INTERPRETATION OF HYDROCARBON GENERATION, MIGRATION AND THERMAL HISTORY OF MESOPOTAMIAN BASIN SOUTHERN IRAQ BASED 1D PETROMOD SOFTWARE

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ABSTRACT

Seven oilfields are selected in the Mesopotamian basin, southern Iraq for studying thermal history, hydrocarbon generation and migration these are Siba, Zubair, Nahr Umr, Majnoon, Halfaya, Amara and Kumait. The thermal and the basin histories of the basin are modeled using the PetroMod software. Modeling results proved that the generation of oil begins at the end of the Cretaceous and early of Tertiary as a response to the increase of the temperature and burial depth of the Sulaiy and Yamama formations which are in turn accelerate the maturation of organic matter. Therefore, these formations act as main source rocks in the considered basin. The rest of the formations enter the maturation level during Miocene but they aren't capable to generate oil. The migration of oil in both horizontal and vertical directions begins at Miocene in western and southwestern parts of the basin that reflect the significant accumulation of oil in these parts.

Keywords: Thermal history; Generation; Migration; Mesopotamian basin

INTRODUCTION

The oilfields used in this study include Siba, Zubair, Nahr Umr, Majnoon, Halfaya, Kumait, and Amara (Fig. 1). They are located in the southern part of Iraq between 30°58' – 32°08' latitude) and (46°52' – 47°56' longitude) within the Mesopotamian basin. The basin is covered by Quaternary fluvial-plain deposits of the Tigris and Euphrates rivers. Beneath this cover, anticlines and horst lie and are mainly related to long lived paleostructures. In the Basrah area in the extreme south of the basin, these structures may also relate to the movement of Infra-Cambrian Hormuz salt (Jassim and Buday, 2006c). The zone was uplifted

during the Hercynian deformation (Jassim and Goff, 2006). The folds' structures mainly trend NW-SE in the eastern part of the zone and N-S in the southern part, where some structures trending NE-SW occur too (Jassim and Buday, 1987).

The Mesopotamian can be subdivided into three subzones, namely: Euphrates, Tigris, and Zubair. The study area contains oil reservoirs and source rock in Cretaceous and uppermost Jurassic formations at different depths and in a variety of lithologies (Fig. 2). The petroleum system in the basin comprises effective petroleum source rocks represented by Sulaïy and Yamama formations, seal rocks (Tanuma, Shiranish and Rus formations), and reservoir rocks (Yamama, Zubair, Nahr Umr and Mishrif formations) (Amna and Maher, 2016). The evaluation of the source and reservoir characteristics of Albian rock succession, southern Iraq was done by Ibrahim (1983) and concluded that accumulated hydrocarbon in Nahr Umr Formation generated from deepest Cretaceous rocks (Sulaïy and Yamama). Al-Mousawi (1996) used palynofacies to determine the hydrocarbon generation potential of the Sulaïy Formation and assessed that the Sulaïy Formation is an efficient source rock in southern Iraq. Al-Ahmed (2006) showed that the Sargelu Formation are source rocks in the north of Iraq that charge Cretaceous and Tertiary reservoir oil. The oil is of two families, family one is from Sargelu formation while family two is from Sargelu and lower Cretaceous source rocks. Al-Khafaji (2006) used biomarkers and carbon isotopes in the correlation between Mishrif crude oil and possible source rocks in Southern Iraq. He concluded that most of the crude oil accumulated in the Mishrif Formation in Ratawi, north and south Rumaila oil fields are from Jurassic source rocks such as Najmah and Sargelu formations, but the rest of the oil is from Sulaïy Formation. Al-Yaseri (2007) evaluated the thermal maturation, hydrocarbon generation potential and identification of Tar-mat deposits for the uppermost Jurassic (Gotnia Formation) and Cretaceous (Sulaïy, Yamama, Ratawi, Shuaiba, Nahr Umr and Mishrif formations) at southern Iraq. His results indicated that the lower Cretaceous formations contain a sufficient amount of oil-prone (Type II&III) predominately marine organic matter. Results of biomarkers of crude oil indicated that they are generated from carbonate source rocks include algal and bacteria organic matter deposited in an anoxic environment. Al-Haidari (2009) studied the biomarkers of Zubair Formation oil and its sources in the Basra region, southern Iraq. Based on her study, the source rock of oil is carbonate (Sulaïy-Yamama formations) that deposited in the reduced marine environment and mature kerogen type II with algae. This study aims to evaluate the thermal maturity of the different formations in the basin, determine the timing of hydrocarbon generation and

expulsion, construct the geological history of the basin, calculate the heat flow and overburden pressure to reconstruct the 1D basin modeling.

