Evaluation of the nature, origin and potentiality of the subsurface Middle Jurassic and Lower Cretaceous source rocks in Melleiha G-1x well, North Western Desert, Egypt

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Western Desert; TOC; Pyrolysis; Gas chromatography

**Abstract** The present work aims to evaluate the nature and origin of the source rock potentiality of subsurface Middle Jurassic and Lower Cretaceous source rocks in Melleiha G-1x well. This target was achieved throughout the evaluation of total organic carbon, rock Eval pyrolysis and vitrinite reflectance for fifteen cutting samples and three extract samples collected from Khatatba, Alam El Bueib and Kharita formations in the studied well. The result revealed that the main hydrocarbon of source rocks, for the Middle Jurassic (Khatatba Fm.) is mainly mature, and has good capability of producing oil and minor gas. Lower Cretaceous source rocks (Alam El Bueib Fm.) are mature, derived from mixed organic sources and have fair to good capability to generate gas and oil. Kharita Formation of immature source rocks originated from terrestrial origin and has poor to fair potential to produce gas. This indicates that Khatatba and Alam El Bueib formations take the direction of increasing maturity far away from the direction of biodegradation and can be considered as effective source potential in the Melleiha G-1x well.

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**1. Introduction**

The Melleiha G-1x well is located in the northern province of the Western Desert basin (Fig. 1). The subsurface Jurassic and Cretaceous sediments in the North Western Desert Basin, including the studied well have attracted the attention of petroleum geologists, because of their wide areal distribution, huge thickness and their facies characteristics. These sediments have produced a commercial quantity of oil and gas, which lead many Egyptian and foreign exploration companies to concentrate their research in this area since 1970 [1].

The present study is an attempt to identify, and evaluate the nature and origin of the potentiality of subsurface Middle Jurassic and Lower Cretaceous source rocks in Melleiha G-1x well in order to identify the quantity and quality of hydrocarbon generation. They have the capability of hydrocarbon generation for oil and gas. Evaluation of the depositional environments for different organic facies and thermal maturation of the source rocks and organic matters was made. These
targets have been achieved through geochemical analyses (pyrolysis) of “15” rock samples and three gas chromatography analyses for source rock extracts also done in this study.

The studied well lies in the unstable shelf between north-south oriented graben of the Mtruh basin and a very large graben of Shushan basin. These grabens are filled with very thick Jurassic and Lower Cretaceous sediments. It is dominated by NW-SW trending faults which were developed during Late Jurassic–Early Cretaceous and Late Cretaceous–Early Tertiary times [2]. The Melleiha lease is dominated by NW-SE trending small throw faults. This tectonic activity occurred mainly during Late Jurassic–Early Cretaceous times [3].

The sedimentary section of the North Western Desert including study area is shown in Fig. 2. The Middle Jurassic–Lower Cretaceous succession in the study area consists of the Middle Jurassic Khatatba Formation, composed of sandstones, shales, and some carbonates [1]; the Barremian-Early Aptian Alam El Bueib Formation, made up of shales, sandstones and some dolomites; and the Early Albian Kharita Formation is characterized by sandstones with minor intervals of shales.

The hydrocarbon potentiality of the Middle Jurassic and the Lower Cretaceous source rocks in the North Western Desert basin have been discussed by many authors. Sharaf et al. [4] mentioned that the Middle Jurassic (Khatatba Fm.) is an important source rock, while the Lower Cretaceous (Alam El Bueib Fm.) is an effective source rock for hydrocarbon accumulation in the south Matruh area. El Nady [5] revealed that the Alam El Bueib Formation of the Lower Cretaceous source rock is a good source for hydrocarbon generation in West Razzak–Alamein area. El Nady and Hammad [6] stated that the Lower Cretaceous (Kharita Fm.) might act as an important source for oil generation in Bade El Din Concession. Sharaf and El Nady [7] recognized that the oils from Alam El Bueib and Bahariya reservoirs are genetically related, multisourced from Khatatba and Alam El Bueib source rocks with minor contribution from Kohla source rocks. El Nady and Gharem [8] showed that the Khatatba Formation entered the early stage of hydrocarbon generation during Late Cretaceous–Eocene. Alam El Bueib Formation during Late Cretaceous–Oligocene. Bahariya Formation is still immature and does not reach the onset of hydrocarbon generation. Younes [9] proved that, the shale rock of the Khatatba Formation in the Qarun field reached the late mature stage of oil generation. Ramadan et al. [10] recognized that the Alam El Bueib source rock in Tut oil field varies from poor to very good organic richness with kerogen of type III and is characterized by immature to mature rocks. El Nady [11] showed that Masajid Formation started to generate hydrocarbons during Late Cretaceous–Late Khatatba Formation during Late Cretaceous–Eocene and Ras Qattara Formation started to generate hydrocarbons during Paleocene. Tahoun et al. [12] recognized that the Alam El Bueib, Kharita and Bahariya formations in the Western Desert are comprised principally of type IV kerogen and a few type III kerogen components. El Nady [13] based on the results of biomarker analyses of source rocks of some wells in the North Western Desert, suggest that Lower Cretaceous Alam El Bueib source rocks are moderately mature and has organic matter deposited in deltaic environment with significant input of terrestrial, marine algae and bacterial contributions.

