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Original article

Organic Geochemistry of the Hot Shale Member of the Tanez-zuft Formation of wells B1-23 and Q1-23, Ghadames Basin, NW Libya with Regional Correlation

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Abstract
The present work is a source rock assessment of the Hot Shale Member of the Tanezzuft Formation (Early Silurian) using data obtained from wells B1-23 and Q1-23, Ghadames Basin, NW Libya. The geochemical data obtained from HAWK instrument analysis done by Sirte Oil Company on a number of shale samples representing the Hot Shale Member. In terms of organic richness, the Hot Shale Member falls between good and excellent based on the TOC values (1.05-12.39%). The binary plot of TOC versus PP backs up this assumption. In terms of kerogen type, the HI values (126-794 mg/g) display the ex-istence of different types of kerogens, such as types I, II, and III. The binary plots of Tmax versus HI, TOC versus S2, and OI versus HI offer more proof for this hypothesis. In terms of indigeneity, the dominance of indigenous hydrocarbons is suggested by the S1/TOC ratio (0.16-0.81). The binary plot of TOC versus S1 lends credence to this assumption. In terms of thermal maturity, the values of Tmax (417-441 oC) and Ro (0.3-0.78%), and the binary plots of Tmax versus HI, Tmax versus Ro, and PI versus Tmax indicate that the samples of well Q1-23 are primarily contain mature organic matter, whereas the majority of the samples of well B1-23 contain immature organic matter. In terms of petroleum potential, the Hot Shale Member exhibits a variety of petroleum potential, as shown by the binary plot of TOC versus HI. In terms of kinetic parameters, the activation energies (47-84 kcal/mol) have a gaussian shape.
Keywords. Organic Geochemistry, Source Rock, Hot Shale Member, Tanezzuft Formation, Ghadames Basin, Libya.

Introduction

Desio [1] provided the first definition of the Tanezzuft Formation. The Wadi Tanezzuft in the Murzuq Basin is the type locality; however, Desio [1] did not identify the base and top of the formation at the type locality. Klitzslch [2] described the complete section of the formation at south Ghat. In this site the total thickness is 370 m and the formation is mainly composed of graptolitic shales with lesser amounts of siltstone and sandstone. There is an unconformable contact with the underlying Mamuniyat Formation, while there is a gradual transition with the overlying Akakus Formation [1]. There are two members of the Tanezzuft Formation; the Hot Shale Member at the base and the Cold Shale Member on top. The Hot Shale Member is composed of black shale that has high TOC content. The member is distinguished by unusually high radioactivity levels that are strongly linked to uranium existence [3]. Based on the palynostratigraphic and palynofa-cies, El Diasty [4] proposed ages of Early-Middle Rhuddanian (Early Silurian) and Late Rhuddanian-Telychnian (Early Silurian) for the Hot Shale Member and the Cold Shale Member, respectively. The sedimentological characteristics suggested that the Hot Shale Member was deposited in restricted to open marine environments [5].

The Ghadames Basin is considered one of the main sedimentary basins in Libya. It is a sizable intracratonic sag basin. It has an area of 350,000 km^2. The depocentre of the basin is situated in Algeria. The eastern side of the basin is represented by the Libyan part, which rises to the Tripoli–Tibisti Arch and including the Zamzam Depression which stretches towards the east [6]. Up to 21,000 ft of basin-fill can be found in Algeria, but no more than 18,000 ft can be found in Libya. Its boundaries are the Dahar–Nafusah Arch to the north, the Hoggar Massif in Algeria and the Qarqaf Arch in Libya to the south, and the Amguid-El Biod Uplift in Algeria to the west. The basin protrudes beneath the western portion of the Sirte Basin to the east. Fig. 1 shows the time stratigraphic chart of west Libya.

The Ghadames Basin contains large reserves of gas (2.4 Tcf) and oil (64 MM bbl of oil and 39 MM bbl of condensates) in Libya. The majority of the Libyan discoveries are found in the Silurian and Devonian reservoirs, with minor discoveries in the Triassic deposits [6]. There are two proved source rocks in the Ghadames Basin: (1) The Hot Shale Member of the Tanezzuft Formation (Early Silurian); and (2) The Awaynat Wanin/Frasnian Shale (Late Devonian).

In this work, a geochemical evaluation of the Hot Shale Member of the Tanezzuft Formation was conducted in wells B1-23 and Q1-23, Ghadames Basin, NW Libya (Fig. 2). This evaluation included the following: (1) Organic richness; (2) Kerogen type; (3) Indigeneity; (4) Thermal maturity; (5) Petroleum Potential; and (6)

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Kinetic Parameters. Fig. 3 shows regional correlation of gamma-ray profiles through the Hot Shale Member between the studied wells and wells J1-23, A1-61, and E1-23.

