**The Cenomanian/Turonian oceanic anoxic event in the Razzak Field, north Western Desert, Egypt: source rock potential and paleoenvironmental association**

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**ABSTRACT**

The Western Desert of Egypt is one of the world’s most prolific Jurassic and Cretaceous hydrocarbon provinces. It is one of many basins that experienced organic-rich sedimentation during the late Cenomanian/early Turonian referred to as oceanic anoxic event 2 (OAE2). The Razzak #7 oil well in the Razzak Field in the northern part of the Western Desert encountered the Upper Cretaceous Abu Roash Formation. This study analyzed 23 samples from the upper “G”, “F”, and lower “E” members of the Abu Roash Formation for palynomorphs, particulate organic matter, total organic carbon (TOC) and δ13Corg in order to identify the OAE2, determine hydrocarbon source rock potential, and interpret the depositional environment. The studied samples are generally poor in palynomorphs, but show a marked biofacies change between the lower “E” member and the rest of the studied samples. Palynofacies analysis (kerogen quality and quantity) indicates the presence of oil and gas prone materials (kerogen types I and II/III, respectively), and implies reducing marine paleoenvironmental conditions. Detailed carbon stable isotopic and organic carbon analyses indicate that fluctuations in the δ13Corg profile across the Abu Roash upper “G”, “F”, and lower “E” members correspond well with changes in TOC values. A positive δ13Corg excursion (~2.01 ‰) believed to mark the short-term global OAE2 was identified within the organic-rich shaly limestone in the basal part of the Abu Roash “F” member. This excursion also coincides with the peak TOC measurement (24.61 wt.%) in the samples.

**Keywords:** OAE2, Cenomanian/Turonian, palynofacies, TOC, δ13Corg, Abu Roash Formation

**1. Introduction**

Egypt has a very long history of oil exploration and production. It is now known that ancient Egyptians used oil from seeps for mummification and coffin protection (Schlumberger, 1995). Today, the Mesozoic strata in the Western Desert are among the world’s major hydrocarbon producers. The Razzak Field is located in the northernmost part of the Western Desert (Fig. 1), and represents one of several hydrocarbon discoveries located in this highly faulted sedimentary basin (Shahin et al., 1986). About 70 % of total world petroleum resources are concentrated in the Tethys realm where the basin is located (Ulmishek and Klemme, 1990). During the Cenomanian/Turonian (C/T), organic-rich shales, marls and limestones with TOC contents of locally up to 40 % were deposited on the oxygen-deprived shelf and slope regions across North Africa and in deep-sea basins of the adjacent oceans (Herbin et al., 1986; Lüning et al., 2004). Klemme and Ulmishek (1991) pointed out that Aptian−Turonian strata, which include layers attributed to the short-term global oceanic anoxic events OAE1a, OAE1b, and OAE2, have sourced almost one-third of the world's hydrocarbon reserves.

The Razzak #7 well penetrates the Upper Cretaceous carbonate-rich Abu Roash Formation (the subject of this paper) as well as the Bahariya Formation. The Abu Roash Formation (Fig. 2) is subdivided into seven informal members (“G” to “A”) and was previously dated late Cenomanian to Santonian based on microfossils such as foraminifera and palynomorphs (Norton, 1967; Robertson Research International and Associated Research Consultants, 1982; Hantar, 1990; Schrank and Ibrahim, 1995; Abdel-Kireem et al., 1995, 1996). Issawi et al. (1999) stated that the Abu Roash Formation is mainly represented by a sequence of limestone with shale and sandstone interbeds that has easily recognizable and well defined members in the subsurface. “B”, “D”, and “F” members are relatively clean carbonates, while “A”, “C”, “E”, and “G” members are largely fine clastics. South of the Razzak Field, in the Abu Gharadig Field (Fig. 1), Khaled (1999) reported that the “G” member is composed of interbedded limestones, gray to grayish green shales, and siltstones, whereas the “E” member is made up of interbedded gray to greenish gray shales and limestones. The Abu Roash Formation conformably overlies the Bahariya Formation; and underlies the Khoman Formation where the contact is sharp lithologically and paleontologically (Fig. 2). The Abu Roash “G”, “F”, and “E” members are considered to be the most outstanding and prolific source rocks in the Western Desert (Schlumberger, 1995).

