



The Petroleum System of Zubair Formation in Zubair Subzone, Southern Iraq

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Abstract:

The Lower Cretaceous Zubair Formation is the most important reservoir in the south of Iraq and adjacent countries, as well as the shale intervals, may be the possible source rock. The parameters of the possible source rock within Zubair Formation are accepted, regarding quantity, quality, and thermal maturity.

From the total organic carbon values standpoint, shale intervals of Zubair Formation are generally good source rocks, except in the lower parts. While the kerogen types are generally type III gas-oil prone, mix type II/III, and type II oil-prone. The main type of organic matters was amorphous organic matters, which is principally related to oil-prone source rock.

The Rock-Eval Pyrolysis shows that the organic geochemical properties presented an effective and/or potential source rock depending on the values of S1, S2, and S3 and their derivatives. The source rock has started the oil expulsion, where the S1/TOC values were mainly more than 0.2 mg HC / g TOC.

The modelling explains that the Zubair Formation, wholly, has been entered the onset, partially, the peak, and rarely the end of oil generation in the studied Subzones. This conclusion depends on the calculated temperatures, geothermal gradients, and Vitrinite reflectance calibration.

Keywords: Petroleum system, Reservoir analysis, Source rock properties, Zubair Formation.

Introduction:

The Lower Cretaceous Zubair Formation can be considered as an important reservoir in the south of Iraq and some of the adjacent countries due to good reservoir properties [1, 2]. Zubair Formation is divided mainly, into five lithological units in southern Iraq [3, 4, 5], which are characterized by the cyclic mode of deposition as will be mentioned later. As well as, it is divided into three or two units elsewhere, which this difference in divisions is built upon the depositional environment [1]. It is worthy to mention that the shale components represent the source rock properties within the formation because these shale intervals contain some of rare elements and pyrite, which that prove reductive and acidic depositional environment. This evidence is reinforcing the belief of forming the source rock (SR) within Zubair Formation [2].

The scope of the present research is to calibrate and evaluate the essential elements and processes of the Petroleum System (PS). On the other hand, PS concepts are reducing the evaluation problems and risks and lead to new exploration mode [6]. The investigation of the thermal history and kinetics, include the processes as generation, migration, and accumulation, in addition to petroleum charge and timing [7].

Geological Setting:

The area of study lies in the Mesopotamian zone of the unstable shelf, Figure (1). The Mesopotamian Zone is divided into three subzones, Zubair, Euphrates, and Tigris subzone. Zubair subzone is the project of this research [5].

Zubair Subzone is characterized by many of elongated folds of N-S to NW-SE direction representing by the giant oilfields in Basra province [8]. These folds, which finally enclosure in Late Cretaceous, characterized by linear and narrow anticlines with a little appearance to faulted basement rock.

Material and Methods:

Twenty-three cores and cuttings samples were collected from Zubair Formation and their suggested hard data source rocks from four fields in the Zubair subzone which represented by Basrah regions. These data were used to the different geochemical analysis as shown in Table (1), for Rock-Eval pyrolysis. These samples are subjected to organic geochemical analysis with pyrolysis for source rocks evaluations in Geomark Research Ltd in Houston, Texas.

1. Quantity of Organic Matter:

The quantity of Organic Matter (OM) is usually expressed as Total Organic Carbon TOC [9]. TOC determination can be considered as the first step to provide basic geochemical information in order to evaluate the source rocks, as well as to select a sample for more detailed analysis.

The results of measured TOC values in the Zubair Formation vary in Zubair Subzone as shown in Table (2) [10]. The TOC results show that approximately the same pattern of distribution except in the lower part, namely lower shale member, characterized by a decrease in TOC, which may indicate a terrestrial OM invasion or oxic paralic siliciclastic environments represented by delta front, delta-top set, or fluvio-deltaic environment which containing on recycling [11].

Table (1): The members, wells names, depths, and results of Rock-Eval pyrolysis of Zubair Formation.

