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Crude oil classification based on age and provenance from the Southern Iraq: A review

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Abstract: A collection of 165 crude oils, 12 oil seeps, and 24 extracts and recovered samples from 25 oil exploratory wells and 6 oil seeps in the Southern Mesopotamian Basin were studied. Biomarker configurations and other organic geochemistry parameters were used to discover the depositional environments and to classify the oil samples as provenance groups. Petroleum liquids were geochemically classified into four groups. The first group of oils, Middle Jurassic Zagros Fold Belt, is located in the Maysan, Basra, and Thi qar provinces of the basin that has pristane/phytane (Pr/Ph) proportions ≤0.97 and contains sufficient gammacerane. Methylphenanthrene index 1 (MPI 1) values show that the first group of oils is mature. Oils from Group 2, Upper Jurassic–Lower Cretaceous Sulaiy/Yamama, by disparity have Pr/Ph proportions between 0.72 and 1.12 and relatively moderate C_{28}/C_{29} steranes, 0.52-0.88. Ts/Tm ratios indicate thermal maturity for Group 2 oils. Unlike oils from other groups, the oils from Group 3, Cretaceous to Tertiary oils, in Subba Field hold the highest canonical variable (CV) values that range between 0.43 and –2.30. The fourth group, Late Triassic-Middle Jurassic oil seeps, is the oldest among all groups. This group holds an average carbon isotope ratio –28.25‰ and –28.10‰ for saturates and aromatics respectively, which are the lowest values among all oils in the studied region. The Tithonian-Berriasian Sulaiy/Yamama oils further divided into three subgroups. The first subgroup, A, has carbon preference index (CPI) values of ≤1.08 (average 0.86) and C_{28}/C_{29} sterane of 0.56-1.13 with an average of 0.65. Second subgroup, B, holds CPI ≤1.18 (average 0.99) and C_{28}/C_{29} sterane 0.55-0.82 with an average of 0.63. The last subgroup, C, has CPI values ≤0.93 (average 0.85) and high C_{27} and C_{29} steranes (average 46.5% and 39.61%, respectively). In the same way, the Group 3 can be further subdivided into two subgroups based on values of carbon isotopes for saturates and aromatics. The oils from this group are heterogeneous and can be further divided into Tertiary Subgroup and Cretaceous Subgroup.

Keywords: Biomarker, Mesopotamian Basin, petroleum, oil classification, maturity, depositional environment, petroleum's physical property, Iraq

INTRODUCTION

The Mesopotamian Basin occurred as a consequence of rifting during the Triassic on the margin of New Tethys Sea (Ayres *et al*., 1982). In this producing area, the source rocks are mainly limestone and shale (Pitman *et al*., 2004); predominantly condensed sections (Sharland *et al*., 2001) deposited during Middle–Upper Jurassic which considered one of the supreme petroleum systems in the world (Beydoun, 1992; Alsharhan & Nairn, 2003; Aqrawi *et al*., 2010) that encompass oil and gas fields throughout Iraq. Lower Cretaceous reservoir units are the main oil reservoirs in the Mesopotamian Basin, Southern Iraq. In Southern Iraq, Yamama Formation encompasses hydrocarbons at 26 structures (Sadooni, 1993; Jassim & Al-Gailani, 2006). The Mishrif Formation contains about 30% of Iraq's total oil reserves (Al-Khersan, 1975; Reulet, 1982; Aqrawi *et al*., 1998).

Seventy-three oilfields have been identified in Iraq, since the late-1920s. These oilfields are mostly situated in the northern and southern parts, and several are located in the Western Iraq. Although the Mesopotamian Basin is considered as one of the prevalent petroleum basins (Al-Sakini, 1992; Sadooni & Aqrawi, 2000), it has not been investigated well. Only a few investigations have been published (Abeed *et al*., 2012). Some investigations have been done on the potential source rocks in the area. The presence of potential source rocks in the Mesopotamian Basin is Sulaiy, Yamama and Ratawi, and Zubair formations (Al-Ameri *et al*., 2009; Abeed *et al*., 2011). Lower Cretaceous units encompass huge petroleum amounts in the basin (Al-Obaidi, 2009) such as Nahr Umar Formation, which contain hydrocarbon that originated from underlying Cretaceous formations like Sulaiy and Yamama (Ibrahim, 1983). The petroleum potentiality of Upper Jurassic Sulaiy Formation in Southern Iraq also was confirmed by Sadooni (1997) as it contains sufficient amount of mature TOC, kerogen type II, based on its palynological facies and depositional environment setting (Al-Ameri & Batten, 1997; Al-Ameri & Al-Musawi, 2011; Al-Ameri *et al*., 1999; Al-Musawi, 2010; Al-Ameri *et al*., 2013; Abeed *et al*., 2013; Al-Ahmed & Al-Obaidi, 2016). Similarly, the Yamama and Ratawi formations are also considered as a good source rocks

(Al-Musawi, 2010; Al-Agaili, 2012; Al-Ameri & Al-Zaidi, 2014; Al-Ibrahim & Al-Ameri, 2015; Al-Khafaji, 2015). All three formations' organic matter is mature within the oil window. The Zubair and Nahr Umar formations' organic matter are also considered quantitatively good, but are at the early thermal maturation (Al-Shahwan, 2002). The shale units within Zubair Formation encompass pyrite which demonstrates reductive depositional setting; thus it might have source rock properties (Idan *et al*., 2015). The Sulaiy, Yamama, Ratawi, Zubair, and Nahr Umar formations are the most likely source rocks in the region which have fed the reservoirs. However, the giant amount of petroleum stored in these reservoirs suggests contribution from other source rocks (Jafar, 2010). The biomarkers and carbon isotopes that were used to correlate crude oils in Mishrif Formation reservoir with possible source rocks; Naokelekan and Sargelu formations, in Southern Iraq proved the link between crude oils in Ratawi, North Rumayla, and South Rumayla oil fields with Jurassic source rocks (Al-Khafaji, 2006).

Nevertheless, without a broad analysis of oils across the area, the geochemical setting of the existing hydrocarbons remains unclear. The basin (Figure 1) encompasses oils from different types of source rocks such as carbonate-rich and mixture of marl and shale.

In this study, 165 crude oils, 12 oil seeps, and inferred 24 source rock samples (Tables 1 and 2) that are located in the Southern Iraq were reevaluated. The main objective of this research is to recognize genetic and provenance classification of crude oils in the studied area to determine the age and depositional settings of source-rocks by utilizing traditional geochemical factors.

GEOLOGICAL SETTING

The studied region (Figure 1) is sited at the Iraq's southern portion within the Mesopotamian Basin, of the Stable Shelf on the basis of longitudinal tectonic classification of Iraq. The Mesopotamian Zone is a comparatively plane terrain which has a slope of no more than 10 cm per km that extends from Baiji to the Persian Gulf. It is surrounded by the folded ranges of Pesh-i- Kuh in the Northeast and Hemrin and Makhul in the North. The Southwest margin is affected by existence of faults (Aqrawi *et al*., 2010).

The Stable Shelf is a monocline slightly exaggerated by Late Cretaceous and Tertiary distortion. Perhaps it was raised during the Hercynian Orogeny; however, it dwindled between Late Permian until Late Tertiary (Jassim & Buday, 2006). The bearings of the structures in this region were prejudiced by the geometry of the basement blocks, Palaeozoic epirogenic events and Mesozoic bending. The Precambrian basement is 5 km, 11 km, and 13 km deep in the Center, West, and East of the area, respectively (Jassim & Buday, 2006).

In the Mesopotamian Zone, the fold structures generally have NW-SE and N-S directions in the eastern part and southern part, correspondingly. Structures of this area usually have positive residual gravity irregularity excluding the structures of Zubair and Rumayla which associated with