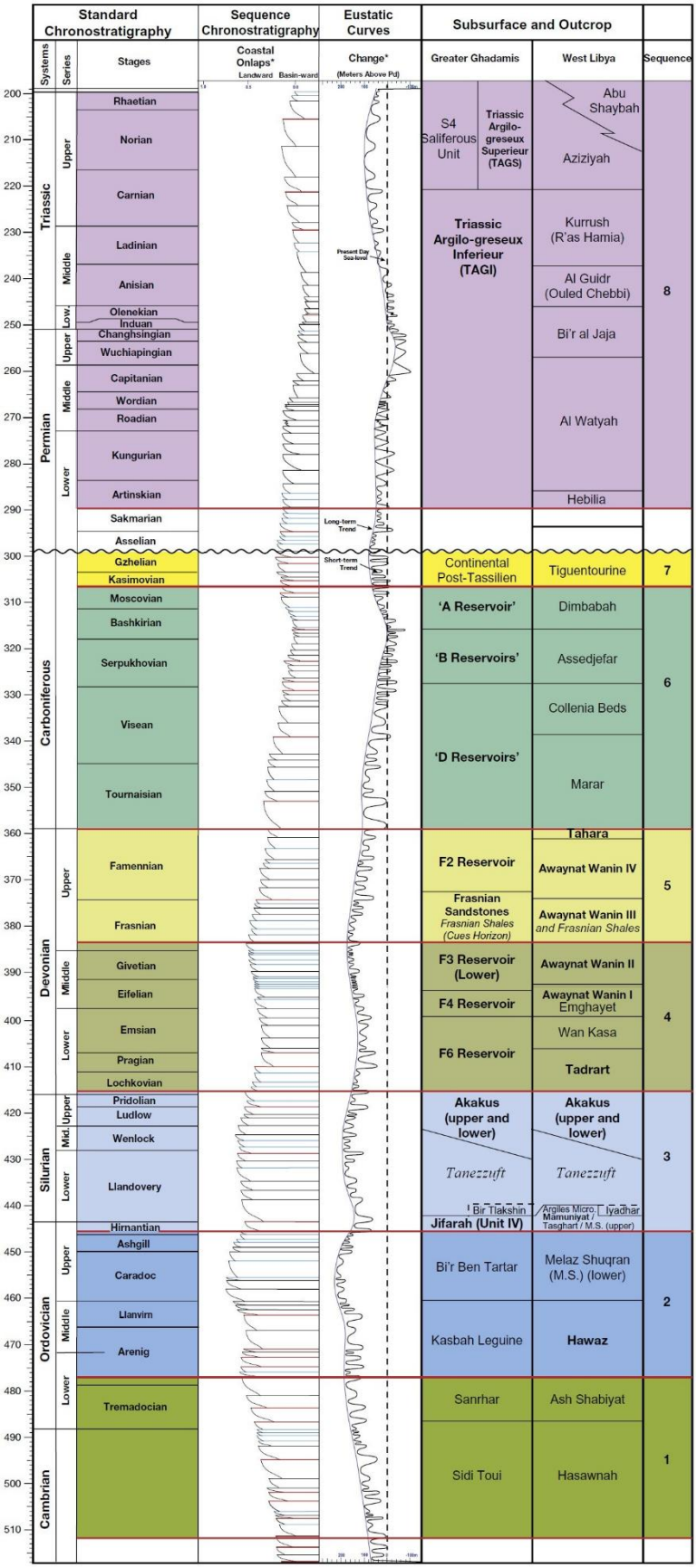

Figure 1. Time stratigraphic chart of west Libya (bold lettering indicates petroleum reservoir; italic script indicates source rock) (after [19-21]).

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Previous Work

With the exception of wells B1-23 and Q1-23, there have been numerous prior geochemical studies of the Hot Shale Member in many wells in the Ghadames and Murzuq basins [7-18].

Methods

In this study, geochemical data provided by Sirte Oil Company were used. The following steps were followed in order to complete the current work:

(1) Seventeen cutting shale samples were selected from wells B1-23 (at depths 4595.28 to 4733ft) and Q1-23 (at depths 9652 to 9773.62ft).

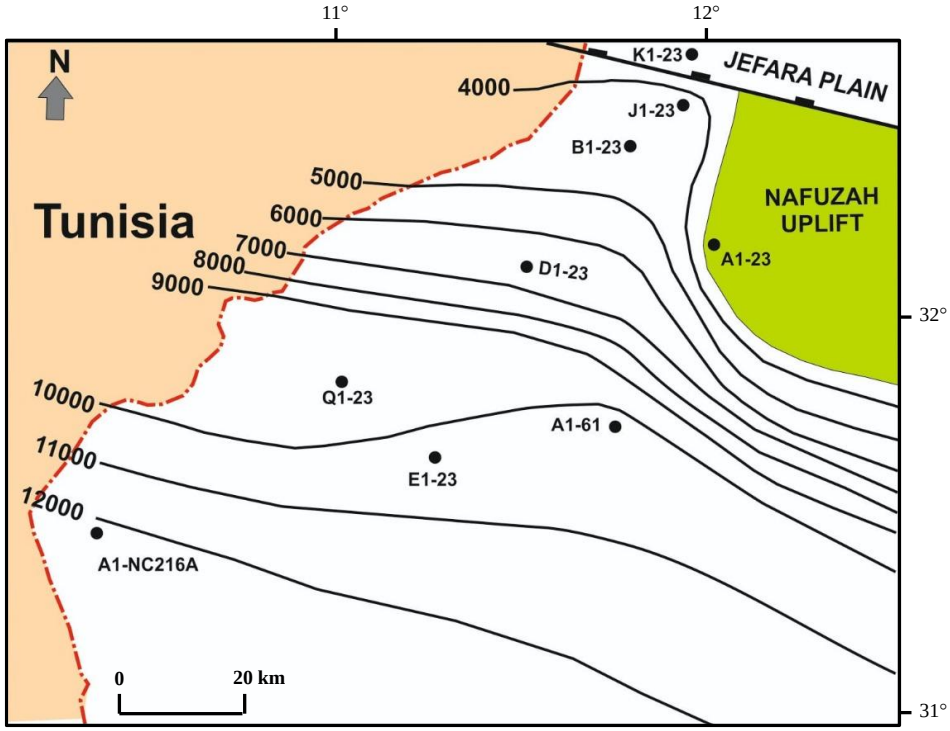

Figure 2. Location map of wells B1-23, Q1-23J1-23, A1-61, and E1-23.

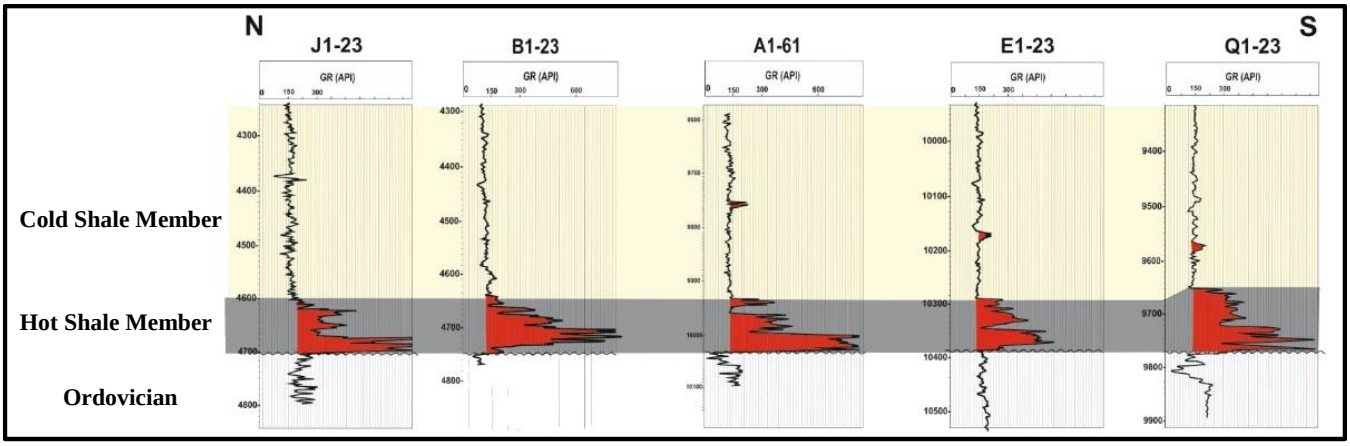

Figure 3. Regional correlation of gamma-ray profiles through the Hot Shale Member in five wells in the Ghadames Basin.

(2) The HAWK Pyrolysis was used to determine the values of TOC, S1, S2, S3, T_{max}, Ro, HI, OI, PI, CaCO3, CC, AI, GOC, NGOC, OSI, and PCI.

