International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 39 العدد
Part 1 المجلد

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

http://www.doi.org/10.62341/istj-vol39-1-46od

Received	**2026/08/20**	**تم استلام الورقة العلمية في**
Accepted	**2026/09/06**	**تم قبول الورقة العلمية في**
Published	**2026/09/08**	**تم نشر الورقة العلمية في**

Mineralogical and Geochemical Characteristics of the Nubian Formation in Well MM1-82, Sirte Basin, Libya

***Osama Rahil Shaltami[1] and Issa Saleh Issa Mohammed[2]**
[1]Department of Earth Sciences, Faculty of Science
Benghazi University, Libya
[2]Sirte Oil Company, Libya
osama.rahil@yahoo.com*

Abstract:
A comprehensive mineralogical and geochemical assessment of the Early Cretaceous Nubian Formation, comprising the Lower Nubian Sandstone, Varicolored Shale, and Upper Nubian Sandstone, was conducted using samples from well MM1-82 in the Sirte Basin, north-central Libya. Four analytical techniques were employed: X-ray diffraction (XRD), Rock-Eval pyrolysis, gas chromatography (GC), and isotope ratio mass spectrometry (IRMS). Mineralogically, the shale intervals of the Lower Nubian Sandstone consist of argillaceous shale (CM), silica-rich argillaceous shale (CM-1), and mixed argillaceous shale (CM-2), whereas the Varicolored Shale is predominantly argillaceous. The sandstone intervals comprise quartz arenite, lithic sandstone, arkose, and subarkose. Geochemical results indicate poor to fair organic richness, with kerogen types II, II/III, III, and IV. The Lower Nubian Sandstone, Varicolored Shale, and Upper Nubian Sandstone exhibit early mature, immature to early mature, and immature thermal maturity levels, respectively. Indigenous hydrocarbons were detected in all studied samples except those from the Upper Nubian Sandstone. The Lower Nubian Sandstone has fair to good oil-source potential, while the Varicolored Shale ranges from very poor to gas- and/or oil-prone. Despite its immature thermal maturity, the Upper Nubian Sandstone represents the most prospective interval due to its high oil saturation and excellent recoverable oil potential. Shale oil

http://www.doi.org/10.62341/istj-vol39-1-46od

analysis indicates that Lower Nubian Sandstone contains thermally mature oil derived from multiple marine-related source rocks.
Keywords: Mineralogy, Organic Geochemistry, Nubian Formation, Sirte Basin, Libya.

الخصائص المعدنية والجيوكيميائية لتكوين النوبة في البئرMM1-82، حوض سرت، ليبيا

أسامة رحيل الشلطامي[1] عيسى صالح عيسى محمد[2]
[1]قسم علوم الأرض، كلية العلوم، جامعة بنغازي، ليبيا
[2]شركة سرت، ليبيا

ملخص:

أُجري تقييم شامل للخصائص المعدنية والجيوكيميائية لتكوين النوبة من العصر الطباشيري المبكر، الذي يتكون من الحجر الرملي النوبي السفلي، والطفل متعدد الألوان، والحجر الرملي النوبي العلوي، باستخدام عينات من البئر MM1-82 في حوض سرت، شمال وسط ليبيا. واستُخدمت أربع تقنيات تحليلية، هي: حيود الأشعة السينية (XRD)، والتحليل الحراري الصخري (Rock-Eval)، والكروماتوغرافيا الغازية (GC)، وقياس طيف الكتلة لنسب النظائر (IRMS). من الناحية المعدنية، تتكون الطبقات الطفلية في الحجر الرملي النوبي السفلي من طفل طيني (CM)، وطفل طيني غني بالسيليكا (CM-1)، وطفل طيني مختلط (CM-2)، بينما يغلب الطابع الطيني على الطفل متعدد الألوان. وتشمل الوحدات الرملية الحجر الرملي الكوارتزي، والحجر الرملي الليثي، والأركوز، وشبه الأركوز. وتشير النتائج الجيوكيميائية إلى ضعف إلى اعتدال الثراء العضوي، مع وجود أنواع الكيروجين II وII/III وIII وIV. ويتميز الحجر الرملي النوبي السفلي، والطفل متعدد الألوان، والحجر الرملي النوبي العلوي بدرجات نضج حراري مبكرة، وغير ناضجة إلى مبكرة، وغير ناضجة، على التوالي. وكُشف عن هيدروكربونات أصلية في جميع العينات باستثناء الحجر الرملي النوبي العلوي. ويتميز الحجر الرملي النوبي السفلي بإمكانات مصدرية نفطية متوسطة إلى جيدة، بينما تتراوح إمكانات الطفل متعدد الألوان من ضعيفة جدًا إلى مولدة للغاز و/أو النفط. وعلى الرغم من عدم نضجه حراريًا، يمثل الحجر الرملي

http://www.doi.org/10.62341/istj-vol39-1-46od

النوبي العلوي الوحدة الأكثر وعدًا نظرًا لارتفاع تشبعه بالنفط وإمكاناته الممتازة للنفط القابل للاستخراج. وتشير تحليلات النفط الصخري إلى وجود نفط ناضج حراريًا في الحجر الرملي النوبي السفلي، مشتق من عدة صخور مصدر مرتبطة ببيئات بحرية.
الكلمات المفتاحية: علم المعادن، جيوكيميائية العضوية، التكوين النوبي، حوض سرت، ليبيا.

1. Introduction

The main source of Libya's oil is the Sirte Basin, a large, extremely prolific sedimentary basin that stretches into the Gulf of Sirte from north-central Libya. With over 22 massive oil fields and intricate horst and graben formations, this Mesozoic-Cenozoic rift basin, which spans over 600,000 km^2, is home to 89% of Libya's petroleum reserves [1], [2], [3], [4], [5], [6]. The Sirte Arch collapse (Late Jurassi-Early Cretaceous) is thought to be the genesis of the basin [7], [8], [9]. With significant fault lines, the basin has a complicated tectonic activity history [10]. The age of the sediments in the basin ranges from Precambrian to Quaternary (Fig. 1).

The term "Nubian Sandstone" in Libya was proposed by Desio (1935), [11]. There is no mention of "Nubian Sandstone" in the Libyan geological map. The term "Nubian Sandstone" is still widely used by Libyan geologists, particularly in the southeast part of the Sirte Basin [12]. In contrast, the Nubian Sandstone is referred to as Sarir Sandstone and Kalanshiyu Sandstone in the eastern part of the Sirte Basin [8]. The typical section of the Nubian Formation is located in well R3-82, which is approximately 1143 meters thick [13].

The Lower Nubian Sandstone, the Variegated Shale, and the Upper Nubian Sandstone are the three units that make up the formation in the typical section. The Lower Sarir Sandstone, the Red Shale, the Middle Sarir Sandstone, the Variegated Shale, and the Upper Sarir Sandstone are the five units into which Ambrose (2000) demonstrated that the Sarir Formation may be divided. The Lower Nubian Sandstone (Middle Sarir Sandstone) and the Upper Nubian Sandstone (Upper Sarir Sandstone) are the key reservoirs in the Sirte Basin, while the Variegated Shale is a significant source rock [8]. [14].

http://www.doi.org/10.62341/istj-vol39-1-46od

The Nubian Formation was primarily deposited in fluvial and lacustrine environments. These sediments are of Early Cretaceous age [8].