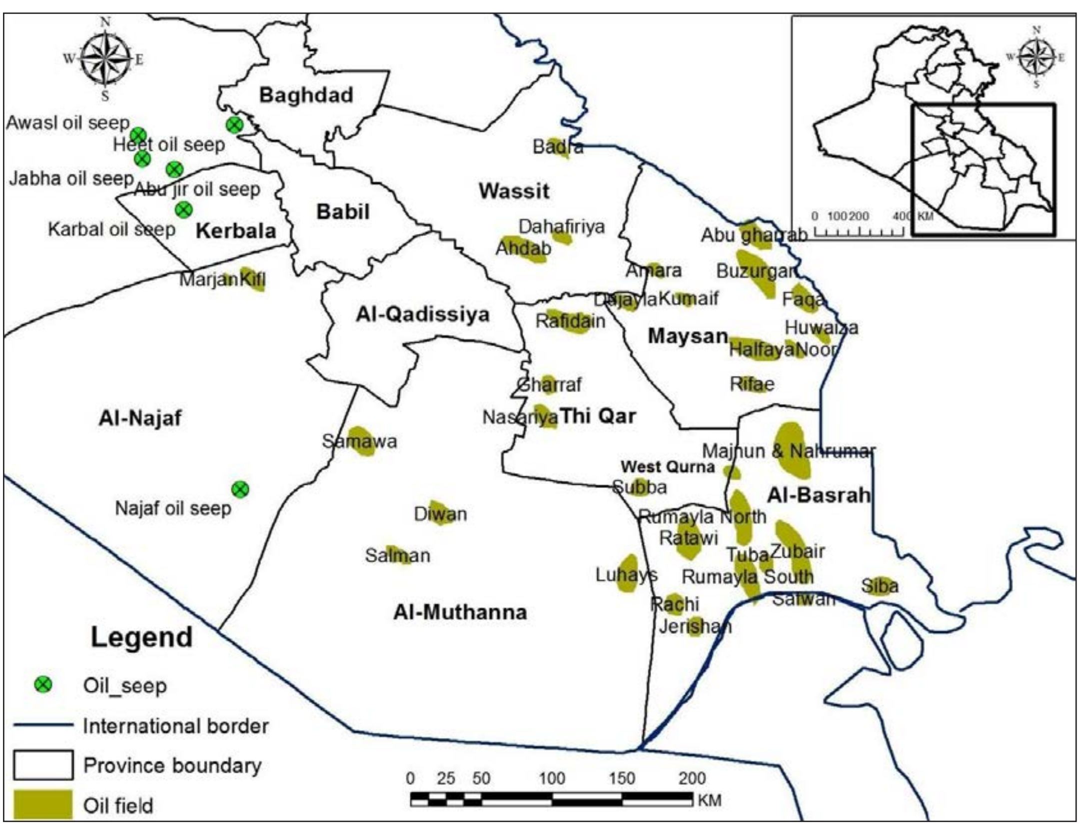

Figure 1: Index map of Southern Mesopotamian Basin, Iraq displaying the wells' locations (adapted from Aqrawi *et al*., 2010).

the negative residual gravity anomaly. The negative gravity anomalies within the structures are related to halokinetic movement of Infracambrian evaporite (Jassim & Buday, 2006). Therefore, the structures of Rumayla, Zubair, and Nahr Umar are not connected to the Alpine Orogeny, but are likely interrelated to passive diapirs movement of Infracambrian evaporite.

There are three subzones within the Mesopotamian Zone: the Zubair Subzone in the South, the Euphrates Subzone in the West, and the Tigris Subzone in the Northeast. The Tigris Subzone is the broadest part of the Mesopotamian Zone which contains expansive synclines and narrow anticlines associated with normal faults (Al-Heety *et al*., 2017).

In the Mesopotamian Zone, the sedimentary column thickens to the east. It comprises 1100 m, 500-700 m, 700-1400 m, 200-900 m, and 150-1500 m of Jurassic, Lower Cretaceous, Upper Cretaceous, Palaeogene, and Neogene and Quaternary sections, respectively (Jassim & Buday, 2006).

Effective source rocks in the area include Middle Jurassic to Cretaceous units which are represented by Sargelu, Naokelekan, Sulaiy, Yamama, Ratawi, and Zubair strata (Al-Ameri *et al*., 2009; Abeed *et al*., 2011) occurring all over the basin (Figure 2).

The total organic carbon (TOC) wt.% of samples from the Zubair Formation fluctuates between 0.40 and 1.00 wt.%; nevertheless, two extraordinary samples had 2.70 and 22.00 wt.% TOC and are marginally immature to mature with Ro = 0.30–0.80% (Al-Ameri *et al*., 2009; Abeed, 2012). Ratawi Formation samples had 0.60 to 1.40 wt.% TOC, mature with Ro = 0.50–1.00% and Yamama Formation's samples contain 0.30 to 2.70 wt.% TOC while samples from Sulaiy Formation have the highest TOC wt.% reaching up to 10.00 wt.% (Al-Ameri *et al*., 2009; Abeed, 2012).

SAMPLES AND METHODS

A total of 201 geochemical data points from 126 boreholes in 25 oilfields in the Southern Mesopotamian Basin (Tables 1 and 2) were extracted from numerous previous published and unpublished studies (including Master's thesis and PhD dissertations: Al-Ameri *et al*., 2009; Al-Musawi, 2010; Al-Ameri *et al*., 2011; Abeed *et al*., 2012; Al-Agaili, 2012; Al-Ameri & Al-Khafaji, 2014; Al-Ameri & Al-Zaidi, 2014; Al-Ameri *et al*., 2015; Al-Ibrahim & Al-Ameri, 2015; Al-Khafaji, 2015; Awadh & Hussien, 2015; Eqal, 2015; Idan *et al*., 2015; Al-Ahmed & Al-Obaidi, 2016; Al-Khafaji *et al*., 2017; Hasan & Al-Dulaimi, 2017; Deng *et al*., 2018).

The combined data was reviewed and used to establish links and increase clarity in the previous studies. The crude oils in each of Kut, Maysan, Thi qar, Muthana, Basra, and oil seeps in Najaf, Karbala, and Anbar provinces (Figure 1) were described and categorized based on bulk and molecular concentrations.

Later, the biomarker configurations and constraints of the crude oils in the entire basin established the palaeoenvironment, depositional environments, and to group the oils geochemically. Finally, the crude oils were linked to source rocks according to geochemical similarities and dissimilarities.

PHYSICAL AND CHEMICAL PROPERTIES OF CRUDE OILS

For the succeeding annotations, refer to Tables 1 and 2, and for abbreviations, Appendix A.

Physical and chemical properties of the Southern Mesopotamian oils vary with specific gravities. The specific gravity revealed different values e.g. 0.83 g/cm^3 in Nahr Umar-11 and 0.95 g/cm^3 in the Faqa-11. Samples from Halfaya-1 condensate had specific gravities as low as 0.77 g/cm^3.

Viscosities reach 310 centipoise for Basra oils generally (Ali & Al-Ausi, 2008). Pour point reaches –15 ºC for Basra light oils (Aalund, 1983). Kinematic viscosity reaches 25.4 mm^2 /sec at 25 ºC as of Nasariya oils (Al-Yasiri & Khathi, 2016).

The total sulfur contents, wt.%, are 1.58 and 5.90 for Subba-8 and West Qurna-35, correspondingly and one condensate sample has sulfur content of 0.63 wt.% that belongs to Halfaya-1 in Khasib Formation reservoir.

Other properties such as water content can be as high as 2.40 vol.% in Noor crude oil, H_2S content reaches 0.49 ppm in Halfaya crude oil, CO_2 content reaches up to 0.96 ppm in Noor crude oil, and salt content can be as great as 44 ppm in Noor crude oil (Jasim, 2019). The oil in West Qurna-15 contains 1.1-5.0 mole % H_2S by oil volume (Chafeet, 2016).

The vanadium concentration ranges from 0.50 ppm in Zubair-4 to 163.00 ppm in Halfaya-109. The nickel concentration ranges from 0.18 ppm in Zubair-4 to 41.00 ppm in Halfaya-9. Subba-8 oil neither contains vanadium nor nickel. The data required for oil classification according to Tissot & Welte's (1984) classification is available for 126 oils in the Southern Iraq. 102 (81%) of oils are aromatic asphaltic, 18 (14%) oils are aromatic intermediate, 4 oils are paraffinic, and 2 oils are paraffinic naphthenic.

OUTCOMES AND DISCUSSIONS

Classification of oils

The crude oil samples from Southern Iraq were reassessed and then classified into four groups (Figure 3). Group 1 [the oils from Abu Gharab, Faqa, Huwaiza, Buzurgan, Halfaya, Noor, Amara, and Rafae fields] from Maysan Province, Nasariya in Thi qar Province, and Majnun in Basra Province; Group 2 [Ratawi, Tuba, Rumayla South, Rumayla North, Nahr Umar, Safwan, Zubair, West Qurna, and Luhays in Basra Province; Ahdab in Kut Province; and Najaf oil and gas seep in Najaf Province]; Group 3 [the oils from Subba Oil Field] from Thi qar Province; and Group 4 [the oil seeps from Karbala, Abu Jir, Jabha, Heet, and Awasel] from western boundary of the Mesopotamian Basin in Karbala and Anbar provinces.