No.	Member	Well	Depth (m)	TOC	S1	S2	S3	Tmax
1.	Upper Shale Member	RU_78	3237	3.48	1.28	7.84	0.45	427
2.		RU_78	3249	2.58	0.05	0.15	0.32	429
3.		WQ_1	3056	0.28	0.19	0.76	0.38	432
4.		WQ_1	3104	0.52	0.42	0.92	1.47	431
5.	Upper Sandstone Member	R_27	3214.16	1.03	2.98	5.12	0.38	424
6.		R_36	3179.64	1.8	0.25	1.24	0.36	425
7.		RU_4	3257.1	0.6	0.12	0.85	0.49	431
8.		RU_10	3126.5	9.1	2.56	36.57	1.12	430
9.		WQ_2	3251.78	0.26	0.05	0.16	0.26	433
10.		WQ_2	3255.78	3.8	0.89	7.63	0.57	430
11.		Zb_45	3338	1.36	7.17	8.37	0.46	415
12.		Zb_45	3362	2.17	0.41	4.21	0.33	431
13.		Zb_45	3391	3.06	0.36	7.25	0.36	432
14.		Zb_109	3203.5	0.49	0.05	0.3	0.34	443
15.		Zb_109	3233	0.4	0.05	0.29	0.16	437
16.	Middle Shale Member	RU_4	3296.1	0.78	2.23	2.85	0.24	425
17.		RU_4	3309.3	25.4	5	68.62	3.82	434
18.		RU_10	3211.6	0.69	3.72	2.42	0.32	420
19.		WQ_1	3342	0.55	0.09	0.48	0.34	436
20.		WQ_1	3384	0.69	0.14	0.71	0.27	435
21.	Lower Sandstone Member	RU_4	3417.6	0.77	0.14	0.74	0.26	434
22.		WQ_1	3424	32.58	0.37	0.11	0.25	0.33
23.	Lower Shale Member	RU_4	3387.5	4.23	0.47	8.16	0.45	437

The quantity of TOC in rocks is closely related to sediment particle size. High TOC in sediments is due to the preservation and transportation of OM, not organic productivity [12]. The preservation of TOC generally increases from high-energy, which mainly coarse-

grained sediments, to low energy, which characterized by fine-grained sediments, as well as the sand unit with high values of TOC refer to the interbedded shale layers of prodelta and fine-grained sand interval, which may indicate low to moderate energy environment. These may interpret the relatively high values of TOC in the sand layers Zubair Formation.

Table (2) Details of average TOC in Zubair subzone.

Subzone	Member	TOC Averages
Zubair Subzone	Zubair Formation	1.88
	Upper Shale member	1.02
	Upper sandstone member	1.99
	Middle shale member	2.72
	Lower Sandstone member	2.34
	Lower Shale member	0.77

