Petroleum Systems in the North Western Desert of Egypt

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Abstract: The northern part of the Western Desert, bound from the east by the River Nile, occupies a vast area of intracratonic sub-basins covered by the prospective Paleozoic to Tertiary sediments. Structural, stratigraphic and maturation studies indicate that migration studies guided by buoyancy drive, was initiated in the depocenters from potential Devonian and Jurassic source beds during Early Senonian and trapped in pre-Laramide structures. Pods of active sources were defined based on maturity modeling and mapping isopachs and pyrolysis results. Hydrocarbon charges, losses from catchment areas and recovery factors were normalized statistically. The least preservation risk is considered for hydrocarbons migrated from Cretaceous sources after the Alpine tectonics. Accordingly, the WD can be subdivided into five petroleum systems: Safa-Bahariya (!) system, Safa-Alamein (!) system, Safa-Khataba (!) system, Zaitun-Safa (.) system, and Khataba-Kharita (.) system. The five systems are under explored, being estimated to host 48 Boeb Eurr, about 15 times the proven ultimate recoverable reserves in the whole WD.

[Ahmed Nabil Shahin and Amira Mohamed Al-Awadly Petroleum Systems in the North Western Desert of Egypt. Life Science Journal. 2011;8(2):676-685] (ISSN:1097-8135). http://www.lifesciencesite.com.

Keyword: Petroleum System, North Western Desert.

Introduction:

The Western Desert (WD) of Egypt occupies a vast area of about 700,000 mi² of an intracratonic basin in an unstable shelf region where basinal areas are widespread. The northern part of the WD has about 110,000 mi³ of prospective sedimentary rocks, ranging in age from Paleozoic to Tertiary, in four main basins: Abu Gharadig, Alamein, Matruh-Shushan, and Fagur (shahin, 1989) (Fig 1). The objectives of this study are to classify the WD in terms of Petroleum Systems and carry an evaluation of the possible source of formation in each system.

Methods of Study

The approach used involves:

1. Interpretation of the analytical results of total organic carbon, Pyrolysis, and vitrinite reflectance measurements (Tissot and Welte, 1978 and Espitalie, *et al.*, 1977 and 1985) of over "467" cutting samples from "16" wells.
2. The time of generation and migration as well as the magnitude of the erosional events were estimated through the geochemical-geothermal-geohistory subsidence models (Lopatin, 1971 and Waples, 1980, 1985) combined with and verified by vitrinite reflectance measurements .
3. The Geochemical mass balance method (Tissot and Welte, 1978; Waples, 1985) has the advantage of covering most of the key genetic factors of oil and gas occurrence, e.g. the respective rock and oil densities, the level of maturation reached, and the volume of the effective source rocks resulted from modeling. Each of these variables was then exposed to quantitative risk analysis employing Mote Carlo simulation technique (Newendrop, 1975) and amounts of oil generated in each system were calculated (Table 1). Based on the expulsion and migration efficiency factors suggested by Momper (1975), Barker and Dickey (1984), and Waples (1985), and the recovery factors established in the SB(!) system (Shahin *et. al.*, 1986), the amounts of undiscovered recoverable oil and gas were estimated. For easy comparison among systems, the exploration performance parameters (Table 1) were normalized in relation to sedimentary volumes of the respective basins.

Petroleum Systems

The petroleum system emphasizes the genetic relation between specific source rock(s) and the resulting petroleum accumulations. It includes all essential elements and processes needed for oil and gas accumulations.

1. Elements of the Petroleum Systems

Source rock evaluation

An effective petroleum source rock must be containing organic matter higher than 0.5-1.0 weight percent total organic carbon (wt% TOC), capable of generating hydrocarbons, and reached a level of thermal maturation high enough to generate and expel commercial quantities of oil and / or gas. Peters (1986) rated a content of 0.5-1 wt% TOC as a fair source, 1-2 wt% TOC as a good source and more than 2 wt% TOC as a very good source. Such rating

was adopted in the present work.(Tissot and Welte (1978) and waples (1980 and 1985).

The geochemical analysis, including organic carbon (Fig 2), pyrolysis S2 (Fig 3), vitrinite reflectance measurements (Fig 4), and kerogen type based on pyrolysis HI and OI (van Krevelen-type cross plot) (Fig 5), suggest the following:

1. Createaceous Formations (Bahariya, Abu Roash and Kharieta) are immature to mature covering a wide range from poor to v. good potential to generate both oil and gas.

2. Jurassic Formations (Safa, Masajid and Khatatba) are immature to marginally mature covering a wide range from poor to good potential to generate both oil and gas.

