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Paleoenvironmental and Palynofacies Insights from Lower Cretaceous Strata in the Obaiyed Field, Shushan Basin, North Western Desert, Egypt

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Abstract: Semi-quantitative and qualitative analyses of the total particulate organic matter (TPOM) constituents in nineteen cutting samples from the Lower Cretaceous successions of the OBA D-8 borehole, Obaiyed Field, Shushan Basin, north Western Desert of Egypt. The analyses were conducted to identify the prevailing palynofacies and paleoenvironments. The combined data derived from the palynofacies assemblages and palynomorphs groups, the ternary plots along with the lithological composition indicate two palynofacies (PF) units; they are PF-1 and PF-2. PF-1was corresponds to sediments recovered from the clastics of the Alam El Bueib Formation. These sediments were situated in a marginal marine (deltaic) environment during a marine regression phase, with suboxic-anoxic to oxic settings, resulting in poor to relatively good organic matter preservation status. PF-2 corresponds to sediments recovered from the Alamein (mixed clastics-carbonates) and the Dahab and Kharita clastics formations. Sediments of PF-2 were deposited during a progressive marine regression phase beneath suboxic to anoxic conditions in an inner marine habitat. Sea level rose during the Late Valanginian-Hauterivian; the Aptian high stand and the Albian high stand were superimposed by the Early Cretaceous uplift (Valanginian-Albian) associated with the rifting of the Shushan Basin.
Keywords: Cretaceous, particulate organic matter, palynofacies, suboxic-anoxic to oxic.

1. Introduction

The Lower Cretaceous subsurface deposits in several basins of the north Western Desert of Egypt serve as hydrocarbon sources and reservoirs [**1**]. Numerous palynological studies made on the Western Desert in Egypt provided insight into the nature of the microflora and depositional environments of the Lower Cretaceous [**2**-**19**]. The Obaiyed Oil Field is situated in a location distinguished by a deep foundation rock, thick sedimentary column, and a complicated structural regime. The area's structural style can be explained in terms of global tectonics, which affects the northern part of the Western Desert and is linked to the movement of North Africa towards Europe during the Late Cretaceous Syrian Arc deformation phase, which had a significant impact on the area [**20**]. Furthermore, sedimentation in the Shushan Basin along with other costal basins in the Western Desert was mainly controlled by the Tethyan sea level changes, which were sometimes masked by the strong tectonic activities [**11**, **12**, **19**, **21**].

According to [**22**], the study of organic matter in sedimentary rocks focuses on the biosphere-geosphere interaction. A thorough understanding of this issue requires knowledge of the ecological and sedimentological processes that regulate the production, sedimentation, and preservation of organic matter. For many geologists, describing the organic matter found in sedimentary rocks is a key subject. Using palynofacies analysis, we aim to assess the Obaiyed Field, one of the largest tight gas sand reservoir in northwest Africa and a part of the Shushan Basin. Based on the recovered palynofacies associations, we infer the paleoenvironmental conditions that prevailed during the deposition of the studied successions. This advances our knowledge of the paleoenvironment of the northern Western Desert in general and the Obaiyed Field in particular by allowing us to conduct thorough semi-quantitative analyses of the recovered palynomorphs and the palynodebris types of the formations of Alam El Bueib, Alamein, Dahab, and Kharita.

2. Geological Setting and Lithostratigraphy

The coastal basins formed as rifts in the early Mesozoic by the late Cimmerian Orogeny, due to the opening of the Neo-Tethyan Ocean and the closing of the Palaeo-Tethyan Ocean [**23**]. Additionally, there is well-documented lower Cretaceous active continental rifting in Arabia and North Africa [**24**, **25**]. This regional tectonics led to the construction of several extensional intracratonic rift basins throughout the northern Western Desert, such as the Shushan Basin [**1**, **25**, **26**]. The Shushan basin is one of the biggest Mesozoic coastal basins in northeast Africa (Matruh, Dahab, Shushan, and Natrun) and is a half-graben system with Jurassic, Cretaceous, and Paleogene deposits up to 7.5 km thick [**27**, **28**] It is situated in the northern section of the Western Desert, which extends northeast to southwest. It has thick sediment dating from the Jurassic to the Palaeogene (Figures **1**, **2**). It is also characterized by parallel, elongated, titled fault block formations, also known as horst and half-graben structures, with upthrown blocks eroded (Figure **1**).

According to [**31**], it encompasses the majority of Egypt's unstable shelf and covers approximately 3800 km2, and to

[32], the basin has high hydrocarbon accumulation potential. The Obaiyed Field, which is found in the southwestern section of the Shushan Basin, is regarded as the greatest Jurassic gas/condensate field in the Shushan Basin and the northern portion of the Western Desert in general. Located 50 kilometers south of the Mediterranean shore in latitudes 31º 02' and 31º 12` N and longitudes 26º 34' and 26º 45' E. The Upper Cretaceous compression event inverted pre-existing Jurassic normal faults, resulting in primarily an asymmetric fold system. The reservoirs comprise Bathonian sandstone that unconformably overlies the pre-rift Palaeozoic stages [28]. Where that is produced from the Khatatba Formation, which overlays the Paleozoic high with an unconformity surface at a depth of around 4000 m [20] (Figures 1, 2). The Middle and Upper Cretaceous, Middle Miocene, Upper Jurassic, and Carboniferous are the four main sedimentary cycles that have been discovered. For these cycles, maximum southward transgression was a characteristic. Northward regressive events happened throughout both the Triassic and Lower Jurassic periods, and they remained to be active during the Lower Cretaceous and Upper Eocene [33] (Figure 2).

