

Organic Geochemistry and Source Rock Potential of Naokelekan Formation in Selected Wells, North Iraq

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Abstract

In this study, organic geochemical characteristics and potential of Upper Oxfordian–Lower Kimmeridgian aged bituminous shale beds in Naokelekan formation (North Iraq) were investigated by using TOC and pyrolysis analyses. The Total Organic Carbon (TOC) contents for the studied samples varying between from 0.46–21.33%, average 7.06% and Taq Taq-1 well as good hydrocarbon potential (0.85–1.66 %, with average of 1.06%), whereas Jk-1 well can be rated as an very good hydrocarbon potential from 1.04–4.16 %, with average of 2.15 %. The low Hydrogen Index (HI = 24–605 mg HC/g TOC) for Bj-1 well, (HI = 147–673 mg HC/g TOC) in the Jk-1 well while in Taq Taq-1 well (HI = 9–48 mg HC/g TOC) indicate that kerogen type for the vast majority of the studied samples is Type II/I for Bj-1 well and Type IV with few samples, Type of I and II kerogens in the Taq Taq-1 and Jk-1 well. Consequently most of the organic matter of Bj-1 and Jk-1 well tends to generate petrol, even though a small portion of them exhibit a tendency to generate gas. While all samples of Taq Taq-1 well tends to generate gas. The studied bituminous rock samples characterized by low T_{max} (434–602 °C) for Bj-1, Taq Taq-1 (344–429 °C) and (419–602 °C) for Jk-1 well. These values show, in terms of potential of hydrocarbon generation, that the studied samples have a source rock potential of organic matter from immature to over mature. Additionally, the S_1 hydrocarbon type values indicate no external contribution of migrated hydrocarbons to the bituminous rocks of the studied area.

Keywords: Soruce rock, Rock Eval, Kerogen, Naokelekan formation, North Iraq.

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Ethical: This study follows all ethical practices during writing.

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1. Introduction

Rock-Eval pyrolysis has been a widely used method in organic geochemistry tool for examining the oil and gas potential and maturity of different rock samples. The available information concerning the TOC content, thermal maturation, and burial history are seriously required for better understanding of the existence of other hydrocarbon resources [1]. The dominant organic matter in oil shales is derived from one or more primary sources, the terrestrial plants, lacustrine algae and marine organisms. These include large lake basins of tectonic origin, small lakes, lagoons and shallow seas [2].

Naokelekan Formation one of the most important source rocks in Iraq. The Formation crops out mainly within the High Folded Zone of northern Iraq. Additionally, it is found within drilled oil wells of Low Folded Zone in Iraq Such as at Taq Taq, Jabal Kand and Biji oil fields.

50 core and cutting Samples from Naokelekan formation has been collected from Bj-1, Taq Taq-1 and Jk-1 wells and have been sent to Turkish TPAO Research Center / Petroleum Geochemistry Department (Ankara) to determine hydrocarbon potential for these samples by Rock Eval analysis, TOC (Total Organic Carbon) analysis and S1, S2, S3, Tmax, Oxygen Index, Hydrogen Index results for three wells.

2. Geological Settings

Oil Fields within the northern Iraq coincide with part of the Zagros Fold Belt and regionally extends within an elongated folded zone between the thrust zone in a triple junction boundary between Iran and Turkey with Iraq. Also, it extends towards the Mesopotamian Foredeep with Khleisya uplift towards the southwestern part of northern Iraq; well locations are plotted on location map of (Fig.1) Locating this studied area is according to Buday [3]; Al-Sharhan and Nairn [4]; Sharland, et al. [5]; Aqrabi, et al. [6] and the Arabian Peninsula Basins map prepared by the US Geological Survey [7].

Tectonically, Iraq lies in the border area between the Arabian part of the African (Nubian-Arabian) Platform and the Asian branches of the Alpine Geosyncline. The platform of Iraqi territory is divided into two basic units, the Stable and Unstable Shelf. The Stable Shelf is characterized by reduced thickness of sedimentary cover and by the lack of folding. The Unstable Shelf has thick and folded sedimentary cover [3].

