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Hydrocarbon Potentials in the Northern Western Desert of Egypt

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1. Introduction

The Western Desert of Egypt covers two thirds of the whole area of Egypt. The coastal basins (Matruh, Shushan, Alamein and Natrun) located in the northern half of the Western Desert 75 kilometers to the southwest of Matruh City, covering an area of about 3800 Km^2 which forms the major part of the unstable shelf as defined by Said (1990). It is located northeast-southwest trending basin. This basin characterizes by its high oil and gas accumulations and its oil productivity about 45,000 BOPD from 150 producing wells in 16 oilfields, which represents more than one third of the oil production from the northern Western Desert of Egypt (EGPC, 1992).

Khalda was the first discovered field in 1970 by Conco Egypt Inc. and Phoenix Resources and after that followed the discovery of Kahraman, Meleiha, Tut, Salam, Yasser, Shrouk, Safir, Hayat and Kenz oilfields (Figure1).

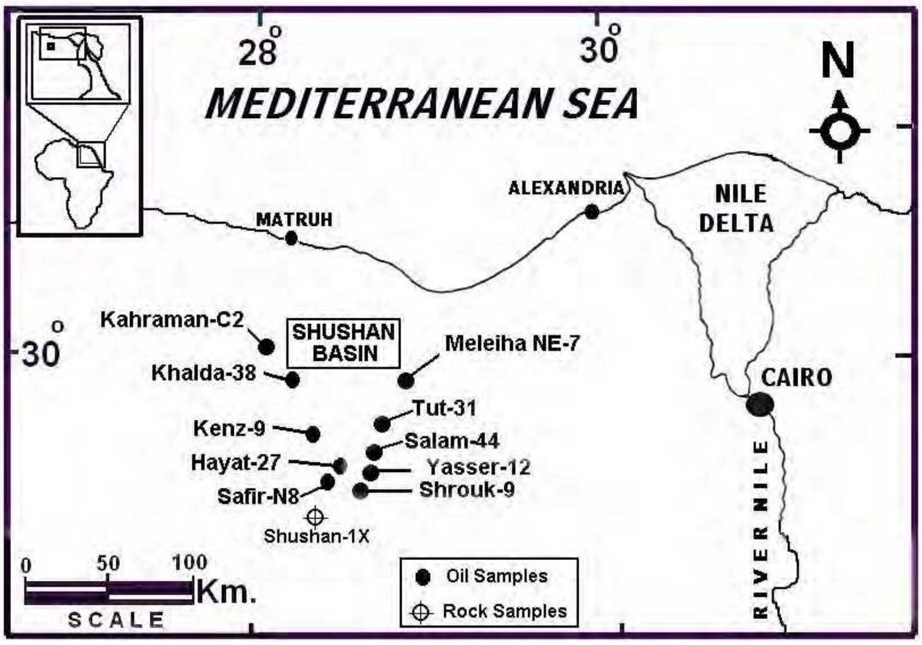

Fig. 1. Location map to the Shushan Basin oilfields.

The sedimentary cover within the northern coastal basins reaches about 14,000 ft. The stratigraphic column includes most of the sedimentary succession from Pre-Middle Jurassic to Recent (Figure 2).

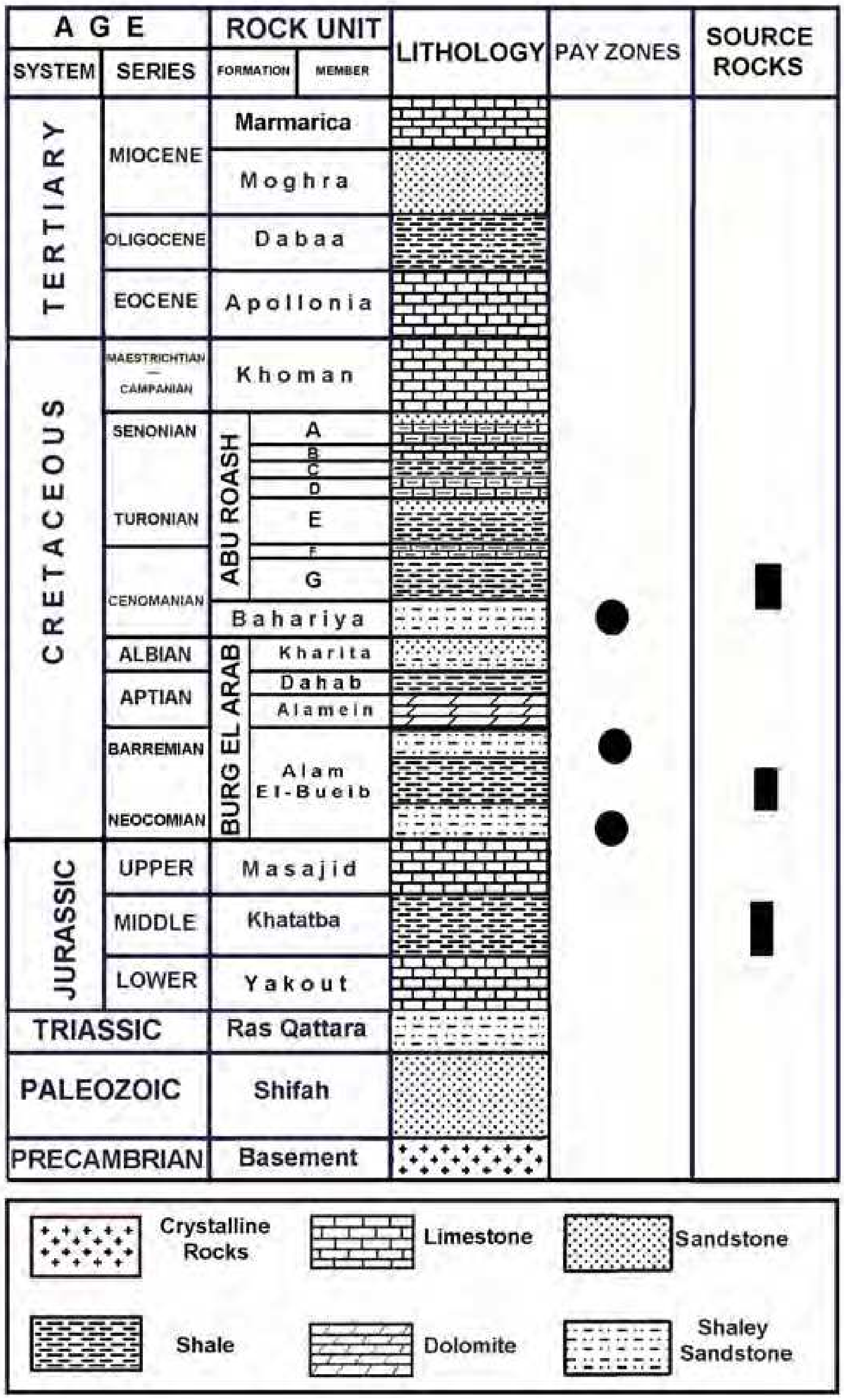

Fig. 2. Generalized lithostratigraphic column of the north Western Desert of Egypt, modified after Abdou (1998).

The northern coastal basins have potential hydrocarbon traps within the sandstones of Lower Cretaceous (Alam El-Bueib Member) and Upper Cretaceous (Bahariya Formation).

The main objectives of this paper are to evaluate the hydrocarbon generation potentials using the Rock-Eval pyrolysis technique applied to shale rock samples representing the succession of Khatatba, Alam El-Bueib and Abu Roash-G formation in addition to burial history modeling to evaluate the degree of thermal maturation in the well Shushan-1X.

The biomarker characteristics as well as stable carbon isotope composition applied on crude oils produced from Bahariya and Alam El-Bueib reservoirs from the different fields of Shushan Basin. This technique was applied on the shale source rock extracts for correlation between them to conclude the depositional environmental conditions prevailing during the hydrocarbon generation.

2. Sampling and analytical techniques

Source rock potential was evaluated by measuring the amount of hydrocarbons generated through thermal cracking of the contained kerogen by Rock-Eval pyrolysis technique. This method was applied on fifteen selected core shale rock samples from Khatatba, Alam El-Bueib and Abu Roash-G lithostratigraphic succession of the well Shushan-1X. These samples were analyzed for total organic carbon, Rock-Eval pyrolysis and vitrinite reflectance measurements. Ten crude oil samples were collected from different pay zones (Alam El-Bueib and Bahariya reservoirs) of the all fields located within Shushan Basin and were analyzed for the biomarker properties and stable carbon isotopes. Meanwhile, three extracts from core shale representing the source rocks of (Khatatba, Alam El-Bueib and Abu Roash-G formations) were used for the same purposes. The crude oils and the extracts from shale source rocks were fractionated by column chromatography where asphaltenes were precipitated with hexane, and the soluble fraction was separated into saturates, aromatics and resins (NSO compounds) on a silica-alumina column by successive elution with hexane, benzene and benzene-methanol. The solvents were evaporated and the weight percent of each component was determined. Gas chromatography (GC) was carried out on Perkin-Elmer 9600 for the saturate fractions equipped with a capillary column (30m x 0.32mm i.d) and the gas chromatograph was programmed from 40^{o}C to 340^{o}C at10 ^{o}C/min with a 2 min. hold at 40^{o}C and a 20 minutes hold at 340^{o}C. The saturate fractions were analyzed using an automated Gas Chromatograph-Mass Spectrometer (GC-MS); the fractions were injected into a Finnigan-MAT

SSQ-7000 operated at 70 ev with a scan range of m/z (50-600), fitted with DB-5 (J&W) fused silica capillary column (60 m × 0.32 mm i.d) with helium as carrier gas. The temperature was programmed from 60^{o}C (1 min. isothermal) to 300^{o}C (50 min. isothermal) at 3^{o}C/min. GC-MS analysis of the saturate fraction targeted: terpanes (m/z 191) and steranes (m/z 217). Stable carbon isotope analyses were performed on the saturate and aromatic fractions of crude oils and extracts using a Micromass 602 D Mass-Spectrometer. Data are reported as δ^{13}C relative to the PDB (‰) standard. Both the Rock-Eval Pyrolysis and the biomarker fingerprints were conducted by StratoChem Services, New Maadi, Cairo.