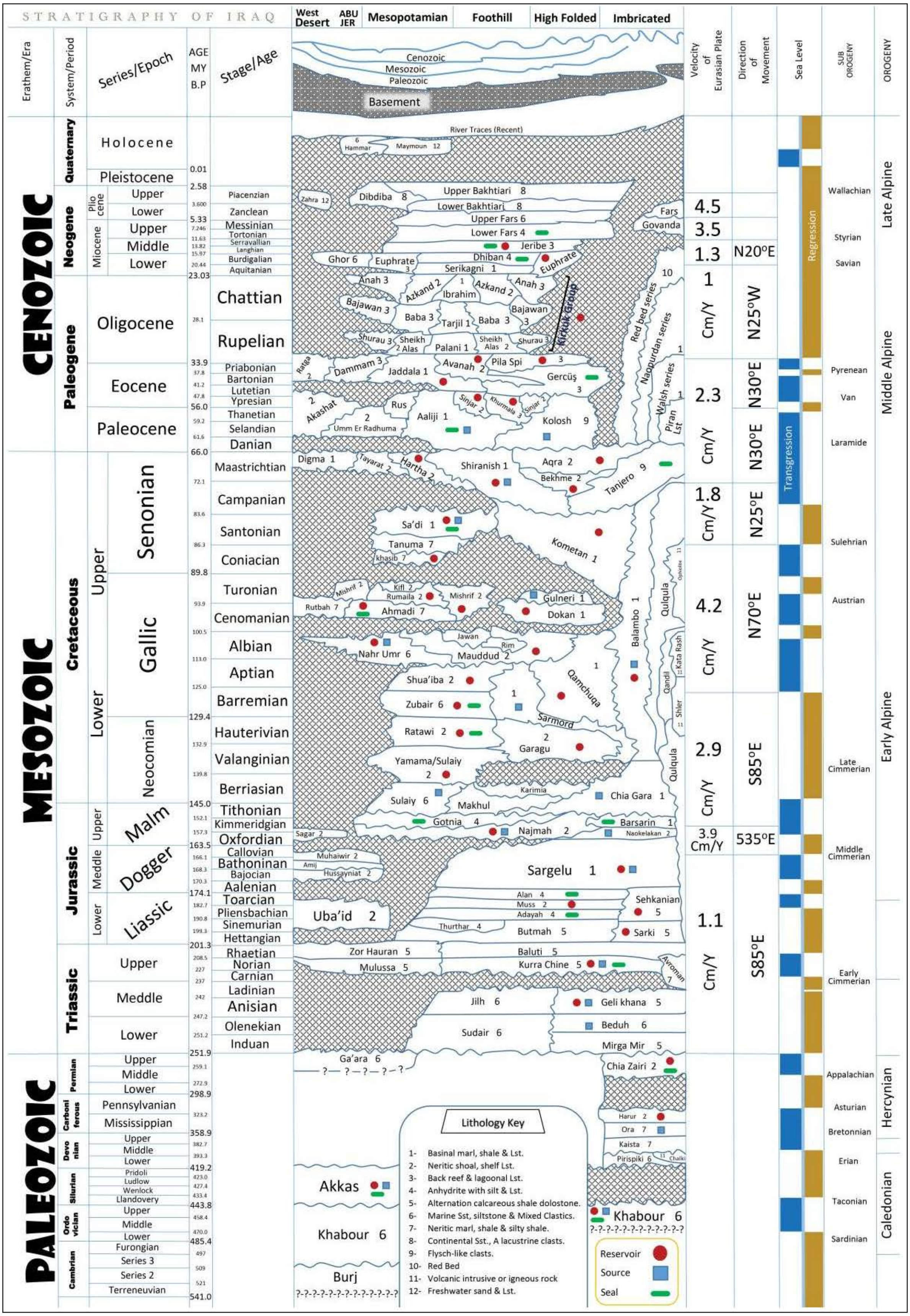

Figure 2: Stratigraphic correlation chart of the Mesopotamian Basin, Iraq (redrawn by Bawan, 2015, pers. comm.).

Table 1a: Geochemical properties of oils from different wells in Southern Iraq.

Field	API	%S	ppm Ni	ppm V	%Sat.	%Aro.	%NSO	%Asph.	Pr/Ph	Pr/ n-C_{17}	Ph/ n-C_{18}	$\delta^{13}C_{at.}$
Abo Gharab	20.9	4.3	34.2	3.6	22.8	48.4	15.5	13.4	0.6	0.1	0.3	-27.6
Faqa	20.3	3.9			22.9	49.5	14.8	12.8	0.6	0.1	0.3	-27.6
Buzurgan	22.3	3.8	23.0	2.3	22.5	46.7	14.5	16.4	0.6	0.1	0.3	-27.7
Halfaya	28.2	3.3	26.7	102.0	33.0	39.4	14.0	13.6	0.7	0.2	0.3	-27.6
Noor			28.0	2.8	31.5	40.0	14.7	13.8	0.6	0.2	0.2	
Amara	21.6	3.5	19.1	45.5	25.8	42.5	15.9	15.9	0.7	0.1	0.3	-27.5
Nasariya	26.8	3.9	16.7	67.8	28.9	49.0	17.4	4.7	0.8	0.2	0.3	-27.5
Majnun					24.7	46.5	14.9	14.0	0.8	0.2	0.3	-27.6
Ratawi	33.2	3.1	16.3	64.7	42.8	34.7	13.6	8.9	0.7	0.2	0.3	
Luhays	27.1	4.3	35.0	113.0	31.5	52.1	13.4	3.0	0.7	0.2	0.3	
Tuba	25.0	4.2	12.0	40.0	26.2	48.9	19.3	5.7	0.7	0.2	0.4	
Rumayla South	31.0	3.8			27.2	45.6	19.0	8.2	0.7	0.2	0.3	
Rumayla North					45.0	36.7	11.4	6.9	0.7	0.2	0.3	
Nahr Umar	40.0	2.3			42.3	27.1	29.6	0.9	0.7	0.3	0.4	
Safwan		3.3			25.9	49.2	23.0	1.9	0.8	0.2	0.4	
Zubair-A	27.3	3.9	0.2	0.5	31.9	42.5	21.8	3.8	0.7	0.2	0.4	-27.5
Ahdab	23.0								0.5	0.3	0.5	-27.2
Zubair-B	25.3	4.2	15.0	62.0	23.5	58.2	11.5	6.8	0.8	0.2	0.3	-27.3
West Qurna	25.9	6.0	25.3	92.8	19.0	52.2	18.3	10.5	0.8	0.2	0.4	-28.1
Subba-A	39.9	1.6	0.0	0.0	32.1	27.2	20.5	20.2	0.8	0.2	0.2	-27.3
Subba-B					7.7	15.3	20.6	56.4				-25.7
Abu Jir					6.1	24.3	17.9	51.7				-28.5
Heet					5.9	24.6	22.8	46.7				-28.4
Jabha					7.9	30.6	18.7	42.9				-28.2
Awasel					6.5	18.8	17.0	57.7				-28.2

Group 1 oils (Middle Jurassic Zagros Fold Belt)

The oils from Abu Gharab, Faqa, Buzurgan, Huwaiza, Halfaya, Noor, Amara, and Rafae fields which are located in Maysan Province belong to this group. The first three fields cross into Iranian land. The oils from Nasariya in Thi qar and Majnun in Basra fields belong to this group, too. The oil pay zones range between 4430-1987 m depth and are accumulated in reservoirs ranging from Tithonian-Berriasian (Sulaiy)-Early Miocene (Jeribe-Euphrate).

The dimensions (length and width) of these oil-fields are: Majnun (48, 11 km), Faqa (30, 10 km), Noor (20, 6.5 km), Amara (16, 5 km) according to the seismic data collected from the Oil South Company in 1987. The oils from this group have an API° between 15.30-37.80 and sulfur content 2.00-5.12 wt.% excluding one sample from Halfaya-1 Well in Khasib Formation reservoir that has an API° of 52.80 and sulfur content of 0.63 wt.%.

This assemblage of oils holds CPI values between 0.83-1.18 and Pr/Ph proportions of ≤0.97. A low Pr/Ph proportion designates anoxic depositional settings (Haven *et al*., 1987, 1988). A ratio of Pr/n-C_{17} to Ph/n-C_{18} designates maturity of oils (Peters *et al*., 1999). From this ratio, the source rocks that have generated oils to this group were deposited in a reducing setting. All samples have Pr/n-C_{17}<0.5 indicating marine depositional environment (Peters & Moldowan, 1993). The existence of gammacerane in Halfaya and Nasariya oils indicates commonly hypersaline depositional setting for oils' source (Philp *et al*., 1991). The oils from this group have moderately great quantities of algal-originated C_{27} steranes e.g. Nasariya-1 (Figure 4). The proportions of Pr/n-C_{17} and Ph/n-C_{18} are similarly supports the algal and bacterial organic matter contribution to these oils. In addition to abundance of gammecerane which indicates Middle Jurassic age, a low relative abundance ratio of C_{28} to C_{29} sterane, 0.33 to 0.69 also indicates Middle Jurassic age (Grantham & Wakefield, 1988).

The oils' carbon isotope ratios are between –28.12‰ and –27.00‰ (mean –27.56‰) for saturates and between –27.92 and –27.16 for aromatics with an average value of –27.66. These ranges are corresponding to marine organic

Table 1b: Geochemical properties of oils from different wells in Southern Iraq.