The Western Desert's sedimentary succession is composed of the following tectonically and eustatically controlled depositional cycles [29]: The clastic facies cycle that encompasses the whole Paleozoic and Lower Jurassic formations is what distinguishes the oldest sedimentary rocks, which include sandstone, siltstone, and shale. A carbonate section of middle and upper Jurassic formations; Together, the Lower Cretaceous and Upper Cretaceous form a lower Cenomanian clastic cycle. The Upper Cenomanian and Upper to Middle Eocene are again categorized for deposits of carbonate in the northern Western Desert.

The topmost clastic cycle is made up of the Upper Eocene-Oligocene, Miocene, and more recent sections. Excessively unconformable to the Masajid Formation are the (Berriasian/Valanginian-Barremian) Lower Cretaceous of the Formation of Alam El Bueib, which is a deltaic to shallow marine clastic due to the regional "Late Cimmerian event" of the Latest Jurassic through the unconformity surface in the Shushan Basin that links to the division of the Upper Jurassic from the Lower Cretaceous. The faulting of Blocks and elevation of a huge portion of the northern African margin, including the northwest Egyptian desert, resulted from this event. The NE drift of Africa towards Europe and the opening of the North Atlantic Ocean were linked to this tectonic event [34- 36]. The formation of Alam EL Bueib are followed by shales sequence of shallow marine from the Dahab Formation and deltaic to shallow marine clastics and carbonates from the Alamein Formation of Aptian age. Over most of the Western Desert, the Kharita Formation which is composed of sandstone with frequent shale alternations from deltaic to shallow marine, rests on the Dahab Formation conformably. However, in certain areas, due to the erosion of certain sediment overburdens, as reported in the studied well, there is another unconformity surface [28, 29, 34, 37].

3. Materials and Methods

The current study looks at palynological investigations of 19 ditch-cutting samples from the Alam El Bueib, Alamein, Dahab, and Kharita formations in the OBA D-8 well, which were processed for palynological contents and palaeoenvironmental analysis of the Lower Cretaceous, northern Western Desert, Egypt.

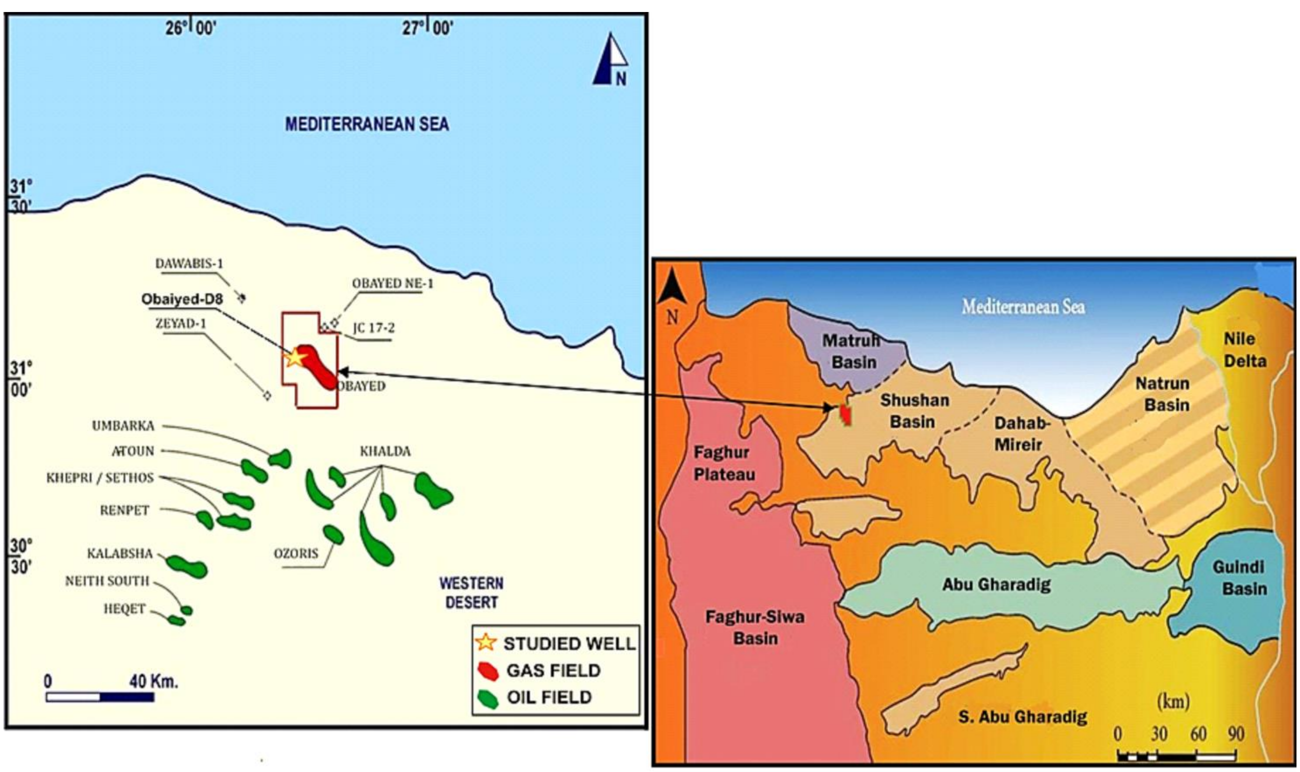

Figure 1: Location map of Mesozoic basins in the northern Western Desert of Egypt, showing Shushan Basin including the Obaiyed field and the Obaiyed-D8 well (modified after [29] & [30]).

