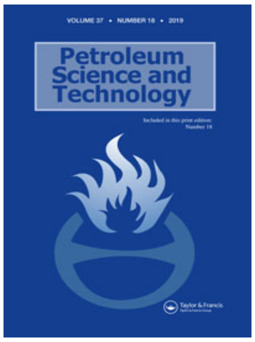

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Geochemical investigation of Yamama crude oils and their inferred source rocks in the Mesopotamian Basin, Southern Iraq

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ABSTRACT
Ten oil samples from the Yamama reservoirs and ten extracts of purported source rocks from sixteen wells in the Mesopotamian Basin, Southern Iraq have been analyzed using GC, GC/MS and Stable Carbon Isotope. Yamama oils were non-biodegraded, moderate to higher maturity based on C_{27}Ts of range from 0.17 to 0.77and TAS3 of 0.3 to 0.63, marine carbonate and marl source rocks, deposited under saline, anoxic conditions. Two oil groups were investigated based on the results of the geochemical analysis. These oils have similarly biomarkers ratios to those of the Middle Jurassic to Early Cretaceous source rocks in the Mesopotamian Basin.

KEYWORDS
Biomarkers; carbon isotope; Iraq; Mesopotamian Basin; Sargelu Formation; Sulaiy and Yamama source; Yamama crude oils

1. Introduction

The Sulaiy, Yamama, and Ratawi formations are part of the Lower Berriasian cycle and form the lower part of the Yamama Group of (Sadooni and Aqrawi 2000), which is equivalent to the Thamama Group of the southern parts of the Arabian Plate. The Yamama Formation is a proven oil-producer in most southern Iraq oil fields such as Ratawi, Rumaila North, Zubair, Majnoon, West Qurna, Nahr Umr, and Luhais, (Figure 1; Aqrawi et al. 2010).

The Yamama Formation has been divided across southern Iraq into five reservoirs units (A, B, C, D and E) separated by four tight lime mudstones barriers (Figure 2). The best oil potential is within the oolitic shoals and the cleaner reefal facies. The carbonate reservoir units are separated by barrier units formed of dark lime mudstone, which are believed to be deposited in a lagoonal setting, (Sadooni 1993). These horizons are probably the local source rocks within the Yamama Formation. No previous attempt has been made to investigate the potentiality of these mudstone units (Figure 3).

The hydrocarbon-generation potential of the Sulaiy Formation has been investigated by several authors in many parts of the Arabian Plate including (e.g. Aqrawi and Badics 2015; Al-Khafaji et al. 2018). Most workers suggested that the Sulaiy and Yamama formation have been carbonate deposited, at least partially, under suboxic-anoxic conditions responsible for the development of these organic-rich source rocks, (Abeed et al. 2011). Other important source rocks for the oil accumulations of southern Iraq oilfields are those from the Jurassic such as the Najmah and Sargelu formations. These are shaly limestone, marl and limestone, deep water, sub-basinal to basinal sediments which were deposited under anoxic conditions (Pitman et al. 2004).

The objective of this study is to characterize the types, compositions and origin of the Yamama Formation oils and its correlation with the possible source rocks in southern Iraq.

