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Visual Kerogen Analysis for Source Rocks Assessment: A Case Study of Some Subsurface Cretaceous (Valanginian-Cenomanian) Strata from Shushan Basin, Northern Western Desert, Egypt

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Abstract: In the Shushan Basin, we examined the organic matter under transmitted light microscopy for spore coloration index (SCI) and kerogen type assessment. We used this index to estimate tentative values of the Thermal Alteration Index (TAI) and the Vitrinite Reflectance (Ro) that are equivalent to these SCI values on available standard color charts. Based on that, we inferred the degree of the thermal maturity of the investigated Early (to earliest Late) Cretaceous rock units. We confirmed their previously described high potential as sources of hydrocarbons. However, the Alam El-Bueib, Alamein, Dahab, Kharita, and Bahariya formations contain abundant AOM, frequent opaque phytoclasts, and common non-opaques, indicating oil- and gas-prone kerogen types II and III and reflect mature to overmature hydrocarbon generation potentiality.
Keywords: Kerogen, Spore Colouration Index, Thermal maturity, Hydrocarbon Potential, Shushan Basin

1. Introduction and Geological Setting

The northwestern part of Egypt has been subjected to a range of tectonic processes since the Paleozoic, resulting in the development of various sedimentary basins and sub-basins, ridges, troughs, and platforms (e.g. [1, 2]). The hydrocarbon source rock potential of the Mesozoic succession is considerably better understood than that of the Paleozoic because it has been more thoroughly explored by comprehensive analyses (e.g., [3-18]).

These basins were filled by a thick sedimentary sequence ranging in age from Jurassic to Paleogene. The Shushan basin represents a Mesozoic coastal basin in northeast Africa and is located in the northern part of the Western Desert, striking in a northeast-southwest trend. The Jurassic to Paleogene is a thick sediment succession. The Mesozoic coastal Shushan Basin in northeast Africa is located in the northern section of the Western Desert, with a northeast-southwest trend (Figure 1). It covers around 3800 km2 and forms a considerable part of the Unstable Shelf of Egypt [19]. It has a substantial hydrocarbon accumulation potential [20] and is considered a vital hydrocarbon province in northern Egypt [21-23]. The Shushan Basin is part of a tectonic system that originated from the movement of North Africa toward Europe. Accordingly, the basin evolved through three major tectonic events, which are listed in chronological order as follows [24]: a) Jurassic to the early Cretaceous rifting event, b) Late Cretaceous to the early Paleogene compressional event, c) Miocene and Post Miocene extensional event., During these tectonic events, the Shushan Basin formed as a half-graben basin filled with Paleogene strata up to 7.5 km thick [1].

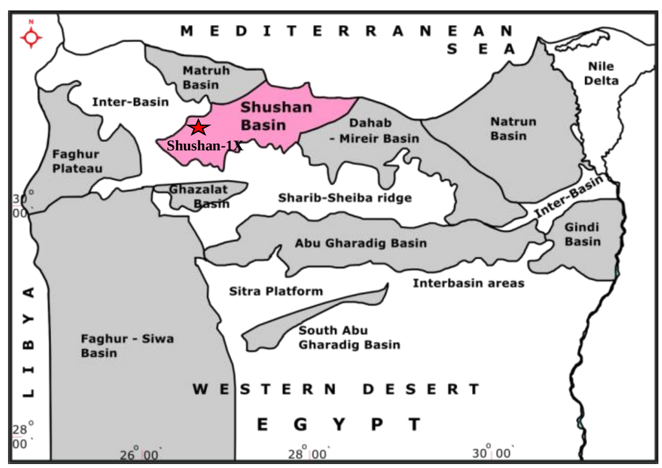

Figure 1. Map showing the location of the investigated Shushan-1X borehole and positions of the main Mesozoic basins in the Western Desert of Egypt (modified from [23]).

The area of the Shushan Basin witnessed Jurassic and Early Cretaceous extension, followed by Late Cretaceous and Early Paleogene inversion [25]. The sedimentary infill in the Shushan Basin combines a sedimentary succession ranging in age from the Middle Jurassic to the Recent (Figure 2), approximately 14,000 feet (4267.2 m.) thick [26]. The sedimentary sequence is considered foreland deposits because the basin is located on the northern border of the Afro-Arabian shield [1, 25]. The Paleozoic basement rocks unconformably overlie these deposits. The beds display a general slope to the north, resulting in the northward thickening of the sedimentary sequence [26].

