Egyptian Geophysical Society
EGS Journal, Vol. 18, No. 1, 165-181 (2020)

OLIGOCENE SOURCE ROCK GEOCHEMICAL CHARACTERIZATION FOR ONSHORE AND OFFSHORE, EASTERN NILE DELTA BASIN, EGYPT

N. ABDEL HALIM[(2)], *M. EL-SHAFEIY*[(1)], *M. EL-KAMMAR*[(1)] *and G. EL-BAKRY*[(2)]

(1) Geology Department, Faculty of Science, Cairo University, Giza 12613, Egypt
(2) British Petroleum Company, BP, Egypt.

التوصيف الجيوكيميائي لصخور المصدر فى عصر الأوليجوسين
في شرق حوض دلتا النيل البري والبحري، مصر

الخلاصة: يعد حوض دلتا النيل من اهم الأحواض الترسيبية في العالم. بدأت حديثا دراسات مستفيضة في التركيز على منشأ الهيدروكربونات، والتي لم يتم فهم آلية انتقالها بشكل تام. اسْتُخْدِمت في هذه الدراسة بيانات الآبار لتقييم صخور المصدر في عصر الأوليجوسين الحاملة للمواد العضوية والذي يعتقد أنه مصدر اكتشافات عصر النيوجين. معايير التقييم إشتملت علي: إجمالي محتوى الكربون العضوي (TOCwt %) والنضج الحراري وخصائص الحفريات الجيوكيميائي. أظهر التقييم الجيوكيميائي أن الثراء العضوي تراوح بين متوسط إلى جيد مما يتوافق مع النوع الثالث من الكيروجين. وقد تبين أن المواد العضوية في البئر البري قنطرة الجنوبي-١ غير ناضجة أما في البئر البحري-C فقد تبين أن المواد العضوية بلغت ذروة انتاج المواد البترولية. تعد صخور المصدر للبئر البحري-C فعالة لتوليد و إنتاج المواد البترولية أما بئر قنطرة الجنوبي-١ فتعد مصدراً محتملاً لإنتاج وتوليد المواد البترولية إذا ما تعرض لظروف مناسبة. كما كشفت بيانات كروماتوجرافيا الغاز عن هيمنة أكبر للشموع النباتية وترسب الرواسب فى بيئة مؤكسدة (البئر-C) و ظروف قليلة التركيز إلى منعدمة الأكسدة (جنوب القنطرة -١). تشير المؤشرات الحيوية المتعلقة بالنضج إلى أن معظم العينات تحتوي على مواد غير ناضجة إلى مواد في بداية النضج.

ABSTRACT: *The Nile Delta Basin is considered as one of the most important basins in the world. Recently, extensive studies have started to focus on the origin of the hydrocarbons, where its migration mechanism is not fully understood.In this study,two wells were used to evaluate the Oligocene source rock, which is believed to be the source of Neogene discoveries.The evaluation parameters include; total organic carbon (TOCwt%), quality of organic material, thermal maturity, and geochemical fossils characteristics. The geochemical evaluation showed that organic richness range from fair to goodgenerative potential with mainly kerogen type III and II-III.The organic material of the study wells shows generally early mature to mature organic materialthat are ableto generate hydrocarbons. The Source rock in the wells is considered as a potential to relic source for generating hydrocarbons when subjected to appropriate conditions. The Gas Chromatography data revealed the predominance of higher plant waxes and the deposition of sediments under oxicto dysoxic condition, whereas South Qantara-1shows slight marine affinity. The maturity-related biomarkers (e.g., 20S/(20R+20S)Steranes, Moretane/Hopane ratio, and Ts/(Ts+Tm)Trisnorhopanes) implied that most of the samples contain immature to earlymature organic material. Considerable correlations were observed between thelipids of the rock extract and the condensates of onshore and rarely offshore wells. However, oil samples did not show a considerable correlation with rock extract or even among each other.*

1. INTRODUCTION

The Nile Delta has been a subject of a lot of researches since the last century. The exploration activities started since 1947 by the Standard Oil Company of Egypt (SOE), whereas the actual exploration activities have not started until 1963. Seismic acquisition was done for the first time in 1964 by IEOC Company in the Nile Delta. The hydrocarbon potentiality of the Nile Delta sedimentary sequence is limited to the Neogene formations, as it is trapped against listric fault system or over tilted fault blocks (WEC, 1995). Also, Pre-Miocene formations can be considered as a source rock of oil generation-potential (Abdel Aal et al., 2000). The Nile Delta basin contains thick sequence of potential hydrocarbon source rocks that generate methane gas and condensate essentially (Shaaban et al., 2006) and produce mainly from reservoirs of Miocene and Pliocene ages (Fig. 2). The Oligocene-Miocene sediments may include the best source rocks in the northern Nile delta block (EGPC, 1994), based on their organic carbon content and Rock-Eval pyrolysis data.

Geochemical correlation is important to improve the exploration success for a particular petroleum system, define reservoir compartments to enhance production, and identify the origin of environment-contaminating hydrocarbons (Peters et al., 2005).

To our knowledge, the published work on the Nile Delta Oligocene source rocks and their potential is sporadic. The reported hydrocarbon-source rock relationship is not well understood and need further investigation. As the shallow formations are believed to be immature, the hydrocarbons were believed to be sourced from the older Oligocene shelfal shales (Sharaf, 2003; Shaaban et al., 2006).

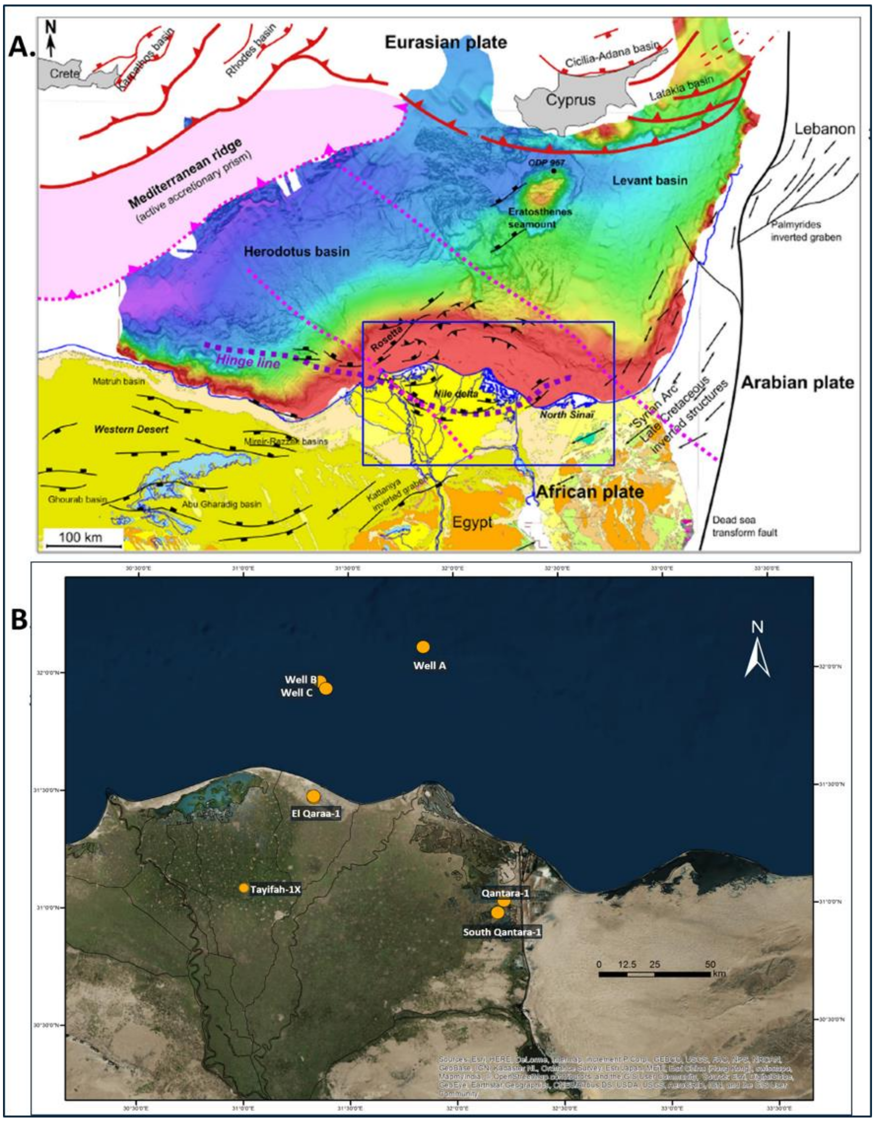

Figure 1: A): A Structural sketch of the East Mediterranean (after Tassy et al., 2015), where the blue rectangular bounds the study area. B): Google Earth map shows the location of the study wells in the Nile Delta basin of Egypt.

The Nile Delta is considered as gas-prone area, producing mainly methane and condensate, although there is few oil-producing wells (Khaled et al., 2003). The purpose of this work is to characterize the different source rock intervals and their classification in East Nile Delta using Rock-Eval and molecular fossils analyses.

2. GEOLOGICAL SETTING

The location and development of the Nile delta was affected by three significant tectonic events (Morgan, 1990). These comprise the Jurassic time extension due to the NE-SW trending rift system, the Cretaceous compression due to Syrian Arc event and several tectonic events in the Tertiary including the Red Sea and Gulf of Suez rift. The facies distribution and formation of structural petroleum traps was controlled by these events (e.g., Said, 1990; Zaghloul et al., 1999) (Figs. 1, 2, and 3). The location of the Nile Delta basin lies between three major tectonic elements; the Red Sea rift, the African-Anatolian plate boundary, and the Syrian Arc tectonics (Ghassal et al., 2016). In the early Jurassic the Neo-Tethys started opening leading to the development of wide Jurassic to Cretaceous carbonate platform attached to the continental system on the south from Western Desert to Sinai (Said 1990; Parisot et al., 1996; Tassy et al., 2015). This causes also opening of 2 major sets of tectonic elements; NNW trending folds with thrust faults and left-lateral ENE trending strike-slip faults (Meshref, 1990; Dolson et al., 2000; Abdel Aal et al., 2001; Ghassal et al., 2016).