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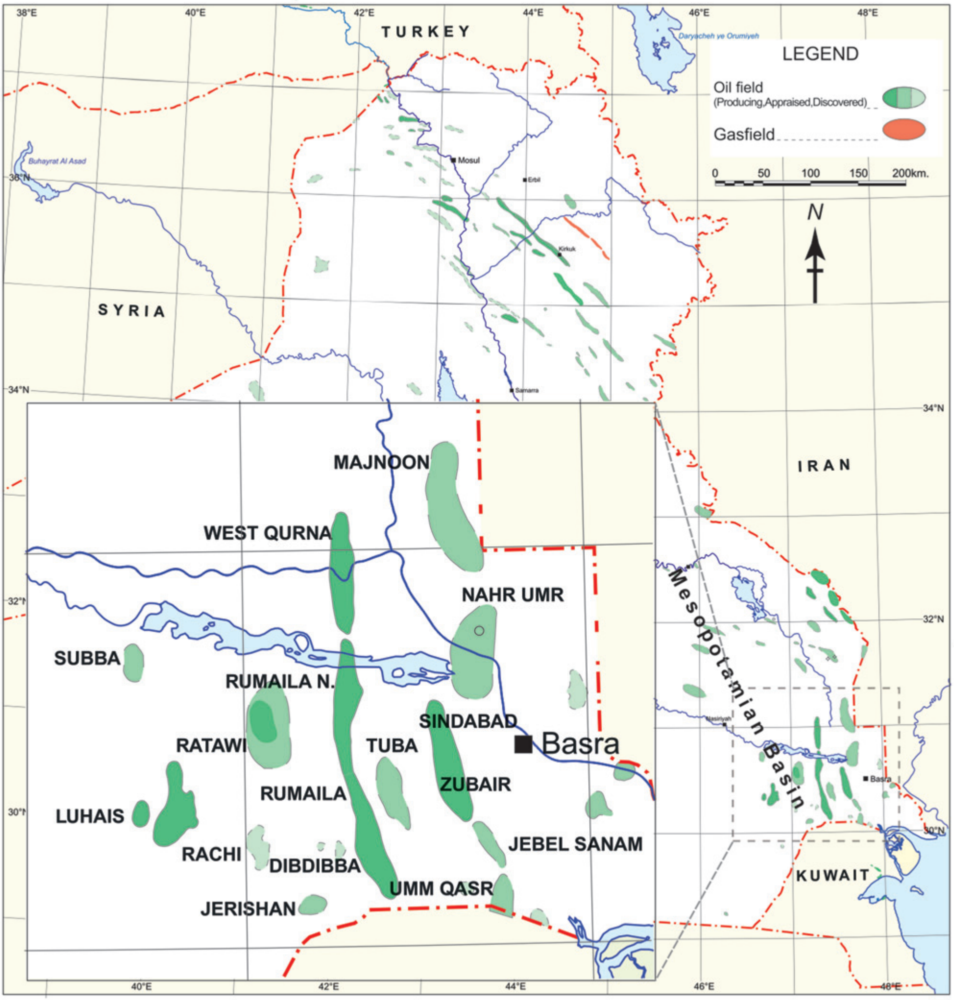

Figure 1. Location map for the northeast Arabian Peninsula in Iraq, which shows Iraqi basins with oil and gas field locations.

2. Samples and experimental methods

Ten Yamama-reservoired oil samples were collected from the wells of Diwan-1, Dima-1, Jeraishan, and 1, Luhais-12, Nahr Umr-9, Ratawi-3, Ratawi 5, Ratawi 6 and Ratawi 7. Geochemical source rock extracts analyses were conducted on ten core samples taken from the wells of Rumaila North, Tuba, Samawa, Diwan, Ratawi, West Qurna, Zubair, and Suba oilfields. These samples were subjected also to biomarker fingerprinting and bulk carbon isotope analysis. Analyses were performed by Geomark Research Ltd, Houston (USA). The studied sample and the collected data are shown in (Table 1).

3. Results and discussion

3.1. Biodegradation, Organic matter input and depositional environment

All samples have high amount of low-weight molecular n-alkanes (Figure 4A) with low values of pristane/n-C_{17} in the range of 0.16 to 0.19, phytane/n- C_{18} ratios within the range of 0.23 to 0.31,

