Assessment of Petroleum System Elements of the Jurassic Sediments in Matruh Basin, North Western Desert, Egypt.

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Abstract
The Middle Jurassic sandstones of Upper and Lower Safa members acts as a hydrocarbon reservoirs in the subsurface in Matruh basin, Western Desert, Egypt. The present study aimed to achieve and analyze the Jurassic petroleum systems elements through the evaluation of the source rocks, reservoir rocks, determination of seal rocks and traps, in addition to the main processes that control any petroleum system, such as, maturation, generation, migration and trapping. Therefore, we can provide a guide for future hydrocarbon exploration and development. Several softwares have been used, Interactive Petrophysics IP used for different petrophysical models construction and PetroMod 2012.2 (1D) for geological & geochemical models construction and prediction. Source rock evaluation showed that there are two main source rocks in the Jurassic sediments, Upper and Lower Safa Shales and showed that both of them are considered as a very good in their total organic carbon content (TOC), and characterized by kerogen type III with minor of type II which reflect its capability to generate mainly gas with some oil. The Tmax and Ro of these source rocks are indicate that the Upper Safa source rocks are located in the late to over mature stages and lied in the gas generation stage, while the Lower Safa source rocks are located in the early to over mature stages and lied in gas and oil generation stage. The petrophysical evaluation indicate that there are two main reservoir units, Upper and Lower Safa sands, and it showed that the net effective pay thickness in the Upper Safa reservoir is ranging between 29 and 67.5 ft, the average effective porosity is 8.55 % and average hydrocarbon saturation is 78 %, while in the Lower Safa reservoir, the net effective pay thickness ranging between 29 and 53 ft, the average effective porosity is 8.9 % and average hydrocarbon saturation is 75 %, this indicates that both Upper and Lower Safa reservoirs can be considered as two of the most promising reservoirs in the northern part of the Western Desert of Egypt. Top seal for the Jurassic Safa Sands is provided by local intra-formational shale intervals within Upper and Lower Safa themselves, the overburden shales of Zahra member and effective compact carbonates of Masajid Formation. The traps are typically of structure type.

Keywords: Petroleum System, Basin Modeling, Jurassic, Matruh Basin, Western Desert, Egypt.

1. Introduction
Matruh Basin is a part of the northern Western Desert of Egypt, which has numerous of oil and gas potentialities and may jump soon as a great petroleum province. The Western Desert still has a significant hydrocarbon potential as recent oil and gas discoveries have suggested (Dolson et al. 2001). Perhaps 90 % of undiscovered oil reserves and 80% of undiscovered gas reserves in Egypt are located in the Western Desert (Zein El-Din et al. 2001). The area of study deals with this basin and lies between latitudes 30° 55’ 41” - 30° 57’ 37” N and longitudes 27° 23’ 18” - 27° 25’ 18” E, (Fig. 1).

2. Geological Settings
The general structural and stratigraphic aspects of the Western Desert have been subjected to
many studies, such as; Amin (1961), Said (1962 and 1990), Norton (1967), Parker (1982), Meshref (1982), El-Khadragy and Sharaf (1994), Shalaby et al. (2000), Zein El-Dein et al. (2001), El-Khadragy et al. (2010) and others, however, two major fault trends are affecting the study area, the first trend oriented East - West, while the second oriented North East - South West.

The generalized stratigraphic column of the northern Western Desert includes most of the sedimentary succession from Pre-Cambrian basement complex to Recent (Fig. 2), generally the total thickness increases progressively to the north and northeast directions and ranges from about 6000 ft in the south to about 25,000 ft in the coastal area.

The Safa is divided into Lower and Upper parts by the Kabrit member, which characterized by the dominance of limestones. The Lower Safa member is underlies the Kabrit member, which overlaid by the Upper Safa member. The Upper and Lower Safa members are composed of shales, sandstone, siltstones with minor of limestone streaks and coals seams. Upper and Lower Safa are now the most important gas, condensate and oil productive zones in the Matruh basin.