2. Materials and methods

Fifteen cutting samples of argillaceous siltstones and silty shales represented the Middle Jurassic rock unit (Khatatba Fm.), and the Lower Cretaceous rock unit (Alam El Bueib and Kharita fms.). These samples were taken at different depths from Melleiha G-1x. The location of the studied samples is shown in Fig. 3. The lithology of these samples is sandstones, shales, and some carbonates.

The samples were finely ground. Total organic carbon (TOC) was determined by carbon analyzer (TOC 2000) after the removal of carbonates by treatment with hydrochloric acid (10%). Rock–Eval pyrolysis was performed according to the procedure described by Espitalie et al. [14] to obtain S1, S2, S3 and Tmax data. Vitrinite reflectance ($R_o$%) measurements were made on thin sections under reflected light.

The saturated hydrocarbon fractions were analyzed by high resolution of GC. The analysis was performed on a Hewlett Packard 5890 series II instrument equipped with a split–splitless injector, a flame ionization detector and a fused silica capillary column (30 m × 0.25 mm). The GC oven was started at 60–160 °C, held isothermally for 2 min, and then programmed to 300 °C at 10 °C/min and held isothermally for 10 min.
The injector and detector temperatures were 260 and 300 °C, respectively.

3. Results and discussion

3.1. Total organic carbon

The TOC values represent the total organic carbon in the rock and the measure of organic richness. It is used in subsequent calculations to determine the oil prone nature of the source rocks [15]. The Middle Jurassic Khatatba Formation has “TOC” values ranging from 1.10 to 2.34 wt% at a depth of 3320–3720 m (Table 1). This shows that the organic richness of Khatatba Formation ranges from good to very good (Fig. 4a). Lower Cretaceous Alam El Bueib Formation has “TOC” values ranging from 0.53 to 1.98 wt% at a depth of 2496–2900 m (Table 1). These values indicate fair to good organic richness (Fig. 4a). In contrast, Kharita Formation has organic richness ranging from poor to fair (Fig. 4a), as indicated by “TOC” values of 0.32–0.99 wt.% (Table 1).

3.2. Hydrocarbon potentiality

The potential of rock sample is evaluated by measuring the amount of hydrocarbons (S2) generated by thermal cracking of the contained kerogen [15]. Fig. 4b illustrates the general trends of the varying abilities of the organic matter for the studied rock unit to potential of hydrocarbons generation.

The volatile hydrocarbon “S1” from Rock Eval analysis, shows that the samples from Middle Jurassic Khatatba Formation have “S1” values from 1.46 to 2.70 mg/g (Table 1). Data reveal a high amount of the volatile hydrocarbon generation [16]. The pyrolysis derived “S2” values of the...
Middle Jurassic Khatatba Formation ranging from 5.32 to 9.99 mg/g (Table 1) revealed good capability of hydrocarbon generation (Fig. 4b). The generation potential ($S_1 + S_2$) of the Khatatba Formation ranging from 6.88 to 21.21 mg HC/g rock (Table 1) revealed that the organic richness of this formation varies from good to very good of hydrocarbon potentiality [17]. The type of hydrocarbon products ($S_2/S_3$) ranging from 3.28 to 5.91 (Table 1) indicates mainly in favor of oil generation.

The Lower Cretaceous Alam El Bueib Formation has ”$S_1$” values ranging from 0.40 to 1.20 mg/g, (Table 1) indicating a minor variation in the volatile hydrocarbons. The Alam El Bueib Formation is characterized by ”$S_2$” values ranging from 1.51 to 5.87 mg/g (Table 1) indicating fair to good source potential (Fig. 4b). The generation potential ($S_1 + S_2$) ranging from 2.01 to 7.10 mg HC/g rock (Table 1) reveals the organic richness of this formation varies from fair to good. The type of hydrocarbon products ($S_2/S_3$) ranging from 3.28 to 5.91 (Table 1) indicates mainly in favor of oil generation while, the ”$S_2$” values of Kharita Formation ranging from 0.38 to 2.92 mg/g (Table 1) reflects poor to fair source potential (Fig. 4b). The ”$S_1$” values ranges from 0.01 to 0.14 mg/g (Table 1). These indicate a low amount of hydrocarbon generation which is underestimated by ”$S_1$” values [16]. The generation potential ($S_1 + S_2$) was obtained from pyrolysis analysis ranging from 0.39 to 3.10 mg HC/g (Table 1). These data indicate that the Kharita Formation having organic matters are rated from poor to fair generation potential. The type of hydrocarbon products (QI) $S_2/S_3$ ratio of Kharita Formation ranging from 0.42 to 1.89 (Table 1) indicating mainly poor for oil generation.