3. Source rock evaluation

A potential source rock has the capability of generation and expulsion thermally mature oil and gas accumulations (Peters and Cassa, 1994). Source rock evaluation includes quantity and quality of organic matter in addition to thermal maturity or burial heating of organic matter buried in sedimentary succession (Waples, 1994).

The source rock potential and the hydrocarbon generation of the northern Western Desert of Egypt were studied by many authors among them, Parker (1982), Shahin and Shehab (1988), Taher *et al.,* (1988), Zein El-Din *et al.,* (1990), Abdel-Gawad *et al.,* (1996), Abdou (1998), McCain (1998), Abdel-Aziz and Hassan (1998), Khaled (1999), Ghanem *et al.,* (1999), Sharaf *et al.,* (1999), Wever (2000), Waly *et al.,* (2001), Al-Sharhan and Abdel-Gawad (2002), Shahin and El-Lebbudy (2002), Metwally and Pigott (2002), El-Gayar *et al.,* (2002), Younes (2002), El-Nadi *et al.,* (2003) and Harb *et al.,* (2003).

Accordingly, these studies concluded that the stratigraphic section of the northern Western Desert contains multiple source rocks of different degrees of thermal maturation. The dark shale of Khatatba Formation that considered mature source rock with an excellent capability for both oil and gas generation. Shale rocks of Alam El-Bueib and Abu Roash-G formations considered a marginally to good mature source rock for oil generation during the Late Cretaceous.

Source rock evaluation were applied on fifteen core shale rock samples representing the lithostratigraphic section of the Khatatba, Alam El-Bueib and Abu Roash-G formations of the well Shushan-1X including total organic carbon (wt.%), pyrolysis parameters (S1 and S2 values) and vitrinite reflectance measurements (Ro%) to evaluate their organic richness, kerogen types, and the degree of thermal maturity in the northern Western Desert of Egypt.

4. Quantity of organic matter

The available Rock-Eval pyrolysis data of the studied rock units from the well Shushan-1X are summarized in (Table 1) and graphically represented in (Figure 3). The results show that organic-rich intervals are present at three stratigraphic intervals starting with the oldest.

Khatatba Formation:

It consists of dark shale contains TOC ranges between 3.60 and 4.20 wt.% indicating an excellent source rock (Peters and Cassa, 1994). The pyrolysis yield S1+S2 varies between 8.00 and 10.65 kg HC/ton rock and the productivity index (S1/S1+S2) of these rocks ranges between 1.35 and 1.70 therefore the shale rocks of the Khatatba Formation has an excellent source rock potential.

Alam El-Bueib Member:

The shale section of Alam El-Bueib Member contains TOC varies from 1.85 to 2.40 wt.% indicating a good source rock. The pyrolysis yield S1+S2 ranges between 3.60 and 4.50 kg HC/ton rock and the productivity index (S1/S1+S2) of these rocks are generally less than unity, therefore the shale rocks of the Alam El-Bueib Member has a good source rock generating potential.

Abu Roash-G Member:

The organic richness of Abu Roash-G Member varies from 1.10 to 1.50 TOC (wt.%) reflect a medium to good source rock. The pyrolysis yield S1+S2 ranges between 0.85 and 1.10 kg HC/ton rock and the productivity index (S1/S1+S2) of these rocks are generally less than unity, therefore the shale rocks of Abu Roash-G Member indicating fair source rock generating potential.

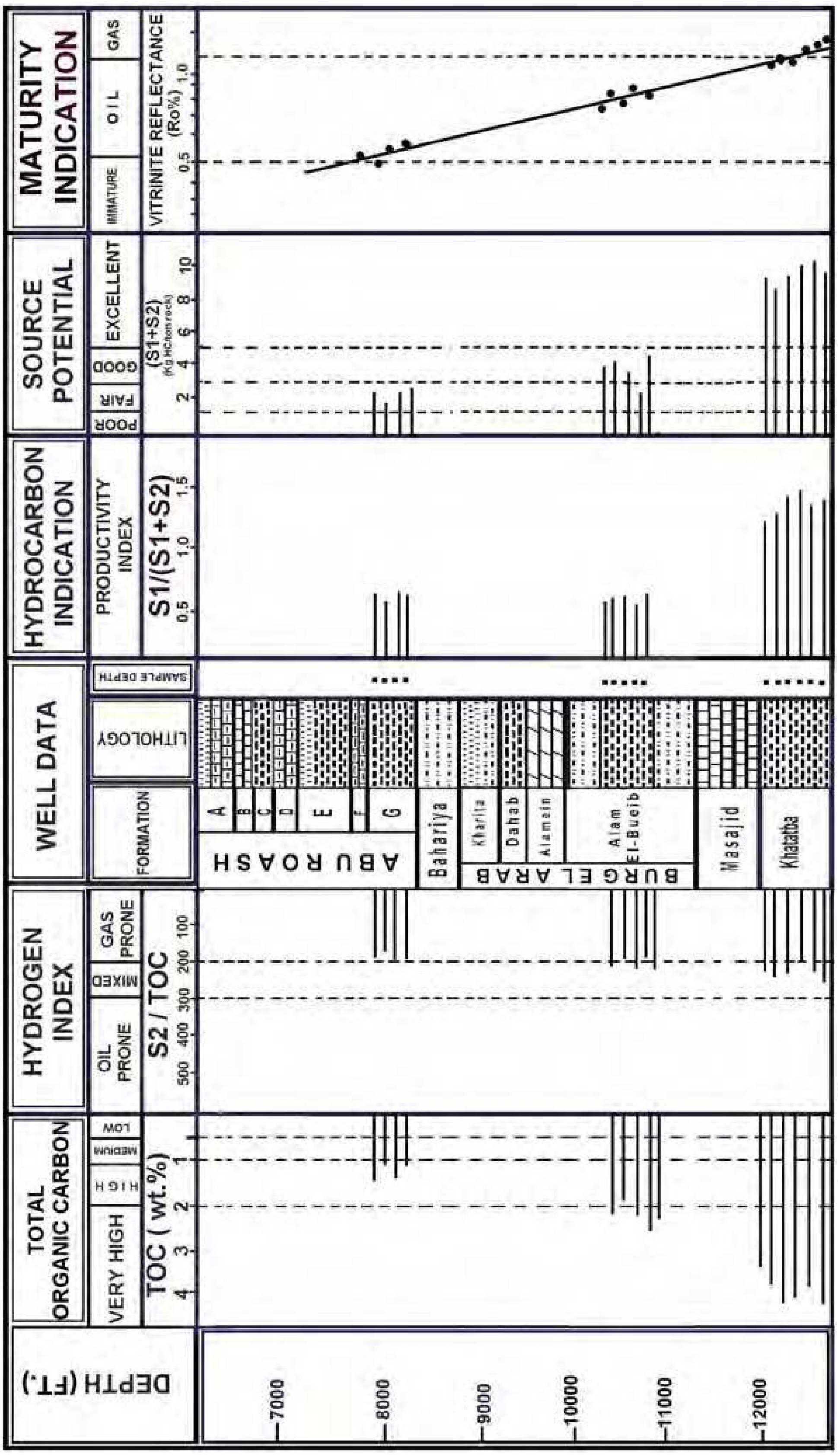

Fig. 3. Idealized geochemical log to the well Shushan-1X, showing Rock-Eval pyrolysis data, total organic carbon and vitrinite reflectance measurements.

5. Type of organic matters (kerogen types)

Kerogen types are distinguished using the Hydrogen Index (HI) versus Oxygen Index (OI) on Van Krevelen Diagram originally developed to characterize kerogen types (Van Krevelen, 1961 and modified by Tissot *et al.,* 1974). Figure (4) shows a plot of hydrogen index (HI) versus oxygen index (OI) on Van Krevelen diagram for the studied shale source rock intervals of Khatatba, Alam El-Bueib and Abu Roash-G from well Shushan-1X. The figure shows that Khatatba Alam El-Bueib and Abu Roash shales contain mixed kerogen types II-III. This kerogen type of mixed vitrinite-inertinite derived from land plants and preserved remains of algae (Peters *et al.,*1994). Mixed kerogen type characterizes mixed environment containing admixture of continental and marginal marine organic matter have the ability to generate oil and gas accumulations (Hunt, 1996).

6. Thermal maturity of organic matters

Thermal maturation of organic material is a process controlled by both temperature and time (Waples, 1994). The vitrinite reflectance is used to predict the hydrocarbon generation and maturation.

