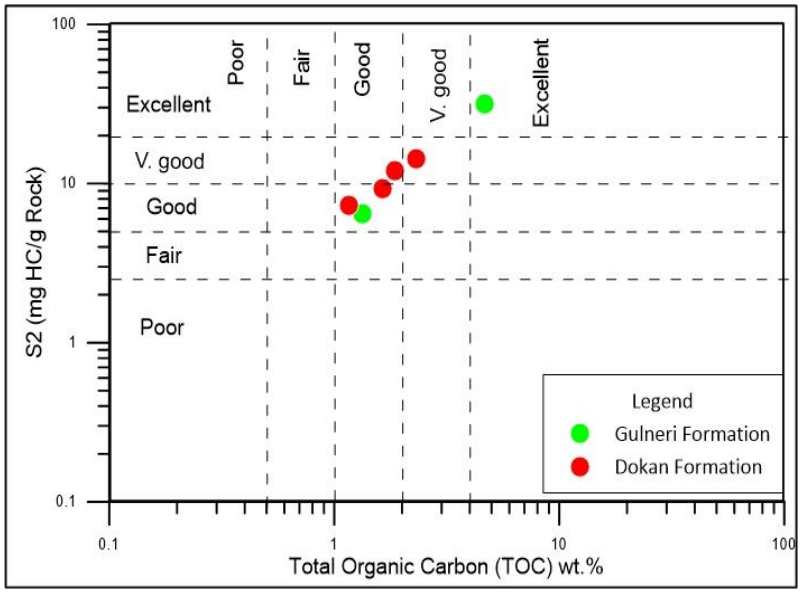

Figure 3: Cross plot of S2 versus Total Organic carbon (TOC wt.%) of Dokan and Gulneri formations in BH-13 well (The diagram from Dembicki Jr, 2009).

4.1.2. Organic matter quality

Most source rock evaluations rely on Rock-Eval pyrolysis to provide information about kerogen type. A simple approach to this interpretation is to use the Hydrogen Index (HI) or the S2/S3 ratio (Hydrocarbon Index; QI). The analyzed samples of Dokan Formation having HI of 571 mg HC/g TOC to 650 and Gulneri Formation with HI of 485 to 684 mg HC/g TOC, according (Peters, 1986; Peters & Cassa, 1994), both Dokan and Gulneri formations indicating type I and II kerogens with oil generating potentiality (Tables 1 and 2). The same conclusion was obtained from a cross plot of HI versus Oxygen Index (OI). The studied Dokan and Gulneri formations samples show that both formations are of type I and II kerogen (Figure 4). The (S2/S3) ratio shows that the Gulneri Formation has type I kerogen oil-generating potential, while the Dokan Formation has type II kerogen and oil-generating potential also (Table 2).

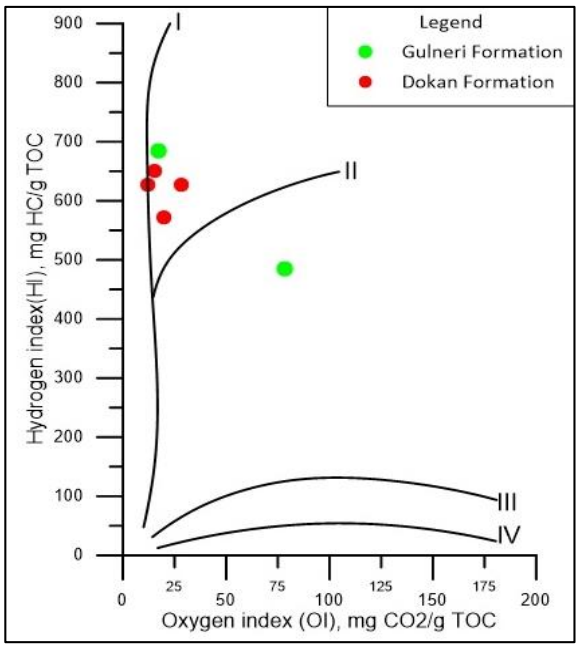

Figure 4: HI versus OI plot of Dokan and Gulneri formations from BH-13 well section (Diagrm from Espitalié et al., 1977)

The hydrocarbon within the Dokan Formation is not indigenous (migrated), while one of the Gulneri Formation samples is indigenous the other one is located on the slanted line separating the indigenous from non-indigenous hydrocarbon or contaminated. (Figure 5).