The age of the Safa is Callovian / Middle Bathonian. The Safa is represented by coastal marine/shelf rocks with thin Tidal sands. (EGPC, 1998).

Fig. 1: Location map for the study area and its relation to the main basins in the north Western Desert of Egypt (after Schlumberger, 1995).
3. Materials and Input

In this study, the major materials which applied include the wire line logs of four wells (Matruh 1-1 X, Matruh -5, Matruh -6 and Samaa -1X), thicknesses and absolute ages of the stratigraphic units in the subsurface, percentage of lithology of the stratigraphic units, surface temperature, geochemical analysis were done by eight samples that are collected from the Matruh 1-1X well, measurements were made, TOC (Total Organic Carbon Content), one R0% (Vitrinite reflectance) value, Rock-Eval pyrolysis parameters, HI (Hydrogen index), OI (Oxygen index) and PI (Production index).

4. Results and Discussion

1) Petroleum System Elements

A petroleum system is defined as a natural hydrocarbon system that includes active source rocks, the generated hydrocarbons, and essential elements and processes that lead to hydrocarbon accumulations (Magoon, 1988; Magoon and Dow, 2000). On the other hand, the petroleum system can be defined as the essential elements (source rock, reservoir rock, seal rock, and overburden rock) and processes (generation, migration, accumulation and trap formation) as well as all genetically related petroleum that occurs in seeps, shows, and accumulations.

a- Source Rocks:

The Early – Middle Jurassic Upper and Lower Safa Shales are the main source rocks for hydrocarbon generation and expulsion for the Jurassic reservoirs in the Matruh Basin. Eight ditch samples from the Matruh 1-1X well have been analyzed and showed that Upper and Lower Safa Shales are considered as a very good SR as the measured TOC values range from 2.26 to 56.79 wt.% and 5.91 to 75.04 wt.% for Upper and Lower Safa source rocks respectively (Fig. 3). Both of these source rocks are characterized by type (III) with input of type (II) kerogen and this indicates the capability of generating gas with low amount of oil (Figs. 4 and 5). The Tmax values range from 466 to 473 °C and 442 to 478 °C for Upper and Lower Safa source rocks respectively (Fig. 6), in addition, vitrinite reflectance (%Ro) values of 1.4 to 1.5% and 1 to 1.36 % for Upper and Lower Safa source rocks respectively, (Fig. 7), this indicates that the Upper Safa source rocks are located in the late to over mature stages and lied in the gas generation stage, while the Lower Safa source rocks are located in the early to over mature stages and lied in gas and oil generation stage. The genetic potential values are ranging from 2.38 to 99 mg/g rock and 8.27 to 98 mg/g rock for Upper and Lower Safa source rocks respectively, which indicates good to very good source potential (Fig. 8), based on the classification of (Peter, 1986).
**Fig. 3:** Total Organic carbon richness (TOC) of Upper and Lower Safa source rocks.

**Fig. 4:** Kerogen type of Upper and Lower Safa source rock.

**Fig. 5:** Modified Van Krevelen type diagram (HI versus OI Crossplot) showing kerogen type of Jurassic Upper and Lower Safa.

**Fig. 6:** Thermal maturity of Upper and Lower Safa source rocks.
Fig. 7: Maturation of Upper and Lower Safa source rocks.