Stratigraphically, [19] classified the Cretaceous into two units: The lower unit comprises Lower Cretaceous clastic rocks, while the upper unit is composed mainly of carbonates rocks. These rock units from base to top are Alam El Bueib Formation (Neocomian – Early Aptian), Alamein Formation (Early Cretaceous – Middle Aptian), Dahab Formation (Aptian – Early Albian), Kharita Formation (Early Cretaceous – Albian), Bahariya Formation (Early Cenomanian). The Alam El Bueib Formation (Neocomian – Early Aptian), it is made up of sandstone that has been interbedded with thin shale layers from shallow marine or fluvial-deltaic settings [12]. The Alamein Formation (Early Cretaceous – Middle Aptian) is mainly composed of shallow marine dolomite and limestone. It is deposited under moderately energetic subtidal external marine environments [12]. The Dahab formation (Aptian – Early Albian) is made up of shales, siltstones, sandstones, and small carbonate interbeds that conformably overlie and conformably underlie the Alamein Formation. The Kharita Formation (Early Cretaceous – Albian), consists of sandstone and a few shale interbeds of shallow marine origin [27]. It is situated on top of the Dahab Formation and below the Bahariya Formation. The Kharita Formation is the most likely, having been formed on a large shallow marine shelf in a high-energy (mainly littoral) environment and containing several gas-prone carbonaceous shales with strong gas production potential [12]. The Bahariya Formation (Early Cenomanian) consists of glauconitic and pyritic sandstone interbedded with shales, siltstones and carbonates. It conformably overlies the Kharita Formation and underlies the Abu Roash Formation. Bahariya Formation was deposited under a fluviomarine environment in the Western Desert [12]. The Cretaceous rocks (Aptian and Cenomanian–Turonian) deposited on Palaeo-highs under relatively high energy conditions are the main hydrocarbon reservoirs of the Western Desert [12].

Palynomorphs are plant and animal structures resistant to decay and acid treatment, making them ideal for environmental investigations. Thermal alteration index (TAI), maturity level, and spore color index (SCI) for source rock potential have also been estimated using visual kerogen analysis. Authors referred to the organic components as "organic matter" (e.g., [28]), "palynodebris" (e.g., [29, 30], or "kerogen" (e.g., [31]), with the latter being the most often popular term today. [31] introduced the word kerogen to characterize the scattered particulate organic matter of sedimentary rocks insoluble in hydrochloric (HCl) and hydrofluoric (HF) acids in a purely palynological sense. This research aims to identify the kerogen types and their maturation levels of the studied material of the Shushan-IX well, Shushan Basin, through the palynological procedure for its hydrocarbon potential.

2. Materials and method

135 ditch-cutting samples were selected from the Shushan-1X well, Shushan Basin, northern Western Desert, Egypt, drilled by [32]. These samples from Alam EL-Bueib, Alamein, Dahab, Kharita, and Bahariya formations were studied for their kerogen characterization. Also, these samples were analyzed and processed following standard palynological laboratory procedures for digesting the samples and removing silicates and carbonates (e.g., [33, 34]). Neither oxidation nor ultrasonic treatments were utilized to maintain the organic components for the optical color measurements and kerogen content. Then, using glycerin jelly as a mounting medium, two and/or three slides from each sample are prepared. Each slide was examined using Leica DM 500 transmission light microscopy and photomicrographs taken with an ICC50 HD camera. All microscope slides and residues are archived at the Geological Museum, Department of Geology, South Valley University, Qena (Egypt).