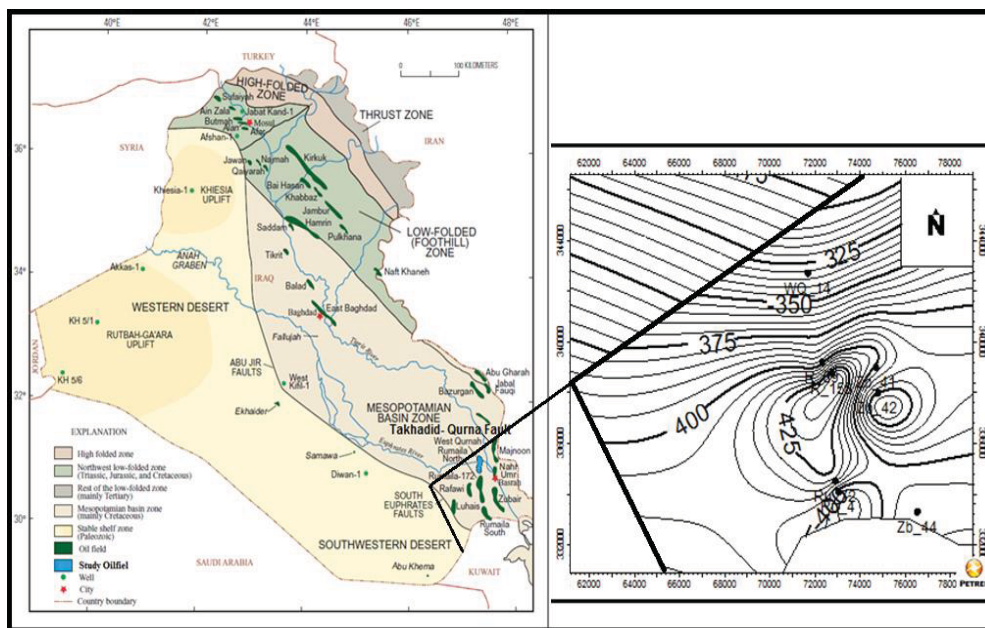


Fig. (1) The tectonic zonation and the area of study representing by target oil fields, the left, while the right is an isochore map to Zubair formation in the area of interest. [13]

2. Quality of Organic Matters:

The soluble fraction of sedimentary OM is referred to as bitumen, of which biomarker make up a minor but extremely significant part as mentioned in chapter three. The different kerogen types have different hydrocarbons (HC) generation potentials, which are

essentially related to their hydrogen content. The amount of HC which is generated and expelled from an SR increases as the atomic H/C ratio increases [9]. Thus, the most useful classification of kerogen is based on this ratio. The amorphous and algal, lipid-rich terrestrial kerogens like resinite and cutinite are oil-prone. Amorphous kerogens are the most abundant type of OM in SR. The kerogen typing is integrated by visual kerogen characteristics, as previously mentioned, and HI vs. OI and S2 vs. TOC crosses plots, as explained in Figures (2 and 3). The main values of HI in Zubair intervals in the studied area were between 50-200 mg HC/g TOC, Table (3).

Table (3) shows the HI values in the studied area and its juxtapositions.

No.	No. of values	Values range 0-50	Values range 50-200	Values range 200-300	Values range 300-600	Values range >600	Area of Values Measurements
1.	420	24	284	43	61	8	Zubair Formation in the south of Iraq.
2.	175	9	133	11	21	1	Zubair Formation in Zubair Subzone.

As a result, the kerogen type of the Zubair Formation can be considered as type III gas-oil prone, II/III oil-gas prone, II oil-prone, and less frequently of type I oil-prone as shown in Table (3).

S1 versus TOC:

A plot of S1 vs. TOC can be used to discriminate between indigenous and non-indigenous HC. Migrated or contaminants HC are indicated when S1 values are higher comparing with TOC, which have to be relatively low in the same sample. This case is represented by the values above the slanted line in Figure 4. However, the cross plots show that most of the samples are indigenous.

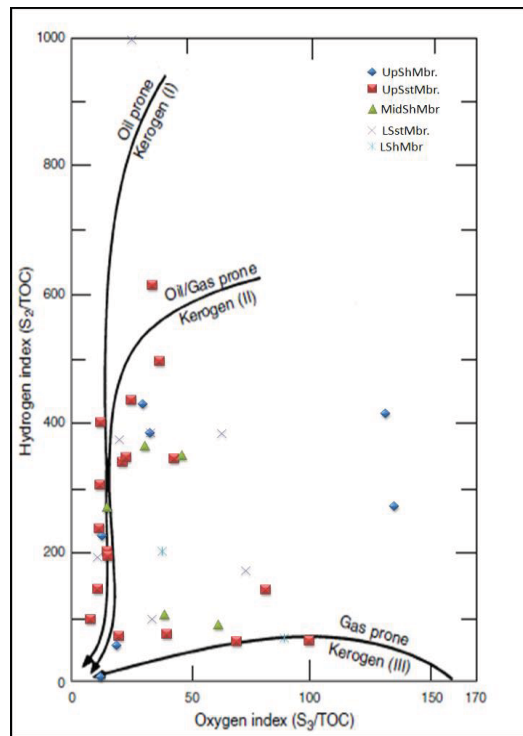


Fig. (2) The kerogen types in the study area depending on Hydrogen index versus Oxygen index in Zubair Subzone [14].