In the western Shushan Basin (Lat. 31° 05′ 41.68″ N, Long. 26° 35′ 06.32″ E; Figure 1), BAPTCO drilled the well as part of an exploratory program. Approximately 20 grams were digested using standard laboratory processing methods [38]. The palynological processing of samples was first treated with 32% hydrochloric acid (HCl) to remove carbonates (CaCO3), then washed several times with distilled water until neutral. They were then macerated in 40% hydrofluoric acid (HF) to dissolve silicates and washed many times until neutralized. Following digestion, residues were sieved over a 15 µm nylon screen. Nitric acid and other oxidizing agents were deliberately avoided to preserve the integrity and morphology of the organic components. This residue was used in a palynofacies analysis. A portion of the residue was subjected to low-frequency ultrasonic vibration for a few seconds in order to concentrate palynomorphs and count them exclusively. Light microscopy was used to analyze three to five slides from each sample, which had been mounted with glycerin jelly. POM concentration was measured on each slide, with an initial 500 debris classed to be abundant (>35%), frequent (16-35%), common (5-15%), or rare (<5%).

To undertake semi-quantitative examinations of organic matter, samples were examined with an Axiolab transmitted white light microscope at various magnifications (× 10, × 20, and × 40 objective) and for photomicrography by its digital camera. Rock samples were stored in the Geological Museum, Geology Department, Faculty of Science, Sohag University in Egypt, while paleontological slides and organic remains were stored in glass tubes. A semi-quantitative investigation (500 counts, a separate count) of particulate organic matter (POM) on these samples was conducted, which identified palynofacies constituents and provided palaeoenvironmental interpretations based on [22] analysis of the fraction of unique (POM) terms. Also, [22] employed the AOM-Phytoclasts-Palynomorphs (APP) ternary plot to deduce the reducing/oxidizing conditions. A total of around 200 specimens (another separate count) of various palynomorphs were counted, allowing for the calculation of relative percentages among groupings. The ratio of continental to marine palynomorphs (Cont/Mar ratio) is frequently used to differentiate between proximal and distal environments. It was computed by dividing the total number of counted marine palynomorphs by the total number of palynomorphs in each sample and multiplying by 100.