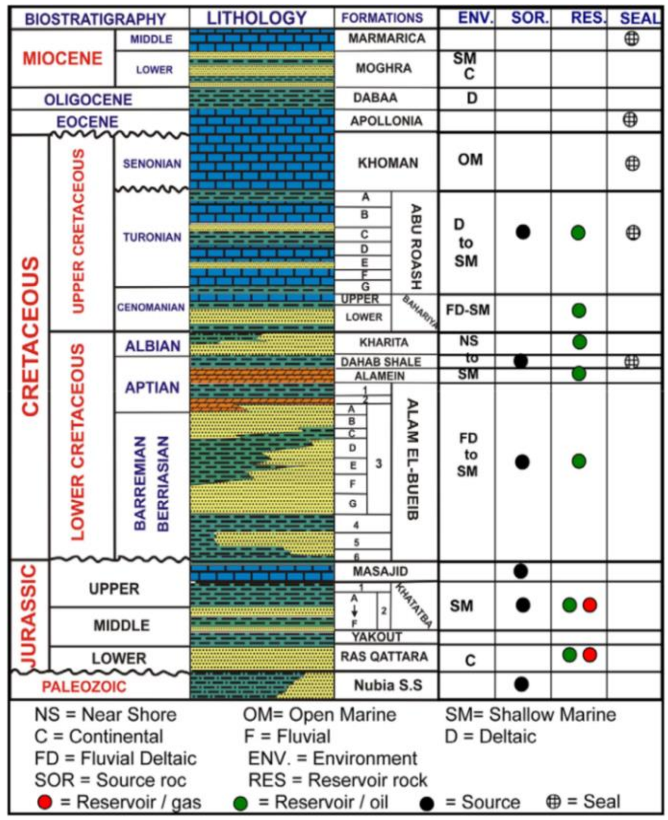

Figure 2. Simplified stratigraphic column of the Western Desert, Egypt (modified after [7, 8].

Transmitted light microscopy of the kerogen assemblage involves a comprehensive examination of all elements of organic rock assembly. Several aspects of organic matter should subsequently be examined [35, 36]. 500 particles were counted and classified as abundant (>35%), frequent (16-35%), common (5-15%), and unusual (<5%). Kerogen assemblages are classified and counted based on each type of kerogen particle, each of which has a unique hydrocarbon generation capacity [37], to determine the relative percentages of three groups: amorphous organic matter (AOM), vitrinites (land-plant materials), and inertinites (recycled), where the relative Numeric Frequencies (RNF%) of palynofacies assemblages that use Liptinite-Vitrinite-Inertinite (LVI) and Vitrinite/Huminite-Liptinite-Inertinite (VHI) categories are displayed as ternary plots and imply fields of the respective kinds of hydrocarbons generated [35]. The color of spores or pollen grains are used in this work to calculate the thermal alteration index (TAI) values. Vitrinite reflectance (Ro%) by selecting the hue of simple, thin-walled psilate spores (e.g., *Deltoidospora*) by using the standard color chart adapted after [**34, 41**] and to determine the extent of thermal maturation of kerogen [**31, 35, 38**]. When compared to powerful organic geochemical and vitrinite reflectance (Ro %) analyses (e.g. [**17, 18, 39, 40**]). Furthermore, we used the [**42**] liptinite-vitrinite-inertinite (LVI) plot to facilitate the characterization of the kerogen assemblages and designate the probable hydrocarbons that may have been generated from them (i.e., oil, wet gas, and dry gas) by plotting the values calculated from the studied samples on the [**42**] LVI ternary.

3. Results and discussion

The two principal components of organic matter in sediments and sedimentary rocks are kerogen (a percentage of organic matter that is insoluble in organic solvents) and bitumen (a portion of the organic matter soluble in organic solvents). Kerogen was first named in 1912 by [**43**], who described it as the discrete organic matter of ancient sediments that is insoluble in conventional organic solvents, as opposed to extractable organic matter (bitumen). [**44-46**], added definitions. Kerogen is a diagenetic derivative of the original organic matter retained in sediments due to burial under favorable temperature and pressure.

The subsequent thermal alteration (catagenesis) converts kerogen to bitumen, which is then converted into oil or gas, depending on the type of organic matter present and the current environmental alteration setting (e.g. [**31, 35, 47**] presented simple palynofacies categorizing sedimentary organic matter for quick kerogen typing.

This categorization deals with the percentage frequency of AOM, brown and/or black phytoclasts, and palynomorphs.

