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FULL LENGTH ARTICLE

Geochemical and biomarker characteristics of crude oils and source rock hydrocarbon extracts: An implication to their correlation, depositional environment and maturation in the Northern Western Desert, Egypt

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Abstract Oil–oil and oil–source rock correlations are used in this study in order to achieve their relationship, depositional environments and diagenetic processes in the source rocks. Three oil samples and source rock hydrocarbon extracts were analyzed using relative geochemical analyses, and gas chromatography–mass spectrometry are used for this purpose. The results revealed that the extracts of the Alam El Bueib and Khatatba formations are derived from mixed organic sources in which terrestrial dominates marine sources, and deposited in transitional environments under less anoxic conditions. The extracts of Bahariya formation are derived from mixed marine inputs with a limited terrestrial contribution. The Alam El Bueib oil shows more contribution of terrestrial than marine sources. Also, a genetic close relation between them supported the indigenous mixed source of Alam El Bueib oil which related to different sources including the Khatatba, Alam El Bueib and Bahariya formations. Accordingly, the Alam El Bueib formation can be considered as an important source for petroleum generation in the Northern Western Desert.

1. Introduction

Oil–oil and oil–source rock correlations are more difficult than oil–oil correlations. This is due to many problems in their sampling, analyses and/or interpretation of the available data. Such interpretations must be confirmed by different parame-

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ters such as gross composition of oil and source rock extracts, biomarker analyses. These parameters solve most of problems in oil–source correlations, because the differences in the chemical composition of the oil and the organic matters retained in the source rock are a function of migration fractionation and post-migration alteration [1]. The oil itself is affected greatly after reaching the final reservoir. Therefore, the bulk correlation parameters previously discussed in oil–oil correlation are not useful in oil–source correlation.

Geochemical studies on oils from the North Western Desert were carried out by many workers. Zein El Din et al. [2] recognized two oil families in the North Western Desert namely: Abu Gharadig and Umbarka groups of marine and terrestrial origin respectively. Mostafa et al. [3] recognized four oil types in the North Western Desert. Oils from Shushan and Matruh Basins are characterized by terrestrial wax input, while oils from Abu Gharadig Basin are generated from marine siliciclastic source rocks, and those from Alamein Basin are seemed to be derived from mixed marine/terrigenous sources. El Nady [4] divided the oil of some oilfields of the North Western Desert into two types: (1) waxy oil was from non-marine origin. (2) Non waxy oil was sourced from carbonates source rocks. Ghanem et al. [5] recognized two oil groups in the North Western Desert (light and heavy oil), which are rich in terrigenous organic matter. Sharaf and El Nady [6] recognized that the oils from the Alam El Bueib and Bahariya reservoirs are originated from the Khatatba and Alam El Bueib source rocks with a minor contribution of the Kohla source rocks. El Nady et al. [7] classified the crude oils of the Meleiha oil field into two classes namely, paraffinic and deltaic oils, originating from marine and terrigenous sources, respectively. El Nady [8] reported that the oils from the Khatatba and Alam El Bueib formations are mature, derived from source rocks containing marine and terrestrial organic matter, and similar to that of the Khatatba source rock extract. El Nady and Harb [9] revealed a genetic close relationship and remarkable similarities in the origin and maturation for the oils and extracts of the Khatatba and Alam El Bueib source rocks of some oilfields in the North Western Desert. El Nady [10] showed that there is a good correlation between the extracts of the Bahariya and Khatatba formations and crude oils from the Qarun and Misaada oilfields. El Nady [11] concluded that the crude oils of some wells in the Northern part of the Western Desert originated mainly from marine organic sources deposited in a reducing environment. The present study aims to do a correlation of geochemical and biomarker characters of oil–oil and source rock hydrocarbon extracts, and infer their depositional environments and maturation.

2. Materials

Three oil samples are collected from different wells scattered within the study area namely: Salam-3x, Yasser-1x, Tut-1x (Fig. 1). Three source rock hydrocarbon extract samples are collected from well Salam-3x, well Yasser-x and well Tut-1x to represent the Jurassic Khatatba formation and Cretaceous Bahariya and Alam El Bueib formations, respectively. For the biological marker correlations three source rock hydrocarbon extracts from the Khatatba, Alam El Bueib and Bahariya formations and oil sample from Alam El Bueib reservoir are recognized.

Figure 1 Location map studied wells in the Northern Western Desert, Egypt.