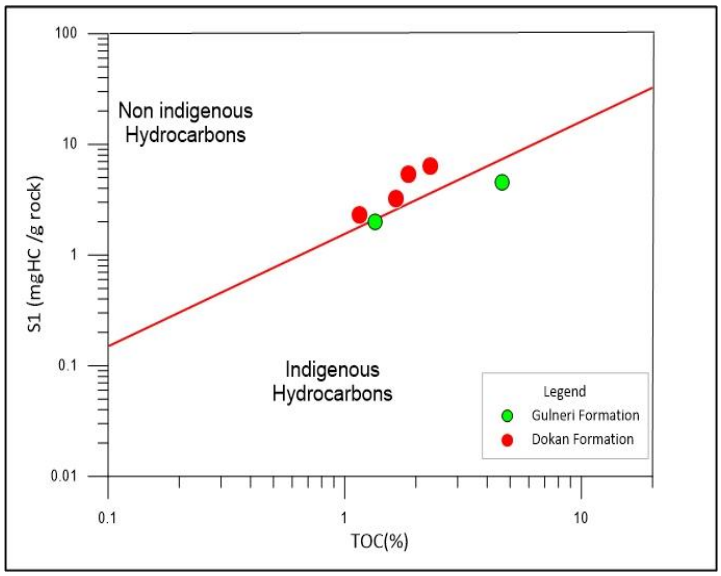

Figure 5: cross plot of S1 versus TOC wt.% of Dokan and Gulneri formations from BH-13 well section (diagram after Hunt, 1996).

4.1.3. Thermal maturity and hydrocarbon generation potential

T_{max} and Production Index (PI) are the primary Rock-Eval parameters for assessing thermal maturity (Espitalié et al., 1985). reported that oil generation from source rock started from T_{max} = 435 – 465 °C, and PI between 0.2 and 0.4. When the T_{max} value is less than 435 °C, and PI less than 0.2, the organic matter is immature, and gas generation starts at T_{max} 470 °C and PI more than 0.4.

The T_{max} values of both Dokan and Gulneri formations show an immature state of organic matter content and high HI (hydrogen content) (Figure 6). Immature rocks where T_{max} is less than 435 °C, PI is greater than 0.2, and S1/TOC is greater than 0.3, this may be due to oil-based mud contamination or migrated oil (Peters, 1986). In this study, the PI values of all samples of the Dokan Formation and one sample of the Gulneri Formation are (0.24 – 0.31), the T_{max} is less than 435 °C, and the S1/TOC is greater than 0.2, this indicates that the hydrocarbons from older rocks of Lower Cretaceous formations such as Balambo, Sarmord, and Chia Gara formations or Jurassic formations such as Naokelekan, Sargelu formations were migrated to the Dokan and Gulneri formations (Table 1) (Figure 7).

The (Sarraj, 2017) study was about the Dokan and Gulneri formations in the K-130 well section and obtained the same conclusion regarding the maturity stage of organic matter (immature), hence cannot generating oil and gas.

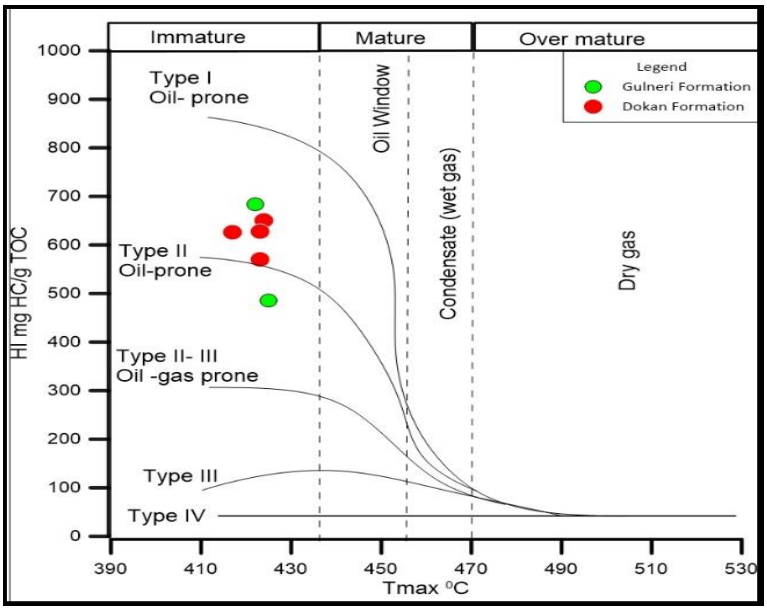

Figure 6: Cross plot of HI and T_{max} of Dokan and Gulneri formations in the BH-13 well section (modified after (Jackson et al., 1985).