Fig. 1: Map of the studied fields and wells

Fig. 2: Stratigraphic columns in southern Iraq (Sadooni and Aqrabi, 2000)
(A) Zubair oilfield (Zb-42) and (B) Halfaya oilfield (HF-4)

METHODS

The burial history and thermal maturity of the basin were constructed using 1D PetroMod. The main input data includes age and thickness. TOC and HI, kinetic data are also used to construct the thermal history, generation and migration models, (Fig. 3). Data for boundary conditions such as heat flow also used. Heat flow is computed as (MaCulloh and Naeser, 1989):

$$Q_z = k \frac{dt}{dz} \dots\dots\dots (1)$$

Where:

Q_z : Vertical component of heat flow (MW.m^{-1}); k : thermal conductivity ($\text{W.m}^{-1} \cdot ^\circ\text{C}^{-1}$).

$\frac{dt}{dz}$: Geothermal gradient ($^\circ\text{C/km}$).

Layer	Top [m]	Base [m]	Thick. [m]	Eroded [m]	Depo. from [Ma]	Depo. to [Ma]	Eroded from [Ma]	Eroded to [Ma]	Lithology	PSE	TOC [%]	Kinetic	HI [mgHC/gTOC]
Dibdiba	0	364	364	350	10.20	5.00	5.00	0.00	SANDcongl				
Lower Fares	364	573	209		16.50	10.20			LIMEarly				
Ghar	573	697	124		23.00	16.50			SANDcongl				
Dammam	697	920	223	491	45.00	36.50	36.50	23.00	LIMEdolom				
Rus	920	990	70		53.00	45.00			LIME&EVAP				
Umm Er Radhuma	990	1454	464		62.30	53.00			LIME&EVAP				
Tayarat	1454	1658	204	282	68.20	65.00	65.00	62.30	LIME&EVAP				
Shiranish	1658	1749	91		70.40	68.20			LIMEarly				
Hartha	1749	1907	158		80.00	70.40			LIMESTONE				
Sadi	1907	2125	218		86.00	80.00			LIMESTONE				
Tanuma	2125	2150	25		87.00	86.00			SHALE	Seal Rock			
Khasib	2150	2213	63		89.00	87.00			LIMESTONE	Reservoir Rock			
Mishrif	2213	2364	151	100	92.00	90.00	90.00	89.00	LIMESTONE	Reservoir Rock			
Rumaila	2364	2455	91		93.00	92.00			LIMEshaly				
Ahmadi	2455	2601	146		94.00	93.00			SHALE&LIME				
Maaddud	2601	2740	139		95.00	94.00			LIMESTONE		0.40	Abu-Ali(1999)_TII-(Qusaiba)	555.02
Naher Umr	2740	2998	258		107.00	95.00			SAND&SHALE	Reservoir Rock	0.78	Abu-Ali(1999)_TII-(Qusaiba)	20.00
Shuaiba	2998	3096	98		112.00	107.00			LIMESTONE		0.76	Abu-Ali(1999)_TII-(Qusaiba)	
U.Sh.msr	3096	3197	100		113.00	112.00			SHALE	Seal Rock	0.82	Abu-Ali(1999)_TII-(Qusaiba)	
U.Stl.mbr	3197	3300	102		114.00	113.00			SANDSTONE	Reservoir Rock	0.67	Abu-Ali(1999)_TII-(Qusaiba)	
M.Sh.mbr	3300	3361	62		115.00	114.00			SHALE	Source Rock	0.89	Abu-Ali(1999)_TII-(Qusaiba)	
L.ss.mbr	3361	3423	62		116.00	115.00			SANDSTONE	Reservoir Rock		Abu-Ali(1999)_TII-(Qusaiba)	
L.Sh.mbr	3423	3473	50		118.00	116.00			SHALE	Seal Rock	0.72	Abu-Ali(1999)_TII-(Qusaiba)	
Ratawi	3473	3605	132		125.00	118.00			SHALE&LIME	Source Rock	0.68	Abu-Ali(1999)_TII-(Qusaiba)	545.82
Yamama	3605	3972	367		135.00	125.00			LIMEdolom	Reservoir Rock	1.16	Abu-Ali(1999)_TII-(Qusaiba)	632.34
Sulaib	3972	4209	237		140.00	135.00			LIMEshaly	Source Rock	1.07	Abu-Ali(1999)_TII-(Qusaiba)	644.08

