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ORIGINAL PAPER

Determination and applications of chemical analysis to evaluate Jurassic hydrocarbon potentiality in Northern Iraq

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Abstract Chemical analysis was carried out to evaluate the potentiality of rock samples having hydrocarbon characteristics, identified by chemical methods as one of the approaches to evaluate the source rocks encountered from Sehkanian, Sargelu, Naokelekan, Sarmord and Ghia Gara of (Middle to Upper Jurassic–Lower Cretaceous) stratigraphic sequence of Iraq, representing source rocks, which are recovered from oil exploratory wells Butmah-15, Ajeel-8, Makhul-2, Qarachuq (1 and 2) and TaqTaq-1 (Bm-15, Aj-8, Mk-2, Qc-1,Qc-2 and Taq-1) alternatively, located in the northern part of Iraq and also the outcrop samples extracted from the type locality at Surdash Anticline. Additional samples were taken from another exposure section of the Jurassic rocks from Banik village, those various samples represent Varity of palynofacies. The bulk of chemical analysis enables to enhance the potentiality of the source rocks, leading to believe generating tremendous amount of oil and subordinate gas promising more than earlier predictions for forming super giant oil and thermogenic gas fields in this area. The value of the production indices determines that the system of the oil in Iraq is not widely different from the depocenters of the surrounding countries. Accordingly Iraq is considered as an ideal and systematic basin that all the total petroleum system elements are available, giving indications of good source rocks, extensive reservoirs and excellent seals. Typical oil fields, which as determined by the remarkable total organic carbon exceeds 20 %, and maturation evidences accompanied with maximum temperature up to 450°C indicate obviously various values of the hydrogen and oxygen indices, kerogen type II and type III, of marine to mixed to terrestrial origin that lead to determine that the oil and gas prone Sargelu, Naokelekan and Ghia Gara were good source rocks. Meanwhile Barsarin and Sarmord were reservoir rocks. The area of study is widely promising to produce oil with condensed gas.

Keywords Hydrocarbon potentiality · Total petroleum system · Jurassic

Introduction

The sequence of the studied formations, which represent the ideality and formative rock packages, characterizing the whole scope of the source rocks, extended through wide spread areas of Iraqi outcrops and oil exploratory wells (Fig. 1). Jurassic–Cretaceous–Neogene that extended through the Mesopotamian basin represents systematic sequences for both good generating source rocks and excellent caprocks (Fig. 2).

The stratigraphic sequences (Fig. 3) explain the most productive basins, by means of rate of sedimentation covering the burial particulates causing increase in thermal history of each basin, and causes typical oil and gas prone by the thermal maturation, and causes typical oil and gas prone by the thermal maturation. The hydrocarbon potential source rock packages evaluated by chemical analytical data reflect the whole scope of the prolific well sites extended through the Mesopotamian basin lead to the expectations for forming supergiant oil and/or gas fields, thus the consequences giving rise to extensive explanations for the most productive basins as well.

The rate of sedimentation process in the Mesopotamian basin forms systematic burial for the particulates (living

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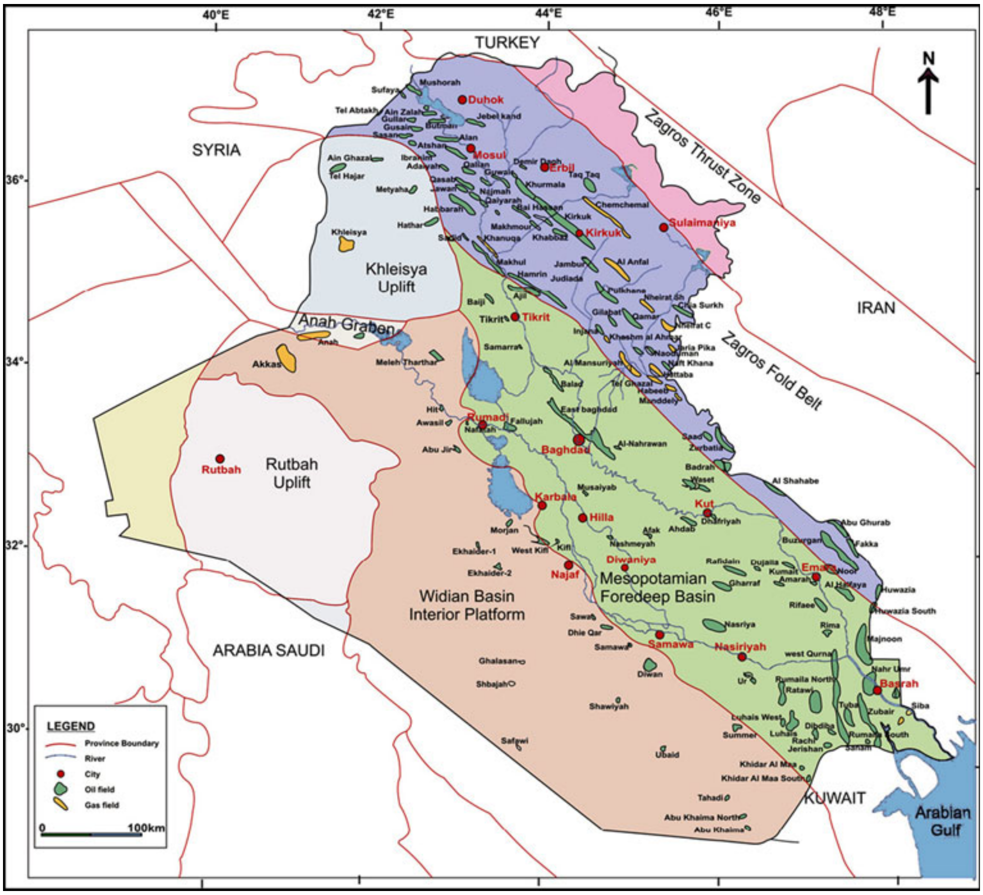