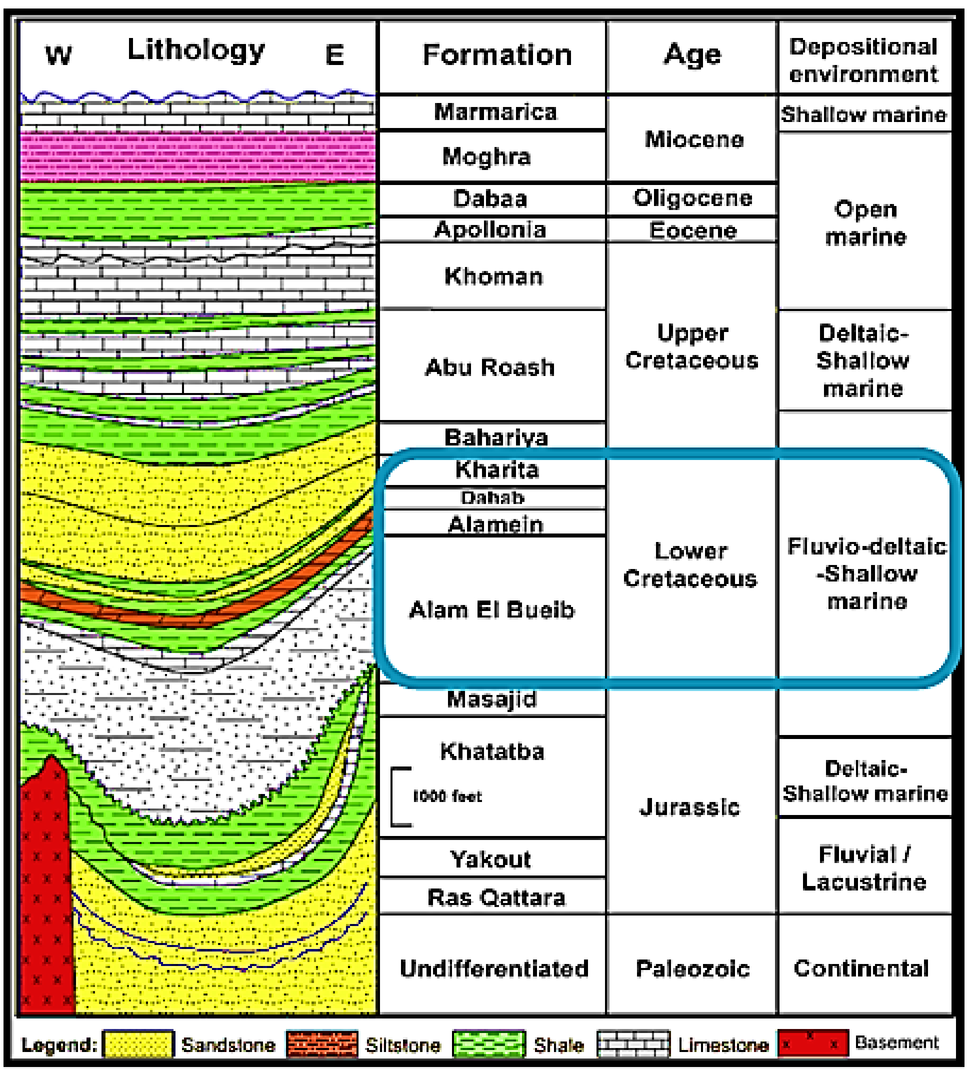

Figure 2: Generalized stratigraphic column of Shushan Basin showing the Mesozcoic (Jurassic and Cretaceous) and Cenozoic (Upper Paleogene-Lower Neogene) formations, their sedimentary environments, and the regional unconformity surfaces in the basin (Modified after [29]).

4. Results

The palynological content is consistent across all analyzed formations, with samples yielding low to moderate palynomorph abundances, low diversity, and poor preservation. Four types of particulate organic matter were identified (palynomorphs, translucent phytoclasts, opaque phytoclasts, and amorphous organic matter (AOM)) with moderate preservation conditions. Palynomorphs of marine and terrestrial origin are most prevalent in the Alam El Bueib, Alamein, Dahab, and Kharita formations, with only a moderate upward increase (up to 8.8% in sample 9 at depth 811 m, 2660 ft.). Throughout the interval under investigation, terrestrial palynomorphs represented by pollen grains and spores are the most common components. They account for up to 97% of the overall palynomorph contents (separate count), while marine palynomorphs (dinoflagellate cysts) appear in extremely low percentages (Fig. **3**, **4A**, Table **1**). Spores are most abundant (up to 52% of total palynomorphs) in the smooth (sub) triangular forms of the genera *Deltoidospora*, *Triplanosporites*, *Concavissimisporites punctatus* and *Dictyophyllidites*. Gymnosperms, particularly *Araucariacites*, *Spheropollenites*, and *Classopollis*, are common (up to 38% of total palynomorphs). Angiosperms include *Afropollis jardinus*, *Afropollis* aff. *Jardinus*, and *Monocolpopollenites* are frequent (up to 7% of total palynomorphs, (Figure **3**, **4A**, Table **1**).

Brown wood is the dominant element of the TPOM, with cuticles, membranous tissues, and tracheids having minor frequencies. The translucent phytoclasts and opaque phytoclasts make up the vast majority of the palynofacies composition. They represent up to 53% of total kerogen. Opaques phytoclasts are often have equidimensional outlines, although lath-shaped particles have also been discovered. Translucent phytoclasts make up about 15-26% of total kerogen throughout the examined formations, primarily as deteriorated and comminuted clasts (Figure **3**, Table **1**). Some terrestrial plant remnants, like cuticles and wood tracheids, are still intact. Opaque phytoclasts are oxidized or carbonized brownish-black to black woody tissues that are common constituents (28–36% of total kerogen) in the study timeframe. AOM includes all particulate organic components that look structureless under transmitted light microscopy, such as bacterially generated AOM, degraded sea phytoplankton remnants, and amorphous diagenetic products of macrophyte tissues [**22**]. AOM dominates all of the examined samples, accounting for 35-49% of total kerogen in these strata but at a smaller level than the preceding components, accounting for up to 42% of total kerogen (Figure **3**, Table **1**). An increase in phytoclasts and palynomorphs is associated with an up-section drop in AOM in the study timeframe, where palynomorph abundances do not follow the same pattern as the preceding elements of palynofacies (up to 4% of total kerogen).

5. Discussions:

The palynofacies composition and palynomorph distribution of the examined samples indicate dominance of AOM. Each palynofacies unit was identified by significant vertical shifts in the percentage frequency of terrestrial and/or marine palynomorphs and structured organic matter. According to [**12**, **14**, **15**, **17**, **19**, **39**- **42**]; chosen palynofacies parameters of known environmental importance for the palaeoenvironmental interpretation such as the relative abundance of translucent and opaque phytoclasts as well as AOM. Additionally, the continental to marine (Cont/Mar) palynomorph ratio. Following the combination of these parameters with sedimentological criteria, two palynofacies assemblages were identified, which may be differentiated into two depositional environments from base to top based on the differences in the following proportions of the palynofacies elements: The marginal marine (Deltaic) environment and the inner-shallow marine habitat.