Fig. 3: The main input data to the PetroMod software

The thermal conductivity was calculated as Selley (1998)

$$k = k_m^{(1-\phi)} * k_w^\phi \quad \dots\dots\dots (2)$$

Where:

k : bulk thermal conductivity.

k_w : water conductivity (0.59 W. m⁻¹. °C⁻¹).

ϕ : porosity (%) (Calculate from well logs).

k_m : rock matrix conductivity (1.45 for Shale, 3.75 for Dolomite, 2.64 for Sandstone, 2.56 for Limestone, 5.4 for Anhydrite).

The steps for calculating heat flow are:

1. The porosity was calculated via density, neutron, and sonic logs.
2. Lithological sections of wells were used to assign the k_m values.
3. The value of T_s , T_D and BHT from well logs records were used for estimating for the geothermal gradient.

Applying the above equations show reasonable values of heat flows. These values range 27 to 70 MW/m² that may reflect the maturity of the organic matter (Fig. 4). The paleowater depths

for the studied wells were estimated depending upon the depositional environments for each formation.

Fig. 4: Heat flow of the selected wells in the study area

RESULTS AND DISCUSSION

Petroleum Generation

A. Vitrinite Reflectance (R_o)

Vitrinite reflectance is an optical parameter that widely used as an indicator to describe the organic matter maturity (Allen and Allen, 2005). For values (R_o) are not constant for each formation, but shows the time of entry into the maturity stage of each formation according to the algorithm developed by Sweeney and Burnham (1990), and value (0.55) represents the beginning of maturity as shown in Figures (5 to 12) and (Table. 1).