Fig. 1 Map of Iraq show oil and gas field within Mesopotamian Basin (modified from Pitman et al. 2004)

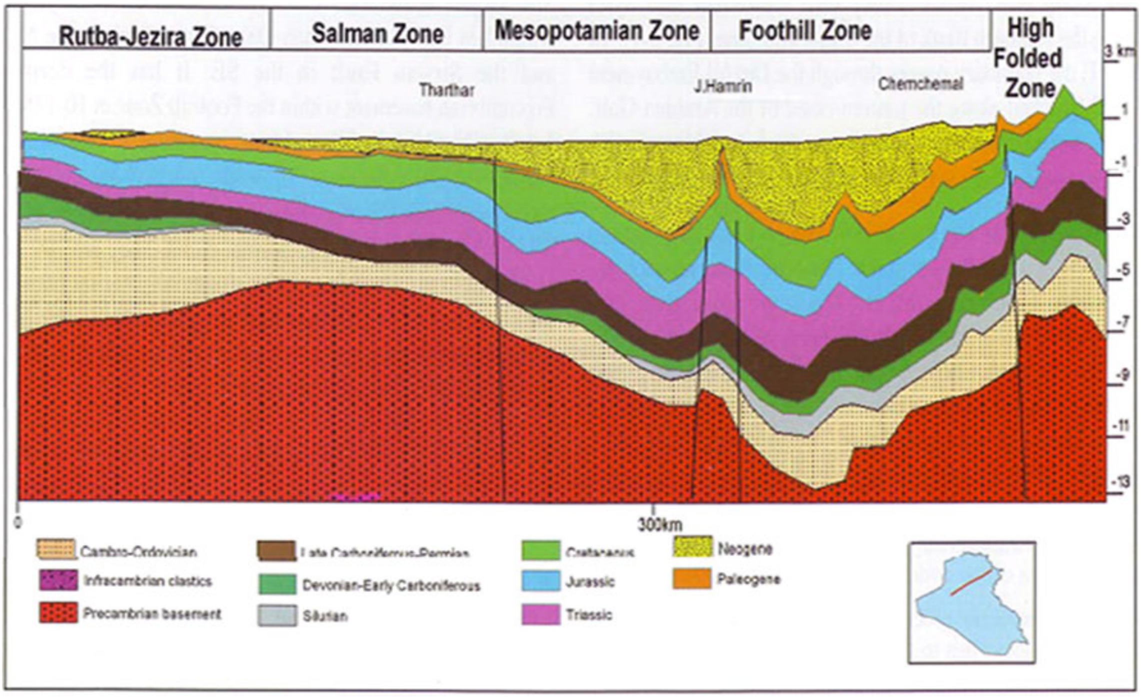


Fig. 2 Cross section through central Iraq passing through the stable shelf, the Foothill and High Folded Zone showing the basement in Iraq in Foothill zone (Jassim and Goff 2006)

