The Middle Cretaceous – Lower Miocene 3D petroleum system Modeling of Kupal Oil Field, South West of Iran, Dezful Embayment

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Abstract
The Middle Cretaceous–Lower Miocene petroleum system of the Kupal oil field, located in the Dezful Embayment has been studied. The Kazhdumi and Pabdeh are main source rocks, the Sarvak, Ilam and Asmari formations are reservoir and the Gachsaran formation is the seal rock. According to geochemical analysis, the Kazhdumi and Pabdeh contributed to oil generation and feeding the Asmari and Bangestan reservoirs. Also, the lateral migration from the Kupal to other fields is ruled out but vertical migration led to feeding the Asmari and Bangestan reservoirs. Considering burial history diagrams and modeling of 3D petroleum system in the syncline area between the Marun and Kupal fields, oil generation phases from the Kazhdumi and Pabdeh formations were about 9 and 6 million years ago, respectively. Also in the syncline area between these structures (about 7 and 3 million years ago), the hydrocarbon expulsion started from the Kazhdumi and Pabdeh formations, respectively. Based on 3D hydrocarbon system modeling, in the drainage area of the Kupal oil field, about 51% of the hydrocarbon composition of the Kazhdumi source rock transformed into coke and consumed during the geological periods; but the Pabdeh source rock is remained intact, and only about 18% of the hydrocarbon composition of this formation is transformed into coke. Also the oil volume generated from the Pabdeh and Kazhdumi in the Kupal field are estimated to be 42 and 113 billion barrels, respectively.

Keywords: *Petroleum System Modeling, Source Rock, Generation, Expulsion, Migration, Dezful Embayment, Kupal Oil Field*

Introduction

The petroleum system includes the essential elements and processes as well as all genetically related hydrocarbons that occur in petroleum shows, seeps, and accumulations whose provenance is a single pod of active source rock (Magoon and Dow, 1994). Each petroleum system consists of 5 elements including source, reservoir and seal rocks, trap and migration paths; which are essential for the accumulation of hydrocarbon. For petroleum generation and accumulation, these elements have to be juxtaposed in the suitable framework of time and space (Magoon, 1988 in Magoon and Dow, 1994; Bordenave, 1990:1995: 2002; Alsharhan, 2014).

Bordenave and Burwood (1990), Bordenave & Huc (1995), Bordenave & Burwood (2005), Bordenave & Hegre (2010) and Bordenave (2014) believe that in the Zagros Folded Belt and the Persian Gulf, five major petroleum systems have caused the accumulation of hydrocarbons in numerous oil and gas fields among which, the Middle Cretaceous–Early Miocene petroleum system is the most important in the Dezful Embayment. Accordingly, Kazhdumi and Pabdeh source rocks have fed the Asmari and Bangestan reservoirs in this system.

In Iran, among the first researches on the petroleum system modeling in the sedimentary basin of the Zagros region were Bordenave and Burwood (1990 and 1995) and Bordenave (2002). In their work the Asmari and Bangestan reservoirs oil's were analyzed and correlated to the Kazhdumi and Pabdeh source rocks. Then, Bordenave and Hegre (2005 and 2010) and Bordenave (2014), in separate researches, have reviewed one–dimensional performance of various Zagros petroleum systems during the geological periods. Rashidi *et al.* (2014) simulated two–dimensional petroleum system model of the Qom Formation in the central Iran's Sarajeh area. In this model, the origin of the gas and oil in the reservoirs, the thermal history, the time of hydrocarbon generation, and the maturity of the source rock have been investigated. Zeinalzadeh *et al.* (2010 and 2015), Opera *et al.* (2013), Darabi (2014), Baniasad *et al.* (2016) and Karimi *et al.* (2016) have studied the source of gas and oil in Asmari and Bangestan reservoirs, the time of hydrocarbons generation and maturation of Kazhdumi, Gurpi and Pabdeh source rocks by performing one and two dimensional burial history and thermal maturation modeling of the Middle Cretaceous– Early Miocene Petroleum System of several oil fields (Gachsaran, Bibi–Hakima, Rag–e–Safid, KilurKarim, Siahmakan, Aghajari, Pazanan, Darquain, Binak and Ahvaz) in the southern Dezful embayment. Mohsenian *et al.* (2014), Mashhadi *et al.* (2015), Baniasad *et al.* (2017) modeled burial history and petroleum systems of the Paleozoic, Mesozoic and Cenozoic source rocks in the Persian Gulf. In these researches, the potential and time of hydrocarbons generation of the Silurian, Jurassic, Cretaceous and Eocene source rocks in South Pars, Golshan, Balal and northwestern fields of the Persian Gulf have been investigated.

In the Middle East, Pitman *et al.* (2004) has conducted a comprehensive study on the generation and migration of hydrocarbons in the Iraqi Mesopotamian Basin. Abu–Ali and Littke (2005), as well as Abeed *et al.* (2013) have modeled the Paleozoic petroleum system of the Saudi Arabia and the Upper Cretaceous–Jurassic fields of South Iraq, respectively.

Currently, due to the lack of three–dimensional (3D) petroleum systems modeling in the south–western Iranian oil fields, this study has been conducted as a pilot project. The Kupal oil field has been considered due to the fact that the source and reservoir rocks in this field are about 1,000 m deeper than the nearby fields (such as Ramin, Marun, Aghajari and Haftkel oil fields), so it is likely that the Kazhdumi source rock has entered the oil window phase earlier than the nearby fields.

Geological framework:

Tectonic setting

The Dezful Embayment is a part of the central Zagros Mountains and a rich oil province in southwestern Iran (Bordenave, 1990 and 1995), which has long been attractive for geologist and experts of oil companies. This structural zone contains approximately 8% of world oil reservoirs (Bordenave & Hegre, 2005 and 2010) and 90% of the oil reserves of Iran (McQuillan, 1991). The Dezful Embayment is characterized by a higher thickness of Tertiary deposits compared to the Fars and Lurestan areas and is about 3000 to 6000 meters lower than its neighboring areas (Motiee, 1995; Sherkati *et al.,* 2004:2006). The Zagros folding began in the middle Miocene (about 12 million years ago) and covers the entire belt until the early Pliocene (about 3 million years ago), (Agard *et al.,* 2005 and 2011). This evidence is coinciding with the petroleum generation processes in this region of the world (Bordenave & Hegre, 2005).

The Kupal oil field is located 60 kilometers to the east of Ahvaz city in Khuzestan province, and it is an extension of Aghajari anticline fold in the central part of the Dezful Embayment. This filed is among the giant Iranian oil fields. The subsurface structure of the Kupal oil field neighbors Marun oil field to the southwest, Ramin oil field to the northwest and Aghajari oil field to the southeast. It lies within the latitude 31° 10' to 33° 31' and longitude 49° 8' to 49° 27' and the average height of the field is 155 m above mean sea level (Fig. 1).

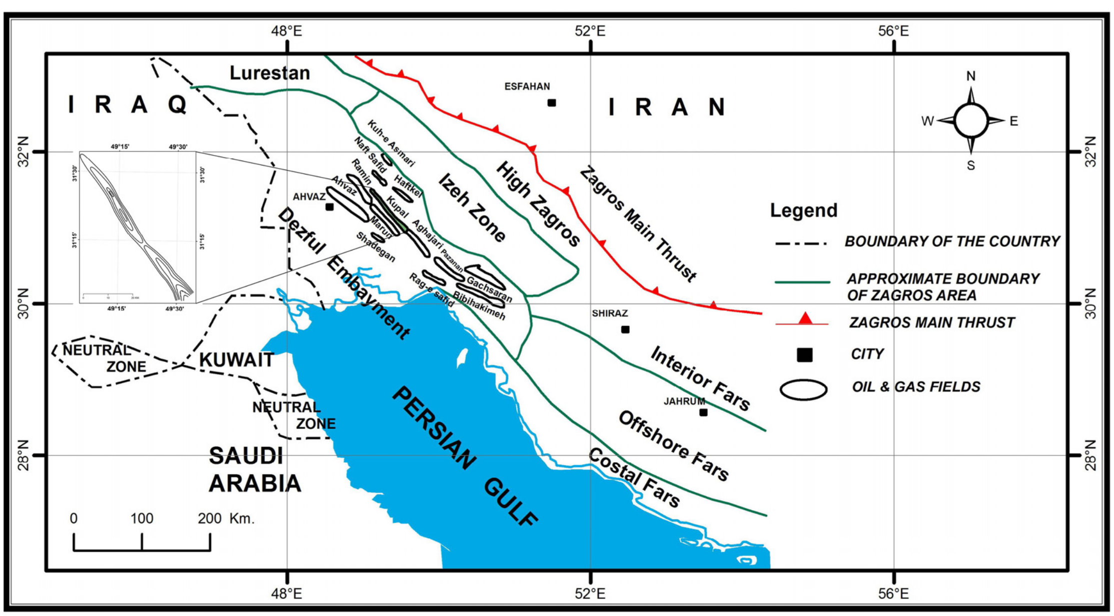

Figure 1. The location map of Dezful Embayment and study area

Stratigraphic Units

The outcrops in the Kupal anticline consist of alluvial deposits, Bakhtiari Formation and sandstone hills of Aghajari Formation (Lahbari member) as well as gently dipped sedimentary layers (maximum 12 degrees). The underground anticline of this petroleum system is covered by alluvial deposits, the Bakhtiari Formation and Fars group (Gachsaran, Mishan and Aghajari formations) and overlies the Dariyan Formation, gradually (Aghanabati, 2004), (Fig. 2).

Gachsaran Seal Rock

Gachsaran evaporate Formation is one of the most important seal rocks for the Asmari reservoir in the Dezful Embayment (James and Wynd, 1965; Motiee, 1995) which extends to the Persian Gulf Basin. Salt rock, anhydrite, limestone, red and gray marls are the main lithostratigraphic units of this formation. The Gachsaran Formation is deposited in the Dezful Embayment during upper Oligocene to middle Miocene (Aghanabati, 2004). So, its sedimentation has been completed on the Langhian stage, which matches the Styrian Orogenic phase of the Late Alpine (Bahroudi & Koyi, 2004). The average thickness of this formation in the Kupal oil field is 720 m and with average sedimentation rate of about 120 m in a million years (Fig. 2 and Table 1).

Asmari & Bangestan Reservoirs

So far, 59 oil wells are drilled in the Kupal oil field out of which 36 wells are completed in the Asmari and 20 wells are completed in the Bangestan reservoirs. The Asmari Formation is mostly extended in the Dezful Embayment (up to 550 m in thickness). Northward it extends to the Iraq and southward to Oman area (James and Wynd, 1965; Piryae *et al.,* 2014). The Asmari formation is the main reservoir of this petroleum system and lithologically, the upper two–thirds of it consists of carbonate rocks including limestone and dolomite and the remaining one–third (at its base) comprises clastic sediments such as shale and sandstone. This formation is overlain by the Gachsaran Formation with the age of the lower to middle Miocene and overlies the Pabdeh Formation whose age ranges from Paleocene to Eocene.

The Bangestan Reservoir mainly consists of carbonate rocks including limestone but in the base comprises clastic sediments such as shale. This reservoir is overlain by the Gurpi Formation with the age of the Upper Cretaceous and overlies the Kazhdumi Formation whose age is Middle Cretaceous (Aghanabati, 2004).

On the basis of data from drilled wells which penetrated the entire thickness of the Asmari and Bangestan reservoirs; it shows average thickness of this reservoirs are 425 m and 1100 m as a whole, respectively. Moreover, the estimated average sedimentation rate for the Asmari is about 28.3 m and for both the Ilam and Sarvak Formations (Bangestan reservoir) it is about 77 m, in a million years (Fig. 2 and Table 1). The Asmari and Bangestan are under–saturated reservoirs with no gas cap column conditions, in which the propulsion force is produced only through the oil expansion, and therefore, they do not have an active water zone (Ansari & Safaee, 1986; Roghanian and Farazmand, 2008).

Table 1. The age, average thickness, average sedimentation rate, Paleo-water depth and sediment-water interface temperature of the Middle Cretaceous – Lower Miocene petroleum system formations of Kupal oil field.

Formation	Average Thickness (m.)	Age (Ma)	Rate of Sedimentation(m.y.)	PWD (m)	SWIT ©	Petroleum System Element
Alluvium	70	0	35	0	22	Over burden rock
Bakhtiyari		2		0	20	
Aghajari	2450	9	350	15	19.86	
Mishan	250	13	62.5	10	20.59	
Gachsaran	720	18	120	2	21.3	Seal rock
Asmari	425	33	28.3	50	23.31	Reservoir rock
Pabdeh	170	60	6.3	150	23.92	Source rock
Hiatous	-	65	-	0	27.29	-
Gurpi	145	82	8.5	130	26.37	-
Ilam	45	86	11	50	29	Reservoir rock
Sarvak	1055	98	66	160	27	
Kazhdumi	260	112	18.6	50	29	Source rock

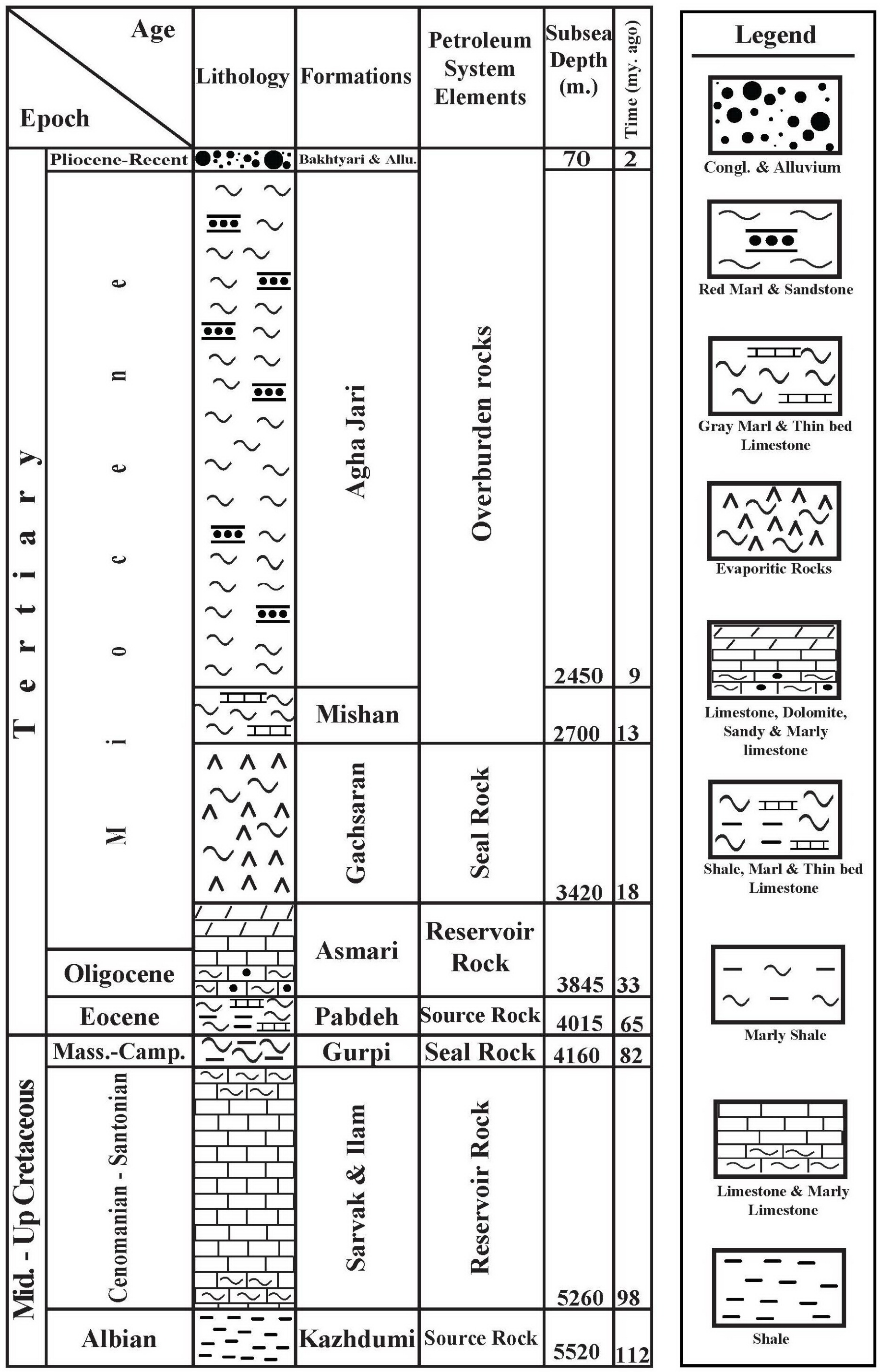

Figure 2. A schematic chronostratigraphic section of the Kupal and nearby fields from the Middle Cretaceous till present time

Pabdeh & Kazhdumi Source Rocks

The Pabdeh Formation is a Carbonate – Terriginous lithostratigraphic unit that deposited in the various sedimentary environments of the remains of Neotethys Tertiary basin and extends from Fars province to Iraq (James & Wynd, 1965; Piryae *et al.,* 2014). This formation in the Dezful Embayment deposited in a reducing condition dominated the platform. It led to its good potential for source rock (with a thickness of about 200 m) in some oil fields such as Reg–e–Safid, Bibi–Hakima, Kupal located in northern Dezful Embayment (Bordenave and Burwood, 1990 and 1995). The Pabdeh Formation in the Kupal oil field consists of gray to brown shale intervals, clayey limestone along with marl and has been completely drilled in 20 oil wells. Its average thickness and its average sedimentation rate were 170 m and about 6.3 m in a million years, respectively (Fig. 2 and Table 1).