According to Ref. [**35**], the following kerogen types may be detected: A) Kerogen type I (highly oil-prone material), B) Kerogen type II (oil-prone material), C) Kerogen type III (gas-prone material), and finally, D) Kerogen type IV (inert material). This categorization is used in this study because it is easy and may be established using normal palynological slides, as has been done in this work by acids without additional treatments, such as ultrasonication or oxidation. The Alam El Bueib and Alamein formations from the Shushan-1X well, which covers the interval (12380-10030 ft.), include abundant AOM (avg. 52% of the total kerogen material), frequent non-opaque (avg. 33%) and common opaque phytoclasts (avg. 15%) Appendix (1). Simple thin-walled psilate spores (*Deltoidospora*) are medium to dark brown.

Therefore, they reflect an over-mature state, corresponding to a thermal alteration index (TAI) of 4 to 3+ and corresponding theoretical vitrinite reflectance values of 1.3-2.0% (Figure **3**). The hydrocarbon generation potential in each of these formations varies from gas-prone III to oil-prone II); they are mature to over-mature to generate hydrocarbons. However, the majority of samples of the studied sequence penetrated by the studied well fell in the fields of wet gas and oil (Figure **4A**). A few scattered samples, however, enter the field of dry gas.

AOM is common (avg. 55% of the total kerogen material) in samples from the Dahab, Kharita, and Bahariya formations, depths from 10000 to 5340 ft.), whereas non-opaque (avg. 27%) and opaque phytoclasts (avg. 18%) are frequent (Appendix, 1).