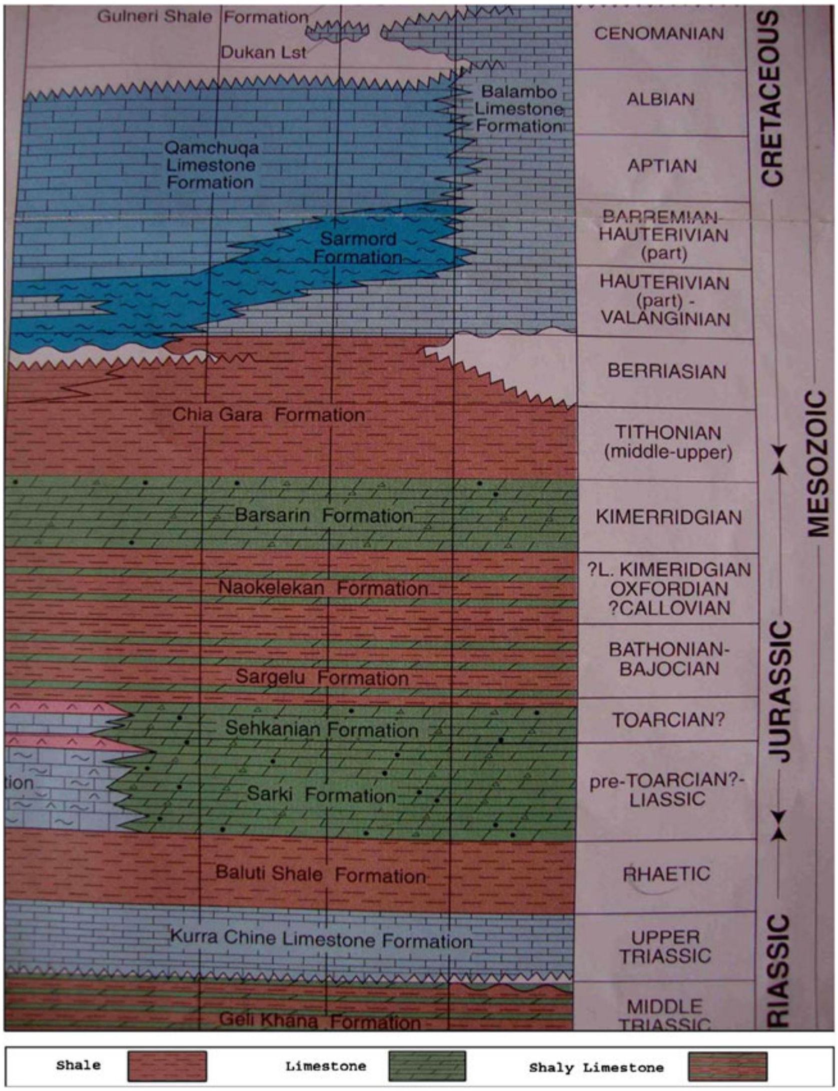


Fig. 3 The stratigraphic section through the studied area (Lexiuqe; Van Bellen et al. 2005)

bioorganisms) which is transported with huge process of sedimentation having so many species of the palynomorphs that subjected to thermal maturation processes, throughout geologic past eras, to release biomarkers detected by chemical analysis using modern specific methods and techniques to prove the type of hydrocarbon prolific well sites as well as the conditions, and state of the environmental deposition media. This research mainly enhances the role of chemical analysis among other approaches (Batten 1999), palynological analysis (optical), biomarker parameters and how to set up models of various dimensions making use of the input data that can serve the complementary fashion that enables to perform the upstream sector (Al-Ahmed 2006).

Chemical analysis certainly is an aid to resolve so many problems and reduces the risk assessments for the most expensive well drilling sites. Screening for core and cutting samples should be followed in any successful exploring programmes to cancel less than 0.5 % of total organic carbon (TOC) samples.

Total petroleum system of Jurassic–Cretaceous period

Passive margin conditions along the Arabian plate during the Jurassic through late Cretaceous periods produced abroad stable shelf environment (Fig. 2). Flooding of this warm plate form in warm equatorial latitudes allowed for continued deposition of shallow marine carbonates over the Greater Arabian Basin (Murris 1980; Al-Husseini 1997).

In particular Jurassic geologic conditions of the subcontinent resulted in deposition of the following ideal sequence of primary petroleum system elements: thick oil prone source rocks, extensive reservoir facies and excellent seals. Widespread early and middle Jurassic marine transgression deposited a thick sequence of shallow marine shelf carbonates, and plate form evaporates. Late Jurassic (Oxfordian and early Kimmeridgian) differential subsidence and sea level rise resulted in the formation of broad, intra-shelf subbasins. These were the depocenters for the main Jurassic source rocks; Late Jurassic (Tithonian) eustatic variations of