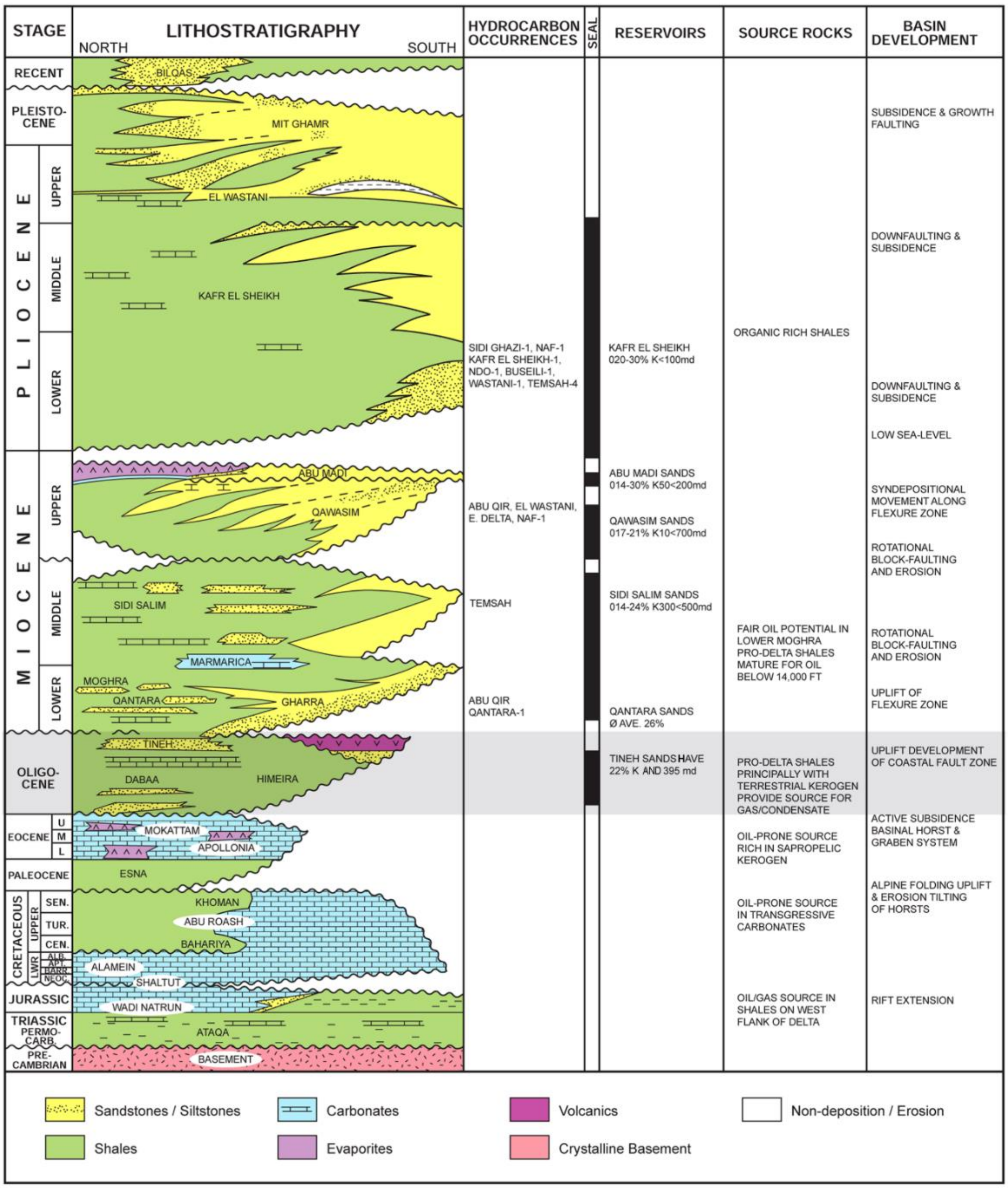

Figure 2: Generalized lithostratigraphic columns for the Nile Delta showing the main hydrocarbon occurrences, seals, reservoirs and source rocks and the positions of the major unconformities (C & C Reservoir, 2009). The grey shaded interval represents the interval of interest.

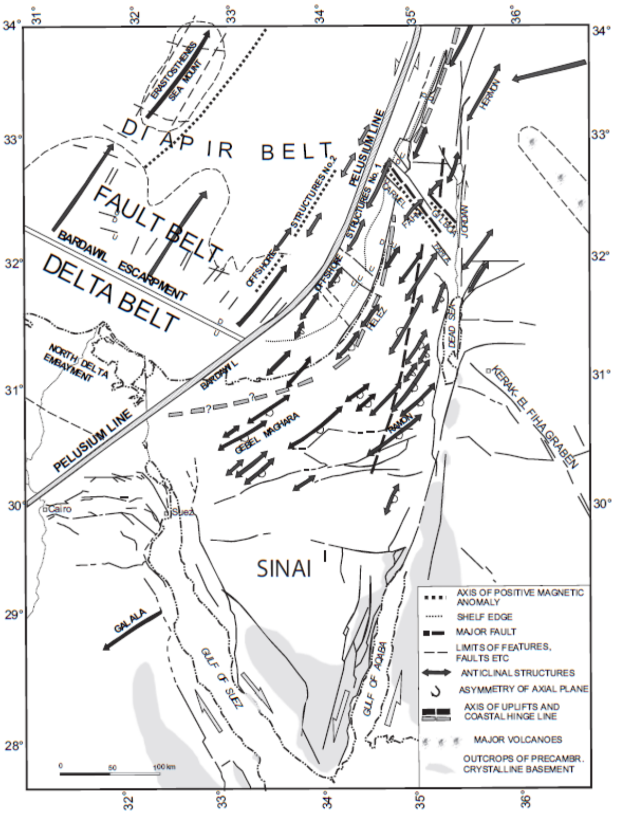

Figure 3: A schematic tectonic map of NE Egypt (after Shaaban, 2006).

In the Late Jurassic, Turkey started to separate from Africa and the drainage direction was redirected to the north after it had been southward. During the Early Cretaceous to Eocene, regional compression took place in north east of Nile Delta due to subduction of African-Arabian plate beneath the Euro-Asiatic margin (Livermore and Simith, 1985; Carey, 1976; Shaaban et al., 2006). This compression and subduction affected the sedimentation due to Syrian arc's structures and resulted in ENE-trending structures at the same time of Tethys closure (Harms and Wray, 1990; Zaghloul et al., 1999). The Syrian arc event caused regional erosion of the Upper Cretaceous-Lower Eocene rocks (Ghassal et al., 2016). Listric normal faults at the latest Cretaceous-Eocene period affected the whole Tertiary basinal argillaceous strata along the hinge-zone. An Active subsidence took place during the Late Eocene and Early Oligocene in the northern Nile Delta basin to match the uplift in the north Sinai and Eastern Desert (opening of the Gulf of Suez rift and Aqaba-Jordon shear), which resulted in the deposition of deep marine shales and marls (Kamel et al., 1998). In the late Oligocene, a widespread uplift took place, which resulted in a regional unconformity (Kamel et al., 1998). According to Shaaban (2006), 2 tectonic-related sedimentary super cycles can be recognized within the Oligo-Miocene succession as two structural re-organization took place during the Middle Oligocene and Middle Miocene. The Oligocene section in the Nile Delta is represented by eustatic sea level falling (Guiraud and Bosworth, 1999). The investigation of the few wells penetrated the Oligocene implies upper-middle slope to fluvial systems, as well as basalts in the south and west of the Nile Delta (Barber, 1981; Meneisy 1990; Harms and Wary, 1990; Said, 1990; Barakat, 2010; Ghassal et al., 2016). During the Middle Oligocene, a major lowstand occurred with a large palaeo-drainage developed in western Nile Delta, which fed the shallow marine clastics northward beyond the hingeline (Dolson et al., 2005). A tectonically-induced sea level fall is considered at the end of the Oligocene with deposition of lowstand clastics (El-Heiny and Enani, 1996). The lowstand system tracts represent marine turbiditic onlap. The upper highstand system tracts are characterized by a highstand shelf progrdation and give rise to downlap surface changing into marine hiatus of deposition in a condensed section basinward (Figs. 4 and 5).

During the Serravalian to Lower Tortonian time, the Red Sea breakup took place, which affected the Nile Delta strata (Dolson et al., 2001). The Messinian Crisis was an essential tectonic event related to the late stage closure of the African plate against Europe, causing the closure of the Straits of Gibraltar and evaporation of the Mediterranean Sea (Halbouty and El Baz, 1992).

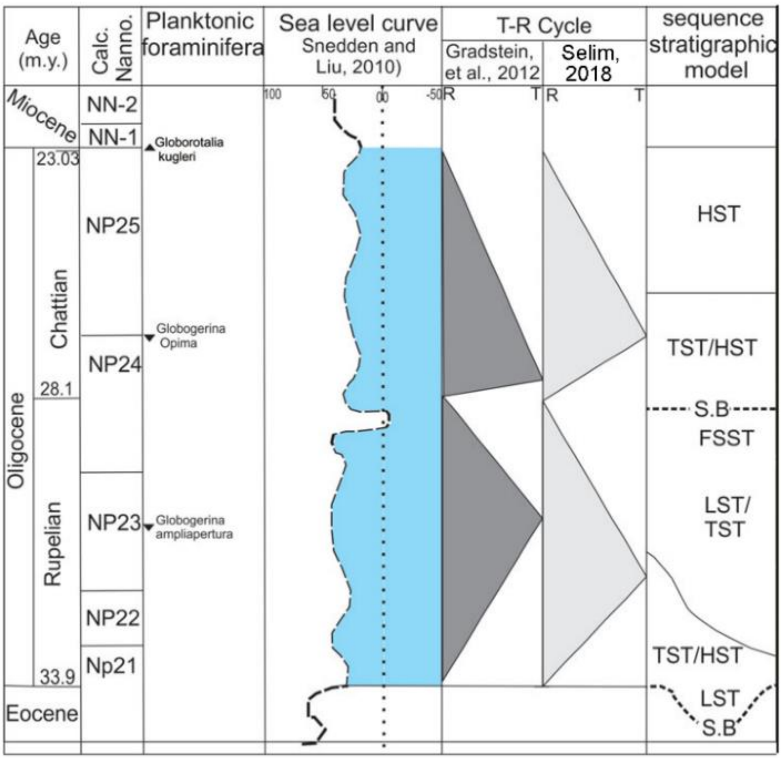

Figure 4: Oligocene chronostratigraphy (Ahmed, 2004), Sea level curve (Snedden and Liu, 2010), transgressive-regressive and depositional cycles (Gradstein et al., 2012; Selim, 2016). FSST - falling stage system tract; LST - lowstand systems tract; TST - transgressive systems tract; HST - highstand systems tract; T - transgressive; R– regressive; S.B. - sequence boundary. The figure is after (Selim, 2016).