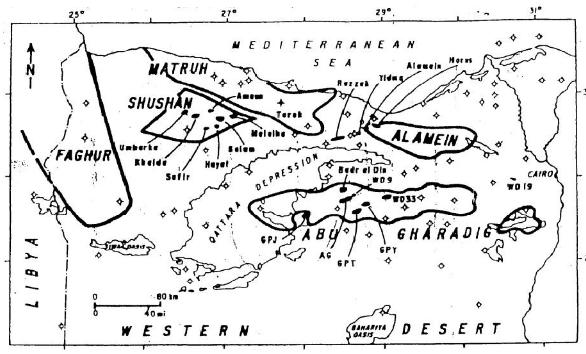
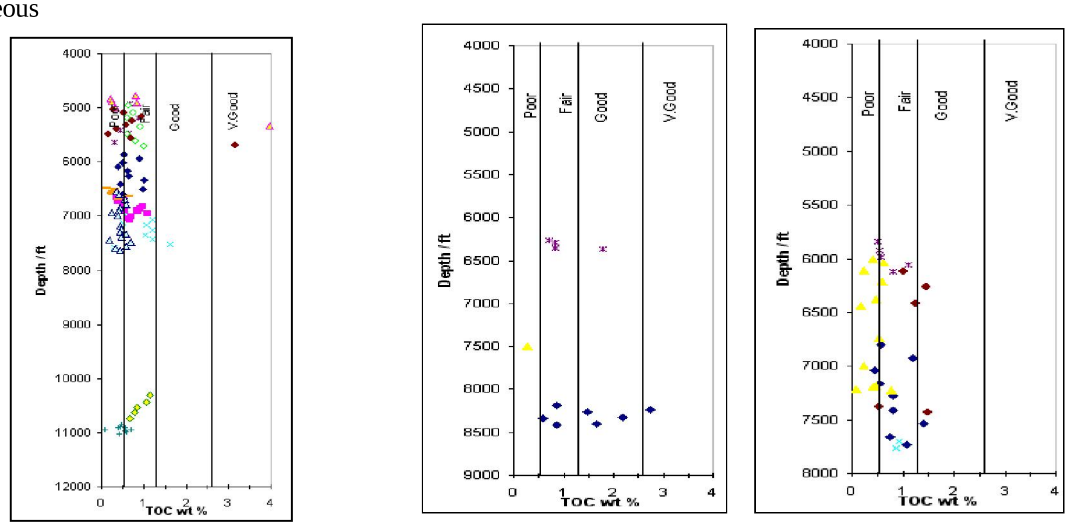


Fig 1: Fields and hydrocarbon generating basins in the northern Western Desert. (Shahin, 1998)

Cretaceous



Jurassic

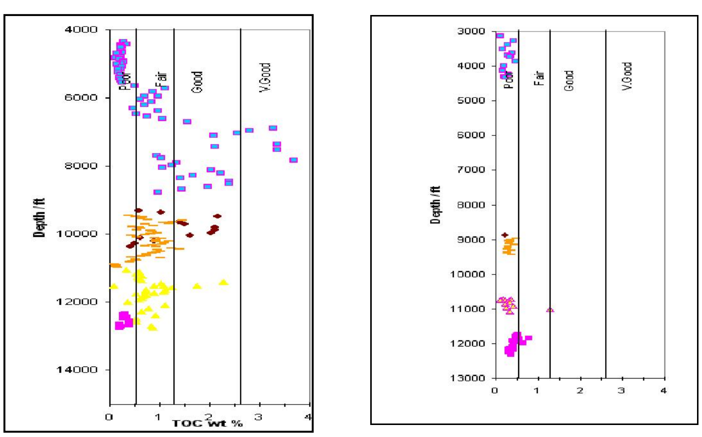
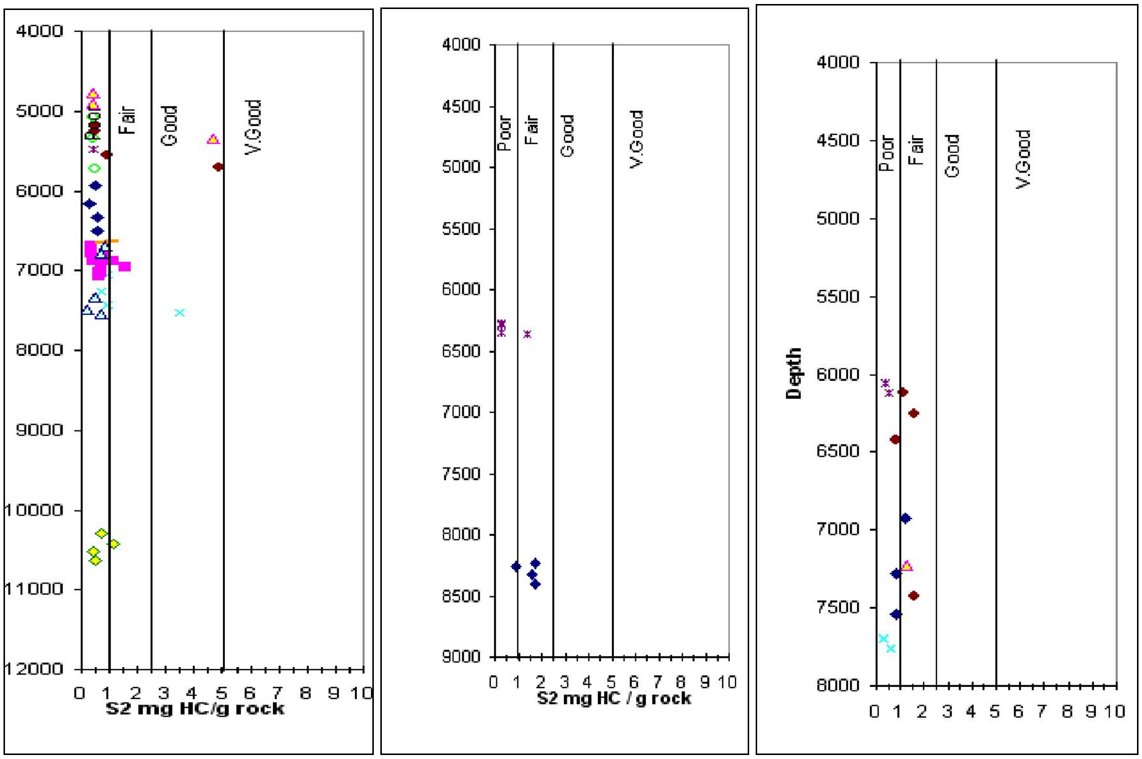


Fig 2: Organic richness of potential source rocks in the northern WD, in weight percent total organic carbon. Symbols represent samples from different wells.

