ZANCO Journal of Pure and Applied Sciences
The official scientific journal of Salahaddin University-Erbil
ZJPAS (2017), 29 (2); 88-95
http://dx.doi.org/10.21271/ZJPAS.29.2.9

Petroleum System Modeling of Jabal Kand Oil Field, Northern Iraq

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ARTICLE INFO

Article History:
Received: 06/06/2016
Accepted: 08/12/2016
Published: 07/06/2017

Keywords:
PetroMode
Hydrocarbon generation
Jabal Kand
Petroleum system
Northern Iraq.

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ABSTRACT

The petroleum system of Jabal Kand Oil Field shows that the formations such as Tertiary Kolosh, Cretaceous Shiranish, and Jurassic Sargelu are immature and have not generated any oil Ro< 0.55%. They are neglected as compared to formations below them which are also source rocks. The Kurra Chine Formation is mature with Ro> 0.55%. Other formations such as Gele Khana and other Triassic formations are with high maturity with Ro≥ 1.3% and are within wet and dry gas window while older formations are either within dry gas zone or completely generated hydrocarbon and depleted after hydrocarbon was expelled and migrated to reservoir rock of structure traps.

1. INTRODUCTION

The Jabal Kand-1 Well is located 30 km to the north of Mosul city (coordination latitude: 36º 39' 52.8" and longitude: 43º 01' 36.8"). The ground level elevation is 398.4 m and Rotary Table Kelly Bushing (R.T.K.B.) elevation is 406 m. The well was drilled to the depth of 5848 m R.T.K.B. and penetrated Paleozoic Chia Zairi and Harur formations (North Oil Company, 1983). The Jabal Kand structure is 33 km long and 5 km wide (Jassim and Goff, 2006). This structure is a long, twisting structure with a minimum of three peaks on top of the Lower Fars (Fatha) Formation. The well is located on the middle dome (North Oil Company, 1983). The presence of structural complication features was not verified by any indicators from the Dipmeter, but a NW-SE axial trend migration of the axis to the NE direction during the Carboniferous-Upper Jurassic can be inferred. Additional structural development and migration of the axis to the SW direction occurred during Lower Cretaceous-Miocene (North Oil Company, 1983). The well was completed in 1983 (Jassim and Goff, 2006).

A petroleum system includes a mature source rock, reservoir rock, cap rock, and overburden rock. In addition, it includes the processes such as stratigraphic or structural trap formation and the generation-migration-accumulation of petroleum. In order for petroleum accumulation to be present, all required elements and processes should be within a specific time and place (Magoon and Dow, 1994).

The study tries to determine the burial history, the thermal history, and the maturity history of the source rocks of the basin to reduce petroleum exploration risk.

2. MATERIALS AND METHODS

The studied well was modeled using PetroMod 1-D modeling software (one of the most famous commercial modeling software) developed by Integrated Exploration System GmbH. The 1-D burial history models are point locations, mainly wells.

For chronostratigraphic divisions, the time scale of the Lexique Stratigraphique International (Bellen et al., 1959) and International Commission on Stratigraphy (2008) was used. The input data include thickness, lithology, heat flow and absolute ages for each formation and each episode. The 1-D model includes 23 formations from the base of the Lower Carboniferous Harur Formation to the Middle Miocene Lower Fars (Fatha) Formation and is based on the UTM Zone 38 (Northern Hemisphere) coordinate system using the WGS 84 datum. The stratigraphic units, their ages, and lithologies are shown in Table 1. The compositional mixtures or lithology characterized as end member rock types was assigned to the facies in each formation. The thermal conductivities and heat capacities with their thermal properties of different rock types are either user defined or software default values. The T_{max} values and their mathematically determined Ro% equivalent, obtained by Rock-Eval pyrolysis, were used for calibration.

3. RESULTS AND DISCUSSIONS

Basin modeling combines several geological parameters to assess the formation and evolution of sedimentary basins to help evaluation of prospective hydrocarbon reserves. The scale of the model ranges in size from a single well to a whole basin.