The Kazhdumi Formation is also carbonate – terrigenous in lithology, deposited in a reducing condition on the platform environment of the Cretaceous sea of the Neotethys (Khuzestan, Coastal Fars and Hormozgan regions) and Persian Gulf. In the Zagros, at the Albian stage, due to gradual sea–level rise, marine bituminous shales, pelagic marls and platform limestones began to precipitate. So that, the Dezful Embayment formed the deepest part of the Kazhdumi basin (Bordenave & Burwood, 1990). In the Zagros, the largest thickness of this unit (about 250 to 500 m) in seen in the Dezful Embayment (James and Wynd, 1965; Ghalavand, 1996; Soleimani *et al.,* 2014; Piryae *et al.,* 2017).

In the Kupal oil field, the Kazhdumi Formation is not drilled. Thus, due to the lack of data from the Kupal field, the lithological and geochemical data of neighboring fields, such as Marun and Aghajari, are used in this research. In these oil fields, the average thickness and sedimentation rate of the Kazhdumi is about 260 m and 18.6 m in a million years, respectively, and no noticeable changes are seen in the thickness and facies of this formation (Fig. 2 and Table 1).

Bordenave and Nili (1973) showed that the average content of organic matter in the Pabdeh Formation is 2 to 5%, and in the Kazhdumi Formation is more than 5%. According to Tissot and Welte (1984), and Hunt (1996) classifications, the Pabdeh and Kazhdumi formations have been able to form very good to excellent source rocks in the Dezful Embayment.

Data and Methods:

Generally, in the petroleum systems modeling and reconstruction of the burial history, various parameters such as the number and type of possible source rock, geochemical data, heat flow, lithostratigraphic data, paleo water depth and dynamic data of reservoir rocks are used (Hantschel and Kauerauf., 2009; Peters *et al.,* 2012: 2017). In figure 3, a sample of flow chart diagram for the petroleum system modeling in the Temis software is shown.

The first step for the petroleum system analysis is to build the structural–sedimentary model of geological history of the studied area, in which geological events such as sedimentation, interruption, erosion, and tectonic events are defined within a specified time zone (in terms of million years ago).

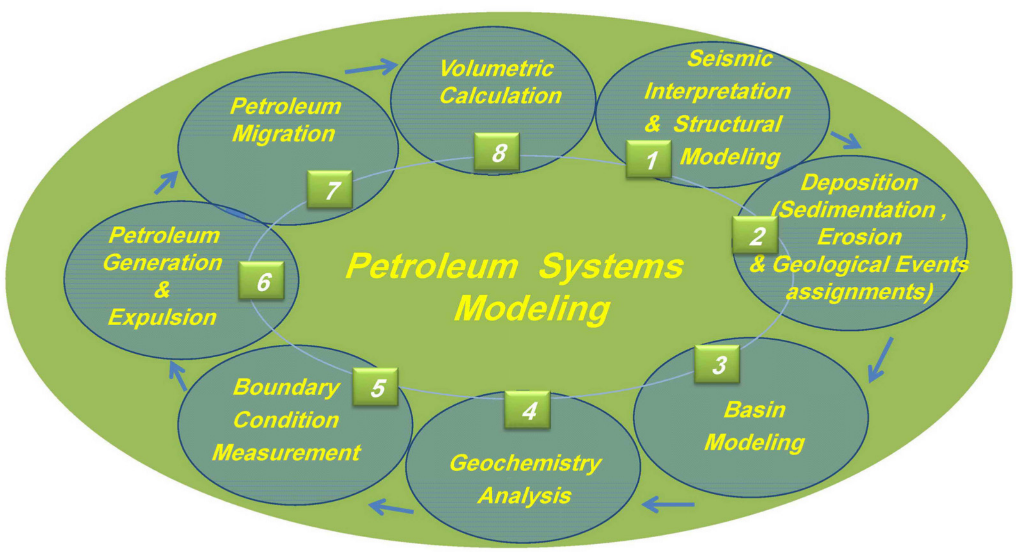

Figure 3. A flow chart diagram for the petroleum system modeling in the Temis software (Adapted from Hantschel and Kauerauf, 2009; Peters *et al*., 2012; 2017)

After that, the chemical and geochemical data, temperature, pressure and other parameters of hydrocarbon fluids are imported into the software and this information are calibrated during the modeling of the petroleum system with the data obtained from the drilled wells. Finally, the results are processed and analyzed based on different hydrocarbon composition scenarios (Hantschel & Kauerauf, 2009; Peters *et al.,* 2012). These steps are as follows:

Structural Geology Data

In order to model the middle Cretaceous – Miocene petroleum system in the Kupal oil field, first, the structural geologic model is created based on 3D seismic data. In this step, to perform the seismic data interpretation, a workstation was set up and the coordinate system suitable for the studied area was selected as WGS 1984–UTM in the 39N zone. After that, based on interpretation of seismic and drilled wells data, the geological structure model was created from surface to the Kazhdumi Formation. At the end, the top formations data, fault and fractures data as well as vertical closure were inputted into the relevant software and imported to the petroleum system modeler, i.e. Temis Flow.

On the basis of 3D seismic data, the underground structure of the Kupal oil field is in the form of a roughly–symmetrical elongated anticline with extremely mild folding and two culminations on the Asmari and Bangestan horizons. The main culmination is located in the northwest part of the field and is referred to as the western Kupal. The smaller culmination, located in the southeastern part of the field, is known as the eastern Kupal and it is home to only one well (Well No. 2). The faults of the Kupal oil field include three thrust faults with a dip ranging from 20 to 60 degrees. The principle fault in the southwest flank has formed the main structure of the field, with its vertical displacement in various sections reaching up to 300 meters.

The results of the interpretation of the sub–surface structure of the Kupal oil field in the western and eastern culminations in two selected seismic profiles are shown in figures 4 and 5.

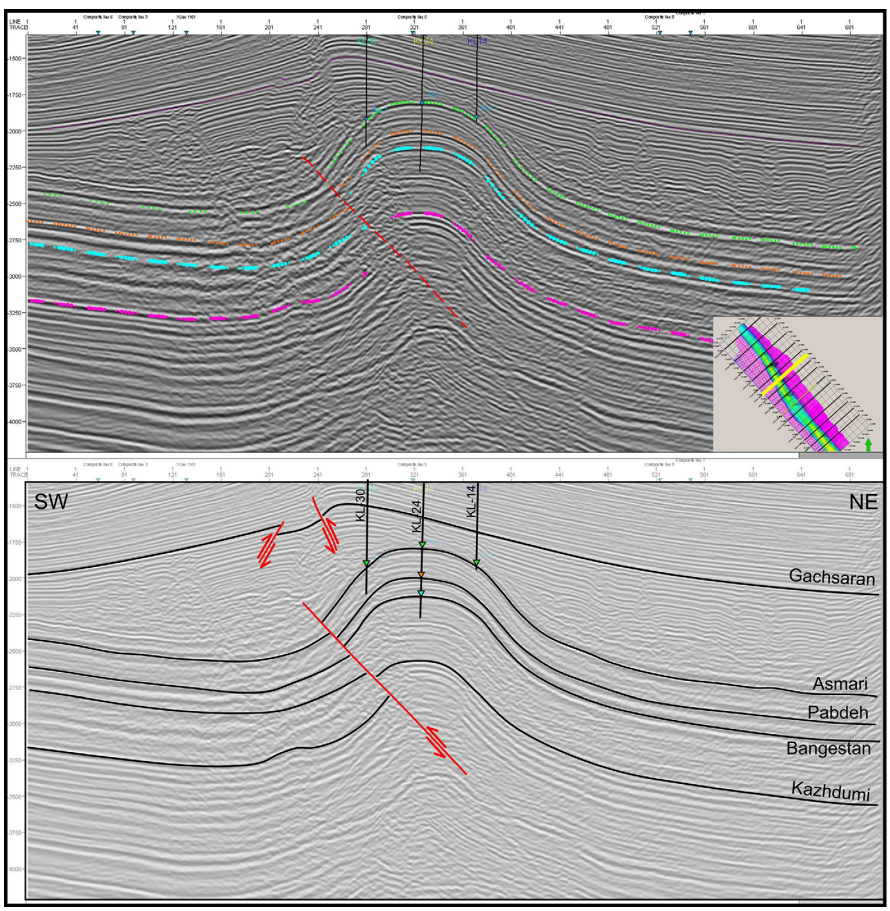

Figure 4. Seismic cross-axial profile in the western culmination of Kupal anticline which passes through wells no. 14, 24, and 30

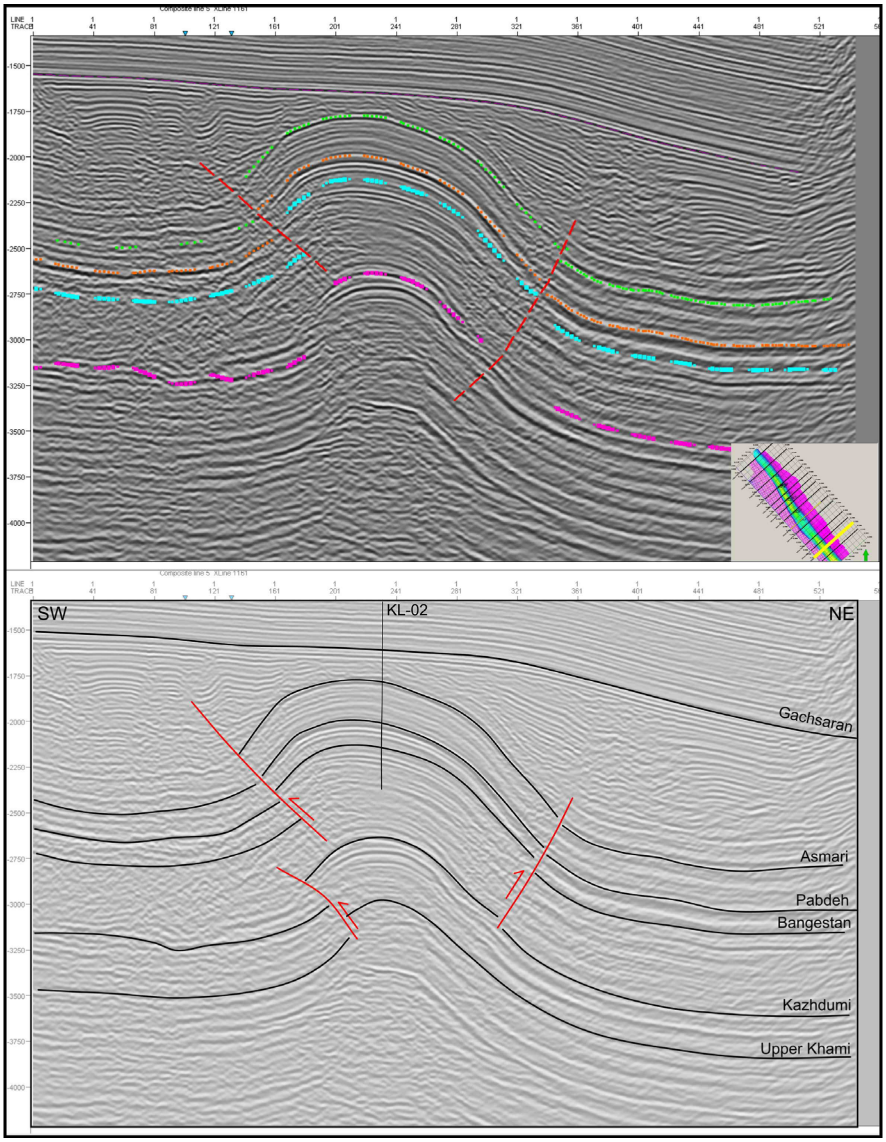

Figure 5. Seismic cross-axial profile in the eastern culmination of Kupal anticline which passes through Well no.2

Figure 4 is a seismic cross–axial profile of the western culmination of the Kupal anticline which passes through wells No. 24, 14 and 30. In this section the Kupal anticline shows harmonic structure (from Asmari to Jurassic) and a nearly symmetrical fold in the area around these wells. The anticline in this area has generated the main culmination of the Kupal structure. The southwest flank of thrust fault has led to a large displacement of about 300 m for the Bangestan horizon. The folding model in this section of the field is also consistent with the fault propagation fold (Sherkati *et al*., 2004 and 2006; McClay *et al.,* 2011).

Figure 5 is a seismic cross–axial profile of the eastern culmination of the Kupal anticline which passes through Well No. 2. In this section the Kupal anticline shows inharmonic structure (from Asmari to Jurassic) and an asymmetrical fold around this well. In this part of the field, increasing tension compared to its nose and reduction of the space in the anticline core has led to occurrence of at least three thrust faults in both flanks, showing a vertical displacement of 100 to 300 m in the Asmari and Bangestan horizons. Due to the activity of this fault, the anticline has been reformed to a Transported Fault Propagation Fold (Sherkati *et al.,* 2004 and 2006; McClay *et al.,* 2011).

The information obtained from the image logs (Wells No. 20, 41 and 48) show that in the Bangestan reservoir of the Kupal oil field, the open fractures often show three main directions: Longitudinal set with N15W/S15E direction (Along of Zagros trend), Cross axial set with N30E/S30W direction and Oblique set with E–W direction and a dip ranging from 35 to 84 degrees for all of trends. The results of fracture modeling also show that the maximum vertical and horizontal permeability are about 44.7 md and 14.9 md respectively (Fardin*,* 2018).

Also, the information obtained from the image logs (Wells No. 30, 41, 42, 47, 52 and 53) show that in the Asmari reservoir, the open fractures have often four main directions: Longitudinal set with N40W/S40E direction (Along of Zagros trend), Cross axial set with N35E/S35W direction, Oblique sets with E–W and N–S directions and a dip ranging from 35 to 84 degrees for all of trends. The results of fracture modeling also show that the maximum vertical and horizontal permeability are about 89.7 md and 34.3 md, respectively (Farsimadan*,* 2019).

The investigation show that faults and related fractures sets, the dissolution, interparticle and intercrystalline porosities play a very important role in the migration of hydrocarbons from source rocks to the reservoir rocks and displacement of hydrocarbons in the Asmari and Bangestan reservoir rocks (Zohrabzadeh *et al.,*2018).

Lithology, Stratigraphic & Dating Data

The lithological data, thickness, age, sedimentation rate of formations or sedimentary layers, the time of discontinuities and sedimentary hiatus, the depth of sedimentary formations and basement, as well as the depth of the Paleowater were prepared based on 56 drill wells data and its petrophysical evaluations and then were imported into software (Table 1). The Paleo Water Depth (P.W.D.) is one of the important parameters in calculating tectonic subsidence, erosion, and also in the estimation of Paleo heat flow (Clift and Turner, 1998). The Paleo Water Depth for the middle and upper Cretaceous formations has been extracted from common report of the IFP group (Institut français du pétrole) and Exploration Management Department of the National Iranian Oil Companies, which was published in 2001 as " Introducing the petroleum systems of the Dezful Embayment and Northern Fars " (Van Buchem *et al.,* 2001). For other formations, geological reports of the Dezful Embayment have been used. The age and sedimentation rates of the formations, as well as sediment interruptions, were obtained on the basis of paleontological charts of wells no. 1 & 3 (Jalali, 1968 and 1971), Middle East chronostratigraphic charts (Al–Hosseini, 2008), International Commission on Stratigraphy (2018), Strontium isotope analysis (Allan & Whit ford, 2004) and other researches in Arabian plate (Ziegler, 2001).

Due to the lack of deep seismic data, the studies conducted by Alavi and Sherkati are used to determine the depth of the basement (Alavi, 2007; Sherkati *et al.,* 2005 and 2006). Accordingly, the approximate depth of the basement in the Marun and Kupal oil fields is about 11–12 km.

Thermometry Data

Petroleum geochemists agree that the occurrence of petroleum in the subsurface is related to temperature, either to the generation and expulsion of oil and gas from the source rock, or to the accumulation, cracking, and preservation of hydrocarbons in its reservoir rock in a trap.