Fig. 8: Genetic potential of the Upper and Lower Safa source rocks.

b- Reservoir Rocks:

The petrophysical evaluation of Jurassic section in the area of study which has been done for four wells (Matruh 1-1X, Matruh -5, Matruh -6 and Samaa -1X) in Matruh field was carefully analyzed and showed that there are two main reservoirs, these reservoirs are Upper and Lower Safa reservoirs which are located in the Early – Middle Jurassic. The results of log analysis of the Upper Safa reservoir showed that the thickness of the net effective pay ranges between 29 and 67.5 ft. with an average effective porosity of 8.55 % and an average hydrocarbon saturation of 78 %, and showed that the Lower Safa reservoir net effective pay ranges in thickness between 29 and 53 ft., the effective porosity reaches 8.9 % and the hydrocarbon saturation reaches 75%. All petrophysical parameters are illustrated in the form of iso-parametric maps and litho–saturation crossplots. The iso-parametric maps show the lateral variation of petrophysical parameters and help in new prospective well locations. These maps show that the Upper Safa attains its best reservoir characteristics towards the E, SE, SW and N parts of the study area due to the increase in effective porosity, net pay thickness and hydrocarbon saturation and decrease in shale volume and water saturation. The optimum Lower Safa reservoir characteristics occupy mainly the northern parts of the study area. This may due to the increase of the effective porosity, net pay thickness and hydrocarbon saturation, and the decrease of the shale volume and the water saturation, it also attains good characteristics in the area along the F2 fault, south, southeast and southwest from the Matruh -5 well, (Figs. 9 - 18).
Fig. 10: Effective porosity distribution map of the Upper Safa reservoir.

Fig. 11: Net reservoir distribution map of the Upper Safa reservoir.

Fig. 12: Hydrocarbon saturation distribution map of the Upper Safa reservoir.

Fig. 13: Net pay thickness distribution map of the Upper Safa reservoir.
Fig. 14: Shale volume distribution map of the Lower Safa reservoir.

Fig. 15: Effective porosity distribution map of the Lower Safa reservoir.

Fig. 16: Net reservoir distribution map of the Lower Safa reservoir.

Fig. 17: Hydrocarbon saturation map of the Lower Safa reservoir.
c- Seal Rocks:
Seal rock is an essential element of the petroleum system, which capable of preventing the hydrocarbons from escaping out of the petroleum system. In the study area, the Jurassic Upper and Lower Safa reservoirs are generally sealed by local intra-formational shale intervals of Upper and Lower Safa themselves, the overburden shales of Zahra member and effective compact carbonates of Masajid Formation. The intra formational shales ranging in the thickness from 10’ to 100’ (Fig. 19).

d- Traps:
The structure elements were the main factors determining the trapping of oil in almost all the discoveries. Syrian arc-related structural trends form the bulk of the productive traps discovered in the Western Desert (Dolson et al., 2001). For the study area, traps are typically of the structural type, consisting of two main fault blocks “two up-thrown 3-way dip closures”, these fault blocks are formed by two major faults the first one take the East – West & the second take the North East – South West directions, however, traps are developed in the faults direction.

e- Overburden Rocks:
The overburden rocks in the Matruh Basin comprises all the formations overlying the Jurassic Safa Formation, i.e., Zahra, Masajid, Alam El-Buieb, Alamein, Dahab, Kharita, Bahariya, Abu Roash, Khoman, Apollonia, Dabaa, Moghra and Marmarica Formations with average total thickness of 14000 ft; The lithology of the overlying rocks is variable, including mix of claystones, limestone, dolomite and sandstones. Based on corrected bottom hole temperature (BHT) and the surface temperature, the average geothermal gradient of the overburden rocks is around 1.4625 deg F / 100 ft which provide favorable conditions for the source rock maturation and petroleum generation in the study area.

II) Petroleum System Processes
The processes of the petroleum system comprise the maturation, generation, migration, accumulation, and the preservation of the hydrocarbons in the trap. Source rock maturation has been studied and mentioned in the elements of the petroleum system,
therefore, the rest of the processes will be discussed as follow:

**a - Hydrocarbon Generation**

Burial and thermal history models of the studied wells were constructed using PetroMod 2012.2 software. The data needed to construct these models include (Formation tops or true stratigraphic thickness, Geologic age of the time-rock unit, geothermal gradient, erosion and the non-deposition periods or hiatus. Accordingly, four burial histories and hydrocarbon generation models were constructed for (Matruh 1-1X, Matruh -5, Matruh -6 and Samaa -1X), these burial history curves are plotted from the geological data of the studied wells. The timing of hydrocarbon generation and expulsion of the source rock is assessed by reconstruction of 1D model of burial history of the studied wells. Table (1) showing the depth of the peak and end of hydrocarbon generation window for each well (Figs. 20 - 23); The timing of oil generation ranging from 135.69 MY at 6466 ft to 138.22 MY at 6617 ft in the Matruh -6 and Matruh 1-1X wells respectively; The timing of gas generation ranging from 63.28 MY at 13862 ft to 68.79 MY at 16216 ft in the Matruh -6 and Matruh 1-1X wells respectively; However, our Jurassic source rocks might have begun to generate oil during the Early Cretaceous in our wells, On the other hand it might have begun to generate gas during the Late Cretaceous to Early Paleogene and still in generation until now and the total drilled depths of Matruh 1-1X, Matruh -5, Matruh -6 and Samaa -1X wells are 16339, 15840, 15600 and 15700 ft, respectively.

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Depth of Oil Generation (ft)</th>
<th>Onset of Oil Generation (MaBp)</th>
<th>Depth of Gas Generation (ft)</th>
<th>Onset of Gas Generation (MaBp)</th>
</tr>
</thead>
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<tr>
<td>Matruh 1-1X</td>
<td>6617</td>
<td>138.22</td>
<td>16216</td>
<td>68.78</td>
</tr>
<tr>
<td>Matruh -5</td>
<td>6565</td>
<td>136.58</td>
<td>14389</td>
<td>66.62</td>
</tr>
<tr>
<td>Matruh -6</td>
<td>6466</td>
<td>135.69</td>
<td>13802</td>
<td>62.28</td>
</tr>
<tr>
<td>Samaa -1X</td>
<td>6597</td>
<td>135.69</td>
<td>13905</td>
<td>63.28</td>
</tr>
</tbody>
</table>

Table 1: Depth and time of hydrocarbon generation.
b- Hydrocarbon Expulsion

Hydrocarbon are expelled from the source rock as discrete phases depending on the hydrocarbon saturation of the source rock, conduits-micro fractures and overpressure caused by oil and gas generation and fluid expansion on temperature increase and capillary pressure. The hydrocarbon expulsion in Matruh Basin for Safa Formation started during the Lower Cretaceous, it started with oil generation; during the Late Cretaceous to Early Paleogene started the gas generation which is the main hydrocarbon type in our wells due to the higher percentage of gas-prone kerogen type.

c- Migration and accumulation

Upper and Lower Safa reservoirs seem to have been charged directly from the local intra-formational shale intervals of Upper and Lower Safa themselves by short-distance vertical migration along the fault plane, then accumulated, and preserved in situ.

5. Conclusions

Two integrated local petroleum systems have been proven and can be named as Upper and Lower Safa Petroleum Systems. Each petroleum system include elements and processes that can be described as follows:

1- Source rocks: Upper and Lower Safa shales considered to be a very good source rocks.

2- Reservoir rocks: Upper and Lower Safa sandstones are the main reservoirs within the Jurassic section in Matruh basin.

3- Sealed by the intra-formational shale of Upper and Lower Safa, the overlying shale of Zahra and the compact carbonate of Masajid.

4- Trapped by the structural elements.

The processes include: 5- Maturation (the Upper and Lower Safa source rocks are located in the very mature and mature stages). 6- Generation (based on the basin analysis, both Upper and Lower Safa source rocks reach the oil and gas windows, and generated oil and are still generating gas until the present time).

7- Migration (Upper and Lower Safa reservoirs seem to have been charged directly from the local intra-formational shale intervals of Upper and Lower Safa themselves by short-distance vertical migration along the fault plane), then 8- Accumulated, and 9- Preserved in situ.
References