5.1. Palynofacies Unit 1 (PF-1)

This palynofacies unit is documented from the Alam El Bueib Formation, which ranges in depth from 1045 to 945 m (3430-3100 ft). It is characterized by high percentage of phytoclasts (avg. 52% phytoclasts of total kerogen) and AOM (avg. 44% AOM of total kerogen), which show a relative increase compared to PF-2, and common sporomorphs (avg. 2.85% of total kerogen). Marine palynomorphs have been characterized by uncommon (avg. 0.95 % of total kerogen), which show relatively increased frequencies than PF-2 but still less common than terrestrial palynomorphs (Figures **3**, **5 A**, **B**, **C**). The rare dinoflagellate cyst abundances in this PF-1 suggests deposition of samples 1-4 in a brackish marginal marine environment, where stressed marginal marine environments with below-normal salinity are known to be characterized by rare dinoflagellate cysts [**43**, **44**]. In comparison to the lowermost part of PF-1, the uppermost part (samples 4 and 5) of PF-1 exhibits a minor increase in dinoflagellate cyst abundance, indicating a more distant depositional setting [**22**]. As water depth increases, it has been shown that the percentage of dinoflagellate cysts increases offshore [**45**, **46**]. This indicates that during the deposition of PF-1, a minor marine transgression associated with a local sea level increase occurred [**44**]. Most likely, this has to do with the globally late Barremian-Aptian transgression [**31**, **47**]. Also, the Late Jurassic rifting process continued into the Early Cretaceous, as seen by the growth thickening of the siliciclastic-dominated Alam el Bueib Formation. Extension most likely came to a halt before the deposition of the shale-dominated Dahab Formation and the transgression platform carbonate of the Aptian Alamein Formation [**48**-**50**]. Since microforaminiferal test linings (MTLs) are suggestive of marine conditions [**44**, **51**] and usually exhibit extremely low frequencies in distal deltaic facies [**52**], their limited presence (0.5%) in the PF-1 confirms the proposed minor transgression. The presence of *Spiniferites* sp. indicates deposition in near-shore water [**53**]. Second-order sea level for the Neotethyan Early Cretaceous (late Valanginian– Barremian) period exhibits a slight increase in sea level in the late Valanginian period, a significant increase that emerges in the Hauterivian–early Barremian period, a slight decrease in the late Barremian period, and a prolonged stagnation in the Aptian–early Albian period [**54**]. This sequence's strata were formed under suboxic-anoxic to oxic conditions during a regressive period in marginal marine (deltaic) environments (Figure **3**).

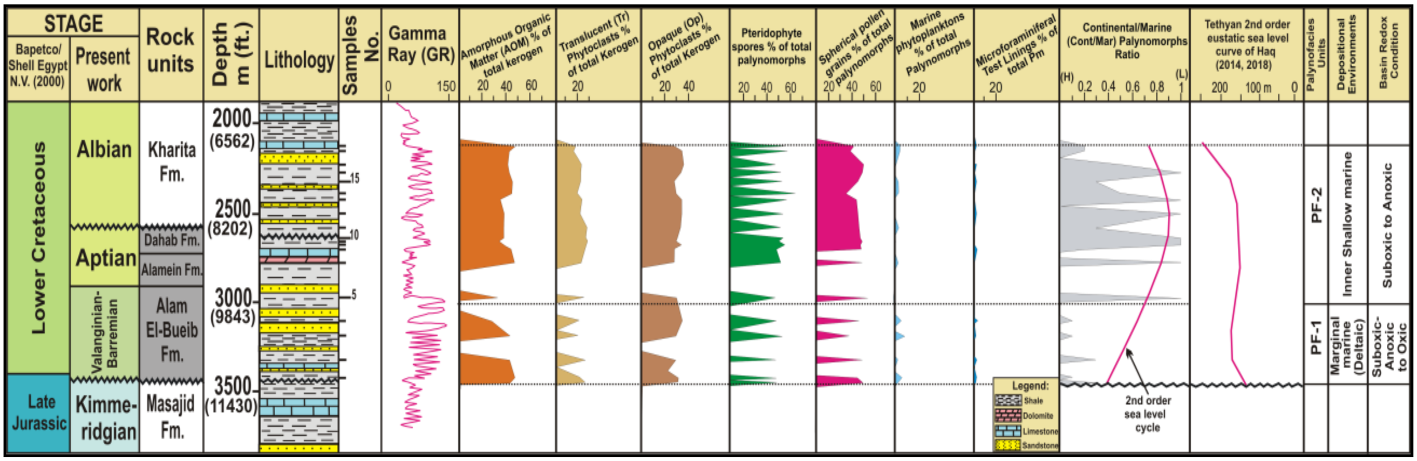

Figure 3: Lower Cretaceous lithological log, the profile of gamma-ray, and certain palynofacies elements as vertical distributions to determine curves of the relative sea level and the depositional environments/trends (this work) throuh the well of OBA D-8, Shushan Basin, and north Western Desert, Egypt.