3.1. Burial History and Thermal Maturation Modeling

Burial history, thermal maturity, and timing of petroleum generation were modeled for several key source-rock horizons at Jabal Kand-1. The formations from the oldest to youngest are the Harur, Chia Zairi, Mirga Mir, Beduh, Gele Khana, Kurra Chine, Baluti, Butmah, Adaiyah, Mus, Alan, Sargelu, Gotnia, Garagu, Sarmord, Qamchuqa, Aqra, Shiranish, Kolosh, Khurmala, Gercus, Pila Spi, Lower Fars (Fatha) formations (Fig. 1).

The results of the model indicate that peak petroleum generation from the Paleozoic Harur Formation oil- and gas-prone source rock in the deepest parts of the basin occurred and the accumulation and preservation happened from Mid Triassic (Fig. 2). The Jurassic Sargelu Formation is supposed to be more mature than it is but the absence of Upper Jurassic Najmah and Chia Gara formations and comparatively low thickness of overburden rocks (2107 m) have not contributed to increase the temperature to cook Sargelu. The Mid Sargelu Formation oil and gas-prone source rock not entered the oil window in the Miocene and it is still not within the oil window at the present time (Fig. 2). The Cretaceous source rock has no significance in the study area because of tectonic activity (obduction) and non-deposition of Oligocene-Lower Miocene and erosion of Upper Miocene-Pleistocene sediments. Also the relatively reduced thickness of the Middle Miocene sediments (some hundred meters) and the erosion or non-deposition of Lower Bakhtiary, Upper Bakhtiary, and Alluvial during Pliocene-Pleistocene time seems to be relevant for hydrocarbon maturity (Fig. 3).

3.2. Temperature and Heat Flow Analysis

The goal of heat-flow analysis is temperature calculation, a prerequisite for determining geochemical reaction rates. The provided bottom hole temperature data from well logs and final geologic reports for Jabal Kand-1 Well (Fig. 4) were used to estimate the present heat flow in Mosul area.

Table 1: Data used to generate burial-history curves in well Jabal Kand-1 in Mosul area, Northern Iraq.

Formation	Top (m)	Base (m)	Thickness (m)	Eroded (m)	Depo. From [Ma}	Depo. to [Ma]	Eroded From [Ma]	Eroded to [Ma]	Lithology	PSE	TOC (wt.%)	HI (mg HC/g TOC)
Lower Fars	-398	-242	156	250	13.7	11.6	11.6	0.1	Evap. shaly	Seal Rock		
Pila Spi	-242	177	419	100	40.4	33.0	33.0	13.7	Lime. Dolom.	Reservoir Rock		
Gercus	177	413	236		48.6	40.4			Shale & sand	Seal Rock		
Khurmala	413	606	193		55.8	48.6			Limestone (shaly)	Reservoir Rock		
Kolosh	606	911	305		63.6	55.8			Shle. & Lime.	Source Rock		
Shiranish	911	1013	102		75.0	63.6			Shale calc.	Reservoir Rock		
Aqra	1013	1054	41		89.8	75.0			Limestone (micrite)	Reservoir Rock		
Qamchuqa	1054	1242	188	100	113.0	93.9	93.9	89.8	Lime. dolom	Reservoir Rock		
Sarmord	1242	1275	33		133.9	113.0			LimestoneE	Reservoir Rock		
Garagu	1275	1360	85		140.2	133.9			Lime. sandy	Reservoir Rock		
Gotnia	1360	1677	317	250	159.0	149.0	149.0	140.2	Lime. & Evap.	Seal Rock		
Sargelu	1677	1890	213	150	177.2	164.7	164.7	159.0	Lime. marly	Source Rock	3.93	444
Alan	1890	1991	101		180.0	177.2			Lime. & Evap.	Seal Rock		
Mus	1991	2047	56		186.0	180.0			Lime. marly	Reservoir Rock		
Adiyah	2047	2085	38		190.5	186.0			Lime. & Evap.	Reservoir Rock		
Butmah	2085	2479	394		199.6	190.5			Lime. dolom	Reservoir Rock		
Baluti	2479	2535	56		202.0	199.6			Evap. shaly	Seal Rock		
Kurra Chine	2535	3682	1147	170	227.3	205.0	205.0	202.0	Shale carb.	Reservoir Rock		
Gele Khana	3682	4463	781		239.0	227.3			Shale carb	Source Rock	0.79	144
Beduh	4463	4530	67		241.0	239.0			Limestone (shaly)	Reservoir Rock		
Mirga Mir	4530	4695	165		247.0	241.0			Dolomite	Reservoir Rock		
Chia Zairi	4695	5325	630		270.6	247.0			Limestone	Reservoir Rock		
Harur	5325	5848	523	110	359.2	340.3	340.3	270.6	Limestone (shaly)	Source Rock		