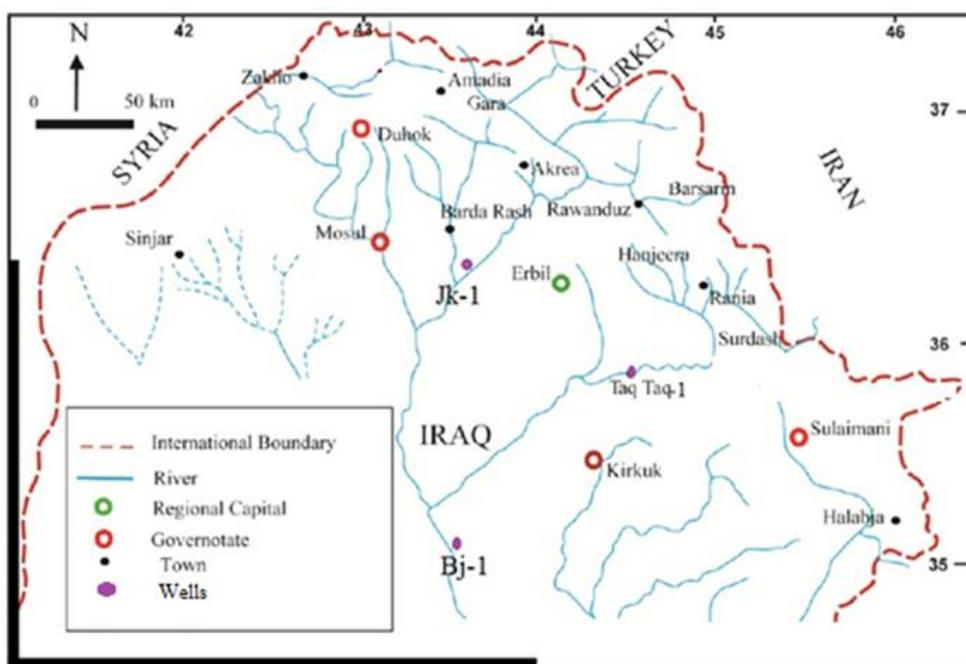


Fig-1. Location map of Iraq showing studied area of North Iraq with locations of oil exploration wells

Stratigraphically, Naokelekan Formation consists of laminated bituminous limestone, alternated with bituminous shale (coal horizon) and thin bedded, highly bituminous dolomite and limestone. Formation age is assigned as Upper Oxfordian–Lower Kimmeridgian according to the study of ammonites of the Upper Jurassic [8]. The depositional environment of the formation was interpreted as euxinic in a slow subsiding basin [3].

3. Materials and Methods

A total of 50 oil shale samples of the Naokelekan Formation were collected from 3 wells (Bj-1, Taq Taq-1 and Jk-1). These samples were crushed, pulverized and then homogenized. Rock-Eval pyrolysis was conducted using the Rock-Eval 6 analyzer manufactured by Vinci Technologies at the Geochemistry Laboratories of the Turkish Petroleum Corporation (TPAO). The analysis yielded several parameters, including S1, S2, S3, TOC and Tmax (Tables 1, 2, 3). Rock-Eval pyrolysis was conducted using the Rock-Eval 6 analyzer manufactured by Vinci Technologies at the Geochemistry Laboratories of the Turkish Petroleum Corporation (TPAO). The analysis yielded several parameters, including S1, S2, S3, TOC and Tmax (Tables 1, 2, 3).

Table-1. Rock-Eval pyrolysis data are tabulated for the Naokelekan Formation in the Bj-1 well, North Iraq