3. Methodology

(1) The crude oils and source rock extracts samples were separated into saturate, aromatics and resins by column chromatography. The column was packed with 1:1 (by weight) alumina overlying silica gel such that the weight of the sample (asphaltenes free) was about 2% of the combined weight of the packed materials. Successive elution with *n*-heptane, toluene and chloroform yielded saturates, aromatics and resins component fractions, respectively. The obtained fractions were made free from solvents by evaporation. The results are expressed as weight percent to the whole oils and extracts.

(2) Saturated hydrocarbon fractions were achieved by gas chromatographic analysis using the Perkin Elmer Instrument Model 8700, provided with a flame ionization detector (FID). The oven temperature was programmed for 100 to 320 °C at 3 °C/min and the final time 20 min. SPB-1 capillary column was of 60 m in length and 0.53 i. d. Nitrogen was used as a carrier gas, the optimum flow rate was 6 ml min. Gas chromatography–mass spectrometry used a 50 m × 0.25 mm fused silica capillary column of bonded SE 54 installed with a finnigan MAT TSQ-70 combined gas chromatography/quadrupole mass spectrometer. The column oven was programmed from 100 to 310 °C at 4 °C/min. These analyses were carried out in the laboratories of the Egyptian Petroleum Research Institute.

4. Results and discussions

4.1. Specific compounds

The saturate and aromatic hydrocarbons as well as, the asphaltenes and resins of the studied crude oil and source rock extracts are listed in Table 1. It is obvious that, all the oil samples are enriched with saturated hydrocarbon fractions as they represent more than ≈70% and more than 56% paraffins, less than 16% naphthenes of the crude oil samples (Table 1) indicating paraffinic high waxy oil type [12]. Moreover, the abundance of paraffins over naphthenes and NSO compounds suggests that, all the oils are mainly mature. On the other hand, the source rock extracts of the Bahariya, Alam El Bueib

Table 1 Geochemical characteristics of crude oils and source rock extracts.

Data	Cross composition						Isoprenoid/n-alkanes		
	Saturates (%)	Aromatics (%)	NSO (%)	Paraffins (%)	Naphthenes (%)	Pri./Phy.	Pri./n-C_{17}	Phy./n-C_{18}	CPI
Crude oils									
Bahariya	78.53	12.6	9.31	78.15	5.55	1.75	0.28	0.11	0.98
Alam El Bueib	71.32	21.8	6.97	74.44	6.43	1.15	0.26	0.15	1.07
Khatatba	85.50	10.73	4.50	56.83	12.74	1.54	0.30	0.19	1.09
Source rock extracts									
Bahariya	49.30	19.56	31.14	51.10	29.34	0.98	0.43	0.46	1.12
Alam El Bueib	69.70	15.29	15.01	66.94	17.77	1.33	0.17	0.14	1.04
Khatatba	64.70	29	6.50	60.52	10.48	1.44	0.49	0.32	1.00

and Khatatba formations have paraffins percent exceeding the percentages of the naphthenes and NSO compounds (Table 1) indicating mature source rocks [12]. Such results confirm a genetic relationship between the studied crude oils and source rock extracts.

Crude oils and source rock extracts in the study area show remarkable similarities in the gross chemical composition, as both have high percent of saturated hydrocarbon contents, exceeding the aromatic and asphaltenes and resins fractions (Table 1). These show a great relation between oils and extracted samples as both are related to normal oils, however the oil samples appear slightly more mature than the extracts.

4.2. n-Paraffins

The distribution mode of *n*-paraffins is used to shed light on the genetic origin of oils [12]. It is known that the amorphous sapropelic organic matter is characterized with a maximum peak concentration of C_{15}–C_{25}, reflecting marine organic sources [13]. Furthermore, the organic matters which were derived from the remains of higher vascular plants (terrestrial) are characterized by a maximum concentration of *n*-paraffins at n-C_{25}–C_{29} [12]. The gas chromatograms of the saturated hydrocarbons of Bahariya and Alam El Bueib oils (Fig. 2) are characterized by predominance of light hydrocarbons. However it contains moderate to large amount of heavy *n*-alkanes. The gas chromatograms of the Khatatba Jurassic oils show abundant light hydrocarbons in the range of C_{15}–C_{17} and contain low to moderate amount of heavy normal alkanes (Fig. 2). This indicates that the oil produced from Alam El Bueib, and Khatatba reservoirs are genetically related. Also, such results indicate that the studied samples are paraffinic waxy type, moderately mature to mature, derived mainly from mixed organic sources deposited under transitional environment [14]. The carbon preference index (CPI) of the studied oils ranges from 0.98 to 1.09 (Table 1) supporting that the oils are mature.