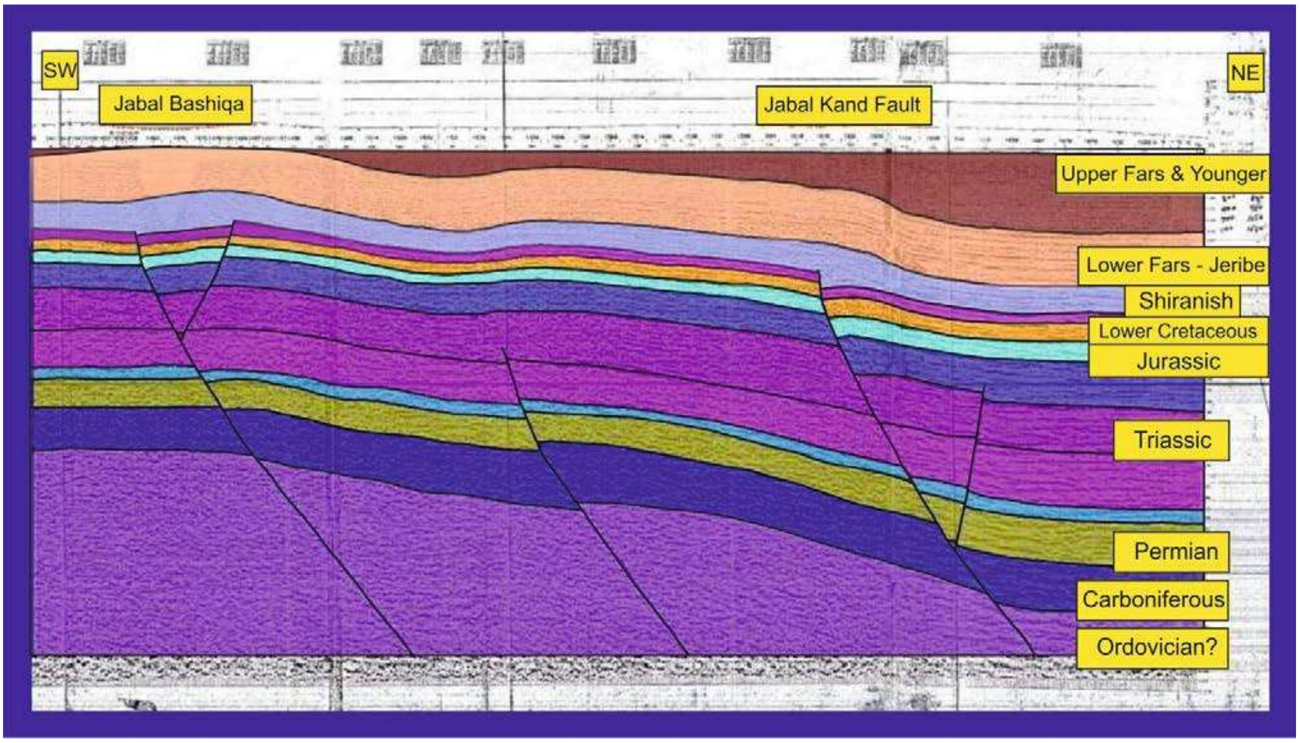

Figure 1: seismic crosses the plunge of and the ends of Jabals Kand and Bashiqa (Kent, 2010).