Fig. 5: Vitritine reflectance for well Zb-42

Fig. 6: Vitritine reflectance for well Sb-3

Fig. 7: Vitritine reflectance for well NR-9

Fig. 8: Vitritine reflectance for well NR-12

Fig. 9: Vitritine reflectance for well Mj-12

Fig. 10: Vitritine reflectance for well Kt-1

Fig. 11: Vitritine reflectance for well HF-5

Fig. 12: Vitritine reflectance for well Am-2

Table 1: Vitrinite reflectance values for the studied wells

Well No.	Fn.	Start		Stage	End		Stage
		Ro %	Time (Ma)		Ro%	Time (Ma)	
Zb-42	Sulaiy	0.55	58.05	Early oil	0.82	0	Main oil
	Yamama	0.55	38.96	Early oil	0.72	0	Main oil
	Ratawi	0.55	14.16	Early oil	0.68	0	Early oil
	L. Sst. Member	0.55	10.54	Early oil	0.65	0	Early oil
	M. Sh. Member	0.55	9.88	Early oil	0.64	0	Early oil
	U. Sst. Member	0.55	9.04	Early oil	0.63	0	Early oil
	Shuaiba	0.55	7.13	Early oil	0.59	0	Early oil
	Nahr Umr	0.55	4.43	Early oil	0.56	0	Early oil
Sb-3	Yamama	0.55	41.04	Early oil	0.77	0	Main oil
	Ratawi	0.55	26.38	Early oil	0.72	0	Main oil
	Zubair	0.55	11.01	Early oil	0.67	0	Early oil
	Shuaiba	0.55	9.27	Early oil	0.63	0	Early oil
Sb-3	Nahr Umr	0.55	7.6	Early oil	0.6	0	Early oil
	Mauddud	0.55	4.39	Early oil	0.58	0	Early oil
NR-9	Yamama	0.55	37.29	Early oil	0.94	0	Main oil
	Ratawi	0.55	14.95	Early oil	0.82	0	Main oil
	Zubair	0.55	12.69	Early oil	0.77	0	Main oil
	Shuaiba	0.55	9.63	Early oil	0.71	0	Main oil
	Nahr Umr	0.55	8.87	Early oil	0.68	0	Early oil
	Mauddud	0.55	8.15	Early oil	0.65	0	Early oil
	Ahmadi	0.55	7.44	Early oil	0.63	0	Early oil
	Rumaila	0.55	6.59	Early oil	0.61	0	Early oil
	Mishrif	0.55	5.58	Early oil	0.6	0	Early oil
NR-12	Yamama	0.55	51.67	Early oil	1	0	Late oil
	Ratawi	0.55	46.81	Early oil	0.89	0	Main oil
	Zubair	0.55	40.51	Early oil	0.83	0	Main oil
	Shuaiba	0.55	9.45	Early oil	0.76	0	Main oil
	Nahr Umr	0.55	9.18	Early oil	0.73	0	Main oil
	Mauddud	0.55	8.15	Early oil	0.69	0	Early oil
	Ahmadi	0.55	7.59	Early oil	0.65	0	Early oil
	Rumaila	0.55	7.05	Early oil	0.64	0	Early oil
	Mishrif	0.55	6.6	Early oil	0.61	0	Early oil
	Khasib	0.55	5.51	Early oil	0.58	0	Early oil
	Tanuma	0.55	5.3	Early oil	0.56	0	Early oil
Mj-12	Yamama	0.55	41.04	Early oil	0.89	0	Main oil
	Ratawi	0.55	36.58	Early oil	0.82	0	Main oil
	Zubair	0.55	11.76	Early oil	0.78	0	Main oil
	Shuaiba	0.55	10.88	Early oil	0.73	0	Main oil
	Nahr Umr	0.55	9.98	Early oil	0.7	0	Main oil
	Mauddud	0.55	9.09	Early oil	0.66	0	Early oil
	Ahmadi	0.55	8.06	Early oil	0.63	0	Early oil
	Rumaila	0.55	7.05	Early oil	0.62	0	Early oil
Kt-1	Yamama	0.55	11.04	Early oil	0.81	0	Main oil
	Ratawi	0.55	10.62	Early oil	0.79	0	Main oil
	Zubair	0.55	9.89	Early oil	0.76	0	Main oil
	Shuaiba	0.55	9.45	Early oil	0.73	0	Main oil
	Nahr Umr	0.55	9.18	Early oil	0.71	0	Main oil
	Mauddud	0.55	8.62	Early oil	0.69	0	Early oil

Table 1: continued....