(3) Four distinct HAWK pyrolysis heating rates (5, 10, 15, 25, and 50 °C/min) were used to analyze the entire rock samples for bulk kinetics modeling. The bulk kinetic model, which consists of a single frequency factor and an activation energy distribution, uses the produced bulk petroleum formation curves as input. Kinetics 2015 software is being used.

(4) Statistical treatment was carried out using the SPSS© program.

(5) The TOC, HI, and T_{max} maps were drawn using the ArcMap 10.5 program.

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RESULTS AND DISCUSSION

Statistical Treatment

The data obtained from the HAWK pyrolysis technique are listed in Tables 1 and 2. The statistical treatment included descriptive statistics (Table 3), correlation matrix (Table 4), principal component analysis (Table 5 and Fig. 4), and cluster analysis (Fig. 5 and Table 6).

Table 1. HAWK pyrolysis data of the Hot Shale Member in wells B1-23 and Q1-23

Well ID	Sample ID	Depth (ft)	TOC	S1	S2	S3	PP	OI	HI	T_{max}
Q1-23	2942-9652	9652	1.05	0.38	2.38	0.12	2.76	11	225	441
	2951-9682	9682	3.87	3.14	22.4	0.6	25.5	15	578	439
	2954-9691	9691	1.71	0.74	4.84	0.37	5.58	21	283	440
	9692	9692	1.89	0.79	5.58	0.49	6.37	25	294	440
	2964-9724	9724.4	9.94	5.15	23.4	1.24	28.6	12	235	439
	9744	9744	11.07	2.64	23.9	1	26.5	9	215	437
	2976-9763	9763	4.4	1.23	9.23	0.81	10.5	18	209	437
	9764	9764	4.19	1.33	10	0.67	11.3	16	238	439
	2979-9773	9773.62	6.84	1.59	8.64	2.87	10.2	41	126	430
B1-23	1401-07	4595.28	2.16	0.43	6.88	0.6	7.31	27	317	432
	1410-16	4625	2.26	0.57	6.47	0.32	7.04	14	286	432
	1419-25	4654.32	3.48	0.93	12.9	0.35	13.8	10	369	431
	4674	4674	2.47	1.35	19.6	0.51	21	21	794	425
	1428-34	4683.84	11.91	3.05	59.1	0.95	62.1	8	495	428
	1434	4703.52	9.75	3.29	60.1	1.15	63.4	11	615	423
	1437-43	4713.36	12.39	4.13	73.5	1.99	77.7	16	593	421
	4733	4733	5.34	0.84	28.3	1.38	29.2	26	531	417

Table 2. HAWK pyrolysis data of the Hot Shale Member in wells B1-23 and Q1-23

Well ID	Ro	AI	$CaCO_3$	CC	GOC	PI	NGOC	OSI	PCI
Q1-23	0.78	0.86	3	0.36	0.26	0.14	0.79	36.2	2.29
	0.74	3.17	39.8	4.77	2.21	0.12	1.66	81.1	21.2
	0.76	1.4	6.92	0.83	0.5	0.13	1.21	43.3	4.63
	0.76	1.55	19.8	2.38	0.57	0.12	1.32	41.8	5.29
	0.74	8.15	6.33	0.76	2.48	0.18	7.47	51.8	23.7
	0.71	9.08	7.68	0.92	2.3	0.1	8.77	23.9	22
	0.71	3.61	6.2	0.74	0.93	0.12	3.47	28	8.68
	0.74	3.43	10.78	1.29	1	0.12	3.18	31.7	9.41
	0.58	5.61	2.21	0.26	1	0.16	5.84	23.3	8.49
B1-23	0.62	1.77	3.06	0.37	0.65	0.06	1.51	19.9	6.07
	0.62	1.86	3.34	0.4	0.62	0.08	1.64	25.2	5.84
	0.6	2.86	8.39	1	1.19	0.07	2.29	26.7	11.5
	0.5	2.03				0.06		54.7	17.4
	0.54	9.77	12.6	1.51	5.33	0.05	6.58	25.6	51.6
	0.5	8	55.6	6.67	5.46	0.05	4.29	33.7	52.6
	0.42	10.2	70	8.4	6.71	0.05	5.69	33.3	64.5
	0.3	4.38				0.03		15.7	24.2

(AI = adsorption index; $CaCO_3$ = calcium carbonate equivalent (wt%); CC = carbonate carbon (wt%); GOC = generative organic carbon; HI = hydrogen index (mg/g); NGOC = non-generative organic carbon; OI = oxygen index (mg/g); OSI = oil saturation index; PCI = pyrolyzable carbon index (mg/g); PI = production index; PP = petroleum potential (mg/g); Ro = vitrinite reflectance (wt%); S1 = quantity of free hydrocarbons (mg/g); S2 = quantity of thermally generated (cracked) hydrocarbons (mg/g); S3 = quantity of CO_2 generated during pyrolysis (mg/g); T_{max} = temperature at which maximum rate of generation of hydrocarbons occurs (^oC); TOC = total organic carbon (wt%))

The descriptive statistics show that there is a large variation in the values of analyzed parameters. This large range indicates a variation in the organic richness, petroleum potential, and thermal maturity as well as the presence of different kerogen types. In the correlation matrix, S1 and S2 have positive correlations with TOC (r = 0.83 and 0.82, respectively), which indicates the influence of S1 and S2 from TOC. Moreover, the weak

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negative correlation shown by T_{max} and Ro with TOC (r = −0.39 and −0.37, respectively) suggests that thermal maturity is unaffected by the amount of organic matter.

Table 3. Descriptive statistics of the analyzed parameters

Parameters	N	Minimum	Maximum	Mean
TOC	17	1.05	12.4	5.57
S1	17	0.38	5.15	1.86
S2	17	2.38	73.5	22.2
S3	17	0.12	2.87	0.91
PP	17	2.76	77.7	24
OI	17	8	41	17.7
HI	17	126	794	377
T_{max}	17	417	441	432
Ro	17	0.3	0.78	0.62
AI	17	0.86	10.2	4.57
$CaCO_3$	15	2.21	70	17.1
CC	15	0.26	8.4	2.04
GOC	15	0.26	6.71	2.08
PI	17	0.03	0.18	0.1
NGOC	15	0.79	8.77	3.71
OSI	17	15.7	81	34.5
PCI	17	2.29	64	20

Table 4. Correlation matrix of the analyzed parameters

	TOC	S1	S2	S3	OI	HI	T_{max}	Ro	AI	$CaCO_3$
TOC	1.00									
S1	0.83	1.00								
S2	0.82	0.71	1.00							
S3	0.61	0.44	0.42	1.00						
OI	-0.30	-0.37	-0.35	0.50	1.00					
HI	0.17	0.27	0.61	-0.04	-0.18	1.00				
T_{max}	-0.39	-0.14	-0.64	-0.46	-0.15	-0.65	1.00			
Ro	-0.37	-0.11	-0.61	-0.47	-0.19	-0.63	0.99	1.00		
AI	1.00	0.83	0.82	0.61	-0.31	0.17	-0.39	-0.37	1.00	
$CaCO_3$	0.37	0.35	0.69	0.33	-0.01	0.84	-0.72	-0.72	0.37	1.00

The principal component analysis yielded three components. A simplified explanation of these components is given below:

First principal component (PC1): It is the most potent component, making up roughly 59.61% of the variables. Positive loading is seen for TOC, S1, S2, PP, HI, AI, $CaCO_3$, CC, GOC, and PCI in this component. Furthermore, it loads negatively for T_{max} and Ro. This component appears to be important for interpreting the organic richness, petroleum potential, thermal maturity and kerogen type.