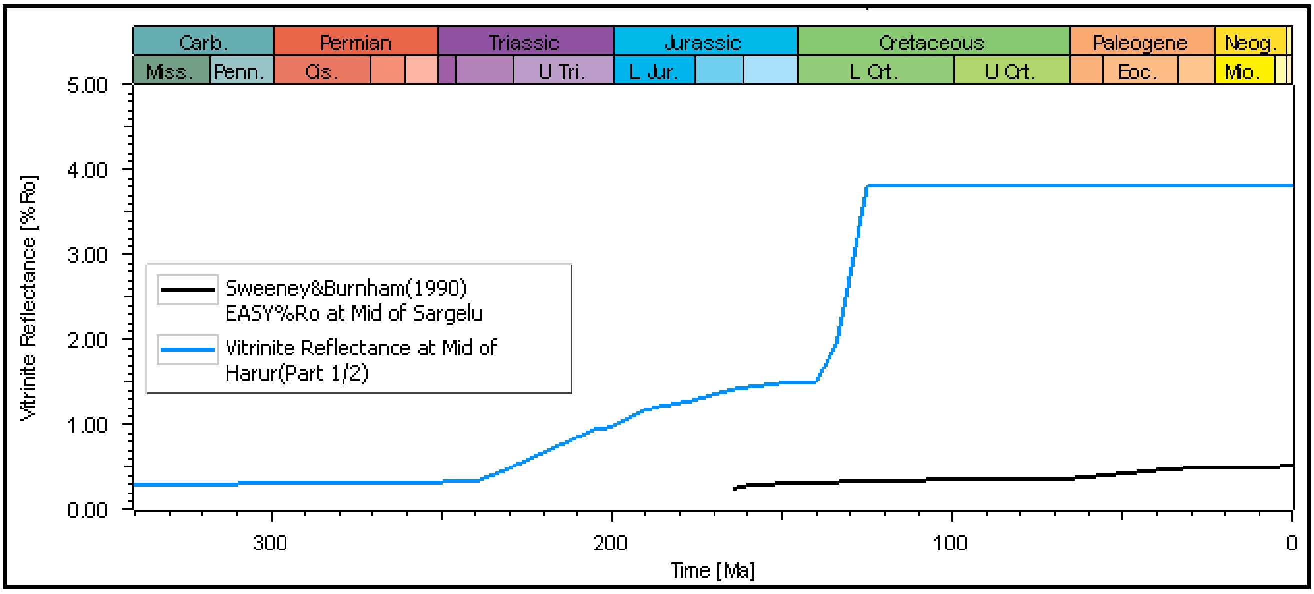

Figure 2: Calculated vitrinite time profile of well Jabal Kand-1 in Mosul area, Northern Iraq. The figure shows that Harur Formation entered oil window in the Mid Triassic and entered gas window in the Early Jurassic. The Sargelu Formation has not entered oil window and it is still not within oil window at the present time.