NO	Depth M	TOC %	S1 (mg HC/g Rock)	S2 (mg HC/g Roc)	S3 (mg HC/g Rock)	PI	Tmax	HI, mg HC/g TOC	OI, mg CO ₂ /g TOC
1	2383	1	0.77	4.19	0.61	0.15	434	419	61
2	2384	1.11	0.83	4.55	0.38	0.15	434	410	34
3	2385	3.05	2.33	18.49	0.78	0.11	435	605	26
4	2386	2.88	1.17	10.5	0.72	0.1	435	365	25
5	2387	1.99	0.57	5.45	0.84	0.09	430	278	42
6	2388	1.12	0.4	3.78	0.66	0.1	435	338	59
7	2389	0.46	0.24	0.96	0.39	0.2	426	209	85
8	2391	5.26	0.99	24.47	1	0.04	441	465	19
9	2392	5.44	1.14	19.49	1.07	0.06	438	358	20
10	2393	2.26	0.68	8.15	0.77	0.08	438	361	34
11	2394	0.92	0.33	2.35	0.5	0.12	431	255	54
12	2401	22.89	2.02	119.72	2.97	0.02	441	523	13
13	2402	15.91	1.66	82.18	2.64	0.02	442	517	17
14	2403	13.64	1.47	68.02	2.87	0.02	441	499	21
15	2404	21.03	1.54	107.79	4.2	0.01	442	513	20
16	2405	19.35	1.36	91.79	3.41	0.01	440	474	18
17	2407	10.37	1.1	47.61	3.61	0.02	441	459	35
18	2409	13.3	1.47	67.92	2.18	0.02	442	511	16
19	2410	13.64	1.3	68.52	1.91	0.02	442	502	14
20	2411	11.96	1.4	64.62	2.08	0.02	442	540	17
21	2412	8.94	1.05	44.05	1.22	0.02	439	493	14
22	2413	6.07	0.86	29.19	1.39	0.03	439	481	23
23	2414	3.59	0.55	16.54	0.87	0.03	439	461	24
24	2432	1.19	0.3	2.07	0.6	0.13	437	174	50
25	2433	1.08	0.4	0.43	0.6	0.48	581	40	56
26	2434	3.39	0.88	1.21	0.83	0.42	583	36	24
27	2435	2.79	0.68	0.92	0.63	0.42	579	33	23
28	2436	7.67	1.09	2.81	0.85	0.28	585	37	11
29	2437	5.58	0.89	1.82	0.94	0.33	584	33	17
30	2438	9.91	1.03	2.91	1.35	0.26	594	29	14
31	2439	9.54	1.03	2.7	1.33	0.28	595	28	14
32	2440	3.42	0.65	0.87	0.88	0.43	597	25	26
33	2441	2.29	0.46	0.56	0.63	0.45	602	24	28

Table-2. Rock-Eval pyrolysis data are tabulated for the Naokelekan Formation in the Taq Taq-1 well, North Iraq

NO	Depth M	TOC%	S1 (mg HC/g Rock)	S2 (mg HC/g Rock)	S3 (mg HC/g Rock)	PI	Tmax	HI, mg HC/g TOC	OI, mg CO ₂ /g TOC
1	2061	1.04	0.35	3.01	0.41	0.11	427	289	39
2	2063	3.65	1.61	16.05	0.82	0.09	429	440	22
3	2068	3.51	2	15.98	0.86	0.11	427	455	25
4	2072	4.16	6.92	28	1.31	0.2	344	673	31
5	2074	1.93	1.03	8.55	0.5	0.11	428	443	26
6	2077	1.4	0.85	4.2	0.75	0.17	423	300	54
7	2078	1.73	0.69	4.33	0.88	0.14	423	250	51
8	2088	1.43	0.52	2.59	1.16	0.17	425	181	81
9	2089	1.11	0.41	1.63	1.29	0.2	425	147	116
10	2090	1.62	0.66	4.8	1.22	0.12	429	296	75

Table-3. Rock-Eval pyrolysis data are tabulated for the Naokelekan Formation in the Jk-1 well, North Iraq

NO	Depth M	TOC%	S1 (mg HC/g Rock)	S2 (mg HC/g Rock)	S3 (mg HC/g Rock)	PI	Tmax	HI, mg HC/g TOC	OI, mg CO ₂ /g TOC
1	3219	0.95	0.1	0.09	0.54	0.51	419	9	57
2	3220	1.22	0.15	0.12	0.54	0.55	433	10	44
3	3221	0.85	0.1	0.27	0.68	0.27	433	32	80
4	3224	0.87	0.29	0.31	0.41	0.49	584	36	47
5	3225	1.04	0.23	0.27	0.89	0.46	595	26	86
6	3226	1.66	0.47	0.43	0.61	0.53	602	26	37
7	3230	0.85	0.32	0.41	0.59	0.44	445	48	69

A Flame Ionization Detector (FID) was used to measure the concentration of organic compounds generated during pyrolysis. The first peak S1 represents hydrocarbons that can be thermally distilled from a rock. The second peak S2 represents hydrocarbons generated by the pyrolytic degradation of the kerogen in the rock. The third peak S3 stands for the carbon dioxide generated during temperature programming up to 390 °C, and is analyzed using a Thermal Conductivity Detector (TCD). The Hydrogen Index (HI) corresponds to the quantity of pyrolyzable organic compounds from S2 relative to the TOC in the samples (mg HC/g TOC) and can be successfully used to assess the oil generation potential of the rock and the type of organic matter.