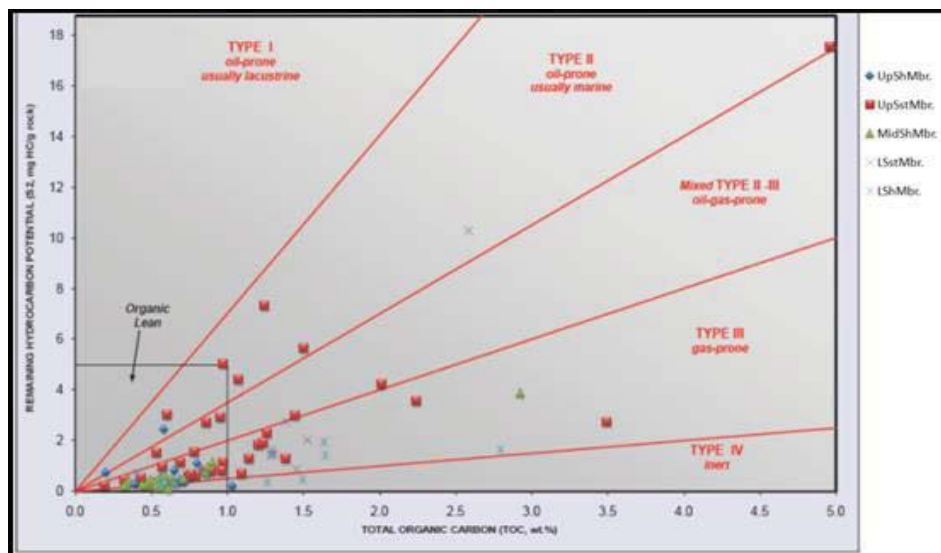


Fig. (3) The relation between TOC vs. S₂ values to differentiate kerogen types in Zubair Subzone, which the main types are Type III, II/III, and II Kerogen [15].

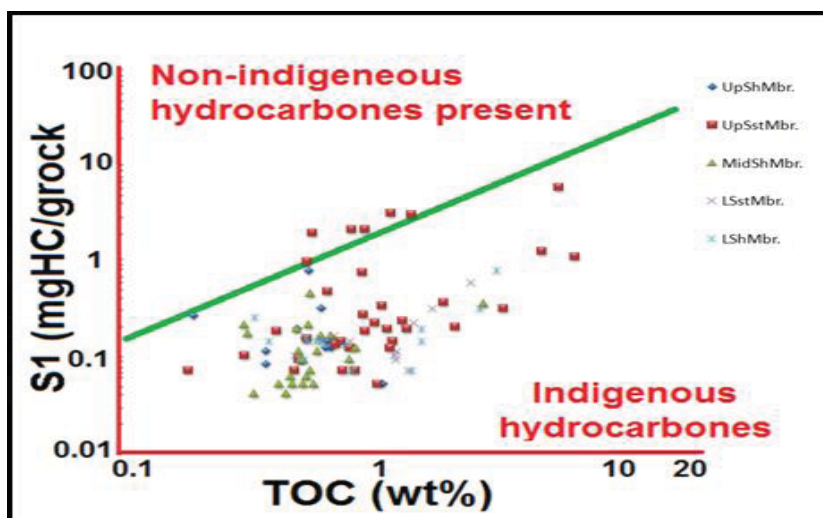


Fig. (4) S1 vs. TOC identifying migration or contaminants hydrocarbon, and showing the limitation of this phenomenon in Zubair Subzone [9].