This investigation relied on mineral and chemical data from the Mellitah Oil and Gas BV Libyan Branch, as will be clarified later. This company utilized the term Varicolored Shale rather than Variegated Shale, but it still used the classification of Ibrahim (1991) for the Nubian Formation [13]. Evaluating the mineralogical and organic geochemical characteristics of the Nubian Formation in well MM1-82, Sirte Basin, north central Libya (Figs. 2 and 3) is the objective of this study. The previous studies [2], [15], [16], [5], [17] suggested that no published research has been done on the Nubian Formation in well MM1-82

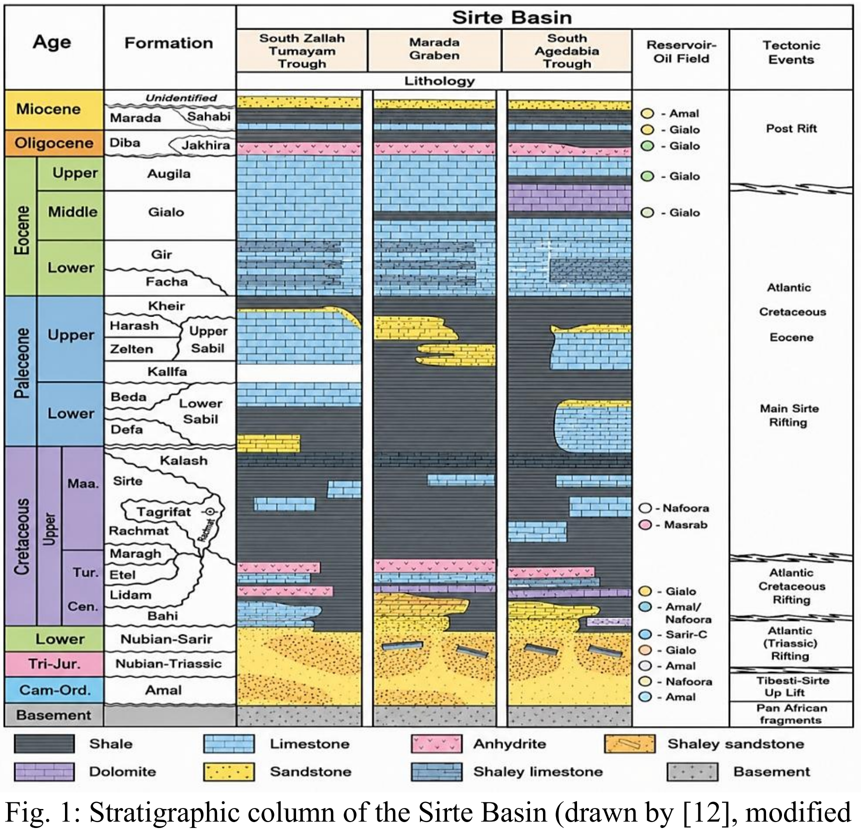


Fig. 1: Stratigraphic column of the Sirte Basin (drawn by [12], modified by [18] and colored by the authors).

http://www.doi.org/10.62341/istj-vol39-1-46od

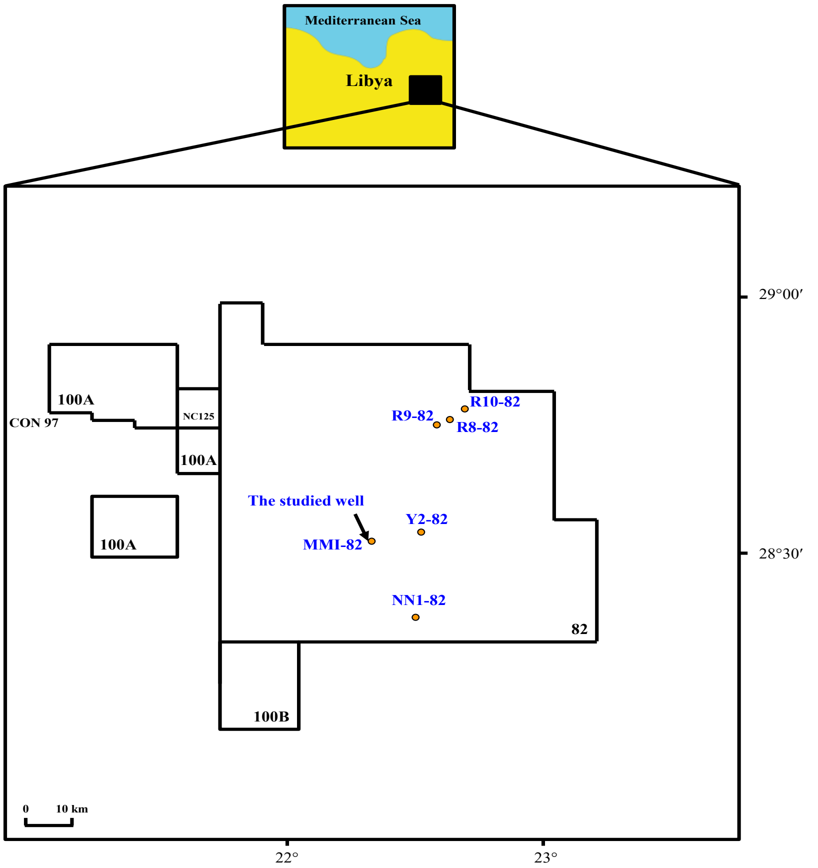


Fig. 2: Composite map showing the location of concession 82 and the location of well MM1-82.

2. Methodology

The mineral and chemical data acquired from the Mellitah Oil and Gas BV Libyan Branch was used as the basis for this study. The following is the methods:

(1) Forty-eight cutting samples were chosen from well MMI1-82 at depths 11810 to 13588 ft. Moreover, one oil sample was taken at a depth of 12810.1 ft from the Lower Nubian Sandstone.

(2) X-ray diffraction (XRD) examination was used to ascertain the mineral composition of the samples.

(3) The source rock characteristics of the samples were evaluated employing the Rock-Eval pyrolysis.

http://www.doi.org/10.62341/istj-vol39-1-46od

(4) The saturated, aromatic, resin, and asphaltene fractions of the oil sample were measured using gas chromatography (GC).
(5) Using isotope ratio mass spectrometry (IRMS), the carbon isotope values of the biomarkers were ascertained.

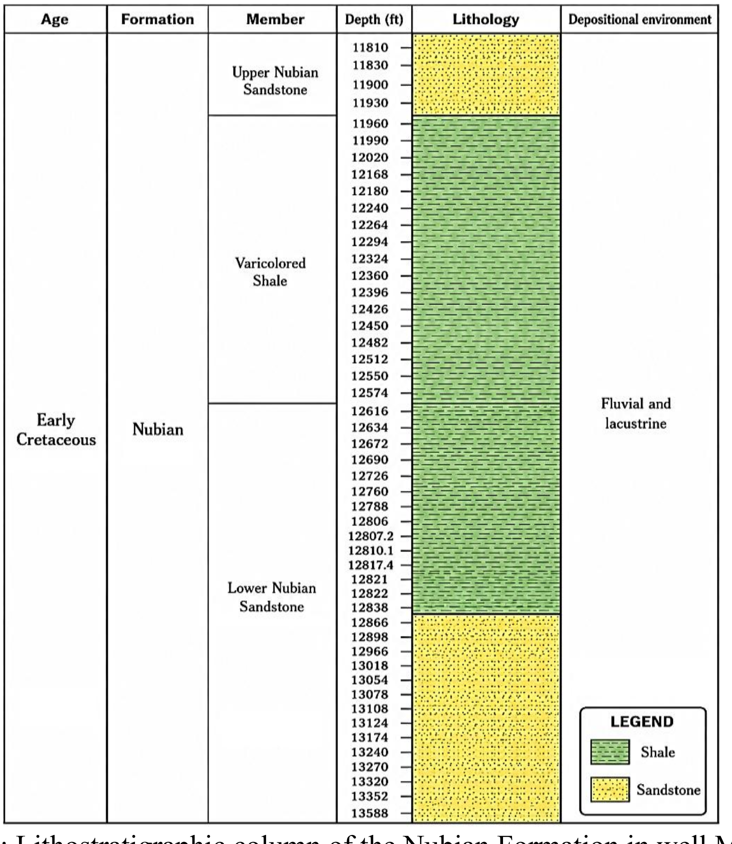


Fig. 3: Lithostratigraphic column of the Nubian Formation in well MM1-82.

The abbreviations and equations of the parameters used in this work are depicted in Table 1. The explanation of these parameters is presented in Table 2.