4. Results and Discussions

Pyrolysis techniques were used to establish the hydrocarbon potential and kerogen type as well as source rock type.

4.1. Organic Matter Richness

Total organic carbon analysis (TOC) describes the quantity of organic carbon in a rock sample including both kerogen and bitumen [9].

TOC of Naokelekan formation for Bj-1 well show an excellent hydrocarbon potential (0.46-21.33%, with an average of 7.06%) and Taq Taq-1 well as good hydrocarbon potential (0.85-1.66 %, with an average of 1.06%), additionally Jk-1 well show very good hydrocarbon potential (1.04-4.16 %, with an average of 2.15 %, Tables 1, 2, 3).

4.2. Organic Matter Types

The term kerogen is to designate organic constituents of sedimentary rocks that are neither soluble in aqueous alkaline solvents nor in the common organic solvents [10].

All organic matter particles generated from phytoplankton, zooplankton, remains of bacteria, and higher plants have been recognized as the main contributors to kerogen in sediments [10]. The minor amounts of substances soluble in organic solvents associated with kerogen are collectively called bitumen.

Based on the Rock-Eval data (Tables 1, 2, 3), source rocks can be characterized using the cross plot of TOC versus Hydrogen Index (HI) [11]. This plot showed that the Naokelekan samples (well Bj-1, Biji Oil field) have a fair to good oil source with mixed gas source. On the other hand, (well Taq Taq-1, Taq Taq Oil field) is a gas source; while well Jk-1 (Jabal Qand Oil field) has a fair oil source (Fig.2).

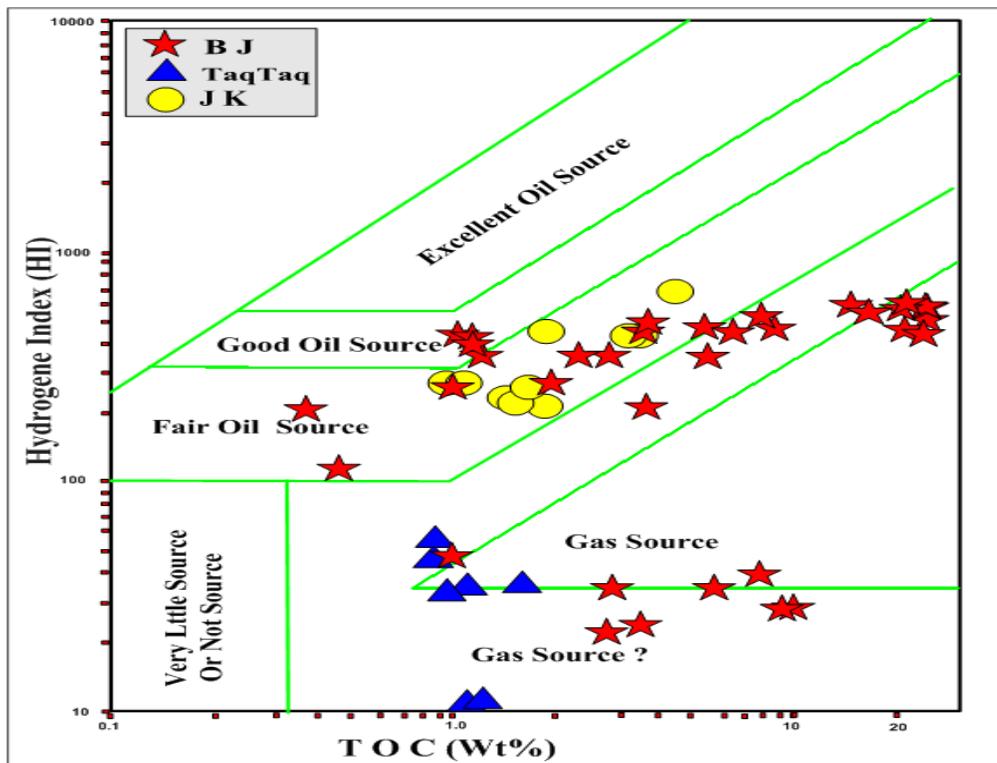


Fig-2. Source rock characterization based on HI versus TOC updated after Jackson, et al. [11]

Furthermore, the cross plot of TOC versus S₂, (Fig.3) indicates that the kerogen of the Naokelekan Formation (well Bj-1), is excellent to poor, Taq Taq-1 well is fair to good and Jk-1 well is refer excellent to fair.