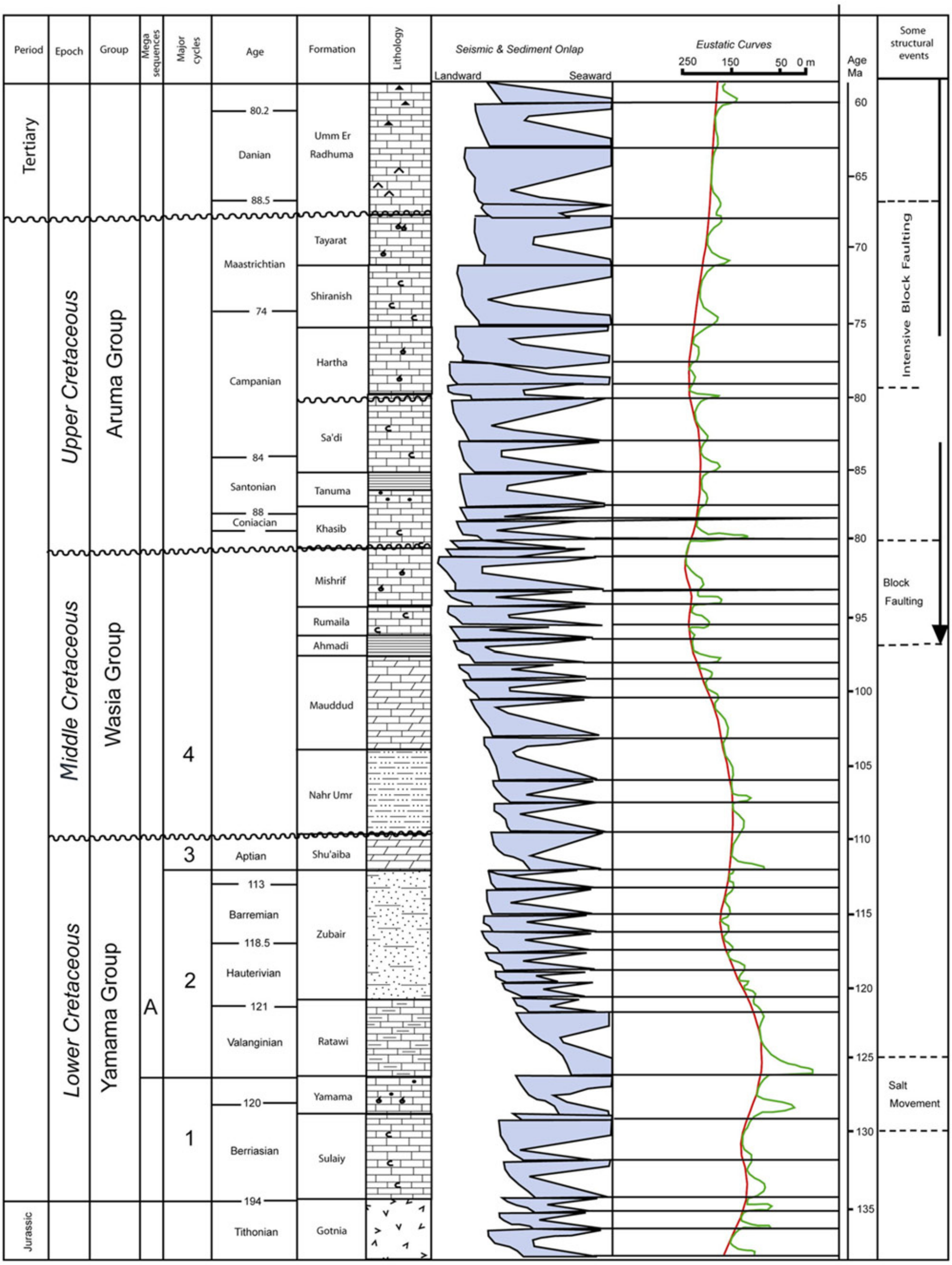

Figure 2. Generalized stratigraphic column of Jurassic–Cretaceous sequences of southern Iraq showing petroleum elements.

(Figure 4B), Pr/Ph ratios <1, high C_{35}/C_{34} 22S hopane with an average of 0.99. All these parameters suggest that the studied oil samples are not biodegraded and characterized by high contributions of anoxic marine algal organic matter source rocks input, and mature oils. (Peters et al. 1999). This is also confirmed by a high 30-norhopane/hopane with an average of 1.56, which is typical of anoxic marl or carbonate source rocks. Oils from marine carbonate and marl source rocks are also distinguished by low C_{24}/C_{23} tricyclic terpanes within the range of 0.27 to 0.33, high C_{22}/C_{21} in the range of 0.98 to 1.09 and high C_{35}/C_{34} 22S hopane with an average of 0.99.

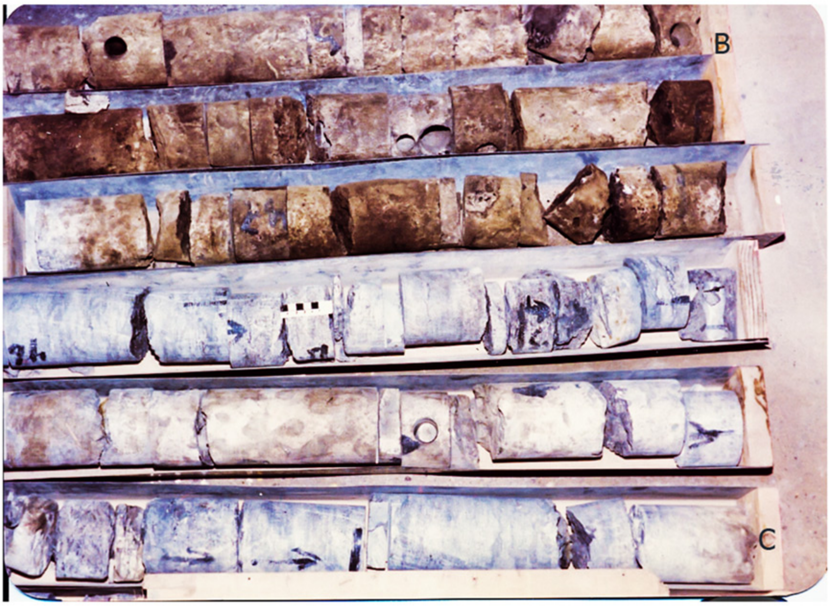

Figure 3. Cores from the Yamama Formation in the well West Qurna-15 showing an oil-stained reservoir unit at the top and argillaceous limestone barrier unit at the lower part. Core box length is 1 meter.