3. Thermal Maturity of Source Rocks:

The pyrolysis Tmax values in Zubair Formation are mainly up to 430 C°, Table (1). As presented in this research, little of S2 values are under than (0.2) mg HC/g rock, therefore the Tmax values are accepted as an indicator for thermal maturity and kerogen typing, although, type IIS kerogen is sometimes recorded. The expected Tmax which is needed to generate and expels HC in Zubair Formation is might be 430-434C° in Type II, II/III and III Kerogen [16]. These values indicate that the OM in the units of studied formation is thermally mature with respect to HC generation, Figure (5).

Otherwise, the readings of Vitrinite reflectance (Ro) are very rare, so the equation of [17] is used to determine Ro in Zubair Formation as whole, the values of Ro which evolved from this equation have indicated the Zubair Formation is mainly within the oil Zone maturity [18] as in Figure (6).

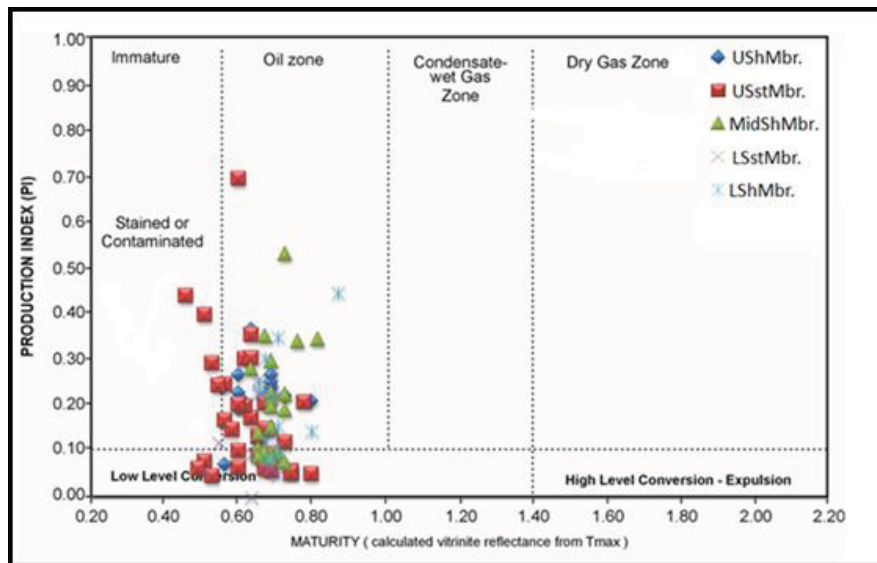


Fig. (5) The Production Index (Transformation Ratio or PI) versus calculated Ro as an indicator to maturity, which it is referred to onset of generation and expulsion in Zubair Subzone and indicate that Zubair Formation entered the oil window.

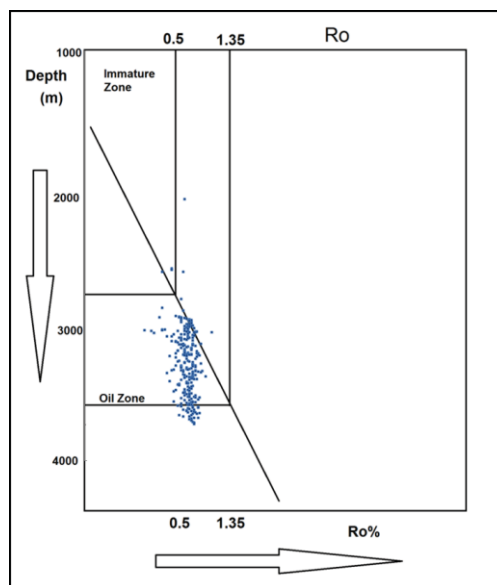


Fig. (6) The main values of Ro are representing the oil zone maturity [18].