Second principal component (PC2): 15.62% of all variables are accounted for by this component. Positive loading is evident for S3 and NGOC. HI exhibits negative loading. It seems that this component is also essential to comprehending the kerogen type.

Third principal component (PC3): This component clarifies 12.8% of all variables. For OSI, negative loading is obvious. This component is essentially irrelevant.

The dendrogram cluster analysis divided the TOC content into three different groups, while the division of the rest of the source rock properties is unclear. Below is a description of the three TOC groups:

Group I: The samples of this group have the lowest TOC content (1.05-2.47%).

Group II: Compared to Group I, this group contains more TOC content (3.48-6.84%).

Group III: The highest TOC content (9.75-12.39%) is found in this group.

Table 5. Principal component analysis of the analyzed parameters

Eigenvalues	10.13	2.65	2.18
% of Variance	59.61	15.62	12.80
Cumulative %	59.61	75.22	88.03

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Principal components	PC1	PC2	PC3
TOC	0.87	0.44	0.15
S1	0.77	0.24	0.55
S2	0.99	-0.07	0.01
S3	0.50	0.66	-0.12
PP	0.99	-0.05	0.05
OI	-0.32	0.34	-0.34
HI	0.75	-0.62	0.06
T_{max}	-0.80	0.01	0.55
Ro	-0.80	-0.02	0.56
AI	0.87	0.44	0.15
$CaCO_3$	0.79	-0.43	0.11
CC	0.79	-0.43	0.11
GOC	0.99	-0.04	0.04
PI	-0.56	0.45	0.58
NGOC	0.59	0.74	0.20
OSI	-0.01	-0.40	0.82
PCI	0.99	-0.05	0.05

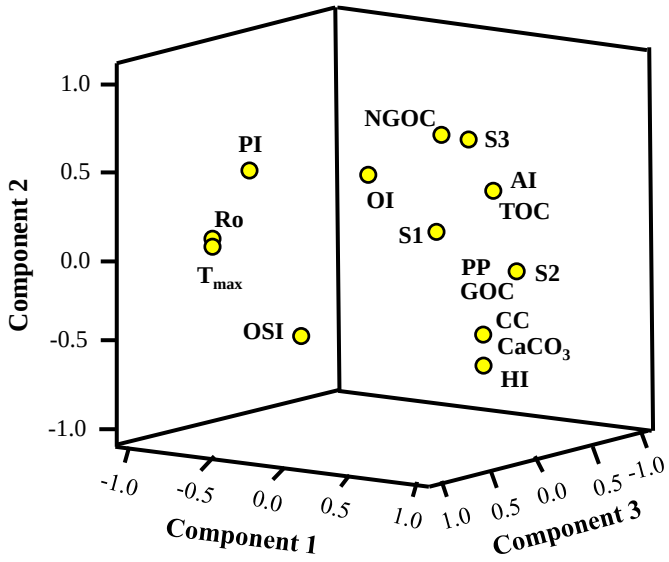

Figure 4. Plot of PC loadings of the analyzed parameters.

Organic Richness

Petroleum should be produced in proportion to the amount of organic richness in the source rock since it is a byproduct of the organic matter that are distributed in the source rock [22]. The TOC content of sedimentary rocks is a crucial criterion for assessing their organic richness because it is a prerequisite for the production of oil or gas [23]. Peters and Cassa [24] categorized the organic richness into five classes based on the TOC content: (1) Poor (TOC ranges from 0 to 0.5%); (2) Fair (TOC ranges from 0.5 to 1%); (3) Good (TOC ranges from 1 to 2%); (4) Very good (TOC ranges from 2 to 4%); and (5) Excellent (TOC>4%). The TOC values (1.05-12.39%) indicate that the organic richness of the Hot Shale Member ranges from good to excellent. This hypothesis is confirmed by the binary plot of TOC versus PP (Fig. 6). The TOC map is shown in Fig. 7.

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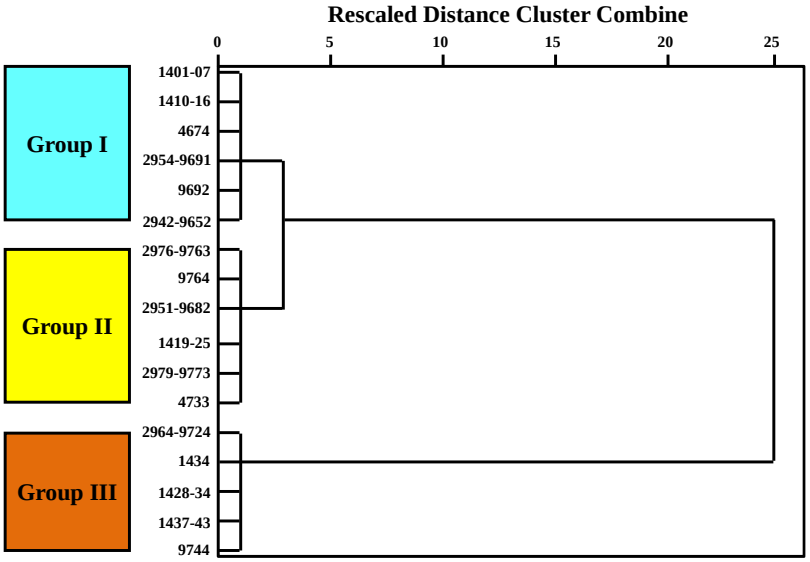

Figure 5. Dendrogram from cluster analysis (Ward method) of the analyzed parameters.