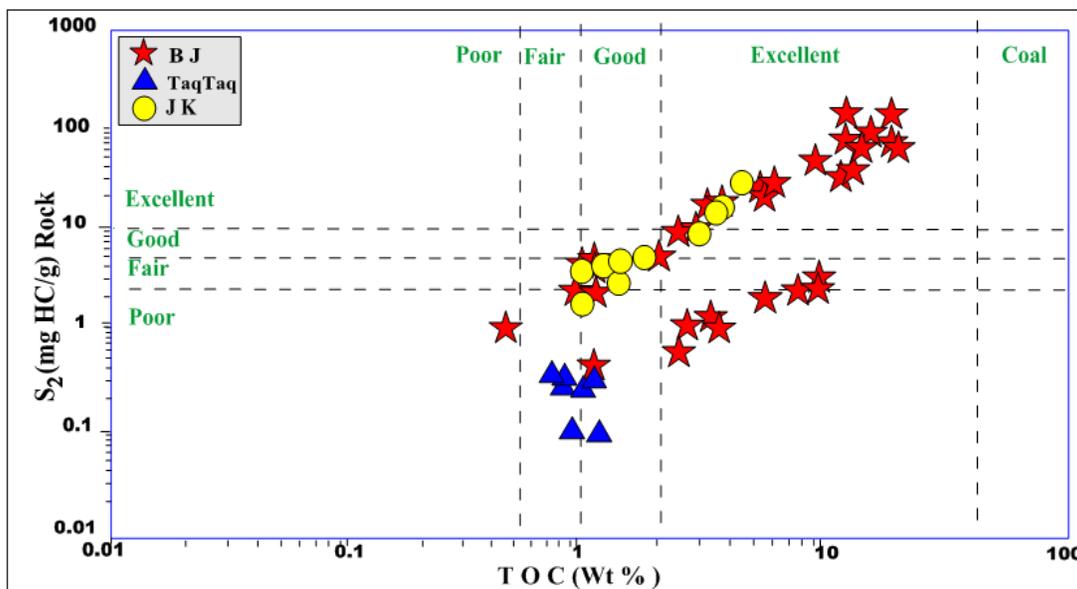


Fig-3. Cross plot of TOCwt% versus S₂, shows the quantity of organic modified after Hunt [12]

The Hydrogen Index (HI) versus Oxygen Index (OI) based on Rock-Eval pyrolysis data (Tables 1, 2, 3), can be plotted on a modified van Krevelen diagram and interpreted [9]. It is observed from (Fig.4) that Type-I, II is the dominant organic matter in the Bj-1 well with few sample as Type IV kerogen, while Taq Taq-1 and Jk-1 well rock samples are represented by Type-IV and -I/II kerogens.