Petroleum geologists recognized that the subsurface temperature increases with depth at a rate specified by the geothermal gradient. The present–day gradient probably differs from the paleogradient, and that vitrinite reflectance measures a maximum temperature along this gradient. The maximum subsurface temperature for any rock unit is assumed to occur at maximum burial depth, past or present, and is the thermal maturity of that source or reservoir rock. Thus, thermal maturity, rather than depth, is the best way to describe petroleum occurrence (Magoon *et al.,* 1999).

In this Research, the Sediment Water Interface Temperature (S.W.I.T.) data at the time of formations deposition and heat flow data were imported into the software, and S.W.I.T. reconstruction was carried out using a graph provided by Wygrala (1989), (Fig. 6 and Table 1).

The petroleum systems modeling in the Saudi Arabia shows that the constant heat flow of 60 mw/m^2 corresponds to the measured Vitrinite reflectance data in the wells location (Abu–Ali and Littke, 2005). For southern Iraq, the constant heat flow of 50 mw/m^2 is considered for the modeling of Upper Jurassic–Cretaceous oil system (Abeed *et al,* 2013). Rudkiewicz *et al.,* (2007) presented a map of the amount of thermal flow for coastal regions of Iran, in which the amount of heat flow that used to 42 mw/m^2 for Dezful Embayment in this study.

Geochemical Data

The geochemical data has been used in the topics of correlation, migration and petroleum system modeling of the Middle Cretaceous–lower Miocene of the Kupal field. These data were extracted from rock and fluid samples of the source rocks (Pabdeh and Kazhdumi) and reservoir rocks (Asmari and Bangestan) from more than of 30 wells of Kupal and the nearby fields such as Aghajari, Marun and Haftkel. The results of the following researches were also used: (Mobin, 2001; Fajrak, 2008; Ashkan, 2004 and 2009; Alizadeh *et al.,* 2007 and 2012; Khani, 2011; Opera *et al.,* 2013; Asadi Mehmandosti *et al.,* 2015; Mashhadi, *et al.,* 2015; Sfidari *et al.,* 2016).

The desired data includes organic matter percent, type of organic matter, source rock maturity, temperature, hydrogen and oxygen index, carbon 13 isotope, biomarkers and kinetic data. The percentage of organic carbon in the Pabdeh and Kazhdumi formations in the Kupal oil field and the nearby fields is shown in Table 2. The data show that these two formations have the sufficient amount of organic carbon required for the hydrocarbon generation.

The quality of the organic matter involves the evaluation of the type of existing organic matter or type of Kerogen in the source rock (Hunt, 1996).

Table 2. Display of organic carbon values in Pabdeh and Kazhdumi source rocks in the Kupal and nearby fields.

Formation	Field	Number of Wells	TOC Mean(%)	TOC Min(%)	TOC Max(%)
Pabdeh Source Rock	Aghajari	15	1.6473	0.2	4.33
	Kupal	12	2.8228	0.96	5.11
	Marun	46	2.4835	0.38	5.4
	Haftkel	2	0.415	0.37	0.46
	Total	75	2.1409	0.2	6.59
kazhdumi Source Rock	Aghajari	11	2.2618	0.97	4.43
	Kupal	-	* 2.85	-	-
	Marun	29	2.8555	0.74	4.93
	Haftkel	2	1.15	0.54	1.76
	Total	42	2.5321	0.17	6.11
	* Assumed from Marun oil Field				

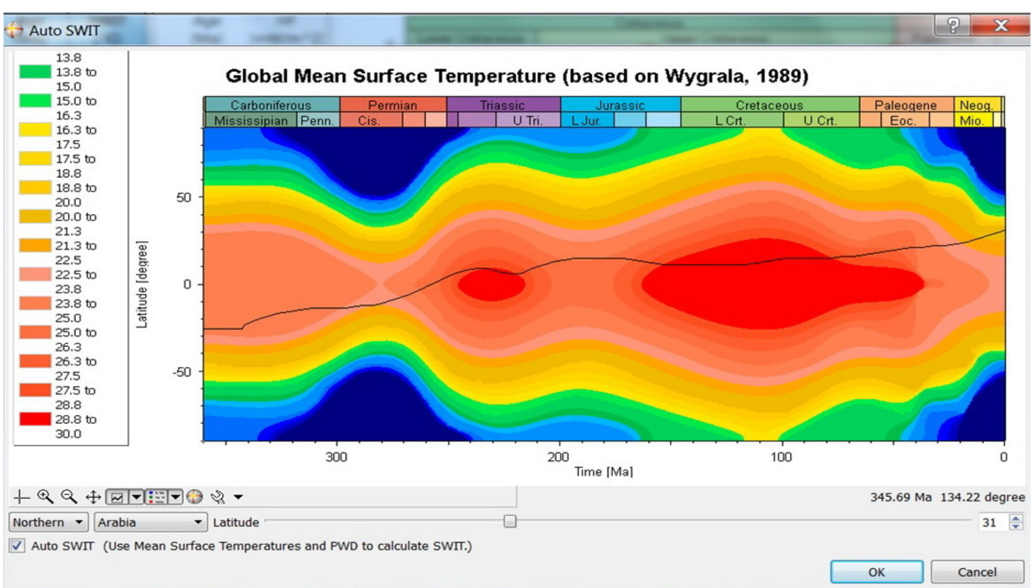

Figure 6. Estimation of the mean earth surface temperature during the geological periods in the Marun and Kupal oil fields area (Adapted from Wygrala, 1989)

This issue is of great importance in modeling the petroleum system; because the organic matter type affects the kinetics of source rock.

Vankrevelen (1961) diagram was used to determine the quality and type of organic matter of Pabdeh and Kazhdumi source rocks in the Kupal and nearby fields (Fig. 7).

As shown, the organic matter found in these two source rocks is Kerogen type II and commonly found in marine sediments that consists of mixtures of phytoplankton, zooplankton, microorganisms (bacteria) and plant membrane material (pollen and cuticle). This type of Kerogen has a high potential for production of liquid hydrocarbons (Hunt, 1996).

To determine the origin of the Asmari and Bangestan reservoirs crude oil, the SARA Analysis were used along with triangular charts of aromatic, saturated and polar fractions (Tissot and Welte, 1984), (Fig. 8). The results show that the composition of Asmari and Bangestan oils in the Kupal field are Paraffinic to Naphthenic types. The oils composition of the Asmari and Bangestan reservoirs of the Haftkel field are Paraffinic to Naphthenic and Naphthenic type, respectively; and also are Paraffinic type in the Asmari and Bangestan reservoirs of the Aghajari and Marun oil fields.

To evaluate the Asmari and Bangestan source rock lithology in the Kupal and its nearby fields, the comparison diagram of C29H / C30H ratio versus C24T / C23T oil biomarkers (Peters *et al.,* 2005) were used, (Fig. 9). The results show that the source rock of the Asmari and Bangestan reservoir in the Kupal field has marly–carbonate facies, but in the Marun and Aghajari fields have marly and in the Haftkel field has carbonate facies.

Different stages of Kerogen maturity are presented in the Vitrinite reflectance method by Peters and Cassa (1994). Thermal maturity evaluation of source rock organic matter and Asmari – Bangestan reservoirs oils of the Kupal field by the Vitrinite reflectance is shown in Table 3.

Table 3. The thermal maturity values of the Asmari and Bangestan reservoir oils and Pabdeh and Kazhdumi source rocks samples in Kupal and nearby fields.

Well No.	Formation	Depth(m.)	RO(mean)	Well No.	Formation	Depth(m.)	RO(mean)
Kl-06	Asmari	3595	0.68	**Mn-222**	Asmari	2666	0.46
		3608	0.66		Pabdeh	2850	0.52
		3623	0.59		Ilam	3188	0.83
		3629	0.62		Sarvak	3532	0.88
Kl-38	Asmari	3659	0.62		Kazhdumi	4300	0.92
Kl-49	Asmari	3680	0.63			4454	0.98
		3683	0.59	**Mn-240**	Pabdeh	2905	0.5
		3688	0.60			2975	0.39
Kl-51	Asmari	3732	0.60	**Aj-140**	Asmari	1862	0.48
Kl-38	Pabdeh	3781	0.60			1998	0.38
		3809	0.60			2036	0.44
		3819	0.62		Pabdeh	2092	0.41
		3834	0.60			2183	0.49
	Ilam	4054	0.67			2222	0.5
		4066	0.75			2294	0.55
Mn-45	Pabdeh	3222	0.48		Sarvak	2708	0.6
		3261	0.41			3484	0.85
		3313	0.39			3560	0.83
		3359	0.41			3640	0.8
	Ilam	3654	0.61		Kazhdumi	3700	1
		3688	0.63			3900	1.04
Mn-291	Pabdeh	2844	0.37			3960	0.92
		2916	0.42				
	Kazhdumi	4490	0.74				
		4554	0.82				

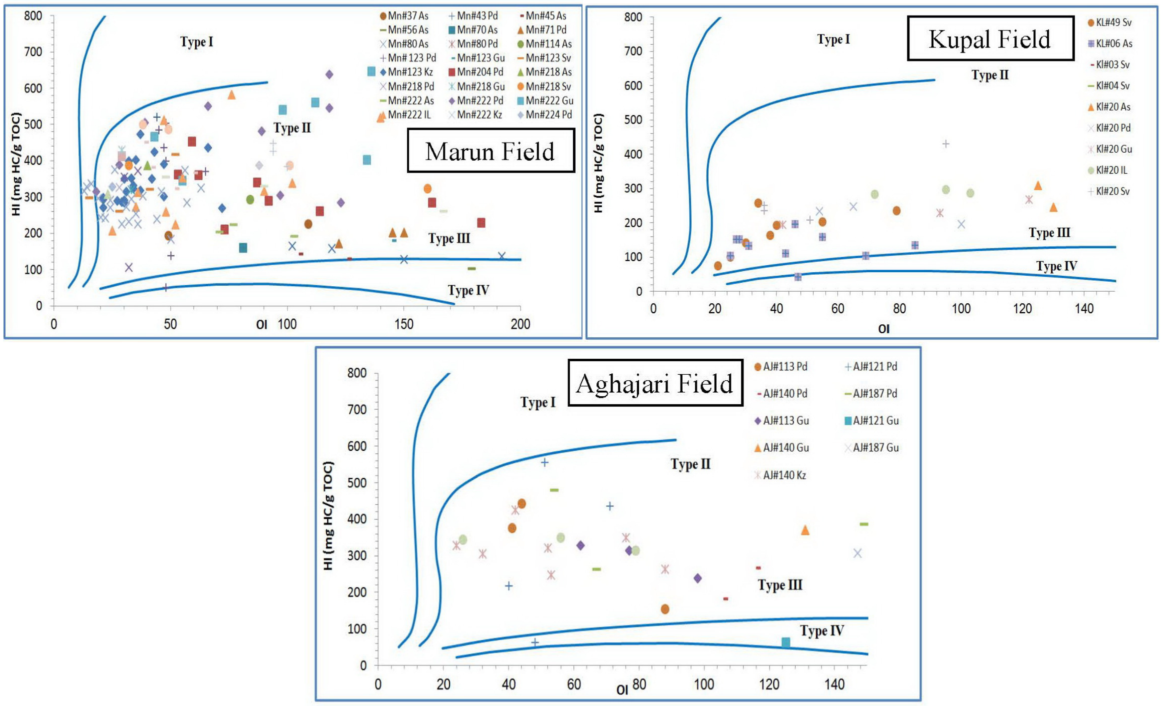

Figure 7. The diagram showing the type of organic matter in the Asmari and Bangestan reservoirs of Kupal and nearby fields using hydrogen and oxygen indexes (Adapted from Vankrevelen, 1961).

The results show that in the Kupal field, Pabdeh and Kazhdumi formations have the required maturity to produce hydrocarbons. Also, the range of maturity variations in the Asmari and Bangestan reservoir is dispersed, which can be indicative of the Asmari reservoir charging by the Pabdeh and Kazhdumi source rocks at different times, which is achieved by micro–thermometry fluid inclusions studies (Ebadollahzadeh, 2015).

To correlate the maturity of these two formations in the Kupal and nearby fields, the ratios of C29–Sterane 20S saturation biomarkers versus C29–Sterane αββ (Peters *et al.,* 2005) was used (Fig. 10).

Petroleum geochemists believe that the composition of the oil that migrates into the reservoir does not have much difference with the remaining bitumen in the source rock. These parameters can be biomarkers, carbon and sulfur stable isotopes, and other genetic parameters (Peters and Fowler, 2002; Waples and Curiale, 1999). In this regard, the ratio of saturated and aromatic biomarkers (Fig. 11) and carbon isotope 13 (Table 4), was used to correlate oil to the source rocks. The existence of the Oleanane biomarker in the Asmari oil of the Kupal field indicates that this reservoir has been fed by the Pabdeh Formation; whereas this biomarker does not exist in Asmari reservoir of the Aghajari and Marun fields. Also, due to the difference in the amount of biomarkers in the Asmari and Bangestan reservoirs of the Kupal oil field, in comparison with the nearby fields, the migration of hydrocarbons from the Kupal oil field to Marun and Aghajari oil fields and vice versa has not taken place.

One of the most accurate geochemical methods for oil to oil or oil to source rock correlation is the measurement of carbon–13 isotope that is measured by a mass spectrometer device. Usually, the isotopic composition of aromatics is closer to the isotopic composition of crude oil and shows little variations in the maturity or alteration of oil stages, therefore, this parameter is considered as an acceptable method for the correlation of oil to oil, and oil to source rock (Sofer, 1984). Using these data, we can also investigate the degree of oil mixing and the status of oil migration. Most hydrocarbon reserves contain up to –21 to –32 mol% carbon 13 isotope in their composition, which is similar to the carbon 13 isotope content of marine plankton species (Kasai Najafi, 2011; Rahimpour–Bonab *et al.,* 2013). In the saturated, aromatic, asphaltene and resin compositions of the Asmari and Bangestan reservoirs located in the Dezful Embayment, the amount of carbon isotope 13 is about –26.5 to –27.5 mol%, which is characterized to be of the petroleum type generated by the Kazhdumi Formation.

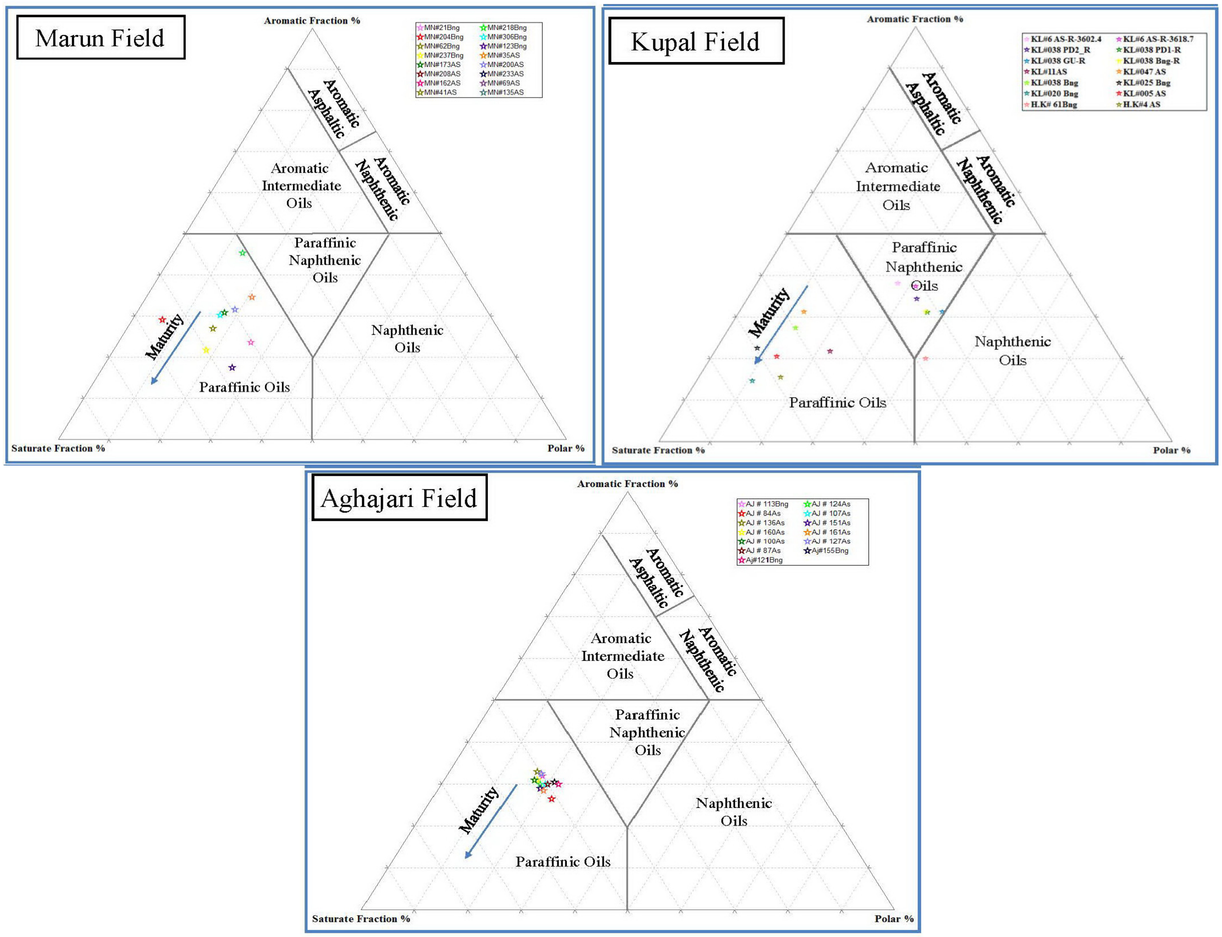

Figure 8. Triangular chart showing the type of Asmari and Bangestan reservoirs oils in Kupal and nearby fields using the SARA analysis results (Adapted from Tissot and Welte, 1984).