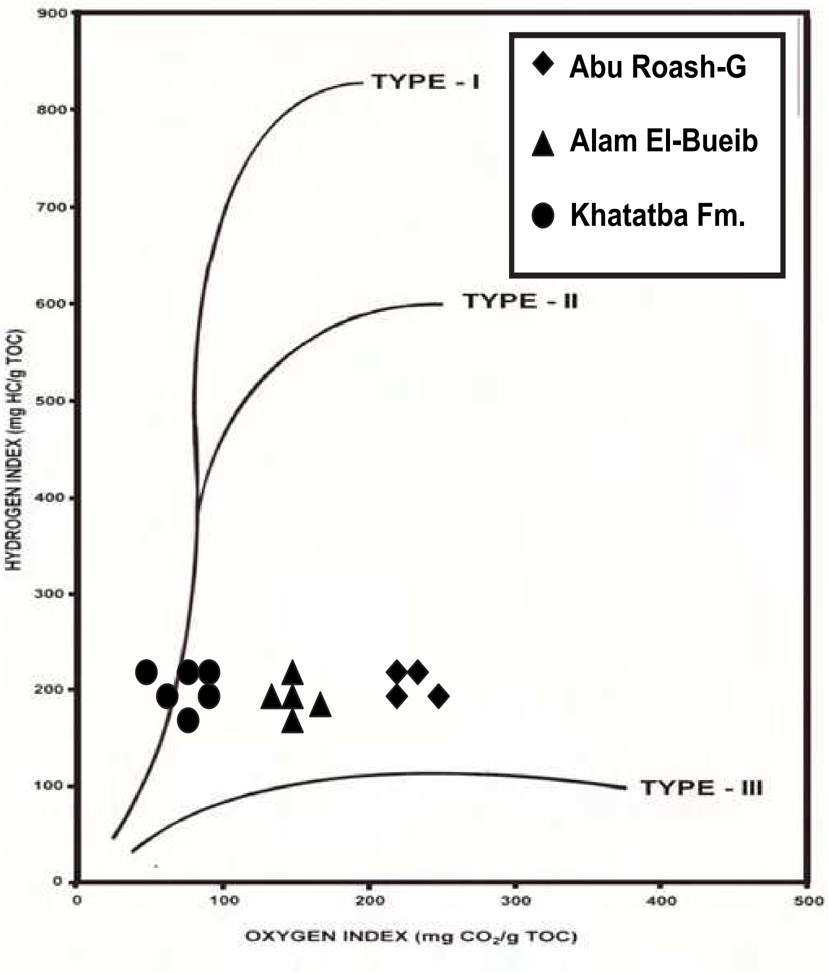

Fig. 4. Hydrogen index (HI) versus oxygen index (OI) and the locations of source rock kerogen types after Van Krevelen (1961).

The data of vitrinite reflectance measurements (Ro%) for the well Shushan-1X were plotted against depth (Figure 3) to indicate the phases of hydrocarbon generation and expulsion. Based on the maturity profile in the burial history model of the well Shushan-1X (Fig.5). The burial history model of the different hydrocarbon bearing rock units indicate that the shale source rock of Khatatba Formation entered the late mature stage of oil and gas generation window between vitrinite reflectance measurements between 1.0-1.3 Ro% during the Late Cretaceous. The shale source rock of Alam El-Bueib Member entered the mid mature stage of oil generation window between vitrinite reflectance measurements between 0.7-1.0 Ro% during the Late Cretaceous while shale source rock of Abu Roash-G Member entered the early mature stage of oil generation at vitrinite reflectance values between 0.5-0.7 Ro% at time varying from Late Cretaceous to Late Eocene.

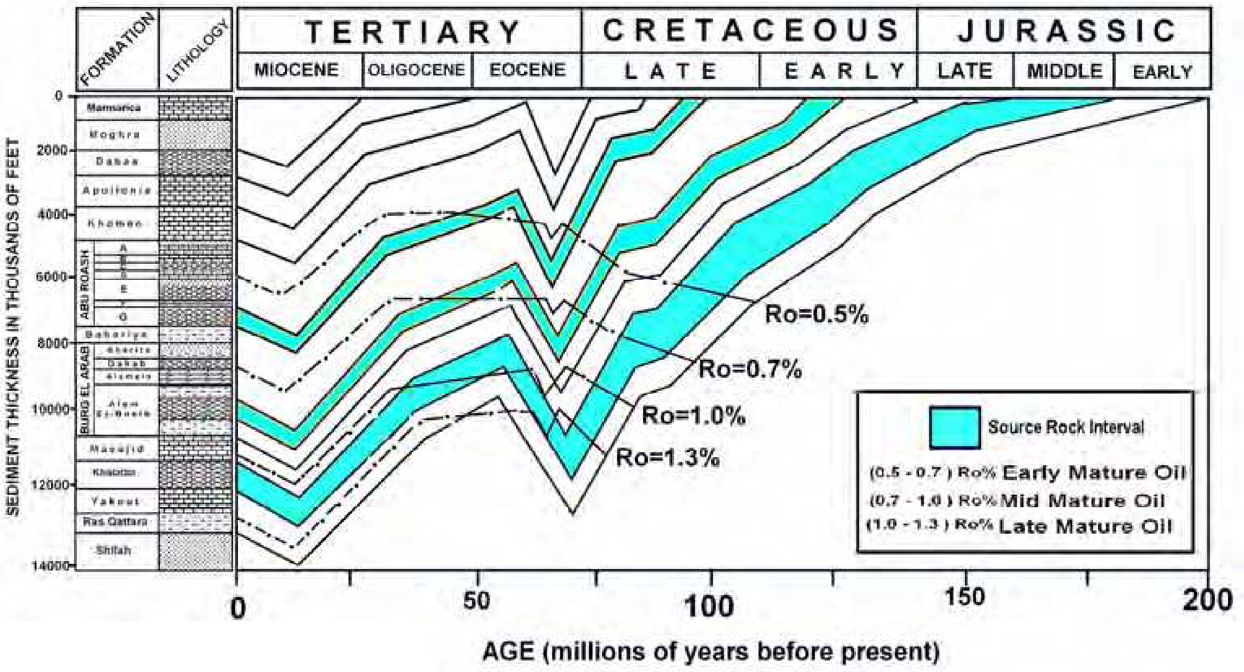

Fig. 5. Burial history model of the well Shushan-1X and stages of hydrocarbon generation windows.

The relationship between Hydrogen Index (HI) with Maximum Temperature (Tmax$_)$ and Total Organic Carbon (TOC) to the studied shale source rocks of the Khatatba, Alam El-Bueib and Abu Roash-G succession (Figures 6 & 7) indicate that the shale source rocks of Khatatba Formation located within the oil and gas generation window and considered excellent source rock potential. Meanwhile, the shale rocks of Alam El-Bueib and Abu Roash-G members are considered good source rock for oil generation having a less degree of thermal maturation in comparable with the shale source rock of Khatatba Formation.

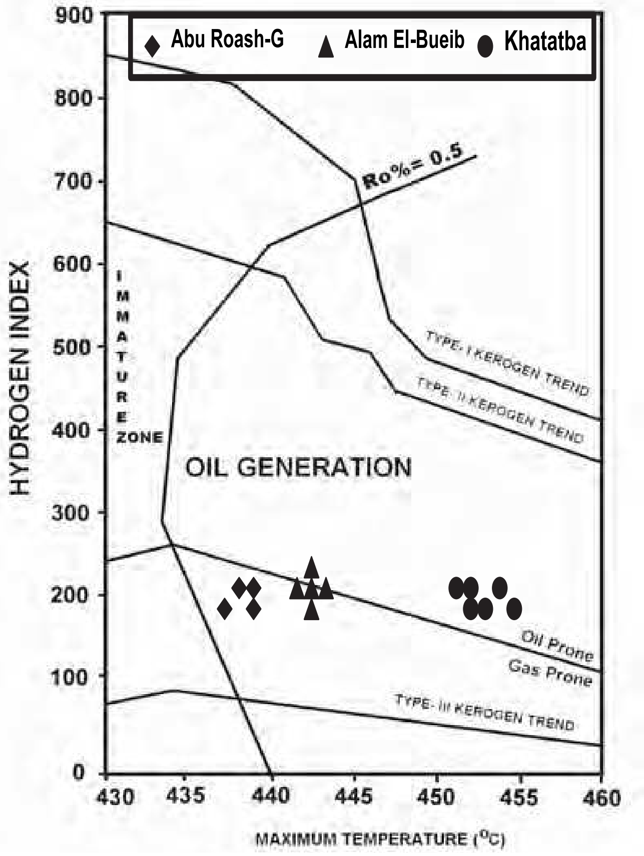

Fig. 6. Relation between HI and T_{max}. and the locations of Khatatba, Alam El-Bueib and Abu Roash-G source rocks.