Field	$\delta^{13}C_{aro.}$	CV	CPI	C_{19}/C_{23} T	Tet/C_{23} T	%C_{27}	%C_{28}	%C_{29}	OL/H	C_{29}/H	$C_{35}S/C_{34}S$	C_{31}R/H
Abo Gharab	-27.6	-3.0	1.0									
Faqa	-27.6	-3.3	1.1									
Buzurgan	-27.8	-3.3	1.1									
Halfaya	-27.6	-3.2	1.1	0.1	1.3	34.9	24.6	40.5	0.0	1.7	1.0	0.6
Noor			1.1									
Amara	-27.3	-2.8	1.1	0.1	1.3	33.3	24.3	42.5		1.2	1.0	0.3
Nasariya	-27.8	-3.8	1.0	-3.8	1.2	35.8	22.7	41.5	0.0	1.6	1.1	0.3
Majnun	-27.7	-3.3	0.9			33.6	25.1	41.3			1.0	0.4
Ratawi			0.9	0.2	1.6	34.3	25.0	40.7	0.0	1.5	0.1	0.3
Luhays			0.8	0.1	1.2	38.6	25.5	35.9	0.0	1.6	1.0	0.3
Tuba			0.8	0.1	1.5	40.3	25.3	34.4	0.0	1.4		
Rumayla South			0.9	0.1	1.3	33.4	25.5	41.2	0.0	1.5	1.1	0.4
Rumayla North			1.1	0.1	1.3	33.7	26.2	40.1	0.0	1.4	1.1	0.4
Nahr Umar			0.8									
Safwan			0.8									
Zubair-A		-3.8	0.8	0.1	1.3	33.7	25.2	41.1	0.0	1.4	1.1	0.4
Najaf	-27.4	-2.9								1.5	0.9	0.4
Ahdab			1.0			40.3	23.1	36.6				
Zubair-B	-27.5	-3.9	0.8			46.3	13.6	40.2		1.7	1.0	0.3
West Qurna	-27.5	-3.5	0.9			46.5	14.0	39.5		1.7	1.1	0.3
Subba-A	-26.9	-2.2	1.0	0.1	1.7	36.4	22.9	40.7	0.0	1.5	0.4	0.4
Subba-B	-23.9	0.4		7.4	2.1	20.5	24.3	55.2	0.0	0.8	1.0	0.3
Karbala	-28.0	-2.8								1.1	0.9	0.3
Abu Jir	-28.1	-2.1				26.1	21.7	52.2	0.0	1.1	1.0	0.3
Heet	-28.2	-2.6				30.9	23.3	45.8	0.0	1.1	1.1	0.3
Jabha	-28.2	-3.0				34.7	21.4	43.9	0.0	1.1	1.0	0.3
Awasel	-28.1	-2.7				32.7	21.5	45.8	0.0	1.1	1.0	0.3

matter type (Sofer, 1984). The CV was used to distinguish waxy oil from non-waxy oil; the CV values for this group of oils are between –5.03 and –1.89 with an average –3.32 which are less than 0.47; therefore, all of the oils are from a non-waxy source (Sofer, 1984).

Group 2 oils (Upper Jurassic–Lower Cretaceous Sulaiy/Yamama)

This group includes more than 40% of crude oil samples from this study. The oils from these oil fields Ratawi, Tuba, Rumayla North, Rumayla South, Nahr Umar, Safwan (Safwan is the fourth dome of the Zubair Oil Field in Iraq and extends into Abdalli, Kuwait), Zubair, West Qurna, Luhays in Basra Province; Ahdab in Kut Province; and Najaf oil and gas seep in Najaf Province.

The dimensions, length and width, of West Qurna, Shuaiba, Rafidiya, and Safwan are (35, 8), (34, 17), (11, 8), and (6, 4), respectively. The Shuaiba, Rafidiya, and Safwan auditoriums are called Zubair, while the West Qurna, North Rumayla, and South Rumayla belong to one structure based on seismic data reported by Oil South Company in 1987.

The geochemically heterogeneous relationship among oils in this group suggests further sub-grouping. Based on some biomarker and isotope parameters, the Malm oils are not linked together very strongly. This diverse relationship between oils from the different reservoirs was not investigated within earlier studies. To examine the genetic connection among the oils considered within this group, the use of many biomarker ratios is required because the oils appear to have more than one source. A relative abundance ratio of C_{28} to C_{29} sterane ranges between 0.32 and 1.13 indicates Upper Jurassic to Lower Cretaceous age. Gammacerane content in Zubair oils is another parameter that differentiates the oils and suggests mixed origin. The concentration of gammacerane in oils is variable indicating that the Upper Jurassic sources are contributed to the oils with different proportions. The Pr/Ph ratio also has a wide range and is between 0.10 and 0.88. Based on C_{28} to C_{29}

Table 1c: Geochemical properties of oils from different wells in Southern Iraq.

Field	GA/C_{30}H	GA/C_{31}R	C_{27}Ts/Tm	C_{29}Ts/Tm	TAS_3	MPI	OEP
Abu Gharab							1.0
Faqa							1.0
Buzurgan							0.9
Halfaya		0.2	0.2			0.8	0.9
Noor							1.0
Amara							1.0
Nasariya	0.2	0.2	0.2	0.1			1.0
Ratawi	0.0	0.2	0.3	0.1	0.3	0.2	
Luhays	0.1	0.2	0.2	0.1	0.3	0.2	
Tuba	0.1	0.2	0.3	0.1	0.3	0.3	
West Qurna					0.2		
Rumayla South	0.1	0.2	0.2	0.1	0.2	0.3	
Rumayla North		0.2	0.2	0.1			
Nahr Umar	0.0					0.2	
Safwan	0.0						
Zubair-A	0.1	0.2	0.2	0.1	0.2	0.2	
Ahdab	0.1		0.3			117.4	1.0
Zubair-B	0.3		0.2				
West Qurna	0.2		0.2			0.3	
Subba-A		0.2	0.4	0.1	0.6		
Subba-B		0.1	0.0	0.1			
Karbala							
Abu Jir		0.5					
Heet		0.7					
Jabha		0.4					
Awasel		0.5					

Source of data: Abeed *et al*., 2012; Al-Ahmed & Al-Obaidi, 2016; Al-Agaili, 2012; Al-Ameri *et al*., 2009; Al-Ameri *et al*., 2011; Al-Ameri & Al-Khafaji, 2014; Al-Ameri & Al-Zaidi, 2014; Al-Ameri *et al*., 2015; Al-Ibrahim & Al-Ameri, 2015; Al-Khafaji *et al*., 2017; Al-Khafaji, 2015; Al-Musawi, 2010; Awadh & Hussien, 2015; Deng *et al*., 2018; Eqal, 2015; Hasan & Al-Dulaimi, 2017; Idan *et al*., 2015.

sterane, gammacerane concentration, and Pr/Ph ratios the following subgroups are proposed (Figure 5):

Subgroup A

This subgroup includes oils from Ratawi, Luhays, Tuba, West Qurna (wells number 238, 245, 268, 269, and 284), Rumayla South, Rumayla North, Nahr Umar, Safwan, Zubair (except well number 163), and Najaf oil and gas seep. The oils have an API° ≤40 (average 28.33) and sulfur content ranges between 2.27% for Tuba-3b and 5.38% for Luhays-12 (average 3.77%). More than half of the oils are aromatic asphaltic, more than third of them are aromatic intermediate, and the rest of them are paraffinic naphthenic and paraffinic.

Based on environmental classification, oils from marine origin have low nickel to vanadium ratio (Ni/V<1) and moderate to high sulfur content (Lewan, 1984; Barwise, 1990; Peters & Moldowan, 1993). All oils have Ni/V<1 (0.13-0.36) and sulfur content ranges from 2.27-5.38 wt.% (average 3.77 wt.%); therefore, the oils are from marine origin. These oils have CPI values of ≤1.08 (average 0.86) and Pr/Ph proportions of ≤0.88 (average 0.71) proposing that they were originated from marine organic matter (Haven *et al*., 1987, 1988). The ratios of Pr/n-C_{17} to Ph/n-C_{18} are also indicating that the oils were originated from marine organic matter under reducing condition.

Higher virtual richness ratios of C_{28} to C_{29} sterane (0.56-1.13 with an average of 0.65) e.g. Zubair-4 oil (Figure 6) indicate Upper Jurassic to Cretaceous age. This subgroup has low C_{28}% sterane content (22.30-31.00%, average 25.20%) and high C_{27} and C_{29} steranes (average 36.36% and 39.44%, respectively) which indicate the mixed algae and land plant source (Peters & Moldowan, 1993; Gürgey, 2002). The Najaf oil seep has C_{28}/C_{29} sterane ratio of 0.70 which lies within the range of this subgroup.

A lower content of gammacerane in this group of oils is another parameter that supports the age of this

Table 2: Geochemical properties of extracts from different wells in Southern Iraq. The data from Al-Musawi, 2010; Al-Ameri *et al*., 2011; Idan *et al*., 2015.