Cretaceous



Jurassic

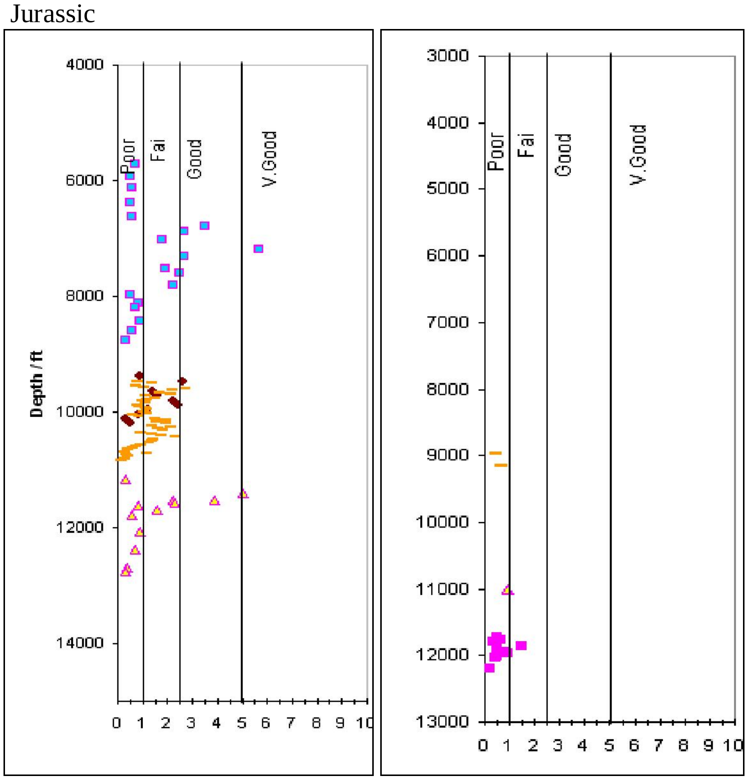
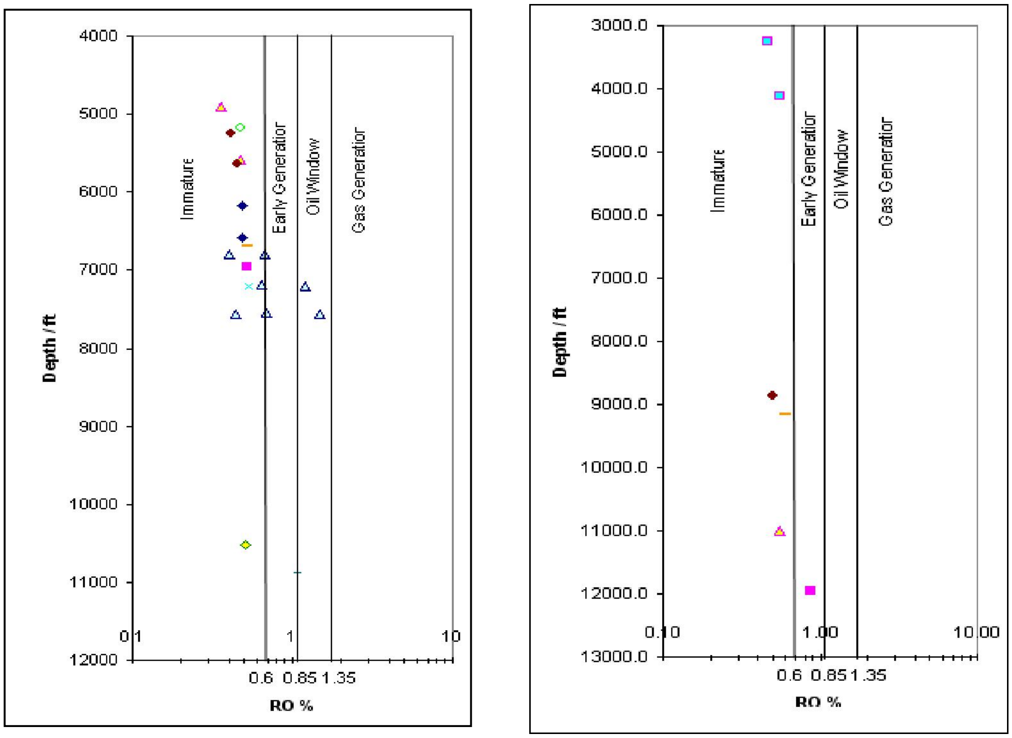


Fig 3: Hydrocarbon generating potential expressed in the pyrolysis – S2 values in ppm. Symbols represent samples from different wells