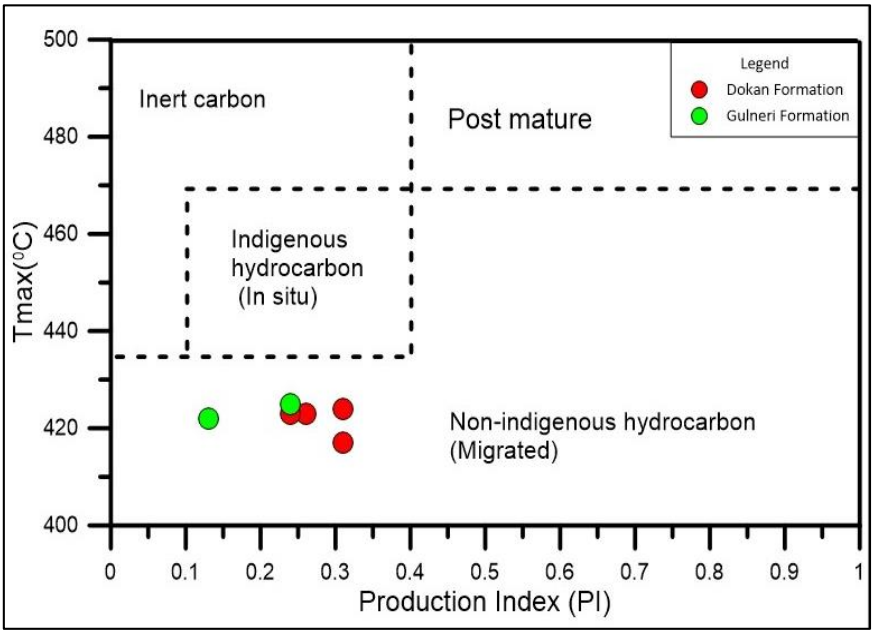

Figure 7: Cross plot of T_{max} and Production Index (PI) of Dokan and Gulneri formations in BH-13 well (after Espitalié et al., 1977)

4.2. Optical Examination

4.2.1. Palynofacies types

Through studying the Dokan and Gulneri formations optically by using transmitted light microscopy, it is clear that the amorphous organic matter (AOM) is the predominant sedimentary organic matter nearly greater than 89 %, while the phytoclasts and palynomorphs are rare (Table 3). Depending on the percentage of the aforementioned sedimentary organic matter components, one primary palynofacies type can be recognized. As there is no great

variation in these components, two secondary palynofacies types are recognized (Table 3) (Figure 8).

Table 3: Sedimentary organic matter components percentage of Dokan and Gulneri formations in BH-13 well.

Formation	Sample number	Depth (m)	Depth (feet)	phytoclasts %			Palynomorphs %	AOM %
				Blade	Equidimensional	Translucent		
Gulneri	1	1594.1	5230	1	1	0	1	97
	2	1597.1	5240	0	2	0	2	96
	3	1598.6	5245	0	1	0	1	98
Dokan	4	1603.2	5260	0	1	1	1	97
	5	1606.2	5270	0	1	0	1	98
	6	1612.3	5290	0	1	0	2	97
	7	1623	5325	0	1	0	1	98
	8	1629.1	5345	1	2	0	2	95
	9	1631.4	5352	2	6	0	2	90
	10	1633.7	5360	1	2	0	2	95
	11	1636.7	5370	1	2	0	2	95