Well	Depth (m)	Formation	Pr/ Ph	Pr/ n-C_{17}	Ph/ n-C_{18}	CPI	C_{22}/ C_{21}T	C_{24}/ C_{23}T	% C_{27}	% C_{28}	% C_{29}	C_{29}/ H	C_{35}S/ C_{34}S	C_{31}R/ H	OEP
Zubair-45	3338		0.0	0.0	0.4		1.4	0.4				1.4	1.1	0.4	
Rafidain-3	3448		0.7	0.2	0.2										
Gharraf-1	3364		1.2	0.3	0.3										
Rumayla South-4	3309		0.8	0.5	0.5										
Rumayla South-10	3127		0.6	0.1	0.2										
Rumayla South-78	3214		0.6	0.1	0.2		0.9	0.3				1.5	1.0	0.4	
Rumayila North-1	2788	Nahr Umar							27.3	27.7	45.0				
Rumayla North-1	3088	Shu'aiba							39.5	26.1	34.4				
Rumayla North-27	3214		1.5	1.0	0.5		1.7	0.3				1.6	1.0	0.4	
Rumayla North-167	4493	Sulaiy							30.1	35.0	34.9				
Rumayla North-167	4498	Sulaily	1.2	0.4	0.5	1.3									1.2
Rumayla North-172	4800	Sargelu	0.5	0.2	0.4	1.0									1.0
West Qurnah-2	3256		2.3	0.5	0.2										
West Qurnah-60	4010	Yamamma							35.5	22.7	41.8				
Abu Gharab-2	3320	Jaddala	1.0	0.2	0.3	1.1									1.1
Halfaya-2	4002	Rumaila	0.8	0.2	0.3	1.1									1.0
Amara-3	4518	Sulaily	0.5	0.3	0.4	1.0									1.0
Noor-1	4901	Sulaily	0.6	0.2	0.3	1.0									1.0
Nahr Umar-7	3051	Zubair							32.9	25.4	41.7				
Nahr Umar-7	3076	Zubair							34.9	24.2	40.9				
Nahr Umar-7	3400	Yamamma							32.8	25.2	42.0				
Nahr Umar-7	3444	Yamamma							36.0	22.0	42.0				
Nahr Umar-9	3815	Yamamma							31.9	23.5	44.6				
Nahr Umar-9	3909	Yamamma							32.0	24.9	43.1				

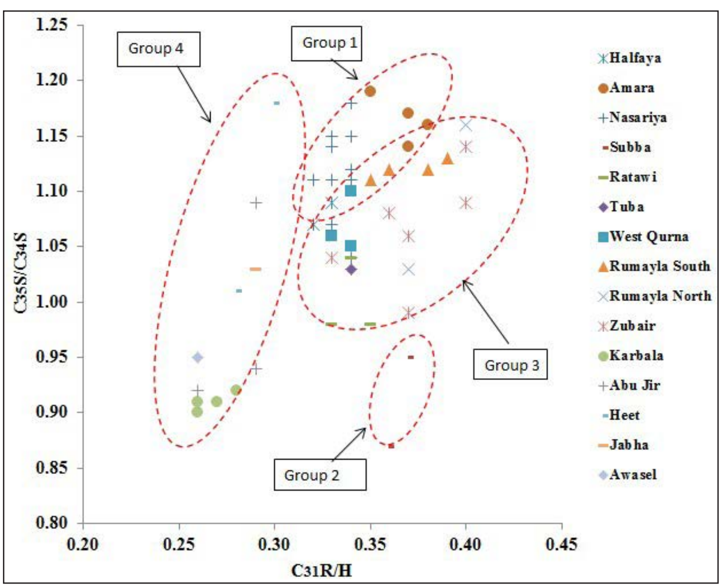

Figure 3: 3: Plot of 17α, 21β-30-homohopane (22R)/hopane (C_{31}R/H) versus C_{35} extended hopane/C_{34} extended hopane (22S) (C_{35}S/C_{34}S) for oils from Southern Mesopotamian Basin, Iraq. The plot differentiates oils. Samples have C_{35}/C_{34} values range (0.87-1.19), pointing a high saline reducing carbonate depositional setting with no obtainable free oxygen.

group to be Upper Jurassic-Lower Cretaceous (Grantham & Wakefield, 1988). The oleanane is originated from vascular plants which appeared during Late Cretaceous (Ekweozor & Udo, 1988). The low values or no presence of oleanane do not indicate that the Cretaceous sources were not contributed to oils because the oils probably

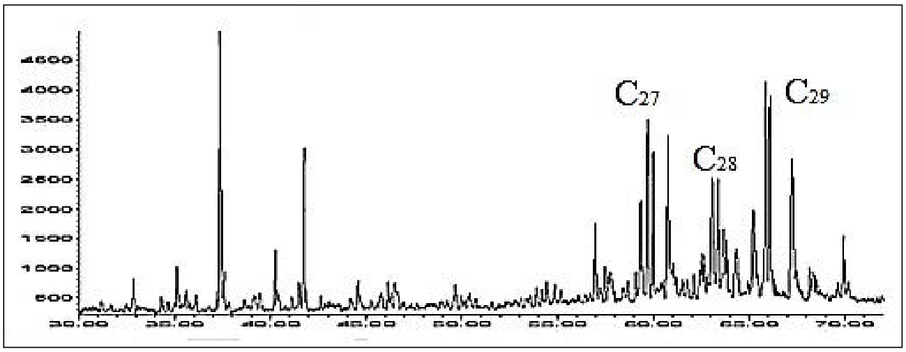

Figure 4: Biomarker analyses for crude oil from well Nasariya-1 which represents Group 1. Figure shows the analyses of m/z 217 (Al-Ameri & Al-Zaidi, 2014). .

were derived from sources with no angiosperm content (Ekweozor & Udo, 1988). The gammacerane index (gammacerane/hopane) for oils is 0.02-0.26 indicating a low salinity environment of deposition for the initial organic matter (Peters & Moldowan, 1993).

The $C_{35}S/C_{34}S$ hopane proportions are 0.98-1.16 except for Luhays-12 and Najaf oil seep (0.14 and 0.94, respectively) and the C_{29} norhopane/C_{30} hopane ratios are 1.32-1.63 and Najaf oil seep has the ratio of 1.54. The proportions of $C_{35}S/C_{34}S$ >0.8 along with C_{29} norhopane/C_{30} hopane >0.6 designates carbonate source under reducing and anoxic marine environments (Haven *et al*., 1988). In the same way, a carbonate source under marine reducing settings was verified by the high C_{22}/C_{21} ratios, 0.92-1.21 and low C_{24}/C_{23} ratios, 0.26-0.35 tricyclic terpane for oils from this subgroup (Peters *et al*., 2005). The Najaf oil seep has very similar C_{22}/C_{21} ratios, 0.88 and C_{24}/C_{23} ratios, 0.36 tricyclic terpane.

Subgroup B

This subgroup includes oils from Ahdab Oil Field in Kut Province. The samples include 22 oil-bearing cores from 7 main producing zones of the Mid-Upper Cretaceous in wells X-12, X-13, and X-15 and 3 bitumen samples from the Kh-2 and Ru-3 layers in well X-13.

This subgroup of oils hold high CPI values of ≤1.18 (average 0.99) and lowest Pr/Ph proportions of ≤0.60 (average 0.47) proposing that they were originated from marine organic matter (Haven *et al*., 1987, 1988). The ratios of Pr/n-C_{17} to Ph/n-C_{18} propose that the oils from this subgroup were derived from marine organic matter that was deposited under reducing condition.

A higher virtual richness ratio of C_{28} to C_{29} sterane (0.55-0.82 with an average of 0.63) indicates Upper Jurassic to Cretaceous age. A low content of gammacerane in this subgroup of oils is another parameter that supports the age of this group to be Upper Jurassic-Lower Cretaceous (Grantham & Wakefield, 1988). The low value or no presence of oleanane in some samples do not indicate that the oils were generated from sources older than the Cretaceous because the oils perhaps derived from sources with no higher plant content (Ekweozor & Udo, 1988). The gammacerane index

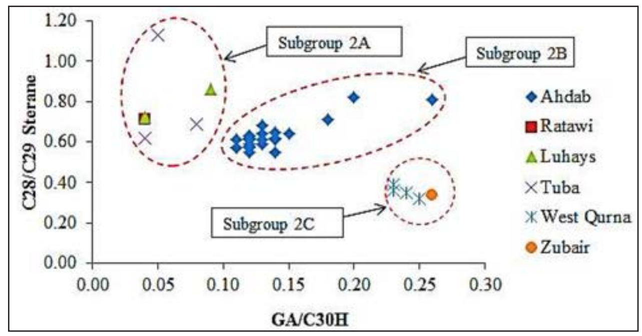

Figure 5: Gammacerane to C_{30} Hopane ratios against comparative %C_{28} B/relative %C_{29} B ratios for oils from Southern Mesopotamian Basin, Iraq. The plot differentiates Ratawi, Luhays, Tuba, Ahdab, West Qurna, and Zubair oils.

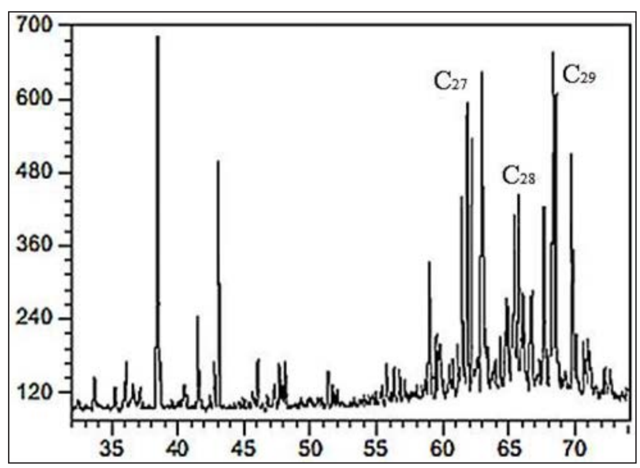

Figure 6: Biomarker analyses for crude oil from well Zubair-4 which represents Group 2A. Figure shows the analyses of m/z 217 steranes (Al-Ameri *et al*., 2009).