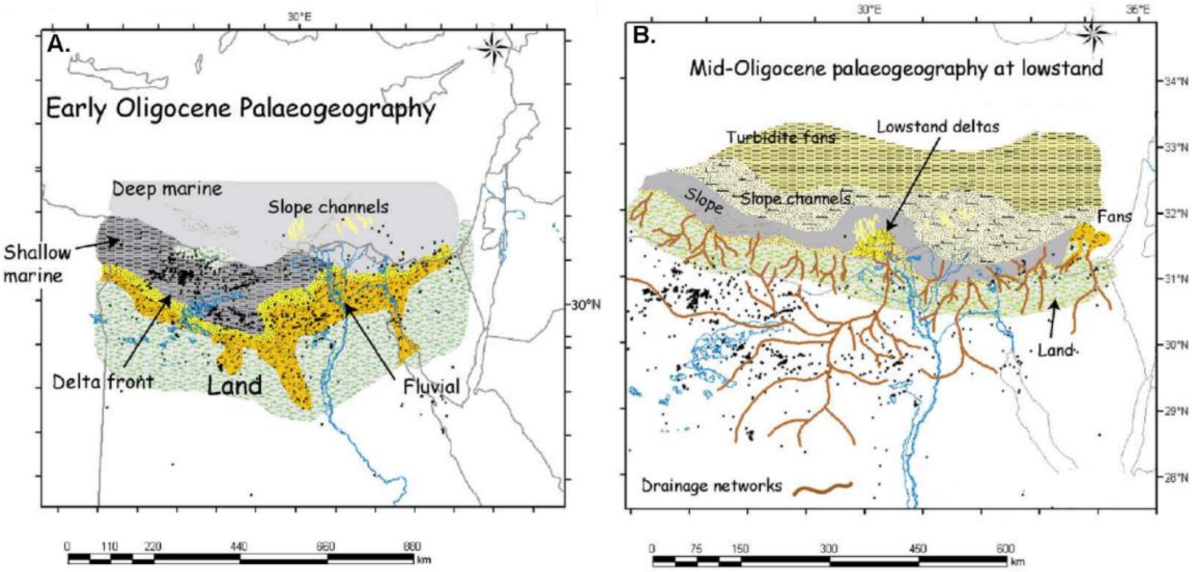

Figure 5: A. Early Oligocene palaeogeography at maximum highstand. As the Gulf of Suez and Red Sea rifts began to uplift, large regressive deltas pushed northwestward across Egypt toward the Mediterranean. B. Mid-Oligocene maximum lowstand. A major drop in sea level occurred at approximately 32 million years, where a strong erosional network developed across the northern coastline (Dolson et al., 2005).

This lead to an increase of erosional unconformities in the up-section of the Nile Delta, at which basin-wide lowstand salts took place throughout the deeper portions of the Mediterranean, and accordingly thick evaporites deposited during the Messinian time (Dolson et al., 2001). Many Pliocene discoveries have been made in traps associated with growth faults, which sole out into the Messinian evaporites and salts (Felt et al., 1999). These evaporites are widespread across the Nile Delta, concentrated in the NE Delta, and seal the Miocene reservoirs (Sarhan and Hemdan, 1994). The hydrocarbon potential of the Nile Delta sedimentary sequence is restricted to the Neogene formations and trapped against listric fault system or over tilted-faulted blocks (WEC, 1995). However, the Pre-Miocene formations, outline the base of these Neogene sequence, are considered as a potential source rock for hydrocarbon generation. The Nile Delta basin generates methane and condensate from thick interval of potential source rocks. (e.g., Shaaban et al., 2006) and produce mainly from fields of Miocene and Pliocene ages. Additionally, the Nile Delta can be considered as gas- and oil-prone since the oil has been discovered in El-Temsah and Abu Qir fields (EGPC, 1994; Khaled et al., 2003). In the south, it is characterized by a gradual northward dip of Middle Eocene-carbonates, which is gently folded and dissected by approximately E-W normal fault, some of these faults extent to Pliocene sediment (Kamel et al, 1998).

Organic geochemical studies took place on the Miocene source rocks of the Nile Delta basin (Zein El Din et al., 1988; Abu El- Ella, 1990; El Nady, 2007) and suggested that the onshore northern part around Abu Madi field has the highest level of source rock maturity. Halim et al. (1996) found that gases produced are of thermogenic origin in the Nile Delta gases, which are sourced mainly from Type II kerogen. On the other hand, Metwalli (2000) studied several on- and offshore wells in the Nile Delta and concluded that these gases are of biogenic and thermogenic sources. Shaaban et al. (2006) claimed that the Oligocene-early Miocene shales and mudstones are the main source rocks in the Nile Delta, which are characterized by medium to high organic carbon contents belong to Type III kerogen.

3. METHODOLOGY

3.1. Sampling:

Geochemical analyses were done for 479 samples. 51 samples were collected from the onshore well South Qantara-1 and 428 samples were collected from the offshore Well C. Age-wise, 133 samples are belonging to the Upper Oligocene and 346 samples are from the Lower Oligocene. The lithology of the samples varies from shale, marl, and rarely siltstone. For the geochemical fossils analysis, samples from 7 wells were used namely; Well A and Well B (offshore), South Qantara-1, Qantara-1, El Qar'a-1, El Qar'a-8, and Tayifah-1 (onshore).

3.2. Total Organic Carbon (TOC wt%) and Rock Eval Pyrolysis:

The samples were provided by BP Egypt and the sample preparation and analyses were done in the labs of StratoChem©, Egypt. LECO 320 carbon analyzer was used for TOC% determination. About 200 mg of the ground material was treated with HCl acid to dissolve any inorganic carbon that may present in the samples. Then combusted in LECO Furnace, which measure the concentration of the carbon dioxide and convert it to TOC (wt%). The samples with more than 0.5 TOC wt% were subjected to Rock-Eval pyrolysis, which act as a thermal stimulation for cracking the kerogen in programmed system. About 60-100 mg of the sample was heated in certain pre-programmed temperature pattern; different values are detected and measured by the furnace. At 300 °C, the free hydrocarbon is volatized (S1 mg HC/g rock), at 600 °C the remaining hydrocarbons are released and it is considered as simulated pyrolytic cracking of kerogen (S2 mg HC/g rock) from which the generative potential of the source rock can be measured. At ~ 400 °C the carbon dioxide is released and quantified as mg CO2/ g rock (S3). The amount of S3 is a measure of the amount of oxygen in the kerogen.

3.3. Gas Chromatography (GC) and Gas Chromatography -Mass Spectrometry (GC-MS):

Only samples that exhibit relatively high TOC content were analyzed for their molecular fossils. Gas Chromatography analysis was performed on 10 samples; 1 extract (South Qantara-1), 3 oil samples (Well A and Tayifah-1), 3 Miocene-reservoired condensate samples from onshore-producing wells (El Qar'a-1, El Qar'a-8, and Qantara-1), and 3 condensate samples belong to Oligocene reservoir (Well B and well C) (Table 2). The samples were injected in the GC thin hot coiled column where the molecules are carried by an inert gas till the end of the column, which is attached to a detector that monitor the separated compounds. Separation is a result of the differences in vapour pressure. In the resulted chromatogram, the compounds concentration is recorded and each peak represents a single compound. Identification of compounds represented by various peaks is carried out by comparison of retention times, in case of flame ionization detector (FID), for the n-alkanes and isoprenoids distribution.

The hydrocarbons are separated by Medium Pressure Liquid Chromatography (MPLC) into saturated (aliphatic) and aromatic fractions. These fractions are then analyzed by Gas Chromatography-Mass Spectrometry (GC-MS) that allows separation, identification and quantification of each compound. Qualitative and quantitative analysis is performed on crude oils, the saturated, and aromatic fractions by injecting one microliter volumes into a cool-on column injector. GC-MS is used in determination of sample properties such as source characteristics and the biodegradation extent in the samples.

4. RESULTS AND DISCUSSION

4.1. Source rock evaluation:

4.1.1. Quantity of Organic Matter (TOC wt%):

The two studied wells meet the Oligocene section at different depths (South Qantara-1 at ~ 2900 m and Well C at ~ 4900m). The TOC wt% in South Qantara-1 ranges between 0.88% and 1.36% for the Upper Oligocene and between 0.38% and 1.19% for the Lower Oligocene. In Well C, it ranged between 0.44% and 1.26% for the Upper Oligocene and between 0.32% and 2.02% for the Lower Oligocene (Fig. 6A & B). The studied source rock can be classified as fair to good generative potential (Peters and Cassa, 1994).

4.1.2. Genetic type and classification of organic matter:

The determination of the genetic type of organic matter is essential in predicting the oil and gas potential and also in typifying the kerogen. To differentiate between genetic types of organic matter, hydrogen index (HI) can be used (Waples, 1985; Hunt, 1991; Peters et al., 2005). Accordingly, a HI between 50-200 mg HC/g TOC indicates a gas-generating potential (kerogen type III).