Mineralogical and Geochemical Characteristics of the Nubian Formation in Well MM1-82, Sirte Basin, Libya
http://www.doi.org/10.62341/istj-vol39-1-46od

Table 1: Abbreviations and Equations of The Parameters Utilized in This Work

Parameter	Abbreviation and equation
Total organic carbon (wt%)	TOC
Quantity of free hydrocarbons (mg/g)	S1
Quantity of generated hydrocarbons (mg/g)	S2
Quantity of CO_2 generated during pyrolysis (mg/g)	S3
Temperature at which maximum rate of generation of hydrocarbons occurs (°C)	T_{max}
Hydrogen index (mg/g)	HI = S2/TOC × 100
Oxygen index (mg/g)	OI = S3/TOC × 100
Oil saturation index (mg/g)	OSI = S1/TOC × 100
Production index	PI = S1/(S1+S2)
Pyrolyzable carbon index (mg/g)	PCI = (S1+S2)/(10*TOC)
Saturated hydrocarbons	SAT
Aromatic hydrocarbons	ARO
Resins plus asphaltenes	NSO
Saturated hydrocarbons, aromatic hydrocarbons and resins plus asphaltenes	SARA
Stable carbon isotope of saturated hydrocarbons (‰)	$\delta^{13}C_{SAT}$
Stable carbon isotope of aromatic hydrocarbons (‰)	$\delta^{13}C_{ARO}$
Stable carbon isotope of resins plus asphaltenes (‰)	$\delta^{13}C_{NSO}$
18α-22,29,30-trisnorneohopane/ 17α-22,29,30-trisnorhopane	Ts/Tm
Tricyclic terpanes	Tri
Tetracyclic terpanes	Tet
Steranes	S
Hopanes	Ht
Gammacerane index	Gam
Methylphenanthrene index-1	MPI-1
Vitrinite reflectance	$R_0 = 0.018 \times T_{max} - 7.16$
Crucial vitrinite reflectance	VRc = 0.6 x MPI-1+0.4

Table 2: Interpretation of the parameters

Objective	Parameter	Values	Interpretation	Reference
Organic richness	TOC (%)	0–0.5	Poor	Peters and Cassa (1994)
		0.5–1	Fair	
		1–2	Good	
		2–4	Very good	
		>4	Excellent	
	S1 (mg/g)	0–0.5	Poor	
		0.5–1	Fair	
		1–2	Good	
		2–4	Very good	
		>4	Excellent	
	S2 (mg/g)	0–2.5	Poor	
		2.5–5	Fair	
		5–10	Good	
		10–20	Very good	
		>20	Excellent	
	PCI (mg/g)	<0.1	Poor	Espitalié et al. (1985)
		0.1–0.3	Fair	
		0.3–0.6	Good	
		>0.6	Very good to excellent	
Kerogen type	HI (mg/g)	<50	Type IV	Peters and Cassa (1994)
		50–200	Type III	
		200–300	Type II-III	
		300–600	Type II	
		>600	Type I	
	S2/S3	<1	Type IV	
		1–5	Type III	
		5–10	Type II-III	
		10–15	Type II	
		>15	Type I	
	PCI (mg/g)	>0.7	Type I	Tissot and Welte (1984)
		0.4–0.7	Type II	
		0.2–0.4	Type II-III	
		0.1–0.2	Type III	
		<0.1	Type IV	
Thermal maturity	T_{max} (°C)	<435	Immature	Peters and Cassa (1994)
		435–445	Early mature	
		445–450	Peak mature	
		450–470	Late mature	
		>470	Postmature	
	R_0	0.2–0.6	Immature	
		0.6–0.65	Early mature	
		0.65–0.9	Peak mature	
		0.9–1.35	Late mature	
		>1.35	Postmature	
	PI	<0.1	Immature	
		0.1–0.15	Early mature	
		0.25–0.4	Peak mature	
		>0.4	Late mature	
		-	Postmature	

Mineralogical and Geochemical Characteristics of the Nubian Formation in Well MM1-82, Sirte Basin, Libya
http://www.doi.org/10.62341/istj-vol39-1-46od

Table 2: Continued

Objective	Parameter	Values	Interpretation	Reference
Thermal maturity	MPI-1	<0.4	Immature to early mature	Radke (1988)
		0.4–0.7	Early oil window	
		0.7–1.3	Peak oil generation	
		>1.3	Late oil window to condensate/gas generation	
	VRc	<0.5	Immature	Tissot and Welte (1984)
		0.5–0.7	Early mature	
		0.7–1	Peak oil window	
		1–1.3	Late oil window	
		1.3–2	Wet gas/condensate window	
		>2	Dry gas window	
Indigeneity	S1/TOC	<1.5	Indigenous hydrocarbons	Hunt (1996)
		>1.5	Nonindigenous hydrocarbons	
Unconventional hydrocarbons	OSI (mg/g)	<25	Little or no movable oil	Jarvie (2012)
		25–100	Low oil saturation	
		100–200	Moderate oil saturation	
		200-300	High oil saturation; possible oil crossover effect	
		>300	Often indicates oil-stained or oil-saturated rock	
Oil-source rock correlation	C_{29}/C_{30}	<1	Shale or clay-rich sources	Andrew et al. (2001)
		>1	Carbonate or evaporite sources	
	C_{31}/C_{30}	<0.3	Lacustrine or terrestrial influence	Peters et al. (2005)
		0.3–0.6	Mixed marine-terrestrial source	
		>0.6–1	Marine source, reducing conditions	
		>1	Strongly anoxic marine environment	
	Ts/Tm	<0.2	Carbonate source rocks, low maturity, or both	Moldowan et al. (1985)
		0.2–0.5	Mixed lithology and maturity effects	
		0.5–1	Mature shale source rocks	
		>1	Highly mature, clay-rich source rocks	
Depositional environment	Gam	<0.1	Freshwater to normal marine conditions	
		0.1–0.3	Moderate water stratification	
		0.3–0.5	Saline and stratified environment	
		>0.5	Strongly stratified and hypersaline environment	
	S/(S+Ht)	<0.3	Hopane-dominated, strong bacterial input	Peters et al. (2005)
		0.3–0.5	Mixed organic matter sources	
		0.5–0.7	Sterane-rich, algal/marine influence	
		>0.7	Strong algal/eukaryotic dominance	
	Tri/Tet	<0.5	Tetracyclic terpanes dominant	
		0.5–1	Mixed influence	
		>1	Tricyclic terpanes dominant	
		>2	Strong tricyclic enrichment	

3. Results and Discussion

3.1. Mineralogy

The mineral composition of the Varicolored Shale and the Lower Nubian Sandstone was determined (38 samples, Table 3). The Varicolored Shale samples consist of shale, whereas the Lower Nubian Sandstone samples are a mixture of shale and sandstone. The detected minerals are clay minerals, quartz, calcite, and dolomite. Regarding the carbonate minerals, there is a clear dominance of dolomite.

http://www.doi.org/10.62341/istj-vol39-1-46od

Table 3: Mineral composition of the Varicolored Shale and the Lower Nubian Sandstone in well MMI-82

Member	Depth (ft)	Lithology	Quartz	Calcite	Dolomite	Clay minerals
Varicolored Shale	12240	Shale	10	0	8	82
	12264		3	0	9	88
	12294		3	0	12	85
	12324		2	0	11	87
	12360		3	2	12	83
	12396		10	3	9	78
	12426		2	2	10	86
	12450		3	3	10	84
	12482		2	2	15	81
	12512		2	3	13	82
	12550		2	4	14	80
	12574		5	4	11	80
Lower Nubian Sandstone	12616	Shale	2	3	12	83
	12634		1	1	18	80
	12672		7	2	10	81
	12690		10	4	7	79
	12726		5	5	8	82
	12760		14	4	12	70
	12788		24	2	10	64
	12806		24	2	9	65
	12807.2		40	0	0	60
	12810.1		32	0	0	68
	12817.4		25	0	0	75
	12821		26	0	0	74
	12822		27	0	0	73
	12838		11	3	9	77
	12866	Sandstone	55	0	7	38
	12898		46	3	7	44
	12966		40	1	10	49
	13018		61	2	8	29
	13054		84	0	4	12
	13078		92	0	1	7
	13108		91	0	2	7
	13124		71	0	5	24
	13174		72	0	3	25
	13240		84	0	4	12
	13270		56	0	7	37
	13320		88	0	7	5

The Lower Nubian Sandstone has three types of shale: argillaceous shale, silica rich-argillaceous shale, and mixed argillaceous shale (CM, CM-1, and CM-2, respectively), while the Varicolored Shale is primarily composed of argillaceous shale (CM) (Fig. 4). Moreover, quartz arenite, lithic sandstone, arkose, and subarkose are the detected types in the sandstone of the Lower Nubian Sandstone (Fig. 5).

