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Source rock potential and depositional environment of Upper Cretaceous sedimentary rocks, Abu Gharadig Basin, Western Desert, Egypt: An integrated palynological, organic and inorganic geochemical study

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ABSTRACT

The Abu Gharadig Basin in the northern part of the Western Desert, Egypt is among the most important petroleum provinces in Egypt. Here, Cenomanian to Santonian rocks of Bahariya Formation and Abu Roash A-G members from the GPT-3 well were investigated for their depositional environment, kerogen quality, petroleum generation potential and thermal maturity by geochemical, petrological and palynological methods. The sediments of the Bahariya and Abu Roash formations excluding the Abu Roash "F" Member represent variable shallow marine environments with poor preservation of marine organic matter, whereas there is an excellent preservation in the Abu Roash "F" Member. The basal part of this member is characterized by anoxic, carbonate-rich depositional conditions, high TOC values up to 7%, high HI up to 700 mgHC/gTOC and liptinite-dominated organic matter. Depletion of iron leads to sulfur incorporation into organic matter which is reflected in high thiophene/benzene ratios. Above, sediments are enriched in "terrestrial elements" Fe, Ti, as well as K and Mn. This pattern and the occurrence of the fresh/brackish water algae *Botryococcus* suggests a regression phase during deposition. The upper part of the Abu Roash "F" Member is again characterized by fully marine, suboxic conditions and a lower thiophene/benzene ratio. The source rock section demonstrates lower thermal maturity compared to the above and below sections based on all microscopic, pyrolysis and biomarker data. This indicates thermal maturity retardation/suppression most likely due to a different organic facies and early diagenetic transformation of kerogen as indicated by the geochemical and palynological data. The source rock heterogeneity indicates a relatively shallow marine environment where the changes in bottom water conditions are very sensitive to sea level fluctuations. Residual oil characterization reveals two reservoir compartments, which are in the Abu Roash "D" and "C" members.

The Abu Roash "F" source rocks are compared with time-equivalent sediments in the Tarfaya Basin in Morocco, which represent more distal settings. The more proximal group (A) is characterized by S/Fe ratios between 0.57 and 0.67 indicating suboxic conditions. It has TOC and HI values not exceeding 4% and 600 mgHC/gTOC, respectively, at variable $CaCO_3$ contents. The more distal Tarfaya sediments (group B) have higher TOC and HI as well as high organic sulfur contents. Group A is higher in terrigenous element concentrations. The T_{max} of immature source rocks ranges from 410 to 415 °C in organic-sulfur rich samples and from 420 to 430 °C in organic-sulfur poor samples revealing an important impact of organic facies on maturity parameters. Furthermore, there is an inverse relationship between S/Fe and Al_2O_3/TOC which might become an important tool in paleoenvironmental reconstructions as well as petroleum source rock studies.

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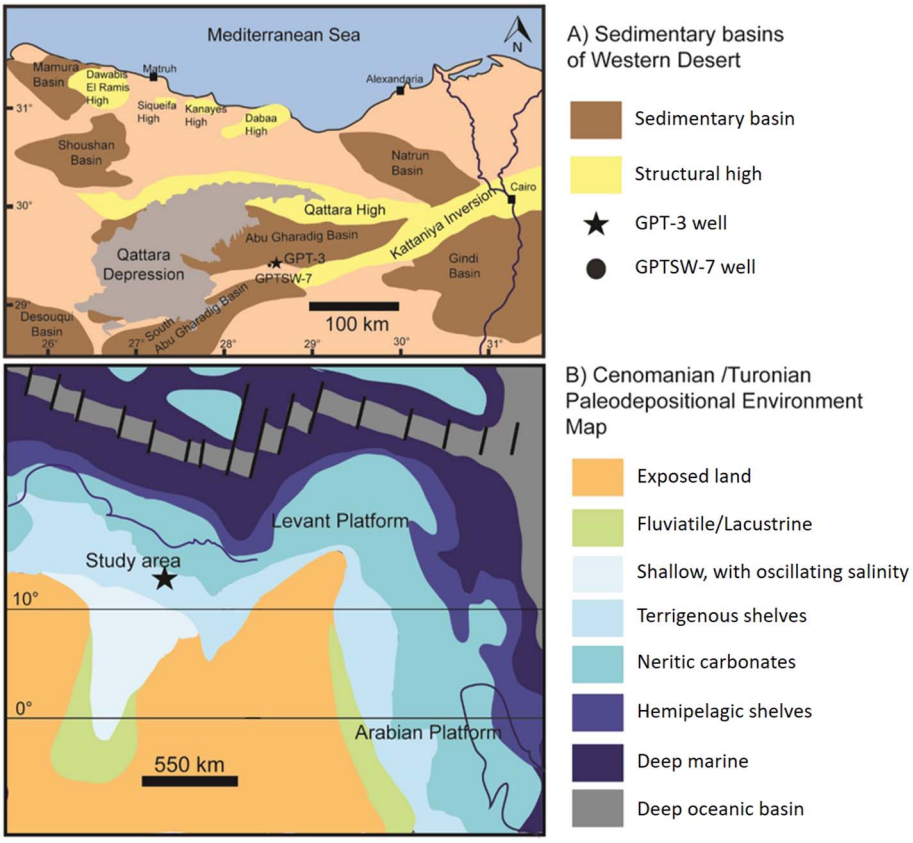