Several palynological and organic geochemical studies have been published on the Abu Roash Formation at many localities in the Western Desert (Barakat et al., 1987; El Beialy, 1994, 1995; Schrank and Ibrahim, 1995; Ibrahim, 1996, 2002; Zobaa et al., 2008; Ibrahim et al., 2009; El Beialy et al., 2010). A majority of these studies have focused on the palynomorph contents, palynostratigraphy and palynofacies of the strata. However, very few of these palynological studies (Barakat et al., 1987; Zobaa et al., 2008; El Beialy et al., 2010) have addressed hydrocarbon source rock potential of the sediments.

This paper focuses on the palynofacies and organic geochemistry of the Abu Roash upper “G”, “F”, and lower “E” members with the aim of identifying the OAE2 interval in the Razzak Field, which can subsequently be utilized 1) as a unique marker for correlation, and 2) in constructing a robust chronostratigraphic and/or chemostratigraphic framework for the Razzak Field. Particulate organic matter (kerogen), palynomorph, TOC and δ13Corg analyses provide data used for interpreting source rock potential and paleoenvironmental conditions, thereby contributing to our understanding of the hydrocarbon and geological evolution of the Western Desert in general, and the Razzak Field in particular.

**2. Material and methods**

Twenty-three cutting samples from the Abu Roash upper “G”, “F”, and lower “E” members were processed for palynological contents and organic geochemistry. Palynological processing involved digestion of samples in hydrochloric and hydrofluoric acids to remove carbonates, silicates, and fluorides (resulting from hydrofluoric acid treatment) from the sediments (Traverse, 2007). Acid digestion was followed by preparation of kerogen slides for palynofacies analysis. The remaining residues were centrifuged in heavy liquid (ZnBr2), screened through 10 µm nylon sieves, and used to prepare additional slides to identify palynomorphs in the samples. Transmitted light microscopy was used to scan the slides for their palynological contents. Two-hundred particulate organic matter particles (each with a minimum size of 5 µm) were point counted per kerogen slide and used for palynofacies analysis. All palynological slides and residues used for this study are stored in the palynological collection at Missouri University of Science and Technology.

Carbon isotopic and TOC analyses were performed at the Stable Isotope Mass Spectrometer Laboratory, University of Florida. Samples were acidified with hydrochloric acid to remove the inorganic carbon fraction. They were then rinsed with water three times, dried at 50° C, and ground. Percentage of the organic carbon was measured using a Carlo Erba NA1500 CNS elemental analyzer. Carbon (δ13Corg) isotope was measured using a Thermo Finnigan DeltaPlus XL isotope ratio mass spectrometer with a ConFlo III interface linked to a Costech ECS 4010 Elemental Combustion System with Zero Blank autosampler (elemental analyzer).

**3. Results**

The types of particulate organic matter identified are palynomorphs, phytoclasts, opaques, and amorphous organic matter (AOM) (Plate 1). Marine and terrestrially derived palynomorphs are mostly absent in the Abu Roash upper “G” and lower “F” members, increasing very slightly up-section (up to 2.7 % in sample 49). Phytoclasts are common constituents (14.3– 51.3 %) of the upper “F” and lower “E” members, mainly as degraded and comminuted clasts (Fig. 3; Appendix Table 1). However, some structured terrestrial plant fragments such as cuticle, wood tracheid and cortex tissues are also preserved (Plate 1). Opaques (black debris) are oxidized or carbonized brownish-black to black woody tissues, and are very minor components in the studied interval. AOM comprises all particulate organic components that appear structureless at the scale of light microscopy, including bacterially derived AOM, degraded marine phytoplankton remains, and amorphous diagenetic products of macrophyte tissues (Tyson, 1995). AOM dominates the upper “G” and lower “F” members, and constitutes ≥ 94 % of the kerogen assemblage in these sediments (Fig. 3; Appendix Table 1). An up-section decrease in AOM in the studied interval correlates with an increase in phytoclasts and palynomorphs.