Table 6. Cluster analysis of the analyzed parameters

Parameters	Group I	Group II	Group III
TOC	1.05-2.47	3.48-6.84	9.75-12.4
S1	0.38-1.35	0.84-3.14	2.64-5.15
S2	2.38-19.6	8.64.28.3	23.4-73.5
S3	0.12-0.6	0.35-2.87	0.95-1.99
PP	2.76-21	10.2-29.1	26.5-77.7
OI	11-27	10-41	8-16
HI	225-794	126-578	215-615
T_{max}	425-441	417-439	421-439
Ro	0.5-0.78	0.3-0.74	0.42-0.74
AI	0.86-2.03	2.86-5.61	8-10.2
$CaCO_3$	3-19.8	2.21-39.8	6.33-70
CC	0.36-2.38	0.26-4.77	0.76-8.4
GOC	0.26-0.65	0.93-2.21	2.3-6.71
PI	0.06-0.14	0.03-0.16	0.05-0.18
NGOC	0.79-1.64	1.66-5.84	4.29-8.77
OSI	19.9-54.7	15.7-81.1	23.9-51.8
PCI	2.29-17.4	8.49-24.2	22-64.5

Kerogen Type

The portion of organic matter found in sedimentary rocks known as kerogen is insoluble in typical organic solvents. Kerogens are composed of various organic matter [22]. Based on the HI values, Peters and Cassa [24] classified kerogen into five classes: (1) Type I (HI>600 mg/g); (2) Type II (HI ranges from 300 to 600 mg/g); (3) Type II-III (HI ranges from 200 to 300 mg/g); (4) Type III (HI ranges from 50 to 200 mg/g); and (5) Type IV (HI<50 mg/g). In the Hot Shale Member, the presence of various kerogen types, including types I, II, and III, is indicated by the HI values (126-794 mg/g). The binary plots of OI versus HI (Fig. 8), TOC versus S2 (Fig. 9), and T_{max} versus HI (Fig. 10) provide additional evidence for this assumption. Fig. 11 shows the HI map.

Indigeneity

Hydrocarbons in source rocks are classified into: (1) Indigenous hydrocarbons; and (2) Nonindigenous hydrocarbons. The S1/TOC ratio has been used to determine the type of hydrocarbons. Values below 1.5 are thought to represent indigenous hydrocarbons, while values above 1.5 are indicative of nonindigenous hydrocarbons [25]. In the Hot Shale Member, the S1/TOC ratio ranges from 0.16 to 0.81, indicating the dominance of indigenous hydrocarbons. The binary plot of TOC versus S1 (Fig. 12) supports this hypothesis.

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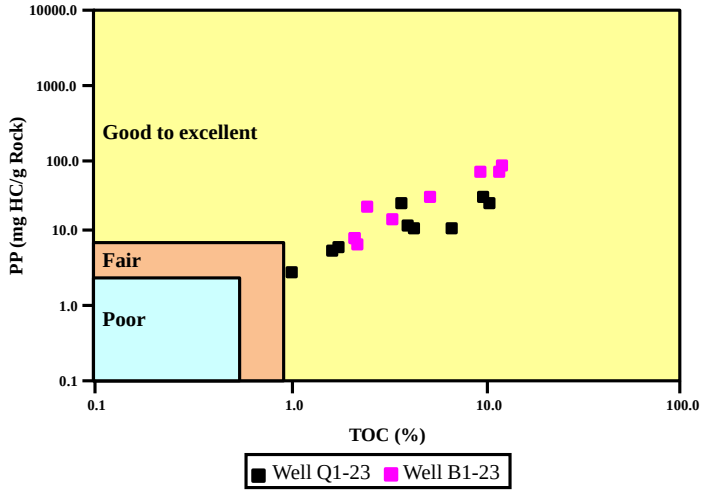

Figure 6. Binary plot of TOC vs. PP showing the organic richness of the Hot Shale Member (fields after [22]).

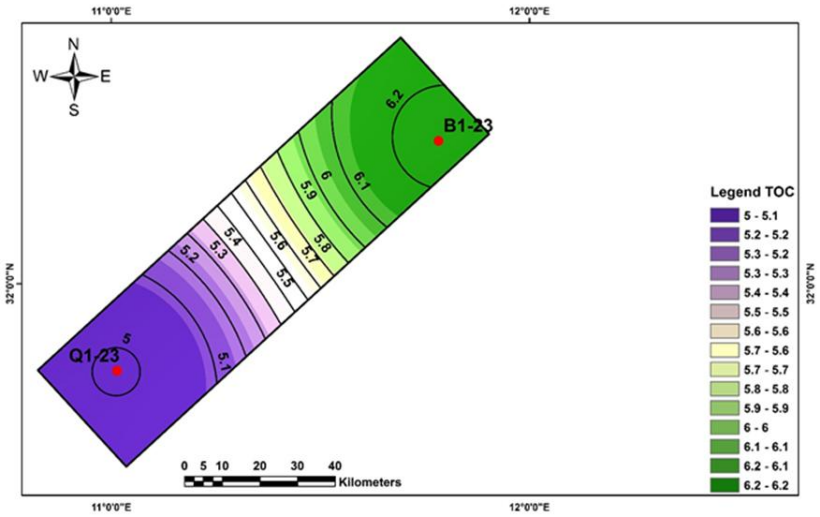

Figure 7. TOC map between the studied wells.

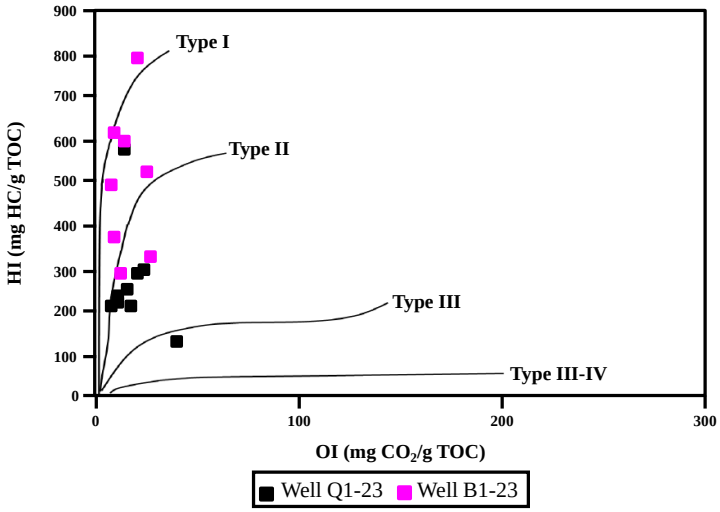

Figure 8. Binary plot of OI vs. HI showing the kerogen type for the Hot Shale Member (fields after [26]).