http://www.doi.org/10.62341/istj-vol39-1-46od

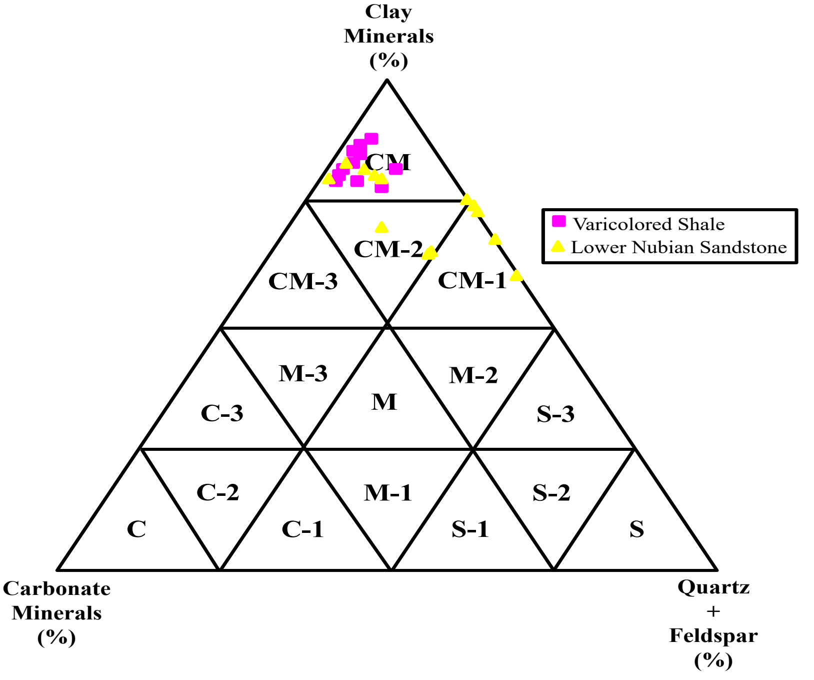


Fig. 4: Ternary plot of clay minerals-carbonate minerals

Fig. 4: Ternary plot of clay minerals-carbonate minerals- quartz+feldspar showing the shale classification of the Varicolored Shale and the Lower Nubian Sandstone in well MMI-82 (CM = argillaceous shale; CM-1 = silica rich-argillaceous shale; CM-2 = mixed argillaceous shale; CM-3 = carbonate rich-argillaceous shale; M = mixed shale; M-1 = calcareous/siliceous mixed shale; M-2 = argillaceous/siliceous mixed shale; M-3 = argillaceous/ calcareous mixed shale; C = calcareous shale; C-1 = silica rich-calcareous shale; C-2 = mixed calcareous shale; C-3 = clay rich-calcareous shale; S = siliceous shale; S-1 = carbonate rich-siliceous shale; S-2 = mixed siliceous shale; S-3 = clay rich-siliceous shale) (fields after [19]).

http://www.doi.org/10.62341/istj-vol39-1-46od

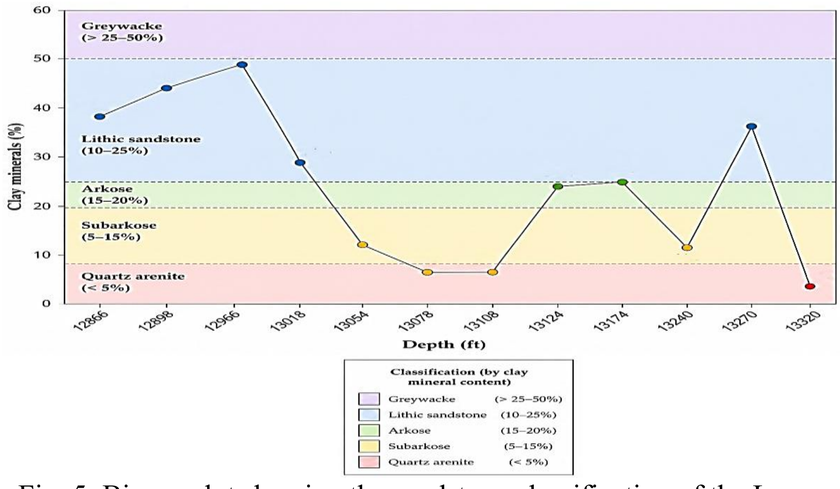


Fig. 5: Binary plot showing the sandstone classification of the Lower Nubian Sandstone in well MM1-82 (fields after [20]).

3.2. Source Rock Geochemistry

Fifteen samples from the Nubian Formation underwent Rock-Eval pyrolysis to assess the source rock (Table 4).

Table 4: Rock Eval pyrolysis data of the Nubian Formation in well MMI1-82

Member	Depth (ft)	TOC	S1	S2	S3	OI	HI	T_{max}	R_0	PI	OSI	PCI
Upper Nubian Sandstone	11810	0.78	1.86	0.84	1.47	188	108	431	0.6	0.69	238.46	0.35
	11830	0.72	2.18	0.87	4.61	640	121	427	0.53	0.71	302.78	0.42
	11900	0.25	0.76	0.24	0.81	324	96	430	0.58	0.76	304	0.4
	11930	0.38	1.17	0.39	1.27	334	103	427	0.53	0.75	307.89	0.41
Varicolored Shale	11960	0.78	0.15	0.49	0.83	106	63	430	0.58	0.23	19.23	0.08
	11990	0.44	0.04	0.18	0.5	114	41	434	0.65	0.18	9.09	0.05
	12020	0.91	0.04	0.38	0.86	95	42	434	0.65	0.1	4.40	0.05
	12168	0.87	0.12	0.36	0.88	101	41	431	0.6	0.25	13.79	0.06
	12180	0.57	0.05	0.47	0.51	89	82	437	0.71	0.1	8.77	0.09
	12360	0.34	0.12	0.32	0.24	71	94	438	0.72	0.27	35.29	0.13
	12396	0.27	0.09	0.2	0.26	96	74	434	0.65	0.31	33.33	0.11
	12426	0.24	0.07	0.19	0.24	100	79	435	0.67	0.27	29.17	0.11
	12450	0.23	0.08	0.17	0.24	104	74	437	0.71	0.32	34.78	0.11
Lower Nubian Sandstone	13352	0.6	0.14	1	0.59	98	165	443	0.81	0.12	23.33	0.19
	13588	0.4	0.17	1.29	0.45	113	323	442	0.8	0.12	42.5	0.37

The studied members have two categories of organic richness: poor and fair (Fig. 6). The examined members contain several types of kerogen (II, II-III, III, and IV) (Fig. 7).