### 3.3. Organic matter types

Waples [18] used the hydrogen index (HI) values (mg S2/g TOC) to differentiate the types of organic matter. The hydrogen index values of the Middle Jurassic Khatatba Formation...
ranging from 377 to 484 mg/g and oxygen index ranging from 81 to 130 mg/g (Table 1) indicate that the Khatatba source rocks have mainly type II kerogen. The relation between hydrogen index and oxygen index (Fig. 5) confirms this conclusion and shows that the source rocks of this formation have the capability of generating mainly oil with minor gas. This type of kerogen was derived mainly from mixed organic sources deposited under reducing and oxidizing conditions [19].

The Lower Cretaceous Alam El Bueib Formation has HI values between 219 and 334 mg/g and oxygen index ranging from 119 to 192 mg/g (Table 1) reflecting type II/III kerogen. This type of organic matter originated mainly from mixed organic sources. The hydrogen index versus oxygen index (Fig. 5) reflects that this formation has the capability to generate mixed oil and gas. HI of Kharita Formation ranging from 119 to 262 mg/g and OI ranging from 119 to 295 mg/g (Table 1) suggest type III kerogen. This type of organic matter is derived from terrestrial plant debris and aquatic organic matter deposited in an oxidizing environment that produces mainly algae [19]. These low values of hydrogen index indicate that Kharita Formation has the potential source for generating mainly gas as shown in the modified Van Krevelen diagram (Fig. 5).

3.4. Thermal maturation

The maturity level of the organic matter for any source rock could be estimated by many criteria obtained from Rock–Eval analysis as Tmax, vitrinite reflectance R₀ (%), production index (PI) [15,20].

Samples of Middle Jurassic (Khatatba Fm.) and Lower Cretaceous (Alam El Bueib Fm.) have Tmax values ranging from 434 to 445 °C, vitrinite reflectance (R₀, %) from 0.56 to 0.86% and production index (PI) range from 0.14 to 0.23 (Table 1). These data indicate that Khatatba and Alam El Bueib formations are mostly mature source rocks and lies within the oil zone of hydrocarbon generation. The oil generation zone (Fig. 6a). Kharita Formation has Tmax values ranging from 428 to 436 °C, the PI ranging from 0.01 to 0.04 and R₀ (%) from 0.32 to 0.58 (Table 1). These data reflect immature source rocks and lie in the marginal zone of oil generation (Fig. 6b).

3.5. n-Alkanes distributions

Waples [18] and Peters and Moldowan [21] recognized that the n-alkanes in terrestrial plants have dominant odd number of carbon atoms, especially n-C23, n-C25, n-C27, n-C29 and n-C31. On the other hand, marine algae produce n-alkanes having a maximum distribution in n-C17 or n-C22 depending on the species present with no preference for either odd or even carbon atoms.

The representative fingerprints of gas chromatography for the saturated hydrocarbon fractions of the studied samples of Middle Jurassic source rocks (Khatatba Formation), there is a marked increase in normal alkanes of n-C17 to n-C22 and moderately to low concentration of heavy normal alkanes (Fig. 7a) with CPI values ranging from 1.08 to 1.10 (Table 2) indicating marine organic source.

Lower Cretaceous (Alam El Bueib Formation) contains type II/III kerogen which is characterized by a maximum peak concentration of normal alkanes in the range of n-C15, n-C19, n-C29 and a low concentration of heavy normal alkanes with odd carbon preference index (Fig. 7b), with CPI values ranging from 0.95 to 1.02.
ranging from 1.19 to 1.21 (Table 2). This indicates that the organic matters of this formation were originated mainly from mixed organic sources. The representative fingerprints of Kharita Formation show high concentrations of normal alkanes in the range of n-C23, n-C25, n-C27, n-C29 and moderate to low concentrations of heavy normal alkanes with odd carbon preference index (Fig. 7c); CPI values range from 1.99 to 2.14 (Table 2) indicating a significant input of terrestrial plant organisms to the sediments.