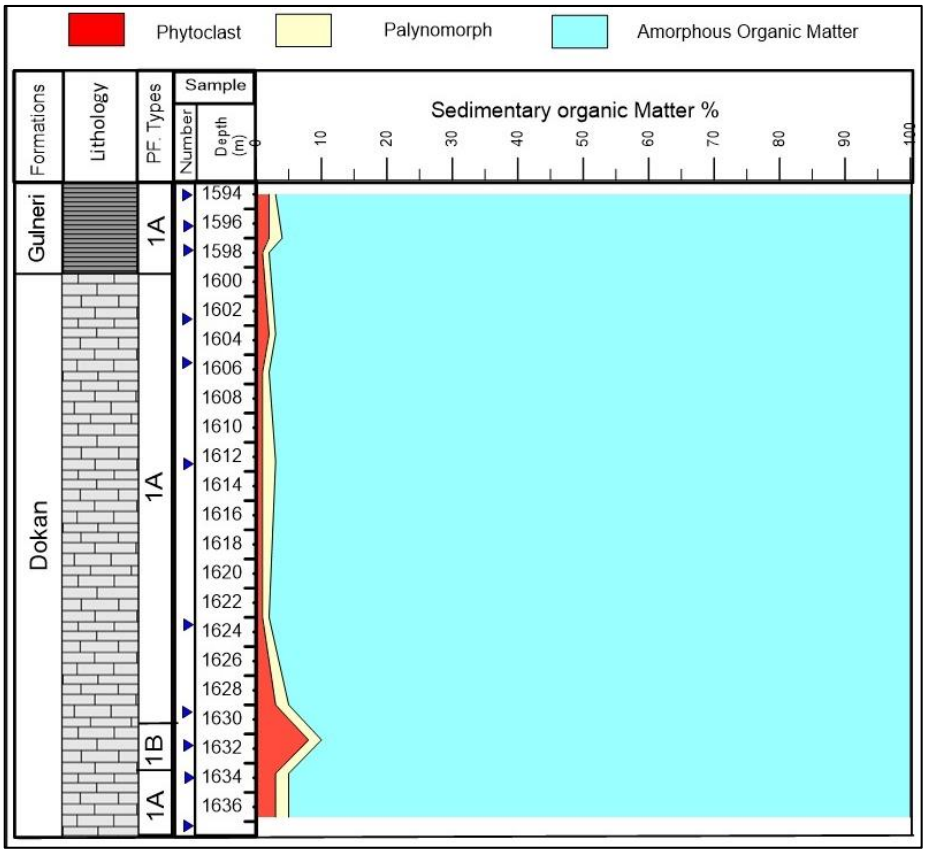

Figure 8: Percentage of organic matter components of the Dokan and Gulneri formations in BH-13 well.

In this study, catalogs, atlas, and published papers used for the identification of palynomorphs are (Demske et al., 2013; Saxena & Tripathi, 2011; SILVA, 2015)

4.2.1.1. Primary palynofacies Type 1 (PF1)

This primary palynofacies can be seen in both formations in the studied section, characterized by a predominant percentage of amorphous organic matter (90 – 98) %, followed by phytoclasts (1 – 8) % and palynomorphs (1 – 2) %. The palynomorphs are of bad preservation due to masking. The phytoclasts are composed of the blade, equidimensional and translucent, and the palynomorphs are composed of Foraminiferal test lining (FTL), scolecodonts, dinoflagellate cyst, fungal spore, and pollen grains. Lithologically it is composed of light grey limestone and grey shale (Figure 8 – 10).

There is a slight variation in the percentage of phytoclasts and palynomorphs in the two sections. Therefore, there is one primary (main) palynofacies type (PF1), which is subdivided into two secondary palynofacies types (PF1A, and PF1B) depending on the ratio of phytoclasts and palynomorphs (Table 3).

4.2.1.1.1. Secondary palynofacies type 1A (PF1A)

Most of the samples in the both Dokan and Gulneri formations are of this palynofacies type. The ratio of AOM is (95 – 98%) higher as compared to palynofacies type 1B, Phytoclasts, and palynomorphs are slightly less than the secondary palynofacies type 1B. Lithologically composed of light gray limestone and gray shale.

The ratio of AOM is about (95 – 98) %, phytoclasts (1 – 3) %, and palynomorphs ratio (1 – 2) % (Figure 8 and Figure 9 A-H, Figure 11A).

4.2.1.1.2. Secondary palynofacies type 1B (PF1B)

This palynofacies is identified in the lower part of the Dokan Formation, at a depth of 1631.4 m (5352 feet), with the percentage of AOM (90%), phytoclasts (10%), and palynomorphs (2%). Composed of light grey limestone (Figure 8, Figure 9 I, and Figure 10 B).

4.3. Interpretation of paleodepositional environment

As mentioned earlier, the AOM in this study comprised the dominant components. Such a large amount of AOM results from an environment that has both a high preservation potential rate and low energy (Carvalho et al., 2013).