Table 1 A Rock-Eval pyrolysis exploratory oil well and outcrop samples

	Well name	Formation	Depth (ft.)	TOC	S1	S2	S3	$T_{\max}$ (°C)		Cal. %Ro	HI	OI	PI
Rock-Eval pyrolysis exploratory oil well samples													
1	Aj-8	Sargelu and Naokelekan	10,636	11.81	5.57	45.53	0.95	449		0.92	386	8	0.11
2	Aj-8		10,673	3.00	1.85	6.33	0.49	439		0.74	211	16	0.23
3	Aj-8		10,722	1.05	0.47	1.87	1.16	446		0.87	178	110	0.20
4	Aj-8		10,738	1.03	1.50	2.82	0.44	437		0.71	274	43	0.35
5	Aj-8		10,771	0.83	0.60	1.75	0.44	444		0.83	211	53	0.26
6	Aj-8		10,823	1.42	1.19	2.33	1.09	439		0.74	164	77	0.34
7	Aj-8		10,830	1.26	1.02	1.79	0.62	447		0.89	142	49	0.36
8	Aj-8		10,866	0.66	0.57	1.32	0.49	441		0.78	200	74	0.30
9	Bm-15	Sargelu and Sarmord	6,660	0.34	0.20	1.00	0.10	443		0.81	294	29	0.17
10	Bm-15		6,663	0.35	0.26	0.89	0.16	444		0.83	254	46	0.23
11	Bm-15		6,667	1.91	0.53	5.44	0.17	443		0.81	285	9	0.09
12	Bm-15		6,670	0.22	0.35	0.70	0.10	439		0.74	318	45	0.33
13	Bm-15		6,673	0.10	0.18	0.30	0.04	439	–[a]	0.74	300	40	0.38
14	Bm-15		6,677	0.24	0.20	0.59	0.07	439		0.74	246	29	0.25
15	Bm-15		6,680	0.45	0.24	1.69	0.13	442		0.80	376	29	0.12
16	Mk-2	Sargelu and Naokelekan	7,415	20.69	2.53	80.51	0.76	440		0.76	389	4	0.03
17	Mk-2		7,426	16.09	2.48	66.95	1.39	439		0.74	416	9	0.04
18	Mk-2		7,428	13.68	2.02	78.77	0.80	440		0.76	576	6	0.03
19	Mk-2		7,438	13.04	0.99	50.81	0.86	439		0.74	390	7	0.02
20	Mk-2		8,051	4.04	1.41	35.50	0.60	442		0.80	879	15	0.04
Rock-Eval pyrolysis outcrop samples													
21	Surdash 1	Sargelu and Naokelekan and Chia Gara	0	0.57	0.01	0.17	0.47	502	–[a]	1.88	30	82	0.06
22	Surdash 2		0	0.32	0.05	0.21	0.14	504	–[a]	1.91	66	44	0.19
23	Surdash 3		0	0.30	0.10	0.23	0.04	458	–[a]	1.08	77	13	0.30
24	Surdash 4		0	0.90	0.10	0.27	0.57	512	–[a]	2.06	30	63	0.27
25	Qc-1	Naokelekan	8,752	2.47	0.94	2.82	0.20	445		0.85	114	8	0.25
26	Qc-1		8,762	6.97	2.78	11.58	0.49	448		0.90	166	7	0.19
27	Tq-1	Sarglu and Sehkanian and Chia Gara	10,857	1.73	0.11	0.01	0.26	472	–[a]	1.34	1	15	0.92
28	Tq-1		10,855	0.88	0.02	0.02	0.22	473	–[a]	1.35	2	25	0.50
29	Tq-1		10,852	0.16	0.00	0.02	0.03	479	–[a]	1.46	13	19	0.00
30	Tq-1		10,845	0.00	0.00	0.01	0.11	396	–[a]	−1.00	−1	−1	0.00
31	Tq-1		10,848	2.18	0.10	0.03	0.04	472	–[a]	1.34	1	2	0.77
32	Tq-1		10,849	0.78	0.01	0.01	0.13	438	–[a]	0.72	1	17	0.50
33	Tq-1		10,845	2.02	0.10	0.03	0.29	486	–[a]	1.59	1	14	0.77
34	Qc-2	Sargelu and Sehknian and Naokelekan	5,125	0.85	0.35	5.77	0.11	438		0.72	679	13	0.06
35	Qc-2		5,171	0.69	0.24	4.82	0.27	435		0.67	699	39	0.05
36	Qc-2		5,213	0.42	0.32	4.53	0.23	435		0.67	1,079	55	0.07
37	Qc-2		5,253	0.88	0.27	4.96	0.22	440		0.76	564	25	0.05
38	Qc-2		5,322	0.39	0.18	2.14	0.03	437		0.71	549	8	0.08
39	Qc-2		5,371	0.77	0.22	4.78	0.04	438		0.72	621	5	0.04
40	Qc-2		5,417	0.50	0.20	2.86	0.09	436		0.69	572	18	0.07

S1 and S2 in milligrams hydrocarbons per gram of rock, S3 in milligrams carbon dioxide per gram of rock, $T_{\max}$ in degrees Celsius

TOC weight percent organic carbon in rock, *HI* hydrogen index (=S2×100/TOC), *OI* oxygen index (=S3×100/TOC), *S1/TOC* normalized oil content (=S1×100/TOC), *PI* production index [=S1/(S1+S2)], *Cal. %Ro* calculated vitrinite reflectance based on $T_{\max}$, *%Ro* measured vitrinite reflectance

[a] $T_{\max}$ data not reliable due to poor S2 peak

the Arabian plate form resulted in dominant reservoirs and caprocks (Arab Formation carbonates and Arab Formation and Hith Formation evaporate seal rocks). In the northmost Arabian Gulf and sourced within the Jurassic Gotina sub-basin, oil and gas accumulated in the Middle to Upper Jurassic, high-energy calcarenites and oolites of bar or shelf margin origin. These reservoirs are cyclic and interbedded with organic-rich (2–5 % TOC), muddy lime rock source that was deposited under anoxic and dysoxic condition. The restricted, intra-shelf Gotina sub-basin/Barsarin/Sargelu/Najmah TPS is identified in the northern area and consists of the following two assessment units:

1- The proven platform horst/graben-related oil assessment unit
2- The hypothetical basinal oil and gas assessment unit

Sehkanian, Sargelu, Naokelekan, Sarmord, Ghia Gara and Barsarin are relatively varied in generating oil and so (Sargelu, Naokelekan and Ghia Gara) are source rocks, meanwhile Barsarin and Sarmord were reservoir rocks (Table 1).