4. Hydrocarbon Generation Modeling and Reservoir Properties:

Timing of the start, peak and end of HC generation (Transformation Ratio equal to 1, 50, and 99% respectively, for SR, is calculated at each unit of the Zubair Formation [19]. The beginning of HC generation from the possible SR in the Zubair Formation, the peak of HC generation, and the end are explained in Table (4).

As detailed in Table 4, in Zubair Subzone, the studied locations, mainly have reached to the peak of HC generation and some of these such as Zb_41 and Ru_4, 72 are at the end of HC production.

The immature intervals of Zubair Formation, or any other rich source rock, may be targeted as resources for “*Oil Shale*” industry in the near future. The term oil shale generally refers to any sedimentary rock that contains solid bituminous materials that are released as petroleum-like liquids when the rock is heated. To obtain oil from oil shale, the shale must be heated and resultant liquid must be captured. This process is called retorting, and the vessel in which retorting takes place is known as a retort [20]. The calculations assumed that each metric ton of shale produces about 25-30 gallons (each gallon = 4.5 litres) of liquid oil [21 and 22].

**Table (4) Timing of hydrocarbon generation for the possible source rock within
Zubair Formation in Zubair subzone.**

Well	Member	Start (Ma)	Peak (Ma)	End (Ma)
R_158	Upper Shale Member	35		
	Upper Sandstone Member.	43	8	
	Middle Shale Member	48	22	
	Lower Sandstone Member	52	28	
	Lower Shale Member	56	33	
Ru_4	Upper Shale Member	34	4	
	Upper Sandstone Member.	42	15	
	Middle Shale Member	47	20	
	Lower Sandstone Member	50	25	
	Lower Shale Member	54	31	5
WQ_14	Upper Shale Member	14		
	Upper Sandstone Member.	22	1	
	Middle Shale Member	32	5	
	Lower Sandstone Member	37	8	
	Lower Shale Member	39	9	
Zb_41	Upper Shale Member	29	2	
	Upper Sandstone Member.	36	10	
	Middle Shale Member	43	14	
	Lower Sandstone Member	47	19	
	Lower Shale Member	52	25	2

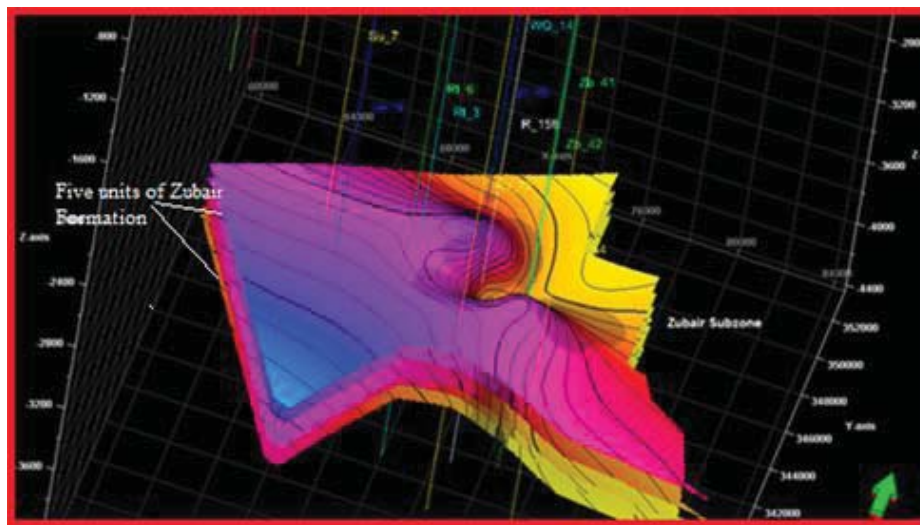


Fig. (7) The 3-D model of the Zubair Formation shows the stratigraphy and tectonic effects on the basin in the Zubair Subzone.