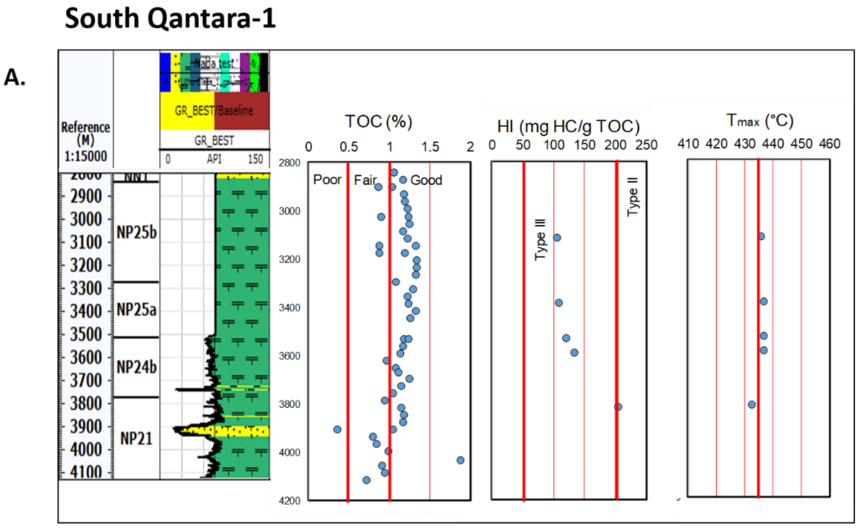

Figure 6 A: Mutual distribution of the organic geochemical variables for the lower and upper Oligocene shales for South Qantara-1

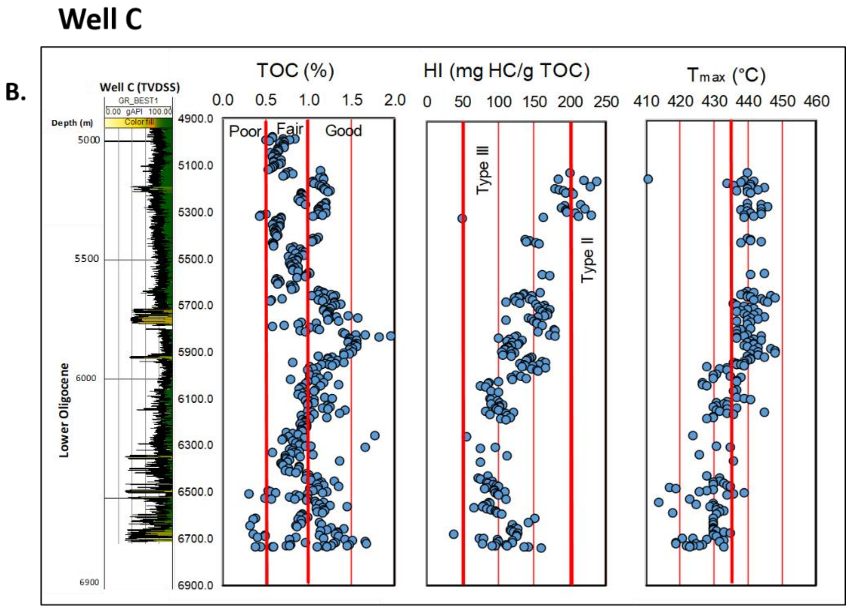

Figure 6 B: Mutual distribution of the organic geochemical variables for the lower and upper Oligocene shales for Well C.

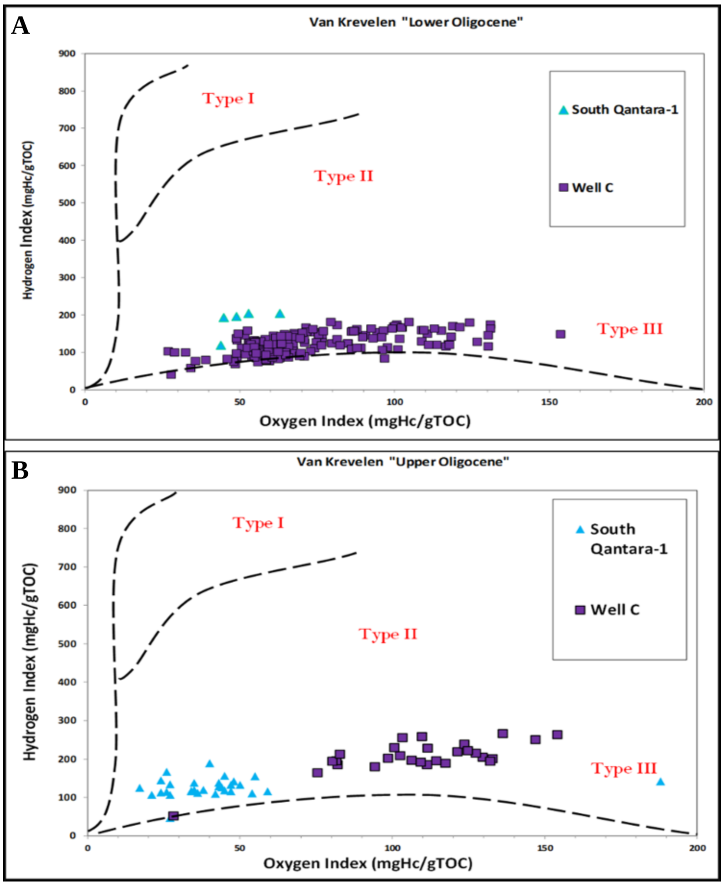

Figure 7: Plot of the studied Lower Oligocene (A) and Upper Oligocene (B) samples on a modified van Krevelen diagram.

When HI ranges between 200-300 mg HC/g TOC, then its kerogen type is II-III, which can produce mixed hydrocarbons (gas and oil but mostly gas). On the other hand, HI ranged 300-600 mg HC/g TOC indicates mainly type II kerogen (oil and gas-prone). Furthermore, HI >600 mg HC/g TOC classifies the kerogen as type I (oil-prone). (Peters et al., 2005)

The relation between OI and HI can be plotted on a modified van Krevelen diagram (Fig. 7), which is used to determine the origin and type of the kerogen (van Krevelen, 1961). Also, the plots of TOC% versus S2 (mg HC/g Rock) (Fig. 8) as well as the T_{max} versus hydrogen index (Fig. 9) cross plots help in determining the kerogen type and thermal maturity level. The 3 plots indicate that the kerogen is mainly type III in the studied wells, whereas some samples from Well C are closer to type II-III (Figs. 7-9).

4.1.3. Thermal maturation:

Many physical and chemical properties of organic matter are changeable during the thermal evolution of a source rock during the diagenesis, catagenesis and metagenesis stages. These changes can be indications for thermal maturity (Tissot and Welte, 1984). Assessment of thermal maturity of organic matter in the studied wells was carried out using pyrolysis T_{max} values (Figs. 9 and 10 and Table 1).

Pyrolysis T_{max} is the most widely used method in evaluating thermal maturity of a source rock, which differs significantly according to the kerogen type (Tissot and Welte, 1984; Peters, 1986; Bordenave, 1993). The oil generation window lies between T_{max} values of 435-465 °C (Peters and Cassa, 1994). The T_{max} values of the Lower Oligocene samples range between 345-452°C and the Upper Oligocene samples range between 337-450°C for both wells (Fig. 10).

4.2. Geochemical Fossils:

4.2.1. Gas Chromatography Analysis (GC-FID):

Some transformations of biomarkers occur as a result of thermal reactions that is controlled by both subsurface temperatures and the length of exposure to those temperatures (Waples and Machihara, 1991). Such transformations can be used as thermal maturity indicators and organic facies indicators. Biomarkers are originated from formerly living organisms and are complex organic compounds. They occur in sediments, rocks, and crude oils (Peters et al., 2005). Most common uses of the geochemical fossils in the correlation parameters (oil-oil and oil-source rock), in the reconstruction of the depositional environment, in the elucidation of chemical transformation during diagenesis and catagensis stages, and in the detection of contamination with foreign components (Tissot and Welte, 1984).

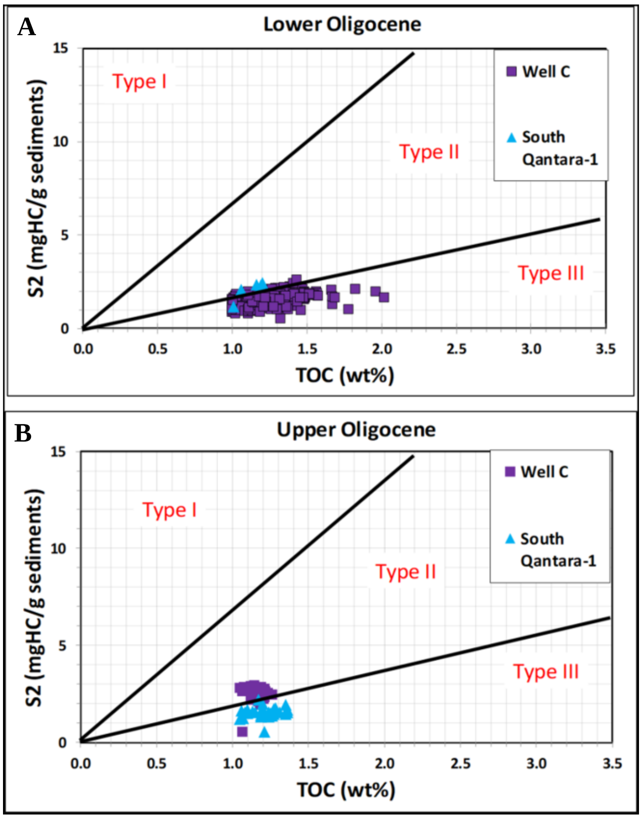

Figure 8: Plot of the study Lower Oligocene (A) and Upper Oligocene (B) samples on a Langford and Blanc-Valleron (1990) diagram.

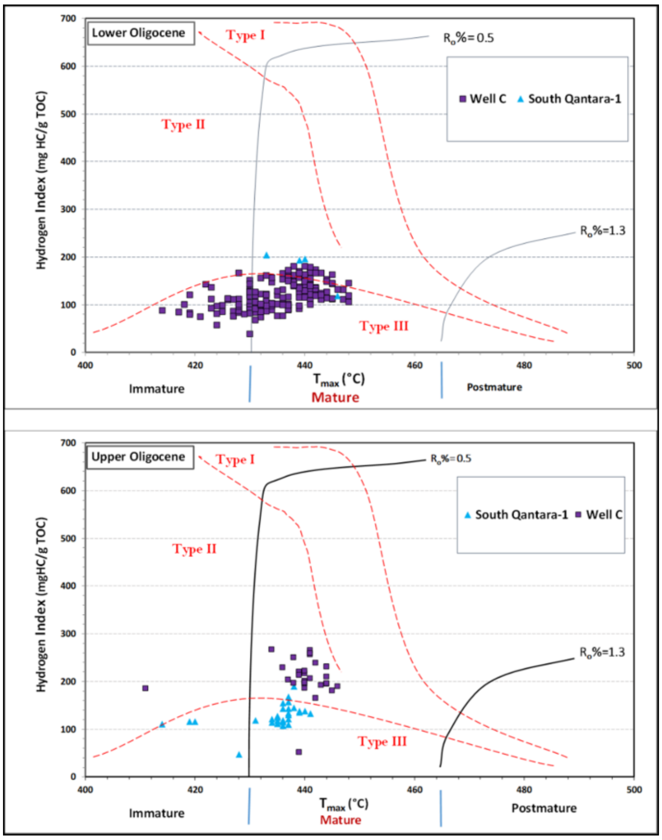

Figure 9: Plot of the study Lower and Upper Oligocene samples on a T_{max} versus hydrogen index diagram.