The GA/C_{35}R ratio, which is a common biomarker for hypersaline/restricted source environments is ranging from 0.11 to 0.25, (Peters et al. 2005).

Stable carbon isotope ratios δ^{13}C values of the samples saturated and aromatic hydrocarbon fractions were ranging from -26.35‰ to -28.1 2‰ and -26.25‰ to -27.75‰, respectively. These data indicate also a marine source input, (Sofer 1984). This is consistent with low C_{26}/C_{25} tricyclic terpane within range of 0.72 to 0.92 and high C_{31} 22R/C_{30} hopane >0.25 in the range of 0.33 to 0.35, (Table 1A).

3.2. Maturity of crude oils

Many biomarkers maturity parameters were used to determine the thermal history of the studied samples. It has been noted that oil samples fall into two groups based on their thermal maturity. The first group (A) which includes samples from the wells of Rt-3, Rt-6, and JR-1 show a high aromatic maturity oils of C_{27} Ts/Tm sterane ratio averaging 0.74 and TAS3 (CR) ratio averaging 0.62. The other samples belonging to the rest of the oil wells (group B) are characterized by a moderate saturated maturity oils with C_{27} Ts/Tm sterane ratio averaging around 0.26 and the average TAS3 (CR) ratio is 0.33, (Figure 5A; Peters et al. 2005). This is consistent with the high API gravity of group (A), which is in the range of 38.1 ^{o} to 39.9 ^{o}, and the average sulfur content which is 1.4 compared with group (B) in which the API gravity ranges between 25.9^{o} and 32.3^{o} and an average sulfur content of 3.4, (Figure 5B; Table 1A).

3.3. Oil-Oil and Oil-Source rock correlation

Geochemical correlation generally become more reliable when more parameters were compared among crude oils, and/or extracts from source rocks to determine whether a genetic relationship exists. (Peters et al. 2005).

Table 1. Selected bulk composition and biomarker parameters for Lower Cretaceous Yamama crude oils (A), and available source rock samples from Mesopotamian Basin (B), South Iraq, illustrating source organic matter

Oil s.	Oil Wells	Depth	Formation	API Gravity	% S	Pr/Ph	Pr/n-C17	Ph/n-C18	n-C27/ n-C17	C15+ Saturate	C15+ Aromatic	C22/C21	C24/C23	C26/C25	GA/ C31R	C35S/C34S	C27%	C28%	C29%	C27 Ts/Tm	TAS3 (CR)
A. Yamama Oil Data																					
1	Rt-6		Yamama	38.1	1.41	0.91	0.17	0.25		−26.35	−26.25	1.01	0.27	0.9	0.17	0.89	37.2	22.6	40.2	0.71	0.63
2	Rt-3		Yamama	38.1	1.46	0.83	0.16	0.26	0.09	−26.46	−26.25	1.01	0.27	0.89	0.16	0.83	37.4	22.1	40.5	0.77	0.63
3	JR-1		Yamama	39.9	1.58	0.83	0.16	0.23	0.16	−26.63	−26.58	1.09	0.28	0.88	0.16	0.87	35.5	21.6	42.9	0.74	0.59
4	Rt-6		Yamama			0.76	0.19	0.29	0.17	−27.42	−27.56	1.05	0.27	0.74	0.25	1.15	32.9	25.2	41.9	0.17	
5	NR-9		Yamama	25.9	5.38	0.78	0.18	0.29	0.16	−27.41	−27.75	1.08	0.26	0.72	0.24	1.14	34.4	24.4	41.2	0.17	0.34
6	Dn-1		Yamama	29	3.51	0.74	0.19	0.3	0.16	−27.81	−27.66	0.99	0.29	0.73	0.22	0.98	33.4	24.6	42	0.22	0.3
7	Da-1		Yamama	31.5	2.23	0.73	0.18	0.28	0.18	−27.86	−27.47	0.98	0.29	0.79	0.11	0.98	35.1	23.5	41.4	0.38	
8	Rt-5		Yamama	30.9	3.58	0.77	0.18	0.28	0.14	−27.64	−27.52	1.03	0.29	0.72	0.2	0.98	34.4	23.8	41.8	0.29	0.34
9	Lu-12		Yamama	32.2	3.35	0.77	0.17	0.28	0.15	−27.5	−27.48	1.03	0.3	0.76	0.2	1.04	33.9	23.7	42.4	0.32	0.36
10	Rt-7		Yamama	32.3	2.37	0.72	0.19	0.31	0.17	−28.1	−27.72	0.93	0.33	0.92	0.16	1.03	33	25.3	41.7	0.28	0.31
B. Source Rock Extracts Data																					
11	SA-1		Sargelu			0.4				27.91-	27.59-	1.03	0.32	0.8	0.09	1.02	34.6	17.2	48.2	1.12	0.43
12	Dewan		Sargelu			0.55	0.2	0.32	0.15	−27.73	−27.33	0.97	0.31	0.64	0.13	0.77	44.4	24.9	30.7	0.34	0.58
13	R-172	4848	Najmah			0.36	0.18	0.33	0	−27.52	−27.52	1.14	0.29	0.76	0.21	1.09	33.1	26.2	40.7	0.18	0.21
14	R-172	4070	Sulaiy			0.51	0.23	0.38	0.01	−27.76	−27.67	0.63	0.21	0.6	0.18		36.8	21	42.1	1.58	0.77
15	R-167	4493	Sulaiy			0.7	0.2	0.32		−26.52	−25.98	0.88	0.23	0.66	0.3		33.9	24.3	41.8		
16	SU-8	3546	Yamama			0.31	0.19	0.38	6.79	−26.86	−26.4	1.36	0.28	0.79	0.12	0.95	37.6	22.2	40.2	0.22	0.26
17	Zb-44	3994	Yamama							−27.21	−26.33	1.7	0.27	0.81	0.23		35.9	22	42		
18	NR-7	3400	Yamama			0.16	0.15	0.4		−27.85	−26.6	1.07	0.25	0.56	0.06	0.43	31.9	20.9	47.2	2.1	0.59
19	WQ-15	3649	Yamama							−27.5	−26.71	1.89	0.42	0.97	0.13	1	33.9	24.3	41.8		
20	Rt-5		Yamama			0.84	0.18	0.29	0.61	−27.51	−26.93	1.24	0.33	0.91	0.13	0.96	35.5	23.6	40.9	0.36	0.24

