Journal of Petroleum
Science and Technology

Geochemical Characterization of Condensates and Gases in Abu Qir Concession in the Western Offshore, Nile Delta, Egypt

Yasmin Kadry Ali[1]*, Lobna Mohamed Sharaf[2], Mosaad Mohamed El Leboudy[3], and Samir Ahmed Hussein[4]

[1]Geochemistry service sector, Stratochem Services Company, Cairo, Egypt
[2]Geology Department, Faculty of Science, Ain Shams University, Cairo, Egypt
[3]Gebel El Zeit Petroleum Company, Cairo, Egypt
[4]Geology Department, Faculty of Science, Ain Shams University, Cairo, Egypt

ABSTRACT

In this study, biomarker analyses were conducted on four condensate samples recovered from Kafr El Sheikh and Abu Madi Reservoirs in Abu Qir concession, NW offshore Nile Delta. Moreover, according to the obtained results, it was indicated that the condensates are genetically related, and they were derived mainly from clay-rich source rocks of mixed organic sources, with significant input of terrestrial organic sources, deposited in low saline fluvio-deltaic environment. These conclusions are supported by the relative abundance of both C_{29} and C_{27} regular steranes, high diasteranes, and Pr /Ph ratios and the lowC_{29}norhopane relative to C_{30}hopane, low isoprenoids/n-alkanes ratios and lack of gammacerane. In addition, biomarker maturity indicators suggested that the condensates were sourced from early mature source rocks. Finally, geochemical and isotopic data from gases indicated that Abu Qir gases are of thermogenic origin generated from source rocks with mixed types II/III kerogens.

Keywords: Petroleum Geochemistry, Condensate Characterization, Gas Characterization.

INTRODUCTION

The Nile Delta is one of the most prolific and prospective gas province in Egypt. The Pliocene clastic sequence, in the offshore Nile Delta and the Mediterranean, is considered as the main target for future exploration due to the huge gas discoveries in the last few years [1]. Abu Qir basin, in the west offshore Nile Delta, has been formed due to the effect of the Late Miocene Serravalian tectonic event [1]. The late Oligocene and Pliocene sediments were controlled by the four reactivated faults named the Bardawil line, Qattara-Eratosthenes line, Pelusium line, and Hinge zone [2,3] (Figure 1A).

The petroleum potentiality of the Nile Delta was studied by many researchers. It was suggested by Helmy and Fouad in 1994 [4] that in the Abu Qir Field /north Abu Qir area, the peak oil generation zone was being developed at an extrapolated depth of about 5000 m to 6000 m, and the mature

***Corresponding author**
Yasmin Kadry Ali
Email: yasmin.kadry@stratochemlabs.com
Tel: +02 2190 0650
Fax: +02 2190 0650

Article history
Received: November 10, 2018
Received in revised form: May 7, 2019
Accepted: June 17, 2019
Available online: December 20, 2019
DOI: 10.22078/jpst.2019.3534.1568

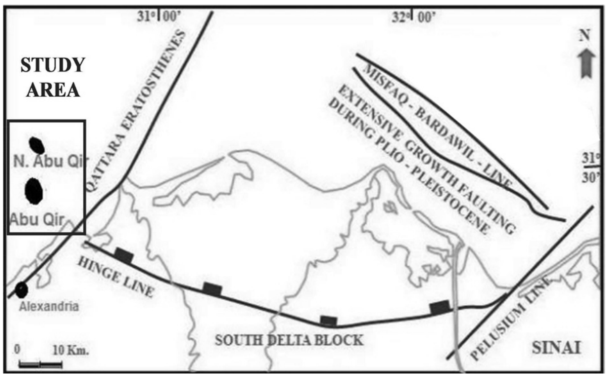


Figure 1A: Outline map of the Nile Delta with the study area in Abu Qir, North Abu Qir and West Abu Qir Fields, Western Nile Delta, Egypt.

source rock for dry gases was expected at 6500 m to 8100 m depth interval. Also, Halim et al in 1996 [5] concluded that the Nile Delta gases appeared to be of thermogenic origin mainly from type II kerogen. It was suggested by Sharaf in 2003 [6] that, in the North East offshore Nile Delta, the Qantara Formation (Early Miocene) has good hydrocarbon generating potential. Moreover, it was stated by her that the Sidi Salem Formation (Middle Miocene) has poor to fair hydrocarbon generating capability, while the Wakar and Kafr El Sheikh formations have poor hydrocarbon generating potential to generate gas and minor oil and they are immature in the drilled sections. Moreover, it was also stated by Sharaf in 2003 that the condensate samples from the Wakar and Sidi Salem reservoirs were generated at early mature stage from a clastic-rich source rocks dominated by terrestrial organic matter of mainly Type III kerogen. Furthermore, it was also added by her that the natural gas which was produced from the Kafr El Sheikh reservoir suggested mixed biogenic/ thermogenic gases. Moreover, in 2006, the origin and the composition of hydrocarbons and natural gases in the offshore Nile Delta were discussed by El Nady [7], and it was concluded by him that the hydrocarbons of Kafr El Sheikh and Sidi Salem formations were derived from source rocks which were rich in marine organic matters at relatively low thermal maturity. In addition, it was concluded by him that the hydrocarbons of Qantara Formation were originated from terrestrial organic matters at high thermal maturity and the natural gases of Abu Madi, Kafr El Sheikh and Qantara formations which were formed from low mature mixed gas under microbial and thermogenic processes. Moreover, oils from the onshore Nile Delta, west Dikirnis Field, and gases from the nearby El-Tamad Field were studied by Leila and Moscariello in 2017, and it was suggested by them that the oil was generated from Late Cretaceous-Early Tertiary clay-rich source rocks, deposited under oxic and normal salinity conditions in a fluvio-deltaic environment [8]. In addition, it was added by them that the natural gases are of thermogenic origin [8]. Moreover, it was indicated by Monir and Shenkarin 2017 that most of the offshoreNile Delta hydrocarbon discoveries share a common source rock of Tertiary age [9].

The purpose of this paper is to characterize condensates recovered from Kafr El Sheikh and Abu Madi reservoirs from Abu Qir fields, western Nile Delta, Egypt. Another objective is to define the origin of the gases, in the study area, based on the chemical gas composition and stable isotope data. Also, the study area lies in the northwestern side of the Nile Delta region, the offshore Mediterranean Sea, between longitudes 30° 00´- 30° 24´E and latitudes 31° 18´- 31° 40´Nas shown in Figure 1B.