Table (1): Level of maturation

Level of Maturity	PI (S1/S1+S2)	T_{max}
Top oil window	~0.1	435-445°C*
Bottom oil window	~0.4	470°C

- Many maturation parameters (particularly T_{max}) depend on type of organic matter.

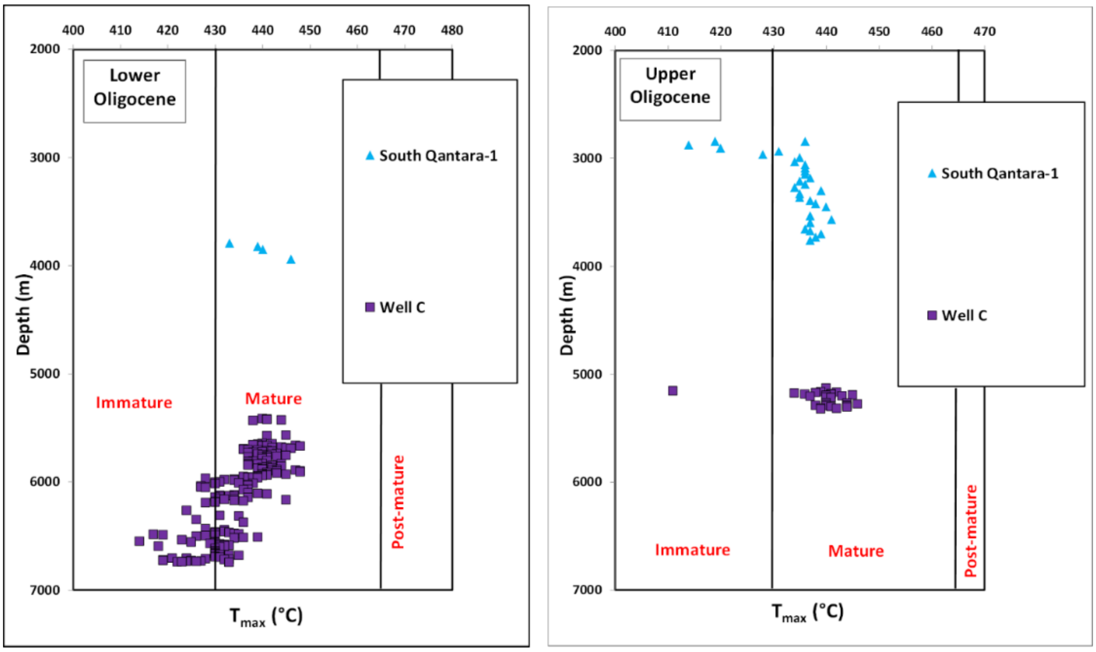

Figure 10: Plot of Lower Oligocene (A) and Upper Oligocene (B) T_{max} versus Depth for the studied wells (solid lines are based on Peters and Cassa, 1994).

Pristane (Pr) and Phytane (Ph) are the most important acyclic isoprenoids hydrocarbons in terms of concentration, as they reflect the paleo-environmental conditions of a source rock and the paleo-redox condition during sedimentation and diagenesis (Didyk et al., 1978). Phytane occurs in relatively high concentrations compared with pristane in reducing environment (e.g., Mohialdeen and Hakimi, 2016). Thus, Pristane/Phytane ratio lower than 1 indicate anoxic conditions and algal organic input (Didyk et al., 1978; Hunt, 1996; Peters et al., 2005). On the other hand, Pr/Ph ratio is around 1 when high level of maturity was reached (Hunt, 1996). Nevertheless, Pr/Ph ratio >1 indicates a source rock containing significant terrestrial input (wax-rich compounds) and oxic to sometimes dysoxic palaeo-redox conditions.

The studied samples exhibit Pr/Ph ratio ranges from 1.4 (extract of South Qantara-1) to 5.5 (Miocene-reservoired condensate of El Qar'a-8; Table 2). This points to a relatively dysoxic palaeo-redox conditions were prevailed during the deposition of South Qantara-1 Oligocene shales with a slight marine affinity than the rest of the wells. The relationship between Pr/n-C_{17} versus Ph/n-C_{18} is used to determine the depositional paleo-redox conditions and thermal maturity of organic material (e.g., Peters et al., 2005). The diagram suggests that the samples do plot in oxic regime with significant terrestrial input (zone A and B) source rock (Fig. 11). Exception is South Qantara-1 extract and well C, which have a slight marine affinity (zone C) source rock (Fig. 11).

4.2.2 Gas Chromatography-Mass Spectrometry (GC-MS):

- Biomarkers as organic facies indicators:

a) *Regular Steranes C_{27}-C_{29} ternary plot:*

The distribution of C_{27}, C_{28} and C_{29} steranes homologues on a ternary diagram was suggested by Haung and Meinchein (1979), as they provided the first evidence to the relative proportions of C_{27}-C_{29} regular

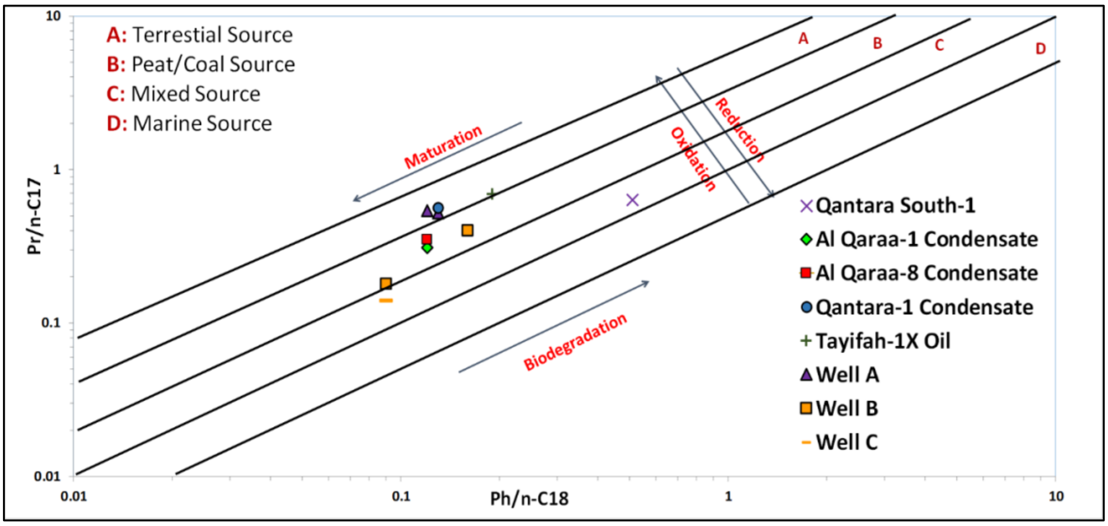

Figure 11: Relationship between isoprenoids and *n*-alkanes showing sources and depositional environments for the studied wells (Shanmugam, 1985).

Table (2): Biomarker parameters of studied samples.

Well	El Qar'a-1	El Qar'a-8	Qantara-1	South Qantara-1	Tayifah-1	Well A		Well C	Well B	
Sample Type	Condensate			Extract	Oil	Oil		Condensate	Condensate	
Depth (m)	3300	3272	3111.5	3730	Unknown	6366	6371	6419.6	5628.7	6148.4
Age	Miocene			Rup./Chattian	Miocene	Oligocene		Oligocene	Oligocene	
Pr/Ph	5.10	5.55	5.15	1.62	4.44	4.41	5.14	2.04	2.78	2.52
Pr/*n* -C17	0.31	0.35	0.56	0.63	0.69	0.52	0.54	0.14	0.40	0.18
Ph/*n* -C18	0.12	0.12	0.13	0.51	0.19	0.13	0.12	0.09	0.16	0.09
CPI	1.00	0.55	1.13		1.15	1.07	1.06	1.07	1.04	1.04
Steroids										
%C27 αββ-R Cholestane	27.80	25.40	21.00	28.94	25.00	16.90	19.20	29.20	21.10	26.50
%C28 αββ-R Ergostane	29.30	32.10	30.80	31.93	31.70	35.00	35.80	32.60	34.70	34.30
%C29 αββ-R Stigmasane	42.90	42.50	48.20	39.13	43.20	48.10	45.00	38.20	44.20	39.20
%C27 ααα-R Cholestane	27.10	28.10	22.10	22.70	31.60	18.80	14.90	58.70	32.90	54.30
%C28 ααα-R Ergostane	22.70	25.30	25.80	37.30	27.30	24.30	32.30	9.90	16.40	16.40
%C29 ααα-R Stigmasane	50.20	46.60	52.20	39.80	41.10	56.90	52.80	31.30	50.70	29.30
C27/C29	0.65	0.60	0.43	0.74	0.58	0.35	0.43	0.76	0.48	0.68
C29/C27	1.54	1.67	2.30	1.35	1.73	2.85	2.34	1.31	2.09	1.48
C28/C29	0.68	0.75	0.64	0.82	0.73	0.73	0.80	0.85	0.79	0.88
Diasteranes/Steranes	0.91	0.95	0.49	0.92	0.39	0.61	0.59	0.55	0.8	0.28
Terpenoids										
Ts/(Ts+Tm) Trisnorhopanes	0.55	0.58	0.49	0.59	0.50	0.38	0.37	0.49	0.63	0.54
Moretane	2.00	1.90	186.30		444.70	101.90	220.90		126.80	17.00
Gammacerane	0.40	0.00	26.60		80.20	15.50	34.40	4.60		6.60
Oleananes	2.10	3.10	198.90		451.80	821.20	1904.60	8.40	27.90	14.50
Norhopane/Hopane	0.54	0.55	0.53	0.21	0.52	0.58	0.54	0.81	0.50	0.65
25-nor-hopane/hopane	0.06	0.06	0.00		0.00					
Diahopane/Hopane	0.07	0.06	0.03		0.04	0.10	0.09	0.11	0.16	0.06
Oleanane/(Olean.+Hopane)	0.15	0.21	0.15	0.14	0.17					
Gammacerane/Hopane	0.03	0.00	0.02		0.03	0.03	0.03	0.06		0.08
Moretane/Hopane	0.15	0.17	0.14		0.16	0.20	0.20	0.18	0.13	0.17
C32 S/(S+R) homohopanes	0.55	0.54	0.57	0.59	0.57	0.60	0.58	0.63	0.59	0.56
Steranes/Hopanes	0.30	0.48	0.11		0.12	0.31	0.34	0.53	0.34	0.19