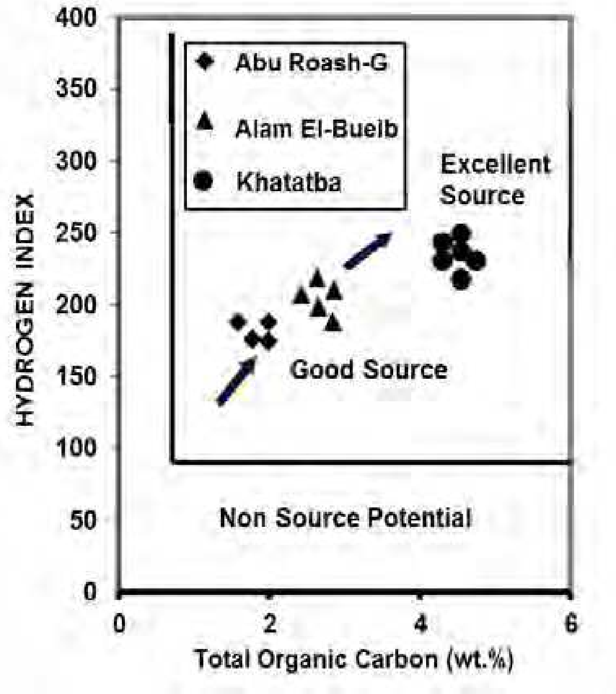

Fig. 7. Relation between HI and TOC and the locations of Khatatba, Alam El-Bueib and Abu Roash-G source rocks.

7. Source rock extracts

Two types of extracts can be identified in this study on the basis of the saturate/aromatic and the pristine/phytane ratios. Type (A) includes Abu Roash-G and Alam El-Bueib while, type (B) represents Khatatba Formation (Table 2).

GC and GC-MS chromatograms (Figure 8) with peak identification in Tables (3&4) of type (A) extracts have a predominance of saturate compounds rather than aromatic with the ratios of saturate/aromatic of about 2.5, pristane/phytane around 0.6 and Ts/Tm 0.5. The plotting of isoprenoids/n-alkanes on the diagram (Figure 9) after Shanmugam (1985) shows that the organic matters in the shale source rocks of Alam el-Bueib and Abu Roash-G are of mixed sources with significant terrestrial contribution as indicated from the low ratio of C_{30} moretane less than 10%. The predominance of C_{27} regular steranes (Figure 10) and diasteranes indicates the greater input of terrestrial organic matters. The low ratio of [20S/20S+20R] $C_{29}\alpha\alpha\alpha$ steranes of about 0.4, which in turn low maturity level of hydrocarbon generation of Alam El-Bueib and Abu Roash-G members shale source rocks.

Type (B) extract of Khatatba Formation of waxy type with the ratio of saturate/aromatic of 1.2, pristane/phytane of 0.7 and Ts/Tm 0.7. The plotting of isoprenoids/n-alkanes on Fig. 9 suggests that the organic matters derivation from terrestrial sources (Moldowan et al., 1985). This conclusion is further supported from the relatively high ratio of C_{30} moretane of 14%. The predominance of C_{27} regular steranes (Figure 10) indicates higher land plants input of terrestrial of sources (Huang and Meinschein, 1979). The high ratio of [20S/20S+20R] $C_{29}\alpha\alpha\alpha$ steranes 0.59,which in turn high maturity level of hydrocarbon generation of Khatatba shale source rocks than the shale source rocks of Alam El-Bueib and Abu Roash-G members.

Depth (ft.)	Formation	TOC wt.%	HI	OI	S1/(S1+S2)	S1+S2	Vitrinite Reflectance Ro%
7850	Abu Roash-G	1.50	195	215	0.55	0.90	0.55
7900	Abu Roash-G	1.10	188	210	0.60	0.85	0.50
8000	Abu Roash-G	1.40	200	207	0.65	0.85	0.57
8050	Abu Roash-G	1.20	200	213	0.60	1.10	0.60
10500	Alam El-Bueib	2.15	205	196	0.71	4.00	0.85
10650	Alam El-Bueib	1.85	200	185	0.72	4.20	0.83
10780	Alam El-Bueib	2.10	210	188	0.65	4.10	0.82
10820	Alam El-Bueib	2.40	195	168	0.62	3.60	0.91
10900	Alam El-Bueib	2.20	205	150	0.61	4.50	0.95
11920	Khatatba	3.60	220	100	1.35	8.00	1.10
11980	Khatatba	3.85	240	89	1.45	9.00	1.22
12000	Khatatba	4.20	235	94	1.62	10.10	1.25
12150	Khatatba	4.10	200	77	1.70	10.00	1.30
12340	Khatatba	3.95	215	87	1.58	10.65	1.35
12560	Khatatba	4.15	245	58	1.69	9.85	1.36

S1: mg HC/g rock., HI (Hydrogen Index): mg HC/g TOC, S1 + S2: Source Potential (Kgm HC/ton rock)
S2: mg CO_2/g rock., OI (Oxygen Index): mg CO_2 / g TOC, S1/(S1+S2): Productivity index

Table 1. Rock-Eval pyrolysis data and vitrinite reflectance (R_o%) data of the shale rock samples representing Abu Roash-G, Alam El-Bueib and Khatatba formations from the well Shushan-1X.

Biomarker Characteristics	Abu Roash-G Extract	Alam El-Bueib Extract	Khatatba Extract
Liguid Chromatography			
Saturates %	59.20	62.18	34.50
Aromatics %	23.50	24.45	26.80
NSO (Polars) %	17.30	13.37	38.70
Sat./Arom.	2.52	2.54	1.28
GC Parameters			
Pr/Ph	0.67	0.68	0.76
Pr/n-C17	0.49	0.44	0.31
Ph/n-C18	0.45	0.40	0.40
CPI	1.03	1.09	1.06
GC- MS Parameters			
1-Terpanes (m/z 191)			
C_{30} Moretane	0.08	0.07	0.14
Ts/Tm	0.54	0.58	0.76
Homohopane Index	1.52	1.48	0.89
2- Steranes (m/z 217)			
C_{27}%	50	48	54
C_{28}%	23	25	24
C_{29}%	27	27	22
[20S/(20S+20R)] C_{29} ααα steranes	0.48	0.46	0.59
StableCarbon Isotopes			
δ^{13}C Saturates ‰ (PDB)	-24.7	-24.8	-26.2
δ^{13}C Aromatics ‰ (PDB)	-22.4	-22.6	-24.3
Canonical Variable Parameter	1.11	0.92	0.69

Table 2. Mathematical classification of crude oils is dependent on the stable carbon isotopic composition of saturate and aromatic fractions of crude oils using the canonical variable parameter postulated by Sofer (1984) that equals (CV= $-2.53\delta^{13}C_{sat.} + 2.22\delta^{13}C_{arom.} - 11.65$).

Peak No.	Compound Name
1	C_{19} Tricyclic terpane
2	C_{20} Tricyclic terpane
3	C_{21} Tricyclic terpane
4	C_{22} Tricyclic terpane
5	C_{23} Tricyclic terpane
6	C_{24} Tricyclic terpane
Ts	C_{27} 18 α (H)-22, 29, 30- trisnorneohopane
Tm	C_{27} 17 α (H)-22, 29, 30- trisnorhopane
9	C_{29} 17 β (H), 21 α (H)- 30-normoretane
10	C_{30} Moretane
11	C_{30}17 β (H), 21 α (H)- moretane
12	C_{31} 17 α (H), 21β (H)-30 homohopane (22S)
	C_{31} 17 α (H), 21β (H)-30 homohopane (22R)
13	C_{32} 17 α (H), 21β (H)-30 bishomohopane (22S)
	C_{32} 17 α (H), 21β (H)-30 bishomohopane (22R)
14	C_{33} 17 α (H), 21β (H)-30 trishomohopane (22S)
	C_{33} 17 α (H), 21β (H)-30 trishomohopane (22R)
15	C_{34} 17 α (H), 21β (H)-30 tetrakishomohopane (22S)
	C_{34} 17 α (H), 21β (H)-30 tetrakishomohopane (22R)
16	C_{35} 17 α (H), 21β (H)-30 pentakishomohopane (22S)
	C_{35} 17 α (H), 21β (H)-30 pentakishomohopane (22R)

Table 3. Peak identification in the m/z 191 mass fragmentogram (Terpanes).

Peak No.	Compound Name
A	13β (H), 17a(H)- diacholestane (20S)
B	13β (H), 17a(H)- diacholestane (20R)
C	13 a (H), 17 β (H)- diacholestane (20S)
	13 a (H), 17 β (H)- diacholestane (20R) +
D	24- Methyl-13β (H), 17a(H)- diacholestane (20S)
	24- Methyl-13β (H), 17a(H)- diacholestane (20R)
E	5 a (H), 14 a (H), 17 a (H) – cholestane (20S)
F	5 a (H), 14 β (H), 17 β (H) – cholestane (20R) +
G	24- Ethyl-13β (H), 17a(H)- diacholestane (20S)
	5 a (H), 14 β (H), 17 β (H) – cholestane (20S) +
H	24- Methyl-13β (H), 17a(H)- diacholestane (20R)
	5 a (H), 14 a (H), 17 a (H) – cholestane (20R)
I	24- Ethyl-13β (H), 17a(H)- diacholestane (20R)
J	24- Ethyl-13 a (H), 17 β (H)- diacholestane (20S)
K	5 a (H), 14 a (H), 17 β (H)– 24-methylcholestane (20S)
L	5 a (H), 14 a (H), 17 β (H)– 24-methylcholestane (20R)+
M	24- Ethyl-13 a (H), 17 β (H)- diacholestane (20R)
N	5 a (H), 14 β (H), 17 β (H)– 24-methylcholestane (20S)
O	24- Propyl-13 a (H), 17 β (H)- diacholestane (20S)
P	5 a (H), 14 a (H), 17 a (H)– 24-methylcholestane (20R)
Q	5 a (H), 14 a (H), 17 a (H)– 24-ethylcholestane (20S)
R	5 a (H), 14 β (H), 17 β (H)– 24-ethylcholestane (20R)
S	5 a (H), 14 β (H), 17 β (H)– 24-ethylcholestane (20S)
T	5 a (H), 14 a (H), 17 a (H)– 24-ethylcholestane (20R)

Table 4. Peak identification in the m/z 217 mass fragmentogram (Steranes).