The gas chromatogram of the Cretaceous oil recovered from the Alam El Bueib reservoir (Fig. 2) reflects a clear similarity in its molecular distribution to those of the source rock extracts of Cretaceous Bahariya and Alam El Bueib formations and Jurassic Khatatba oil (Fig. 2). On the other hand, the carbon preference index (CPI) of the studied oils ranged from 0.98 to 1.09 (Table 1) reflecting a mature oil. Also, the Alam El Bueib, Bahariya and Khatatba source rocks have carbon preference index value of 1.00 (unity) ranging from 1.00 to 1.20 (Table 1) which also, indicates a mature source rocks. This conclusion is confirmed with the result of CPI of the oil recovered from the Khatatba reservoir, however this value is an unreliable indicator to the origin of organic matter, as the maturity increases the CPI values approach to one. This geochemical evidence indicates a genetic relationship between the studied source rocks and crude oils.

4.3. Isoprenoid

The most common isoprenoids which are used in this work have a pristane/phytane ratio. The pristane/phytane ratio has been used as an indicator of depositional environment with a low specificity due to the interferences by thermal maturity and source inputs [14]. The pristane/phytane ratios of the Bahariya and Alam El Bueib and Khatatba oil samples range between 1.75, 1.15 and 1.54, respectively (Table 1). These ratios indicate an oxic depositional environment with more terrestrial input [14]. On the other hand, the isoprenoid ratios of the source rocks (0.98–1.44, Table 1) indicate a slightly oxic depositional environment. This evidence reflects a genetic relationship between the studied crude oils and source rocks.

Pristane/n-C_{17} and phytane/n-C_{18} ratios have been used for oil–source rock correlation. These ratios are influenced by the nature of kerogen and extent of generation and maturation [14]. The resultant ratios of isoprenoids/*n*-alkanes (pristane/n-C_{17} and phytane/n-C_{18}) of Bahariya and Alam El Bueib and Khatatba oils range from 0.26 to 0.30 and 0.11 to 0.19, respectively (Table 1). These ratios reflect that most of the Cretaceous oils were derived from mixed organic sources, deposited under transitional environment (Fig. 3). All the oil samples are mature and show no biodegradation. On the other hand, the isoprenoid/*n*-alkanes ratios reflect that oils and extracts of the Jurassic and Cretaceous rocks are genetically related as they are sourced from mixed organic sources and deposited under transitional environment and show a degree of maturation and show no biodegradation (Fig. 3).

4.4. Polycyclic-hydrocarbons

Polycyclic-hydrocarbon biomarkers (triterpenes) are also considered to be the most powerful tool for oil–source rock correlation due to their resistance to biodegradation [15]. The most common polycyclic biomarker compounds used in this work are moretanes, bisnorhopanes, gammacerane, and pentacyclic extended hopane (homohopanes) (Fig. 4 and Table 2). These