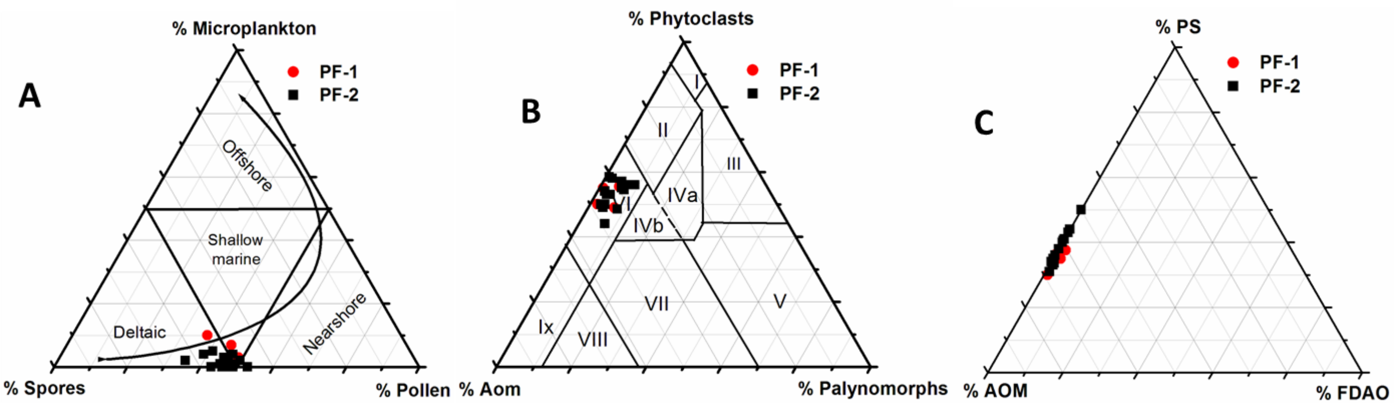

Figure 4: (A) Ternary plot of Spores–Microplankton–Pollen (SMP) displaying the settings of depositional for the studied formations (After [56, 57]), (B) The ternary plot of AOM–Phytoclasts–Palynomorphs (APP) displaying various types of palynofacies and conditions of the redox for the studied samples (in accordance with [44]), (C) The ternary of the percentage frequency of total sedimentary organic matter (% TPOM) [58] in the OBA D-8 well.

Table 1: Palynofacies and paleoenvironmental data presented in Figure 3.

Sample no.	Sample depth m (ft.)	Terrestrial Palynomorphs %	Opaques %	Phytoclasts %	Marine palynomorphs %	AOM %
19	649(2130)	6.2	28	16	0.6	49
18	652 (2140)	7.4	34	15	0.8	43
17	677 (2220)	0.6	36	22	0	41
16	689 (2260)	2.4	33	21	0	44
15	707 (2320)	3.4	29	21	0.2	47
14	728 (2390)	4	30	19	0.4	46
13	738 (2420)	7	34	22	0	37
12	762 (2500)	6.6	34	20	0	39
11	783 (2570)	4.6	33	25	0	38
10	808 (2650)	6.2	31	24	0	39
9	811 (2660)	8.8	30	26	0	35
8	814 (2670)	1.8	34	25	0	40
7	823 (2700)	2.6	29	24	0	44
6	844 (2770)	3.4	29	21	0	47
5	902 (2960)	4.2	30	23	0	43
4	945 (3100)	4.2	35	20	1	39
3	972 (3190)	5.4	30	19	1.6	44
2	1012 (3320)	0.8	30	25	0.2	44
1	1045 (3430)	1	31	20	1	48