sterols in the living organisms that can be related to a specific environment (Waples and Machihara 1991). They proposed that the predominance of C_{29} indicates terrestrial contribution, whereas the dominance of C_{27} indicates contribution from marine phytoplankton, and the dominance of C_{28} indicates a noticeable contribution from lacustrine algae. The ternary diagram of the studied samples indicates a significant predominance of terrestrial input (i.e., C_{29} sterane) than marine and lacustrine homologues. Exception is South Qantara-1 that shows more marine affinity than samples from other wells (Fig. 12). A cross-plot between pristane/phytane ratio versus C_{29}/C_{27} ratio shows the dominance of the land plant organic matter in an oxic environment except some samples from South Qantara-1 and Well C that have dysoxic environment with some marine affinity (Fig. 13).

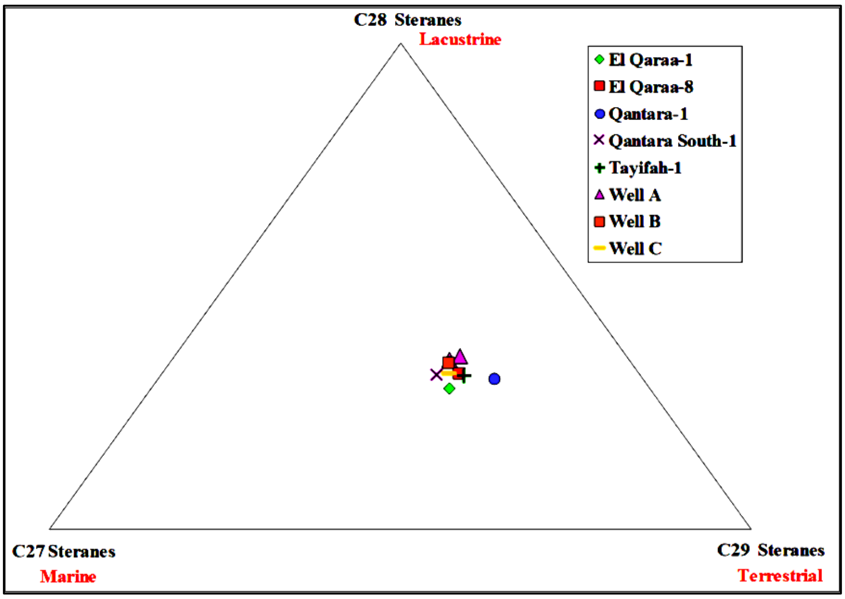

Figure 12: Ternary Diagram for the αββ-regularsteranes composition.

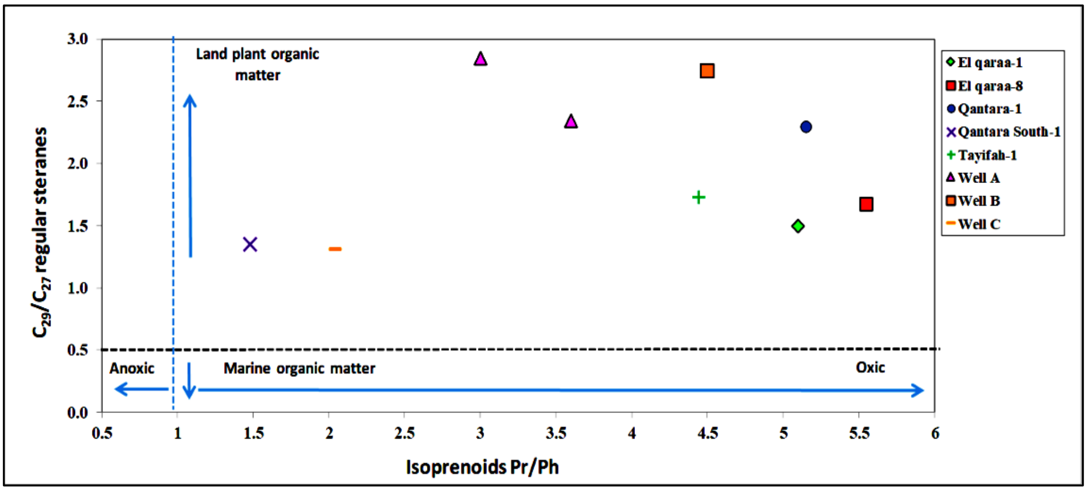

Figure 13: A cross-plots between the isoprenoid pristane/phytane ratio versus C_{29}/C_{27} of the studied samples.

b) Gammacerane:

Abundance of gammacerane in extracts is an indicator of stratified water column with high salinity during deposition (Sinninghe Damste et al., 1995; Ten Haven et al., 1989). Gammacerane is generally reported in marine environment and saline water lakes and indicate hyper salinity (Fu Jimo et al., 1988, 1989; Brassell et al., 1988; Waples and Machihara 1991). The contribution of gammacerane varies from 0 ppm (extract from South Qantara-1) to 80.2 ppm (oil of Tayifah-1), which indicates an episodic stratified water column during the deposition.

c) Oleanane:

The abundance of oleanane in samples commonly implies a high terrigenous input that is preserved in Tertiary or younger source rock (e.g., Peters et al., 2005). The oleanane / (oleanane + hopane) ratio was reported as of continuously increasing values from the Cretaceous Period through the Tertiary Period (Moldowan et al., 1994). Oleanane ratios >0.2 are diagnostic of Tertiary or younger source rocks and related oils. In the present study samples, the oleanane varies from 2.1 (El Qar'a-1) to 1904.6 (Well A) ppm. On the other hand, the oleanane/ (oleanane + hopane) ratio varies from 0.14 (South Qantara-1 extract) to 0.64 (condensate of Well B) ppm. The values indicate more preserved angiosperms in the offshore area than in the onshore area.

- **Biomarkers as Maturity indicators:**

a) ***20S/(20R+20S) Steranes epimer ratio:*** The most important measure of the maturity using biomarkers is the proportion of two epimeric forms (20R and 20S αα sterane). With increasing maturity, the proportion of the 20S increases, as some of the 20R molecules change their configuration (Waples and Machihara, 1991). The application of this ratio is kerogen maturity estimation or oil generation (Waples and Machihara, 1991; Peters et al., 2005). Ratio higher than 0.5 indicates more mature organic matter. The ratio of the present study samples ranges between 0.22 and 0.49. The onshore values decrease from the east (0.44, South Qantara-1) to the west (0.22, Tayifah-1), whereas the offshore values vary from 0.3 (well C) to 0.49 (well A). All data point to immature to marginally mature organic matter (Fig. 14).

b) ***Moretane/Hopane ratios:*** Moretane is less stable than 17α(H)-hopane, and thus its contribution decreases more rapidly with increasing thermal maturity (Kvenvolden and Simoneit, 1990). Moretane is gradually converted into hopanes (e.g., Grantham, 1986). If the ratio is above 0.15, the source rock did not reach the oil window level and the thermal maturity level is immature (Peters et al., 2005). The study samples show Moretane/Hopane ratios that are ranged in the onshore between 0.14 and 0.17, whereas the offshore values vary between 0.11 and 0.2. The data imply that the hydrocarbons are sourced from immature to marginally mature source rock (Table 2).

c) ***Ts/(Ts+Tm) Trisnorhopanes:*** Tm and Ts trisnorhopanes are influenced by thermal maturation, type of organic matter, and lithology (Seifert and Moldowan, 1979; Moldowan et al, 1985). With increasing thermal maturity, the Tm isomer coverts into the Ts one, in terms of contribution (Waples and Machihara 1991). Ts/(Ts+Tm) ratio higher than 0.5 indicates matured organic material. The present study samples show ratios between 0.49 (Qantara-1) and 0.59 (South Qantara-1) for onshore wells and between 0.37 (well A) and 0.63 (well B) for offshore wells, which is in accordance with the aforementioned maturity proxies (i.e., immature to marginally matured; Fig. 15).

4.2.3 Oil-Oil and Oil-Source Rock Correlations

Comparing the molecular, elemental, and isotopic geochemical characteristics among crude oils, condensates, and extracts from potential source rocks is essential to determine whether a genetic relationship exists (Peters et al., 2005). The only source rock extract we have in the present study is from South Qantara-1 well. Based on the molecular fossils data we have; the following correlation-related items can be noticed (Table 2):

- There is an overall enrichment in %C29 steranes relative to the other epimers in all samples; however, a significant increment in %C27 in the extract sample from South Qantara-1 and the condensates from onshore and some offshore wells (Table 2). Consequently, there is a noticeable correlation between the contribution of steranes (particularly %C27 and C27/C29) of the extract sample from South Qantara-1 and the condensate samples from onshore wells (El Qar'a-1 and El Qar'a-8) and, to some extent, with the condensates from offshore wells (Well C & Well B; Table 2).
- The contribution of Diasteranes in condensate samples from onshore wells indicates a potential clay-rich (shaly) source rock (Hughes, 1984; Peters et al., 2005). This implies a potential genetic relation with the Oligocene shales of the present study.