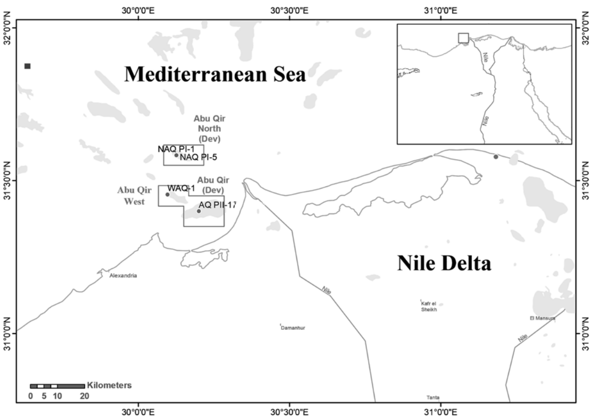


Figure 1B: Location map of the studied wells in Abu Qir, North Abu Qir and West Abu Qir fields, Western Nile Delta, Egypt.

EXPERIMENTAL PROCEDURE

Stratigraphy

The sedimentary sequence penetrated by wells in the study area consists of thick Miocene-Pleistocene siliciclastics (Figure 1C) [10].

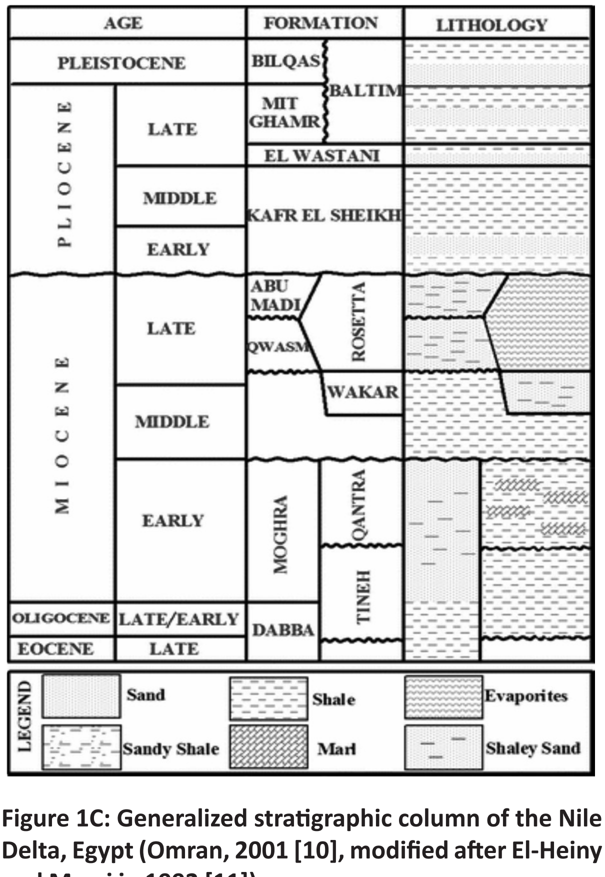


Figure 1C: Generalized stratigraphic column of the Nile Delta, Egypt (Omran, 2001 [10], modified after El-Heiny and Morsi in 1992 [11]).

The lithostratigraphy of the Nile Delta is represented by Miocene sediments (Qantara, Sidi Salem, and Abu Madi Formations) and the Pliocene–Pleistocene sequences (Kafr El Sheikh, El Wastani, and Mit Ghamr Formations) which are represented mainly by shale or clay with sandstone interbeds. Also, Qantara Formation (Early Miocene) is composed of calcareous marine shales and sandstones. In addition, the formation is overlain unconformably by the Sidi Salem Formation (Middle Miocene) which is dominated by shales with some sandstones facies, deposited under marine to fluvial condition. Moreover, it is unconformably overlain by Qawasim and/or Abu Madi Formations. Also, Abu Madi and/or Qawasim Formations (Late Miocene) change into Rosetta Formation in the offshore toward the northwest, which consists of anhydrite, shales, and some sandstones facies. Moreover, these formations are overlain unconformably by Kafr El Sheikh Formation which is composed of shales and sandstones. In addition, the thickness of the Kafr El Sheikh Formation increases towards offshore areas. Furthermore, Kafr El Sheikh Formation is overlain by El Wastani Formation (claystones and sandstones), which represent a transitional facies between the shelf facies of the Kafr El Sheikh Formation and the fluvio-deltaic facies of the overlying Mit Ghamr Formation.

Thick sandstones in the Qantara, Sidi Salem, Abu Madi, and Kafr El Sheikh Formations have proved to be the most suitable reservoir units in the Nile Delta province [12].

Materials and Methods

Four condensate samples from wells Abu Qir PII-17 (AQ PII-17), North Abu Qir PI-1 (NAQ PI-1), North Abu Qir PI-5 (NAQ PI-5), and West Abu Qir-1 (WAQ-1) were analyzed using whole-oil gas chromatography (GC), medium pressure liquid chromatography (MPLC), carbon isotopic analysis, and gas chromatography-mass spectrometry analysis (GC-MS) on the saturate and aromatic fractions. In addition, four gas samples were collected from the previous wells and analyzed for methane (C_1), ethane (C_2), ethylene (C_2H_4), propane (C_3), propylene (C_3H_6), butanes (i-C_4 and n-C_4), pentanes (i-C_5 and n-C_5), C_{6+} and non-hydrocarbons composition and $\delta^{13}C$ isotopic analysis of methane, ethane, propane, and CO_2. Also, be aware that the gases were recovered from the same reservoirs as the condensates. The geochemical analyses were conducted through Stratochem Laboratories and provided by Abu Qir Petroleum Company.

RESULTS AND DISCUSSION

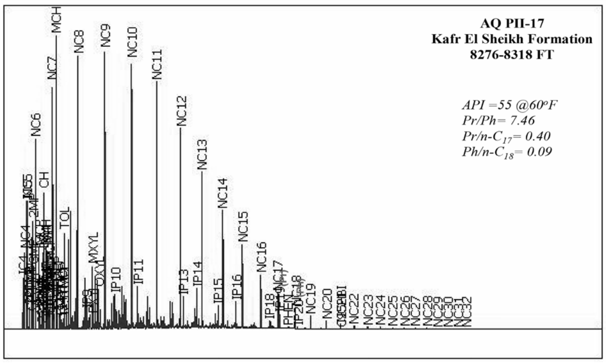
Condensate Characterization

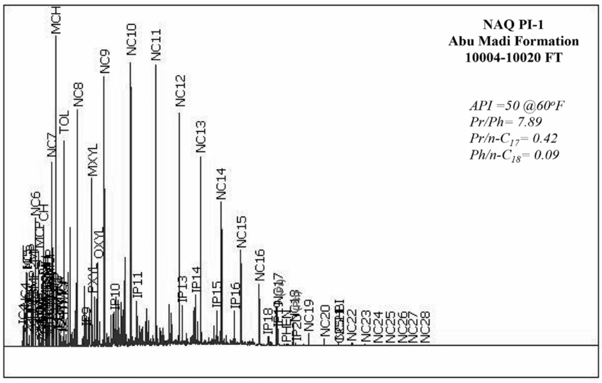
The condensate from AQ PII-17 well was recovered from Kafr El Sheikh reservoir, while the condensates from NAQ PI-1, NAQ PI-5, and WAQ-1 wells were recovered from Abu Madi reservoir. These condensates are paraffinic as they are dominated by saturates (~85-92%) with fairly low amounts of aromatics (~7-14%), very low amounts of NSO's, and asphaltenes (~1-2%) (Table1). In addition, these condensates have high API gravity values of 49° to 57°.