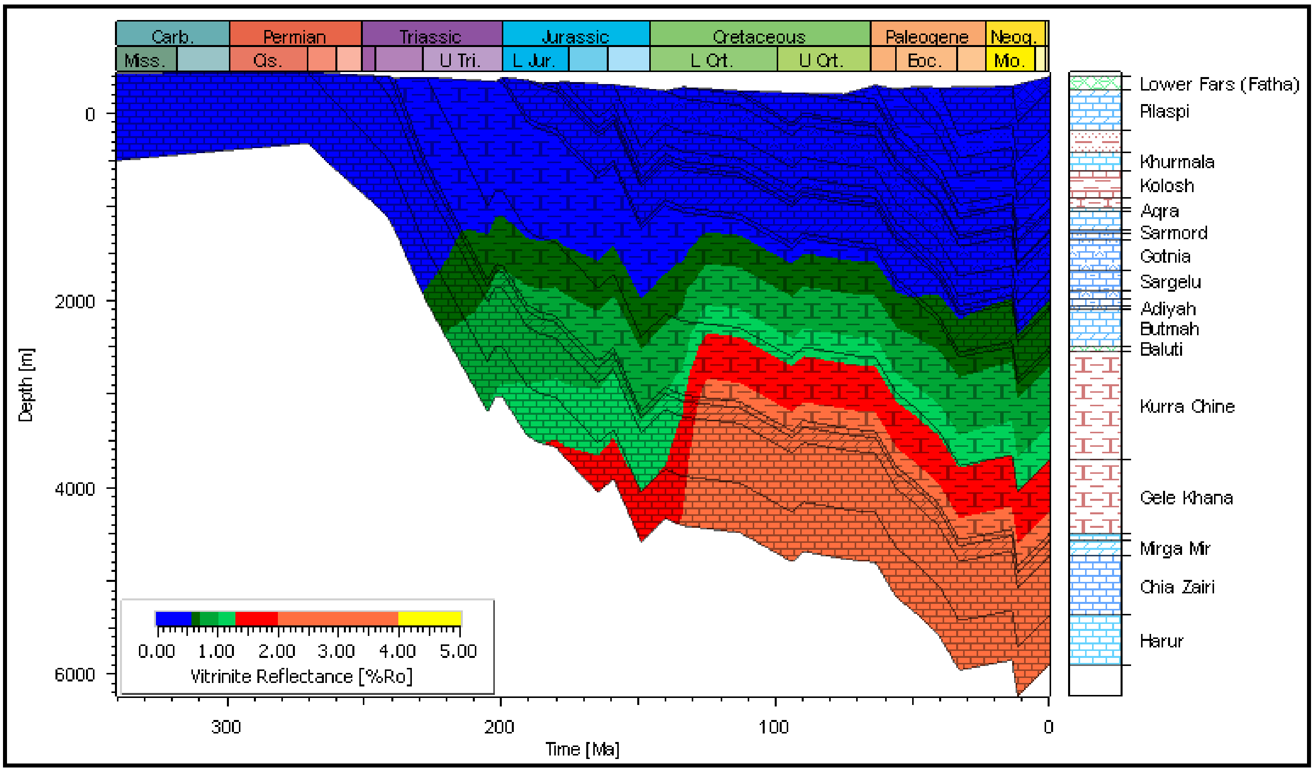

Figure 3: Burial history with vitrinite reflectance (Ro %) of well Jabal Kand-1 in Mosul area, Northern Iraq.

The temperature- versus- depth curve clearly shows intervals of steep and low increases, which is due to the difference in thermal conductivity of rocks (Fig. 5). The figure clearly shows a steep increase in temperature between Gotnia and Baluti formations (Fig. 4). Also the heat flow from the base upward does not remain constant, because changing paleoheat flow caused an increase in pressure and compaction. An important

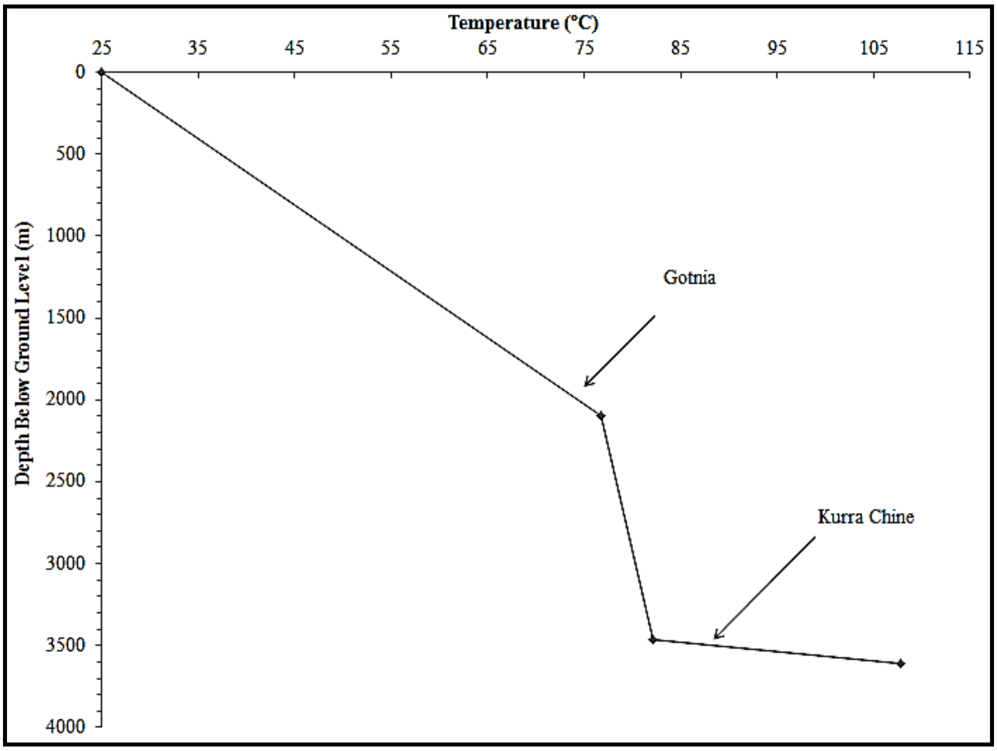

Figure 4: Bottom hole temperature variation with depth of well Jabal Kand-1 in Mosul area, Northern Iraq. The figure shows that temperature rapidly increases between Gotnia and Baluti formations.