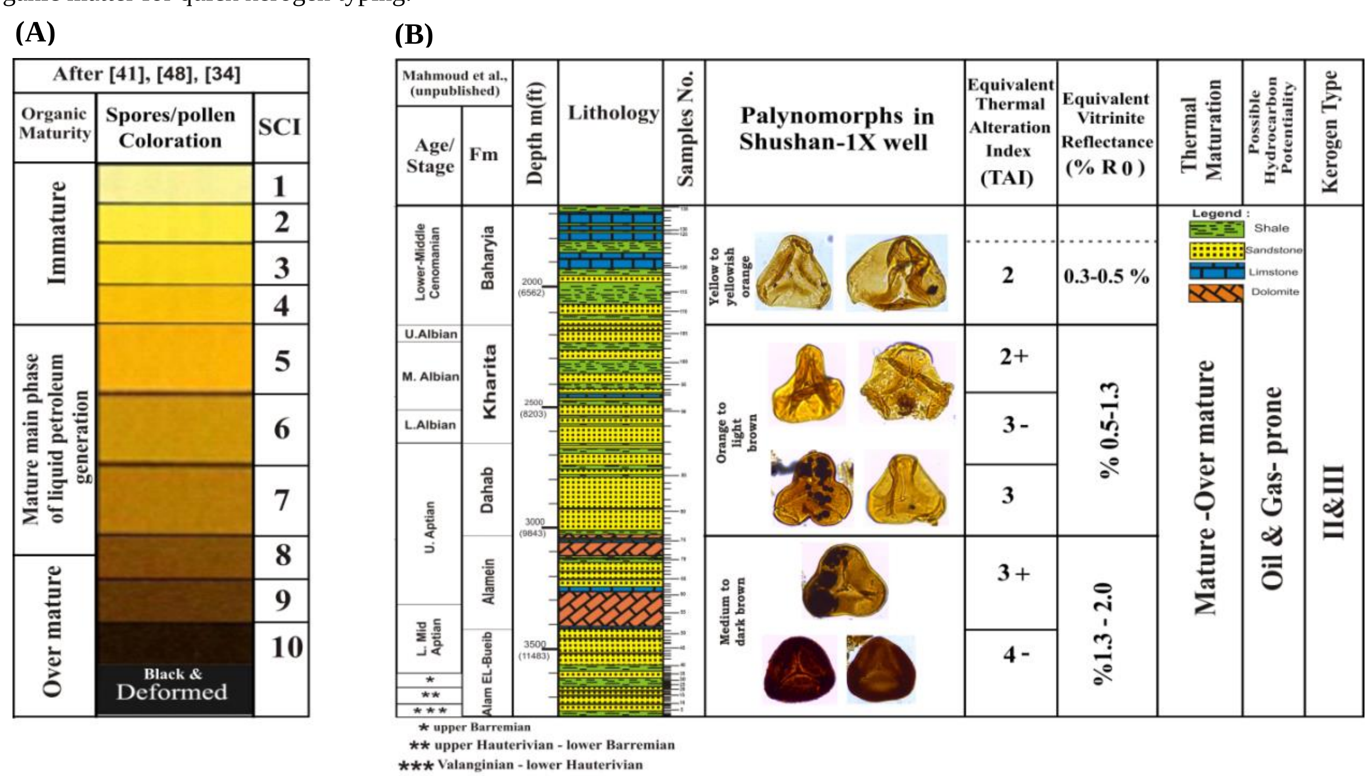

Figure 3. Spore Color Index, SCI (A) used in the tentative estimation of thermal maturation index (TAI), and vitrinite reflectance Ro % (B) in the present study in Shushan-1X well, Northern Western desert, Egypt (Modified from [34, 41, 48]).

The spore color (Figure 3) ranges from yellow to medium brown, equivalent to the thermal alteration index (TAI) of 2- to 3, and theoretical vitrinite reflectance values of 0.3-1.3 %. The hydrocarbon generation potential in each of these formations varies from II to III (Gas to oil-prone), and they are mature to over-mature to generate hydrocarbons (figures. 4A, B). However, most of the samples from the Bahariya Formation fall in the oil field in the diagram of figure 4A. This is well established and confirmed in most of our study samples where the inert material is minor. This can also be seen from the empty (dry gas) field on one of the applied ternary diagram models and the complete absence of type IV (residual organic matter) kerogen on the other ternary plot.

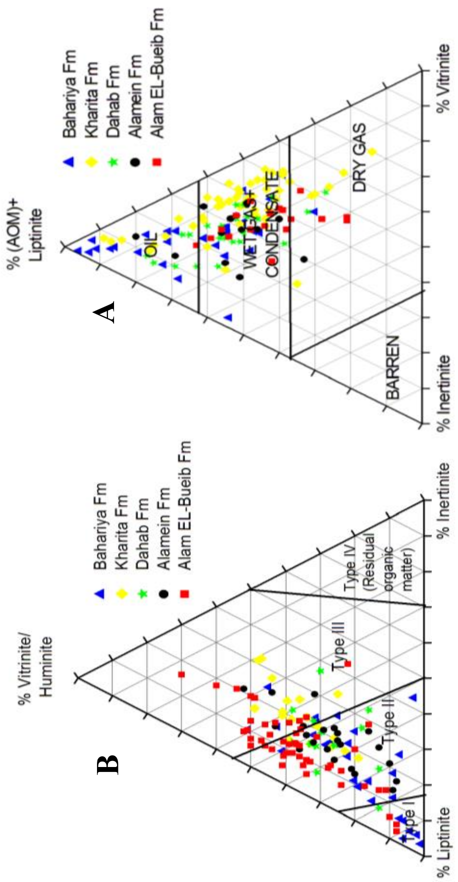

Figure 4. A-Ternary Liptinite -Vitrinite -Inertinite (LVI) kerogen plots (after [42]) with fields indicating predicted hydrocarbon source potential in the Shushan-1X well, B- Ternary plot of kerogen types based on major organic components (modified after [49]).

4. Conclusion

The palynofacies in the Shushan-1X well were counted and categorized using Pearson's color chart [41] to estimate the tentative thermal alteration index (TAI) and the vitrinite reflectance (Ro%) in terms of organic thermal maturity. The variation in the percentage frequency of each particulate organic matter constituent (i.e., palynomorphs, phytoclasts, AOM) in the Shushan-1X well reflects variable hydrocarbon potential states. The Alam El Bueib, Alamein, Dahab, Kharita, and Bahariya formations are mature to over-mature, gas, and oil-prone material of kerogen types III and II. Based on spore coloration, the thermal maturity of the organic matter reflect middle to late maturation phases. Our results are consistent with the previously established data, which revealed high hydrocarbon potential in the northern Western Desert and the Shushan Basin in particular.