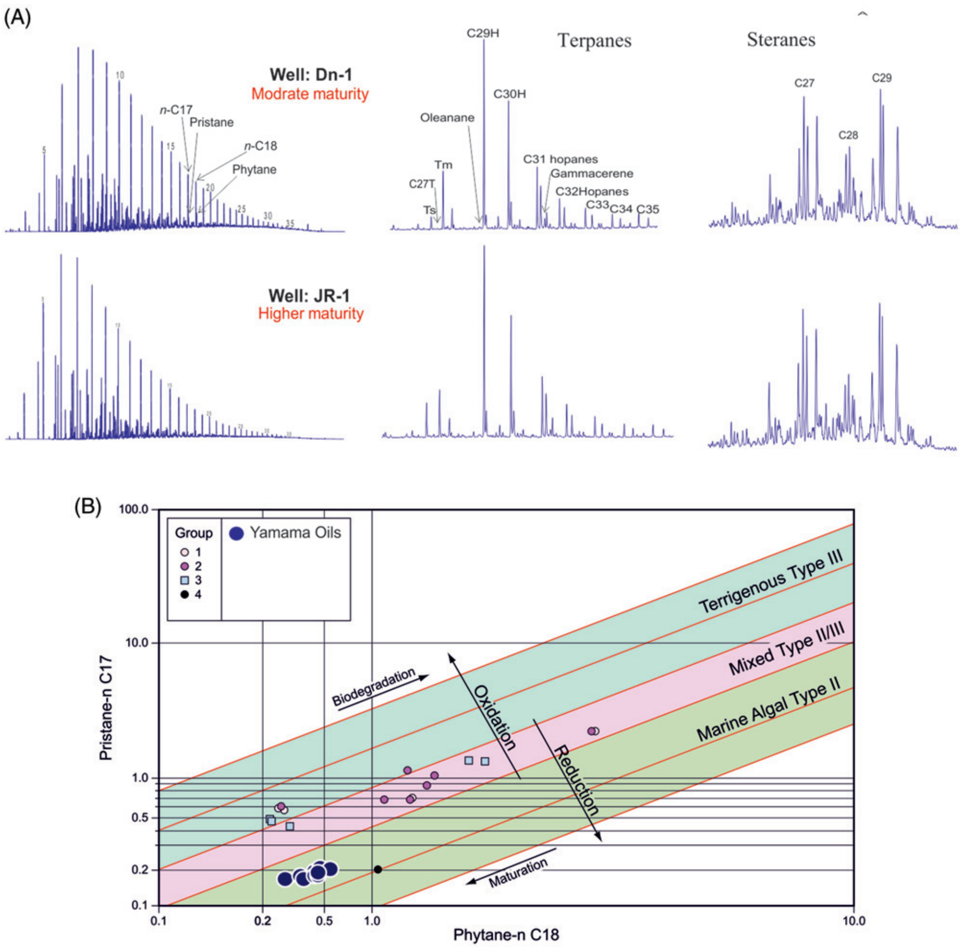

Figure 4. Gas chromatography of saturated hydrocarbon fraction of the analyzed Yamama oils, Terpanes, Steranes and diasteranes distribution in the m/z 191 mass fragmentograms in the saturated fraction of two representative oil samples.