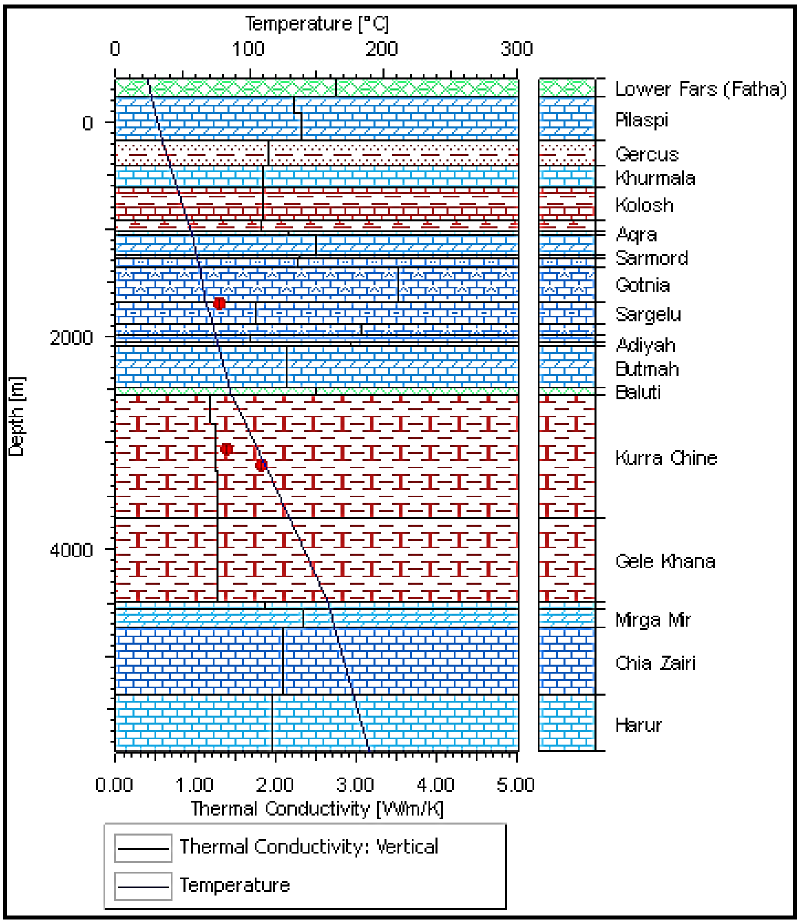

Figure 5: 1D model of the calculated and measured temperature (blue line) and thermal conductivity (vertical lines) versus depth of well Jabal Kand-1 in Mosul area, Northern Iraq.

consequence of this long period of relative stability, with lower and constant rates of subsidence, is that the heat flow can be assumed to be constant through time. Based on this assumption and in agreement with the heat flow values, 42- 80 milliwatt/square meter (mW/m²) considered for foreland basins by Allen and Allen (2005), constant heat flow values were considered for modeled wells. In order to investigate the accuracy of the calibrated thermal and maturity models, the thickness of overburden, timing and duration of hiatus and unconformities and surface erosion intensity, a sensitivity analysis was performed. A good fit between calculated and measured temperature values was attained (Fig. 5) using estimated heat flow value equal to (42 mW/m²) in the studied area, assuming a mean surface temperature of (25ºC) through the region.