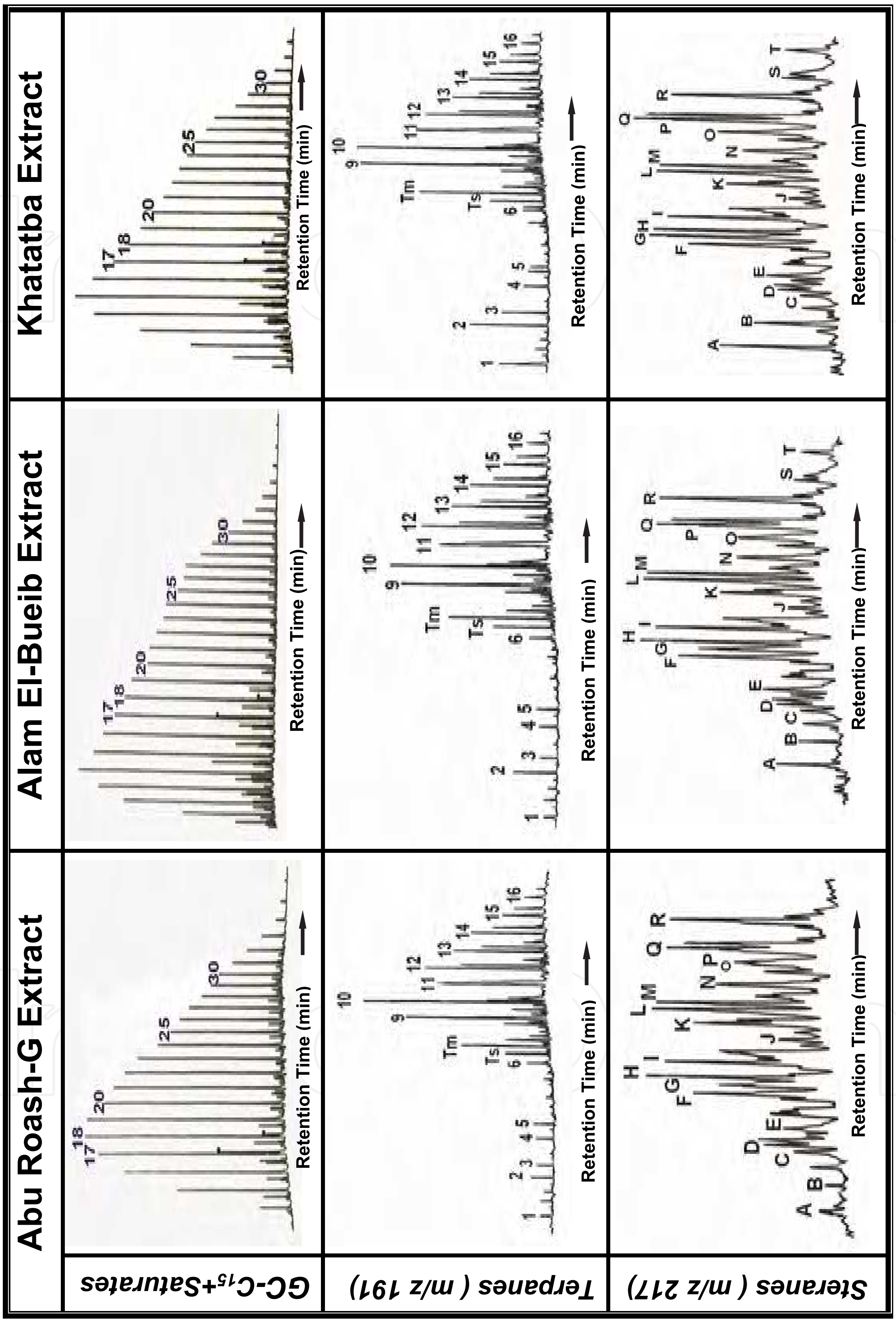

Fig. 8. C_{15}+ saturated hydrocarbons gas chromatograms, Triterpanes (m/z 191) and Steranes (m/z 217) mass fragmentograms for the Khatatba, Alam El-Bueib and Abu Roash-G extracts with peaks identification in tables (3 &4).

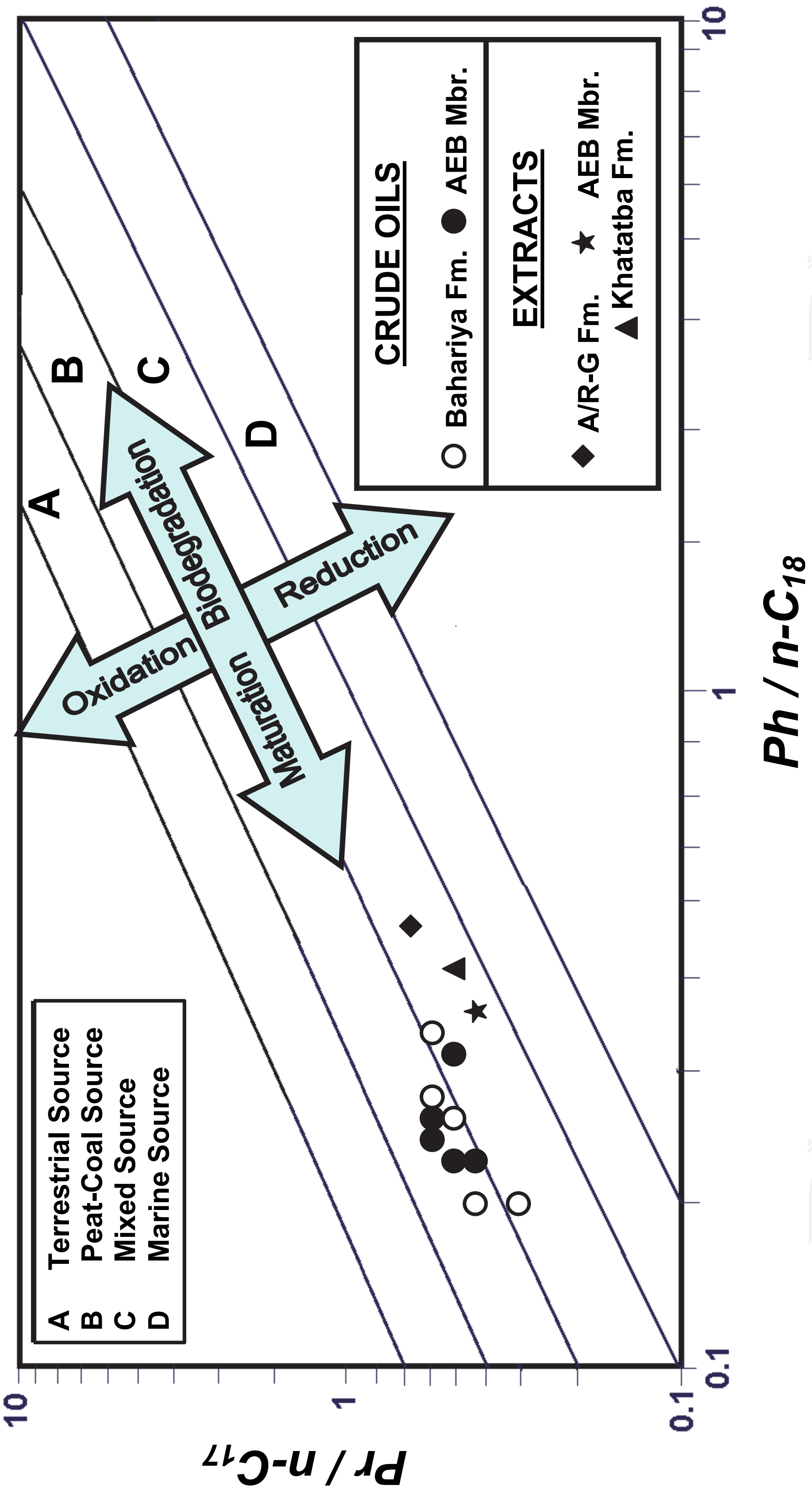

Fig. 9. Relationship between isoprenoid n-alkanes showing source and depositional environments (Shanmugam, 1985) and the locations of crude oils and extracts. from Shushan oilfields.