Kt-1	Ahmadi	0.55	7.7	Early oil	0.66	0	Early oil
	Rumaila	0.55	7.67	Early oil	0.66	0	Early oil
	Mishrif	0.55	7.2	Early oil	0.63	0	Early oil
	Khasib	0.55	6.67	Early oil	0.6	0	Early oil
	Tanuma	0.55	6.02	Early oil	0.59	0	Early oil
	Sadi	0.55	5.07	Early oil	0.58	0	Early oil
	Hartha	0.55	5.16	Early oil	0.55	0	Early oil
HF-5	Yamama	0.55	15.83	Early oil	0.99	0	Main oil
	Ratawi	0.55	12.39	Early oil	0.94	0	Main oil
	Zubair	0.55	11.76	Early oil	0.89	0	Main oil
	Shuaiba	0.55	11.06	Early oil	0.83	0	Main oil
	Nahr Umr	0.55	10.61	Early oil	0.81	0	Main oil
	Mishrif (1/2)	0.55	6	Early oil	0.62	0	Early oil
	Mishrif (2/2)	0.55	5.1	Early oil	0.58	0	Early oil
	Khasib	0.55	3.34	Early oil	0.57	0	Early oil
	Tanuma	0.55	1.58	Early oil	0.55	0	Early oil
	Sadi	0.55	6.67	Early oil	0.63	0	Early oil
	Hartha	0.55	6.57	Early oil	0.61	0	Early oil
	Shrinish	0.55	6.14	Early oil	0.59	0	Early oil
	Aaliji	0.55	5.85	Early oil	0.58	0	Early oil
	Jadali	0.55	4.99	Early oil	0.56	0	Early oil
Am-2	Yamama	0.55	12.71	Early oil	0.73	0	Main oil
	Ratawi	0.55	11.01	Early oil	0.7	0	Main oil
	Zubair	0.55	9.71	Early oil	0.67	0	Early oil
	Shuaiba	0.55	8.2	Early oil	0.64	0	Early oil
	Nahr Umr	0.55	7.92	Early oil	0.63	0	Early oil
	Mauddud	0.55	6.74	Early oil	0.6	0	Early oil
	Ahmadi	0.55	5.89	Early oil	0.58	0	Early oil
HF-5	Yamama	0.55	15.83	Early oil	0.99	0	Main oil
	Ratawi	0.55	12.39	Early oil	0.94	0	Main oil
	Zubair	0.55	11.76	Early oil	0.89	0	Main oil
	Shuaiba	0.55	11.06	Early oil	0.83	0	Main oil
	Nahr Umr	0.55	10.61	Early oil	0.81	0	Main oil
	Mishrif (1/2)	0.55	6	Early oil	0.62	0	Early oil
	Mishrif (2/2)	0.55	5.1	Early oil	0.58	0	Early oil
	Khasib	0.55	3.34	Early oil	0.57	0	Early oil
	Tanuma	0.55	1.58	Early oil	0.55	0	Early oil
	Sadi	0.55	6.67	Early oil	0.63	0	Early oil
	Hartha	0.55	6.57	Early oil	0.61	0	Early oil
	Shrinish	0.55	6.14	Early oil	0.59	0	Early oil
	Aaliji	0.55	5.85	Early oil	0.58	0	Early oil
	Jadali	0.55	4.99	Early oil	0.56	0	Early oil
Am-2	Yamama	0.55	12.71	Early oil	0.73	0	Main oil
	Ratawi	0.55	11.01	Early oil	0.7	0	Main oil
	Zubair	0.55	9.71	Early oil	0.67	0	Early oil
	Shuaiba	0.55	8.2	Early oil	0.64	0	Early oil
	Nahr Umr	0.55	7.92	Early oil	0.63	0	Early oil
	Mauddud	0.55	6.74	Early oil	0.6	0	Early oil
	Ahmadi	0.55	5.89	Early oil	0.58	0	Early oil
	Rumaila	0.55	5.83	Early oil	0.57	0	Early oil
	Mishrif (1/2)	0.55	1.5	Early oil	0.55	0	Early oil

According to the results of the figures (5 to 12), it is obvious that the organic richness of the Siba gas field is better than that for Zubair oilfield. In Nahr Umr oilfield, the organic richness in NR-12 is better than NR-9 well. On the other hand, comparing organic richness in Zubair, Siba and provides that Nahr Umr well have more mature than Zubair and Siba wells. In contrast, the more richness is observed in NR-12 well in Basrah area. In Majnoon oilfield, the order of organic richness of wells was as follows: Mj-11 > Mj-12 > Mj-8. If we compared NR-12 with Mj-11, the first was more mature.

In Amara area, the Mj-12 well has a high value of organic richness than that for Kt-1 well. Although the richness of Kt-1 is better than NR-12, NR-12 reach to the late oil stage in Yamama Formation. If we compared HF-5 with Kt-1 we noticed that HF-5 has more richness. But, the comparison between HF-5 and NR-12 indicated that HF-5 was more richness for all formations except or Yamama Formation which has more richness in NR-12. For Amara oilfield, if we compare with HF-5 the last have better values of richness.

B. Transformation ratio (T_R)

It is defined as the converted mass fraction of the initial reactant (Chilingarian *et al.*, 2005). Anomalously high values for the bitumen ratio (T_R) in immature sediments can be used to show contamination by migrated oil or manmade products (Peters *et al.*, 2005). The difference between the original hydrocarbon potential of a sample before maturation and the measured hydrocarbon potential divided by the original hydrocarbon potential (ranges from 0 to 1) (Peters *et al.*, 2005). Figures (13 to 18) show the transformation ratio in the study area.