The high AOM frequencies reflect more oxygen-depleted conditions and indicate the site of deposition was located to some extent far from active fluvial-deltaic systems of strong terrestrial material influx (El-Soughier et al., 2014; Tyson, 1993).

Fungi are terrestrial organisms that attack wood and leafy detritus (Batten, 1996). They may play a significant role in marine biodegradation (Tyson, 1995).

The FTL are mostly derived from benthic foraminifera, they are considered reliable indicators of marine shelf or slope conditions and are often characterizing a rather shallow shelf or nearshore environment (Lister & Batten, 1988). Scolecodonts represent chitinous parts of benthic polychaete annelid warms, which occur in marine sediments. In this study, the FTL is associated with scolecodonts in all samples of the Gulneri Formation, while one sample, while one sample at a depth of 1629.1 m in the Dokan Formation contains FTL.

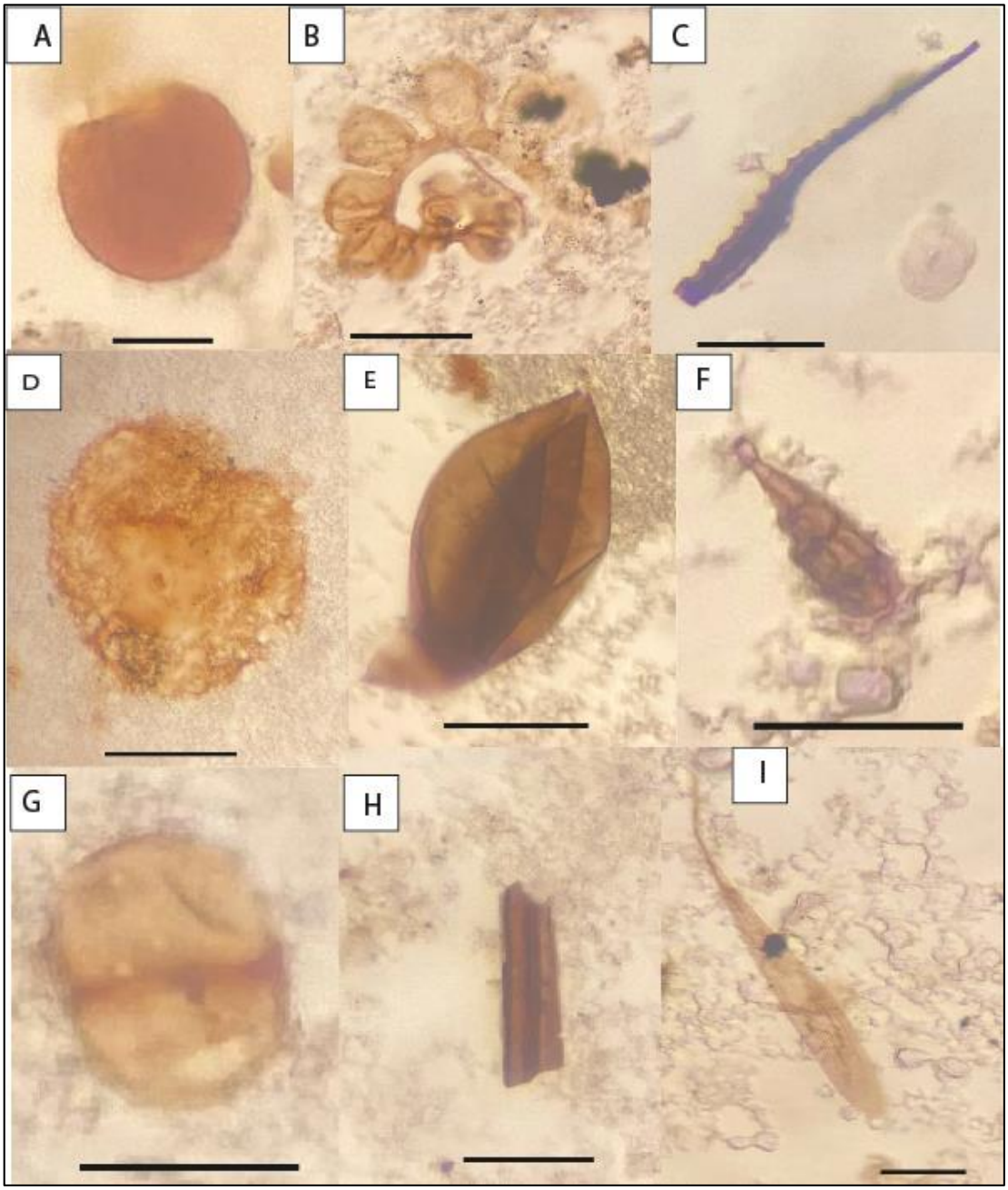

Figure 9: palynomorphs in Dokan and Gulneri formations of BH-13 well section, (A-H) = PF.1A, I = PF.1B, scale Bar = 40µm.
A) *Cleistosphaeridium*, depth: 1594.1 m, Gulneri Formation; **B)** Foraminiferal test lining, 1597.1 m, Gulneri Formation; **C)** Scolecodonts, 1598.6, Gulneri Formation; **D)** *Dinocyst sp.1*, depth 1606.2 m, Dokan Formation; **E)** pollen grains *Juniperus*, depth 1612.3 m, Dokan Formation; **F)** Fungal spore *Pluricellaesporites*, depth 1629.1 m, Dokan Formation; **G)** *Dinocyst sp.2*, depth 1633.7, Dokan Formation; **H)** Tracheid (phytoclasts), depth 1636.7m, Dokan Formation; **I)** Dinocyst *Gotcheodinia* sp., depth 1631.4, Dokan Formation.

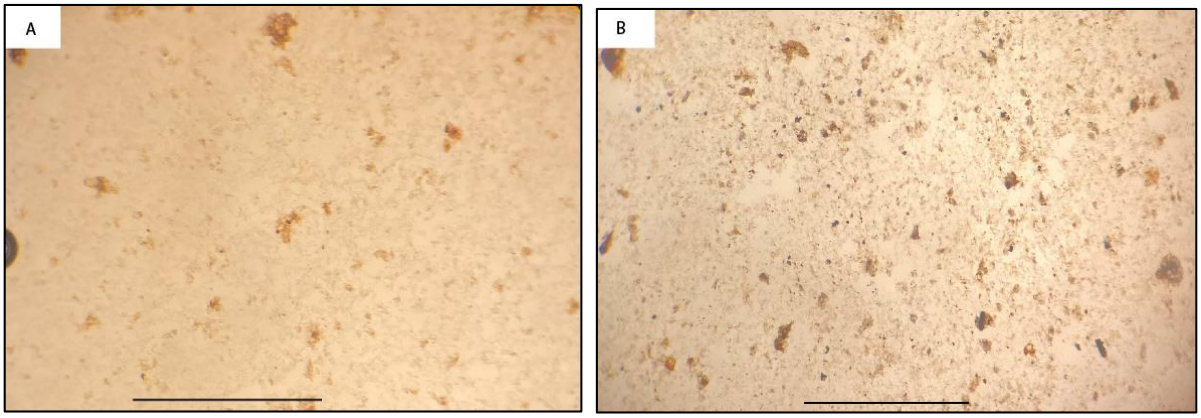

Figure 10: Palynofacies type 1 (A and B) in BH-13 well section, Scale Bar = 0.5 mm.
A) palynofacies type 1 A, depth: 1594.1 m, Gulneri Formation
B) Palynofacies type 1 B, depth: 1631.4 m, Dokan formation.