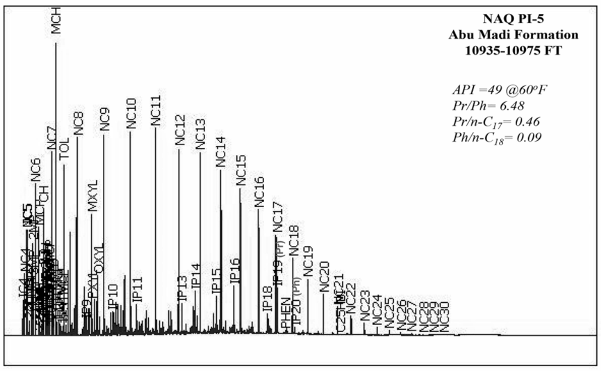
Table 1: Bulk Composition, Isotopes, Gas Chromatography & GCMS Data for condensate samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

Analysis Type	Description	AQ PII-17	NAQ PI-01	NAQ PI-05	WAQ-01
	Formation	Kafr El Sheikh	Abu Madi	Abu Madi	Abu Madi
	Depth	8276-8318 FT	10004-10020 FT	10935-10975 FT	9200-9230 FT
Bulk Analysis	Gravity API	55.32	49.96	48.57	56.77
Liquid chromatography Analysis	Saturate wt.%	91.72	86.85	85.16	91.30
	Aromatic wt.%	6.70	11.98	14.15	7.85
	Saturate/Aromatic	13.69	7.25	6.02	11.64
	NSO wt.%	1.58	1.04	0.69	0.86
	Asphaltene wt.%	0.00	0.13	0.00	0.00
	NSO + Asph wt.%	1.58	1.17	0.69	0.86
Whole Oil GC Ratios	Pr/Ph	7.46	7.89	6.48	5.83
	Pr/nC_{17}	0.40	0.42	0.46	0.32
	Ph/n-C_{18}	0.09	0.09	0.09	0.09
Light HC Ratios	CPI	1.17	1.21	1.18	1.28
	3RP	28.96	19.26	21.51	33.10
	5RP	13.24	12.92	13.95	14.11
	6RP	57.81	67.81	64.55	52.79
Isotopic Analysis	$\delta^{13}C$ Saturate	-28.00	-28.60	-28.80	-28.50
	$\delta^{13}C$ Aromatic	-25.80	-26.00	-26.20	-25.50
Saturate GCMS Analysis	C_{29} S/(S+R) Sterane	0.37		0.25	
	C_{29} $\alpha\beta\beta/(\alpha\beta\beta+\alpha\alpha\alpha)$	0.20		0.28	
	Oleanane /Hopane	0.12		0.26	0.11
	Norhopane/Hopane	0.55	0.78	0.91	0.71
Aromatic GCMS Analysis	DBT/Phenanthrene	0.17	0.14	0.13	0.19

The gas chromatograms of AQ PII-17, NAQ PI-1, NAQ PI-5, and WAQ-1 condensates are quite similar as they contain minimal C_{20+} hydrocarbons (Figure 2). The predominance of low molecular-weight hydrocarbons suggests that the heavy molecules might have fractionated during the migration or may be attributed to low maturity samples. Also, the four samples show moderately slightly odd carbon preference indexes (CPI) (1.17-1.28) (Table 1), suggesting significant terrestrial input to their source rocks[13,14] with suboxic to oxic depositional condition as indicated by the high pristane/phytane (Pr/Ph) ratios (5.83-7.89) (Table 1, Figure 2).







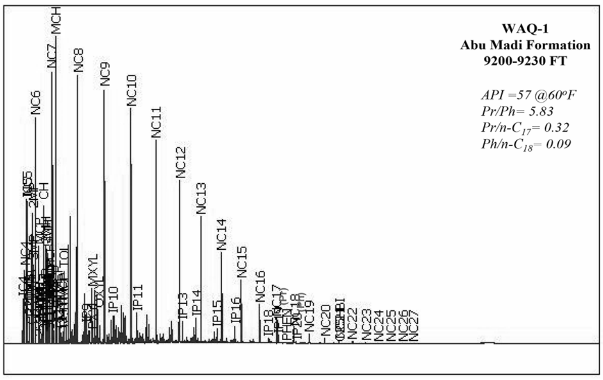


Figure 2: Whole oil gas chromatogram for condensate samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

This conclusion is also supported by isoprenoids/ n-alkanes ratios (Figure 3) which suggest that the condensates are genetically related and have been generated from source rock rich in mixed organic sources with more contributions from terrestrial organic matter, deposited under oxic to the suboxic depositional environment (Figure 3).

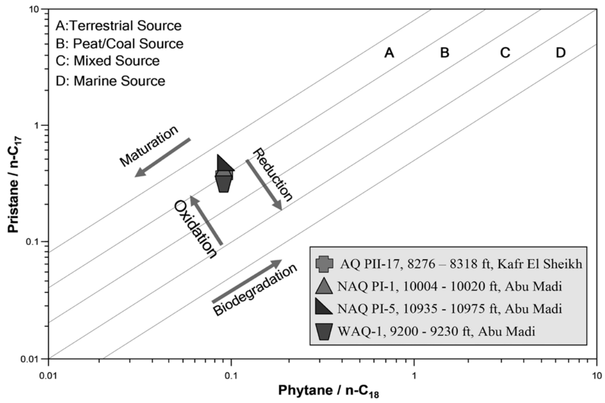


Figure 3: Plot of Phytane/n-C_{18} vs. Pristane/n-C_{17} (after Shanmugam, 1985 [15]) for condensate samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

The Abu Qir condensates have lowdibenzothiophenes (DBT)/phenanthrenes (P) ratios (0.13-0.19) (Table 1). Moreover, DBT to P ratio versus Pristane/ Phytane ratio (Figure 4) can be used to predict the possible source rock facies.