Fig. 13: Transformation ratio (T_R) for well Zb-42

Fig. 14: Transformation ratio (T_R) for well Sb-3

Fig. 15: Transformation ratio (T_R) for well NR-9

Fig. 16: Transformation ratio (T_R) for well Kt-1

Fig. 17: Transformation ratio (T_R) for well HF-5

Fig. 18: Transformation ratio (T_R) for well Am-2

Comparing the transformation ratio of Zb-42 and Sb-3 (Table. 2) demonstrated the Sb-3 was better than the former of Yamama Formation. We also noticed that this ratio was higher in NR-9 than that in Sb-3 for Yamama Formation and Zubair Formation. By comparing NR-9 and Kt-1, NR-9 has higher values of this ratio than Kt-1 for Yamama, Ratawi and Zubair Formations. For Kt-1 and Am-2, Kt-1 was better than Am-2 for Ratawi and Zubair formations, while the comparison between Kt-1 and HF-5 showed that HF-5 has more transformation ratio than Kt-1 for Yamama, Ratawi and Zubair Formations. When comparing this value between NR-9 and HF-5, HF-5 has the larger one for Yamama, Ratawi, Zubair, and Nahr Umr. HF-5 has the greatest values of transformation ratio (69.45%) in Yamama Formation.

Table 2: Transformation ratio (T_R) results for the study area

Well No.	Formation	Start		End	
		T_R %	Time (Ma)	T_R %	Time (Ma)
Zb-42	Sulaiy	1.77	9.9	25.45	0
	Yamama	0.65	9.79	11.27	0
	Ratawi	0.18	16.32	4.73	0
Sb-3	Nahr Umr	0.02	10.42	0.36	0
	Yamama	0.95	12.5	14.86	0
	Zubair	0.2	12.5	3.41	0
NR-9	Yamama	1.09	10.21	58.23	0
	Ratawi	0.36	10.42	35	0
	Zubair	0.55	10.08	19.09	0
	Nahr Umr	0.04	10.29	4.14	0
Kt-1	Yamama	0.73	12.5	23.27	0
	Ratawi	0.14	12.59	18.91	0
	Zubair	0.14	12.51	12.73	0
HF-5	Yamama	0.36	12.5	69.45	0
	Ratawi	0.36	12.59	62.18	0
	Zubair	0.27	12.51	45.82	0
	Nahr Umr	0.18	12.51	22.55	0
	Mauddud	0.14	12.38	12.73	0
	Mishrif (1/2)	0.02	12.6	3.27	0
	Mishrif (2/2)	0.01	12.45	1.38	0
Am-2	Ratawi	0.35	9.83	4.09	0
	Zubair	0.13	9.89	2.07	0

C. Generation Mass

The generation of petroleum components from kerogen (primary cracking) and the secondary cracking of petroleum are usually described with sets of parallel reaction and decomposition kinetics (Hantschel and Kauerauf, 2009). The generation mass (Mega tons (Mtons)) of the study area is shown in Figures (19 to 24).

Fig. 19: Generation Mass for well Zb-42

Fig. 20: Generation Mass for well Sb-3

Fig. 21: Generation Mass for well NR-9

Fig. 22: Generation Mass for well Kt-1

Fig. 23: Generation Mass well HF-5

Fig. 24: Generation Mass for well Am-2

Comparing the generation mass of Zb-42 and Sb-3 wells (Table. 3) demonstrated the Sb-3 was better than for Zb-42. We also noticed a higher value of generation mass in Sb-3 than that in NR-9 for Yamama Formation. The arrangement, of generation mass in Yamama Formation was follows: Sb-3 > Zb-42 > HF-5 > NR-9 > Kt-1. The arrangement, of generation mass in Ratawi Formation was as: HF-5 > NR-9 > Sb-3 > Am-2 > Zb-42 > Kt-1. In Zubair Formation, NR-9 has higher values than Sb-3. The order of generation mass in Zubair Formation was NR-9 > HF-5 > Sb-3 > Kt-1 = Am-2. The order of generation mass in Nahr Umr Formation was NR-9 > HF-5 > Zb-42. The order of generation mass in Mauddud Formation was HF-5 > Zb-42.