On the other hand and as indicated from the wireline logs and thin section analysis, figures 8 and 9, the reservoir rock within the multistory sand bodies had well properties in terms of porosity and permeability. The porosity ranges 18-30%, and the permeability ranges 100-1000md. The seal rock in the upper and lower parts of the formation is precisely efficient, which contain high mud content with low permeability sometimes approximately up to zero value. These results indicate that the main migration pathway may be across the horizontal facies change and/or faults conduits [23 and 24].

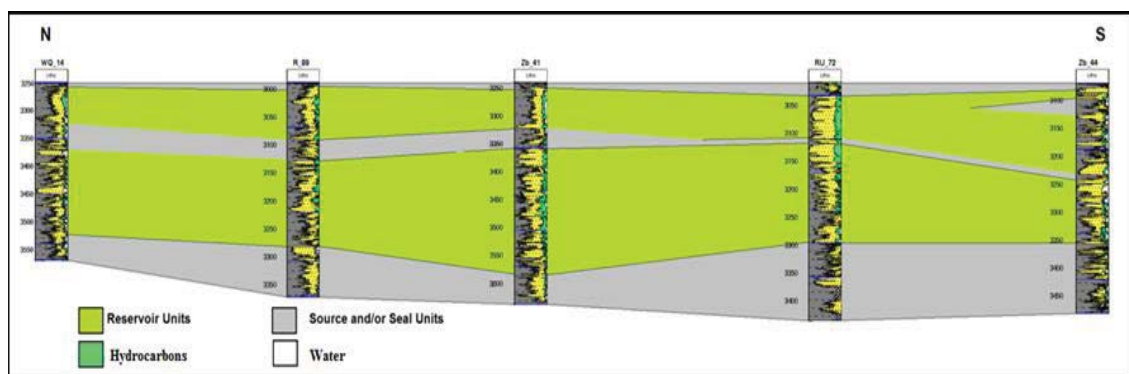


Fig. (8) Correlation of the reservoir, as well as source-seal units of the Zubair Formation, Zubair subzone.

5. Conclusions:

The following is a summary of the main conclusions that can be established from the result of the previous sections:

1. The TOC of Zubair Formation approximately ranges between 0.77-25.8 percentage, while the average values range 0.8-3.0%.
2. The principal kerogen type in Zubair Formation is the gas-oil prone Type III Kerogen with hydrogen index between 50-200 mg HC/g TOC, but oil prone Type II and I Kerogens are available at least in 26m, located mainly in the Zubair Subzone.
3. The pyrolysis parameters introduced that the Zubair Formation is entered the threshold of oil generation and expulsion, fortunately after the trap formation, which is represented by the values of S1 (more than 0.2 mg HC/g TOC), as well as the petroleum potential (more than 2.5 mg HC/g TOC), especially in the Zubair Subzone.
4. The oil of Zubair Formation is indigenous within the studied area as it has been indicated by the relation between S1 vs. TOC.
5. The maturity parameters: Tmax and Ro indicate that the Zubair Formation is mainly within the early-peak oil window.
6. The oil generation prospectivity of the Zubair Formation clearly appeared in the sandstone members. This result may be indicated in thin organic-rich marine shale beads deposited in the prodelta zone and belonged to the offshore facies.
7. The software modelling shows that all members of Zubair Formation are within the start of hydrocarbon generation, but less in the peak and rare at the end of hydrocarbon generation with respect to the transformation ratio.
8. The source rocks of Zubair Formation act as seal especially in the lower and upper parts of the formation. These source-seal rocks are impermeable to allow oils to migrate vertically. This conclusion is not general, where impermeable seal property may not be continuous throughout the basin.