Cretaceous



Jurassic

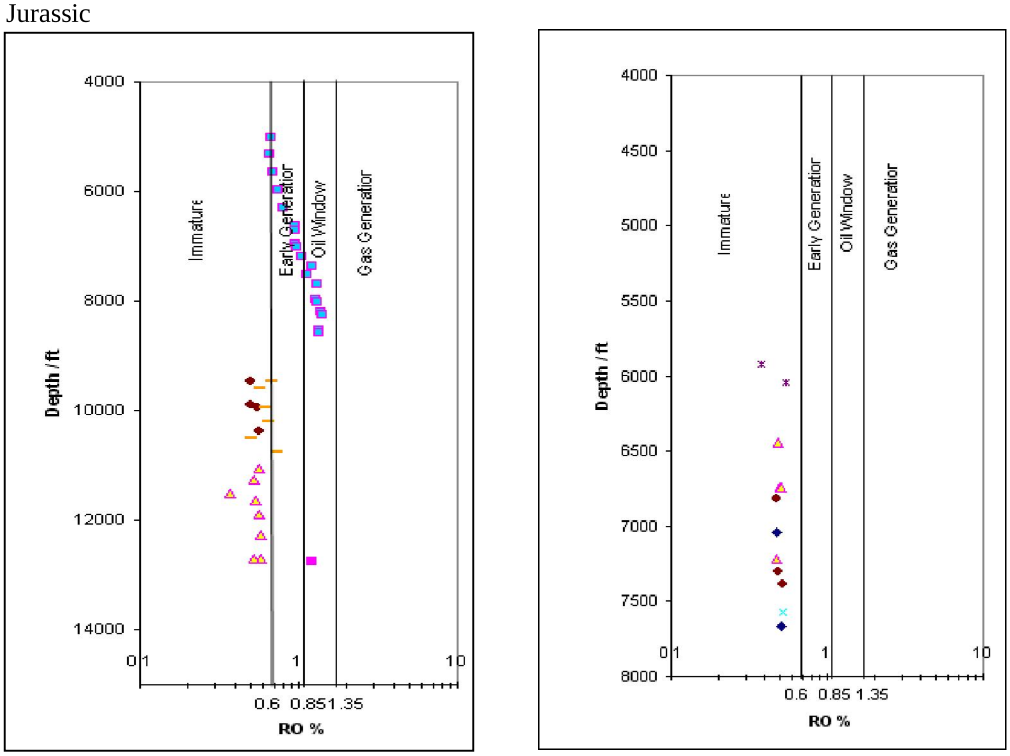
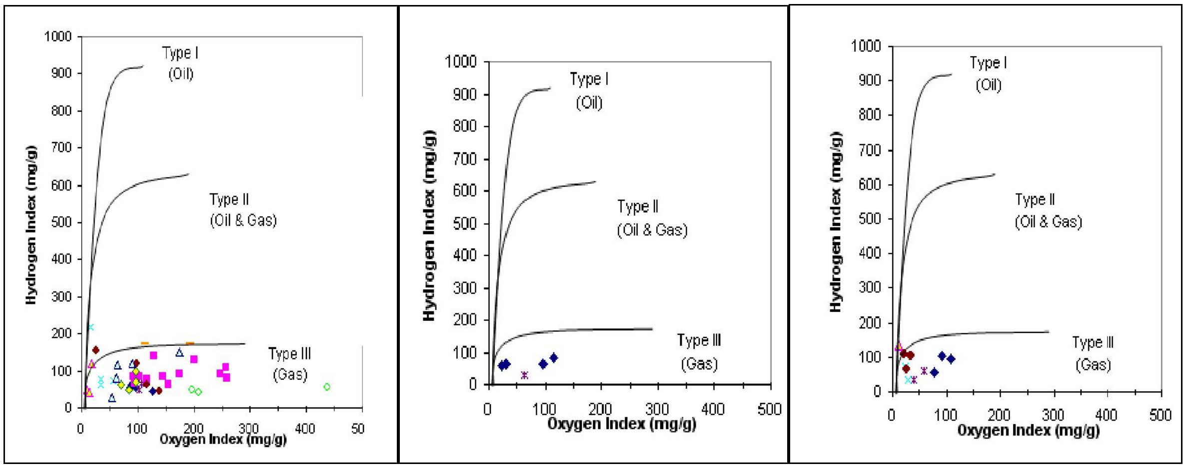


Fig 4: Vitrinite Reflectance, in oil, measurements (Ro%). Symbols represent samples from different wells

Cretaceous



Jurassic

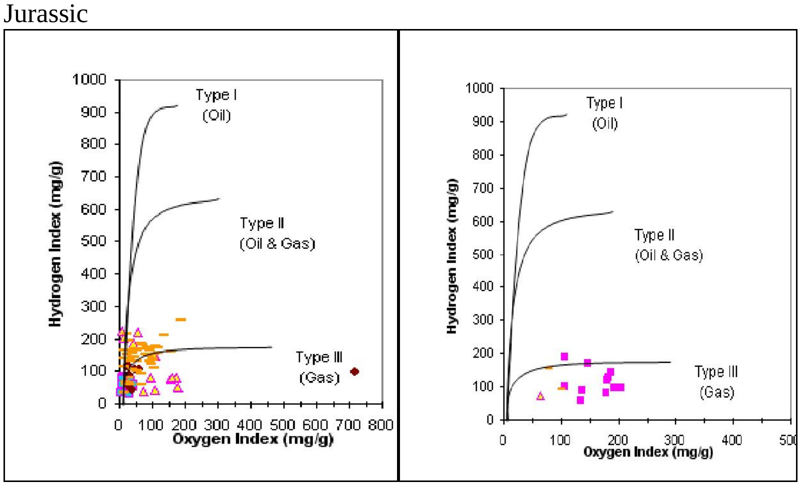


Fig 5: Van Krevelen – type diagram, showing kerogen type of potential source rocks. Symbols represent samples from different wells