Table 3: Generation mass of the study area

Well No.	Formation	Start		End	
		Genration mass (Mtons)	Time (Ma)	Genration mass (Mtons)	Time (Ma)
Zb-42	Sulaiy	0.03	45.67	1.01	0
	Yamama	0.02	41.67	0.74	0
	Ratawi	0.01	9.64	0.06	0
	Nahr Umr	Very few			
	Mauddud	Very few			
Sb-3	Yamama	0.01	46.04	0.83	0
	Zubair	0.01	12.51	0.09	0
NR-9	Yamama	0.01	9.79	0.1	0
	Ratawi	0.01	11.8	0.88	0
	Zubair	0.01	10.08	0.66	0
	Nahr Umr	0.01	10.13	0.23	0
Kt-1	Yamama	Few	12.29	0.01	0
	Ratawi	Few	12.59	0.02	0
	Zubair	Few	12.69	0.03	0
HF-5	Yamama	0.01	12.71	0.65	0
	Ratawi	0.01	12.59	1.05	0
	Zubair	0.01	12.32	0.16	0
	Nahr Umr	Few	12.51	0.04	0
	Mauddud	0.01	12.38	0.2	0
	Mishrif (1/2)	Few	12.6	0.12	0
	Mishrif (2/2)	Few	12.15	0.01	0
Am-2	Ratawi	Few	12.59	0.09	0
	Zubair	Few	12.51	0.03	0

MIGRATION AND ACCUMULATION

The concept of primary migration of oil (expulsion) as a result of the compaction was widely accepted for a long time (Chilingarian *et al.*, 2005). The compaction and consolidation of carbonate oozes are accompanied by crystallization and often with the appearance of numerous micro-fractures, upon lithification, the mobile substance within the deposition in part becomes a component of the rocks and in part acquires the ability to move, upon dolomitization up to 13.1% porosity can from creating further avenues for migration (Chilingarian *et al.*, 2005).

A. Primary Migration

In Zb-42, the expulsion in Sulaiy Formation is higher than in all formations Zb-42 that start at 10.35 Ma by 0.055 Mtons/ km² and end at 0.22 Ma by 1.118 Mtons/ km².while in Yamama Formation is range (0.011– 0.404) Mtons/ km² at (5-0.21) Ma respectively (Fig. 25). In Sb-3, the expulsion in Yamama Formation starts at 0.095 Mtons/ km² in 12.08 Ma (Miocene) to 1.841 Mtons/ km² in 0.42 Ma that index the migration happened at Miocene to Pliocene (Fig. 26). In NR-9, the expulsion in Ratawi starts at 0.036 Mtons/km² at 10.03 Ma to 0.891 Mtons/ km² at 0.2 Ma (Fig. 27). In HF-5, the highest value of expulsion is in Yamama Formation

which is in range 0.013 Mtons/ km² at 12.71 Ma to 0.554 Mtons/ km² at 0.21 Ma. In Ratawi 0.002 Mtons/ km² at 12.59 Ma to 0.323 Mtons/ km² at 0 Ma (Fig. 28).

Fig. 25: Expulsion for Sulaiy and Yamama formations in well Zb-42

Fig. 26 Expulsion for Yamama Formation in well Sb-3

Fig. 27: Expulsion for Ratawi Formation in well NR-9

Fig. 28: Expulsion for Yamama and Ratawi formations in well HF-5

THERMAL HISTORY

The basin thermal history of a basin is an essential controlling factor on the generation and distribution of multiple energy sources acting in the basin (Welte and Yüklér, 1981). For most of the studied wells, the Paleocene to Miocene are the times when the maximum temperature prevailed associated with deep burial. In the study area, deep burial was followed by erosion in Pliocene and Miocene (Fig. 29).

THERMAL CONDUCTIVITY

The conductive heat transport is mainly used to know the distribution of temperature with depth in the continents (Allen and Allen, 2005). Thermal conductivities of sedimentary vary as a function of depth due to their porosity loss with burial. The lithology is a factor affects thermal conductivity. The high thermal conductivity minerals such as quartz, halite, and anhydrite increase thermal conductivity of a rock.