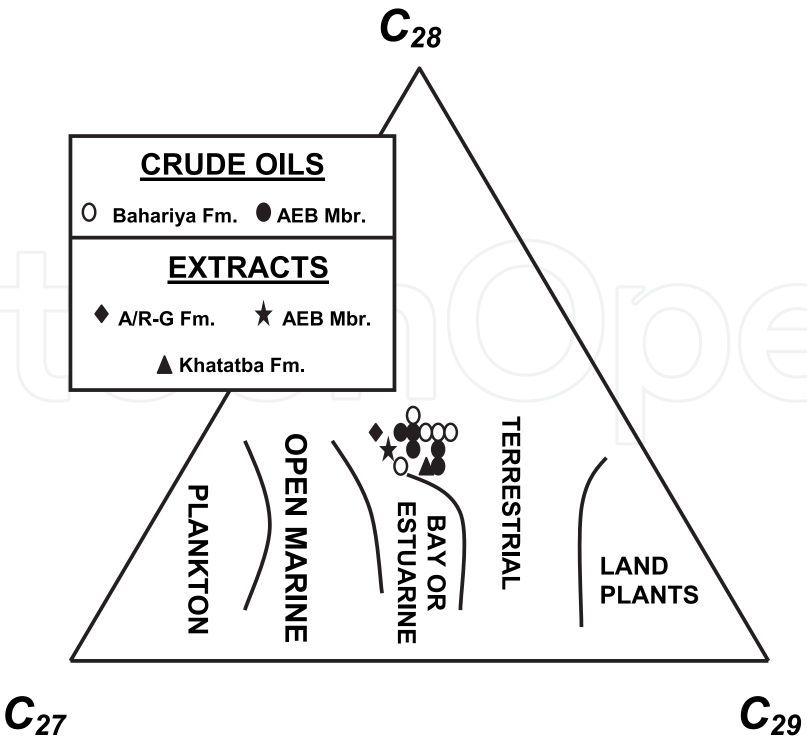

Fig. 10. Distribution of C_{27}, C_{28} and C_{29} steranes illustrating the depositional environments of the studied crude oils and extracts of Shushan oilfields (Huang and Meinschein, 1979).

8. Geochemical relations of fluids

8.1 Crude oils characteristics

Taher *et al*., (1998), Zein El-Din *et al.,* (1990), Younes (2002 and 2003), El-Nadi *et al.,* (2003), Harb et al., (2003) and El-Gayar (2003) used the geochemical fingerprints of crude oils produced from different basins of the northern Western Desert to assess the genetic relationship between hydrocarbon generation and their source rock depositional environments. Ten crude oil samples from several wells recovered from the different producing zones of the Bahariya and Alam El-Bueib reservoirs (Table 5).

8.2 Formational water characteristics

The chemical composition, properties and the calculated reaction statements are given in Table 6. According to Palmer׳s system of formational water characterization (Collins, 1975), the Bahariya and Alam El-Bueib waters (Fig.13) are assigned to "class 6", whose reaction statement is "S_1, S_2, S_3, A_2 and A_3″ (i.e. Primary, secondary and tertiary salinity in addition to secondary and tertiary alkalinity). According to Sulin׳s method of water characterization the ratio of Na/Cl for all the studied samples are generally less than 1 ranging between 0.65 to 0.50 characterized by complete isolation of the hydrocarbon accumulations and the basin of accumulation is considered a good zone for hydrocarbon preservation (El-Zarka and Ahmed, 1983 and Hunt, 1996).

Figure 13, denotes that the Bahariya and Alam El-Bueib water types as chloride-calcium type where this type of waters are the most likely type to be associated with a hydrostatic environment which promotes the accumulation of hydrocarbon in the Jurassic-Cretaceous rocks. Waters of the chloride- calcium type characterized by Cl-Na/Mg >1 indicate an increase of chloride with respect to Na and Mg and $CaCl_2$ is yielded.

The index of base exchange (Cl-Na/Cl) for the studied formational waters equals about 0.2 indicates that the metal ions dissolved in the water have been exchanged with the alkali metals on the clays constituting the source rocks of Khatatba, Alam el-Bueib and Abu Roash-G. The predominant cation sequence is Na >Ca >Mg >Fe, while the predominant anion sequence is Cl >SO_4 >HCO_3.

The salinity of formational water decreases stratigraphically upwards from Alam El-Bueib to Bahariya this related most probably to the mutual reaction between formation water with oil and source rocks during upward migration process (El-Zarka and Younes, 1987).

8.3 Family (I): Bahariya crude oils

Family (I) represents Bahariya crude oils which have a wide range of API gravities between 32.6^o and 43.3^o with correspond to a high variation of sulfur content, which was found to be ranges between 0.05 and 0.13 wt.%. Liquid chromatograph data indicate a predominant composition of saturates to become more than 65%, with saturate/aromatic ratio more than 2.30. The plot of Pr/n-C_{17} versus Ph/n-C_{18} (Figure 9) suggests that these oils were derived from peat coal source environment of terrestrial origin (Shanmugam, 1985).

Mass fragmentograms of triterpane (m/z 191) and sterane (m/z 217) are shown in Figure 11, with peaks identification in (Tables 3&4). The ratio of C_{30} moretane was found to be <10% further suggests that the Bahariya crude oils may be derived from mixed source rocks dominated by terrestrial organic matters (Moldowan et al., 1985 and Zumberge, 1987). The regular C_{27} sterane distribution (Figure 10) further suggests their derivation from higher land plants input of terrestrial and estuarine environments (Huang and Meinschein, 1979). The ratio of [20S/(20S+20R)] $C_{29}\alpha\alpha\alpha$ sterane was found to be around 0.4, which in turn that these crude oils were generated at low level of thermal maturation (Peters and Fowler, 2002).

8.4 Family (II): Alam El-Bueib crude oils

Family (II) represents Alam El-Bueib crude oils which have low range of API gravities between 40.0^o and 42.9^o with correspond to a low variation of sulfur content, which was found to be ranged between 0.03 and 0.07 wt.%. The plotting of isoprenoids/n-alkanes on the diagram (Figure 9) suggests that these oils were derived from peat coal source environment derived from terrestrial sources (Shanmugam, 1985).

Mass fragmentograms of triterpane (m/z 191) and sterane (m/z 217) are shown in Figure 11, with peaks identification in Tables 4&5. The ratio of C_{30} moretane was found to be >10% further suggests that Alam El-Bueib crude oils may be derived from source rocks of higher input from terrestrial organic matters. The plotting of $C_{27,}$ C_{28} and C_{29} on a triangular diagram (Figure 10) further suggests their derivation from higher land plants input of terrestrial and estuarine environments (Huang and Meinschein, 1979). The ratio of [20S/(20S+20R)] $C_{29}\alpha\alpha\alpha$ sterane was found to be >0.5, which in turn that the Alam El-Bueib crude oils were generated at relatively high level of thermal maturation rather than Bahariya crudes.

Crude Oil Characteristics	W E L L N A M E S									
	Kah-C2	**Kh-38**	**Kenz-9**	**Hay.-27**	**Safir-N8**	**Tut-31**	**Sal.-44**	**Yass.-12**	**Shrouk-9**	**Mel. NE-7**
Reservoir Age	Bahariya	Bahariya	Bahariya	Bahariya	Bahariya	AEB	AEB	AEB	AEB	AEB
API°	32.60	38.00	37.60	43.30	42.00	42.70	40.00	41.60	43.20	42.90
Sulfur (wt.%)	0.13	0.12	0.07	0.05	0.05	0.05	0.05	0.07	0.06	0.03
Liguid Chromatography										
Saturates %	64.10	65.20	65.10	66.30	67.00	64.10	66.30	67.20	71.30	74.30
Aromatics %	27.65	26.40	27.50	28.40	27.20	28.50	27.40	26.10	22.10	20.20
NSO (Polars) %	8.25	8.40	7.40	5.30	5.80	7.40	6.30	6.70	6.60	5.50
Sat./Arom.	2.31	2.47	2.37	2.33	2.46	2.25	2.42	2.57	3.23	3.68
GC Parameters										
Pr / Ph	1.51	1.58	1.47	1.13	1.49	1.68	1.97	2.10	2.15	3.71
Pr / n-C17	0.41	0.37	0.17	0.28	0.35	0.43	0.28	0.43	0.62	0.35
Ph / n-C18	0.31	0.28	0.18	0.19	0.29	0.32	0.21	0.18	0.24	0.12
CPI	1.01	1.01	0.98	1.02	1.00	1.05	1.01	0.97	1.01	1.08
GC- MS Parameters										
1-Terpanes (m/z 191)										
C_{30} Moretane	0.06	0.05	0.04	0.07	0.05	0.13	0.10	0.11	0.12	0.11
Ts/Tm	0.61	0.62	0.57	0.49	0.55	0.71	0.66	0.68	0.69	0.71
Homohopane Index	1.85	1.65	1.48	1.70	1.50	0.90	0.85	0.78	0.69	0.88
2- Steranes (m/z 217)										
C_{27}%	45	44	46	43	47	52	51	55	48	51
C_{28}%	20	23	26	22	25	21	24	20	26	28
C_{29}%	35	33	28	35	28	27	25	25	26	21
[20S/(20S+20R)] C_{29} ααα steranes	0.45	0.46	0.43	0.47	0.46	0.57	0.55	0.54	0.55	0.57
StableCarbon Isotopes										
δ^{13}C Saturates ‰ (PDB)	-24.8	-24.9	-25.9	-24.8	-24.7	-24.6	-25.3	-24.9	-25.2	-25.4
δ^{13}C Aromatics ‰ (PDB)	-22.3	-22.7	-23.3	-22.6	-21.9	-22.3	-21.5	-22.9	-22.6	-23.1
Canonical Variable Parameter	1.59	1.95	2.15	0.92	2.22	1.08	4.62	0.51	1.93	1.32

Table 5. A summary of biomaker characteristics and stable carbon isotope composition of the Bhariya and Alam El-Bueib crude oils from Shushan oilfields.