Fig. 1. A) A location map of the studied GPT-3 well and the main sedimentary basins in the Western Desert, Egypt. B) Paleogeographic map at ~94 Ma of North Egypt and the surrounding areas.
Modified after Philip, 2003.

1. Introduction

Few attempts were carried out to investigate the depositional environment during the Cenomanian/Turonian Boundary Event (CTBE) in the Western Desert basins using integrated geochemical and palynological techniques (e.g. El Beialy et al., 2010; Zobaa et al., 2011). Moreover, the source rock character and oil origin in the Cretaceous succession is poorly understood, although several oil fields exist. The Abu Gharadig Basin is located in the central part of the northern Western Desert between the Qattara Depression to the west, the Qattara High to the north and the Gindi and South Abu Gharadig basins to the east and south, respectively (Fig. 1A). It is one of the oldest producing basins in the Western Desert, which witnessed the first oil discovery in 1970 at the Khalda field (Awad, 1985; Younes, 2012). Moreover, the basin became more appealing after the recent oil discovery in the Abu Roash "C" Member in the El Salmiya Field (Beach Energy, 2014). The basin mainly produces oil and gas from Jurassic and Cretaceous plays (Awad, 1985). The studied well is located in the GPT field that was discovered in 1983 and commenced production in 1990 (Abdel-Rahman, 2013).

The proven source, reservoir and seal rocks found in the Abu Gharadig Basin are mainly within the Jurassic and Cretaceous section (Awad, 1985; Bakr, 2009; El Diasty and Moldowan, 2012; Abdel-Rahman, 2013; El Nady and Harb, 2015; El Nady and El-Naggar, 2016). The Masajid and Khatatba formations are the most common Jurassic source rocks, which represent mostly marine oil-prone facies with occasional non-marine facies within the Khatatba Formation (Shalaby et al., 2012). Furthermore, potential marine source rocks are found in the Lower Cretaceous Alam El Bueib Formation and mixed marine and terrestrial source rocks within the Bahariya Formation. The best source rock facies are in the "F" Member of the Abu Roash Formation that was deposited during the Oceanic Anoxic Event 2 (OAE2; El Beialy et al., 2010; Zobaa et al., 2011), which is a global phenomenon responsible for world-class source rock deposits in several regions around the world during the Cenomanian/Turonian boundary (Jenkyns, 2010). Other members show variable source rock qualities. Oil-prone source rocks were reported at the base of the Khoman Formation in different parts of the basin (Shahin et al., 1986). The best reservoir qualities were encountered in the Bahariya and Abu Roash formations. The main reservoirs in the GPT field produce gas from the Bahariya and Khoman formations as well as the "B" and "D" members of the Abu Roash Formation (Abdel-Rahman, 2013). Jurassic reservoirs are poorly studied and understood, but it can be assumed that part of the Khatatba Formation has good reservoir quality (Ahmed, 2008). The seals in Abu Gharadig Basin are mainly shales and tight carbonates (El Ayouty, 1990). The source rocks that produced the oil and gas are still debated and range from non-marine to marine, partly due to the character of the hydrocarbons suggesting "mixed sources" (El Diasty and Moldowan, 2012; El Nady and Harb, 2015; El Nady and El-Naggar, 2016).

In summary, the Upper Cretaceous Bahariya and Abu Roash formations contain a complete petroleum system in the basin. Using an integrated approach, the present study intends to fill research gaps and provide new data on paleoenvironmental conditions and source rock development during Cenomanian to Santonian times. In addition, maturation, petroleum generation and the origin of the hydrocarbon accumulations in the western Abu Gharadig Basin are discussed, based on new data and previous studies. The data from the current work is compared with published data on almost time-equivalent Cenomanian to Turonian source rocks (Ghassal et al., 2016) to investigate the source rock depositional processes in different marine settings and discuss the main controlling factors that determine the source rock richness and quality.

2. Geologic setting

The Abu Gharadig Basin is a Mesozoic E-W trending elliptical extensional basin where rifting started during the Upper Jurassic, contemporaneously with the opening of the Neotethys and deep crustal