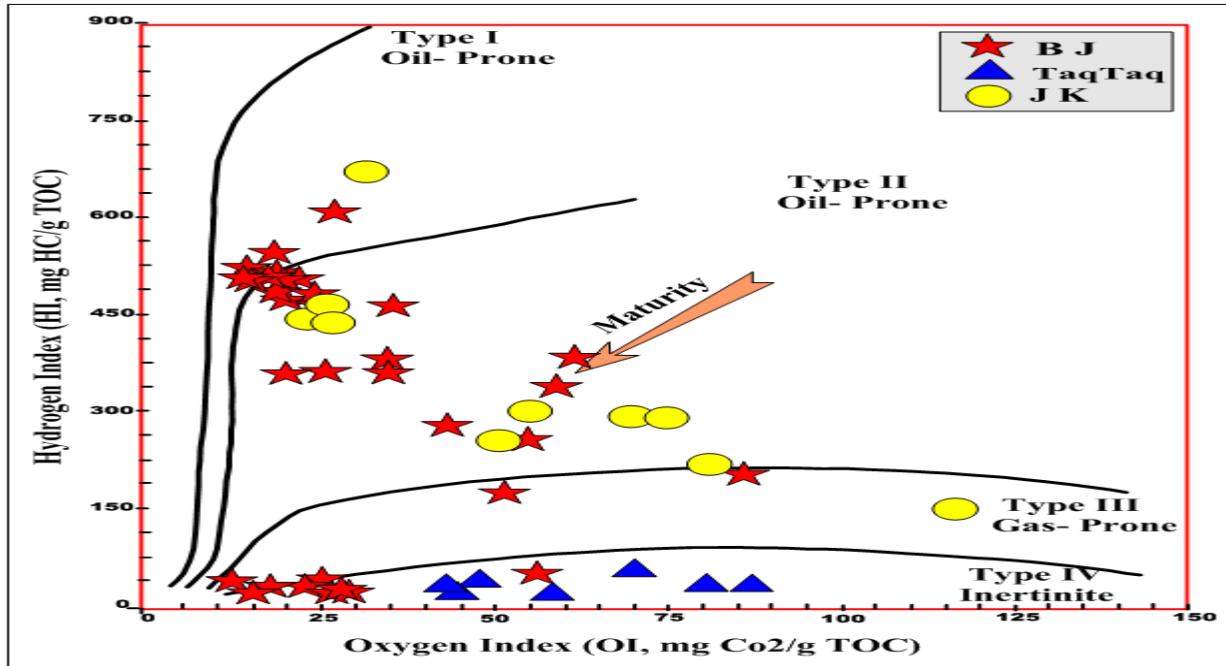


Fig-4. Cross plot of OI versus HI for different kerogen types modified after Hunt [12]; Dembicki [13]

4.3. Thermal Maturity

A source rock that has the possibility of producing a great amount of hydrocarbons is defined as mature. A source rock that lacks this ability is defined as immature, and that which passed the time of significant generation is define as over mature source rock [12].

The temperature at which the greatest amount of S₂ is produced during pyrolysis is called Tmax [13]. To avoid the influence of OI, we commonly used the cross plot of HI versus Tmax to determine thermal maturity and kerogen type [12]. (Fig.5) confirms that the Naokelekan formation in the Bj-1 well and Taq Taq-1 well is immature and lies within Type-II\III, while Jk-1 well samples are immature to over mature Type-II with few samples refer Type IV kerogens.