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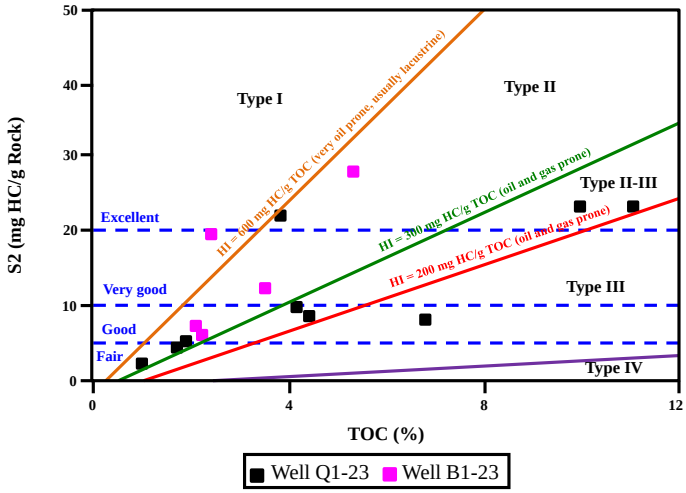

Figure 9. Binary plot of TOC vs. S2 showing the kerogen type for the Hot Shale Member (fields after [27]).

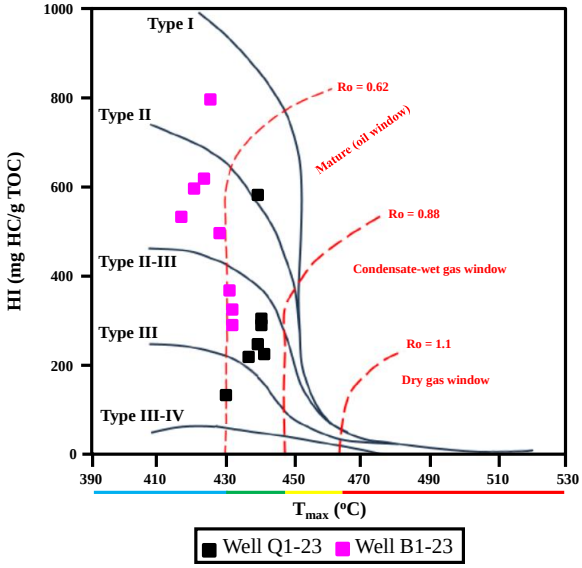

Figure 10. Binary plot of T_{max} vs. HI showing the kerogen type and thermal maturity for the Hot Shale Member (fields after [28]).

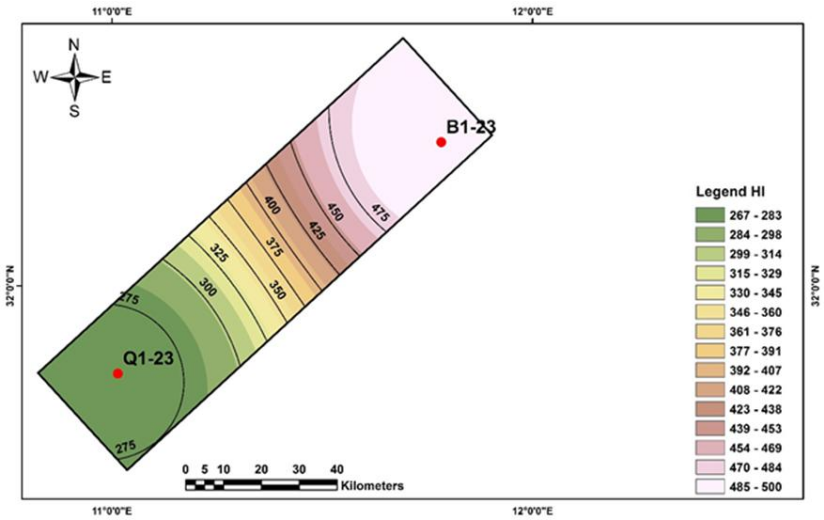

Figure 11. HI map between the studied wells.

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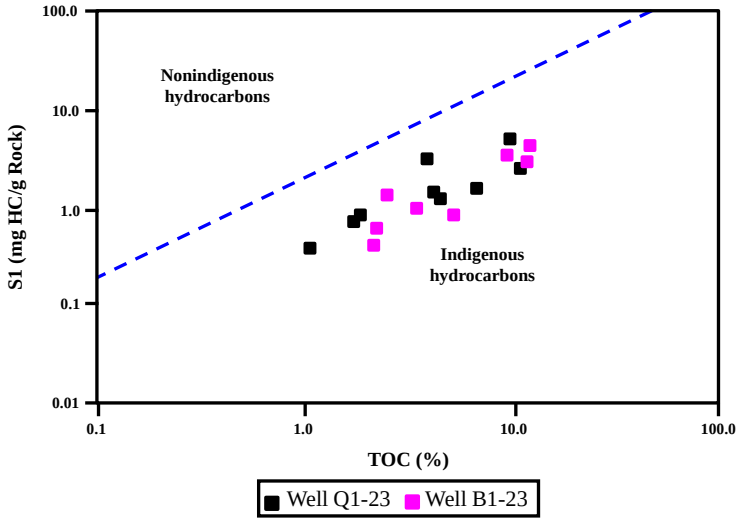

Figure 12. Binary plot of TOC vs. S1 showing the hydrocarbon type in the Hot Shale Member (fields after [25]).

Thermal Maturity

Thermal maturity refers to how much the chemical composition of organic matter is altered by heat reactions. Source rock maturation, reservoir diagenesis, and porosity development are all influenced by thermal maturity and burial history [29]. Numerous parameters, such as T_{max} and Ro can be used to assess the degree of thermal maturity of organic matter [24]. Based on the values of T_{max} and Ro, Peters and Cassa [24] identified six grades of maturity (Table 7). The binary plots of T_{max} versus HI (Fig. 10), T_{max} versus Ro (Fig. 13), and PI versus T_{max} (Fig. 14) indicate that most of the samples of well B1-23 contain immature organic matter, while mature organic matter predominate in the samples of well Q1-23. The values of Tmax (417-441 °C) and Ro (0.3-0.78%) support the aforementioned assumption. Fig. 15 presents the T_{max} map.

Table 7. Geochemical parameters characterizing the degree of thermal maturity (after [24])

Degree of thermal maturity	Ro (%)	T_{max} (°C)
Immature	0.2-0.6	<435
Early mature	0.6-0.65	435-445
Peak mature	0.65-0.9	445-450
Late mature	0.9-1.35	450-470
Postmature	>1.35	>470

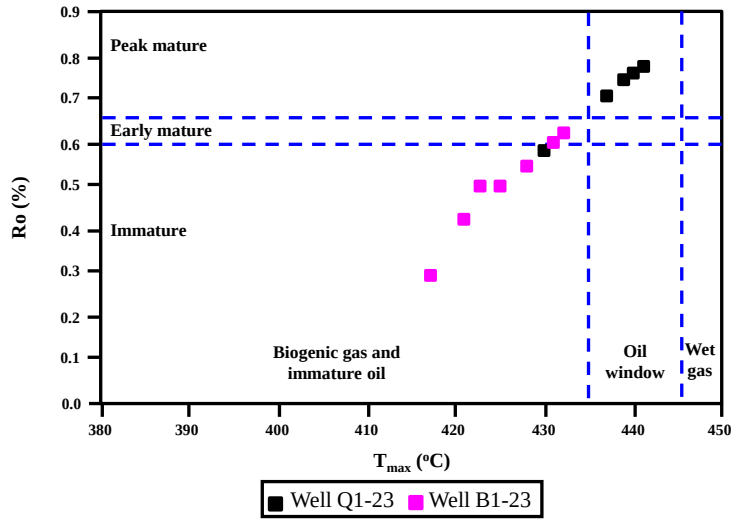

Figure 13. Binary plot of T_{max} vs. Ro showing the thermal maturity for the Hot Shale Member (fields after [30]).