This value for the Pabdeh Formation is about –25 to –25.5 mol% (Kasai Najafi, 2011). The amount of carbon 13 isotopes in the Kupal oil field shows the mixing of Pabdeh and Kazhdumi oil in the Asmari reservoir, whereas this is not the case in the Marun and Aghajari fields (Table 4).

In order to obtain accurate information for determination the time of hydrocarbon generation and expulsion, calculation of the amount of produced hydrocarbon and the migration of oil from the source rock in the modeling of petroleum systems, it is necessary to use different methods of measuring maturity in the laboratory and adapt them to sedimentary basin conditions.

The activation energy values in the Pabdeh Formation drilling samples cutting are in the range of 48–44 Kcal/Mole and average weight 48 Kcal/Mole. Also, the activation energy values in Kazhdumi Formation drilling samples cutting are in the range of 48–70 Kcal/Mole and average weight 50 Kcal/Mole. The distribution pattern of activation energy in the Kazhdumi Formation samples are more uniform, which indicates uniformity in the organic matter contained in these formations. The transformation ratio is described as the ratio of oil and gas that the Kerogen is capable of generating (Tissot & Welte, 1975).

Comprehensive geochemical studies estimated the amount of initial total organic carbon (TOC) in Kazhdumi Formation at an average of 5%, in the Pabdeh Formation, an average of 4%, and the Transformation ratio for the start of generation and expulsion of hydrocarbons in these two formations was 10% and 20% (Bordenave and Hegre, 2005 and 2010).

In this research, based on the burial history and the kinetic analysis, the minimum requirement temperature for generation and expulsion of hydrocarbon in the Kazhdumi Formation was obtained at 112°C and 122°C in the Vitrinite reflectance of the 0.6% and 0.6–0.8%, respectively. Also, the minimum requirement temperature for generation and expulsion of hydrocarbon in the Pabdeh Formation is about 105°C and 112°C, in the Vitrinite reflectance of the 0.6% and 0.6–0.8% respectively (Fig. 12).

Reservoir Engineering Data

The reservoir engineering data include the measured temperature and pressure of intervals in drilled wells, type of hydrocarbon compounds, porosity, effective permeability, relative permeability, capillary pressure, fluid saturation (water, oil and gas), oil and gas density, and reservoir production statistics in the wells.

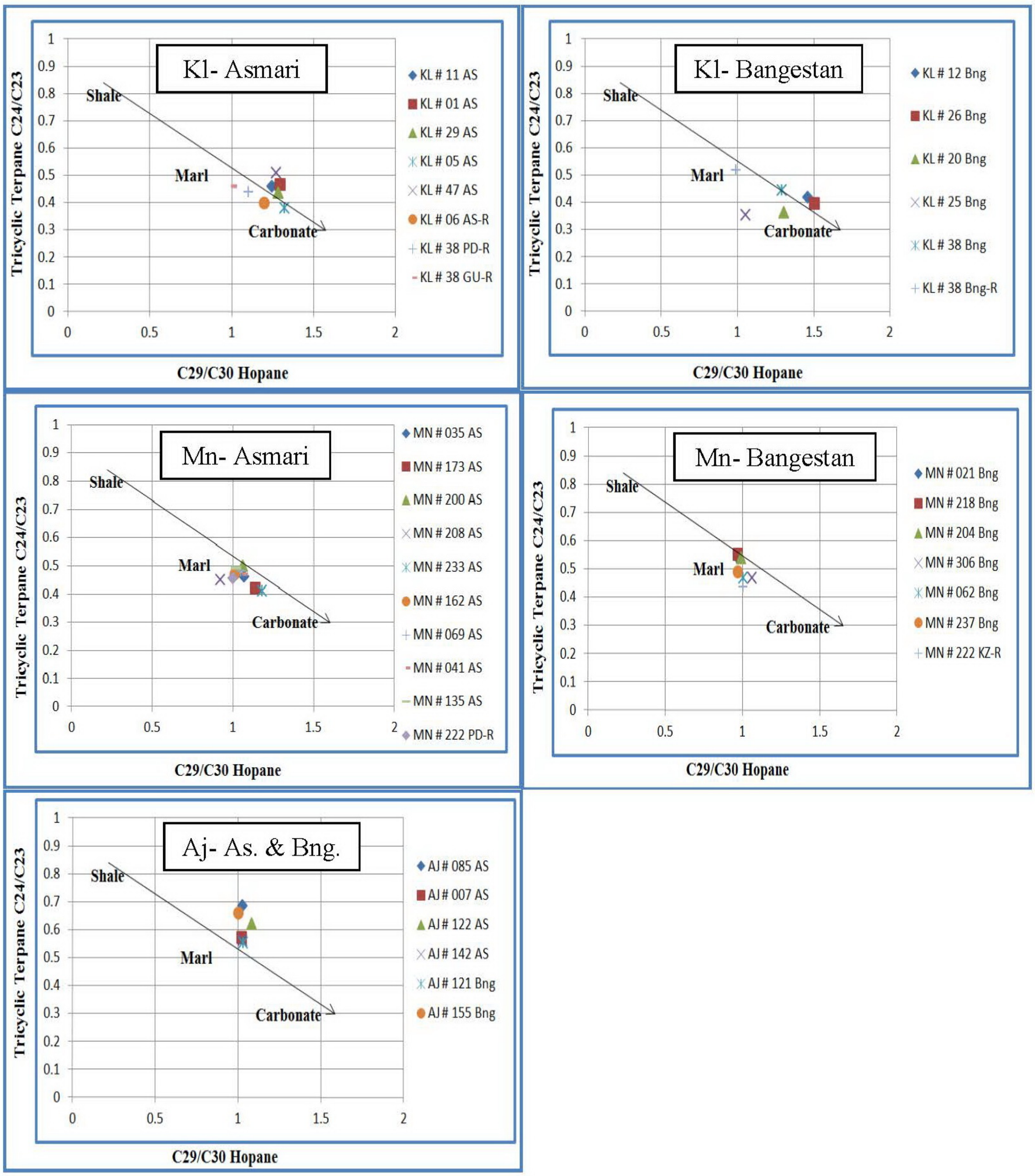

Figure 9. The diagrams showing the source rocks lithology of the Asmari and Bangestan reservoirs oils in the Kupal and nearby fields using by biomarker ratios (Adapted from Peters *et al.,* 2005).

Table 4. The values of Carbon 13 Isotope in saturated and asphaltene samples of Kupal and nearby oil fields.

Sample-ID	Whole oil	Saturate	Aromatic	Resin	Asphaltene
	d13 C	d13 C	d13 C	d13 C	d13 C
	‰ V-PDB	‰ V-PDB	‰ V-PDB	‰ V-PDB	‰ V-PDB
KL-05 As	-26.9	-27.2	-26.7	-26.6	-26.4
KL-06 (3618) As	-26.1	-27.2	-27.3	-25.8	-25.3
KL-06 (3602) As	-26.2	-27.1	-27.4	-25.9	-25.4
KL-47 As	-27.1	-27.2	-26.6	-26.4	-26.3
KL-38 Bng	-26.7	-26.8	-26.2	-26.1	-25.9
KL-25 Bng	-26.7	-26.8	-26.2	-26.1	-26.1
KL-20 Bng	-26.6	-26.7	-26.2	-26.1	-26.0
Mn-035 As	-27.02	-27.23	-26.75	-	-
Mn-173 As	-27.1	-27.33	-26.78	-	-
Mn-200 As	-26.95	-27.27	-26.52	-	-
Mn-208 As	-26.82	-27.26	-26.24	-	-
Mn-233 As	-26.88	-27.26	-26.44	-	-
Mn-162 As	-26.91	-27.29	-26.27	-	-
Mn-069 As	-26.95	-27.29	-26.34	-	-
Mn-041 As	-26.93	-27.26	-26.5	-	-
Mn-135 As	-	-	-	-	-26.8
Mn-123 Bng	-	-	-	-	-27
Mn-062 Bng	-26.92	-27.27	-26.61	-	-
Mn-237 Bng	-26.77	-27.07	-26.33	-	-
AJ-087 As	-26.2	-27.1	-	-	-26.9
AJ-107 As	-26.3	-	-	-	-27.1
AJ 127-As	-26.4	-	-	-	-27
AJ-151 As	-26.5	-	-	-	-27
AJ-121 Bng	-26.3	-26.9	-	-	-26.7

Petrophysical properties are calculated by the program from the entered lithology as per the already existing lithology library in the software. These data are often used to calibrate the petroleum system model (Hantschel & Kauerauf, 2009; Peters & Nelson, 2009).

Petroleum System Modeling Procedure

The Temis Flow software was used to model the Middle Cretaceous–lower Miocene petroleum system in the Kupal oil field. The input information includes structural, stratigraphic, lithology, thermal, geochemical and reservoir engineering data. After modeling, the time of generation and expulsion of hydrocarbon from the source rock, the volume of hydrocarbon generated from the source rock and the volume of hydrocarbon accumulated in the reservoir rock, the type, location and intervals of hydrocarbon production of the reservoir rock can be calculated according to the selected scenario.

In this research, at first the names of formations, top, bottoms, thickness and age of formations, erosion times and eroded formations, Paleowater depth and elements of the petroleum system were imported in the software.

Subsequently, the formations depth maps (Horizons tops) were prepared under CPS–3 grid (ASCII) (*.*), and the faults data with the Earth Vision grid (ASCII) formats (*.*) has been imported in the software. At the end of this step, the geological framework of the studied area and the time of geological events are defined.

In the second step, for each sedimentary formation, the percentage of the lithological composition, porosity data, effective and relative permeability of the rocks, the heat flow of rocks, the sediment density, the capillary pressure and fluids saturation of the rocks were determined and the results were imported into the software in the * .XLS format.

In the third step, the type of Kerogen data, the total organic carbon (TOC) and the initial HI index of the source rock, the kinetic data of the source rock (the initial potential of the organic matter ratio versus the activation energy), the Vitrinite reflectance data, organic matter density and other geochemical data are imported in the software.

After that, Structural Restoration method was used to back–strip the layers to initial sedimentary conditions. The structural restoration is mainly based on the shape of the layers, the function of the faults, mass equilibriums and the volume of rock forming materials, and restored geometry of the basin and sediments deposition during the time laps. In the Kupal oil field, this structural restoration was carried out for the present day and other formations that deposited in 2, 9, 13, 18 and 33 m.y. ago (According to Stratigraphic, Tectonic and Petroleum generation events), (Figs. 13 and 14).

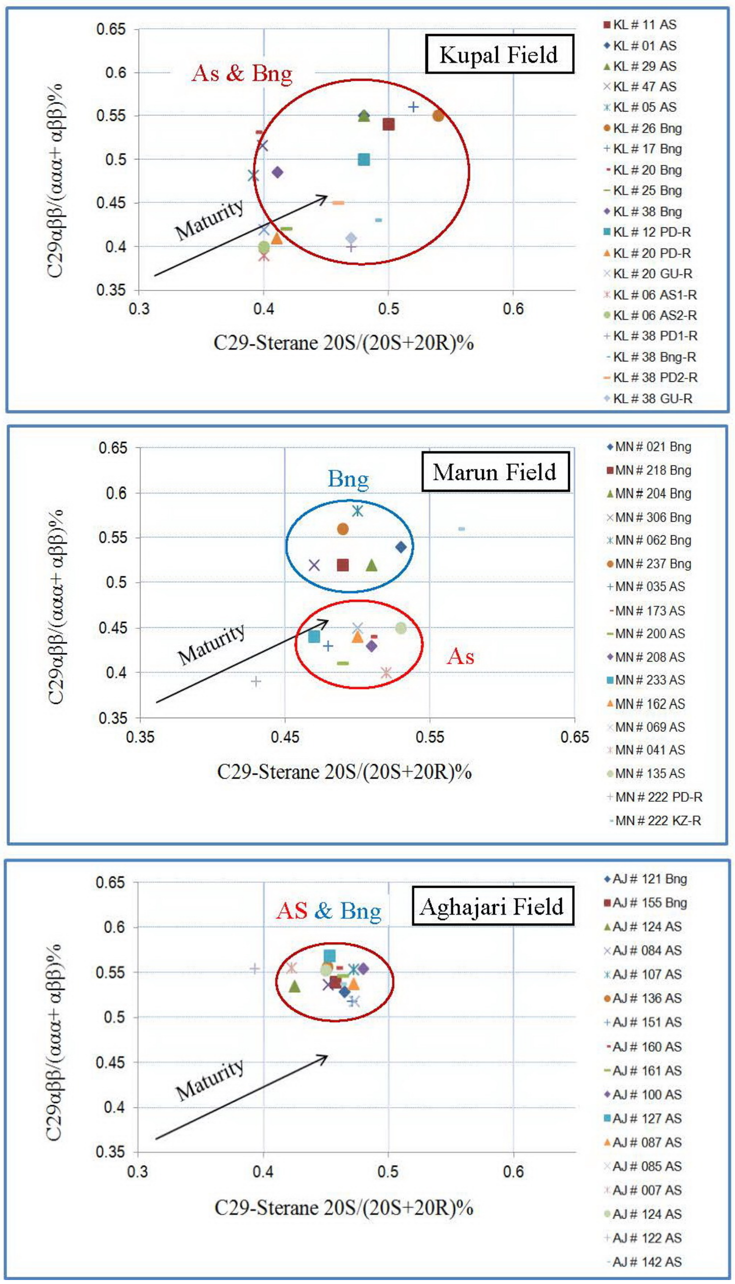

Figure 10. The correlation of rock and Fluid biomarkers of Asmari and Bangestan reservoir of Kupal oil Field against nearby fields based on saturation biomarkers ratio of C29-Sterane 20S versus C29-Sterane αββ (Adapted from Peters *et al.,* 2005)

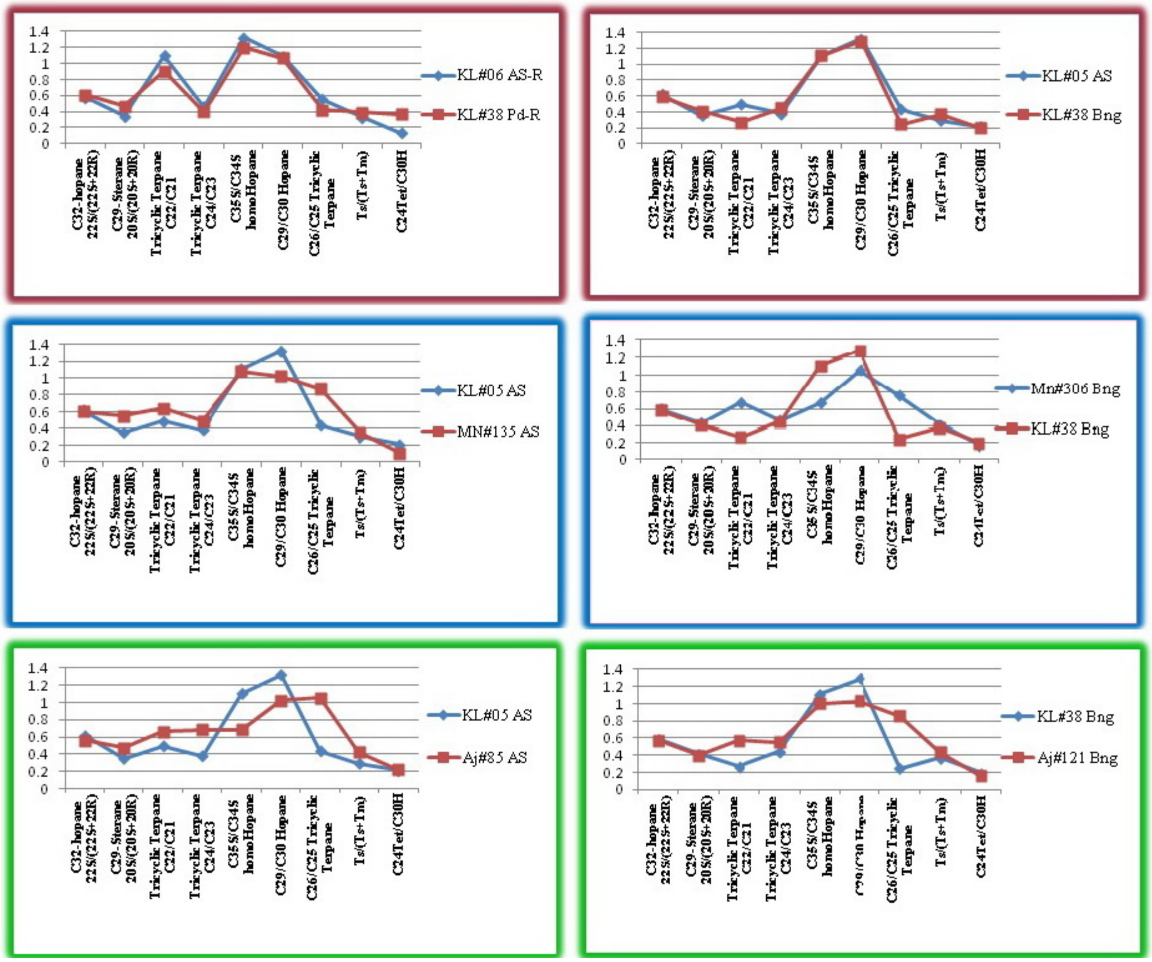

Figure 11. The biomarkers percentage comparison diagrams of the Asmari and Bangestan reservoirs oils in the Kupal and the nearby oil field (Adapted from Peters & Fowler, 2002).