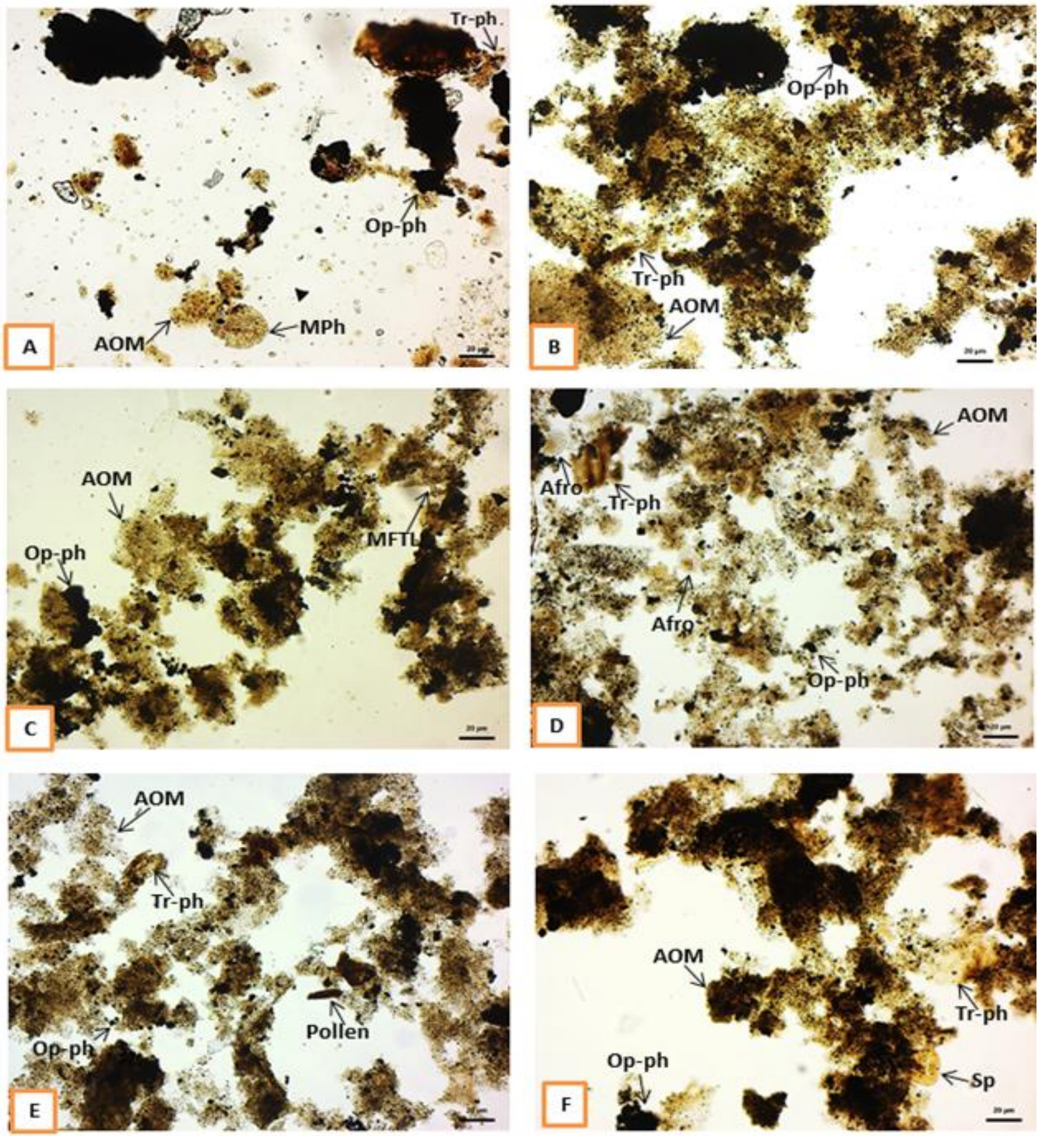

Figure 5: shows photomicrographs of Lower Cretaceous palynofacies (PF) from the examined well. The tags key: MPh, Marine phytoplankton; Sp, Spore; Op-Ph, Opaque phytoclast; AOM, Amorphous organic material; and Tr-Ph, Translucent phytoclast. (A, B, C) PF-1 was predominate by AOM and Opaques Phytoclasts and riched in marine phytoplanktons in Sample 3, depth 3190 ft. (1049 m.), Sample 4, depth 3100 ft. (945 m.), and Sample 2, depth 3320 ft. (1012 m.). (D, E, F) PF-2 was predominate by the AOM and Opaques phytoclasts and riched in conyent of sporomorphs at depths of 2140 ft. (652 m.), 2660 ft. (811 m.), and 2140 ft. (652 m.).

Presence of active fluvio-deltaic systems at the depositional site is often indicated by the preponderance of continental (avg. 2.85% of total kerogen) over marine (avg. 0.95% of total kerogen) palynomorphs [**46**, **55**]. The relative increase in pteridophyte spores (avg. 1.7% of total kerogen) at the expenses of sphaeroidal gymnosperm pollen grains (avg. 1.1% of total kerogen) indicates that PF-1 was deposited in shallow marginal marine environments close to land vegetation with dominant pteridophyte plants. This is predicated from the ecological preference and rates of reproduction of the spore-parent plants, which are known to be not as effective than the gymnosperm pollen-producing plants and to survive in swampy deltaic regions [**22**].

Moreover, compared to the more buoyant and readily transportable spheroidal pollen grains, pteridophyte spores have comparatively low transport efficiency [**22, 38**].

The relative increase in terrestrial palynomorph abundance, which is accompanied by translucent phytoclasts enrichment in the uppermost part (depth 902-649 m.) indicates a shift in the depositional environment. This is what defines the second palynofacies of the studied well section, which will be discussed in depth in the next section (PF-2). Samples 1 to 4 at depths of 1045 and 945 m reflect deposition in the marginal suboxic-anoxic basin, as indicated by moderate preservation of amorphous organic matter (AOM) and the presence of pyrite clots. So, samples of the Alam El Bueib Formation (samples 1-4) were deposited mainly in (deltaic) marginal marine setting within suboxic-anoxic to oxic conditions, field of (VI, Table **2**), according to APP and (% TPOM) ternary plots (Figure **4 B, C**). The assumed marginal marine (deltaic) settings are further supported by plotting the samples of the PF-1 in the ternary diagram of Spores-Microplankton-Pollen (SMP) [**56**, **57**] (Figure **4A**).

Table 2. Key to palynofacies fields indicated in the ternary APP diagram (Simplified from [22]).

Palynofacies field and Environment		Comments	Spores	Microplankton	Kerogen Type
I	Highly proximal shelf or basin	High phytoclast supply dilutes all other components	Usually high	Very low	III, gas prone
II	Marginal dysoxic-anoxic basin	AOM diluted by high phytoclast input, but AOM preservation moderate to good. Amount of marine TOC dependent on basin redox state and dilution.	High	Very low	III, gas prone
III	Heterolithic oxic shelf (proximal shelf)	Generally low AOM preservation.Absolute phytoclast abundance dependent on actual proximity to fluvio-deltaic source. Oxidation and reworking common.	High	Common to abundant. Dinocycts dominant	III or IV gas prone
IV	Shelf to basin transition	Passage from shelf to basin in time (eg. Increased subsidence, water depth) or space (eg. Basin slope). Absolute phytoclast abundance depends on proximity to source and degree of redeposition. Amount of marine TOC depends on basin redox state. Iva dysoxic-suboxic, Ivb suboxic-anoxic.	Moderat e to high	Very low-low	III or II, mainly gas prone
V	Mud-dominated oxic shelf (distal shelf)	Low to moderate AOM (usually degraded) palynomorphs abundant. Light coloured bioturbated. calcareous mudstones are typical.	Usually low	Common to abundant. Dinocysts dominant	III>IV, gas prone
VI	Proximal suboxic-anoxic shelf	High AOM preservation due to reducing basin conditions. Absolute phytoclast content may be moderate to high due to turbidite input and /or general proximity to source.	Variable low to moderat e	Low to common. Dinocysts dominant	II, oil prone
VII	Distal dysoxic-anoxic shelf	Moderate to good AOM preservation. Low to moderate palynomorphs. Dark coloured slightly bioturbated mudstones are typical.	Low	Moderate to common. Dinocysts dominant	II, oil prone
VIII	Distal dysoxic-oxic	AOM –dominated assemblages. Excellent AOM preservation. Low to moderate palynomorphs (partly due to masking). Typical of organic-rich shales deposited under stratified shelf sea conditions.	Low	Low to moderate. Dinocysts dominant, % prasinophytes increasing	II>I,oil prone
IX	Distal suboxic-anoxic basin	AOM-dominated assemblages. Low abundance of palynomorphs partly due to masking. Frequently alginitic-rich. Deep basin or stratified shelf sea deposits, especially sediments starved basins.	Low	Generally low prasinophytes often dominant	II>I, highly oil prone

5.2. Palynofacies Unit 2 (PF-2)

It covers the depths from 902 to 649 m (2130-2960 ft.), spaning the Alamein, Dahab, and Kharita formations. It is distinguished by a high proportion of phytoclasts (avg. 54% of total kerogen) and AOM (avg. 42% of total kerogen). PF-2 shows a relative decrease in AOM and phytoclasts compared to PF-1.