Detailed carbon stable isotopic and organic carbon analyses across the C/T boundary in the Razzak #7 well indicate that the δ13Corg profile fluctuations across the upper Abu Roash “G”, “F”, and basal “E” members correspond well with changes in TOC abundance (Fig. 3; Appendix Table 1). A Positive δ13Corg excursion (~2.01 ‰) exists in the basal part of the Abu Roash “F” member, which is also characterized by high TOC values (10.43–24.61 wt. %), and is predominantly organic-rich, black shaly limestone.

Palynomorph analysis revealed that the studied interval is poorly fossiliferous, as noted by previous workers (Ibrahim et al., 2009; Zobaa et al., 2009a; El Beialy et al., 2010). The few palynomorph species recovered in this study are long ranging and did not allow for precise age dating. Moreover, Cenozoic taxa attributed to caving were common, making biostratigraphic analysis very difficult and unreliable. It was evident, however, that well preserved *in-situ* specimens of the freshwater green alga *Pediastrum* overwhelmingly outnumbered and diluted all other types of palynomorphs in the lowermost “E” member (samples 48–50). Specimens of the freshwater green alga *Tetrastrum* were also common within the same interval. The presence of these algae has significant implications in terms of paleoenvironmental reconstruction (discussed later). Other palynomorphs identified in the studied interval include dinoflagellate cysts such as *Odontochitina* sp., *Oligosphaeridium* *pulcherrimum*, *Cyclonephelium* sp., *Subtilisphaera* sp., and *Florentinia* sp. Pteridophytic spores, and gymnosperm and angiosperm pollen include taxa of genera such as *Gleicheniidites, Triplanosporites,**Bennettiteaepollenites, Ephedripites, Spheripollenites, Foveotricolpites, Psilatricolporites,* and *Retimonocolpites*. A single scolecodont fragment was recovered in sample 64 (Plate 1).

**4. Discussion**

*4.1. C/T oceanic anoxic event (OAE2)*

Oceanic anoxic events represent intervals of globally increased organic carbon sequestration associated with pervasive marine anoxia. Earth has witnessed several oceanic anoxic events during its history that have been preserved in the sedimentary record. Among these, the most prominent and best identified is the OAE2 that occurred at approximately 93.5 million years ago (Turgeon and Creaser, 2008). Several scenarios/mechanisms have been proposed to explain what actually initiated the OAE2. Some authors have attributed it to massive magmatic activity (Sinton and Duncan, 1997; Kerr, 1998; Turgeon and Creaser, 2008). Others, such as Arthur et al. (1988), have related it to increased nutrient upwelling and high primary productivity leading to significant carbon burial and CO2 depletion. The OAE2 can be easily distinguished by a sharp positive excursion in the δ13C profile of carbonates (2–3 ‰) and bulk organic matter (3–6 ‰) (Jenkyns et al., 1994; Turgeon and Creaser, 2008). This excursion has been observed in various parts of the world and has been used as a stratigraphic tool for high-resolution correlation (Gale et al., 1993; Hasegawa, 1997).

In the Razzak #7 oil well, an abrupt positive δ13Corg excursion (~2.01 ‰) was identified within the basal part of the Abu Roash “F” member (sample 61; depth 1566.7 m) (Fig. 3). This is interpreted here to represent the OAE2 in that well and is supported by two pieces of evidence: 1) the lithologic composition of that interval is predominantly organic-rich, black shaly limestone; and 2) the corresponding increase in TOC content, with the highest measured value (24.61 wt. %) occurring at the same depth of the maximum δ13Corg shift (Fig. 3). Both evidences suggest prevailing reducing conditions. The precise identification of the OAE2 is significant because this is the first time it has been recognized in the Razzak Oil Field, and the third time in the Western Desert (Ibrahim et al., 2009; El Beialy et al., 2010), thus providing impetus for using it as a key horizon for subsurface correlation in the Razzak Field.