Chemical analysis

The technique of Rock-Eval pyrolysis

Determination of the elemental composition of kerogen is a relatively time-consuming process. Development of the Rock-Eval technique for alternative method for determination of two indices could be used to replace the H/C and O/C parameters. This technique is a pyrolysis method whereby a sample is exposed to a temperature programmed pyrolysis from ambient to 600°C and the pyrolysis products detected immediately and without any chromatographic separation (Espitalie et al. 1977). The result is basically three peaks: S1, S2 and S3 (modern versions of the Rock-Eval technique produce some additional peaks, but for the purpose of this discussion, the presence of the three mentioned peaks is sufficient).

> S1 corresponds to the material which is normally solvent extracted from a source rock.
> S2 corresponds to the products formed from the thermal breakdown of the kerogen.

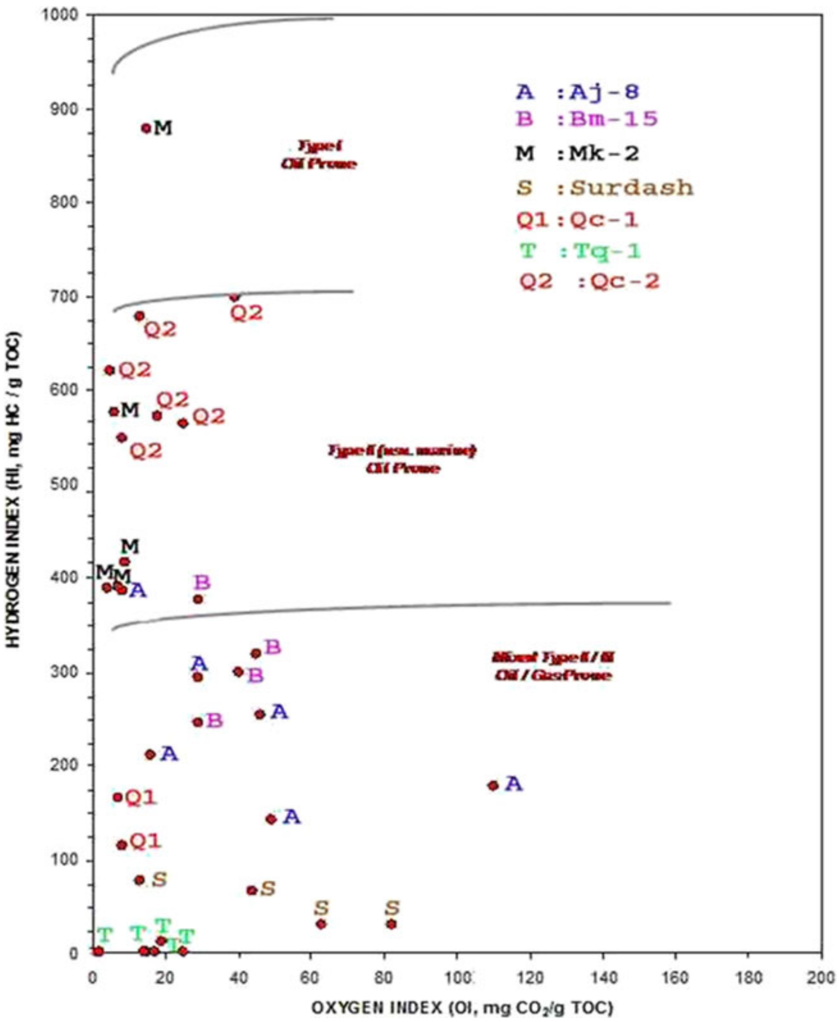


Fig. 4 Determination of kerogen type and potentiality by HI versus OI

S3 is derived from oxygen-containing parts within the kerogen.