http://www.doi.org/10.62341/istj-vol39-1-46od

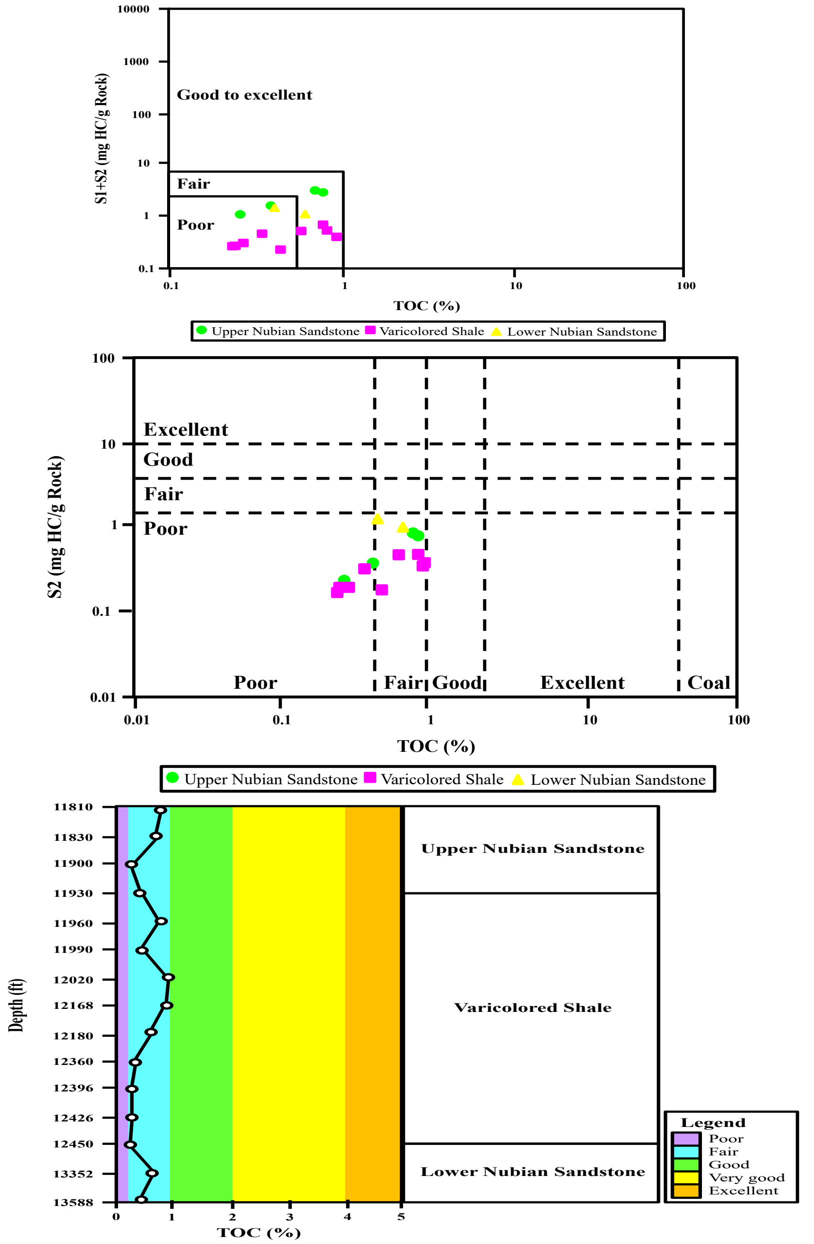
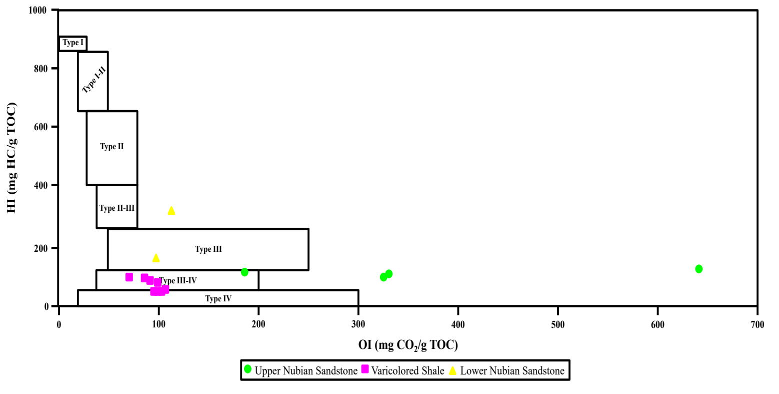
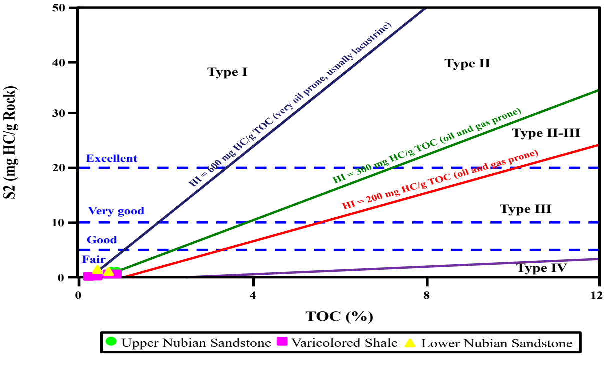
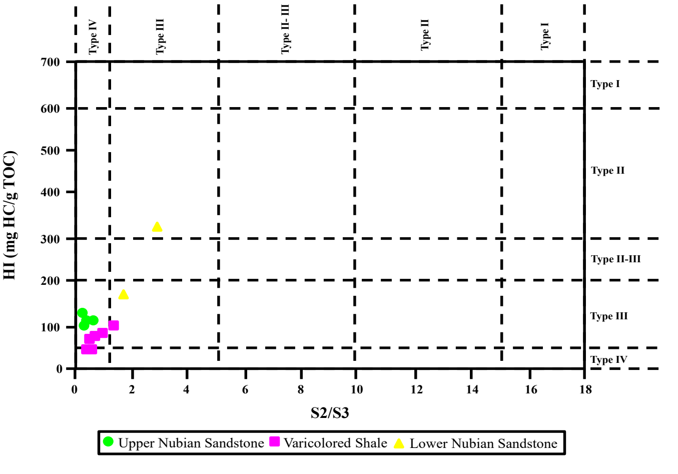


Fig. 6: Binary plots (TOC vs. S1+S2 (fields after [22], TOC vs. S2 (fields after [23]), and TOC vs. depth (fields after [21]) showing the organic richness of the Nubian Formation in well MM1-82

http://www.doi.org/10.62341/istj-vol39-1-46od







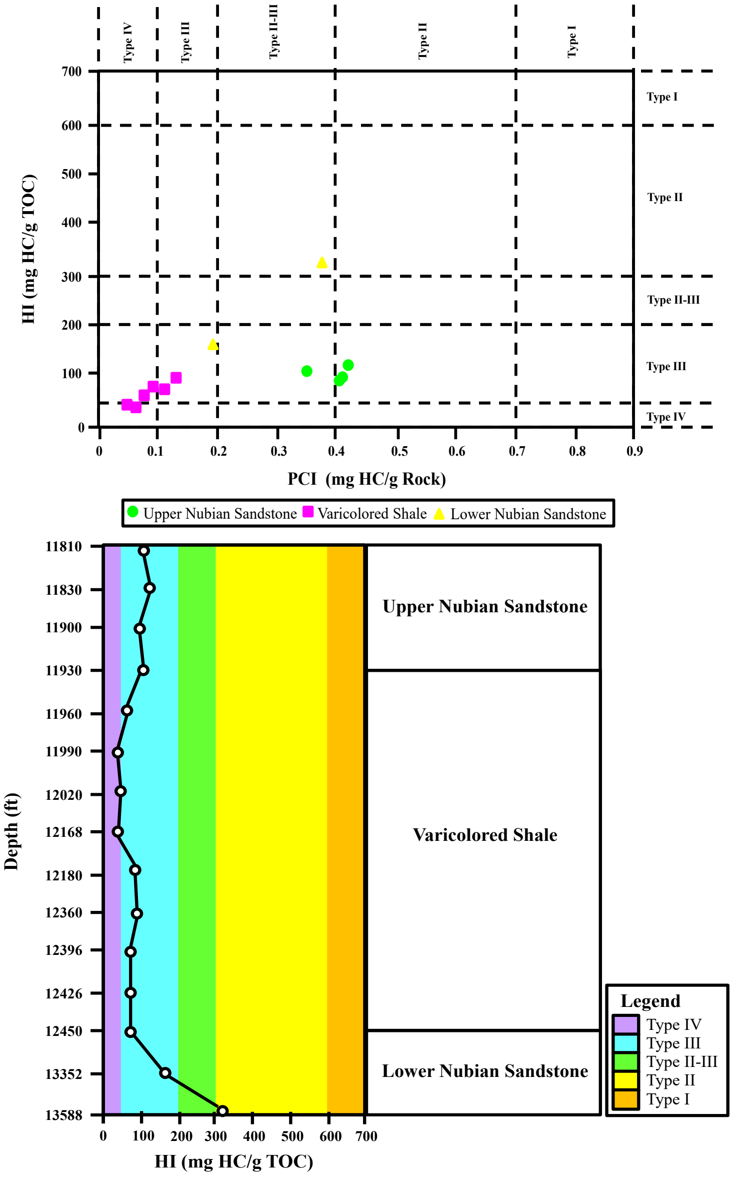


Fig. 7: Binary plots (OI vs. HI (fields after [24]), TOC vs. S2 (fields after [25]), S2/S3 vs. HI (fields after [21]), PCI vs. HI (fields after Reed and Ewan, 1986; [21]) and HI vs. depth (fields after [21]) showing the kerogen type of the Nubian Formation in well MM1-82

The thermal maturity levels of organic matter in the Lower Nubian Sandstone, the Varicolored Shale, and the Upper Nubian Sandstone are early mature, immature to early mature, and immature, respectively (Fig. 8).