3.6. Isoprenoids

Isoprenoids of the organic matters are good indicators of the biogenic origin, and their occurrence is generally associated with diagenetic conditions [22] but they are of limited value in assessing the contribution of particular organism [18,23]. Pristane and phytane are the most common isoprenoids used in this work, and their ratio has been used as an indicator of the oxygen level available during diagenesis. In the present work, the pristane/phytane ratios of the organic matters are 0.53–0.69 for the Khatatba source rock and 0.69–0.74 for Alam El Bueib source rocks (Table 2) reflecting high reducing depositional environment. In contrast, the pristane/phytane ratios of the organic matters of Kharita Formation are 1.76 and 1.78 (Table 2) indicating oxidizing depositional environment.

On the other hand, the isoprenoids/n-alkanes distributions (pristane/n-C17 and phytane/n-C18) provide valuable information about the source of organic matter, the organic facies, biodegradation and the maturation level [24,25].

In the present work, Table 2 shows that the isoprenoids/n-alkanes values of the organic matter of Khatatba source rocks are 0.15 and 0.23 for pristane/n-C17 and phytane/n-C18 are 0.23 and 0.34. These data suggest that the organic matter contains type II kerogen derived from marine environment, mainly algae, deposited under reducing oxidizing conditions (Fig. 8). The pristane/n-C17 and phytane/n-C18 ratios of the Lower Cretaceous Alam El Bueib source rocks ranging from 0.35 to 0.4 and 0.45 to 0.48, respectively (Table 1) indicate that the organic matter contains type II/III kerogen originated mainly from mixed organic sources deposited under transitional conditions (Fig. 8). In addition, it is clear that the studied extract samples of Khatatba and Alam El Bueib formations take the direction of increasing maturity and far away from the direction of biodegradation (Fig. 8). In contrast the organic matter of Kharita Formation was derived mainly from terrestrial type III kerogen and mixed type III/II (Fig. 8). This is indicated by pristane/n-C17 and phytane/n-C18 ratios where it ranged from 1.56 to 2.43 and 0.87 to 0.94 (Table 2). This conclusion is confirmed with the results of type of organic matter (Fig. 5).

Figure 7 Gas chromatogram of saturated hydrocarbon fractions of extract samples of studied formations (a) Khatatba, (b) Alam El Bueib, (c) Kharita formations in Melleiha G-1x well, North Western Desert, Egypt.

Table 2 Geochemical parameters derived from gas chromatography analysis of the studied extract samples from Melleiha G-1x well, North Western Desert, Egypt.

<table>
<thead>
<tr>
<th>Formations</th>
<th>Depth (m)</th>
<th>CPI</th>
<th>Pristane/Phytane</th>
<th>Pristane/n-C17</th>
<th>Phytane/n-C18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khatatba</td>
<td>3470</td>
<td>1.10</td>
<td>0.69</td>
<td>0.23</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>3670</td>
<td>1.08</td>
<td>0.53</td>
<td>0.15</td>
<td>0.23</td>
</tr>
<tr>
<td>Alam El-Bueib</td>
<td>2650</td>
<td>1.19</td>
<td>0.74</td>
<td>0.35</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>2850</td>
<td>1.21</td>
<td>0.69</td>
<td>0.54</td>
<td>0.45</td>
</tr>
<tr>
<td>Kharita</td>
<td>1750</td>
<td>1.99</td>
<td>1.76</td>
<td>2.43</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>1950</td>
<td>2.14</td>
<td>1.78</td>
<td>1.56</td>
<td>0.87</td>
</tr>
</tbody>
</table>
4. Conclusions

Based on TOC, Rock–Eval pyrolysis, vitrinite reflectance measurements and gas chromatographic analyses of Middle Jurassic–Lower Cretaceous source rocks of Melleiha G-1x well in the North Western Desert, we concluded that:

1. Middle Jurassic source of Khatatba source rocks characterized by mature and good potentiality for generating oil. The organic matter contains type II and has capability of generating mainly oil with minor gas. This type of kerogen derived mainly from mixed organic sources deposited under reducing and oxidizing conditions.

2. Lower Cretaceous rocks of Alam El Bueib Formation are mature with fair to good capability to produce mixed oil and gas. The organic matter contains type II/III kerogen originated mainly from mixed organic sources deposited under transitional conditions.

3. Lower Cretaceous source rock of Kharita Formation is immature and has fair potential to produce gas. The organic matter is derived from terrestrial type III kerogen and mixed type III/II deposited under oxidizing depositional environment.

It is clear that the studied extract samples of Khatatba and Alam El Bueib formations take the direction of increasing maturity and far away from the direction of biodegradation and can be considered as effective source potential in the Melleiha G-1x well.

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