Formational Water Characteristics	WELL NAMES									
	Kah-C10	**Sal.-21**	**Yasser-3**	**Hayat-2**	**Shrouk-1**	**Sal.-11**	**Sal.-22**	**Tut-9**	**Tut-10**	**Tut-11**
Reservoir Age	**Bahariya**	**Bahariya**	**Bahariya**	**Bahariya**	**Bahariya**	**Bahariya**	**Bahariya**	**AEB**	**AEB**	**AEB**
Specific Gravity (gm/cm³)	1.09	1.1	1.07	1.08	1.05	1.1	1.1	1.03	1.1	1.14
PH	6	6.3	6.5	6.9	6.6	5.3	5.5	6.0	6.5	6.6
TDS (ppm)	139200	179400	124000	112240	101200	150889	146699	226845	226200	219533
Composition %epm										
CATIONS **Na**	83.6	79.1	83.9	82.1	86.2	76.2	77.5	74.0	72.5	72.7
Ca	12.3	16.2	12.5	14.3	11.1	18.1	17.1	20.0	21.3	19.9
Mg	4	4.6	3.4	3.5	2.6	5.2	5.2	5.8	5.9	7.1
Fe	0.1	0.1	0.2	0.1	0.1	0.3	0.2	0.2	0.3	0.3
ANIONS **Cl**	99.5	99.1	98.4	99.5	97.1	99.4	99.1	99.5	99.6	99.6
So$_4$	0.3	0.7	1.1	0.2	1.9	0.5	0.7	0.4	0.2	0.2
HCO$_3$	0.2	0.2	0.5	0.3	0.5	0.1	0.2	0.1	0.2	0.2
Reaction Statements										
S$_1$	83.6	79.1	83.9	82.1	86.2	76.4	77.5	74.0	72.5	72.7
S$_2$	16.2	20.7	15.6	17.6	13.3	23.2	22.3	25.8	27.2	27.0
S$_3$	-----	-----	------	-----	-----	-----	-----	0.1	0.1	0.1
A$_2$	0.1	0.1	0.3	0.2	0.4	0.2	0.1	------	-----	-----
A$_3$	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Reaction Parameters										
SULIN Na/Cl	0.58	0.50	0.59	0.58	0.61	0.55	0.55	0.54	0.53	0.53
Na-Cl/SO$_4$	-53.3	-28.5	-13.2	-87.0	-6.0	-46.0	-30.8	-63.8	-135.5	-134.5
Cl-Na	15.9	20	14.5	17.4	15	23	21.6	25.5	27.1	26.9
Cl-Na/Mg	3.9	4.3	4.26	4.97	4.38	4.42	4.15	4.39	5.42	3.8
Cl-Na/Cl	0.16	0.2	0.15	0.17	0.15	0.23	0.22	0.26	0.27	0.27
Cl/Na	1.19	1.19	1.17	1.21	1.13	1.30	1.28	1.28	1.37	1.37
WATER TYPE	(Cl-Ca)	(Cl-Ca)	(Cl-Ca)	(Cl-Ca)	(Cl-Ca)	(Cl-Ca)	(Cl-Ca)	(Cl-Ca)	(Cl-Ca)	(Cl-Ca)
TDS (Total Dissolved Salts)	**CHLORIDE – CALCIUM**									

Table 6.

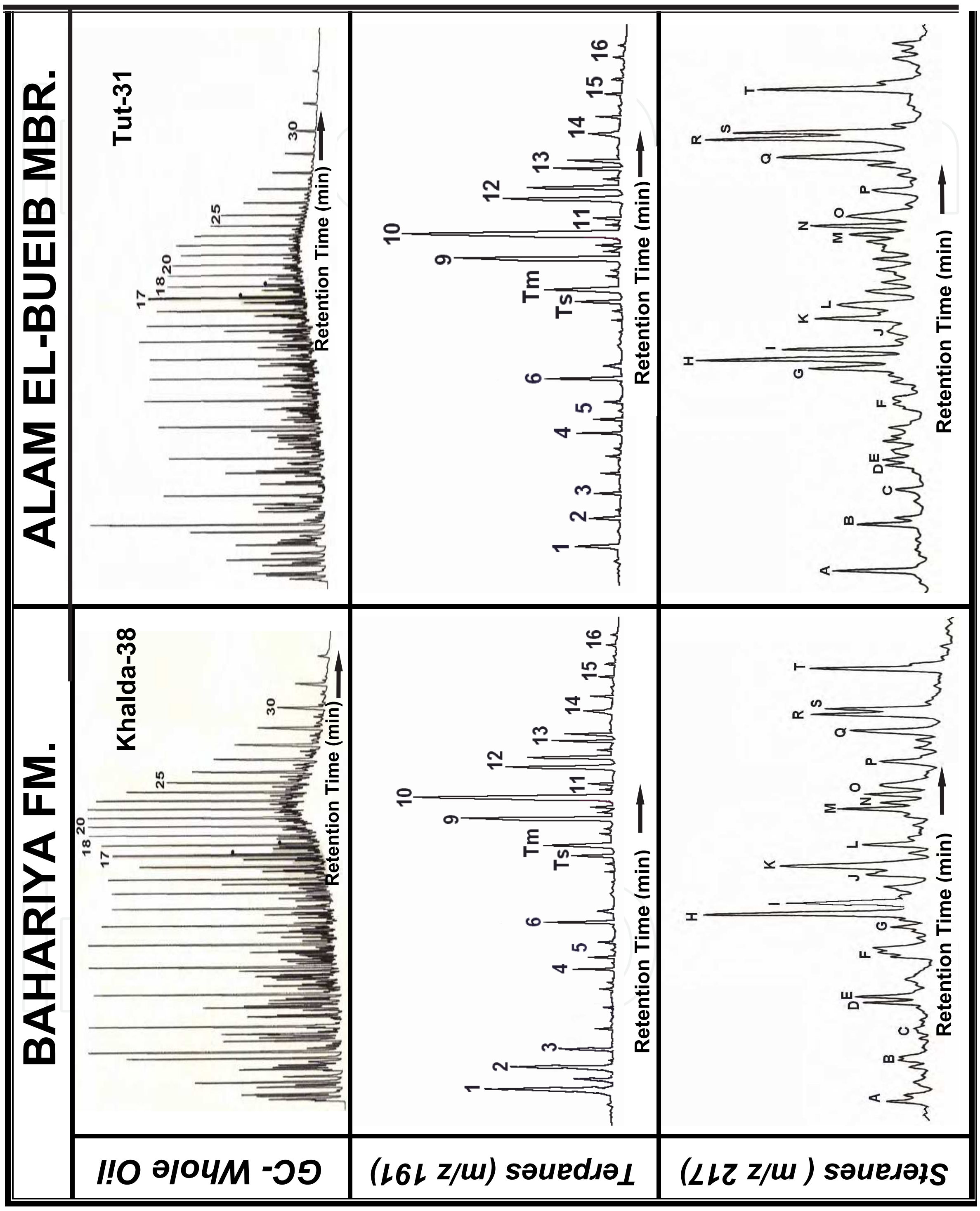

Fig. 11. Gas chromatograms and mass fragmentograms of triterpane m/z 191 and sterane m/z 217, with peaks identification in tables (3 &4) of crude oils from different wells of Shushan oilfields.