3.3. Thermal Maturation

The T_{max} showed systematically normal maturity, due to the non-contaminated samples. As T_{max} values are reliable, the maturity of the source rocks was evaluated on the T_{max} basis where T_{max} could be measured from cuttings (Table 1). In the middle part of Jurassic sequence the maturity is indicated by T_{max}. The measured T_{max} values range between 427ºC (0.53 Ro%) and 436ºC (0.69 Ro%) at depths of 2110 m and 2134 m, respectively in well Jabal Kand-1. This range corresponds to immature to early oil-window because generally, the early oil window is defined by a vitrinite reflectance of Ro=0.55%, the main oil window by a reflectance of Ro=0.70% and the late oil window by a vitrinite reflectance of Ro=1.00% (Sweeney and Burnham, 1990). More than 1700 m erosion can be estimated due to the Lower and Upper Permian, Upper Triassic, Upper Jurassic, Middle Cretaceous, Oligocene, Lower Miocene, and Upper Miocene-Pleistocene uplifts, respectively. This huge amount of eroded and/or non-deposited sediments is responsible for the organic matters' low thermal maturity (Fig. 6).

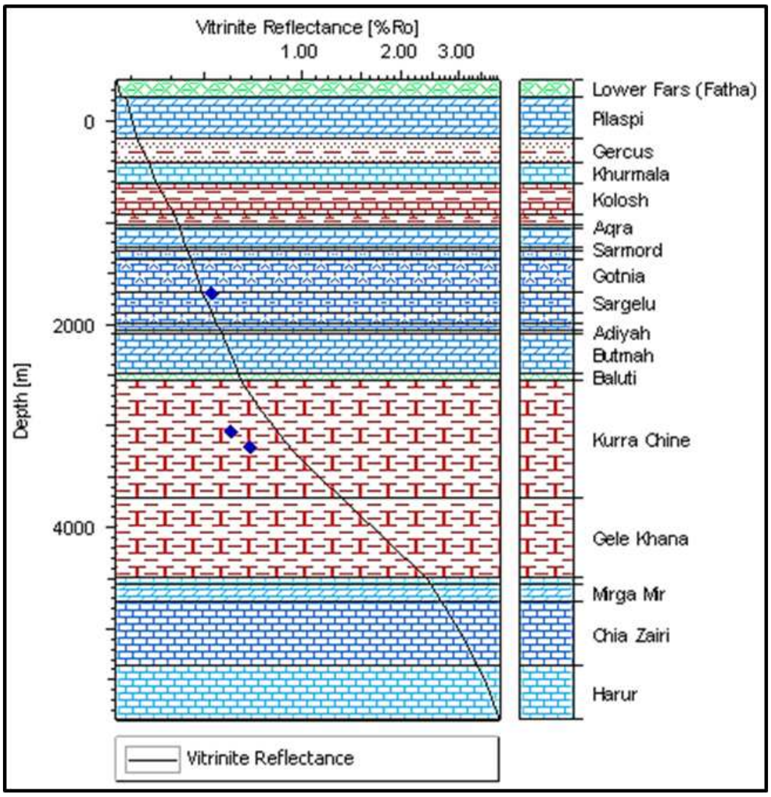

Figure 6: Calculated vitrinite-depth profile with measured values (squares) of well Jabal Kand-1 in Mosul area, Northern Iraq.

3.4. Generic Events Chart

The petroleum system in well Jabal Kand-1 indicates that oil has not started to generate in Sargelu Formation although a trap has formed since Miocene. The Harur Formation started to generate hydrocarbon 207 Ma ago (Fig. 2). Most of the generated oil migrated, resulting in major upward migration and oil accumulations since Late Jurassic and the critical moment started 110 Ma ago (Fig. 3). The uplift and non-deposition during Upper Jurassic and collision caused migrated oil to be lost. Therefore, the well Jabal Kand -1 is not a productive well.

3.5. Burial History

One-dimensional modeling of burial history and thermal maturity was performed on well Jabal Kand-1 by using PetroMod 2012.2 (Fig. 3). The profile as shown in figure 3 for Jabal Kand Oil Field demonstrates the effects of continuous burial on source rocks temperature within stratigraphic section. At the present time, the basin is reaching a maximum burial temperature of 180ºC-190ºC at 5840 m underground. The profile for this well shows that the temperature of source rocks of Paleozoic age represents maximum burial temperature due to burial and tectonic subsidence through the time of the sedimentary basin. As expected, the extensive petroleum generation from Jurassic Sargelu Formation has not occurred because of the small overburden rock thickness and not being deeply buried (the overburden rocks are mostly eroded or not deposited).