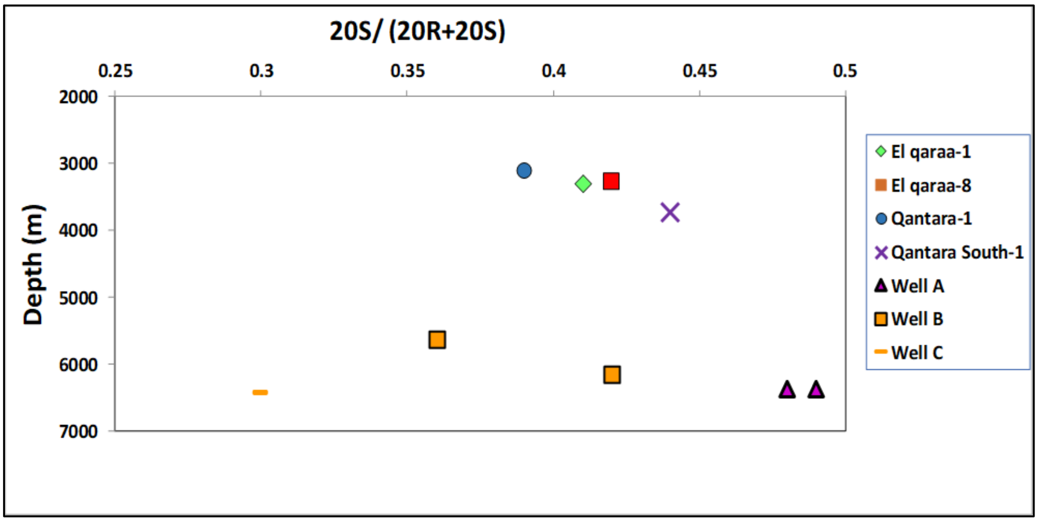

Figure 14: Relationship between αββ-RSteranesepimer ratio and the depth.

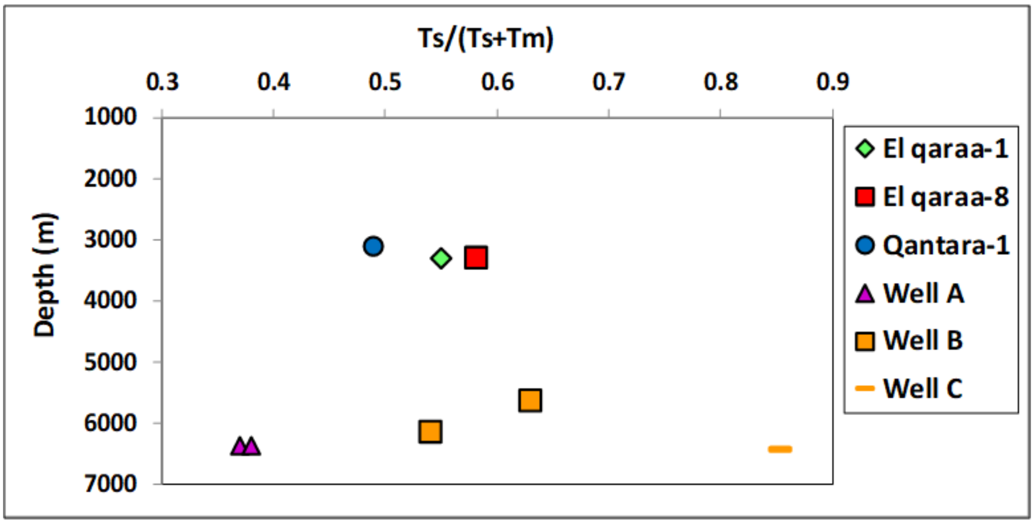

Figure 15: Relationship between Ts/Ts+Tm vs depth showing the effect of overburden on maturity.

- The maturity indicator Ts/(Ts+Tm) Trisnorhopane exhibits a noticeable correlation between South Qantara-1 extract and the condensates from onshore and offshore wells (Table 2), where the values are slightly higher than 0.5.
- The oil samples from Well A and Tayifah-1 did not show noteworthy correlations with the extract sample from South Qantara-1 well.
- The oils from Well A and Tayifah-1 can be correlated for their Pr/Ph ratios (Table 2); however, neither the percentages of the steranes (αββ-R and ααα-R) nor the Diasterane/Sterane ratios show notable correlations.

5. CONCLUSIONS

The followings can be concluded;

1. The quantity of the organic carbon of the studied Oligocene source rock is classified as of fair to good generative potential. They are corresponding to mainly kerogen type III and sometimes type II-III.
2. For evaluating the thermal maturity, pyrolytic Tmax was used. It shows that most of South Qantara-1 samples are located in the mature stage, whereas Well C samples are scattered between the immature and mature stage.
3. The lipid biomarker analysis indicates that Pr/Ph ratios are noticeably high with more terrestrial contribution than marine. Therefore, the sediments tend to be deposited in oxic-dysoxic paleo-redox conditions. The regular steranes C27-C29 ternary diagram indicates more predominant terrestrial homologues (i.e., dominant C29 sterane) than marine and lacustrine homologues. South Qantara-1 sediments tend to have slight marine affinity than other samples. The maturity indicators 20S/(20R+20S) steranes epimer, Moretane/Hopane, and Ts/(Ts+Tm) Trisnorhopanes ratios pinpoint to immature to early mature organic matter.
4. Noticeable correlations were observed between the contribution of steranes and diasteranes, and the Ts/(Ts+Tm) Trisnorhopane ratio of the extract sample from South Qantara-1 and the condensate samples from onshore wells (El Qar'a-1 and El Qar'a-8) and, to a degree, with the condensates from offshore wells (Well C & Well B). On the other hand, oil samples from Well A and Tayifah-1 did not show noteworthy correlations with the extract sample or even among each other.

Acknowledgments:

The authors would like to thank the Egyptian General Petroleum Corporation (EGPC) as well as British Petroleum for providing organic geochemical data, and their kind permission to publish this work.

REFERENCES

Abdel Aal, A., El Barkooky, A., Gerrits, M., Meyer, H., Schwander, M. and Zaki, H., 2000: Tectonic evolution of the Eastern Mediterranean basin and its significance for hydrocarbon prospectivity in the ultradeepwater of the Nile delta, Egypt: The Leading Edge, p. 1086–1102.

Abdel Aal, A.., Barkooky, A. el, Gerrits, M., Meyer, H., Schwander, M., and Zaki, H., 2001: Tectonic evolution of the Eastern Mediterranean and its significance for hydrocarbon prospectivity of the Nile Delta deepwater area: GeoArabia, volume 68, no. 3, pp.363-383.

Abu El-Ella, R. 1990: Maturation history of Neogene-Quaternary sediment, Nile Delta Basin, Egypt. AAPG Bulletin, 74, 77-84.

Ahmed, S., 2004: Biostratigraphical Report of Sindy-1 Well.Earth Resources Exploration, Egyptian General Petroleum Corporation (EGPC) internal report, 35 p.

Alpern, B., and Liabeuf, J.J., 1969: Palynological considerations on the West-phalian and Stephanian: Proposition for a parastratotype: Compete Rendu, Sixième congrès International de Stratigraphie et de Géologie du Carbonifère, Sheffield, 1967, volume I, 109-114.

Barakat, M.K.A., 2010: Modern geophysical techniques for constructing a 3D geological model on the Nile Delta, Egypt, Dissertation M.Sc., Technical University of Berlin.144 p

Barber, P.M., 1981: Messinian subaerial erosion of the proto-Nile Delta, Marine Geology 44, 253–272

Bordenave, M.L., 1993: Applied Petroleum Geochemistry. Editions Technip, Paris. 999 p.

Brassell, S. C., Sheng, G., Fu, J. and Eglinton, G. (1988): Biological markers in lacustrine Chinese oil shales. In: Lacustrine Petroleum Source Rocks (A. J. Fleet, K. Kelts and M. R. Talbot, eds.), Geological Society of London, London, 299-308.

C & C Reservoirs, 2009: Field Evaluation Report, Abu Madi-El Qar'a Field Onshore Nile Delta, Egypt, 43 p.

Carey, S.W., 1976: The expanding earth: Development in geotectonics, Elsevier Publishing Company, Amsterdam, 488.

Didyk, B.M., Simoneit, B.R.T., Brassell, S.C., Eglinton, G., 1978: Organic geochemical indicators of palaeoenvironmental conditions of sedimentation. Nature 272, 216-222.

Dolson, J.C., Shann, M.V., Matbouly, S.I., Hammouda, H., Rashed, R.M., 2000: Egypt in the twenty-first century: petroleum potential in offshore trends. GeoArabia 6, 211-230.

Dolson, J.C., Shann, M.V., Matbouly, S.I., Harwood, C., Rashed, R., Hammouda, H., 2001: The petroleum potential of Egypt. In: Downey MW, Threet JC, Morgan WA (eds) Petroleum provinces of the twenty-first century. AAPG Memoire 74, 453-482.

Dolson, J.C, Boucher, P.J., Siok, J., Heppard, P.D., 2005: Key challenges to realizing full potential in an emerging giant gas province: Nile Delta/ Mediterranean offshore, deep water, Egypt .In: DORE´, A. G. & VINING, B. A. (eds) Petroleum Geology: North-West Europe and Global Perspectives-Proceedings of the 6th Petroleum Geology Conference, 607–624.

Egyptian General Petroleum Corporation, 1994: Nile Delta & North Sinai: fields, discoveries and hydrocarbon potentials (a comprehensive overview): The Egyptian General Petroleum Corporation, Cairo, 387 p.

El-Heiny, I. and Enani, N. 1996: Regional stratigraphic interpretation of Neogene sediments, northern Nile Delta, Egypt, EGPC, 13th Petrol. Exploration and Prod. Confer, Cairo, 1, 170-290.

El Nady, M.M. 2007: Organic geochemistry of source rocks, condensates, and thermal geochemical modeling of Miocene Sequence of some wells, onshore Nile Delta, Egypt. Petroleum Science and Technology, 25(6), 791-817.

Felt, V.L., Bailey, J.W., Hutton, B.A. and Simpson, M.G., 1999: The control of regional geologic process on the architecture of the Nile Delta hydrocarbon systems. AAPG Bulletin, 83(8), 1311.

Fu, J., Sheng, G., and Liu, D., 1988: Organic geochemical characteristics of major types of terrestrial source rocks in China. In: Lacustrine Petroleum Source Rocks (A. J. Fleet, K. Kelts and M. R. Talbot, eds.), Blackwell, London, 279–89.

Fu, J., Sheng, G., 1989: Biological marker composition of typical source rocks and related oils of terrestrial origin in the People's Republic of China; a review. Applied Geochemistry, 4, 13–22.