(gammacerane/hopane) for oils is 0.11-0.26 indicating a low salinity environment of deposition for the initial organic matter (Peters & Moldowan, 1993).

The relative concentrations of C_{27} steranes (average 40.33%) are higher than concentrations of C_{29} steranes (average 36.57%). The average C_{27}/C_{29} sterane ratio is 1.11 that in general specifies marine algae organic matter contribution (Peters & Moldowan, 1993; Gürgey, 2002).

Subgroup C

This subgroup includes oils from West Qurna-41, West Qurna-79, West Qurna-90, and West Qurna-201 wells in West Qurna Oil Field and Zubair-163 Well in Zubair Oil Field. The oils have an API⁰ ≤28 and all oils are aromatic asphaltic. (e.g. Figure 7)

Oils from marine origin have low nickel to vanadium ratio (Ni/V<1) and moderate to high sulfur content (Lewan, 1984; Barwise, 1990; Peters & Moldowan, 1993). All oils have Ni/V<1 (0.24-0.30) and sulfur content ranges from 4.22-5.70 wt.% (average 5.00 wt.%); therefore, the oils are from marine origin.

This subgroup has CPI values ≤0.93 (average 0.85) and Pr/Ph proportions ≤0.84 (average 0.77) proposing that they were originated from marine organic matter (Duan, 2001).

A proportion of Pr/n-C_{17} to Ph/n-C_{18} signifies reducing environment for source rock depositional setting and suggests that the oils had been originated from marine organic matter, having Pr/n-C_{17} and Ph/n-C_{18} proportions characteristic of a marine setting (Peters *et al*., 1999).

The gammacerane index (gammacerane/hopane) for oils is 0.06-0.26 (average 0.19) indicating a low salinity environment of deposition for the initial organic matter (Peters & Moldowan, 1993). The small virtual amount of C_{29} steranes compared to C_{27} steranes suggests marine organic input. Based on these observations, it appears that a marine carbonate that was deposited under reducing condition was likely the source rock which generated the hydrocarbons found. This subgroup has the lowest C_{28}% sterane content (13.28-14.78%, average 14.00%) and high C_{27} and C_{29} steranes (average 46.50% and 39.61%, respectively) which indicates a mixed algae and land plant source. Thus, when sterane C_{27}> C_{29}> C_{28} it indicates the crude oils are primarily originated from plankton (Moldowan *et al*., 1985).

The oils' carbon isotope ratios are between –27.44‰ to –27.16‰ (mean –27.28‰) for saturates and between –27.58 and -27.31 for aromatics with an average value of –27.46. These ranges are corresponding to marine organic matter type (Sofer, 1984). The CV values for this group of oils are between –3.87 and –3.36, respectively with an average –3.59 which are less than 0.47; therefore, all oils are from a non-waxy source (Sofer, 1984).

The Ts/Tm proportion is frequently utilized to deduce maturity of oil (Moldowan *et al*., 1986), but likewise carbonate source rocks contain low proportions of Ts/Tm (McKirdy *et al*., 1983, 1984). The low Ts/Tm proportions (0.17~0.18) in this groups' crude oils again replicate low maturity and saline condition.

Group 3 oils (Cretaceous to Tertiary)

Unlike oils from other groups, the oils from Subba Oil Field holding the highest CV values that range between 0.43 and –2.30 for Subba-14 and Subba-8a, respectively and low Pr/Ph ratios, average 0.83 proposing that they were originated from marine organic matter (Sofer, 1984; Duan, 2001). These high CV values and low Pr/Ph proportions conflict with high relative abundance of C_{29} steranes (average 44.30%). The virtual richness of gammacerane is low in all Subba oils. In contrast to oils from other groups, the relative concentrations of C_{27} are lower than C_{28} and C_{29} steranes e.g. Subba-8 and Subba-14 (Figures 8 and 9) that reflect terrestrial influence environments. Furthermore, the sulfur lessen (1.58 wt.%)

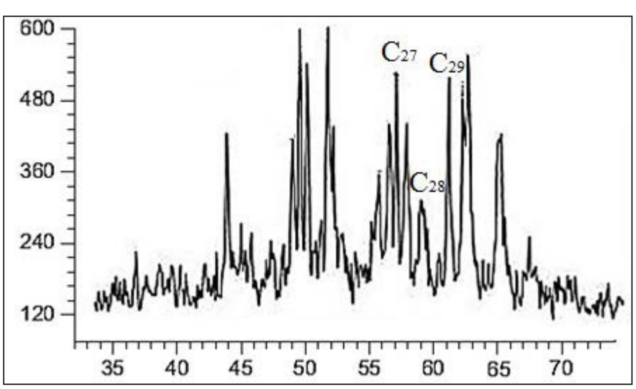

Figure 7: Biomarker analyses for crude oil from well West Qurnah-2 which represents Group 2C. Figure shows the analyses of m/z 217 steranes (Abeed, 2012).

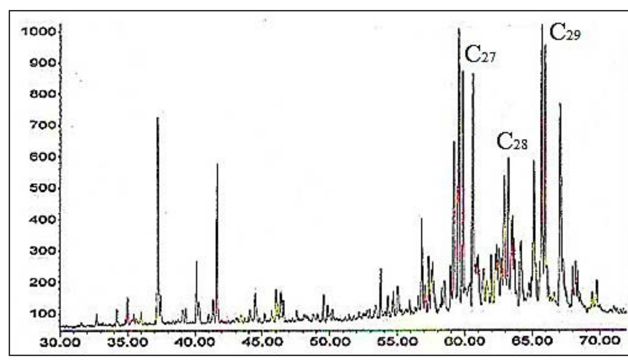

Figure 8: Biomarker analyses for crude oil from well Subba-8 which represents Group 3A. Figure shows the analyses of m/z 217 steranes (Al-Agaili, 2014).

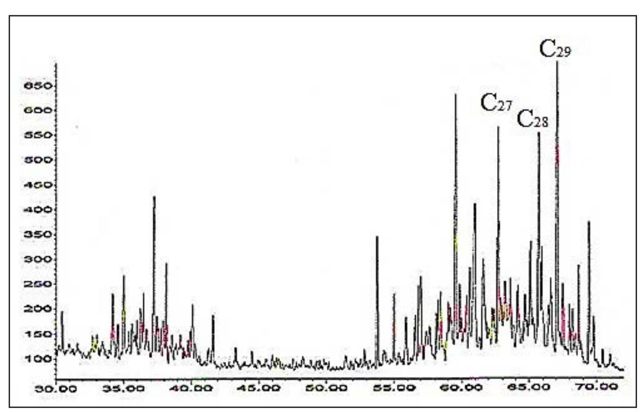

Figure 9: Biomarker analyses for crude oil from well Subba-14 which represents 3B. Figure shows the analyses of m/z 217 steranes (Al-Agaili, 2014).

is detected in Subba oils and these variable proportions is used to distinguish between terrestrial and marine oils in Southern Mesopotamian Basin. This sulfur amount is lower than the range of oils in other groups; therefore, besides the high C_{29} sterane content, the terrestrial influence on this group is probable. The results strongly designate a major input by continental organic matter; thus, the petroleum in this assembly may have originated from different sources.

The oils' carbon isotope ratios are between –27.74‰ and –25.72‰ (mean –26.77‰) for saturates and between –27.30 and –23.87 for aromatics with an average value of –25.86. These ranges are corresponding to marine organic matter type (Sofer, 1984). Based on values of carbon isotopes, tricyclic terpane C_{19} (C_{19} T), tricyclic terpane C_{23} (C_{23} T), tetracyclic C_{24} (Tet), and other biomarkers the oils from this group are heterogeneous and can be further divided into two subgroups (Figure 10). The oils from Subba-8a, Subba-8b, and Subba-9 can be separated from the Subba-14. The first subgroup has more contribution of Cretaceous source rocks and the second subgroup has more characteristics to Tertiary source rocks (Andrusevich *et al*., 1998).

Group 4 (Late Triassic-Middle Jurassic Oil Seeps)

This group includes oil seeps from Heet, Awasel, Jabha, and Abu Jir in Anbar Province and Karbala oil seep in Karbala Province. Oil seeps in the studied area are located sideways the Abu Jir Fault in the western edge of the Mesopotamian Basin. These bitumen ponds about 2 km in diameter are sited at Abu-Jir, Ain Jabha, Ain Heet, and Awasel (Aqrawi *et al*., 2010). The Karbala oil seep is located near Razzaza Creek west of Karbala City (Al-Ameri & Al-Khafaji, 2014).