2. Petroleum System Processes

Maturation studies indicate that migration studies guided by buoyancy drive, was initiated in the depocenters from potential Devonian and Jurassic source beds during Early Senonian and trapped in pre-Laramide structures. Pods of active sources were defined based on maturity modeling and mapping isopachs and pyrolysis results. Hydrocarbon charges, losses from catchment areas and recovery factors were normalized statistically. The least preservation risk is considered for hydrocarbons migrated from Cretaceous sources after the Alpine tectonics**.** Accordingly, the WD can be subdivided into five petroleum systems:-

1. The Safa-Bahariya (!), SB (!), system

The SB (!) occupies an area of 15,400 square kilometers (skm) in the central northern WD and includes Abu Ghradig basin (Fig 1). The system has a drilling density of 3.8 meters per cubic kilometer (m/cmk) resulted in eight fields and two discoveries.

Sedimentary rocks of this system range in age from Middle Jurassic through Plio-Pleistocene. The system can be classified " known (!)" as indicated by biomarker correlation and porphyrin analysis that the system is multi-sourced by Jurassic Safa and Masajid members of the Khatatba Fm and also Cretaceous Khoman, Abu Roash, and Bahariya formations. The Paleozoic Dhiffah and Zeitun formations are also possible sources. The reservoirs are the Bahariya Fm and Abu Roash Members.

Hydrocarbon migration in the eastern SB (!) system is suggested to coincide with, or post-date, the Laramide structural trap-forming episode. The western SB (!) system, despite the possible preservation risk for early maturation, its potential became beyond question after the discovery of Badr El-Din (BED) field (Fig 1). The BED discovery implies that the Laramide-aged structures were not always distributed due to subsequent overprinting by the Oligo-Miocene Alpian tectonic episode of the "Syrian Arc", although the latter is most prominent in the WD. The latest significant event, the Late Miocene “Messinian" salinity crisis, was a gentle event of regression and erosion, though of high magnitude emergence (Shahin, 1987). (Fig 6)

The system is estimated to host 10.4 billion oil-equivalent barrels (Boeb) recoverable (Table 1).

Table 1 : Data summary of the petroleum systems in the northern Western Desert.
Where: B: billion, Ckm: Cubic kilometer, m: meters, M: thousand, MM: million, oeb: oil-equivelant barrels, skm: square km. (Shahin 1998)

2. the Safa-Alamein (!), SA (!) system

SA (!) system falls to the north of SB (!) system, covers an area of 6,300 skm and includes Alamein basin

Systems	**The Safa-Bahariya(!)**	**The Safa-Alamein (!)**	**The Safa-Khataba(!)**	**The Zaitun-Safa(.)**	**The Khataba-Kharita (.)**	All Systems
Basin	***AG***	***Alamein***	***Matruh***	***Faghur***	***Beni Suef***	
Fields and Discoveries	10	5	10	1	1	27
Wells Drilled	160	41	135	10	8	354
Drilled Km	556	96	412	21	24	1109
System Volume Mckm	146	50	158	95	40	489
System Area skm	15400	6300	16000	13700	5200	56600
Source rock Age	K,Jr,Pz	Jr	Jr	Pz	Jr	
Estimated Generated Boeb	150	95	315	27	41	628
Proven Rec. Reserves Boeb	0.6	0.25	0.57	0.01	0.1	1.53
Estimated recoverable Boeb	10	7	23	2	3	45
Drilling Density m/ckm	3.8	1.9	2.6	0.2	0.6	
Descovery Density Moeb/ ckm	4.1	5	3.6	1	2.5	
Response MMoeb/km drilled	1.1	2.6	1.4	0.4	4.3	
Estimated /Proven Reserves	17	28	40	200	30	

(Fig, 1), which feed s five fields and one discovery, including Alamein, the first discovered in the WD. Although ranks last in its sedimentary volume, the system has the highest discovery density (5,000 oeb/ckm) and the most successful exploration response of 2,600 oil-equivalent barrels per meter drilled (oeb/m).

The Jurassic Safa Member (Mbr) of the Khataba Fm is considered the main source hydrocarbons in this system. Reservoirs are the Aptian Alamein Dolomite and the bahariya Fm.

The timing of migration is similar to that of the eastern SB(!) system (Fig 7).

The estimated recoverable reserves are seven Boeb (Shahin, 1989).

3. The Safa-Khataba (!), SK(!) system

SK (!) system is the largest, covering about 16,000 skm and extends northward into the Mediterranean. Matruh and Salam basins are the host for the Safa Mbr effective source and reservoir, where the Salam Field was the first in the WD to produce from the Jurassic.

This system holds about the same volume of sediments and proven reserves as SB(!) system to the south-east, though less explored.

Preservation of hydrocarbon accumulations is considered at low risk, as oil migration post-dates the severe Laramide-related tectonics. Only in the vicinity of Umbarka Field, a greater risk is involved as maturation and migration were earlier (pre-Cenomanian) for its high heat flow. However, Umbarka Field itself is an instance of an old structural trap modified by later successive events with no significant leakage. (Fig 8)

This system is estimated to host 23 Boeb, about half of the WD calculated recoverable reserves (Shahin 1989).