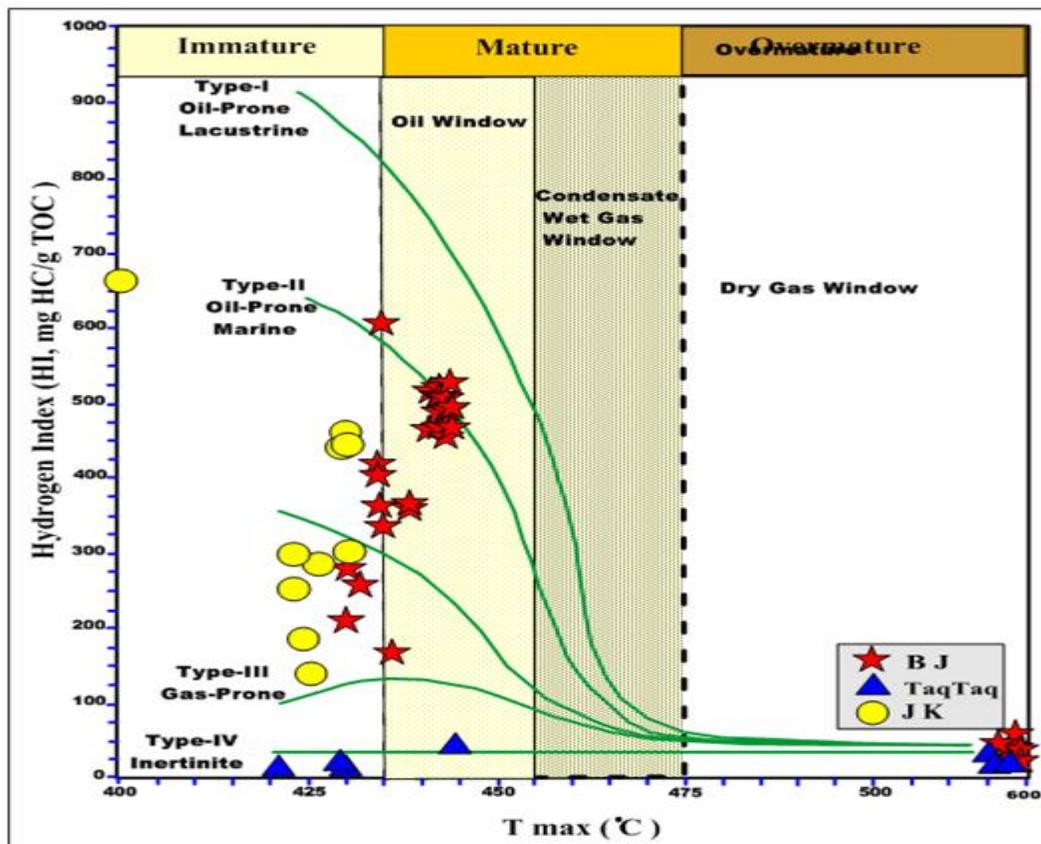


Fig-5. Hydrogen index (HI) versus T_{max} from Espitalié, et al. [14]; Dembicki [13]

On the other hand, the thermal maturity of organic matter can be assessed through the combined relationship between Tmax and the calculated Production Index (PI) [15]. The cross plot of Tmax versus PI (Fig.6) shows that Bj-1 well samples are range from mature to over mature, while Taq Taq-1 well are marginally mature to over mature. The majority of samples for Jk-1 well are immature.

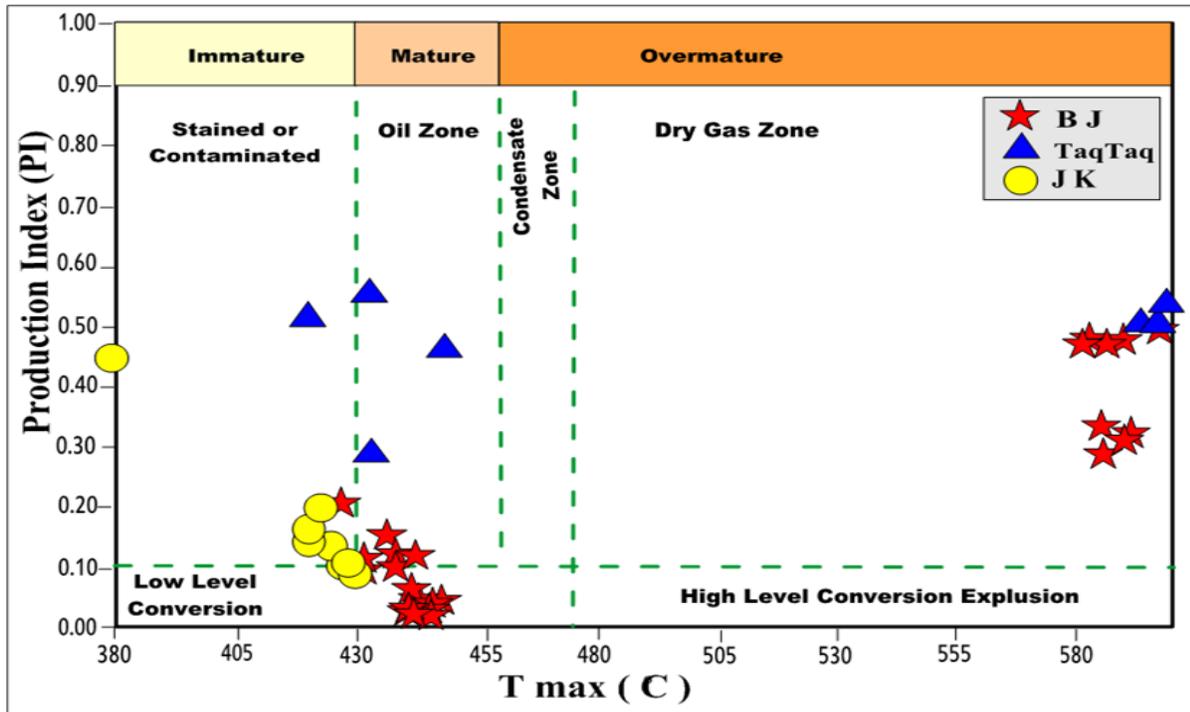


Fig-6. T_{max} versus PI modified after Langford and Blank-Valleron [15]; Espitalié, et al. [14]

4.4. Migrated Hydrocarbons

Nonindigenous hydrocarbons can be detected, if S_1 is high and the TOC is low [15]. Therefore, TOC versus S_1 diagram have been used to separate migrated from non-migrated hydrocarbons for the cutting samples taken from selected wells (Fig.7). Thus all the analyzed samples plot in indigenous hydrocarbons field, reflecting no external contribution of migrated hydrocarbons to the analyzed sample for selected wells.