The oil seeps have a low API^{o} and all of them are aromatic asphaltic. The GA/C_{31}R for oil seeps is 0.43-0.91 (average 0.56) indicating a low salinity environment of deposition for the initial organic matter (Peters & Moldowan, 1993). The small virtual amount of C_{27} (13.10-35.40, average 29.64) steranes compared to C_{29} (42.80-66.90, average 48.29) steranes suggests influence of terrestrial organic matter input, but the concentration value of C_{27} steranes that this group of samples have could be attributed to biodegradation; C_{27} steranes are less stable against biodegradation than C_{29} steranes (Goodwin *et al*., 1983; Volkman *et al*., 1983; Connan, 1984; Peters *et al*., 2005).

Based on these observations, it appears that a reducing marine carbonate was likely the source rock that generated the hydrocarbons found. This group has a low C_{28}% sterane content (20.10-21.50%, average 22.09%), high C_{29}%, and medium C_{27}% (average 46.50% and 39.61%, respectively) sterane content, which indicates biodegradation (Moldowan *et al*., 1985).

A crystalline hydrocarbon, phenanthrenes ($C_{14}H_{10}$) was identified in the studied samples e.g. Awasel seep (Figure 11). A negative correlation was found between the phenanthrenes and quantity of asphalt (Awadh & Hussien, 2015).

The oils' carbon isotope ratios are between –29.00‰ to –27.96‰ (mean –28.25‰) for saturates and between –28.34 and –27.88 for aromatics with an average value of –28.10. These ranges are corresponding to marine organic matter type (Sofer, 1984). The CV values for this group of oils are between –3.47 and –0.17, respectively with an average –2.56 which are less than 0.47; therefore, all of them are from a non-waxy source (Sofer, 1984).

The Ts/Tm proportion is frequently utilized to deduce maturity of oil (Moldowan *et al*., 1986), but likewise carbonate source rocks contain low proportions of Ts/Tm (McKirdy *et al*., 1983, 1984). The low Ts/Tm proportions (0.10~0.13) in this group of crude oils is again replicate low maturity and saline condition.

Thermal maturities

Variety of biomarker constraints such as homohopane ratio 22S/ (22S+22R), sterane, hopane isomer ratios, CPI, Ts/Tm, Pr/Ph, and methylphenanthrene index 1 (MPI

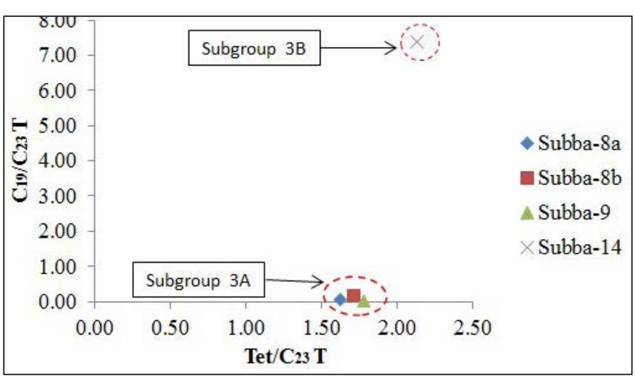

Figure 10: Plot of tetracyclic C_{24} to tricyclic terpane C_{23} ratio (Tet/C_{23} T) versus tricyclic terpane C_{19}/C_{23}, (C_{19}/C_{23} T) for oils from Southern Mesopotamian Basin, Iraq. The plot differentiates Subba-8a, Subba-8b, Subba-9, and Subba-14 oils.

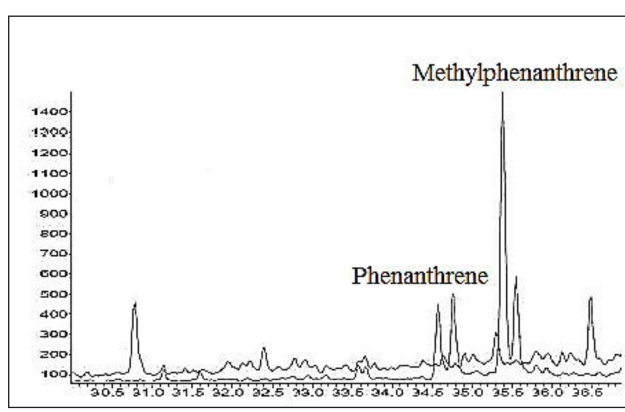

Figure 11: Phenanthrenes in the Awasel oil seep which represents Group 4. Figure shows the analyses of m/z 178 (Awadh &Hussien, 2015).

1) can be used to determine maturity of oils. Molecular maturity constraints such as Pr/Ph, sterane, hopane isomer proportions, and CPI values designate that the Group 1 oils are the most mature among all the groups. The ratio of Ts/Tm and MPI 1 seems to be reliable to indicate the maturity sequence from high to low as following: Group 1 (Halfaya)>Group 2 (Killops & Killops, 2005). The MPI 1 values of the analyzed samples range between 0.18-0.97 with the lowest for Ratawi-3 crude oil and the highest value for Halfaya-1 oil. Accordingly, the studied samples have low to moderate maturity and Halfaya samples are considered as more mature than other samples (Killops & Killops, 2005). The oils can be arranged from least mature to most mature according to average MPI-1 as Ratawi = Nahr Umar (0.19) <Luhays (0.22) <Zubair (0.23) <Rumayla South (0.27) = West Qurna (0.27) <Tuba (0.28) <Halfaya (0.83). The Pr/Ph ratios range between 0.47 and 0.97 for Ratawi-3 and Majnun-10, respectively. The oils' maturity sequence according to average Pr/Ph ratios from high to low is as the following: Buzurgan (0.55) >Abu Gharab (0.56) >Faqa (0.58) >Noor (0.64) >Amara (0.65) >Rumayla South (0.69) >Ratawi (0.70) >Nahr Umar and Luhays (0.71) >Halfaya, Tuba, and Rumayla North (0.73) >Zubair (0.74) >Safwan (0.75) >West Qurna (0.76) >Nasariya (0.78) >Subba (0.83) >Majnun (0.84).

C_{27} Ts/Tm ranges between 0.02 and 0.74 for Subba-14 and Subba-8, respectively and C_{29} Ts/Tm ranges between 0.05 and 0.13 for Subba-14 and Subba-8, respectively. According to average Ts/Tm, the oils can be arranged from least mature to most mature as Luhays, Nasariya, and West Qurna <Rumayla, Ratawi, and Zubair <Halfaya <Tuba <Subba <Ratawi.

The relative abundance of triaromatic steroids (TAS) is one of the commonly-used maturity pointers (Mackenzie, 1984). Assuming all crude oil samples originated from the same type of source rock, the maturity level from lowest to highest are as the following: Rumayla South and Zubair (0.21) >Rumayla North (0.22) >Ratawi (0.33) >Luhays (0.34) >Subba (0.59). However, there are discrepancies in the maturity order according to sterane, hopane, and TAS ratios which commonly related to the depositional environments and subsequently types of source rock. The plot of sulfur wt.% versus APIº shows the maturity of oils from different oil fields (Figure 12).

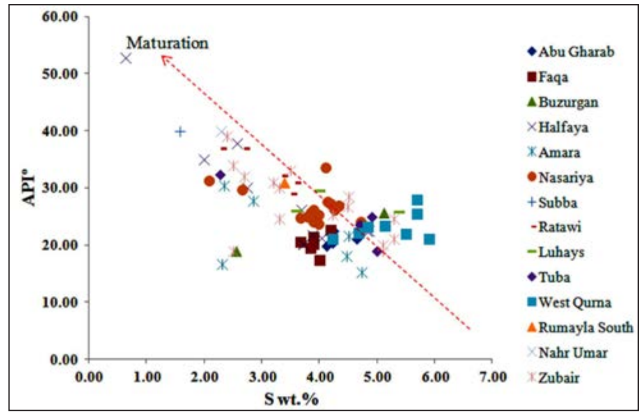

Figure 12: Sulfur wt.% (S wt.%) versus American Petroleum Institute (API) gravity for oils from Southern Mesopotamian Basin. The plot shows maturity trend since there is an inverse relation between S wt.% and APIº.

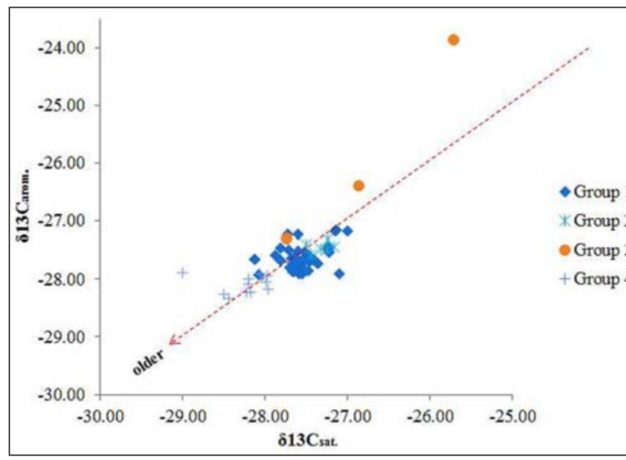

Figure 13: Plot of $\delta^{13}C$ saturates versus $\delta^{13}C$ aromatics for oils from Southern Mesopotamian Basin, Iraq. The plot separates oils and shows their relative ages.