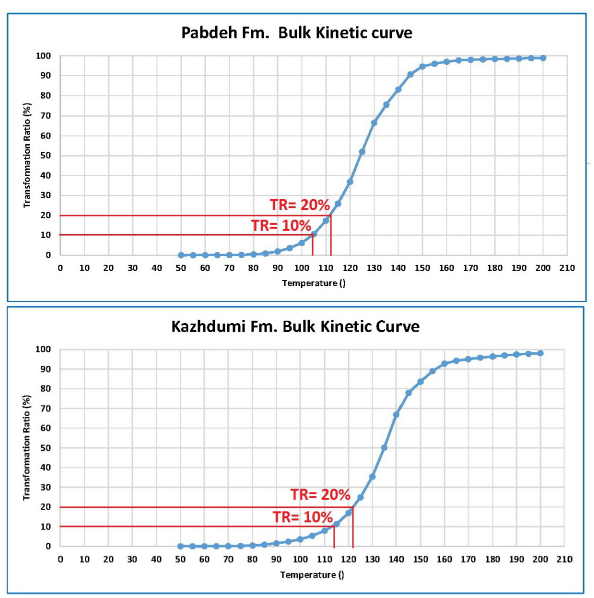

Figure 12. The diagrams of temperature versus the organic matter sample transformation ratio of Kazhdumi and Pabdeh source rock in the Kupal and nearby oil fields

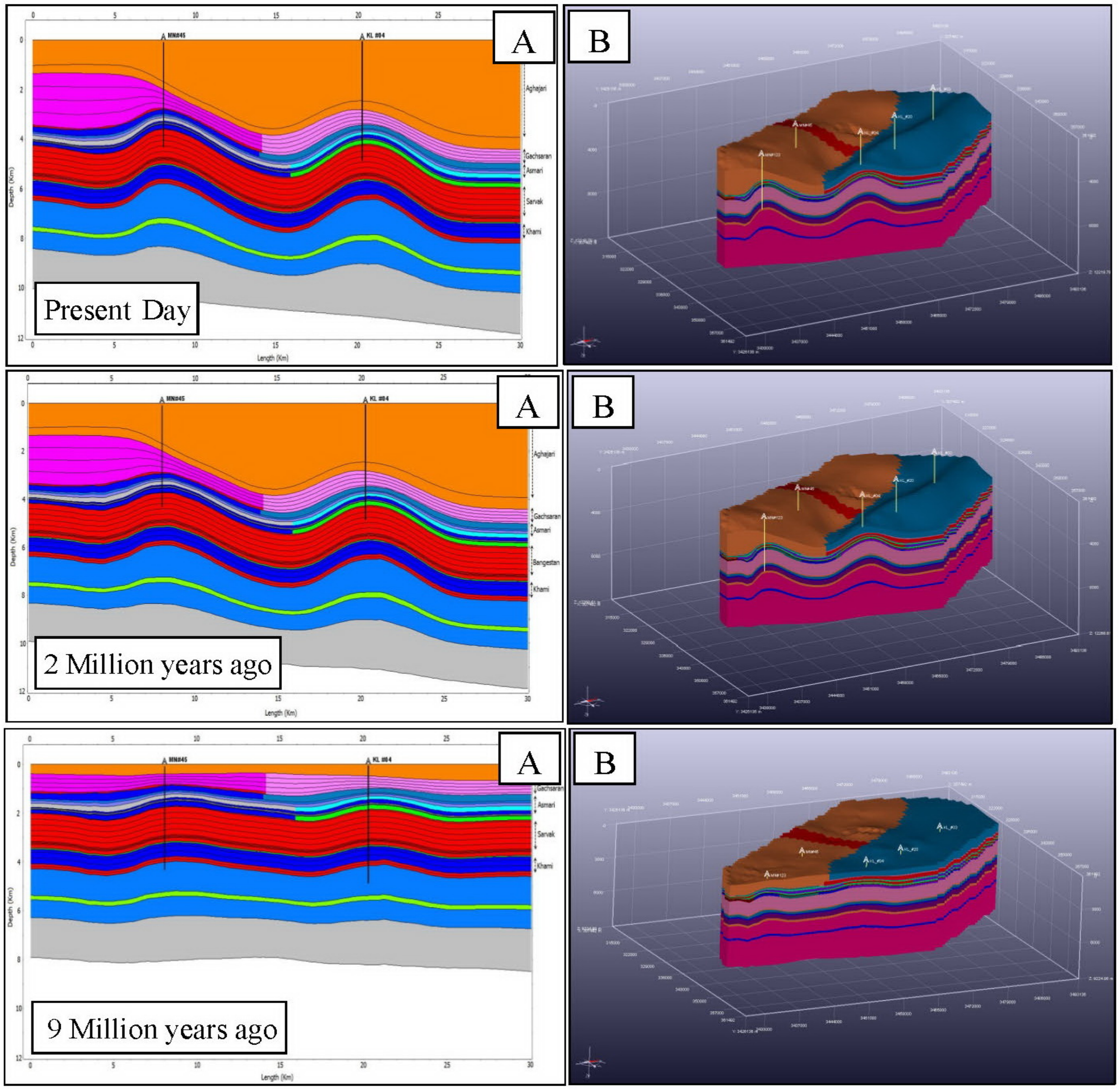

Figure 13. The Structural restoration of the sedimentary formations of the Middle Cretaceous-Lower Miocene petroleum system in the drainage area of the Kupal and Marun oil fields from 9 million years ago till present day.

Based on the conceptual model of the Zagros foreland basin and the time when it began folding, the present structure and sedimentary formations of the Marun and Kupal oil fields were restorated to their nearly horizontal condition, to the time before the Mishan Formation (13 million years ago) was deposited.

Investigations have shown that the critical time for the structural restoration was at the beginning and during the sedimentation of the Aghajari Formation (3 to 9 million years ago); and finally, on three cross profiles it named A, B and C, the maturity and thermal history of this petroleum system after calibrating the data has been analyzed (Fig. 15).

Generally, the heat flow that determines maturity during the geological periods is calibrated with the bore hole data (present–day heat flow), (Barker, 1996; Waples *et al,* 2004) and other thermal markers, such as the percentage of the Vitrinite reflectance (the Paleo heat flow that records the thermal effects in their changes), (Smith and Smith, 2007). In this case study, the temperature calibration was performed by comparing the measured Vitrinite reflectance with a model that best adapts the geological setting of the area. The constant heat flows during the geological periods and the surface temperature for the present day were obtained to be 42 mw/m2 and of 25°C.

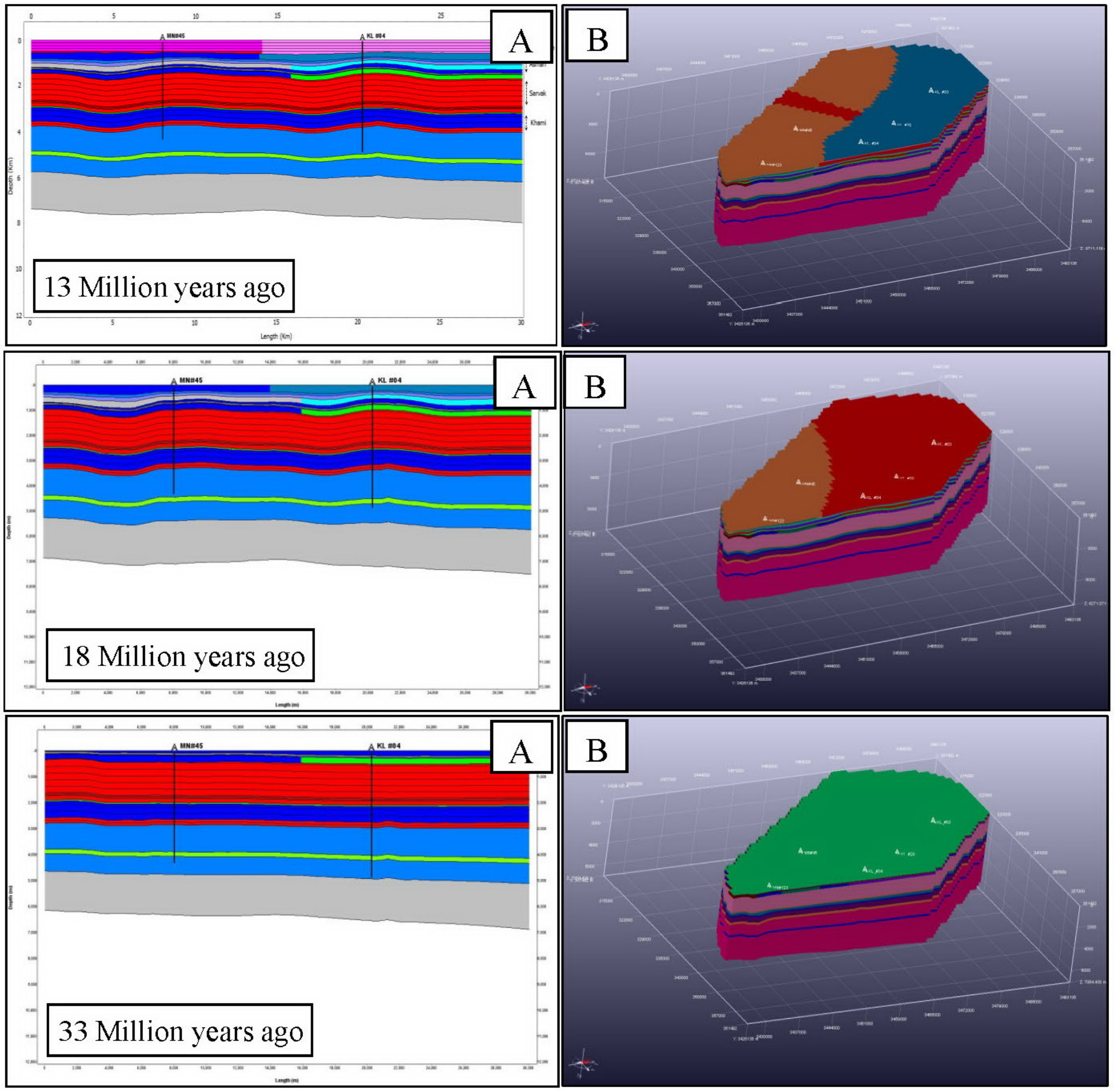

Figure 14. The Structural restoration of the sedimentary formations of the Middle Cretaceous-Lower Miocene petroleum system in the drainage area of the Kupal and Marun oil fields from 33 million years ago till 13 million years ago.

These results are consistent with the information obtained from the foreland basins and Arabian plate (Allen and Allen, 2013). Finally, by importing the static and dynamic data such as porosity, permeability, pressure, temperature and other available information (Fig 16), the model was calibrated and petroleum system modeling was done according to the desired scenarios.

In this research, the selected scenario is a three–class model in which hydrocarbon groups such as C1, C2–C6 and C6+ has been investigated. The results of three–dimensional modeling of the Middle Cretaceous – Lower Miocene petroleum system in the Kupal oil field shows that the migration of hydrocarbons from the Kazhdumi source rock to the Bangestan and Asmari reservoirs and then from the Pabdeh source rock to the Asmari reservoir are often vertical and has been through the faults, fractures and their related porosities. In this mechanism, hydrocarbons from synclines with mild slope initially migrated to the apex of anticline; and then migrate vertically to the axis of structure. Eventually, hydrocarbons have filled up the Asmari reservoir to its spill point (Magoon & Dow, 1994). As a result, some of hydrocarbons may have migrated laterally from Asmari and Bangestan reservoirs spill points to the nearby fields (for examples Aghajari and Marun fields), but geochemical analyzes have shown that the hydrocarbon properties of Asmari and Bangestan reservoirs in the Kupal oil field in terms of maturity, chemical composition, type of source rock lithology, biomarker properties, and other dynamical reservoir oil data, are different from the neighboring oil fields, and the issue of lateral migration to nearby fields is excluded (Fig. 17).

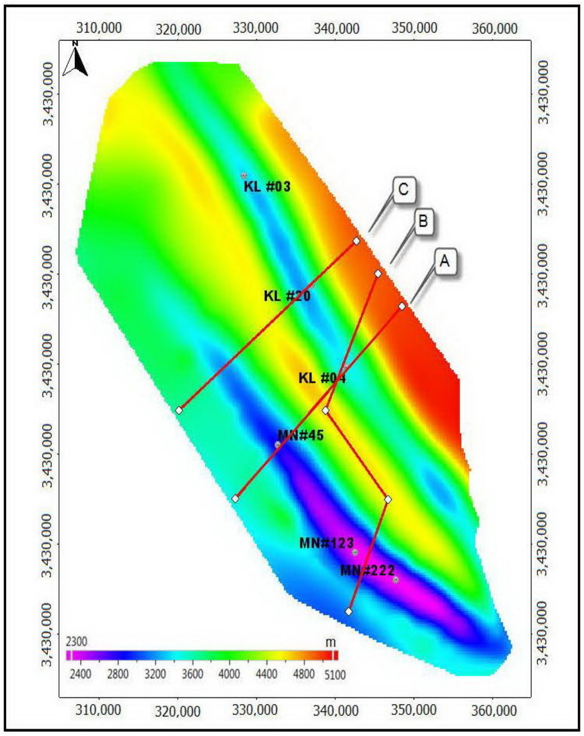

Figure 15. Position of selected cross axial profiles of A, B and C on the Asmari horizon of the Kupal and Marun fields.

Figure 18 shows that the maximum amount of the hydrocarbon expelled from the Kazhdumi and Pabdeh source rocks are from the synclines and the minimum amount are expelled from the crestal part of anticlines. In other words, the crestal parts of the anticline have played less role in charging the Asmari and Bangestan reservoirs of the Kupal oil field. This issue is very important as in the geochemical studies the laboratory samples are taken from the anticlines, and hence it is not often possible to accurately evaluate the source rocks; as a result, sampling from the synclines makes the modeling of the petroleum system more reliable in two or three dimensions, especially in areas where exploration and development of new fields are accompanied by many data deficits.

The Burial History simulates the sedimentation events as captured in a stratigraphic column. Important input data is obtained from well samples complimented by well logs, seismic data or outcrop data represented on a depth–time plot. Each segment of a burial history curve represents either deposition, erosion or a period of no deposition (hiatus).

Burial history graph of the total organic carbon data, temperature, time, and transformation ratio of organic matter to petroleum (Lopatin, 1971, Waples, 1980), (Fig. 19), as well as the results of petroleum system modeling (Figs. 20 , 21 and Table 5), show that the Kazhdumi Formation in the syncline between the Marun and Kupal oil fields has entered the petroleum window phase (Ro≥ 0.6%, TR≥10%, Temp≥112°C) about 9 million years ago and the hydrocarbon has expulsed since 7 million years ago (Ro≥ 0.6–0.8%, TR≥ 20%, Temp ≥122°C).

Also, the Kazhdumi Formation has entered the oil window phase (Ro≥ 0.6%, TR≥10%, Temp ≥105°C) from the 6 million years ago, and since 4 million years ago(Ro≥ 0.6–0.8%, TR≥ 20%, Temp ≥112°C) the expulsion of hydrocarbon has started at axis region of these structures.