Safa-Bahariya(!) system

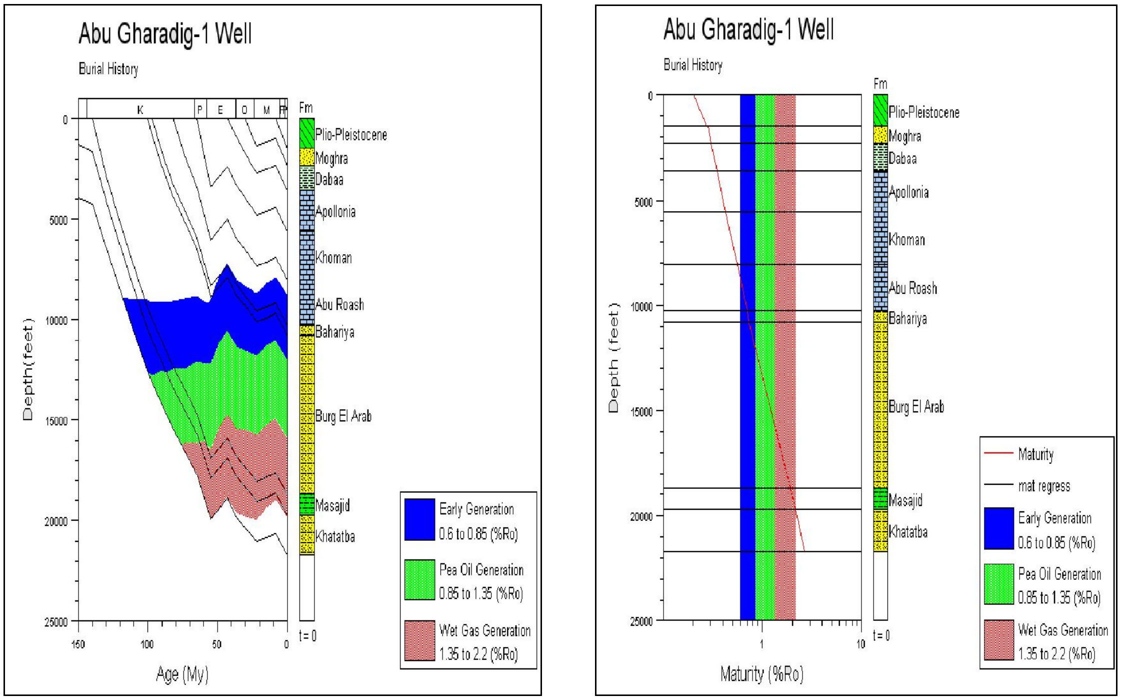


Fig 6 : Thermal burial history of Safa-Bahariya(!) system
E = Eocene O = Oligocene M = Miocene P = Pliocene Q = Quaternary

Safa-Alamein (!) system

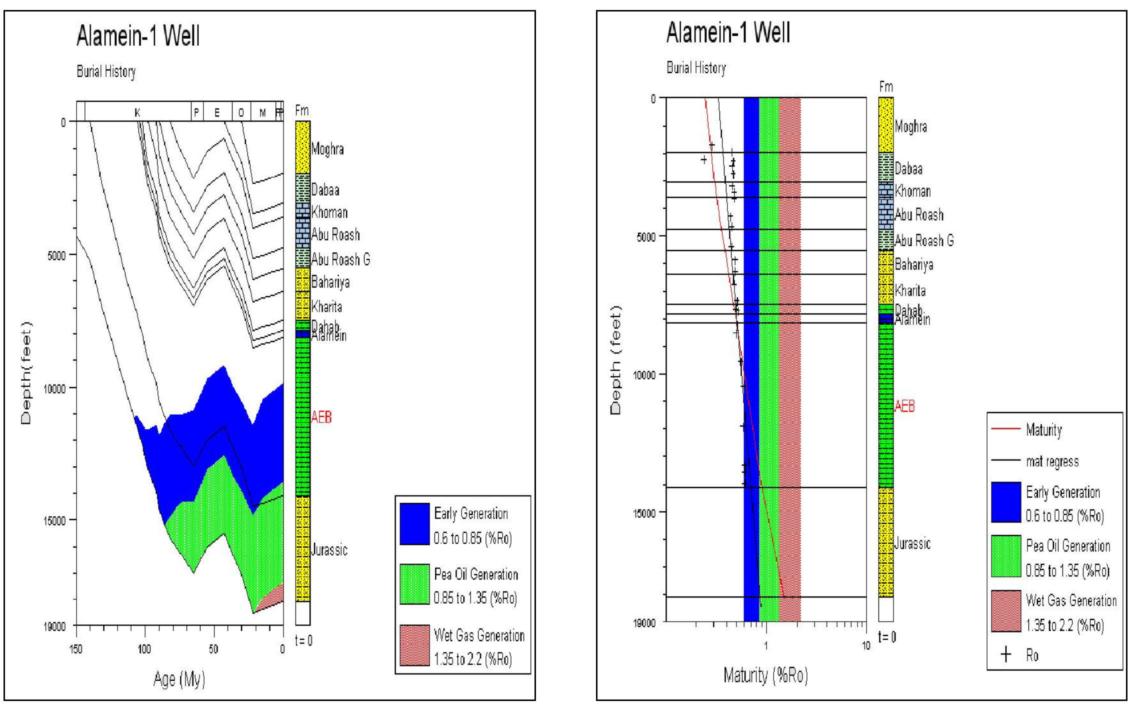


Fig 7: Thermal burial history of Safa-Alamein (!) system.