A thermal maturation depth in Jabal Kand-1 is around 3000 m according to geochemical data (Al-Habba, 1988). The Sargelu Formation is shallower than that depth (2107 m) while it is of high hydrocarbon potential (the primary, pre-expulsion potential; S2 is around 17.8 milligram hydrocarbon per gram rock) and reaches a good thickness (213 m) and it is immature (Al-Habba, 1988). The Early Jurassic sediments (Alan and Mus formations) though thermally mature, have a low hydrocarbon yield potential (Al-Habba, 1988), even though there are Triassic (mature) and Palaeozoic (either within late gas zone or postmature) source rocks.

The earlier study on crude oils in Tawke-3 and Tawke-4 showed that oils belong to Jurassic source rocks and they are within the equilibrium phase (Abdula, 2015). Furthermore, the same study showed that Middle Jurassic source rock is not totally mature in Tawke-15 Well. The maturity of source rocks in well Tawke-15 occurs below the depth of 2,880 m and the depth of expelled oil in TA-15 Well is 2,910 m (Abdula, 2015) which supports immaturity of Jurassic source rocks.

3.6. Porosity for Rock Types

The model showed the present porosity for different rock types and compaction effect (Fig. 7). The lowest porosity was recorded for Chia Zairi Formation (10%) and the highest was recorded for Adaiyah Formation (32%).

4. CONCLUSIONS

Based on the PetroMod burial history and petroleum generation renovation in the area, the Sargelu Formation has not started to generate oil yet. The Harur source rock started to generate oil in the Late Triassic (207 Ma) and the generation lasted until 130 million years ago. The Gele Khana Formation is within wet gas zone. The formations younger than Gele Khana are either within oil window or immature while formations older than Gele Khana are either within dry gas zone or postmature.

ACKNOWLEDGMENTS

The author thanks the Iraqi Ministry of Oil in Baghdad, Iraq and North Oil Company in

Kirkuk, Iraq for their generous help by providing necessary information and cutting samples.

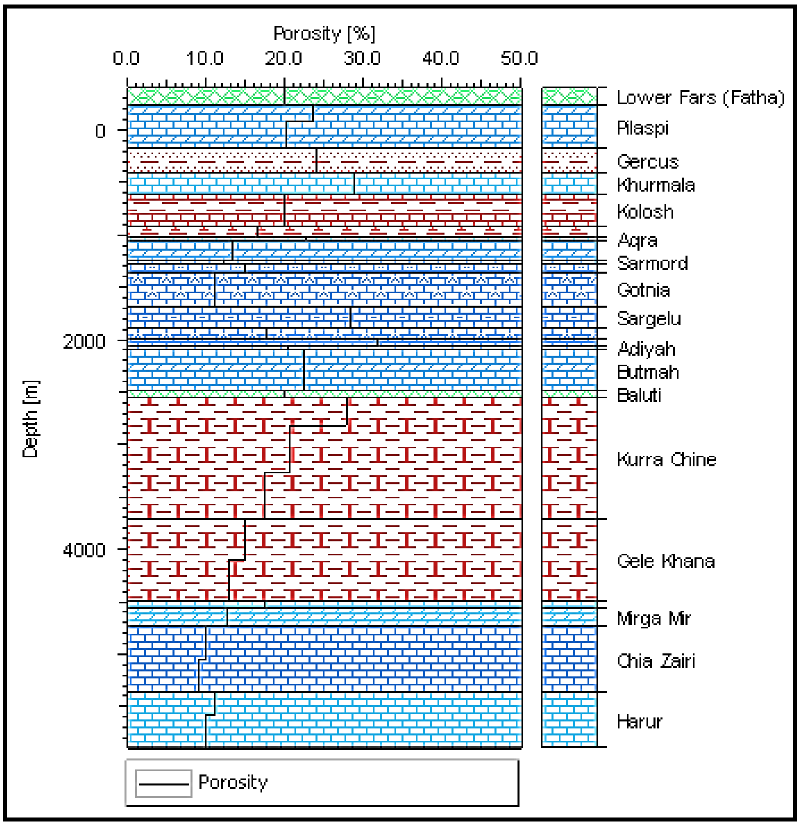

Figure 7: Calculated porosity depth profile for different rock types of well Jabal Kand-1 in Mosul area, Northern Iraq.

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