At the present day, the oil window of the Kazhdumi Formation is closed within the syncline between the Marun and Kupal oil fields and has entered the gas window phase (light wet gas) about 2 million years ago (Ro≥1.35–2%); which indicates the high depth of this formation in the synclines. In most parts of the Kupal and Marun anticlines, Kazhdumi Formation is mature (Ro≥ 0.65–0.9%) and it is within the oil window peak phase (TR≥50%), or super mature (Ro≥1–1.3%) and within the end of the oil window (TR ≥ 80–90%).

The Pabdeh Formation in the Marun Anticline axis has not entered the oil window phase (Ro <0.6%); however, this formation is mature in the areas between Kupal and Marun fields in terms of thermal maturity and the range of maturity includes the primary (Ro≥0.6–0.65%) to middle (Ro≥0.65–0.9%) oil window phases. The immaturity of the Pabdeh Formation in Marun oil field as compared to Kupal oil field is likely to be associated with less burial depth of this formation in the Marun field.

In the syncline of Kupal oil field, Pabdeh Formation has entered the phases of petroleum generation and expulsion about 6 million years ago (Ro≥ 0.6%, TR≥10%, Temp ≥105°C) and 3 million years ago (TR≥ 20%, Ro≥ 0.6–0.8%, Temp ≥121°C), respectively. In the axis area of Kupal anticline, the Pabdeh Formation has entered to primary oil window phase (Ro≥ 0.6% and TR≥10%). This formation in the axis area of the Kupal oil field has entered the phase of hydrocarbon generation and expulsion since about 4 and 2 million years ago, respectively.

In this research, the volume of hydrocarbon generated and expulsed from the source rocks (Schmoker, 1994) was calculated by the Temis software. Generally, calculating the volume of hydrocarbon produced from a source rock is controlled by many factors. The most important of which are the thickness, degree of maturity, specific gravity, lithofacies, pay zone net to gross ratio thickness, type of Kerogen, trend of the total organic carbon variations, hydrogen index, and the artificial maturity parameters such as kerogen bulk kinetic, transformation ratio, porosity, permeability and driven forces (Cooles *et al.*,1986). Based on 3D petroleum system modeling, in the Kupal and Marun drainage area, the total hydrocarbons have been expulsed from the Pabdeh and Kazhdumi source rocks are about 42 and 113 billion barrels, respectively.

Table 5. Results of Rock-Eval Pyrolysis for the studied sources rocks.

Process	Formation	VRo%	T.R.	Temp.©	Tmax©	Products
Early oil Generation	Pabdeh	0.6-0.65	10-20	105-112	435-445	Heavy Oil
(Start of Oil window)	Kazhdumi			110-122		
Middle oil Generation	Pabdeh	0.65-0.9	20-50	112-124	445-450	Intermediate Oil
(Oil window Peak)	Kazhdumi			122-135		
Late oil Generation	Pabdeh	0.9-1.35	50-80	124-143	450-470	Light Oil & Wet Gas
(End of Oil window)	Kazhdumi			135-150		
Gas Generation	Pabdeh	1.35-2	80-95	143-150	>470	Wet Gas
	Kazhdumi			150-165		
Gas Generation	Pabdeh	2-4	>95	>165		Dry Gas
	Kazhdumi					

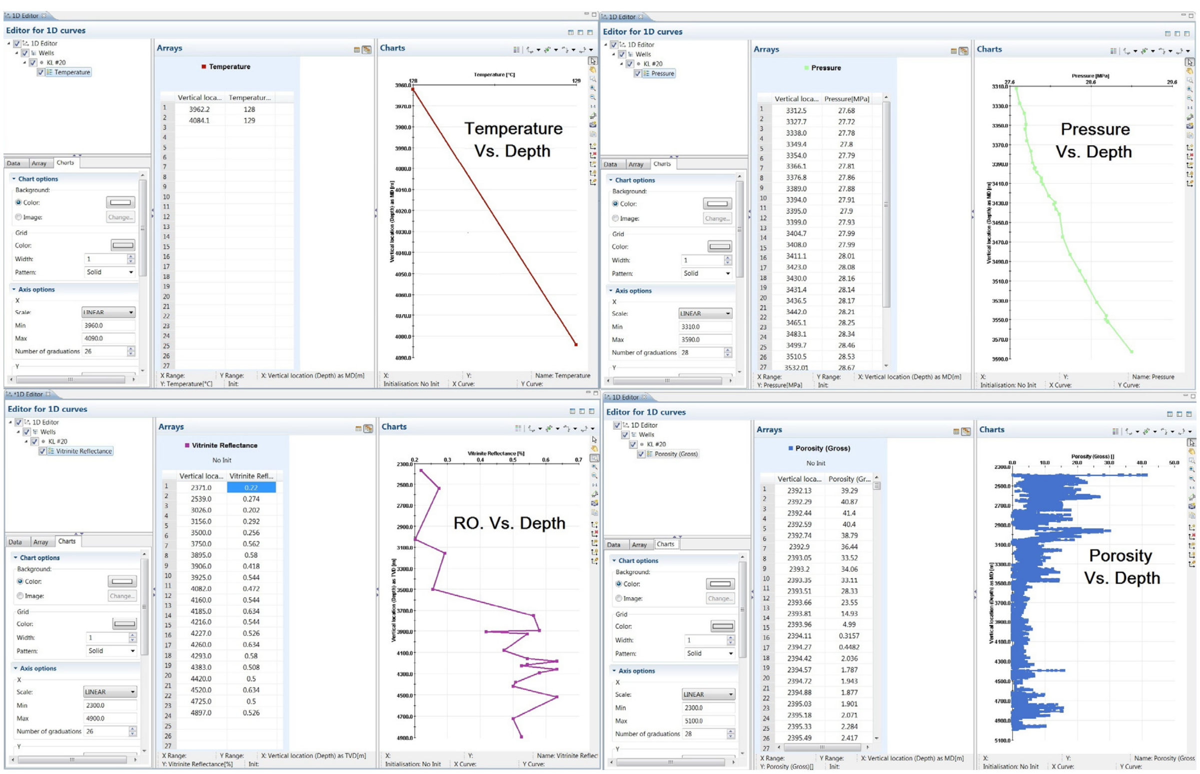

Figure 16. Display of Temperature, Pressure, Porosity and Ro. parameters versus depth to calibrate the Middle Cretaceous – Lower Miocene 3D petroleum system of the Kupal field, well No. 20.

Based on the selected scenario, the minimum percentage gas production belongs to methane and the maximum percentage of hydrocarbons (in the range of ethane to pentane) belongs to the Pabdeh source rock. The reason for this issue is the gasification potential of the Pabdeh source rock as compared with the Kazhdumi source rock; the Kerogen of Kazhdumi Formation has the potential of producing heavier hydrocarbons (Table 6).

The average present day hydrocarbon compounds of the Kazhdumi and Pabdeh source rocks in the Kupal oil field are shown in the table 7. As shown, in the drainage area of the Marun and Kupal oil fields, about 51% of the hydrocarbon composition of the Kazhdumi Formation transformed into coke; therefore, half the hydrocarbon potential of the Kazhdumi source rock is consumed during the geological periods as a result of high temperature and deep burial; But 49% of the remaining potential in this formation include 39% of hydrocarbons belonging to the C6 + family, 5% belongs to methane and 5% belongs to the C2–C5 family. However, The Kazhdumi Formation still has potential production (about 50%) and can be considered as an unconventional source of hydrocarbons.

As shown, most of the hydrocarbon potential of the Pabdeh Formation is remained intact, and only about 18% of the hydrocarbon composition of this unit is transformed into coke in the drainage area of the Marun and Kupal oil fields. Also, 63% of the amount of hydrocarbons belongs to the C6 + family, 17% to methane and 2% to the C2–C5 family. Therefore, the Pabdeh source rock still has production potential (about 82%) and can be considered as an unconventional source for hydrocarbons.

Table 6. The quantities and types of hydrocarbons generated and expelled from the Kazhdumi and Pabdeh source rocks in Kupal oil field.

Formation	Average Thickness (m)	Average Effective Thickness (m)	Source Rock Volume (m^3)	Hydrocarbon Generation Volume (bbl)	C1 Fraction	C1-C5 Fraction	C6+ Fraction
					Expelled [%]	Expelled [%]	Expelled [%]
Pabdeh	164	70	9.56E+10	4.26E+10	0.30%	20.00%	79.70%
Kazhdumi	260	125	2.10E+11	1.13E+11	0.35%	10.00%	89.65%

Table 7. The average hydrocarbon compounds in Kazhdumi and Pabdeh source rocks at present day.

Formation	Mean C1 Fraction (%)	Mean C2-C5 Fractions (%)	Mean C6+ Fractions (%)	Mean Coke Fraction (%)
Pabdeh	2	17	63	18
Kazhdumi	5	5	39	51

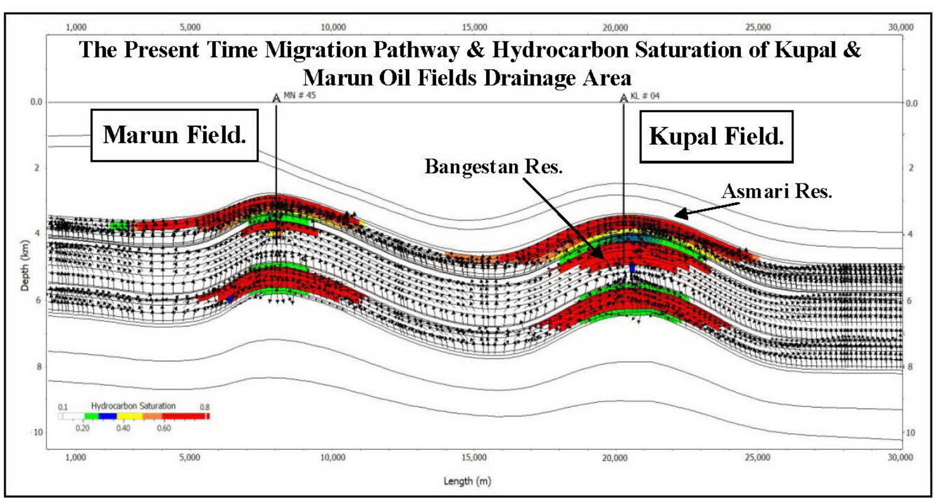

Figure 17. Display of the migration Pathways and locations of accumulated hydrocarbons in the drainage area of the Kupal and Marun fields at the present day.

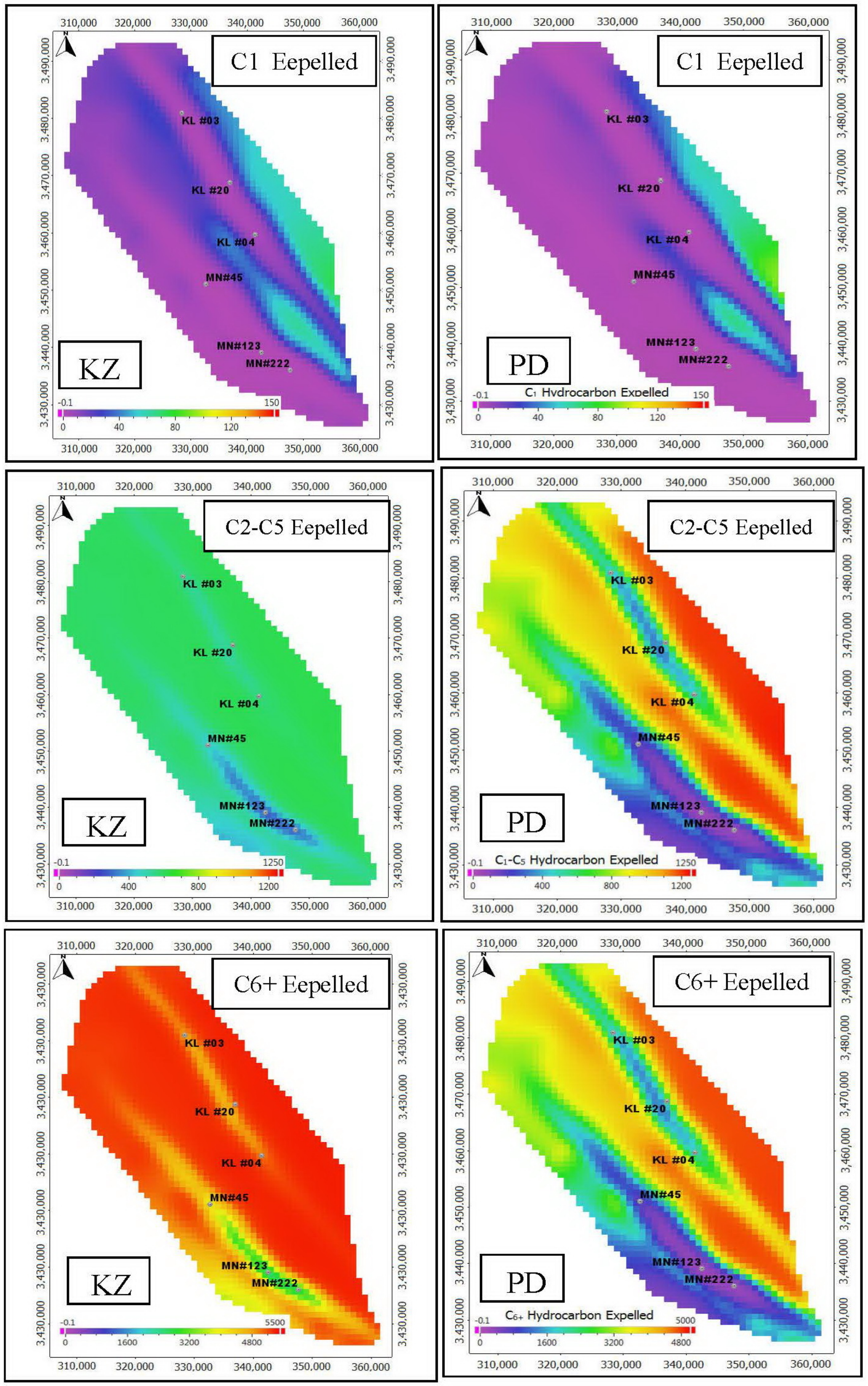

Figure 18. The hydrocarbon compounds expelled from Kazhdumi and Pabdeh source rocks in drainage area of Marun and Kupal oil fields.

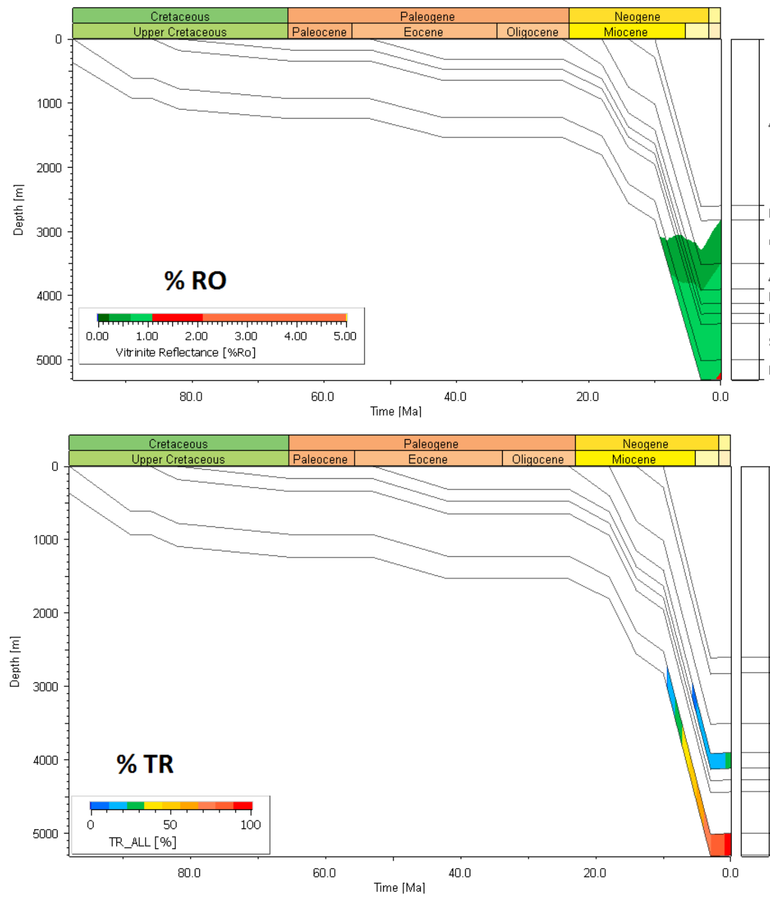

Figure 19. The maturity and Transformation ratio burial History of middle Cretaceous to present day of Kupal oil field.