Yamama oils and source bitumen generated at the different stages of thermal maturity, and provided several indicators that can be used to interpret the depositional environment of the sediments. Oils separated into two groups A and B. Oils of group A, were characterized of saturated, higher API gravity, low sulfur content due to higher thermal maturity confirmed by higher ratios of C_{27}Ts/Tm, TAS3 and C_{24} tetracyclic terpane, higher plant input due to higher C_{19}/C_{23} ratio, anoxic based on higher C_{35} homohopane index, lowest pr/$n$$C_{17}$ and ph/nC_{18}, with low salinity due to lower GA/C31R ratio, than aromatic oils of group B. Oils of group A have also less negative value of $\delta^{13}C_{saturated}$ in the range −26.35 to −26.63‰ compared with those of group B which they have δ13C in the range −27.5 to −27.81‰.

The source rock extracts and oil samples correlation must have equivalent levels of thermal maturity (Hunt 1996). The available source rock are either more or less level maturity than the Yamama oil samples (Table 1B). Two genetic oil groups were identified based on the Sterane C_{27}–C_{28}–C_{29} ternary diagrams (Grantham and Wakefield 1988; Figure 6A), and the stable carbon isotopes of saturated and aromatic hydrocarbons plot (Sofer 1984; Figure 6B), for rocks and oils (Table 1B).

Upper Jurassic-Lower Cretaceous Yamama and Sulaiy source have similar C_{27}, C_{28}, C_{29} steranes ratios with average of 38.8, 22.8 and 42.5 respectively, and δ^{13}C saturated and aromatic of