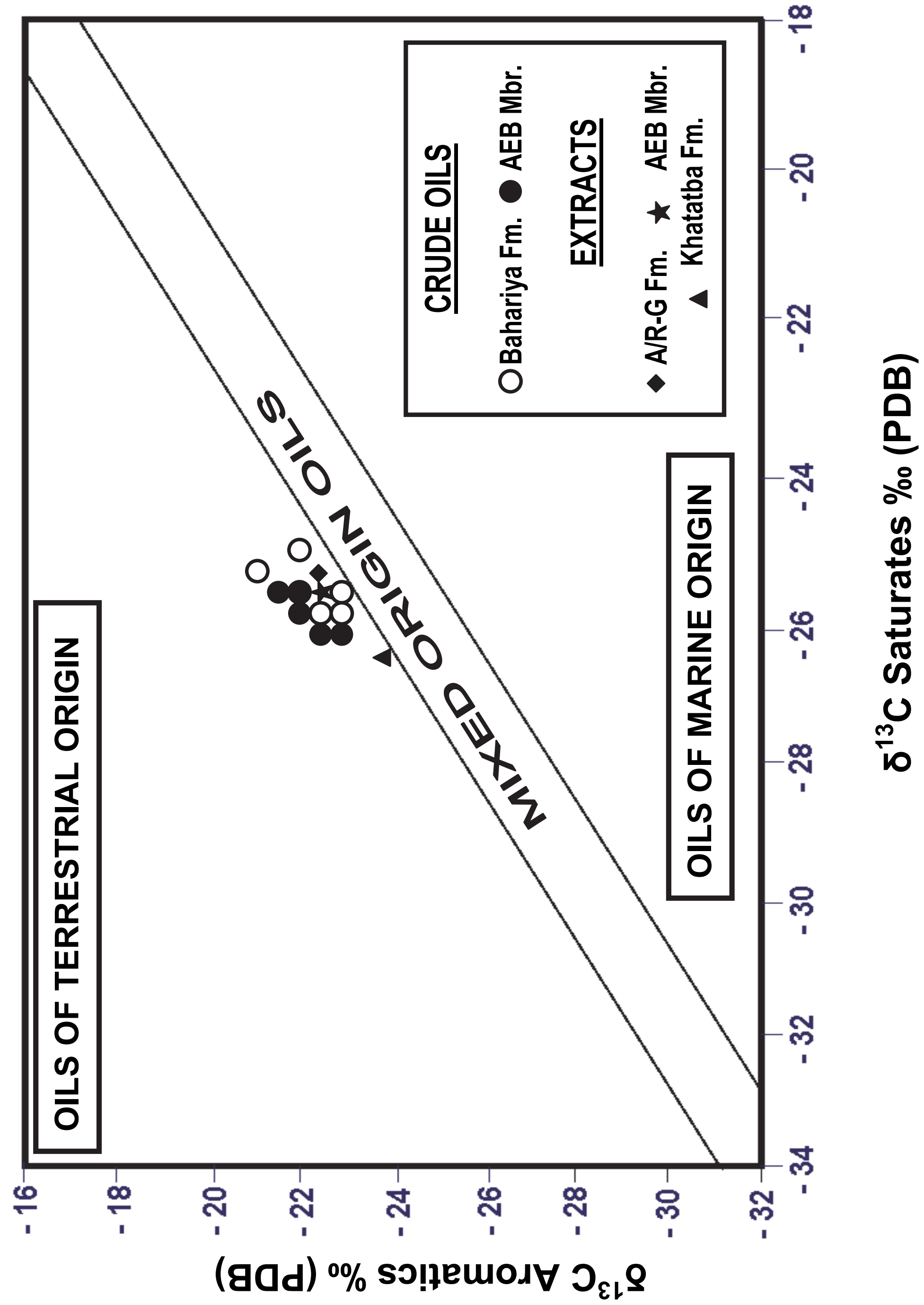

Fig. 12. Relationship between the stable carbon isotope composition of the saturate and aromatic fractions to the crude oils and extracts from Shushan oilfields (Sofer,1984).

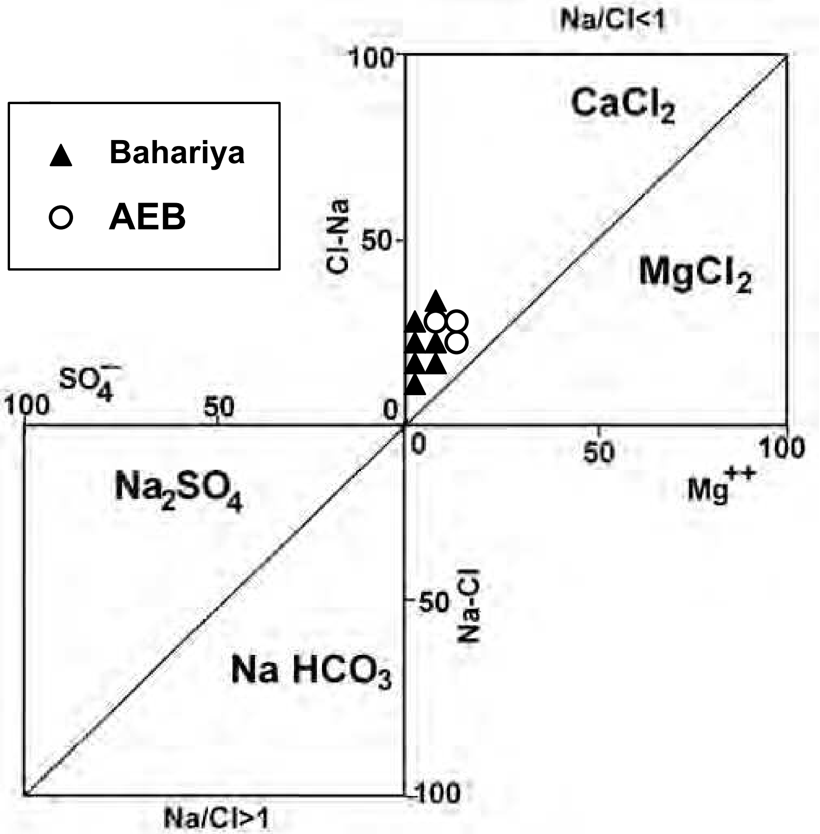

Fig. 13. Location of Bahariya and Alam El-Bueib formation waters on Sulin's diagram.

9. Stable carbon isotope composition

Taher *et al.,* (1988), Zein El-Din *et al.,* (1990) Ghanem *et al.,* (1999) Sharaf et al., (1999) and Younes (2002) used the stable carbon isotope composition to the aromatic and saturate fractions of the Western Desert crude oils and extracts to characterize waxy from non-waxy oil sources. Sofer (1984) distinguished the crude oils derived from marine and non-marine sources for crude oils from different areas of the world including Egypt depending on the stable carbon isotope δ^{13} C compositions to the saturate and aromatic fractions. He applied a mathematical relation to conclude the canonical variable parameter that differentiates between the source of crude oils and their depositional environments.

Despite there are two types of extracts and two types of crude oils but they are isotopically similar and genetically related which may be attributed to slight differences in the degree of thermal maturity. The plotting of the stable carbon isotopic composition to the saturate and aromatic fractions of the studied crude oils in addition to the source rock extracts are shown in (Figure 12). The stable carbon isotopes of the saturate fraction to the extracts range between -26.2 and –24.7 ‰PDB); while for the aromatic fraction ranges between -24.3 and –22.6 ‰PDB. The stable carbon isotopes of the saturate fraction to the crude oils range between -25.4 and –24.7 ‰PDB); while for the aromatic fraction ranges between -23.1 and –21.5 ‰PDB.

The figure reveals that the studied crude oils are of terrestrial origin and the organic matter responsible for hydrocarbon generation in shale source rock of Khatatba, Alam El-Bueib and

Abu Roash-G were probably originated from terrestrial sources. This conclusion is also supported from the calculated canonical variable parameter which was found to be >0.47 for all the studied crude oils and source rock extracts indicate waxy oils type rich in terrigenous organic matters. This is confirm with the results achieved by Zein El-Din *et al.,* (1990), Ghanem *et al.,* (1999) and Younes (2002), who concluded that the Western Desert crude oils are characterized by waxy nature, high maturity level and less negative carbon isotope values derived from terrestrial origin.

10. Inferred oil - source correlation

An oil-source rock correlation is defined as a relationship between geochemical characteristics of crude oils and its original source facies (Curiale, 1994). Many attempts were made to correlate source rock extracts with the biomarker characteristics of crude oils in the Western Desert of Egypt by Taher *et al.,* (1988), Abdel-Gawad *et al.,* (1996), Sharaf *et al.,* (1999) El-Nadi *et al.,* (2003) Harb *et al.,* (2003) and Younes (2003).

10.1 Bahariya oils-type (A) extracts

The organic geochemical characteristics of the type (A) extract has a close similarities with the crude oils reservoired from Bahariya Formation. It is referred to similar biomarker characteristics for both the oils and extracts. They both show a similar C_{30} moretane ratio which found to be <10%, suggest terrestrial land plants influence and similar ratio of [20S/(20S+20R)] $C_{29}\alpha\alpha\alpha$ sterane, which found to be <0.5, reflect that these crude oils were generated at low level of thermal maturation.

10.2 Alam El-Bueib oils-type (B) extracts

Gas chromatograms show that both crude oils of Alam El-Bueib Member and type (B) extracts are of waxy type. They show identical C_{27} regular sterane distributions and similar C_{30} moretane ratio which found to be >10%, further suggest a higher terrestrial land plants input. The identical ratios of [20S/(20S+20R)] $C_{29}\alpha\alpha\alpha$ sterane, which found to be >0.5, reflect that these crude oils were generated from shale source rocks of Khatatba Formation at higher level of thermal maturation than those of Alam El-Bueib and Abu Roash-G source rocks.

11. Conclusions

The organic geochemical characteristics of crude oils and related source rock extracts in Shushan Basin of the northern Western Desert of Egypt revealed two types of extracts (A) and (B) and two families of crude oils. Fair correlation can be seen between type (A) extracts of Alam El-Bueib and Abu Roash-G source rocks and Bahariya crude oils, where the similar biomarker properties as C_{30} moretane ratio <10% and [20S/(20S+20R)] $C_{29}\alpha\alpha\alpha$ sterane <0.5, suggest that the Bahariya crude oils were derived from terrestrial land plants influence at low thermal maturity level. Alam El-Bueib crude oils and type (B) extracts of Khatatba Formation are genetically related and bear the same terrestrial source input but generated at higher thermal maturity level than those of Alam El-Bueib and Abu Roash –G source rocks as indicated from higher C_{30} moretane ratio >10% and [20S/(20S+20R)] $C_{29}\alpha\alpha\alpha$ sterane >0.5.

Organic rich rocks with excellent potential to generate mainly oil are present in the Middle Jurassic Khatatba Formation that entered the late mature stage of oil and gas generation window at vitrinite reflectance measurements between 1.0-1.3 Ro% during the Late Cretaceous. Meanwhile, a good to fair source rocks of Alam El-Bueib and Abu Roash-G Member that located within the early to mid and mature stages of oil generation window between vitrinite reflectance measurements 0.5 and 1.0 Ro% at time varying from Late Cretaceous to Late Eocene.

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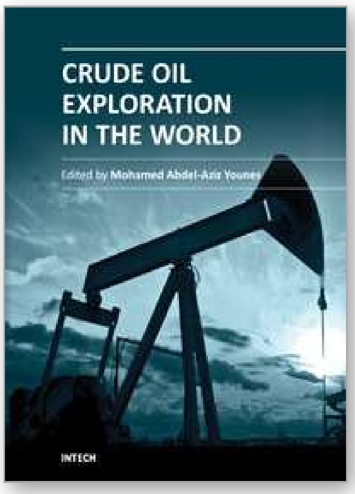

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