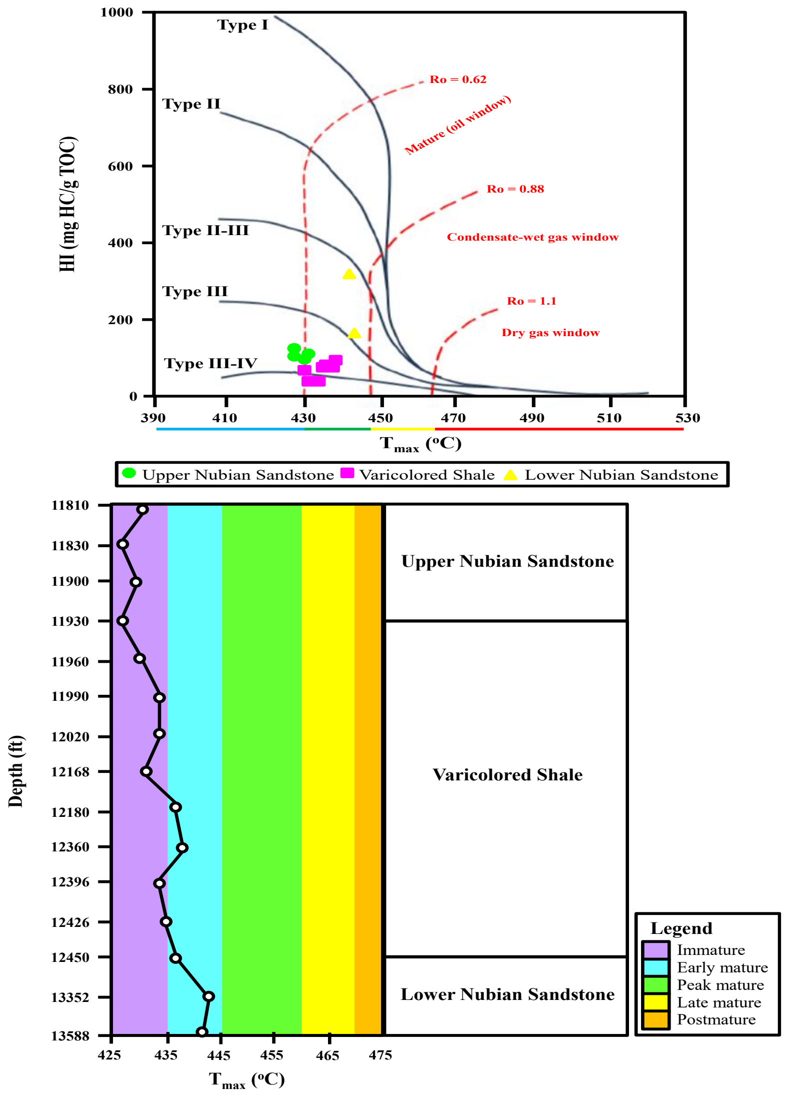


Fig. 8: Binary plots (T_{max} vs. HI (fields after [26]), and Tmax vs. depth (fields after [21]) showing the thermal maturity of organic matter in the Nubian Formation in well MM1-82

The examined samples contain indigenous hydrocarbons (except for the Upper Nubian Sandstone samples, Fig. 9).

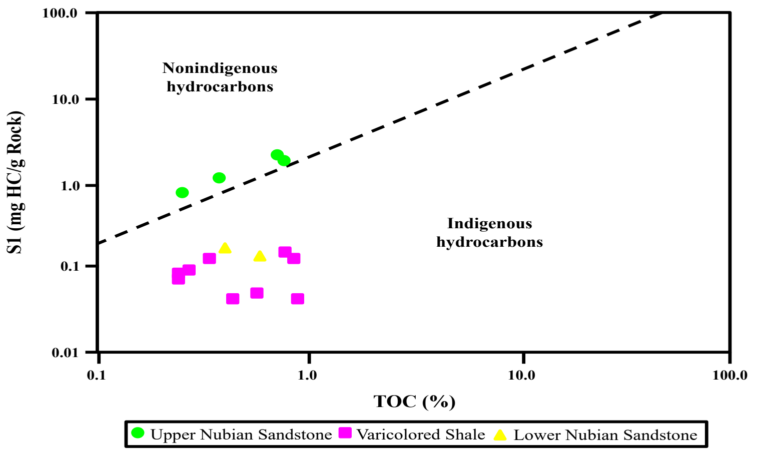


Fig. 9: Binary plot of TOC vs. S1 showing the indigeneity of hydrocarbons in the Nubian Formation in well MM1-82 (fields after [27])

The studied members have various hydrocarbon potential types (Fig. 10): (1) The hydrocarbon potential of the Lower Nubian Sandstone ranges from fair to good oil source; (2) The Varicolored Shale has hydrocarbon potential ranging from very poor to gas and/or oil source; and (3) There are three different categories of hydrocarbon potential in the Upper Nubian Sandstone: very poor, gas and/or oil, and fair oil. The Upper Nubian Sandstone has unusually high oil saturation (238.46–307.89 mg HC/g TOC), according to the binary plot of OSI versus depth (Fig. 11).

This indicates an oil-stained to oil-saturated period with considerable shale oil potential. The Lower Nubian Sandstone and Varicolored Shale, on the other hand, show primarily low OSI values (<50 mg HC/g TOC), indicating limited moveable hydrocarbons and poor to fair potential for recoverable oil. A notable shift in the quality and hydrocarbon retention conditions across the examined succession is shown in the sharp decline in OSI at roughly 11960 ft.

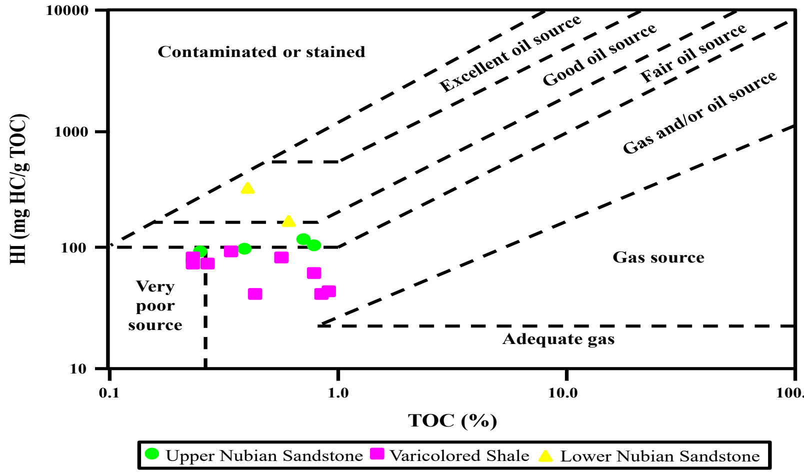


Fig. 10: Binary plot of TOC vs. HI showing the hydrocarbon potential of the Nubian Formation in well MM1-82 (fields after [28])

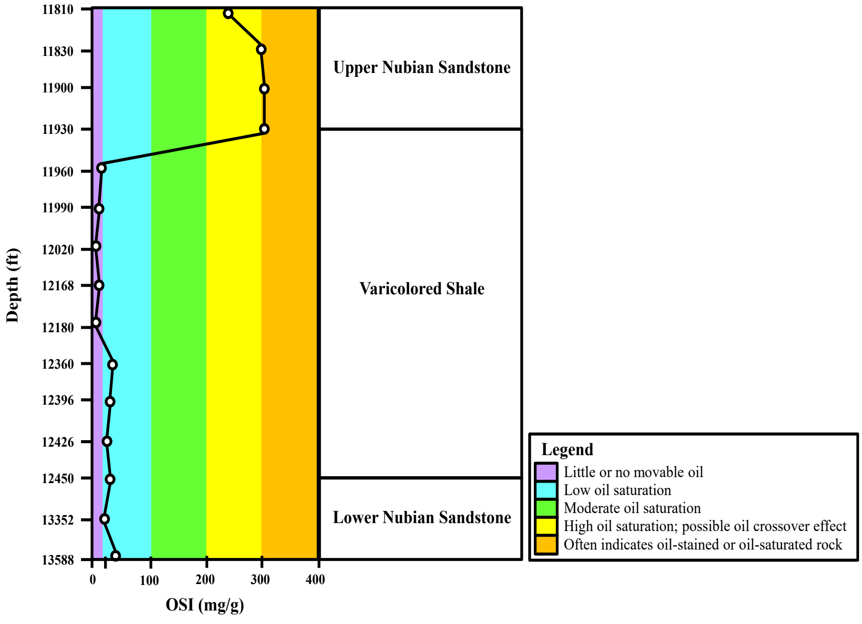


Fig. 11: Binary plot of OSI vs. depth showing the potential for recoverable oil from the Nubian Formation in well MM1-82 (fields after [29])