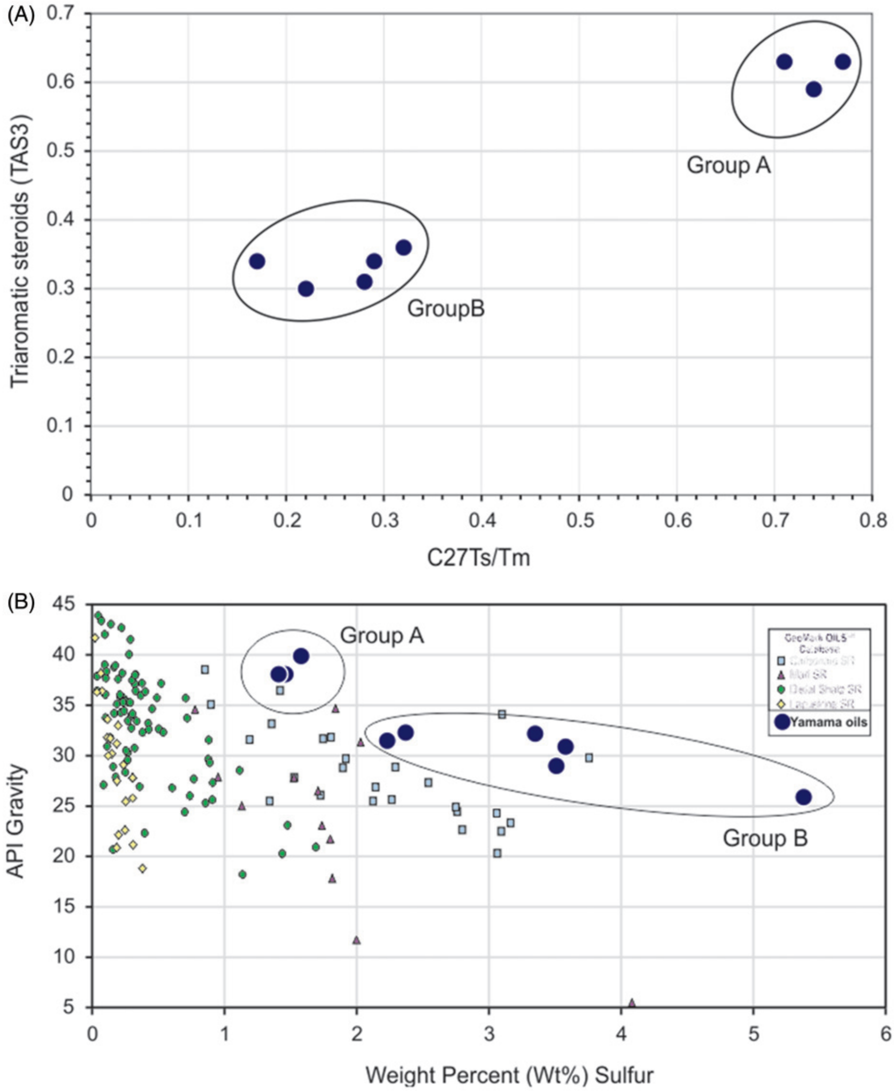

Figure 5. **(A)** C27 Ts/Tm vs Triaromatic Steranes (TAS3) biomarker ratios plot show thermal maturity of samples. **(B)** The plot of API Gravity and weight % sulfur of Yamama -reservoired oils as an indicator of thermal maturity

average -26.97, to those of oils group A. While oils of group B correlated well with rich, marginally mature, Sargelu source rocks. This is consistent with the previous studies (e.g. Al-Ameri et al. 2009; 2014; Abeed et al. 2011).

4. Conclusions

1. Analyzed crude oils were non-biodegraded, derived from marine carbonate and marl source rock deposited under reducing conditions, and high to moderate maturity.
2. Some geochemical parameters showed that oils were separated into two genetic groups. Group A was aromatic, and high maturity oils may be originated from Upper Jurassic to Lower Cretaceous Sulaiy-Yamama Formations. Group B was saturated oils, moderate maturity and may be originated from Middle to upper Jurassic Sargelu Formation.

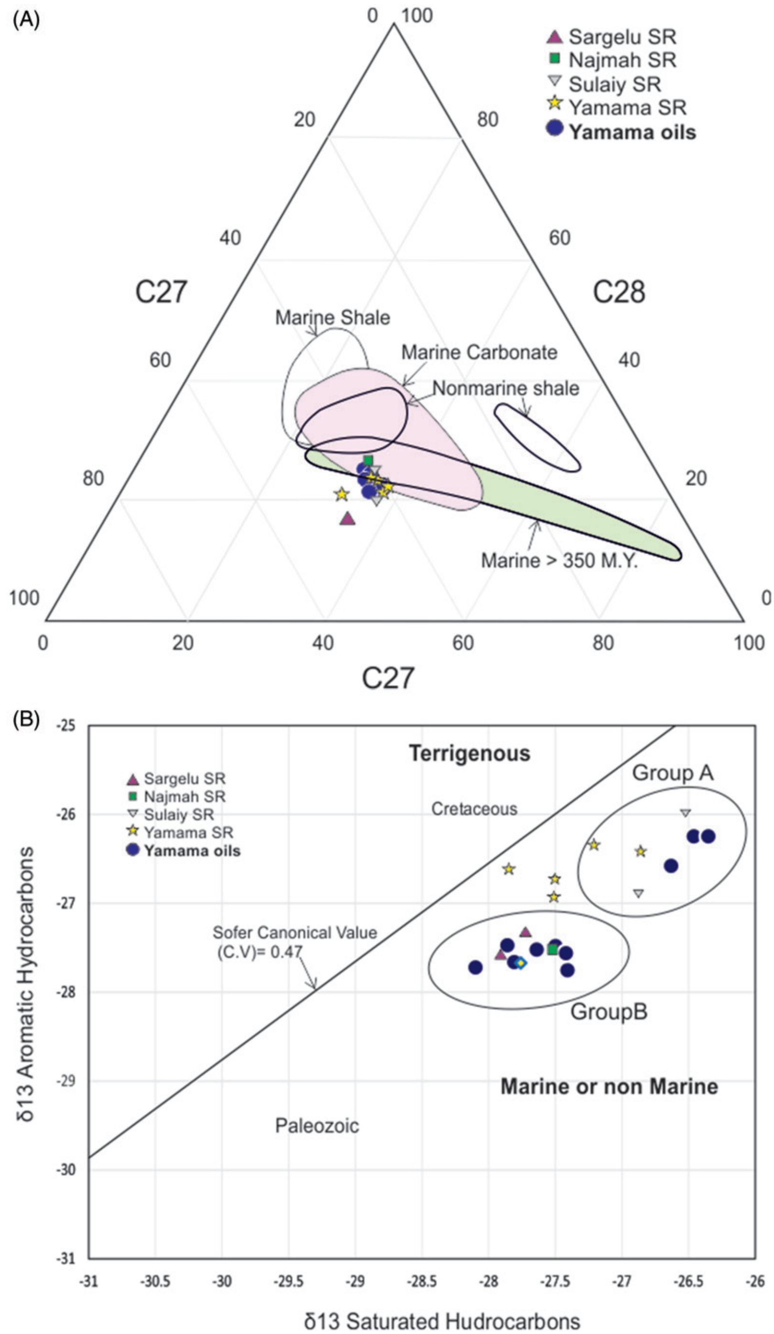

Figure 6. **(A)** Ternary diagram of regular steranes (C27-C29) indicating the relationship between sterane compositions in relation to organic matter input and depositional environments. **(B)** Plot of the δ13C values of aromatic fractions versus of the δ13C values of saturated fractions for analyzed Yamama oils samples. (after Sofer,1984).