Safa-Khataba(!) system

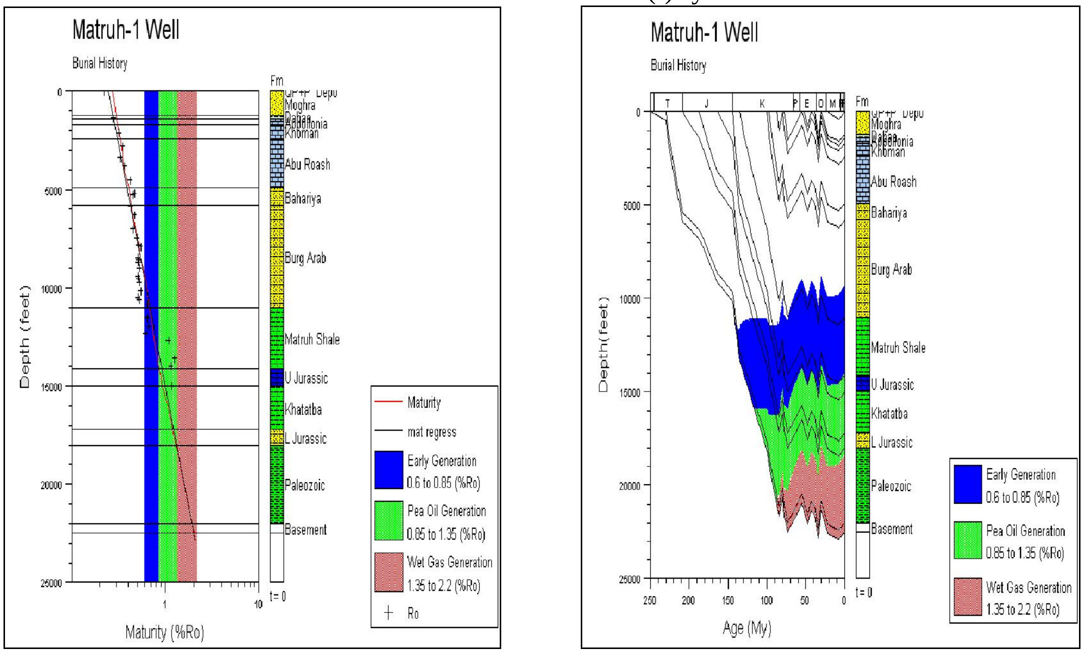


Fig 8: Thermal burial history of Safa-Khataba(!) system

4. The Zaitun-Safa (.), ZS (.) system

This system covers a mature areal extent of 13,700 skm, extends into the Libyan territory to the west. The system can be classified “hypothetical (.)”. The low discovery density can be attributed to lack of exploration.

High generative capacity is indicated within the the oil-prone Devonian Zeitun Fm (3,500 ppm) and the Carboniferous gas-prone Diffah Fm. (3,000 ppm). Peak oil-generation is suggested to have occurred the earliest in the region. Such timing would imply a degree of preservation uncertainty (Fig 9).

This system is estimated to contain recoverable reserves of two Boeb Paleozoic oil and gas (Shahin 1989).

5. The Khataba-Kharita(.), KK(.) system

This system is crossed by the Nile Valley, to the south from Cairo, covers an area of 5,200 skm. This system was established by a 1997 discovery of East Beni Suef Field, with 0.3 Boeb Preliminary in-place reserves in Albian Kharita sands, sourced by Khataba Fm, and estimated to host three Boeb recoverable reserves (Shahin 1989). (Fig 10)

Cumulatively, the five systems are under explored, being estimated to host 48 Boeb recoverable, about 15 times the proven ultimate recoverable reserves in the whole WD.

Summary

According to the interpretation of the analytical results of total organic carbon, Pyrolysis, and vitrinite reflectance measurements, the time of generation and migration through the geochemical-geothermal-geohistory subsidence models and the Geochemical mass balance method the WD can be subdivided into five petroleum systems.

The Safa-Bahariya(!) system, includes Abu Gharadig basin. The system hosts twelve fields and is multi-sourced by Jurassic and Cretaceous intervals. The system is suggested to host 11 billion oil-equivalent barrels as estimated ultimate recoverable reserves(Eurr)

The Safa-Alamein (!) system, includes Alamein basin, which feeds five fields. The Aptian Alamein Dolomite, the main reservoir, is sourced by the Jurassic Safa Mbr. The Eurr are seven Boeb.

The Safa-Khataba(!) system, is the largest and extends northward into the Mediterranean. Matruh and Shushan basins are the host for the Safa Mbr effective source and reservoir. The newly discovered Cretaceous zones in old fields(e.g. Umbaraka Field) indicate preserved accumulations. This system is estimated to host 25 Boeb of Eurr.

The Zaitun-Safa(.) system, extends into the Libyan territory to the west. A recent (2008) 3,000 bpd discovery West Kalabsha area, proved a Jurassic Safa Mbr oil play. This system is estimated to contain ultimate recoverable reserves in excess of two Boeb of Jurassic oil and gas sourced by Paleozoic.

The Khataba-Kharita (.) system, is crossed by the Nile Valley, to the south from Cairo and includes the East Beni Suef Field, with 0-3 Boeb Preliminary in-place reserves in Albian Kharita sands, sourced by Khataba Fm, and estimated to host three Boeb Eurr.