http://www.doi.org/10.62341/istj-vol39-1-46od

3.3. Crude Oil Geochemistry

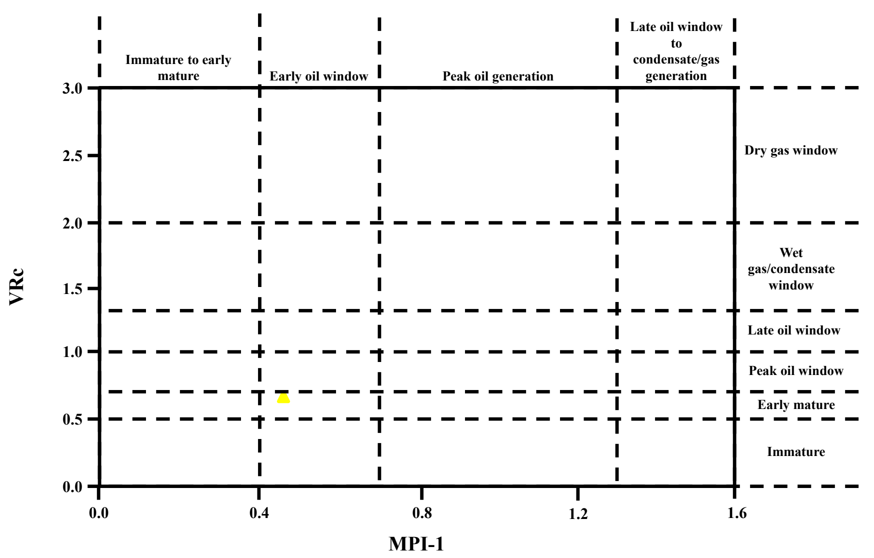
The biomarker data obtained from GC analysis of shale oil from the Lower Nubian Sandstone are presented in Table 5, whereas the stable isotope data derived from IRMS analysis are summarized in Table 6. However, shale oil classification was not performed in this study because American Petroleum Institute (API) gravity data were unavailable. The shale oil from the Lower Nubian Sandstone is thermally mature (Fig. 12). Furthermore, the shale oil was generated from multiple marine source rocks (Fig. 13).

Table 5: GC data of shale oil in the Lower Nubian Sandstone in well in well MM1-82

Depth (ft)	SAT	ARO	NSO	Tri/Tet	C_{29}/C_{30}	C_{31}/C_{30}	Ts/Tm	S/S+Ht	Gam	MPI-1	VRc
12810.1	63	18	19	0.45	1	0.92	0.08	0.61	0.48	0.46	0.68

Table 6: IRMS data of shale oil in the Lower Nubian Sandstone in well in well MM1-82

Depth (ft)	$\delta^{13}C_{SAT}$	$\delta^{13}C_{ARO}$	$\delta^{13}C_{NSO}$
12810.1	-34.03	-32.71	-32.15



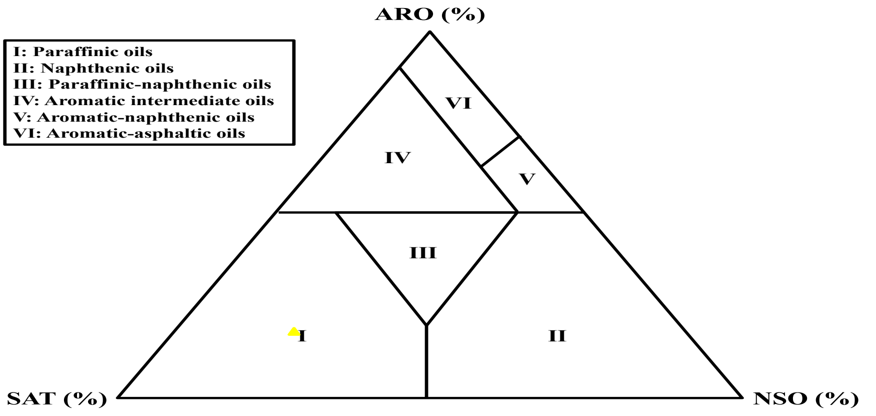
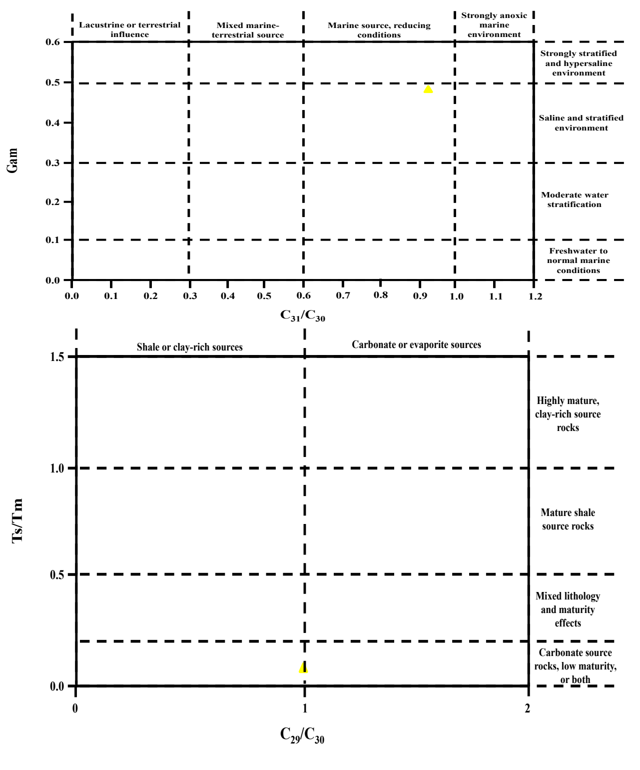


Fig. 12: Ternary plots (MPI-1 vs. VRc (fields after [22], [30]) and SARA (fields after [22]) showing the maturity of shale oil from the Lower Nubian Sandstone in well MM1-82.



Mineralogical and Geochemical Characteristics of the Nubian Formation in Well MM1-82, Sirte Basin, Libya
http://www.doi.org/10.62341/istj-vol39-1-46od

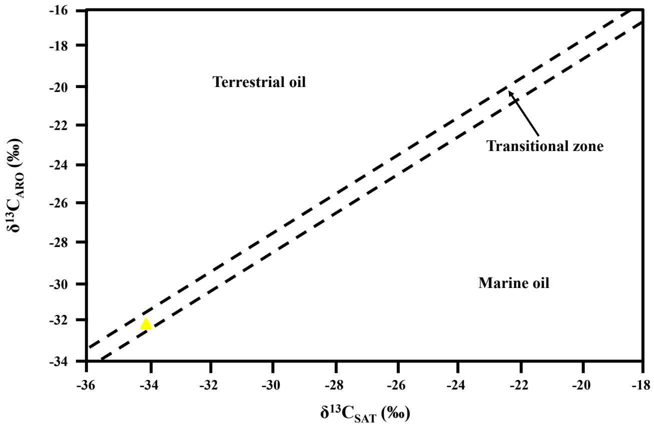


Fig. 13: Binary plots (C_{31}/C_{30} vs. Gam (fields after [31], [32]), C_{29}/C_{30} vs. Ts/Tm (fields after [31], [33]) and $\delta^{13}C_{SAT}$ vs. $\delta^{13}C_{ARO}$ (fields after [34]) showing the shale oil origin from the Lower Nubian Sandstone in well MM1-82

4. Conclusions and Recommendations

The Early Cretaceous Nubian Formation, comprising the Lower Nubian Sandstone, the Variegated Shale, and the Upper Nubian Sandstone in well MMI-82, Sirte Basin, north-central Libya, was subjected to detailed mineralogical and geochemical investigations. The main conclusions of this study are summarized as follows:

(1) The shale units within the Lower Nubian Sandstone can be categorized into argillaceous shale (CM), silica-rich argillaceous shale (CM-1), and mixed argillaceous shale (CM-2). On the other hand, argillaceous shale (CM) makes up the majority of the Varicolored Shale.

(2) The sandstones of the Lower Nubian Sandstone comprise quartz arenite, lithic sandstone, arkose, and subarkose.

(3) The investigated members display generally low organic richness, corresponding to poor and fair categories.

(4) The organic matter in the investigated members is represented by diverse kerogen types, including types II, II–III, III, and IV.

(5) The thermal maturity of organic matter varies among the studied members, with the Lower Nubian Sandstone being early mature, the Varicolored Shale ranging from immature to early

mature, and the Upper Nubian Sandstone remaining immature.

(6) All studied samples, except those belonging to the Upper Nubian Sandstone, contain indigenous hydrocarbons.

(7) The Lower Nubian Sandstone possesses fair to good oil-generating potential. The Varicolored Shale exhibits a broad range of source potential, extending from very poor to gas- and/or oil-prone. Similarly, the Upper Nubian Sandstone shows variable hydrocarbon potential, encompassing very poor, gas- and/or oil-prone, and fair oil source classifications.