*4.2. Source rock potential*

Source rock horizons are considered to be among the most important play elements in any hydrocarbon system. Exploration geologists always pay attention to source rock layers and meticulously study their characteristics in order to fully understand them. Among the crucial aspects studied for any source rock are the amounts of organic matter accumulated during deposition, post-depositional alterations (diagenesis), and degree of thermal maturation. These are fundamental to identifying the hydrocarbon type and potential yield of a given source rock.

 Palynofacies (kerogen) analysis has successfully been used to provide valuable source rock information. It has an excellent degree of accuracy when compared to instrumental geochemical analyses such as TOC, vitrinite reflectance (Ro %), and Rock-Eval Pyrolysis (Zobaa et al., 2007, 2009a, 2009b; El Beialy et al., 2010). Kerogen is a diagenetic product of the original organic matter preserved in the sediments as a result of increased burial under favorable conditions of temperature and pressure. Further alteration (catagenesis) converts kerogen to bitumen, which ultimately transforms into either oil or gas, depending on the type of organic matter present and the prevailing environmental alteration setting. In the present study, we primarily followed the methodology of Tyson (1993, 1995) who discussed four kerogen assemblages (I–IV) that can be routinely used to study hydrocarbon source rock potential. It is worth noting that the term kerogen refers to the dispersed particulate organic matter contained in sedimentary rocks that are resistant to the inorganic (mineral) acids HCl and HF (Tyson, 1995).

Two distinct zones of kerogen material have been identified (Fig. 3). The lower zone occurs within the upper “G” and much of the “F” members (samples 69–55) and is AOM-rich (≥ 94 % of the total kerogen count). This is characteristic of type I kerogen and indicates highly oil prone materials (Tyson, 1993, 1995; Ibrahim et al., 1997; Ibrahim, 2002). Based on visual and instrumental analyses, El Beialy et al. (2010) reported that Abu Roash “F” member in the GPTSW-7 well, north Western Desert contained immature oil prone material composed of 100 % percent AOM. Their observation supports our results and suggests similar depositional conditions for the Razzak #7 and GPTSW-7 wells.

The upper zone occurs within the uppermost “F” and lower “E” members (samples 54–48) and is dominated by both phytoclasts and AOM (average 63 % AOM and 36 % phytoclasts of the total kerogen count). Type II to III kerogen is suggested for this zone, which is indicative of oil to gas prone materials. We note here that Schlumberger (1995) indicated that in the Western Desert, the Abu Roash “F” member is gas prone, which is partially supported by our findings from the Razzak #7 oil well. However, the statement by Schlumberger (1995) is an oversimplification that should be taken with caution since the Western Desert contains many basins with variable depositional, burial, and thermal histories. Previous authors (e.g., Khaled, 1999; El Beialy et al., 2010) have documented similar findings about the “E” member in other basins within the Western Desert.

TOC analysis of the sediments confirms our palynofacies findings. The highest recorded TOC value occurred within the AOM abundant lower zone (Fig. 3), indicating a plethora of organic matter preserved under adequately reducing conditions. This is also in agreement with Tyson (1989) who indicated that the percentage values obtained for TOC correlated well with variations in AOM abundance.

There is an agreement among organic geochemists that a rock can be considered as a source of hydrocarbon if it contains more than 0.5 % TOC for shales, and at least 0.3 % TOC for carbonates (Hasegawa, 1997; Wood et al., 1997; Ibrahim et al., 2002). The TOC values reported here for these Abu Roash carbonates vary from a minimum of 1.10 wt. % in the lower “E” member to a maximum of 24.61 wt. % in the basal “F” member, suggesting that they contain sufficient organic matter for significant generation and expulsion. Moreover, qualitative analysis of palynomorph colors, although sparsely represented, indicates that these sediments may be thermally mature. Accordingly, it is believed that the studied section qualifies as an excellent source rock.