In Zb-42 and Sb-3, the thermal conductivities of Rus and Umm Er-Radhuma formations are high despite their low geothermal gradient. In contrast, the thermal conductivities of Tanuma and Zubair formations are low despite having a high geothermal gradient. In NR-9, NR-7 and NR-12 thermal conductivity is high in Umm Er-Radhuma Formation and low in Tanuma and Zubair Formations. Mj-12 thermal conductivity is high in lower Fars (Fatha) and Umm Er-Radhuma Formations and low in Ghar, Khasib and Ahmadi formations. In Kt-1, HF-5 and Am-2 thermal conductivities are high in Jeribe and Euphrates and approximately same in all other formations. The porosity and the fluid contained within the pores play a major role the difference of thermal conductivities for formations with the same rock composition. If formation contain saline formation water within the pore net, the thermal

conductivity decrease as the porosity increase since the thermal conductivity of formation water is much less than for mineral (Fig. 30).

Fig. 29: Thermal history of the study area

The difference in thermal conductivities of formations having the same lithology could be attributed to porosity variations and contained fluid within pores. When pores fill with formation water, as porosity increases thermal conductivity decrease because thermal conductivity of formation water is much less than for mineral (Fig. 30). The porosity of

typical hydrocarbon productive sandstones ranges between (3-38%) in the gas reservoir and (10-38%) in oil reservoir (Bowen, 2005). Porosity in carbonate rocks can be much more variable in magnitude than it is in sandstone and chalks; it is very high, in few cases exceeding 50%

Fig. 30: Thermal conductivity of the study area

Fig. 30: Continued...

EVENTS CHART FOR THE STUDIED WELLS

Events chart (Fig. 31) summarizes those times when deposition of essential elements and the important processes that took place in the studied wells. The deposition of essential elements took place in Upper Jurassic-Upper Cretaceous. The time of deposition for the sources, reservoirs and seal rocks is only shown because the depositional system of the basin being studied varies laterally and vertically. The overburden rock required to thermally mature the source rock, includes rocks of Tertiary and overlying rock units. Since the hydrocarbon traps are strongly stratigraphic and structure, traps formation occurred during Lower Cretaceous

and Late Cenozoic. Petroleum generation for much of the basin area occurred (12-45) Ma, with peak generation (critical moment) occurring about 13Ma.

Fig. 31: Event charts for the study area

CONCLUSIONS

1. The organic maturity initiated at Upper Cretaceous and Early Tertiary.
2. In both Basrah and Amara oilfields, the rocks mature as the result of increasing the sedimentary burial depth in Miocene (Alpine Orogeny effects)
3. The main oil stage begins in Miocene in Sulaiy and Yamama formations. The exception is the Yamama Formation in NR-12 that entered late oil stage at this age. The formations in Nahr Umr oilfield in Basrah are characterized by high organic maturation due to activity of faulting processes and salt but in general, the organic maturation in the Amara oilfields is greater than Basrah oilfields.
4. Sulaiy and Yamama formations can be considered as a source rocks in the studied oilfields.
5. The maximum transformation ratio (69.45%) was recorded in Yamama Formation in Hf-5 well.
6. Migration of oil starts in Miocene in west and west-south trending.
7. The thermal conductivity of Rus and Umm Er-Radhuma formations in Basrah oilfields is high although they have low thermal gradient, while Zubair, Ahmadi, Khasib, Tanuma and Ghar formations is low although they have high thermal gradient because of the nature of mineral constituents of these formations. In Amara oilfield, both of Jeribe and Euphrates formations have high thermal conductivity; the other formations have low thermal conductivities.
8. Heat flow is in range (27 - 70 mW/m²) which affects the thermal maturity in the studied wells.
9. The essential geological elements required for petroleum accumulation in the Mesopotamian basin include Upper Jurassic-Late Cretaceous source rocks (Sulaiy and Yamama formations), while the Cretaceous and Tertiary rocks were including reservoirs and seal rocks.

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