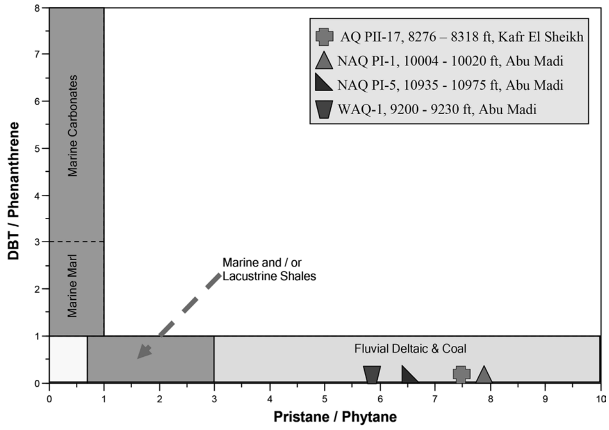


Figure 4: Pristane/Phytane vs. DBT/Phenanthrene cross-plot (after Hughes et al in 1995 [16]) for condensate samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

According to Hughes et al in 1995, hydrocarbons generated from carbonate source rocks yield Pr/Ph ratios < 1 and DBT/P > 1, hydrocarbons from shale source rocks have Pr/Ph ratios of 1-3 and DBT/P < 1, and Fluvio-deltaic source rocks generate hydrocarbon with Pr/Ph ratios of 3-12 and DBT/P < 0.5 [16]. Abu Qir condensate samples have low DBT/P ratios (<0.5) and Pr/Ph ratios greater than 3.0 (Table 1) suggesting shale-rich source rock deposited under fluvio-deltaic environments (transitional environment) (Figure 4).

C_7 ring-preference ternary plot of cyclopentanes (5RP), isoalkanes (3RP), and cyclohexanes (6RP) are useful in predicting source rock depositional environment (Figure 5) [17].

Typically, lacustrine hydrocarbons are rich in 3RP isoalkanes, marine hydrocarbons are rich in 5RP cyclopentanes, and terrigenous hydrocarbons are rich in 6RP cyclohexanes. According to this diagram, Abu Qir condensates show a significant contribution from terrestrial organic matter as they are rich in 6RP (52.79-67.81) in comparison with 3RP and 5RP (19.26-33.10 and 12.92-14.11 respectively) (Table 1).

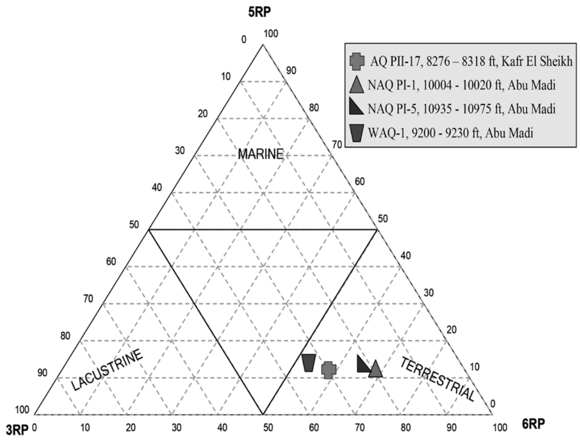


Figure 5: C_7 Ring Preference (RP) (after Mango in 1994 [17]) for condensate samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt. The end members are isoalkanes (3RP), cyclopentanes (5RP), and cyclohexanes + toluene (6RP).

Stable carbon isotopes of ratios for saturate (-28.00 to -28.80) versus aromatic (-25.50 to -26.20) hydrocarbons (Figure 6) show that Abu Qir condensate samples plot near or close to the line separated marine and non-marine sources which suggest mixed organic sources with significant input from terrestrial organic matter. This feature points to transitional source facies.

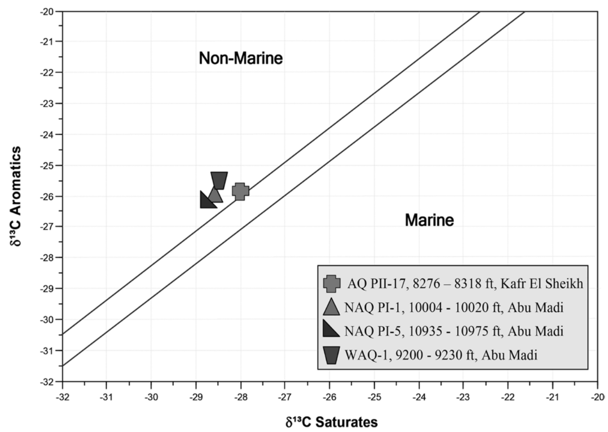


Figure 6: Carbon isotopic composition of aromatics vs. saturates (after Sofer in 1984 [18]) for condensate samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

In Figure 7, mass fragmentograms for the AQ PII-17 and NAQ PI-5 condensate samples (peaks are identified in Table 2) are illustrated.

Table 2: Biomarker peaks identification.

Ion	Peak Label	Compound Name
191	TS	Ts 18α(H)-trisnorhopane
191	TM	Tm 17α(H)-trisnorhopane
191	H29	C_{29} Tm 17α(H)21β(H)-norhopane
191	C29TS	C_{29} Ts 18α(H)-norneohopane
191	DH30	C_{30} 17α(H)-diahopane
191	M29	C_{29} normoretane
191	OL	oleanane
191	H30	C_{30} 17a(H)-hopane
191	M30	C_{30} moretane
191	H31S	C_{31} 22S 17α(H) hopane
191	H31R	C_{31} 22R 17α(H) hopane
191	GAM	gammacerane
191	H32S	C_{32} 22S 17α(H) hopane
191	H32R	C_{32} 22R 17α(H) hopane
191	H33S	C_{33} 22S 17α(H) hopane
191	H33R	C_{33} 22R 17α(H) hopane
191	H34S	C_{34} 22S 17α(H) hopane
191	H34R	C_{34} 22R 17α(H) hopane
191	H35S	C_{35} 22S 17α(H) hopane
191	H35R	C_{35} 22R 17α(H) hopane
217	DIA27S	C_{27} βα 20S diasterane
217	DIA27R	C_{27} βα 20R diasterane
217	DIA28SA	C_{28} βα 20S diasterane a
217	DIA28SB	C_{28} ba 20S diasterane b
217	DIA28RA	C_{28} βα 20R diasterane a
217	DIA28RB	C_{28} βα 20R diasterane b
217	C27S	C_{27} aa 20S sterane
217	BB_D29S	C_{27} ββ 20R + C_{29} dia20S
217	C27BBS	C_{27} ββ 20S sterane
217	C27R	C_{27} aa 20R sterane
217	DIA29R	C_{29} βα 20R diasterane
217	C28S	C_{28} αα 20S sterane
217	C28BBR	C_{28} ββ 20R sterane(+5 baa)
217	C28BBS	C_{28} ββ 20S sterane
217	C28R	C_{28} αα 20R sterane
217	C29S	C_{29} αα 20S sterane
217	C29BBR	C_{29} ββ 20R sterane(+5 baa)
217	C29BBS	C_{29} ββ 20S sterane
217	C29R	C_{29} αα 20R sterane

Unfortunately, the NAQ PI-1 and WAQ-1 condensate samples have a lack in their steranes and terpanes distributions. The predominance of C_{29} and C_{27} regular steranes (Figure 7) suggests a contribution from mixed marine and terrestrial organic sources [19].