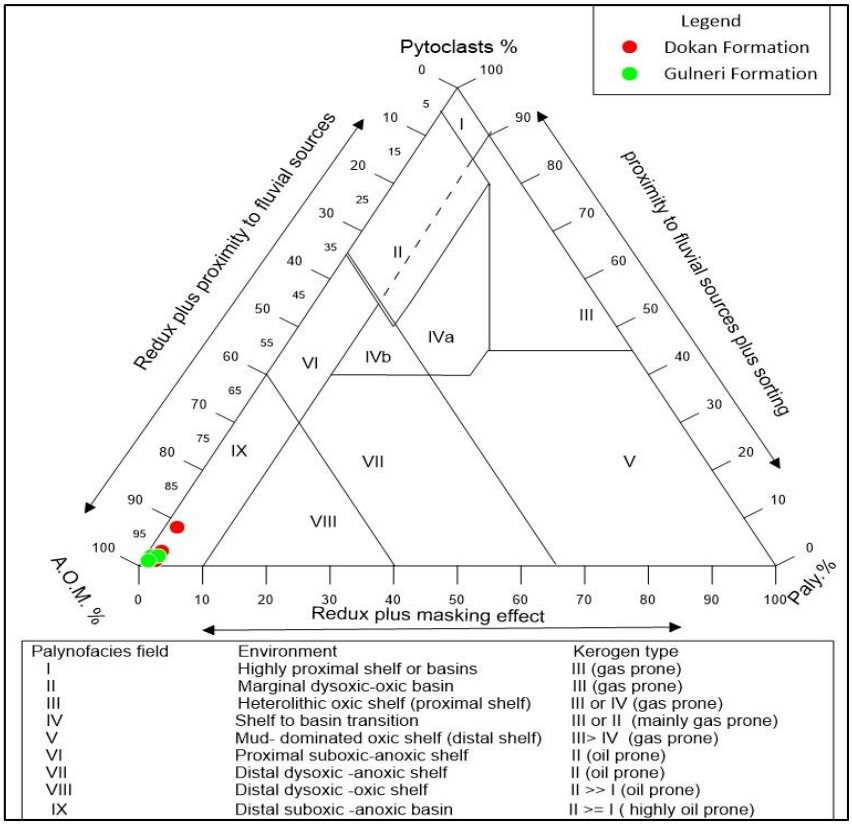

Figure 11: Ternary diagram(APP) showing the distribution of the percentage of AOM, phytoclasts, and palynomorphs for both Dokan and Gulneri formations in the Bh-13 well which is located at IX field (distal suboxic- anoxic basin) (after Tyson, 1995).

Dinoflagellate cysts occur predominantly in marine rocks but also are present in Cretaceous and Cenozoic Lacustrine facies (Filho et al., 2012). They appeared nearly in all samples of both studied formations, but as mentioned earlier, they are of bad preservation, so most of them cannot be identified.

Through plotting the sedimentary organic matter components in the Amorphous, phytoclasts, and palynomorphs (APP) ternary diagram (Tyson, 1993, 1995). The samples of the

two formations are located in one main field (IX) which represents the deposition in a distal suboxic to anoxic basin (Figure 11). This field characterized by the dominance of amorphous organic matter, low abundance of palynomorphs due to masking, frequently rich in alginate, deep basin or starved shelf sea_deposits, and type II kerogen is more than type I (Oil-Prone) (Tyson, 1995).

5. CONCLUSIONS

After studying Dokan and Gulneri formations in BH-13 well, the following conclusions are coming out:

- Dokan Formation has total organic carbon (TOC) wt.% ranging between 1.16 % and 2.3 % (good to very good), and Gulneri Formation has a high TOC of 1.34 % and 4.64 % (good to excellent) quantity of organic matter.
- Pertaining to the quality of organic matter, both Dokan and Gulneri formations are composed of mixed kerogen types I and II.
- The hydrocarbon within the Dokan Formation is not indigenous (migrated), one sample of the Gulneri Formation is indigenous the other one is located on the slanted line separating the indigenous from non-indigenous organic matter, and this may be due to oil-based mud contamination or the hydrocarbon from older rocks of Lower Cretaceous or Jurassic formations were migrated to the Dokan and Gulneri formations.
- Both the Dokan and Gulneri formations are thermally immature source rock, they have no ability to generate oil and gas.
- The palynological study revealed that amorphous organic matter is the predominant organic matter component in both formations with more than 89%, whereas phytoclasts and palynomorphs comprised only a few percentages. There is no great variation in the percentages of the mentioned organic matter components, except a slight increase in the percentage of phytoclasts and palynomorphs in the lower part of the Dokan formation.
- One primary palynofacies type can be recognized (PF1), and this primary palynofacies is divided into two secondary palynofacies (PF1A, and PF1B).
- Through plotting the sedimentary organic matter on Tyson's Amorphous, phytoclasts, and palynomorphs (APP) diagram, it is clear that the two formations are deposited in a distal suboxic to anoxic basin.

ACKNOWLEDGMENT

The Author would like to thank the Northern Oil Company in Kirkuk for providing samples for this study, also many thanks to the directorate of Kurdistan Institution for Strategic Studies and Scientific Research, Sulaimani/ Iraq for analyzing the samples by Rock-Eval -6 pyrolysis. Also profoundly grateful to Dr. Ibrahim M.J. Mohialdeen in the Geology department for his support in reviewing the manuscript.

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