*4.3. Paleoenvironmental reconstruction*

Paleoenvironmental reconstruction is primarily based on kerogen composition and geochemical data. Palynomorphs, when applicable, played a secondary role in our interpretation due to their inadequate and unreliable representation in most of the analyzed samples. The upper “G” and much of the “F” members in the Razzak #7 oil well (depth 1591.1–1545.3 m) contain enormous amounts of marine AOM and are almost barren of other kerogen constituents and palynomorphs (Fig. 3). This argues for anoxic deep marine conditions, which are known to be advantageous for AOM preservation (Tyson, 1995). Terrestrially derived kerogen and palynomorphs were either not transported into the deeper basin, or simply masked by the large amounts of AOM. The absence of marine palynomorphs such as dinoflagellates and acritarchs can be attributed to sediment starvation, which promoted adequate circumstances for anaerobic microbial degradation. This consequently converted marine palynomorphs to AOM. The associated high TOC values in that interval confirm the inferred anoxic sediment starved setting where low sediment contribution allowed more organic matter to accumulate, increasing the organic/inorganic ratio of the sediments. Arthur et al. (1988) stated that the OAE2 took place during a major global sea-level rise. Since the north Western Desert, including the Razzak Field, was part of the Tethyan realm, the region most likely experienced this sea-level rise (Figs. 1, 2). The occurrence of the OAE2 approximately in the middle of this interval (upper “G” and much of the “F”) further confirms the suggested deep marine anoxic conditions.

Some studies have previously noted that the “F” member in the Western Desert was deposited under deep marine depositional conditions (Alsharhan and Abd El-Gawad, 2008; El Beialy et al., 2010). This is, however, in contrast to the shallow marine to brackish water conditions indicated by Ibrahim and Al-Saad (2000) for the Khalda-21 borehole in the Western Desert, based primarily on abundant freshwater algae *Pediastrum* and *Scenedesmus* that were not observed here from the “F” member. This could be related to different local depositional settings between the Razzak #7 oil well and Khalda-21 borehole.

The decline in AOM abundance accompanied by phytoclast enrichment in the uppermost “F” and lower “E” members (depth 1545.3–1527 m) evidently points to a change in the depositional environment. The upward decrease in TOC content, although still relatively high, confirms that change and indicates comparatively less reducing conditions. Tyson (1995) interpreted increased phytoclast contents in conjunction with moderate TOC values as being indicative of proximity to sources of terrestrial organic matter. We agree with this explanation and suggest shallower marine conditions relative to the lower part of the section. These shallower conditions might have been a result of sea-level drop, which allowed more terrestrial components (phytoclasts) to be transported deeper into the basin. This interpretation is in accordance with the global sea-level model that shows a period of sea-level fall soon after the OAE2 (Fig. 2). Increased terrestrial input is also clearly reflected in the palynomorph composition, as noted by the overwhelming abundance of the freshwater chlorococcalean green algae (*Pediastrum* and *Tetrastrum*) in the uppermost part of the studied section (“E” member, depth 1533.1–1527 m). Shallow marine freshwater influenced conditions for the “E” member were earlier indicated by Khaled (1999) and Ibrahim and Al-Saad (2000).

**5. Conclusions**

Palynofacies and organic geochemical analyses of 23 samples from the upper “G”, “F”, and lower “E” members of the Abu Roash Formation have yielded the following information:

1. The sediments are palynomorph-poor, especially in the upper “G” and “F” members with an assemblage of spores, gymnosperm and angiosperm pollen, freshwater algae, dinoflagellate cysts, and one scolecodont specimen.

2. AOM- and TOC-rich, oil prone type I kerogen occurs in the upper “G” and much of the “F” members, in contrast with phytoclast- and AOM-dominated, oil to gas prone type II/III kerogen in the uppermost “F” and lower “E” members.