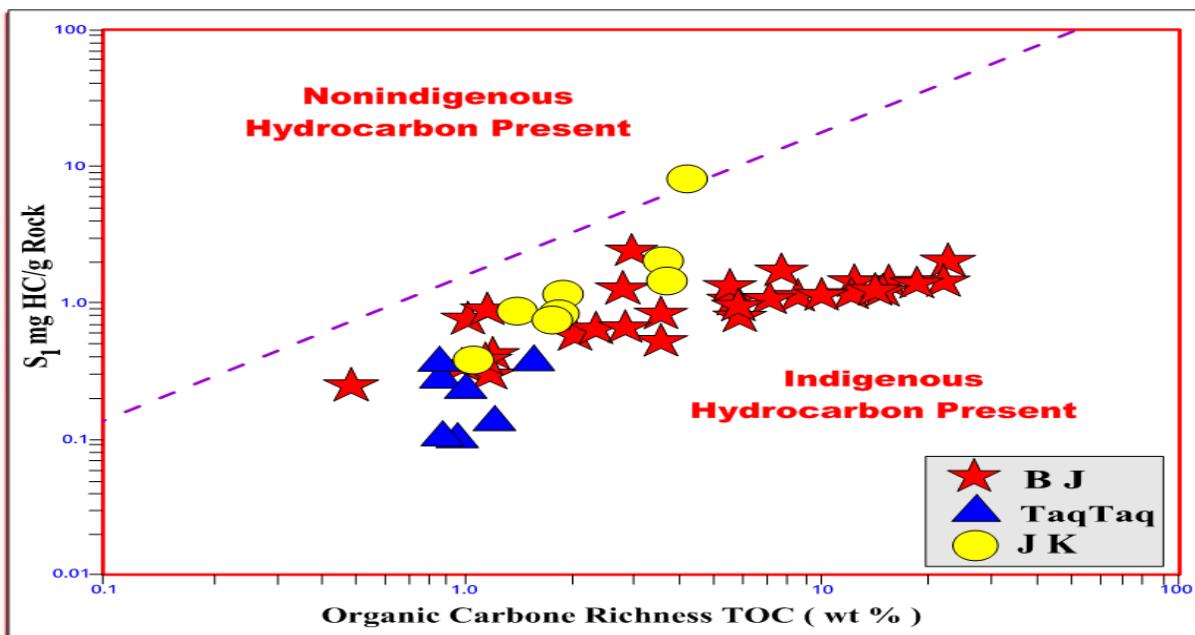


Fig-7. Plot of Rock-Eval S_1 versus TOC (wt%) to distinguish indigenous from non-indigenous hydrocarbons from Hunt [16]; Hunt [12]

5. Conclusions

Rock-Eval pyrolysis data of Naokelekan formation indicate a wide variation of source richness and quality, but all samples contain various quantities of Type-I/II, Type-II (oil prone) and Type-IV (gas-prone) organic matter among the Bj-1, Taq Taq-1 and Jk-1 wells. HI for Bj-1 well (24-605 mg HC/g TOC), Taq Taq-1 (9-48 mg HC/g TOC) and (147-673 mg HC/g TOC) Jk-1 which imply that the studied samples contain mostly Type II\III for Bj-1, Taq Taq-1 and Type II with minor Type IV. HI- OI diagram shows that kerogen type is mainly Type-I\ II for Bj-1, Type-IV with Type -I/II for Taq Taq-1 and Jk-1 wells, while HI- T_{max} diagram classifies that the Naokelekan formation in the Bj-1 well and Taq Taq-1 well is immature and lies within Type-II\III, while Jk-1 well samples are immature to over mature Type-II with few samples refer Type IV kerogen.

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