(8) The Upper Nubian Sandstone represents the most promising interval, characterized by elevated oil saturation and excellent recoverable oil potential, whereas the Varicolored Shale and the Lower Nubian Sandstone exhibit low oil saturation and only poor to fair prospects for recoverable hydrocarbons.

(9) The oil recovered from the Lower Nubian Sandstone has reached a mature stage of thermal evolution and was derived from multiple marine source rocks.

In light of the favorable oil saturation and recoverable hydrocarbon potential of the Upper Nubian Sandstone, further research should focus on detailed reservoir evaluation, petroleum system modeling, and pilot production assessments to determine its suitability for unconventional resource development in the Sirte Basin, Libya.

References

[1] Ahlbrandt, T.S. (2001): The Sirte Basin province of Libya—Sirte-Zelten total petroleum system. U.S. Geological Survey Bulletin 2202–F; 29p.

[2] Burwood, R., Redfern, J. and Cope, M.J. (2003): Geochemical evaluation of East Sirte Basin (Libya) petroleum systems and oil provenance. Geological Society, London, Special Publications; 207: 203-240.

[3] Saheel, A.S., Bin Samsudin, A. and Bin Hamzah, U. (2010): Regional geological and tectonic structures of the Sirt basin from potential field data. American Journal of Scientific and Industrial Research; 1(3): 448-462.

[4] Abdunaser, K.M. (2015): Review of the petroleum geology of the western part of the Sirt Basin, Libya. Journal of African Earth Sciences; 111: 76-91.

[5] Albriki, K., Wang, F., Li, M. and El Zaroug, R. (2021): Source rock maturity evaluation and its implications for regional petroleum charge, Sirt Basin, Libya: Insights from regional geochemical assessments and modelling study. Journal of African Earth Sciences; 176: 104114.

[6] Albriki, K., Guoqi, W., Wang, F., El Zaroug, R. and Abdullah, A. (2024): Nature and occurrence, geochemical characteristics, and families of the crude oils in Sirt Basin, Libya: Implication for super rift basin petroleum system. Journal of African Earth Sciences; 216: 105307.

[7] Thomas, D. (1995): Exploration limited since '70s in Libya‘s Sirte Basin. Oil and gas journal; 93: 11.

[8] Hallett, D. (2002): Petroleum geology of Libya. Amsterdam, Elsevier Inc., 503p.

[9] Saleem, M.A. (2015): Tectonic evolution and structural analysis of south western Sirte Basin, Central Libya. Unpublished PhD Thesis, University of Birmingham, UK.

[10] Abdunaser, K.M. and McCaffrey, K.J.W. (2014): Rift architecture and evolution: The Sirt Basin, Libya: The influence of basement fabrics and oblique tectonics. Journal of African Earth Sciences; 100: 203-226.

[11] Desio, A. (1935): Studi geologic! sulla Cirenaica, sul deserto Libico, sulla Tripolitania e sul Fezzan orientate. Missione scientifica della R. Accad. d'ltalie a Cufra, (1931), Roma; 480p.

[12] Barr, F.T. and Weegar, A.A. (1972): Stratigraphic nomenclature of the Sirte Basin, Libya. Petroleum Exploration Society of Libya, Tripoli; 179p.

[13] Ibrahim, M.W. (1991): Petroleum geology of the Sirt Group sandstones, eastern Sirt Basin. In: M.J. Salem, M.T. Busrewil and A.M. Ben Ashour (Eds) Third Symposium on the Geology of Libya, Amsterdam, Elsevier; 7: 2757-2779.

[14] Ambrose, G. (2000): The geology and hydrocarbon habitat of the Sarir Sandstone, SE Sirt Basin, Libya. Journal of Petroleum Geology; 23(2): 165-192.

[15] Aboglila, S. and Elkhalgi, M. (2013): Organic geochemical evaluation of Cretaceous potential source rocks, east Sirte Basin, Libya. International Journal of Geosciences; 4: 700-710.

[16] USGS (U.S. Geological Survey, 2019): Assessment of shale-oil resources of the Sirte Basin province, Libya, 2019. Fact Sheet 2019–3028; 2p.

[17] Shaltami, O.R., Alsaker, M.S. and Ben Hkoma, M. (2026): Petroleum geochemistry of the Varicolored Shale of the Nubian Formation in wells R8-82, R9-82, and R10-82, Sirte Basin, north central Libya. Al-imad Journal of Humanities and Applied Sciences (AJHAS); 2(1): 335-351.

[18] Aboglila, S., Grice, K., Trinajstic, K., Dawson, D. and Williford, K.H. (2010): Use of biomarker distributions and compound specific isotopes of carbon and hydrogen to delineate hydrocarbon characteristics in the east Sirte Basin (Libya). Organic Geochemistry; 41(12): 1249-1258.

[19] Gamero-Diaz, H., Miller, C. and Lewis, R. (2012): sCore: A classification scheme for organic mudstones based on bulk mineralogy. American Association of Petroleum Geologists, Search and Discovery Article #40951.

[20] Pettijohn, F.J., Potter, P.E. and Siever, R. (1987): Sand and sandstone. 2nd eition, Springer New York; 553p.

[21] Peters, K.E. and Cassa, M.R. (1994): Applied source rock geochemistry. In: Magoon, L.B., Dow, W.G. (Eds.): The petroleum system from source to trap, AAPG Memoir; 60: 93-117.

[22] Tissot, B.P. and Welte, D.H. (1984): Petroleum formation and occurrence. 2nd edition. Springer Berlin, Heidelberg; 702p.

[23] Dembicki, H.J. (2009): Three common source rock evaluation errors made by geologists during prospect or play appraisals. American Association of Petroleum Geologists Bulletin; 93(3): 341-356.

http://www.doi.org/10.62341/istj-vol39-1-46od

[24] Jones, R.W. (1987): Organic facies. In: Brooks, J., Welte D. (Eds.), Advances in Petroleum Geochemistry 2. Academic Press, London; pp. 1-90.
[25] Longford, F.F. and Blanc-Valleron, M.M. (1990): Interpreting Rock–Eval pyrolysis data using graphs of pyrolyzable hydrocarbons vs. total organic carbon. American Association of Petroleum Geologists Bulletin; 74: 799-804.
[26] Hall, L.S., Boreham, C.J., Edwards, D.S., Palu, T.J., Buckler, T., Hill, A.J. and Troup, A. (2016): Cooper Basin source rock geochemistry: Regional hydrocarbon prospectivity of the Cooper Basin. Geoscience Australia, Part2; 62p.
[27] Hunt, J.M. (1996): Petroleum geochemistry and geology. 2nd edition, W. H. Freeman; 743p.
[28] Jackson, K.S., Hawkins, P.J. and Bennett, A.J.R. (1985): Regional facies and geochemical evaluation of southern Denison Trough. Journal of Australian Petroleum Production and Exploration; 20: 143-158.
[29] Jarvie, D.M. (2012): Shale resource systems for oil and gas: Part 1: shale-gas resource systems. In: Breyer, J.A. (Ed.), Shale Reservoirs-Giant Resources for the 21st Century. AAPG Memoir 97, American Association of Petroleum Geologists; pp. 69-87.
[30] Radke, M. (1988): Application of aromatic compounds as maturity indicators in source rocks and crude oils. Marine and Petroleum Geology; 5(3): 224-236.
[31] Moldowan, J.M., Seifert, W.K. and Gallegos, E.J. (1985): Relationship between petroleum composition and depositional environment of petroleum source rocks. American Association of Petroleum Geologists Bulletin (AAPG); 69: 1255-1268.
[32] Peters, K.E., Walters, C.C. and Moldowan, J.M. (2005): The biomarker guide: Biomarkers and isotopes in petroleum exploration and Earth history. 2nd edition, Cambridge University Press; 471p.
[33] Andrew, D.H., Bradley, D.R., David, Z.J., Moldowan, M. and Ulderico, B. (2001): Upper Oligocene lacustrine source rocks and petroleum systems of the northern qaidam basin, North

http://www.doi.org/10.62341/istj-vol39-1-46od

West China. American Association of Petroleum Geologists Bulletin; 85: 601-619.

[34] Sofer, Z. (1984): Stable carbon isotopic compositions of crude oils: Application to source depositional environments and petroleum alteration. American Association of Petroleum Geologists Bulletin; 68: 31-49.