3. A positive excursion (~2.01 ‰) is present in the δ13Corg profile within the organic-rich black shaly limestone of the basal “F” member and coincides with the highest recorded TOC value (24.61 wt. %). It marks the short-term global OAE2, which is identified for the first time in the Razzak Field.

4. The upper “G” and most of the “F” members were deposited under deep marine anoxic conditions, whereas the uppermost “F” and lower “E” member were deposited in relatively shallower, less reducing conditions.

**Acknowledgments**

The authors would like to thank the Egyptian General Petroleum Corporation (EGPC) for providing the samples and well log the for Razzak #7 oil well. Reviews by Nicholas Harris, Associate Editor, and an anonymous reviewer have greatly improved this manuscript. This study was funded by a National Science Foundation grant (OISE-0707183) to Francisca Oboh-Ikuenobe and US-Egypt grant (OTH11-008-001) to Mohamed Ibrahim.

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**Figure captions**

Fig. 1. Composite location map showing: **A-** the position of the Razzak Field along with other major oil and gas fields in the north Western Desert, Egypt; **B-** global reconstruction of the Late Cretaceous (90 Ma ago) demonstrating the approximate position of the north Western Desert (modified from Blakey, 2010).

Fig. 2. Generalized Upper Cretaceous lithostratigraphic column of the Western Desert, Egypt accompanied by primary geomagnetic polarity, transgression-regression cycles, short-term sea-level changes, and anoxic events. Lithostratigraphic units are after Schlumberger (1995). This figure was created using the TSCreator software of Lugowski et al. (2009).

Fig. 3. Composite chart illustrating the lithologic composition of the Abu Roash “G”, “F”, and “E” members in the Razzak #7 oil well, the percentage distribution of particulate organic matter components, interpretation of hydrocarbon source rock potential, and the observed change in the δ13Corg and TOC profiles at the Cenomanian/Turonian boundary.

**Plate 1**

Specimen names are followed by sample number (Kr = kerogen), England Finder reference (if applicable), and magnification. Scale bar equals 10 µm unless otherwise noted.

1–3. Coenobia of *Pediastrum* (a freshwater Chlorococcalean green alga of the Family Hydrodictyaceae: 1, sample 51/1, F33/0, 100X; 2, sample 51/1, N43/0, 100X; 3, sample 50/1, L46/2, 100X.

4, 5. Compound colonies of *Tetrastrum* (a freshwater Chlorococcalean green alga of the Family Scenedesmaceae); sample 48/1, H40/1 and N38/0 respectively, 100X.

6. *Odontochitina* sp.; sample 63/1, O37/4, 40X.

7. *Subtilisphaera* sp.; sample 66/1, K45/1, 40X.

8. *Oligosphaeridium* *pulcherrimum*; sample 51/1, T36/0, 40X.

9. *Bennettiteaepollenites**minimus*; sample 50/1, Q44/4, 100X.

10. *Ephedripites**tortuosus*; sample 51/1, D28/3, 100X.

11. *Ephedripites* *regularis*; sample 64/1, P27/4, 100X.

12. *Foveotricolpites* sp.; sample 50/1, Q46/2, 100X.

13. Scolecodont fragment; sample 64/1, R34/0, 100X.

14. Well preserved diffused edged AOM particle; sample 66/1kr, 40X.

15, 16. Structured phytoclasts (cuticles); sample 49/1kr, 40X.

17, 18. Dark brown structured phytoclasts (tracheids); samples 50/1kr and 49/1kr respectively, 40X.

19. Opaque phytoclast; sample 49/1kr, 40X.

20. Abundant AOM facies; sample 66/1kr, 20X; scale bar equals 50 µm.

21. AOM and phytoclast facies; sample 49/1kr, 20X; scale bar equals 50 µm.

**Appendix**

Table 1. Palynofacies and geochemical data presented in Figure 3.