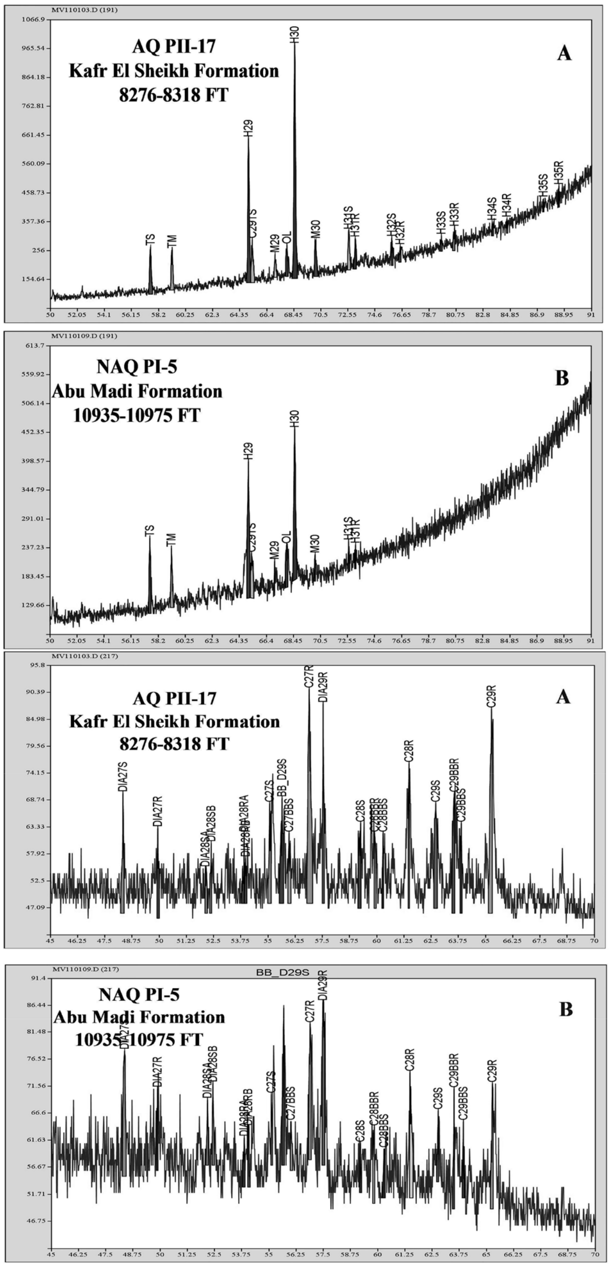


Figure 7: Terpanes distribution (m/z 191) and Steranes distribution (m/z 217) for condensate samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

In addition, the relative increase in diasteranes (Figure7) and the lack of gammacerane (Figure7) suggest that the condensates had been sourced from source rock rich in clay minerals, deposited under low saline environments [20,21]. Moreover, the C_{24} tetracyclic terpanes (Figure 7) suggest a significant input from higher plant materials [22-26]. The presence of oleanane (Figure7) (despite its low concentration), which is considered to be derived from angiosperms of Late Cretaceous and Tertiary ages [27, 28] suggests that Abu Qir condensate may be sourced from Late Cretaceous-Early Tertiary source rocks. Moreover, this conclusion is consistent with the conclusion which has been reached by El-Diasty and Moldowanin 2010 [29], who concluded that the Cretaceous to Early Tertiary sequence in the offshore Nile Delta and the deep Mediterranean water, is considered to be the main source rocks from which light oil, condensate and gas had been generated.

The gradual decrease in the C_{31}-C_{35} extended hopane profile (Figure7) also suggests a clastic clay-rich source rock facies [19]. Also, the presence of moretanes (Figure7) is another indication of a terrestrial organic input [30, 31]. The studied condensates are characterized by low C_{29} norhopanerelative to C_{30} hopane (Table 1, Figure7), suggesting terrigenous organic matter input [30, 32].In addition, all the previous features point to clay-rich source rocks with mixed organic sources with more significant input of terrestrial organic materials.

The 20S/(20S+20R) and ββ(αα+ββ) isomerization ratios of the C_{29} steranes, whose equilibrium values are 0.52-0.55 and 0.67-0.71, can be used as indicators of maturity [20]. Abu Qir condensates have 20S/(20S+20R) and ββ(αα+ββ) C_{29} steranes values (0.25-0.37 and 0.20-0.28 respectively, Table 1) below the equilibrium values suggesting that they might be generated from early mature source rocks (Figure 8).

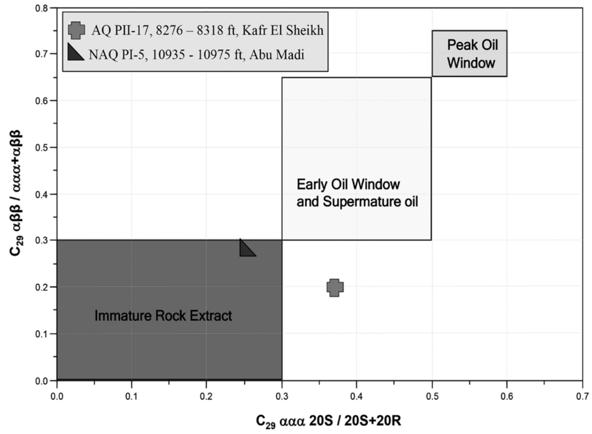


Figure 8: Sterane maturity parameters, C_{29} aaa 20S/(20S+20R) and C_{29} aββ/(aaa + aββ) for condensate samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir and North Abu Qir fields, western Nile Delta, Egypt.

Gases Characterization

Four gas samples from the same previous wells in the Abu Qir concession underwent geochemical and isotopic analyses. Moreover, sample identification and measured gas properties are tabulated in Table 3A.

The chemical composition of the gas samples was dominated by methane (ranging from 90 to 96 %), ethane (from 3 to 5 %), propane (from 1 to 3 %), and very low heavier hydrocarbons (<2 %) (Table 3B). The gas wetness (GWR) ranged from 4-10% (Table 3B).