According to the volumetric calculations performed by the software in the Asmari reservoir of the Kupal oil field (with water saturation cutoff value less than 53.7% and the porosity more than 4.7%), the amount of oil and gas in place are estimated to be about 4.2 billion barrels and 19.8 billion gas cubic meters, respectively. In addition, in the Bangestan reservoir of the Kupal oil field (with water saturation cutoff value less than 46.6% and porosity more than 1.5%) this amount sums up to about 4.8 billion barrels of oil in place and 17.6 billion cubic feet of gas in place (Table 8). Based on 3D model, the primary gas versus oil ratio in the Asmari reservoir is estimated under conventional conditions to be 1352 and in the Bangestan reservoir this value is 1802 cubic feet per barrel. Also, the percentage of derivatives and the types of hydrocarbons accumulated in the Asmari and Bangestan reservoirs in the Kupal oil field are shown in Table 9.

Discussion

The overall results obtained from the petroleum systems modeling of the middle Cretaceous –lower Miocene in the Kupal oil field indicate that Kazhdumi Formation has entered the phase of hydrocarbon generation and expulsion after the sedimentation of the Gachsaran seal rock and during the Zagros region folding (simultaneously with the Aghajari Formation deposition). In other words, this source rock was able to feed both the Asmari and Bangestan reservoirs simultaneously, with the forming of the required elements to form a petroleum system. In this petroleum system, the Pabdeh source rock has also entered the phase of hydrocarbon generation and expulsion with some delay after the Kazhdumi source rock. Therefore, along with the Kazhdumi Formation, the Pabdeh was able to contribute to feeding the Asmari Reservoir in the Kupal oil Field.

So far, it was thought that only Kazhdumi Formation was involved in feeding of the Asmari reservoir; whereas in this research, using petroleum system modeling and geochemical analyzes, it was shown that about 30% of the hydrocarbon contained in this reservoir is supplied from the Pabdeh Formation.

This achievement will be very important in re–estimating the amount of accumulated hydrocarbon in the Asmari reservoir of Kupal oil field.

Conclusions

The results of studying the geochemical and dynamic hydrocarbon fluid data and also modeling of the Middle Cretaceous–Lower Miocene petroleum system in the Kupal field show that the Kazhdumi and Pabdeh source rocks have played a decisive role in the generation of oil and feeding the Asmari and Bangestan reservoirs. This evidence corresponds to the last phase of the Zagros folding and simultaneously with the sedimentation of the Aghajari Formation.

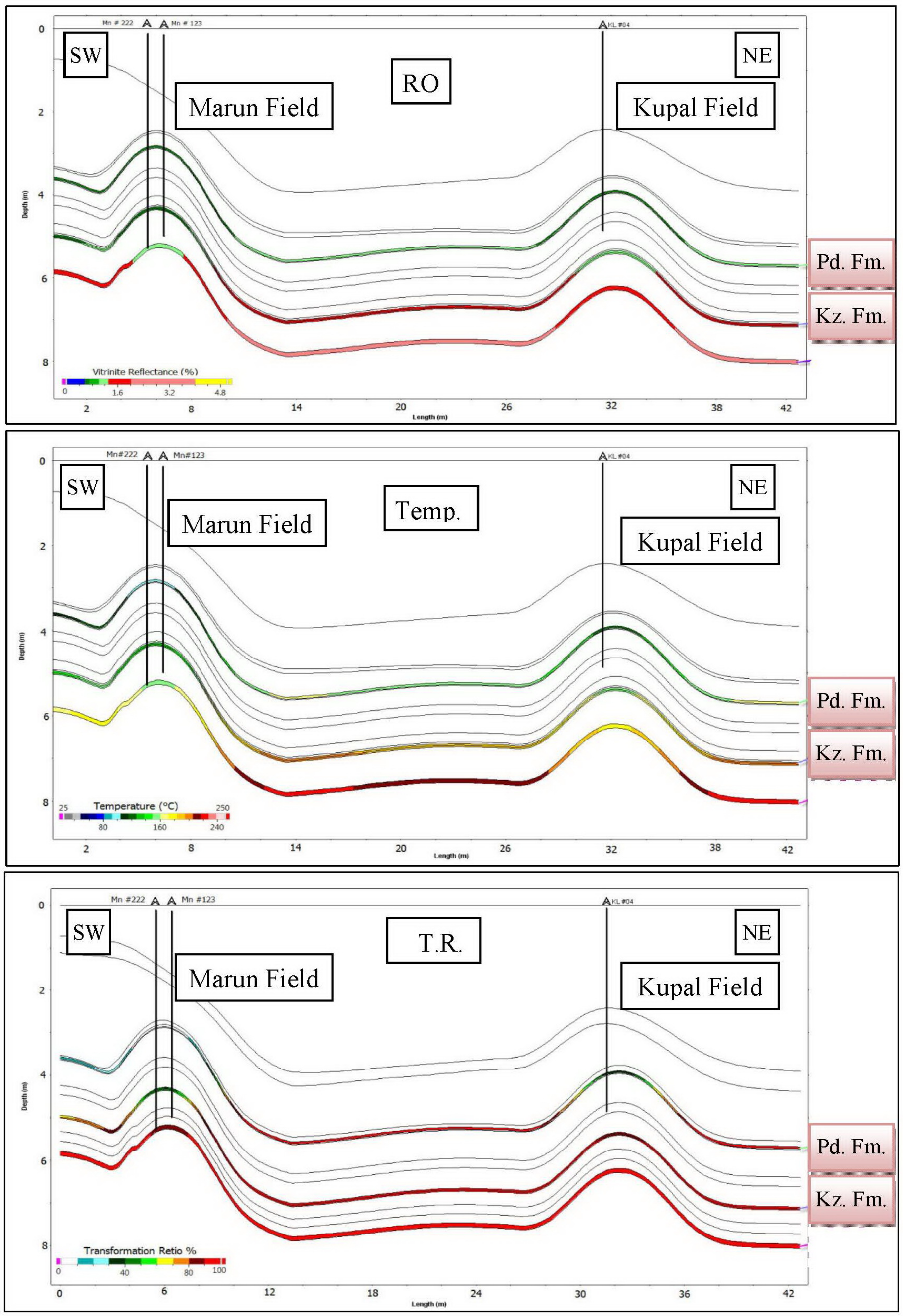

Figure 20. The Vitrinite reflectance, Temperature and Transformation ratio Values of the Kazhdumi and Pabdeh source rocks on Profile (B) at Present day in drainage area between Kupal and Marun oil fields.

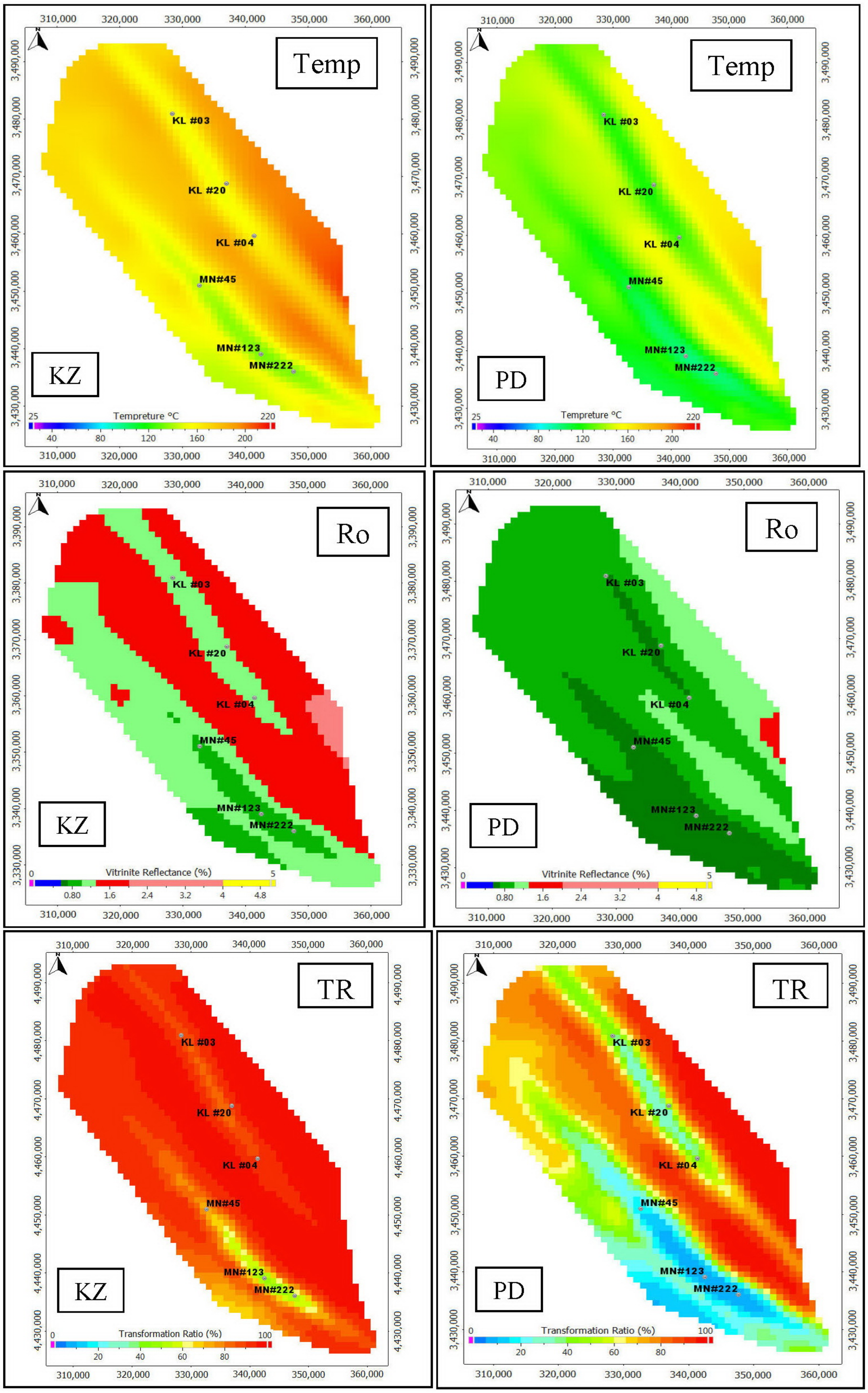

Figure 21. The Vitrinite reflectance, Temperature and Transformation ratio maps of Kazhdumi and Pabdeh source rocks at Present day in drainage area between Kupal and Marun oil fields.

Table 8. The Volume of hydrocarbons accumulated in Asmari and Bangestan reservoirs of the Kupal oil field.

Reservoir	OOIP [m³]	GIIP [m³]	OOIP [bbl]	GIIP [scf]	Mean Vol. GOR of Liquid Phase [ft³/stb]
Asmari	E+086.68	E+085.61	E+094.20	E+101.98	1352
Bangestan	E+087.63	E+084.98	E+094.80	E+101.76	1802
Total	1.43E+09	1.06E+09	9.00E+09	3.74E+10	3154

Table 9. The Quantities and types of accumulated hydrocarbons in the Asmari and Bangestan reservoirs of the Kupal oil field.

Formation	Mean C1 Fraction (%)	Mean C2-C5 Fractions (%)	Pabdeh Mean C6+ Fractions (%)	Kazdumi Mean C6+ Fractions (%)	Oil (%)	Solution Gas (%)	Free Gas (%)	Condensate (%)
Asmari	6	16	40	38	84	16	96	4
Bangestan	3	11	0	86	86	14	92	8

In the syncline area, between the Marun and Kupal fields, the Kazhdumi source rock has entered the phase of petroleum generation about 9 million years ago, and then from 7 million years ago, it has entered the petroleum expulsion phase. However, in the same area, the Pabdeh Formation has entered into the phase of petroleum generation and expulsion, respectively, about 6 and 3 million years ago because of its lesser burial depth. As a result, this source rock has supplied about one third of the oil stored in the Asmari reservoir in the Kupal field. The same results show that the Pabdeh Formation in the nearby fields (Aghajari and Marun) is not sufficiently mature to produce hydrocarbons; and that the lateral migration from the Kupal Field to the nearby fields (and vice versa) is ruled out. In this field, due to development of the fractures and faults system functioning, the vertical migration has the main role in feeding the Asmari and Bangestan reservoirs.

The Kerogen of the Kazhdumi source rock is of type II (with an average of 951 ppm sulfur) which has contributed to the production of sour oil. At the same time, the Kerogen of the Pabdeh source rock is of type II (with an average of less than 5 ppm sulfur) which has contributed to the production of sweet oil.

Now, the Kazhdumi Formation has lost about half of its hydrocarbon generation potential, whereas the Pabdeh Formation has lost only about 18% of its hydrocarbon generation potential. The volumetric calculations by the software modeler, with respect to the porosity and water saturation cutoff, indicate that the Asmari and Bangestan reservoir of the Kupal oil field have about 4.2 and 4.8 billion barrels of oil in–situ, respectively.

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References

Abeed, Q., Littke, R., Strozyk, F., Uffmann, A. K., 2013. The Upper Jurassic Cretaceous petroleum system of southern Iraq: a 3–D basin modeling study. GeoArabia, 18: 179–200

Abu–Ali, M.A., Littke, R., 2005. Paleozoic Petroleum System of Saudi Arabia: a basin modeling approach. GeoArabia, 10: 131–168

Agard, P., Omrani, J., Jolivet, L., Whitechurch, H., Vrielynck, B., Spakman, W., Monie, P., Meyer, B. and Wortel, R., 2011. Zagros orogeny: A subduction–dominated process, Geological Magazine, 148: 1–34

Agard, P., Omrani, J., Jolivet, L., Mouthereau, F., 2005. Convergence history across Zagros (Iran): Constraints from collisional and earlier deformation, International Journal of Earth Science, 94, 19: 401–419

Aghanabati, A., 2004. The Geology of Iran, Geological Survey of Iran pub., 586: 17–34, 236–240, 289–303 (in Persian)

Alavi, M., 2007. Structures of the Zagros fold–thrust belt in Iran, American Journal of Science, 307: 1064–1095

Alavi, M., 2004. Regional Stratigraphy of the Zagros folded–thrust belt of Iran and its Proforeland evolution, American Journal of Science, 304: 1–20.

Al–Husseini, M.I., 2008. Middle East Time Scale, GeoArabia, Journal of Middle East, Petroleum Geosciences, No.4: 13

Alizadeh, B., Khani, B., Alipour, M., Shayesteh, M., Hosseini, S.H., 2012. Thermal modeling and organic geochemical appraisal of petroleum source rocks within the Aghajari Oilfield, SW Iran, JGeope 2 (2), 10: 1–10

Alizadeh, B., Sarafdokht, H., Rajabi, M., Opera, A., Janbaz, M., 2012. Organic geochemistry and petrography of Kazhdumi (Albian – Cenomanian) and Pabdeh (Paleogene) potential source rocks in southern part of the Dezful Embayment, Iran. Organic Geochemistry, Vol.49, 11: 36–46

Alizadeh, B., Adabi M. H., Tezheh F., 2007. Oil–Oil Correlation of Asmari–Bangestan Reservoirs using gas chromatography and stable Isotopes in Marun oil field, SW Iran, Iranian Journal of Science & Technology, Transaction A., 31 (A3:13): 241–253

Allan, T. L., Whit ford, D. J., 2004. Strontium isotope age of Asmari limestone from surface and well selections, CISRO Petroleum, Australia, 8: 1–8

Allen P.A., Allen J.R., 2013. Basin Analysis: Principles & Application to petroleum play assessment, Third edition, Wiley–Blackwell pub., 633p.

Alsharhan, A.S., 2014. Petroleum systems in the Middle East, In: Rollinson, H.R., Searle, M.P., Abbasi, A.I., Al–Lazki, A.I. and Al–Kindi, M.H., Eds., Tectonic Evolution of the Oman Mountains, Geological Society, London, 392: 361–408

Ansari, A., Safaee, J., 1986. Assessment of performance and computation of in situ oil reserve of Asmari reservoir: Kupal oil Field, National Iranian South Oil Co., Report No. P–3987, 80: 1–80, (In Persian)

Asadi Mehmandosti, A., Adabi M.H., Stephen A. Bowden, S.A., Alizadeh, B., 2015. Geochemical investigation, Oil–Oil and Oil–Source Rock Correlation in the Dezful Embayment, Marun Oilfield, Zagros, Iran, Marine and Petroleum Geology, 43: 1–43

Ashkan, M. A., 2013. Geochemical study of Asmari and Bangestan reservoirs of Marun oil field and investigating the H_2S production factors in Asmari reservoir, Report No. R–27, Khuzestan Earth and Mining Engineering Co., 211: (In Persian)

Ashkan, M. A., 2009. Principles of Geochemical Studies of Hydrocarbon Source Rocks with Special Attitude to Zagros Sedimentary Basin, Geochemical Department of Exploration Management, 355: (In Persian)

Ashkan, M. A., 2009.Geochemical study of Asmari and Bangestan reservoirs of Aghajari oil field before gas injection, Report No. R–9, Khuzestan Earth and Mining Engineering Company, 199: (In Persian)

Ashkan, M. A., 2004.Geochemical study of Asmari and Bangestan reservoirs of Kupal oil field Report No. R–2, Khuzestan Earth and Mining Engineering Company, 287: (In Persian)

Bahroudi, A., Koyi, H.A., 2004. Tectono–sedimentary framework of the Gachsaran Formation in the Zagros foreland basin, Journal of Marine and Petroleum Geology, 21 (16): 1295–1395

Baniasad, A., Rabbani, A.R., Moallemi, S.A., Soleimany, B., Rashidi, M., 2017. Petroleum system analysis of the northwestern part of the Persian Gulf, Iranian sector, Organic Geochemistry, 107 (17): 69–85

Baniasad, A., Rabbani, A.R., Sachse, V.F., Littke, R., 2016. 2D basin modeling study of the Binak Trough, northwestern Persian Gulf, Iran, Marine and Petroleum Geology, 77 (16): 882–897

Barker, D.E., 1996. Thermal modeling of petroleum generation, theory and application. Elsevier pub., 503p

Bordenave, M.L., 2014.Petroleum Systems and Distribution of the Oil and Gas Fields in the Iranian Part of the Tethyan Region, in L. Marlow, C. Kendall and L. Yose, eds., Petroleum systems of the Tethyan region: AAPG Memoir 106, 36: 505–540.