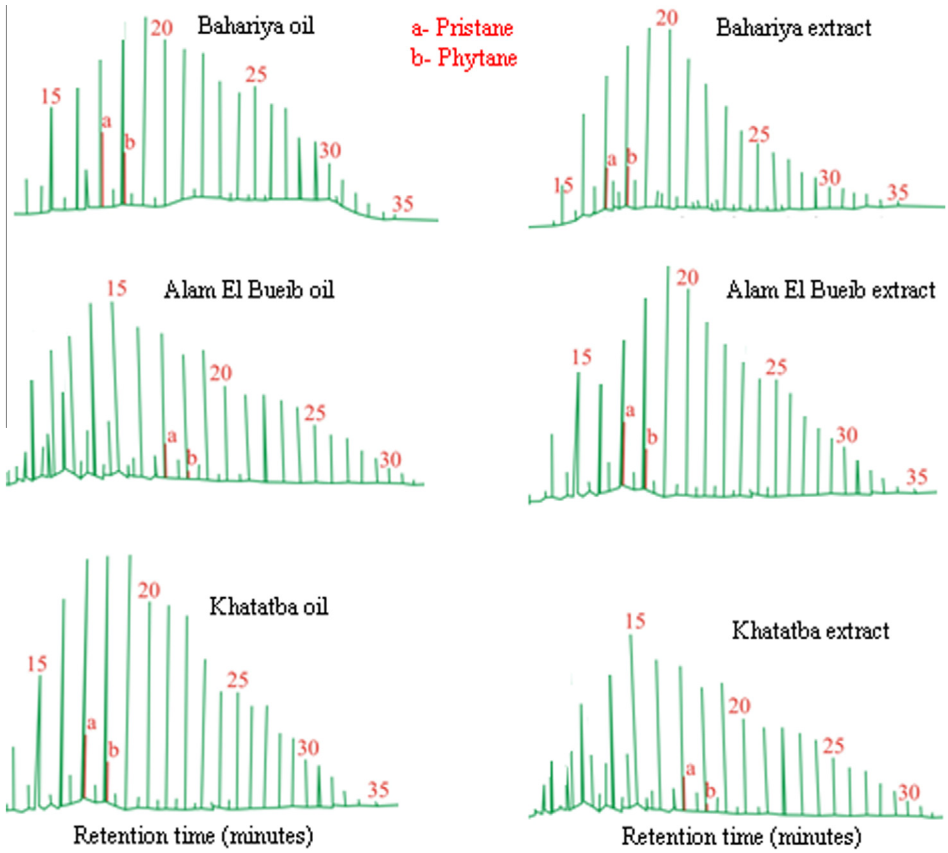

Figure 2 Gas chromatograms of saturated hydrocarbon fractions in the studied oil–oil and oil–source rock extracts.

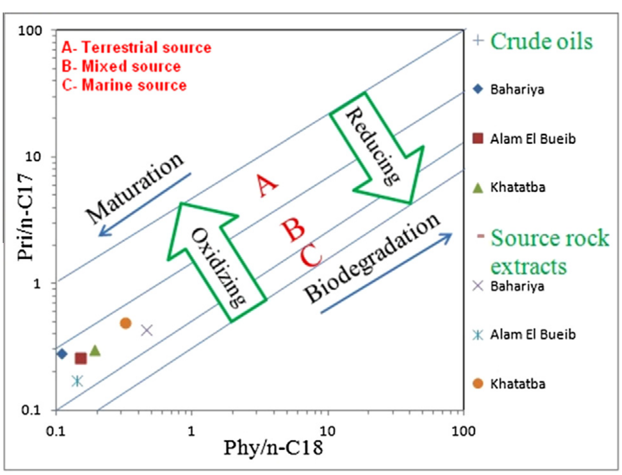

Figure 3 Plot of pristane/n-C_{17} versus phytane/n-C_{18} showing the organic sources and maturation of the studied oil and extract samples [14].

compounds represent an unusual organic input to the sediment and are abundant in many crude oils generated from lacustrine source rocks, often associated with hypersaline environment [16].

4.4.1. Moretanes

Moretanes seemed to be abundant in organic materials of terrestrial origin [17]. Fig. 4 shows that moretanes (peak H, see peak identification in Table 2) in the Alam El Bueib and Khatatba extracts are slightly abundant, indicating contribution from terrestrial sources [17]. The low abundance of moretanes in Bahariya extracts indicates a slightly limited input of terrestrial organic matter as compared to those of Khatatba and Alam El Bueib formations [17]. Moretanes are less stable with an increase in maturity; this is because of their relatively low concentrations in oil samples [17] (Fig. 4).

4.4.2. Bisnorhopanes

Bisnorhopanes are types of pentacyclic triterpane present in significant concentrations in oils and extracts. It is believed that sediments containing large amounts of bisnorhopane were deposited under anoxic conditions [18]. The extract of Bahariya formation (Fig. 4) is more abundant in bisnorhopane (peak E, see peak identification in Table 2) than the Alam El Bueib and Khatatba extracts. This indicates a more anoxic environment [18]. On the other hand, Murchison [19] suggested that bisnorhopane is common in oils with terrestrial affinities. Such contribution is achieved in Alam El Bueib oil as the bisnorhopane peak is well recorded (Fig. 4).

4.4.3. Gammacerane

High gammacerane concentrations were originally considered to be markers for lacustrine facies. Waples and Machihara [20] stated that gammacerane occurs in major or minor concentrations in many rocks that are definitely not of lacustrine origin as they are dominant in marine rocks. Fu Jiamo et al.