Table 3A: Chemical Gas composition and Stable Isotopes for gas samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

Well Name	Formation	Depth	Gas Composition (ppm)															Total HC Gas	Isotopic Values (‰)				
			N_2	O_2+Ar	CO_2	H_2	CO	Methane	Ethane	Ethene	Propane	Propene	*iso*-Butane	*n*-Butane	*iso*-Pentane	*n*-Pentane	Hexanes+	($C_1 \rightarrow C_5$) ppm	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	$\delta^{13}CO_2$	δDC_1
AQ PII-17	Kafr El Sheikh	8276-8318 FT	1400	310	5100	0	0	946700	25400	0	9920	0	2690	2860	1230	1090	3320	989890	-45.2	-28.0	-27.9	-10.9	-166
NAQ PI-01	Abu Madi	10004-10020 FT	990	230	12900	0	0	930700	28100	0	12600	0	3670	3610	1650	1190	4400	981520	-41.7	-29.4	-28.3	-12.9	-158
NAQ PI-05	Abu Madi	10935-10975 FT	1300	360	6300	0	0	931400	28900	0	13400	0	4200	4200	2200	1640	6060	985940	-43.6	-29.3	-28.4	-14.7	-162
WAQ-01	Abu Madi	9200-9230 FT	3300	230	8700	0	0	877600	47400	0	26700	0	9720	9360	4690	3610	8740	979080	-47.1	-28.8	-27.1	-14.7	-171

Table 3B: Calculated Ratios from chemical gas composition for gas samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

Well Name	Formation	Depth	Normalized Gas Composition (Vol. %)							Calculated ratios														GWR	LHR	OCR
			Methane	Ethane	Propane	*iso*-Butane	*n*-Butane	*iso*-Pentane	*n*-Pentane	C_{2+} (%)	$\frac{C_1}{C_2}$	$\frac{C_2}{C_3}$	$\frac{C_2}{\Sigma C_4}$	$\frac{C_2}{\Sigma C_5}$	$\frac{C_1}{(C_1+C_2)}$	$\frac{C_1}{(C_2+C_3)}$	$\frac{C_1}{(C_1 \rightarrow C_5)}$	$\frac{C_2}{(C_2+C_3)}$	$\frac{C_2}{(C_2+\Sigma C_4)}$	$\frac{C_2}{(C_2+\Sigma C_5)}$	$\frac{nC_4}{(nC_4+iC_4)}$	$\frac{nC_5}{(nC_5+iC_5)}$	CO_2 (%)	$\frac{100x\Sigma(C_2 \rightarrow C_5)}{\Sigma(C_1 \rightarrow C_5)}$	$\frac{(C_1+C_2)}{(C_3+C_4+C_5)}$	$\frac{(C_4+C_5)}{C_3}$
AQ PII-17	Kafr El Sheikh	8276-8318 FT	95.64	2.57	1.00	0.27	0.29	0.12	0.11	4.36	37.27	2.56	4.58	10.95	0.97	26.80	0.96	0.72	0.82	0.92	0.52	0.47	0.51	4.36	54.64	0.79
NAQ PI-01	Abu Madi	10004-10020 FT	94.82	2.86	1.28	0.37	0.37	0.17	0.12	5.18	33.12	2.23	3.86	9.89	0.97	22.87	0.95	0.69	0.79	0.91	0.50	0.42	1.29	5.18	42.20	0.80
NAQ PI-05	Abu Madi	10935-10975 FT	94.47	2.93	1.36	0.43	0.43	0.22	0.17	5.53	32.23	2.16	3.44	7.53	0.97	22.02	0.94	0.68	0.77	0.88	0.50	0.43	0.63	5.53	37.45	0.91
WAQ-01	Abu Madi	9200-9230 FT	89.64	4.84	2.73	0.99	0.96	0.48	0.37	10.36	18.51	1.78	2.48	5.71	0.95	11.84	0.90	0.64	0.71	0.85	0.49	0.43	0.87	10.36	17.10	1.03

Light-to-heavy ratio (LHR) versus gas wetness ratio (GWR) [33] provides a tool to predict the type of hydrocarbons in reservoir intervals. The guidelines used to interpret the Haworth et al ratios are:

GWR < 0.5 dry gas; 0.5-17.5 gas; 17.5-40 oil; > 40 residual oil

LHR > 100 - dry gas; < 100 condensate/oil

According to ratios suggested by Haworth et al, Abu Qir gases are associated with light to medium density oils (Figure 9) [33].

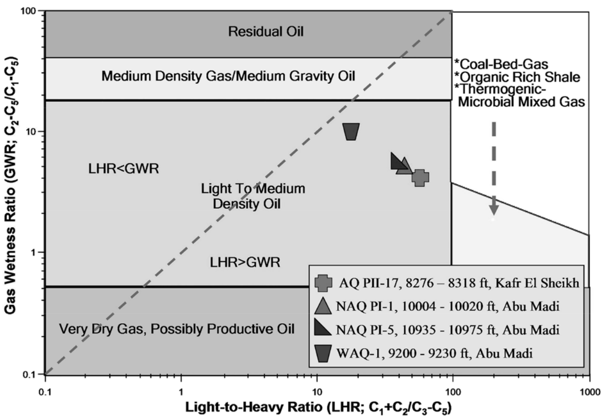


Figure 9: A cross-plot of light-to-heavy ratio (LHR) vs. gas wetness ratio (GWR) [33] to provide a prediction of the hydrocarbon type in potential reservoir intervals for gas samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

These ratios are only used to assess the potential hydrocarbon associations (dry gas, gas/condensate, oil) and do not imply whether any particular zone will be productive commercially or otherwise.

The carbon isotope ranges of methane, ethane, and propane fractions in Abu Qir gas samples showed a normal pattern, i.e. $\delta^{13}C_{methane} < \delta^{13}C_{ethane} < \delta^{13}C_{propane}$ (Table 3A).

Abu Qir gas samples plot in the field of thermogenic gas on Bernard diagram (Figure 10) which provides a genetic characterization of natural gas, based on a compositional ratio $C_1/(C_2+C_3)$ and carbon isotopic value of methane ($\delta^{13}C_{methane}$).

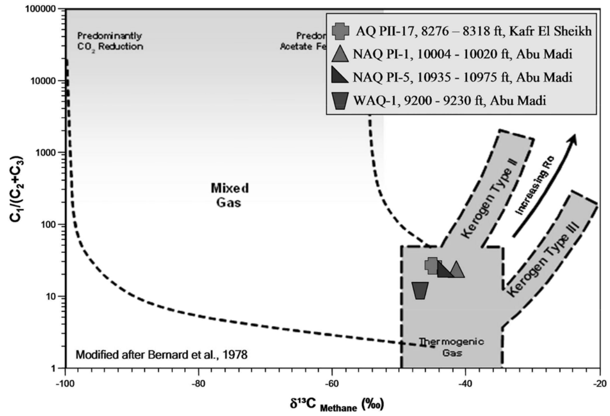


Figure 10: $C_1/(C_2+C_3)$ versus carbon isotopic ratio of methane ($\delta^{13}C_{CH_4}$) (Modified from Bernard in 1978 [34] by Faber and Stahl in 1984 [35]) for gas samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, wester n Nile Delta, Egypt.

The gas samples also lie in the region inferring that their sources are dominated by mixed type II/III kerogen (Figure 10).

Figures 11A and 11B inferred the thermal maturity of the source rock that generated the gases based on the stable carbon isotopic relationships between ethane versus methane and ethane versus propane.