Bordenave, M.L., Hegre, J. A., 2010. Current distribution of oil and gas fields in the Zagros fold Belt of Iran and contiguous offshore as the result of the petroleum systems. In: P. Leturmy, and C. Robin, (Eds.), Tectonic and Stratigraphic evolution of Zagros and Makran during the Mesozoic–Cenozoic, Geological Society, London, Special Publications, 330: 291–353

Bordenave, M.L., Hegre, J.A., 2005. The influence of tectonics on the entrapment of oil in the Dezful Embayment, Zagros fold belt, Iran, Journal of Petroleum Geology, 28(4): 339 – 368

Bordenave, M. L., 2002, The Middle Cretaceous to Early Miocene Petroleum system in the Zagros Domain of Iran, and its prospect Evaluation, American Association of Petroleum Geologist Annual Meeting, Houston, Texas., 9: 1–9

Bordenave, M. L., Huc, A.Y., 1995. The Cretaceous source rocks in the Zagros foothills of Iran, an example of a large size intra–cratonic basin. Oil and Gas science and Technology Revue de Institut –Francais du Petrole, 50: 727–752.

Bordenave, M. L. Burwood, R., 1995. The Albian Kazhdumi Formation of the Dezful embayment, Iran: One of the most efficient petroleum generating systems, in B. J. Katz, ed., Petroleum Source Rocks series, Case Book in Earth Sciences, Springer Verlag, Heidelberg, 14: 183–207.

Bordenave, M.L., Burwood, R., 1990. Source rock distribution and maturation in the Zagros Orogenic belt: provenances of the Asmari and Bangestan reservoir oil accumulation, Organic Geochemistry, 16: 369–387.

Bordenave, M. L., Nili, A. R., 1973. Geochemical project, review and appraisal of the Khuzestan Province: Iranian oil operating companies' report No. 1194, Geological and Exploration Division, Cited in Khosravi Sais (1987), 152 p.

Clift P.D., Turner, j., 1998. Paleogene igneous under plating and subsidence anomalies in the Rockall–Faeroes–Shetland area, Mar Pet Geology 15(3): 223–243, In: Fleet, A.J. & Boldy S.A.R., 1999, Petroleum Geology of Northwest Europe, Geology Society pub. London, 1 (738): 586–592

Cohen, D.A.T., Harper, P.L., Gibbard, J.X., Fan(c), 2018. International Chronostratigraphic Chart, International Commission on Stratigraphy, IUGS, URL: http://www.stratigraphy.org/ICSchart

Cooles, G.P., Mackenzie, A.S., Quigley, T.M., 1986. Calculation of petroleum masses generated and expelled from source rocks, Organic Geochemistry pub., 10: 235–245

Darabi, P., 2014. Two–Dimensional Modeling of Petroleum System in Aghajari and Pazanan oil fields, Shahid Chamran University pub., Ahvaz, Iran, 170 p. (In Persian)

Ebadollahzadeh, H., 2016. Geochemical studies of the Asmari & Bangestan Formations by using fluid inclusion micro thermometry in Kupal oil field, University of Tehran, 127 p. (In Persian)

Fajarak, M.M., 2008. Geochemical Study of Bangestan reservoir in Maruun oil Field, Shahid Chamran University pub., Ahvaz, Iran, 137 p. (In Persian)

Fardin, H., 2018. Fracture Modeling of Bangestan Reservoir in the Kupal Oil Field, National Iranian South Oil Company, Ahvaz, Iran, Report No. 9021, 123: 118–121 (In Persian)

Farsimadan, M., 2019. Fracture Modeling of Asmari Reservoir in the Kupal Oil Field, National Iranian South Oil Company, Ahvaz, Iran, Report No. 9254, 109: 105–107 (In Persian)

Ghalavand, H., 1996. Stratigraphic and Biostratigraphic study of Dariyan and Kazhdumi Formations in the Southwest of Iran (Fars area and Dezful embayment), Shahid Beheshti University, Tehran, Iran, 231 p., (In Persian)

Hantschel, T., Kauerauf, A.I., 2009. Fundamentals of Basin and Petroleum Systems Modeling, Springer. XVI., 476p.

Hunt, J. M., 1996. Petroleum Geochemistry and Geology, 2nd Edition. W.H. Freeman and Company, New York. 743p.

James, G.A., Wynd, J.G., 1965. Stratigraphic Nomenclature of Iranian Oil Consortium Agreement Area, American Association of Petroleum Geologists Bulletin, 49: 2182–2245.

Karimi, A.R., Rabbani, A.R., Kamali, M.R., 2016. A bulk kinetic, burial history and thermal modeling study of the Albian Kazhdumi and the Eocene–Oligocene Pabdeh formations in the Ahvaz anticline, Dezful Embayment, Iran, Journal of Petroleum Science and Engineering, 146 (10): 61–70

Kasai Najafi, M., 2011. Petroleum Systems of Iran, Research Institute of Petroleum Industry, Tehran, Iran, 144 p. (In Persian)

Khani, B., 2011. Geochemical Evaluation of Probable Source Rocks of Aghajari Oil Field, Shahid Chamran University pub., Ahvaz, Iran, 121 p. (In Persian)

Lopatin, N.V., 1971. Temperature and geologic time as factors in coalification, Izvestiya Akademii Nauk USSR Seriya Geologicheskaya, 3: 95–196 (In Russian).Magoon, L.B., Bird, K.J., Burrus, R.C., Hayba, D., Houseknecht, D.W., Keller, M.A., Lillis, P.G., Rowan, E.L., 1999. Evaluation of Hydrocarbon Charge and Timing Using the Petroleum System, In The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska, by ANWR Assessment Team, U.S. Geological Survey Open–File Report 98–34, 66: 5–13

Magoon, L.B., Dow, W.G., 1994, The petroleum system – from source to trap, American Association of Petroleum Geologists, Memoir 60, Tulsa, Oklahoma, 655 p.

Magoon, L.B., 1988. The petroleum system – a classification scheme for research, exploration, and resource assessment, In: Petroleum Systems of the United States (ed.), United States Geological Survey, Bul. 1870 (15): 1–15

Mashhadi, Z.H., Rabbani, A.R., Kamali, M.R., Mirshahani, M. Khajehzadeh, A., 2015. Burial and thermal maturity modeling of the Middle Cretaceous– Early Miocene petroleum system, Iranian sector of the Persian Gulf , Springer pub., Pet. Sci. , 12: 367–390

McClay K.R., Shaw J., Supp, J., 2011. Introduction to Thrust Fault Related Folding, American Association of Petroleum Geologist, Memoir 94 (20): 1–20

McQuillan, H., 1991. The role of basement tectonics in the control of sedimentary facies, structural pattern and salt plug emplacements in the Zagros Fold Belt of southwest Iran, Journal of Southeast Asian Earth Sciences, 5: 453–463

Mobin, B. , 2001, Biomarkers Study of Asmari Reservoir in Marun oil Field, Shahid Chamran University pub., Ahvaz, Iran, 95 p. (In Persian)

Mohsenian, E., Fathi–Mobarakabad, A., Sachsenhofer, R.F., Eskandar, A., 2014. 3D Basin Modeling In The Central Persian Gulf, Offshore Iran, Journal of Petroleum Geology, 37(1), 52: 55–70.

Motiee, H., 1995. The Zagros Oil Geology, Vol. 1 & 2., The Geology Department of Iran, 1024: 1–1024 (In Persian)

Opera, A., Alizadeh, B., Sarafdokht, H., Janbaz, M., Fouladvand, R., Heidarifard, M. H., 2013. Burial history reconstruction and thermal maturity modeling for the Middle Cretaceous–Early Miocene Petroleum System, southern Dezful Embayment, SW Iran, Coal Geology, 120: 14: 1–14.

Peters, K. E., Magoon, L.B., Lampe, C., Hosford Scheirer, A., Lillis, P.G., L. Gautier, D., 2012. A four–dimensional petroleum systems model for the San Joaquin Basin Province, California: Chapter 12 in Petroleum systems and geologic assessment of oil and gas in the San Joaquin Basin Province, California, 35: 1–35

Peters, K. E., Nelson, P. H., 2009. Criteria to Determine Borehole Formation Temperatures for Calibration of Basin and

Petroleum System Models, AAPG Annual Convention and Exhibition, Denver, Colorado, USA, 27: 1–27

Peters, K. E., Walters, C. C., Moldowan, J. M., 2005.The Biomarker Guide. Vol. 1 & 2, 2nd ed., Cambridge University Press, 1190 p.

Peters, K.E., Fowler, M.G., 2002. Applications of petroleum geochemistry to exploration and reservoir management, Organic Geochemistry, 33: 5–36

Peters, K.E., Alan K. Burnham A.K., Walters, C.C., Schenk, O., 2017. Guidelines for Kinetic Input to Basin and Petroleum System Models*, , AAPG Annual Convention & Exhibition, Houston, Texas, Search and Discovery Article #42112, 28: 1–28

Peters, K.E., Cassa, M.R., 1994. Applied source rock geochemistry, In: Magoon, L.B., Dow, W.G. (Eds.), The Petroleum System – From Source to Trap. American Association of Petroleum Geologists Memoir, 60: 93–120

Piryae A., Hemmat, S., Zamannegad, A., 2017. Paleogeography and hydrocarbon potential evaluation of Cretaceous Deposits in the Zagros region, N.I.O.C., Exploration Management, Geology Dep., Report No. GR–2433, 328: 40–75 (In Persian)

Piryae A., Hemmat, S., Feizi, A., Soofiyani, H., Motamedi, B., 2014. Paleogeography of Lower Tertiary Deposits in the Zagros region, N.I.O.C., Exploration Management, Geology Dep., Report No. GR–2362, 223: 2–203 (In Persian)

Pitman, J.K., D. Steinshouer, and M. D. Lewan, 2004. Petroleum generation and migration in the Mesopotamian Basin and Zagros fold belt of Iraq: Results from a basin modeling study: GeoArabia, 9(4, 32): 41–72

Rahimpour Bonab, H., Mirnezhad, H., Sonei R., 2013. The Principles of Stable Isotopes Geochemistry, Alavi Pub., Tehran, Iran, 606 p. (In Persian)

Rashidi M., Jalali M., Seraj H., 2014. Petroleum Systems Modeling in Central Iranian Sedimentary Basin: New Strategy for Old Hydrocarbon Exploration Activities, EAGE pub. BPM12, 5: 1–5

Roghanian, R., Farazmand, M., 2008. Updating simulator model of Asmari reservoir: Kupal oil Field, National Iranian South Oil Company, Report No. P–6313, 145: 1–145. (In Persian)

Rudkiewicz J.L., Sherkati, SH., Letouzey, J., 2007. Evolution of Maturity in Northern Fars and in the Izeh Zone (Iranian Zagros) and Link with Hydrocarbon Prospectivity. In Lacombe, o., Lave, J., Roure, F., Verges, J. (Eds.), Thrust belts and foreland basins. Springer Berlin Heidelberg, part 491: 229–256.

Schmoker, J.W., 1994. Volumetric calculation of hydrocarbons generated. In: Magoon, L.B., Dow, W.G. (Eds.). The Petroleum System – from Source to Trap, 60. American Association of Petroleum Geologists Memoir, pp. 323–326

Sfidari E., Zamanzadeh, S.M., Dashti, Opera, A., Tavakkol, M.H., 2016. Comprehensive source rock evaluation of the Kazhdumi Formation, in the Iranian Zagros Fold belt and adjacent offshore, Marine and Petroleum Geology, Vol. 71, 15: 26–40.

Sherkati, S., Letouzay, J., 2004. Variation of structural style and basin evolution in the central Zagros (Izeh zone and Dezful Embayment), Iran: Marine and Petroleum Geology, 21, 19: 535–554.

Sherkati, S., 2005. Tectonics of sedimentary cover and basement in the Zagros Orogenic belt, Notes on Geometric Modeling of Deformation. N.I.O.C., Exploration Management, Geology Dep., Report NO. GR–2067, 66: 1–66 (In Persian)

Sherkati, S., Molinaro, M., Frizon de Lamotte, D., Letouzey, J., 2005. Detachment folding in the Central and Eastern Zagros fold–belt (Iran): salt mobility, multiple detachments and late basement control, Journal of Structural Geology, 27 (16): 1680–1696

Sherkati, S., Letouzey, J., Frizon de Lamotte, D., 2006. Central Zagros Fold–thrust belt (Iran): New insights from seismic data, field observation, and sandbox modeling, Tectonics, 25: 1– 27.

Smith, J.R., Smith, J.W., 2007. A relationship between the carbon and hydrogen content of coals and their vitrinite reflectance. International Journal of Coal Geology, 70: 79–86.

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

Soleimani B., Monjezi K. and Malaki S., 2014. Microfacies, Diagenetic and Depositional Environment of Kazhdumi Formation (Aptian–Albian), Dezful Embayment, Zagros, NW Iran, Jour. of Geology & Geosciences , Vol. 3, 10: 1–10

Terken, J.M.J., Frewin, N.L., 2000. The Dhahaban petroleum system of Oman. American Association of Petroleum Geologists Bulletin, 84: 523–544.

Tissot, B., Welte, D. H., 1984. Petroleum Formation and Occurrence, 2nd ed. Heidelberg: Springer Verlag.

Tissot, B.P., Espitalie, J., 1975. L‟evolution thermique de la matiere organique des sediments: applications d‟une simulation mathematique. Revue de l‟Institut Franccais du Petrole 30: 743–777.

Van Buchem, F., Letouzey, J., Gaumet, F., Rudkiewicz, J.L., Mengus, J.M., Baghbani, D., Sherkati, S., Asillian, H., Keyvani, F., Ashrafzadeh, R., Ehsani, M.H., 2001.The Petroleum systems of the Dezful Embayment and Northern Fars(Southwest Iran), A joint IFP & NIOC research project, Exploration management Department, Tehran, Iran, 947.

Waples, D. W., Pacheco, J., Vera, A., 2004. A method for correcting log–derived Temperatures in deep wells, calibrated in the Gulf of Mexico, Petroleum Geoscience, 10: 239–245

Waples, D. W., 1980. Time and temperature in petroleum formation: application Lopatin method to petroleum exploration: AAPG Bulletin, 64: 916– 926.

Waples, D.W., Curiale, J.A., 1999. Oil–oil and oil–Source Rock Correlations, In: Exploration for Oil and Gas Traps (E. Beaumont & H. Foster, eds.), American Association of Petroleum Geologist, Tulsa, 1–71

Wygrala, B.P., 1989. Integrated study of an oil field in the southern Po basin, northern Italy. Ber. Kernforschungsanlage Jülich 2313, 217.

Zeinalzadeh, A., Moussavi–Harami, R., Mahboubi, A., Sajjadian, V.A., 2015. Basin and petroleum system modeling of the Cretaceous and Jurassic source rocks of the gas and oil reservoirs in Darquain field, south west Iran, Journal of Natural Gas Science and Engineering, 26 (8): 419–426

Zeinalzadeh, A., Moeinpour, M., Shayesteh, M., Heidarifard, M.H., 2010. 1D and 2D Thermal Modeling of Asmari and Bangestan reservoirs of Gachsaran and Bibi–Hakimeh oil fields, Stratigraphy & Sedimentology Researches Bul., Vol. 26,41,4, Tehran, Iran, 15: 111–124 (In Persian)

Ziegler, M.A., 2001. Late Permian to Holocene paleofacies evolution of the Arabian Plate and its hydrocarbon occurrences, GeoArabia (Manama), 6(3): 445–504.

Zohrabzadeh, M., Rahimpour–Bonab, H., Aleali, M., 2018. Application of 3D–Seismic Data in Detecting Buried Karsts in Asmari Formation: An Example from Kupal Oil Field, Southwest Iran, Geopersia 9 (1): 151–167