PF-2 contains common sporomorphs (avg. 4.6 % of total kerogen), whereas the marine palynomorphs are represented by rare (avg. 0.13 % of total kerogen) (Figures **3**, **5 D**, **E**, **F**). Compared to PF-1, the amounts of terrestrial palynomorphs in PF-2 have increased noticeably (avg. 4.6% of total palynomorphs). The moderate override of pteridophytes (avg. 3% of all palynomorphs) and pollen saccate (avg. 2% of all palynomorphs) over marine palynomorph (avg. 0.13 % of total palynomorphs) suggests marginal marine settings for PF-2 [46]. The interpretation of this marginal setting is further supported by the low dinoflagellate concentrations (avg. 1% of total palynomorphs) [44].

The proximal depositional environment that was relatively close to an active deltaic system is shown by the frequent frequencies of pteridophytes (average 3% of total palynomorphs) and their steady upward increase (samples 5-19). This indicates progressive deposition in a landward direction. This settings are supported by the moderate percentages of translucent phytoclasts (avg. 22% of total kerogen) and high opaque phytoclasts (32% of total kerogen), which show deposition in relatively high energy settings [22].

The fraction of opaque equidimensional material suggests that the phytoclasts source is closer to shore in most of these samples. The higher percentage of opaque phytoclasts indicates substantially more near shoreline and the deposition under oxidizing conditions. This is supported by lithologic constituents such as sandstone and silt as shown in Figure **3**.

Local uplifting was the primary factor influencing the deposition of HST, as demonstrated by Neotethyan of [54], who discovered a connection between a notable rising trend in shallowing and the second-order regional sea level. The long-term sea level stability and Neotethyan minor-major sea level rise stated above (Figure **3**) most likely overprint this upward trend. The Hauterivian-Barremian and early regional block faulting and elevating may have been related to this local uplifting. Many basins, including Shushan, Matruh, and Abu Gharadig, witnessed Aptian rifting [**11**, **19**, **21**, **34**, **36**, **59**]. According to the APP and (% TPOM) ternary plots (Figure **4 B**, **C**) samples from the Alamein and clastics from the Dahab and Kharita formations (samples 5-19) were deposited mostly in an inner shallow marine habitat beneath circumstances of suboxic-anoxic, field of (VI, Table 2). Plotting PF-2 samples in [56, 57] Spores-Microplankton-Pollen (SMP) ternary diagrams lends validity to the interpreted inner shallow marine settings. The sediment deposited beneath conditions of suboxic-anoxic in an inner shallow marine is indicated by the decline in the proportion of AOM (avg. 42% of total kerogen) [60, 61]. The persistence of AOM and terrestrial organic matter, as well as the presence of relatively few marine phytoplanktons in the coarser, bioturbated clastic strata that are weakly bedded, suggest that the PF-2 sediments accumulated in proximal inner shallow marine environments [22, 62]. A semi-arid environment was present during deposition of PF-2, as evidenced by the xerophytic pollen grain *Ephedripites'* slight presence at this palynofacies unit and their total absence in the underlying palynofacies unit (PF-1) [63]. Moreover, the parent plant of *Afropollis* pollen grains is suggested to thrive on coastal plains of moist, indicating a deltaic setting for the PF-2 unit [10, 11]. The above discussion indicates that PF-2 was deposited in the environment of inner shallow marine under circumstances of suboxic-anoxic.

6. Conclusion

The examination of palynofacies collected from nineteen ditch cuttings from the OBA D-8 well has contributed to interpreting the paleoenvironment in the studied part of the Shushan Basin, northern Western Desert, Egypt.

Two main palynofacies units were identified, which allowed the identification of the depositional palaeoenvironments of the formations encountered. PF-1 corresponds to the Formation of Alam El Bueib (samples 1-4), which was deposited in (deltaic) marginal marine habitat through a regression episode of Valanginian-Barremian. However, following a incomplete recovery of late Barremian-Aptian transgression episodes, both locally and globally, the upper part of the formation was deposited in an inner shallow marine context. This occurred under suboxic-anoxic conditions. The Alamein, Dahab, and Kharita formations (upper Barremian-Aptian and Albian) are represented by PF-2. The Alamein Formation carbonate, the Dahab shale Formation, and the Kharita coarse-grained sandstones with shales Formation (samples 5-19) were all deposited in inner shallow marine settings when the local Early Aptian marine regression partially returned. The sediments of PF-2 are deemed to have been deposited in suboxic-anoxic conditions. The Hauterivian-Barremian and Aptian uplift episodes, as well as the Aptian erosion and non-sedimentation, were most likely linked to these regressive conditions.

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