9. Due to the high amounts of oil in Zubair Formation, that maybe indicates a mixed origin of oil in this area.

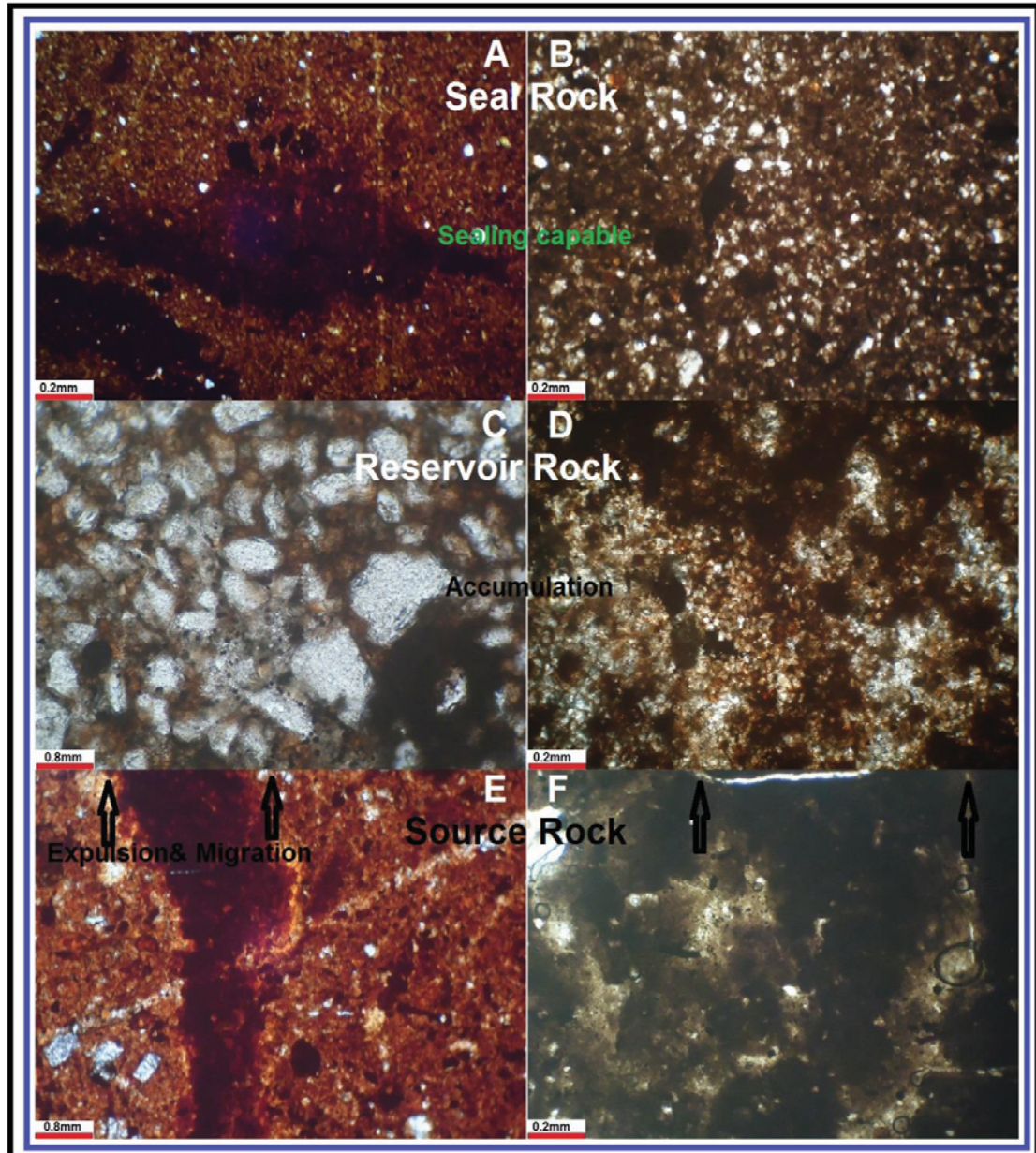


Fig. (9) A proposed model to the petroleum system elements; source, reservoir, and seal rocks, and the migration, accumulation and entrapment of generated hydrocarbons in the Zubair Petroleum System [25].

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