Depositional environment of oils and oil- source correlation

To examine the oils' linkage to prospective source rocks, 24 extracts from Sargelu (Bajocian-Bathonian), Sulaily (Tithonian-Berriasian), Zubair (Berremian-Aptian), Su'aiba (Early Albian), Nahr Umar (Late Albian), Rumayla (Middle Cenomanian), and Jaddala (Early Eocene-Middle Eocene) were used (Figure 2).

The Group 4's source is the oldest among all the groups. Group 1's source is older than Group 2, while Group 3's source is the youngest. This can be inferred from carbon isotope values among groups one, two, three, and four as average carbon isotope ratio is –28.25‰ and –28.10‰ for saturates and aromatics, respectively for Group 4, increases to –27.56‰ and –27.66‰ for saturates and aromatics, correspondingly for Group 1, increases more to –27.28‰ and –27.46‰ for saturates and aromatics, respectively for Group 2, and Group 3 has the highest values, –26.77‰ and –25.86‰ for saturates and aromatics, respectively (Figure 13) (Andrusevich *et al.*, 1998).

Oil's molecular properties and carbon isotope ratios of samples from the Halfaya Oil Field that belong to Group 1 oils were plotted by Al-Ameri *et al.* (2015). The plot designated that the oils were generated from marine algal which deposited under anoxic conditions.

The evidence showed that the oils in Karbala and Najaf seepages have a similarity with the oils that were originated from Sargelu, Butmah, and lower part of Najmah formations (Al-Ameri & Al-Khafaji, 2014).

The source of Najaf oil seep cannot be approved to be Early to Middle Jurassic because it has a C_{28}/C_{29} sterane ratio of 0.70 which lies within the range of Late Jurassic oils. A low content of gammacerane in this oil seep is another parameter that supports the age of this group to be Late Jurassic (Grantham & Wakefield, 1988). The values of carbon isotope –27.50‰ and –27.40‰ for saturate and aromatic, respectively of Najaf oil support Late Jurassic age (Andrusevich *et al*., 1998) and the most likely sources of it are the Naokelekan, Najmah with apparent Sulaiy-Chia Gara formations (Al-Ameri & Al-Khafaji, 2013).

The possible source rocks for Group 2 (Ahdab, Tuba, Rumayla, West Qurna, Luhays, Nahr Umar, Safwan, Zubair, Ratawi, and Najaf) oils are Chia Gara or its equivalent, Yamama/Sulaiy carbonate sequence. This possibility is based on similar biomarker correlation parameters. The younger Cretaceous and the older Jurassic sequences are excluded from being a source due to a great terrestrial influence and an extremely over mature status, correspondingly (Abeed, 2012; Deng *et al*., 2018).

Sargelu Formation is presumed as the key source rock in the region which was deposited in carbonate-rich, saline-hypersaline marine setting. They have low Pr/Ph proportions, 0.52, high odd- to even preference, 1.01. These configurations are comparable to those structures of the Group 1 oils as designated earlier and propose that these oils were originated from Sargelu Formation.

Molecular and non-molecular properties which are associated to the source rock designated that the Subba oils originated from carbonate source rocks or carbonate occasionally mixed with shale or marl deposited in normal salinity environment under anoxic condition (Al-Agaili, 2012). Furthermore, the oils' source rock age is the Middle Triassic-Upper Jurassic and this age coincides with Geli Khana and Sargelu formations (Al-Agaili, 2012), but this age conflicts with carbon isotope values. The values of carbon isotopes $\geq$ –26.86 and $\geq$ –26.40 for saturates and aromatics for Subba-8a and Subbal-14, respectively which indicate Tertiary age, while of Subba-9 is –27.74 and –27.30 for saturates and aromatics, respectively which indicate Cretaceous age (Andrusevich *et al*., 1998).

Compositional resemblances of hopane and sterane biomarkers of crude oils from Tuba, Rumayla, Luhays, Nahr Umar, Safwan, West Qurna, Zubair, and Ratawi oilfields and those that belong to prospective source rocks proposed the Sulaiy and Yamama formations as the effective source beds (Abeed *et al*., 2012; Deng *et al*., 2018). Bulk properties and biomarker parameters of oils in Ratawi-3b, Ratawi-5, Ratawi-7, Luhays-12, Subba-8b, and Tuba-3b wells and of extracts of Yamama Formation indicate multi source of hydrocarbons with some pay having Jurassic and Lower Cretaceous source affinity (Al-Ibrahim & Al-Ameri, 2015). Although, the oils from Ratawi-3b, Ratawi-5, Ratawi-7, Luhays-12, and Tuba-3b from southeastern of Southern Mesopotamian Basin are far from oils in Taq Taq, the similarity can be noticed between them except for the Subba-8b which appears to be different with both groups (Abdula, 2017).

CONCLUSIONS

The oils from Southern Mesopotamian Basin were reevaluated in order to determine their origins and geochemically typing them. The succeeding is the key conclusions from this study:

(1) Four diverse oil groups in Southern Mesopotamian Basin are recognized. They are the followings: Group 1 oils (Middle Jurassic Zagros Fold Belt); Group 2 oils (Upper Jurassic–Lower Cretaceous Sulaiy/Yamama); Group 3 oils (Cretaceous to Tertiary); and Group 4 oils (Late Triassic-Middle Jurassic). In addition to the main groups, the Upper Jurassic-Lower Cretaceous Sulaiy/Yamama further divided into three subgroups. In the same way, the Group 3 oils further subdivided into two sub families.

(2) The oils differ in their thermal maturity level, but all of them are mature and within equilibrium phase.

(3) Oil-source rock association

- The geochemical constraints display a carbonate source in a reducing setting for Group 1 (Middle Jurassic Zagros Fold Belt oils) and Group 2 (Upper Jurassic–Lower Cretaceous Sulaiy/Yamama oils) while a mixture of carbonate and marl for Group 3 (Cretaceous to Tertiary oils) and Group 4 (Late Triassic-Middle Jurassic oil Seeps).
- The biomarker constraints illustrate no indication of molecular input from Triassic source to all oils except Group 4 oils (Late Triassic-Middle Jurassic oil seeps).
- The Middle Jurassic source contributed to oils in Group 1 (Middle Jurassic Zagros Fold Belt) and Group 4 (Late Triassic-Middle Jurassic Oil Seeps).
- The Group 3 oils (Cretaceous to Tertiary) appear to have been generated from various sources, Cretaceous and Tertiary, but with different proportion to each of the oils.

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APPENDIX A

List of abbreviations

API	American Petroleum Institute Gravity
%S	% sulfur
ppm Ni	part per million nickel
ppm V	part per million vanadium
%Sat.	Relative % saturated hydrocarbons
%Aro.	Relative % aromatics hydrocarbons
%NSO	Relative % nitrogene, sulfur and oxygen
%Asph.	Relative % asphaltines hydrocarbons
Pr/Ph	pristane to phytane ratio, peak heights from whole crude gas chromatogram
Pr/n-C_{17}	isoprenoids/n-alkanes ratios (pristane/n-C_{17})
Ph/n-C_{18}	isoprenoids/n-alkanes ratios (phytane/n-C_{18})
$\delta^{13}C$ $_{Sat.}$	Carbon isotope composition: C_{15+} saturated hydrocarbons
$\delta^{13}C$ $_{aro.}$	Carbon isotope composition: C_{15+} aromatics hydrocarbons
CV	Canonical variabl: CV= -2.53δ^{13}Csat.+2.22δ^{13}Caro.-11.65
CPI	Carbon preference index = 2 x (n-C_{23}+n-C_{25})/(n-C_{22}+2 x (n-$_{24}$)+n-C_{26})
C_{19}/C_{23} T	Tricyclic Terpane C_{19}/C_{23}, peak heights from 191m/z
Tet/C_{23}	Tetracyclic C_{24} to Tricyclic Terpane C_{23} ratio, peak heights from 191m/z
C_{22}/C_{21}T	Tricyclic Terpane C_{22}/C_{21}, peak heights from 191m/z
C_{24}/C_{23}T	Tricyclic Terpane C_{24}/C_{23}, peak heights from 191m/z
%C_{27}	Relative % S_5B sterane
%C_{28}	Relative % S_{10}B sterane
%C_{29}	Relative % S_{14}B sterane
OL/H	Oleanane/Hopane
C_{29}/H	Norhopane/Hopane
$C_{35}S/C_{34}S$	C_{35} Extended Hopane/C_{34} Extended Hopane (22S)
C_{31}R/H	17α, 21β-30-homohopane (22R)/Hopane
GA/C_{30}H	Gammacerane/C_{30} Hopane (Gammacerane index)
GA/C_{31}R	Gammacerane Index
C_{27} Ts/Tm	C_{27} 18α(H)-22,29,30-Trisnorneohopane/17αH)-22,29,30-Trisnorhopane
C_{29}Ts/Tm	aka C_{29}D/29H
TAS_3(CR)	[C_{20}+C_{21}]/[C_{20}-C_{28}] triaromatic sterane (a.k.a. ‘cracking ratio’)
MPI-1	Methylphenanthrene Index = 1.5([2-MP] + [3-MP])/([P] + [1-MP] + [9-MP])
OEP	Odd-to Even Preference