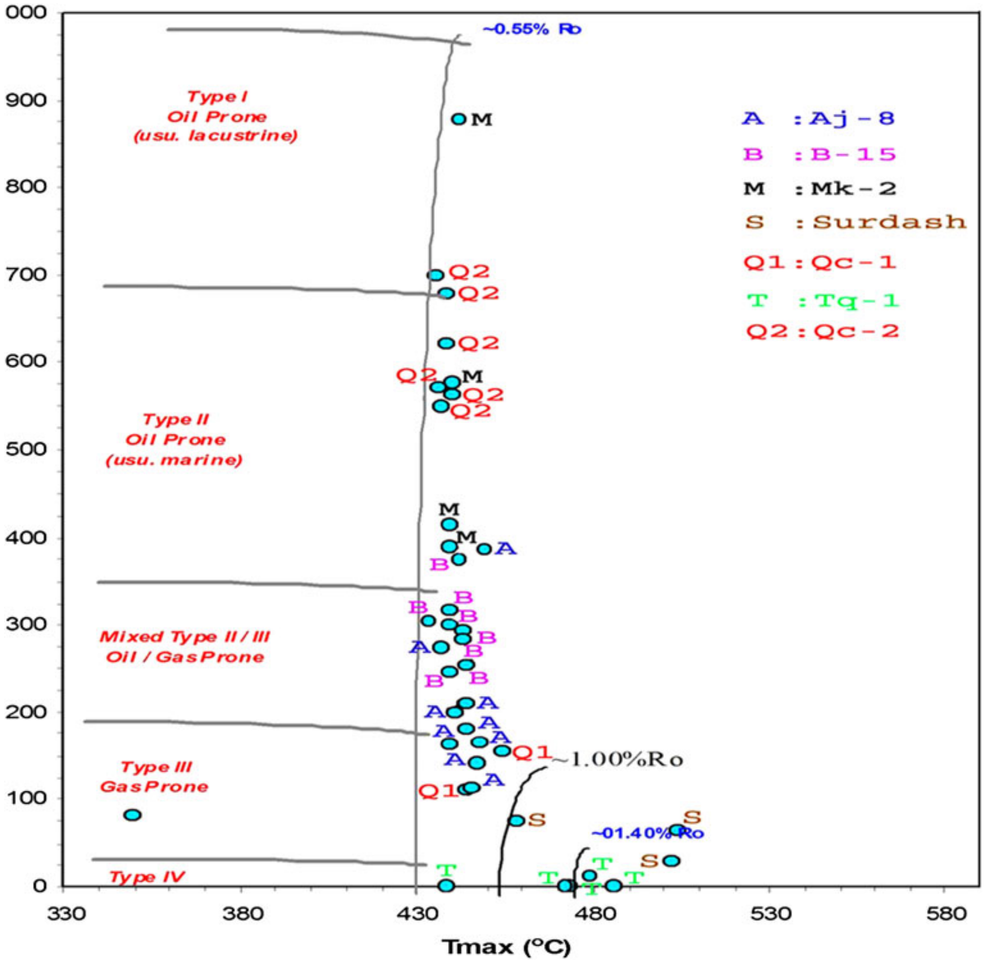
From these three parameters, plus the total organic carbon content of the sample, two important parameters are developed, namely the so-called hydrogen index (HI), which is the S2 peak normalized to the TOC and the oxygen index (OI), which is the S3 peak normalized to the TOC. It has been shown that HI and OI are directly proportional to the H/C and O/C ratios and, therefore, a plot of HI to OI can be used to replace the H/C and O/C values (Fig. 3) on the Tissot–Welte diagram as it was performed in both (Oklahoma University and Geomark Research, Inc., Houston, Texas). For our current study, it was obviously declared in the figures with attached analyses.

There are several indicators available that can be used to estimate the relative maturity of a source rock. The traditional method is measuring the maturity of vitrinite. The chemical composition of the maceral vitrinite is derived from higher plant debris and changes as the level of maturity increases. With increasing maturity the ability of vitrinite to reflect light increases, and hence a vitrinite reflectance scale has been developed which correlates the degree of reflectance with maturity. Maturity changes of vitrinite have been studied by coal chemists for a long period of time (Techmuller 1958). A similar approach was adopted by the petroleum geochemists (Dow 1977).

Another extremely important feature related to the generation of oil or gas is the maturity level of the source rock. Organic matter has to reach a certain level of maturity before it starts too thermally and is converted into liquid or gaseous hydrocarbons. The threshold level for oil generation varies depending upon kerogen type. For example the type II kerogen enriched in sulphur generates oil at lower temperature than type II kerogen that is not enriched in sulphur. Information such as this is critical in any exploration study and for modelling basin (Orr 1986).

Determination of maturity levels is critical to the success of any exploration programme. Recovery of immature, but organic-rich, source rocks would indicate good source potential for such rocks if buried more deeply in other parts of the basin. At the other extreme, an overmature source rock would indicate a mature part of the basin not capable of generating additional liquid hydrocarbons, but possibly gas.