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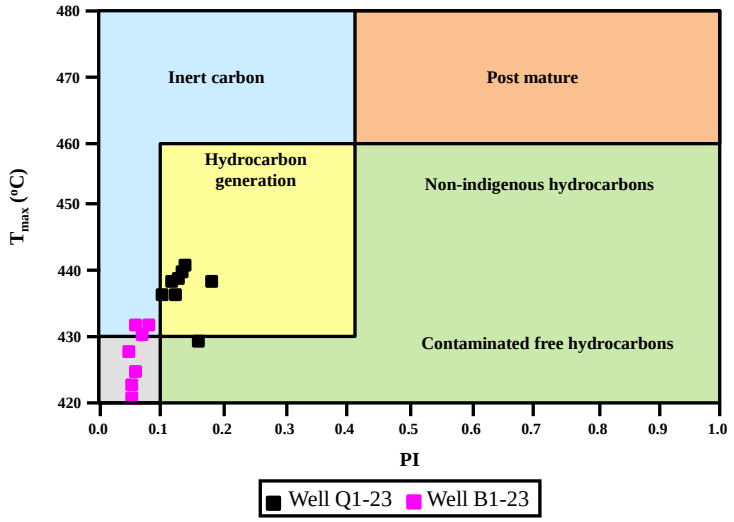

Figure 14. Binary plot of PI vs. T_{max} showing the thermal maturity for the Hot Shale Member (fields after [31]).

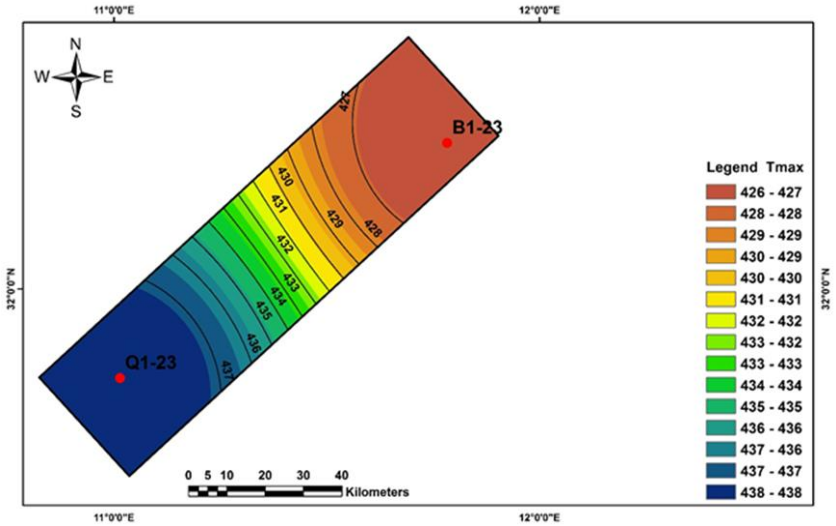

Figure 15. T_{max} map between the studied wells.

Petroleum Potential

As mentioned previously in this work, the Hot Shale Member contains different types of kerogen in addition to variations in TOC content and levels of thermal maturity. These findings suggest that the Hot Shale Member has a range of petroleum potential. The binary plot of TOC versus HI (Fig. 16) provides additional support for this hypothesis.

Kinetic Parameters

Kerogen reactivity, which regulates the depth and temperature of oil and gas generation windows as well as the onset and rate of hydrocarbon generation, is reflected in source rock kinetics. Consequently, knowing source rock kinetics is essential for determining production sweet spots as well as quantitative resource modeling [33]. Tables 8 and 9 dis-play the kinetics parameters of the Hot Shale Member. The activation energies (47-84 kcal/mol) are gaussian in shape (Figs. 17 and 18).

CONCLUSION

A geochemical assessment was done of the Hot Shale Member of the Tanezzuft Formation (Early Silurian) in wells B1-23 and Q1-23, Ghadames Basin, NW Libya. The following are the work's conclusions:

(1) The organic richness of the Hot Shale Member ranges from good to excellent.
(2) The Hot Shale Member holds kerogens of types I, II, and III.
(3) The Hot Shale Member contains indigenous hydrocarbons.
(4) Mature organic matter predominate in well Q1-23 samples, while immature organic matter are present in the majority of well B1-23 samples.
(5) There is a range of petroleum potential in the Hot Shale Member.
(6) The activation energies are gaussian-shaped.

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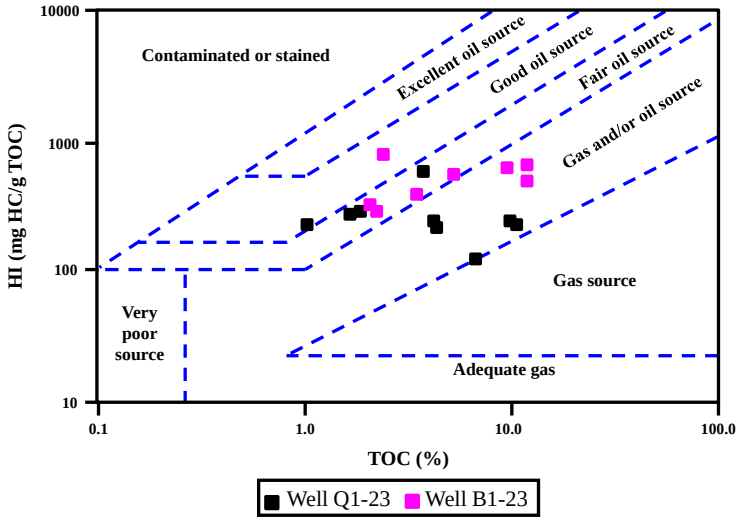

Figure 16. Binary plot of TOC vs. HI showing the petroleum potential for the Hot Shale Member (fields after [32]).