Zaitun-Safa(.) system

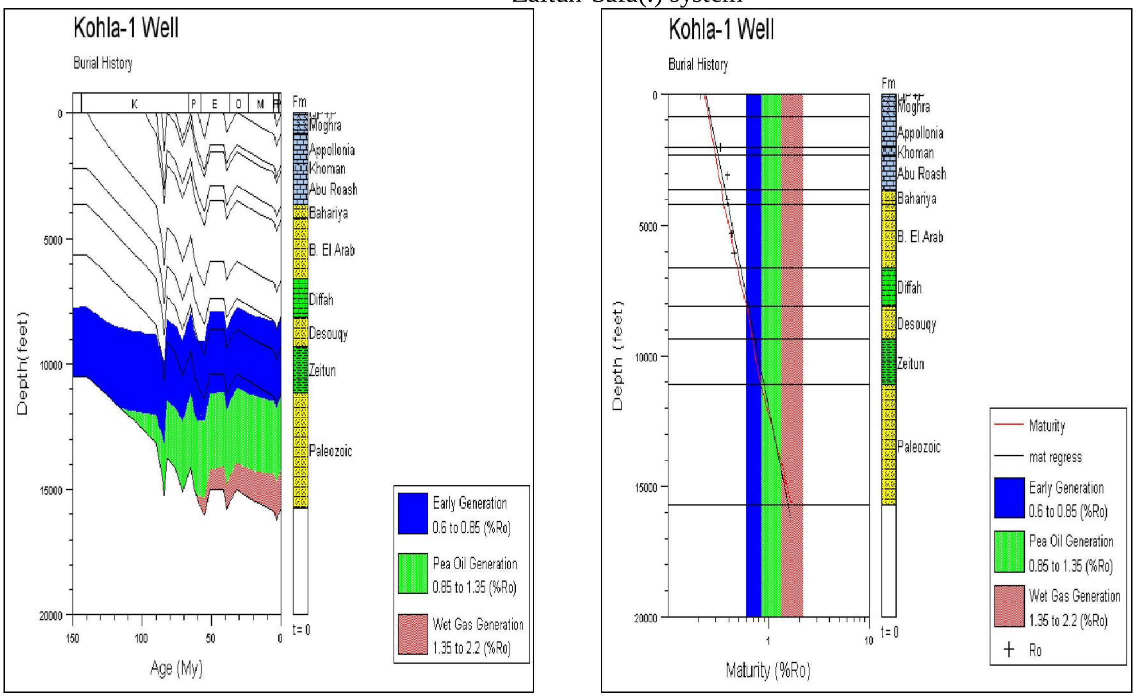


Fig 9: Thermal burial history of Zaitun-Safa(.) system

Khataba-Kharita (.) system

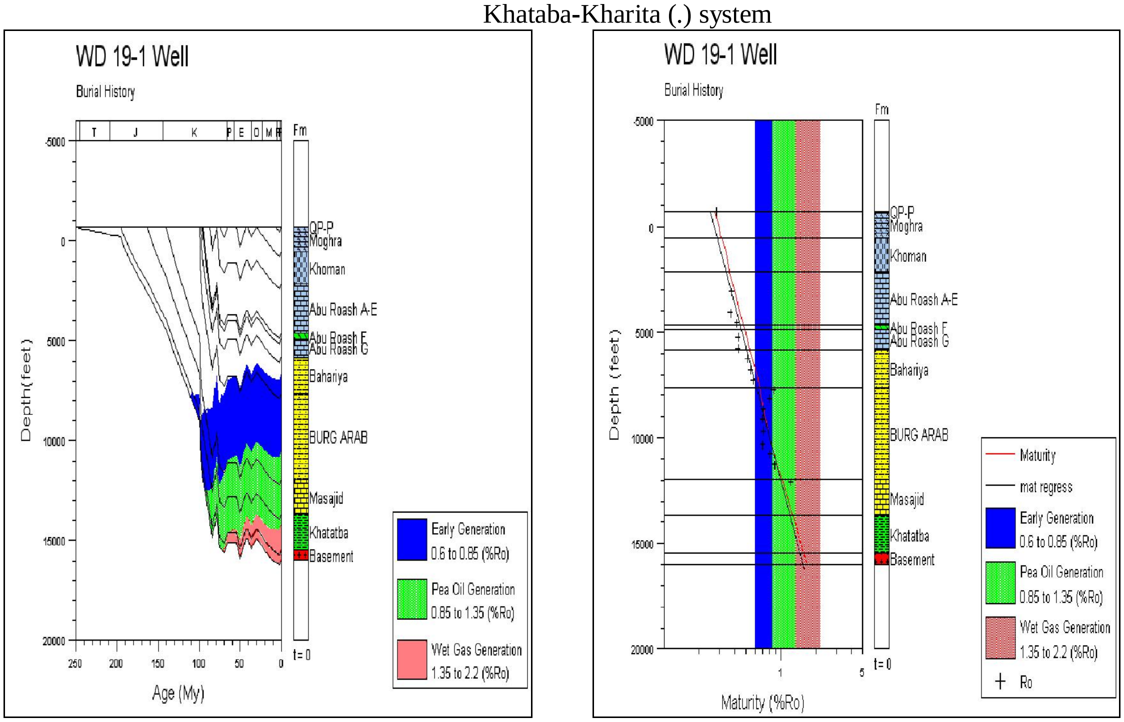


Fig 10: Thermal burial history of Khataba-Kharita (.) system

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