Fig. 5 Kerogen type and mature kerogen conversion and maturity



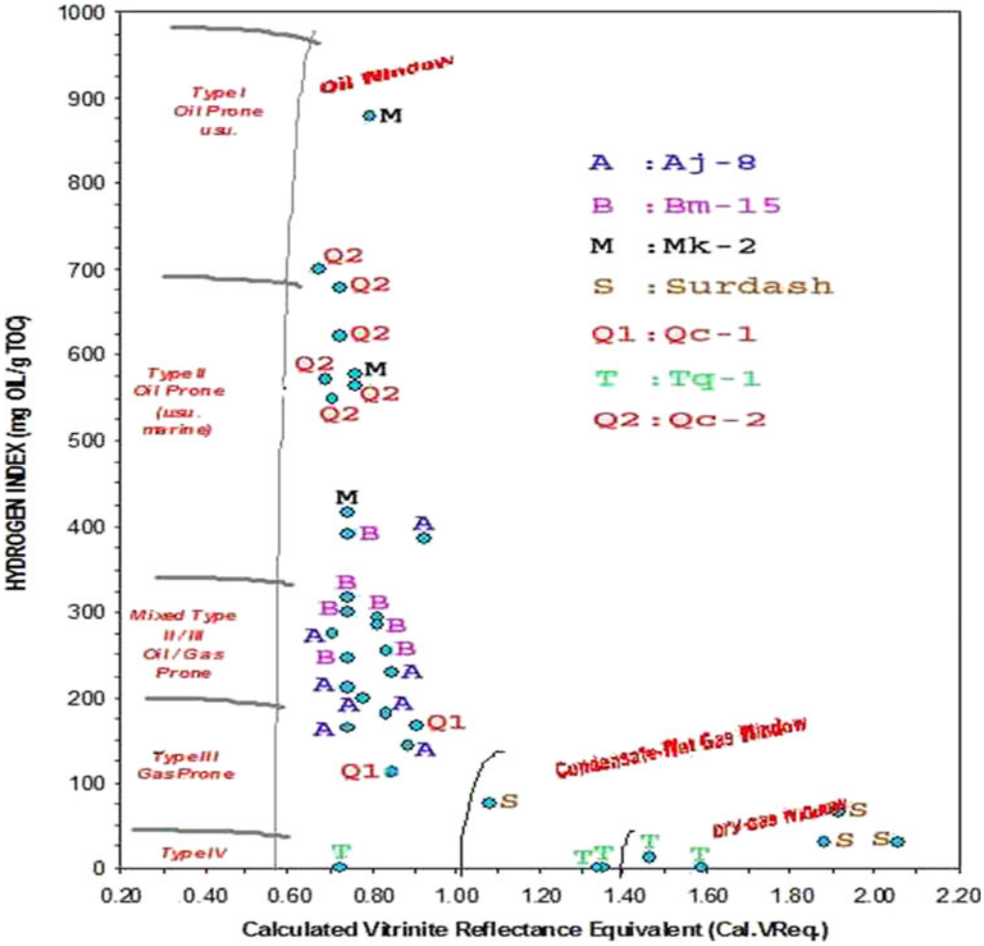


Fig. 6 Kerogen type determined by cal.vitrinite reflectance

Kerogen type and maturity

T_{max} indicates that almost all samples are located within the oil window of kerogen type I, II and III at temperature around 430–460°C; above 460°C, only two samples are located within condensate-wet gas window, and four samples located within dry gas window at temperature exceeds 585°C with very low HI (Fig. 4), and about T_{max}

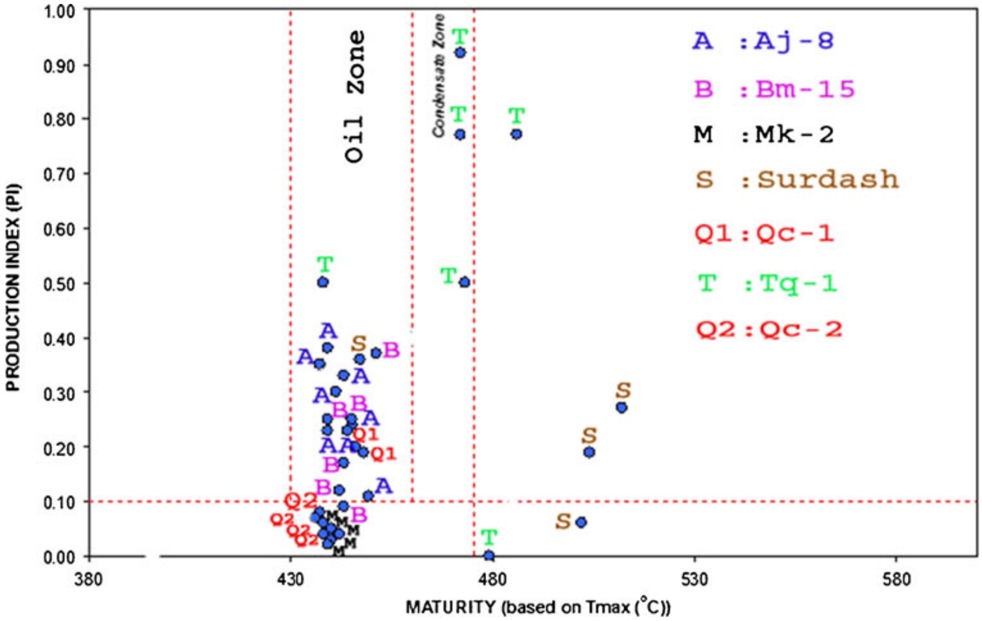
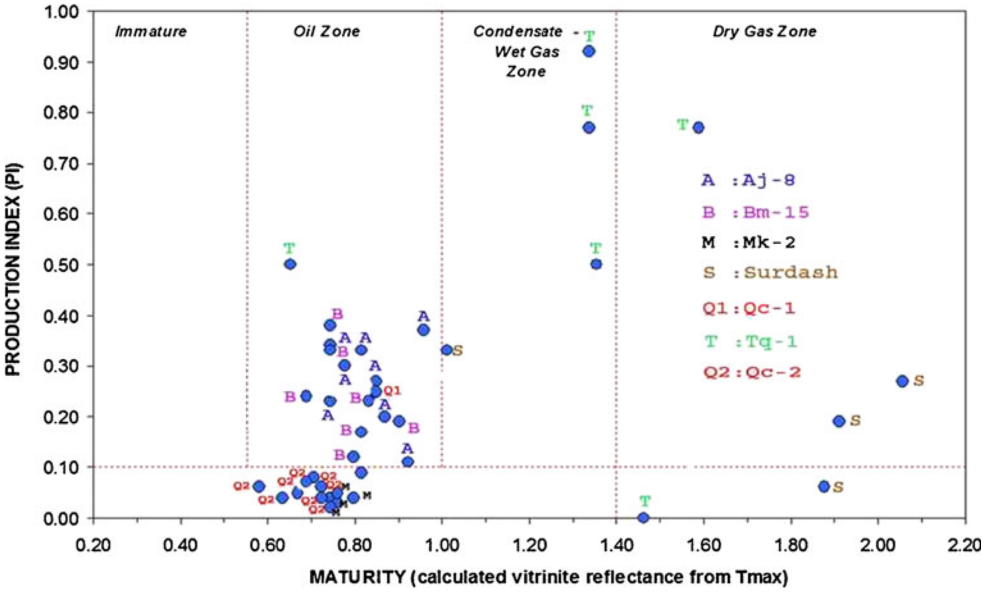