Table 8. Kinetics parameters of the Hot Shale Member in well Q1-23

Percent	Activation energy (cal/mol)
1.15	84000
1.63	49000
1.42	50000
0.00	51000
2.14	52000
49.15	53000
8.37	54000
25.74	55000
0.00	56000
0.00	57000
10.40	58000
Frequency factor = 1000E+14 s^-2	

Table 9. Kinetics parameters of the Hot Shale Member in well B1-23

Percent	Activation energy (cal/mol)
1.03	47000
0.87	48000
1.02	49000
0.00	50000
10.25	51000
47.06	52000
14.27	53000
14.64	54000
4.70	55000
1.96	56000
4.19	57000
Frequency factor = 1000E+14 s^-2	

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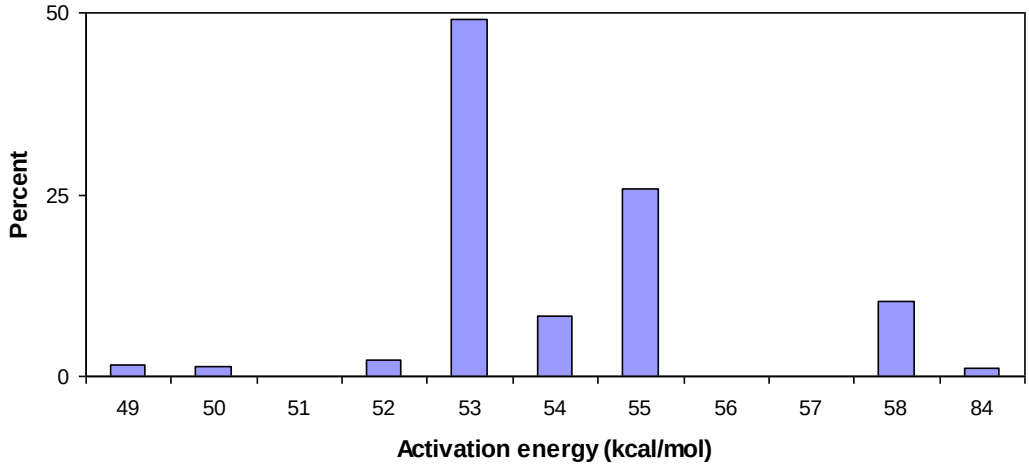

Figure 17. Activation energies of the Hot Shale Member in well Q1-23.

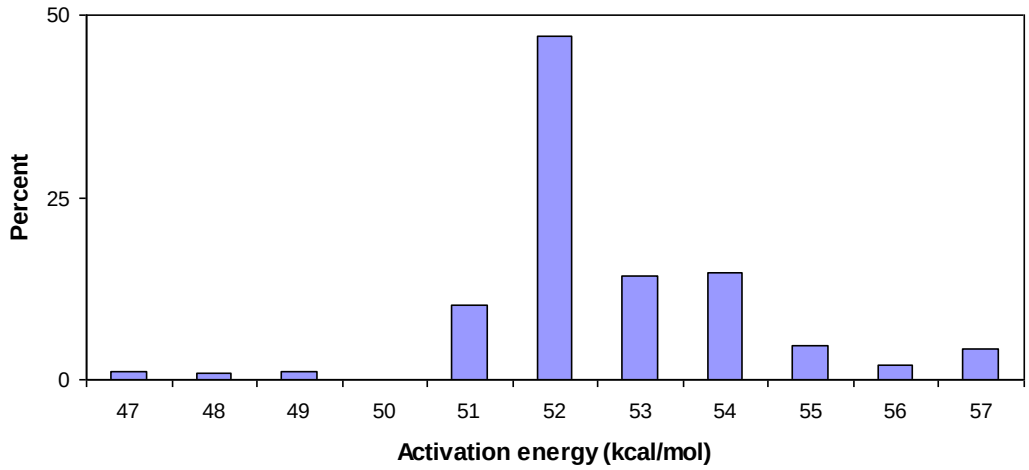

Figure 18. Activation energies of the Hot Shale Member in well B1-23.

Recommendation

Large reserves of unconventional hydrocarbons, such as shale gas and shale oil, are found in Libya. The Hot Shale Member is considered one of the unconventional reservoirs in Libya. The formation of shale oil and shale gas depends on several factors, including high TOC content and high thermal maturity. The current study showed that both of the previous factors are available in the Hot Shale Member in wells B1-23 and Q1-23. Therefore, the authors recommend conducting an analysis of biomarkers to evaluate unconventional hydrocarbons in the studied wells.

Acknowledgments

The authors are grateful to Sirte Oil Company, Libya, for providing the data. Special thanks to the geochemical laboratory that prepared and analyzed the samples.

Conflicts of Interest

Declare conflicts of interest or state “The authors declare no conflicts of interest.” Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results.

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المستخلص

العمل الحالي هو تقييم للصخور المصدرية لعضو الصخر الزيتي الساخن في تكوين تنزفوت (السيلوري المبكر) باستخدام البيانات التي تم الحصول عليها من الآبار B1-23 وQ1-23 ، حوض غدامس، شمال غرب ليبيا. البيانات الجيوكيميائية التي تم الحصول عليها من تحليل أداة HAWK التي أجرتها شركة سرت للنفط على عدد من عينات الصخر الزيتي التي تمثل عضو الصخر الزيتي الساخن. من حيث الثراء العضوي، يقع عضو الصخر الزيتي الساخن بين الجيد والممتاز بناءً على قيم TOC (1.05-12.39٪).يدعم الرسم البياني الثنائي لـ TOC مقابل PP هذا الافتراض. من حيث نوع الكيروجين، تُظهر قيم HI (126-794 مجم / جم) وجود أنواع مختلفة من الكيروجين، مثل الأنواع I و II و III. تقدم المخططات الثنائية لـ Tmax مقابلHI ، و TOCمقابلS2 ، و OI مقابل HI المزيد من الأدلة على هذه الفرضية. من حيث الأصالة، تشير نسبة S1/TOC (0.16-0.81) إلى هيمنة الهيدروكربونات الأصلية. ويعطي الرسم البياني الثنائي لـ TOC مقابل S1 مصداقية لهذا الافتراض. ومن حيث النضج الحراري، تشير قيم Tmax (417-441 درجة مئوية) وRo (0.3-0.78٪)، والرسوم البيانية الثنائية لـ Tmax مقابلHI ، و TmaxمقابلRo ، و PIمقابل Tmax إلى أن عينات البئر Q1-23 تحتوي في المقام الأول على مادة عضوية ناضجة، في حين تحتوي غالبية عينات البئر B1-23 على مادة عضوية غير ناضجة. ومن حيث إمكانات البترول، يُظهر عضو الصخر الزيتي الساخن مجموعة متنوعة من إمكانات البترول، كما هو موضح في الرسم البياني الثنائي لـ TOC مقابل HI. ومن حيث المعلمات الحركية، فإن طاقات التنشيط (47-84 كيلو كالوري/مول) لها شكل غاوسي.

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