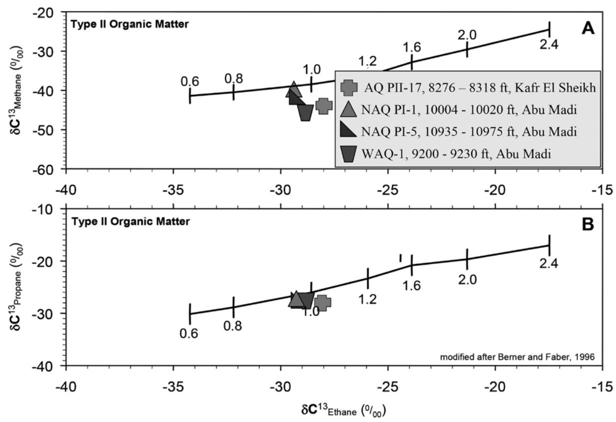


Figure 11A: Thermal maturity (equivalent vitrinite reflectance Ro%) of the generative source rocks based on the stable carbon isotopic of ethane versus methane (A) and ethane versus propane (B) (Berner and Faber, 1996 [36]) for gas samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir Fields, western Nile Delta, Egypt.

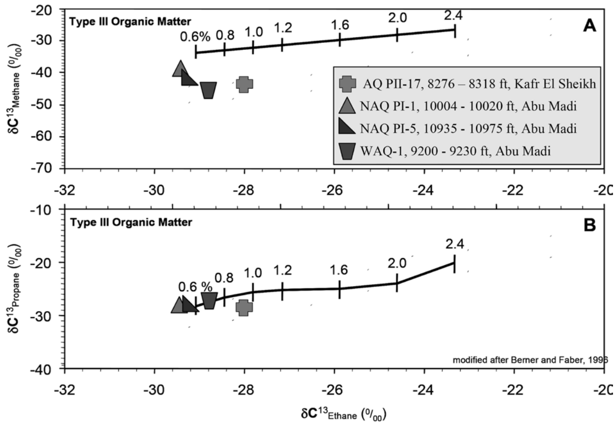


Figure 11B: Thermal maturity (equivalent vitrinite reflectance Ro%) of the generative source rocks based on the stable carbon isotopic of ethane versus methane (A) and ethane versus propane (B) (Berner and Faber, 1996 [36]) for gas samples recovered from Kafr El Sheikh and Abu Madi reservoirs in Abu Qir, North Abu Qir and West Abu Qir fields, western Nile Delta, Egypt.

Abu Qir gases fit the maturity line for types II and II kerogens (Figures 11 A and B). On the other hand, these figures indicated that the studied gases were mainly generated within the zone of the oil window. However, the equivalent vitrinite reflectance percentages (Roeq), from the same figures, suggested that type III kerogen started to generate gas earlier than type II kerogen. Type-II kerogen model suggested maturities of Roeq ~1.0% (Figure 11A), while Type-III kerogen model suggested the values of ~0.6 to 1.0% (Figure 11B). Moreover, mixed gases generated from Type-II and Type III kerogen (oil-associated mixed with dry mature gas) formed through evaporative fractionation could give confusing results such as our case [37, 38]. Therefore, exact gas maturity Roeq values are unknown; however, these thermogenic gases were probably generated from their sources at the high maturity end of the mature wet gas/oil generation levels based on the previous maturity models. Moreover, these gases probably represent mixtures from different sources and different maturities in different proportions, which undoubtedly confuse the issue.

CONCLUSIONS

The geochemical characterization of four condensate samples from wells AQ PII-17, NAQ PI-1, NAQ PI-5, and WAQ-1, offshore the NW Nile Delta, suggest their derivation from clay-rich source rocks with mixed organic sources deposited under oxic to suboxic low salinity conditions, suggesting a transitional environment. The abundance of both C_{27} and C_{29} steranes indicate both terrestrial and marine influence. However, the presence of moretane and the richness of 6RP indicate a more significant contribution from terrestrial organic matter. In addition, the presence of oleanane (albeit in low concentration) may imply Late Cretaceous-Early Tertiary age for the condensate source rocks. Moreover, the maturity indicator ratios indicated that Abu Qir condensates were generated during the early stage of source rock maturation.

Molecular and isotopic composition for the analyzed gases from the AQ Concessions suggests that the studied gases are of thermogenic origin and are dominated by mixed type II/III kerogen. Finally, the different maturity ranges for the studied gases may be attributed to the mixed kerogen Types (II and III) of the studied gases.

ACKNOWLEDGMENTS

The author is grateful to the Egyptian General Petroleum Corporation (E.G.P.C.) and Abu Qir petroleum company for permitting publication of this work.

NOMENCLATURES

CPI: Carbon Preference Indexes

REFERENCES

1. Younes M. A., "Geochemical Characteristics of Natural Gas Formation in the Offshore Nile Delta, Egypt," *Oil-Gas European Magazine*, **2010**, *36*(4), 194-199.
2. Said R., "The geology of Egypt (1st ed.)," Rotterdam, Netherland, **1990**, 743.
3. Sarhan M., Barsoum F., Bertello F., Talaat M., and et al., "The Pliocene Play in the Mediterranean Offshore: Structural Setting and Growth Faults Controlled Hydrocarbon Accumulations in the Nile Delta Basin: A Comparison with the Niger Delta Basin," 13th EGPC, Cairo, **1996**, *1*, 1–19.
4. Helmy M. and Fouad O., "Prospectivity and Play Assessment of Abu Qir Area, Nile Delta, Egypt," EGPC, *12th Petroleum Exploration and Production Conference,* Cairo, **1994**, *1*, 276–292.
5. Halim A. A., Fouad O., Worku T., Khaled A. A., and et al., "Aspects of Reservoir Potential of the Miocene-Pliocene Sequences in North Alexandria and the Surrounding areas, Offshore Nile Delta, Egypt," *13th Petroleum Exploration and Production Conference*, Cairo, **1996**, *1*, 224-241.
6. Sharaf L. M., "Source Rock Evaluation and Geochemistry of Condensates and Natural Gases, Offshore Nile Delta, Egypt," *Journal of Petroleum Geology*, **2003**, *26*(2), 189-209.
7. El-Nady M. M., "Origin and Composition of Liquid Hydrocarbons and Natural Gases of Some Wells in the Offshore Nile Delta, Egypt," *Egyptian Journal of Petroleum*, **2006**, *15*(2), 61-75.
8. Leila M. and Moscariello A., "Organic Geochemistry of Oil and Natural Gas in the West Dikirnis and El Tamad fields, Onshore Nile Delta, Egypt: Interpretation of Potential Source Rocks," *Journal of Petroleum Geology*, **2017**, *40*(1), 37-58.
9. Monir M. and Shenkar O., "Pre-Messinian Petroleum System and Trapping Style, Offshore Western Nile Delta, Egypt," *AAPG/SPE Africa Energy and Technology Conference*, Nairobi City, Kenya, **2017**, 5-7.
10. Omran A., "Deep Thermal Trends and Hydrocarbon Maturity Level Determination Using Bottom Hole Temperature Measurements in the Nile Delta," 1st International Symposium on the Deltas, Modern and Ancient, Cairo, Egypt, **2001**, 185-208.
11. El-Heiny I. and Morsi S., "Stratigraphic Correlation of Neogene Sediments in the Eastern Nile Delta and Gulf of Suez, Egypt," *11th Petroleum Exploration and Production Conference of EGPC*, **1992**, *11*(2), 166-193.
12. EGPC (Egyptian General Petroleum Corporation), "Nile Delta and North Sinai. Fields, Discoveries and Hydrocarbon Potentials (A Comprehensive Overview)," EGPC, Cairo, Egypt, **1994**, 387.
13. Huang W. Y. and Meinschein W. G., "Sterols as Ecological Indicators," *Geochimical et Cosmochimical Acta*, **1979**, *43*, 739-745.
14. Peters K. E. and Moldowan J. M., "The Biomarker Guide, Interpreting Molecular Fossils in Petroleum and Ancient Sediments (1st ed.)," Prentice Hall, **1993**, 363.
15. Shanmugam G., "Significance of Coniferous Rain Forests and Related Oil, Gippsland Basin, Australia," *AAPG Bulletin*, **1985**, *69*, 1241-1254.
16. Hughes W., Holba A., and Dzou L., "The Ratios of Dibenzothiophene to Phenanthrene and Pristane to Phytane as Indicators of