Fig. 7 Production index referring to ideal zone according to maturity (based on T_{max})

Fig. 8 Production index referring to ideal zone according to maturity (based on calculated vitrinite reflectance from $T_{\max}$)



(cal. vitrinite reflectance percentage). So the calculated vitrinite reflectance equivalent (cal.v ref) around 0.60–1.00 indicates that almost all types of kerogen relatively varied in HI are located within oil window, approximately six samples located within the condensate gas window. In the meantime increasing in cal.veq, only three samples are located within the dry gas window (Fig. 5). So this distribution of maturation zone could be illustrated as contour lines indicated the increasing of maturation east world, and separates the immature zone rather than the mature zone. The oil window shows concentration of almost all samples within the range of production index (PI) 0.08–0.4; higher values are often due to migrating hydrocarbons or contaminated, whereas maturity (calculated vitrinite reflectance) from $T_{\max}$ illustrated that the whole samples located within oil the zone (Fig. 6). Calculated %Ro indicating maturity shows that within a depth of 500 m, the majority of the samples are located within the oil zone, and from the depth of 620–700 m still within the oil zone while increasing in depth up to 1 km, conversion toward the condensate zone and thermal maturity increased with depth accordingly. The depth bounded between 3,317 and 3,340 m in Taqtaq-1 oil well indicates the migrated oil that the PI is equal to 1 mg Hc/g TOC, $T_{\max}$ decreases to (−1°C) and TOC increases to more than 1.5.

Based on $T_{\max}$ versus PI (Fig. 7) or transformation ratio which typically climbs from 0.1 to 0.4, from the beginning to the end of the oil generation window, many PI versus depth plots show considerable variation owing to different kerogen types, migrated oil effects and anomalously high number when S2 is too low. Because of measurement errors, PI is meaningless if S2 is below 0.2; many high PI values above 1 mg Hc/g TOC indicate migrated oil, especially if $T_{\max}$ decreases and TOC increases at the same time (Figs. 7 and 8; Hunt 1995).

Conclusion and discussions

Techniques used to assess the petroleum potential of source rocks may be put into two broad categories, optical and chemical. Each has its respective strengths and limitations. In rigorous exploration programme, neither would be used in isolation; rather, both would be applied in a complementary fashion. It is obviously declared that the results of the chemical analysis are very formative referring as a comparison study, among the encountered formations and the locality of the studied wells, in which all the formations are good to very good source rocks, but not all the locations of the same formations show the same oil or gas prone. Qarachuq 1 and 2, Makhul-2, Ajeel-8 and Bm-15 are defiantly indicating the potentiality to oil prone; otherwise, Taqtaq-1 shows potentiality to gas prone with the campaign of the outcropped samples. So the dependable parameters used in chemical analysis by means of schematic sections are systematic and matched with optical (palynological) analysis [2], a sure and fix, suitable approach to determine the promising oil and gas fields. Almost all subsurface samples contain over (20 wt%) value of TOC with Rock-Eval hydrogen indices between 20 and 600, corresponding to the $T_{\max}$ value (440°C) within the oil generative window. Accordingly, very good hydrocarbon generation potential is predicted for whole section either source rock or reservoir rock packages.

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