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References

Abeed, Q., A. J. Al-Khafaji, and R. Littke. 2011. Source rock potential of the Upper Jurassic Lower Cretaceous succession in the Southern part of the Mesopotamian basin (Zubair subzone), Southern Iraq. *Journal of Petroleum Geology* 34 (2):117–34. doi: 10.1111/j.1747-5457.2011.00497.x.

Al-Ameri, T. K., A. J. Al-Khafaji, and J. Zumberge. 2009. Petroleum system analysis of the Mishrif reservoir in the Ratawi, Zubair, North and South Rumaila oil fields, southern Iraq. *GeoArabia* 14(4):91–108.

Al-Ameri, T. K., A. A. Najaf, A. S. Al-Khafaji, J. Zumberge, and J. Pitman. 2014. Hydrocarbon potential of the Sargelu formation, North Iraq. Arabian *Journal of Geosciences* 7(3):987–1000. doi: 10.1007/s12517-013-0875-8.

Al-Khafaji, A., T. Al-Ameri, and Q. Abeed. 2014. Oil and gas play and prospect assessments of babel, Diwania and Karbala governorates (Middle Euphrates region), Iraq. *Arabian Journal of Geosciences* 7(8):3147–61. Volume Issue pp doi: 10.1007/s12517-013-0980-8.

Al-Khafaji, A. 2015. The Mishrif, Yamama, and Nahr Umr reservoirs petroleum system analysis, Nasiriya oilfield, Southern Iraq. *Arabian Journal of Geosciences* 8(2):781–98. doi: 10.1007/s12517-014-1277-2.

Al-Khafaji, A. J., M. H. Hakimi, and A. A. Najaf. 2018. Organic geochemistry characterisation of crude oils from Mishri reservoir rocks in the Southern Mesopotamian basin, South Iraq: Implication for source input and paleoenvironmental conditions. *Egyptian Journal of Petroleum* 27(1):117–30. doi: 10.1016/j.ejpe.2017.02.001.

Aqrawi, A., J. Goff, A. Horbury, and F. Sadooni. 2010. *The petroleum geology of Iraq*. Beaconsfield, UK: Scientific press ltd, 424.

Aqrawi, A. Badics, B. 2015. Geochemical characterisation, volumetric assessment and shale-oil/gas potential of the Middle Jurassic–Lower cretaceous source rocks of NE Arabian plate. *GeoArabia* 20(3):99–140.

Grantham, P., and L. Wakefield. 1988. Variations in the sterane carbon number distributions of marine source rock derived crude oils through geological time. *Organic Geochemistry* 12(1):61–73. doi: 10.1016/0146-6380(88)90115-5.

Hunt, J. M. 1996. *Petroleum geochemistry and geology*. New York: W.H. Freeman and Company, 743.

Peters, C. C., Walters, and J. M. Moldowan. 2005. *The biomarker guide: Biomarkers and isotopes in petroleum exploration and earth history*. (2nd ed.), vol.2, Cambridge: Cambridge University Press.

Peters, K. E., T. H. Fraser, W. Amris, B. Rustanto, and E. Hermanto. 1999. Geochemistry of crude oils from Eastern Indonesia. *American Association of Petroleum Geologists Bulletin* 83:1927–42.

Pitman, J. K., D. Steinhouer, and M. D. Lewan. 2004. Petroleum generation and migration in the Mesopotamian basin and Zagros fold belt of Iraq: results from a basin modelling study. *GeoArabia* 9:41–72.

Sadooni, F. N., A. M. Aqrawi. 2000. Cretaceous sequence stratigraphy and petroleum potential of the Mesopotamian basin, Iraq. *Special Publication 69, Society of Sedimentary Geology*. ISBN 1-56576-075-1, 315–34.

Sadooni, F. N. 1993. Stratigraphic sequence, Microfacies, and petroleum prospects of the Yamama formation, Lower cretaceous, Southern Iraq. *AAPG Bulletin* 77:1971–88.

Sofer, Z. 1984. Stable carbon isotope compositions of crude oils: Application to source depositional environments and petroleum alteration. *AAPG Bulletin* 68:31–49.