Depositional Environment and Lithology of Petroleum Source Rocks," *Geochimical et Cosmochimical Acta*, **1995**, *59*, 3581-3598.

17. Mango F. D., "The Origin of Light Hydrocarbons in Petroleum: Ring Preference in the Closure of Carbocyclic Rings," *Geochimical et Cosmochimical Acta,* **1994**, *58*, 895-901.
18. Sofer Z., "Stable Carbon Isotope Compositions of Crude Oils: Application to Source Depositional Environments and Petroleum Alteration," *AAPG Bulletin*, **1984**, *68*, 31-49.
19. Waples D. W. and Machihara T., "Biomarkers for Geologists: A Practical Guide to the Application of Steranes and Triterpanes in Petroleum Geology," *AAPG Methods in Exploration*, **1991**, *9*, 91.
20. Moldowan J. M., Seifert W. K., and Gallegos E. J., "Relationship between Petroleum Composition and Depositional Environment of Petroleum Source Rocks," *AAPG Bulletin*, **1985**, *69*, 1255-1268.
21. Peters K. E., Fraser T. H., Amris W., Rustanto B., and Hermanto E., "Geochemistry of crude oils from eastern Indonesia," *AAPG Bulletin*, **1999**, *83*, 1927-1942.
22. Philp R. P. and Gilbert T. D., "Biomarker Distributions in Oils Predominantly Derived from Terrigenous Source Material," *Advances in Organic Geochemistry*, Oxford, Pergamon Press, **1986**, 73-84.
23. Abdullah W. H., Murchinson D., Jones J. M., Telnaes N., and et al., "Lower Carboniferous Coal Depositional Environments on Spitsbergen, Svalbard," *Advances in Organic geochemistry,* New York, Pergamon, **1988**, 953-965.
24. Mello M. R., Gaglianone P. C., Brassell S. C., and Maxwell J. R., "Geochemical and Biological Marker Assessment of Depositional Environment Using Brazillian Offshore Oils," *Marine and Petroleum Geology*, **1988**, *5*, 205-223.
25. Murray A. P., Summons R. E., Boreham C. J., and Dowling L. M., "Biomarker and N-alkane Isotope Profiles for Tertiary Oils: Relationship to Source Rock Depositional Setting," *Advances in organic geochemistry*, Organic Geochemistry, **1994**, *22*, 521-542.
26. Guzman-Vega M. A. and Mello M. R., "Origin of Oil in the Sureste Basin, Mexico," *AAPG Bulletin*, **1999**, *83*, 1068-1095.
27. Czochanska Z., Gilbert T. D., Philip R. P., Sheppard C. M., and et al., "Geochemical Application of Sterane and Triterpane Biomarkers to a Description of Oils from the Taranaki Basin in New Zealand," *Organic Geochemistry,* **1988**, *12*, 123-135.
28. Van Aarssen B. G. K., Cox H. C., Hoogendoorm P., and De Leeuw J. W., "A Cadinene Biopolymer in Fossil and Extant Dammar Resins as a Source for Cadinanes and Bicadinanes in Crude Oils from South East Asia," *Geochimical et Cosmochimical Acta*, **1990**, *54*, 3021-3031.
29. El-Diasty W. S. and Moldowan J. M., "The Western Desert Versus Nile Delta: A Comparative Molecular Biomarker Study," *Marine and Petroleum Geology*, **2013**, *46*, 319-334.
30. Connan J., Bouroullec J., Dessort T. D., and Albrecht P.," The Microbial Input in Carbonate-anhydrite Facies of a Sabkha Paleoenvironmental from Guatemala; A Molecular Approach," *Advances in Organic Geochemistry*, Oxford, Pergamon, **1986**, 20-50.
31. Mann A. L., Goodwin N. S., and Lowe S.,

"Geochemical Characteristics of Lacustrine Source Rocks: a Combined Palynological/molecular Study of a Tertiary Sequence from Offshore China. Proc. Indonesian Petroleum Association," *16th Annual Convention,* Jakarta, Indonesian Petroleum Association, **1987**, *1*, 241-258.
32. Zumberge J. E., "Source Rocks of the La Luna Formation (Upper Cretaceous) in the Middle Magdalena Valley, Colombia, In: Palacas J. G., (Editor): Geochemistry and Source Rock Potential of Carbonate Rocks," *AAPG Studies in Geology,* **1984**, *18*, 127-133.
33. Haworth J., Sellens A., and Whittaker A., "Interpretation of Hydrocarbon Shows Using Light (C_1-C_5) Hydrocarbon Gases from Mud-Log Data," *AAPG Bulletin*, **1985**, *69*, 1305-1310.
34. Bernard B. B., "Light Hydrocarbons in Marine Sediments," Ph.D. thesis, Texas A&M University, **1978**, 144.
35. Faber E. and Stahl W., "Geochemical Surface Exploration for Hydrocarbons in the North Sea," *AAPG Bulletin*, **1984**, *68*, 363–386
36. Berner U. and Faber E., "Empirical Carbon Isotope/maturity Relationships for Gases from Algal Kerogens and Terrigenous Organic Matter, Based on Dry, Open-system Pyrolysis," Organic Geochemistry, **1996**, *24*, 947-955.
37. Thompson K. F. M., "Fractionated Aromatic Petroleums and the Generation of Gas-Condensates," *Organic Geochemistry*, **1987**, *11*, 573-590
38. Thompson K. F. M., "Gas-condensate Migration and Oil Fractionation in Deltaic Systems," *Marine and Petroleum Geology*, **1988,** *5*, 237-246.