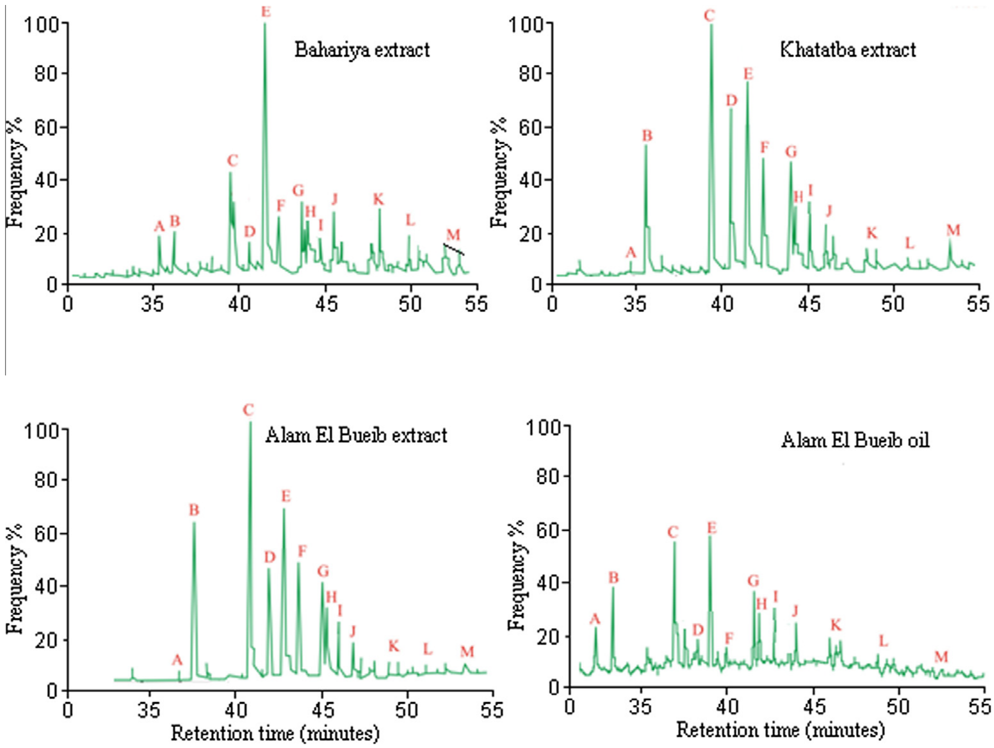

Figure 4 Mass chromatograms (*m/z* 191) of triterpenes in the studied oil and source rock extracts.

Table 2 Peak identification of triterpenes (*m/z* 191) fragmentograms.

Peak No.	Compound name
A	Tricyclic terpane
B	Trisnorneohopan (Ts)
C	Trisnorhopane (Tm)
D	Hopane
E	Bisonorhopans
F	Normoretane
G	Hopane
H	Moretane
I	Gammacerane
J	Homohopane (22R)
K	Homohopane (22R)
L	Homohopane (22S)
M	C_{35} extended hopane

[21] suggested that lacustrine environment has abundant gammacerane and considered also as a salinity marker. Gammacerane (peak I, Fig. 4, see peak identification in Table 2) is only detected, in a relatively low amount, in the Bahariya extract indicating input of marine organic matter in different saline environments. The presence of a relatively high concentration of gammacerane in Khatatba, Aam El Bueib extracts and Alam El Bueib oil (Fig. 4) indicates a contribution from mixed organic sources [21].

4.4.4. Pentacyclic extended hopane

The unusually large amount of C_{35} extended hopane seems to be associated with marine carbonates or evaporites [22]. However Peters and Moldowan [23] prefer to correlate high C_{35}/C_{34} ratios in marine environment with a low redox potential rather than with lithology as not all carbonate rocks have high C_{35} concentration. The concentration of C_{35} extended hopane (Fig. 4, see peak identification in Table 2) is more abundant in the Bahariya extract in comparison to the Khatatba and Alam El Bueib extracts. Such results indicate the marine input of the Bahariya source rocks [22]. On the other hand, the Alam El Bueib oil shows minor concentrations of C_{35} extended hopane (Fig. 4). This indicates a more contribution from terrestrial sources [23].

5. Conclusions

The aforementioned discussions of geochemical characterization of oil and oil–source rock correlations reveal the following:

(1) All examined oil samples are slightly more mature than the extracts. They are deposited in transitional environments with mixed organic source input. On the other hand, the Alam El Bueib oil shows more contribution of terrestrial than marine sources.
(2) The source rock extracts possess a degree of maturation level similar to that of oil samples. The extracts of the Alam El Bueib and Khatatba formations are seen to be derived from mixed organic sources in which terrestrial dominates marine sources, and deposited in transitional environments under less anoxic conditions. The extracts of Bahariya formation are derived from mixed marine inputs with a limited terrestrial contribution. They deposited in transitional to marine, saline and more anoxic environments.

(3) The gross composition and biomarker analyses of oil and source rock extracts support the indigenous mixed source of the Alam El Bueib oil which are related to different sources including the Khatatba, Alam El Bueib and Bahariya formations.

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