Sample No.	Depth(ft)	Formation	Vitrinite %	AOM + Liptinite %	Intertinite
135	5340	Bahariya	2	93	5
134	5390		51	39	10
133	5420		15	77	8
132	5510		45	30	25
131	5580		20	55	25
130	5610		31	47	22
129	5660		22	61	17
128	5760		4	91	5
127	5800		3	54	43
126	5840		31	45	23
125	5960		32	50	18
124	6010		27	55	19
123	6160		9	73	19
122	6260		6	87	7
121	6290		1	96	3
120	6350		7	68	25
119	6400		6	93	2
118	6460		7	85	7
117	6560		9	80	12
116	6610		16	71	13
115	6670		28	54	17
114	6710		25	48	27
113	6790		42	42	15
112	6840		19	71	10
111	6900		28	55	17
110	6940		41	50	9
109	7000		22	58	21
108	7050		20	68	11
107	7110	Kharita	39	48	13
106	7180		19	63	18
105	7230		27	56	17
104	7290		23	59	18
103	7400		36	38	26
102	7450		47	21	32
101	7570		25	42	33
100	7610		49	34	17
99	7670		41	40	19
98	7770		40	37	24
97	7810		38	42	19
96	7890		33	52	15
95	7930		48	21	31
94	8070		41	39	20
93	8160		34	44	22
92	8220		44	28	28
91	8280		26	54	20
90	8330	Kharita	41	39	20
89	8670		31	48	21
88	8710	Dahab	30	33	37
87	8950		18	55	27
86	9120		30	51	20
85	9180		32	46	22
84	9230		38	40	22
83	9270		26	56	18
82	9550		31	53	15
81	9600		13	80	7
80	9650		38	49	13
79	9700		33	52	15
78	9910		31	61	8
77	9960		13	69	18
76	10000		16	51	33
75	10030	Alamein	25	53	22
74	10080		24	56	19
73	10180		20	67	13
72	10210		21	65	14
71	10250		32	39	30
70	10300		43	42	15
69	10360		44	32	24
68	10410		52	27	21
67	10460		36	52	12
66	10520		37	50	13
65	10570		9	77	14
64	10620		16	57	27
63	10660		8	75	17
62	10700		10	69	21
61	10730		13	63	24
60	10770		26	51	23
59	10820		25	55	20
58	10850		26	60	14
57	10890		29	50	21
56	10980		34	49	17
55	11030		35	46	19
54	11070		28	56	16
53	11120		32	52	16
52	11170	Alam EL-Bueib	39	49	12
51	11240		22	35	43
50	11300		20	60	20
49	11340		24	68	8
48	11370		16	55	29
47	11410		31	51	18
46	11450		34	44	22
45	11490	Alam EL-Bueib	34	60	6
44	11530		36	47	18
43	11570		39	43	18
42	11650		36	51	13
41	11690		37	50	13
40	11740		52	39	9
39	11760		27	61	12
38	11770		34	56	10
37	11780		36	51	13
36	11800		44	48	8
35	11810		40	51	9
34	11850		54	26	20
33	11860		36	44	20
32	11880		40	51	9
31	11890		33	57	10
30	11900		43	41	16
29	11910		46	46	8
28	11920		41	48	12
27	11930		60	22	18
26	11950		36	54	10
25	11960		41	52	8
24	11980		51	39	10
23	11990		50	30	20
22	12000		50	42	8
21	12010		47	44	9
20	12030		46	40	14
19	12040		28	62	11
18	12050		49	31	20
17	12060		50	44	6
16	12090		70	14	16
15	12110		37	47	16
14	12120		38	52	10
13	12150		50	37	13
12	12170		45	44	12
11	12200		36	47	18
10	12210		41	54	5
9	12230		35	57	8
8	12260		24	64	12
7	12280		17	71	11
6	12290		37	49	13
5	12300		13	75	12
4	12320		11	76	13
3	12340		8	87	5
2	12360		8	89	3
1	12380		10	84	6

Appendix 1. List of different palynofacies constituents of the Shushan-1X borehole used in the palynofacies analysis and Kerogen assessment.

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