Ghassal, B.I., El Atfy, H., Sachse, V., and Littke, R., 2016: Source rock potential of the Middle Jurassic to Middle Pliocene ,onshore Nile Delta Basin, Egypt. Arabian Journal of Geoscience, 9, 744-765.

Grantham, P.J., 1986: Sterane isomerization and moretane/ hopane ratios in crude oils derived from Tertiary source rocks.Organic Geochemistry, 9, 293–304.

Gradstein, F.M., Ogg, J.G., Schmitz, M.D., and Ogg, G.M., 2012: The Geologic Time Scale. Amsterdam: Elsevier ,1127 p.

Guiraud R. and Bosworth W., 1999: Phanerozoic geodynamic evolution of northeastern Africa and the northwestern Arabian platform. Tectonophysics 315, 73-104.

Hakimi, M.H. and Abdullah, W.H., 2015: Thermal maturity history and petroleum generation modelling for the Upper Jurassic Madbi source rocks in the Marib-Shabowah Basin, Western Yemen. Marine and Petroleum Geology 59, 202-216.

Halbouty, M.T. and F. El-Baz, 1992: The Mediterranean region: Its geologic history and oil and gas potentials in A. Sadek, ed., Geology of the Arab World: Cairo, Egypt, Cairo University, Vol. I, 15-60.

Halim, A.A., Fouda, O., Worku, T., Khaled, A.A. and Fawzi, H. E. 1996: Aspect of reservoir potential of the Miocene-Pliocene sequences in the North

Alexandria and surrounding areas, offshore Nile Delta, Egypt. EGPC, 13th Petrol. Exploration and Production Conference, Cairo, 1, 277-292.

Harms, J.C. and Wray, J.L., 1990: Nile Delta. In: R. Said (Editor), The Geology of Egypt. A.A. Balkema, Rotterdam, 329-343.

Huang, W.Y. and Meinschein, W.G., 1979: Sterols as ecological indicators. Geochim. Cosmochim. Acta 43, 739-745.

Hughes, W.B., 1984: Use of thiophenic organosulfur compounds in characterizing crude oils derived from carbonate versus siliciclastic sources. In: Petroleum Geochemistry and Source Rock Potential of Carbonate Rocks (J. G. Palacas, ed.), American Association of Petroleum Geologists, Tulsa, OK, pp. 181–196.

Hunt, J.M., 1991: Generation of gas and oil from coal and other terrestrial organic matter. Organic Geochemistry 17, 673-680.

Hunt, J.M., 1996: Petroleum geochemistry and geology. Freeman and Company, New York, 743p.

Kamel, H., Eita, T. and Sarhan, M., 1998: Nile Delta hydrocarbon potentiality. EGPC, 14th Petroleum Exploration Production Conference, Cairo, volume2, 485-503

Khaled, K.A., Lobna M. Sharaf, Awad, S.A. and Rashed, A. S., 2003: Maturation and source rock evaluation of mudstones beds in Abu Madi and Kafr el Sheikh formations, Abu Madi Gas Field, Nile Delta, Egypt, Annals of the Egyptian Geological Survey, volume. 26,449-474.

Kvenvolden, K.A. and Simoneit, B.R.T., 1990: Hydrothermally derived petroleum: examples from Guaymas Basin, Gulf of California, and Escanaba Trough, Northeast Pacific Ocean. AAPG Bulletin, 74, 223–237.

Langford, F.F. and Blanc-Valleron, M.M., 1990: Interpreting Rock-Eval pyrolysis data using graphs of pyrolizable hydrocarbons vs. total organic carbon. AAPG Bulletin 74 ,799-804.

Livermore, R.A. and Smith, A.G., 1985: Some boundary condition for the evolution of the Mediterranean region in: Stanley and Wezel (Eds.), Geological evolution of the Mediterranean basin. Springer-Verlag, 323-346.

Meneisy, M.Y. 1990: Vulcanicity. In: Said R (ed) The geology of Egypt. Balkema, Rotterdam, 157–172.

Meshref, W.M., 1990: Tectonic framework. In: Said R (ed) The geology of Egypt. Balkema, Rotterdam-Brookfield, 113-155

Metwalli, M.H., 2000: A new concept for the petroleum geology of the Nile Delta, A. R. Egypt. International Conference Geology of the Arab World (GAW), Cairo University, 2, 713- 734.

MohiEldeen, I.M.J. and Hakimi, M.H., 2016: Geochemical characterization of Tithonian-Berriasian Chia Gara organic-rich rocks in northern Iraq with an emphasis on organic matter enrichment and the relationship to the bioproductivity and anoxia conditions, Journal of Asian Earth Sciences, 116, 181–197.

Moldowan, J.M., Dahl, J., Huizinga, B.J. and et al.1994: Themolecular fossil record of oleanane and its relation toangiosperms. the American Association for the Advancement of Science, 265, 768–71.

Moldowan, J.M., Seifert, W.K. and Gallegos, E.J., 1985: Relationship between petroleum composition and depositional environment of petroleum source rocks. AAPG, 69, 1255–68.

Morgan, P., 1990: Egypt in the framework of global tectonics. In: R. Said (Editor), The Geology of Egypt. A.A. Balkema, Rotterdam, 91-111.

Parisot, T., Verdier, P., Amaral, J., Mounoury, M., 1996: Egypt Western Desert. Elf Aquitaine Production.

Pedersen, T.R. and Calvert, S.E., 1990: Anoxia vs productivity. What controls the formation of organic-carbon-rich sediments and sedimentary rocks: AAPG Bulletin, 74, 454-466.

Peters, K.E., 1986: Guidelines for evaluating petroleum source rock using programmed pyrolysis: AAPG Bulletin, volume 70, no. 3, 318-329.

Peters, K.E. and Cassa, M.R., 1994: Applied source rock geochemistry. In Magoon Leslie, B Dow, W.G (Eds), The petroleum system; from source to trap. AAPG Memoir, 93-120.

Peters, K.E., Walters, C.C., Moldowan, J.M., 2005: The Biomarker Guide, 2nd edition. Cambridge University Press, Cambridge.

Said, R., 1990. The geology of Egypt. Balkema, Rotterdam, 734 p.

Sarhan, M. and Hemdan, K., 1994: North Nile Delta Structural setting and trapping mechanism, Egypt 12th EGPC exploration and production conference, Cairo. 1-130

Saleh, M., H., 2018: The Structural Geometries and Geological Evolution of the Detachment Plio-Pleistocene Fault Systems of the Eastern Nile Delta, Egypt. MSc. Thesis, faculty of Science, Ain Shams University, 172p.

Schlumberger, 1984: Well evaluation conference, Egypt. Schlumberger Middle East S.A. 270p

Well Evaluation Conference (WEC) 1995: Western Desert Egyptian General Petroleum Corporation& Schlumberger Middle East S.A., p. 60-77

Seifert, W.K. and Moldowan, J.M., 1979: The effect of biodegradation on steranes and terpanes in crude oils. Geochimica et CosmochimicaActa, 43, 111–26.

Selim, S.S., 2016: Sedimentological architecture, shelf-edge trajectories and evolution of an Oligocene reservoir, East Nile Delta. Geological Magazine 1, 1-26.

Shaaban, F., Lutz, R., Littke, R., Bueker, C., and Odisho, K., 2006: Source-rock evaluation and basin modeling in NE Egypt (Nile Delta and Northern Sinai): Journal of Petroleum Geology, volume 29, no. 2, 103-124.

Shanmugam, G. 1985: Significance of coniferous rain forests and related oil, Gippsl and Basin, Australia. American Association of Petroleum Geologists Bulletin, 69, 1241-1254.

Sharaf, L.M., 2003: Source rock evaluation and geochemistry of condensates and natural gases, offshore Nile Delta, Egypt: Journal of Petroleum Geology, volume. 26, no. 2, 189-209.

Sinninghe Damst'e, J.S., Kenig, F., Koopmans, M. P., et al., 1995: Evidence for gammacerane as an indicator of water-column stratification. Geochimica et Cosmochimica Acta, 59, 1895–900.

Snedden, W.J. and LIu, C., 2010: A compilation of Phanerozoic sea-level change, coastal on laps and recommended sequence designations. AAPG International Conference and Exhibition. AAPG, Search and Discovery Article #40594.http://www. searchanddiscovery.com/pdfz/documents/2010/40594snedden/ndx_snedden.pdf.html.

Tassy, A., Crouzy, E., Gorini, C., Rubino, J-L., Bouroullec, J-L., Sapin, F., 2015: Egyptian Tethyan margin in the Mesozoic: Evolution of a mixed carbonate-siliciclastic shelf edge (from Western Desert to Sinai). Marine and Petroleum Geology, 68 (A), 565-581

Teichmüller, M., 1971: Andwendung Kolhenpetrographischer Methodenbei der Edröl-und Erdagasprospektion. Edröl Kolhe Erdgas Petrochem., 24: 69-76 p.

Ten Haven, H.L., Rohmer, M., Rullk¨otter, J., and Bisseret, P., 1989: Tetrahymanol, the most likely precursor of gammacerane, occurs ubiquitously in marine sediments. Geochimica et Cosmochimica Acta, 53, 3073-9.

Tissot, B.P. and Welte, D.H., 1984: Petroleum Formation and Occurrence, 2nd edition, Springer, New York, 699p.

Van Krevelen, D.W., 1961: Coal: Typology-Chemistry-Physics-Constitution. Amsterdam: Elsevier Science. 170p.

Waples, D.W., 1985: Geochemistry in Petroleum Exploration. International Human Resources Development Corporation, Boston, 232p.

Waples, D.W. and Machihara, T., 1991: Biomarkers for Geologists. AAPG Methods in exploration seriesNo.9, Tulsa, Oklahoma, 91p.

Zaghloul, Z.M., Elgamal M.M., Shaaban, F.F. and Yousef A.F.A., 1999: Plates interactions and petroleum potentials in the Nile Delta. In : Zaghloul Z, El-Gamal M (eds). Mansoura University, Deltas (ancient and modern), pp 41–53.

Zein El Din, M.Y., Hegazi, A. and Nashaat, M., 1988: The use of geopressure data as a new tool for exploration in the Nile delta Egypt. EGPC 9th Petroleum Exploration and Production Conference, Cairo, 32p. Websites:www.stratochem.com.