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Research paper

Integrated palynological, organic geochemical, and sequence stratigraphic analyses of the middle to upper Cenomanian hydrocarbon reservoir/source Abu Roash "G" Member: A depositional model in northwestern Egypt

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ABSTRACT

The current investigation provides further insight into the petroliferous characteristics of the Abu Roash "G" Member, which is regarded as an important rock unit for the Egyptian oil industry. Forty-seven samples covering the "G" Member were selected from the BED 14-1 and BED 2-4 wells in the Abu Gharadig Basin and from the Abu Tunis 1X well in the Matruh Basin, both of which are located in the north Western Desert. An independent dating of the "G" rocks of BED 2-4 by benthic foraminifera and ostracods, in addition to palynological dating, suggests a middle-late Cenomanian age and provides the biochronostratigraphic framework for the sequence stratigraphic analysis.

Analysis of the vertical distribution of particulate organic matter defines three palynofacies types (PF). PF-1 represents the basal "G", where shales of the BED wells and calcareous shale of Abu Tunis 1X were deposited during a relative sea level rise in an outer middle shelf environment that experienced a notable high primary productivity. Prevailing reducing (suboxic-anoxic) conditions supported preservation of very high amounts of amorphous organic matter (AOM) in PF-1. PF-2 is equated to shales of the middle "G" of BED 14-1 and BED 2-4 and to calcareous shales and limestone of the upper "G" in Abu Tunis 1X. PF-2 was deposited during a relative sea level fall in an inner middle shelf setting under better-developed suboxic-anoxic conditions. PF-3 corresponds to the upper "G" of BED 14-1 and BED 2-4 and represents the shallowest setting, where sandy and silty shales were deposited during a pronounced sea level fall in an inner shelf environment. The same suboxic-anoxic conditions were prevailing during deposition of PF-3. Three bioevents were recorded, which could be of palaeoecological and/or biostratigraphic significance. These are *Senegalinium aenigmaticum-Dinopterygium cladoides* peak, *Dinopterygium cladoides-Dinopterygium alatum* peak, and an acme of *Classopollis brasiliensis*. Sequence stratigraphy of a transect of the four studied sections was carried out to understand the response of the particulate organic matter distribution and depositional system to the sea level changes. Three third-order, depositional genetic sequences were recognized and correlated with the global sea level curve (KCe 2, KCe 3, and KCe 4). The early highstand systems tract (eHST) of the genetically related KCe 3 in all wells is characterized by relatively rich organic matter, where combined remarkably low water circulation and insignificant dilution of organic matter with coarse terrigenous material probably supported good preservation of organic matter.

Spatial distribution of the "G" rocks shows lateral facies changes. This was inferred from sedimentation of an organic-poor (avg. 0.8 TOC wt %), coarse clastic (sandy shales) facies in the studied area in Abu Gharadig Basin. Sedimentation changes laterally into a northeast and northwest organic-rich, finer clastic (shale, calcareous shales, and argillaceous limestone) facies in the western Matruh Basin. The robust anoxic conditions and very low dilution of organic matter by terrigenous influx enhanced the organic richness (avg. 2.4 TOC wt %) of these rocks, which resulted in the formation of promising hydrocarbon source rocks. Thus, for a successful hydrocarbon exploration in the north Western Desert, the promising source section of the "G" Member would be associated with shales, calcareous shales, and argillaceous limestone lithologies. Its depositional environment is mainly confined to outer middle and inner middle shelf settings that have widespread suboxic-anoxic conditions and show eHST pattern. In contrast, the regressive intervals that are denoted by the lowstand systems tract (LST)

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and/or the late HST (lHST) typify the relatively coarse clastics as good quality reservoir rocks that are characterized by poor organic richness due to dilution with terrigenous influx.

1. Introduction

The current work presents a second study in a continuum of an earlier one carried out by Tahoun and Deaf (2016) on the Abu Roash "G" Member in order to understand its hydrocarbon potential. This member extends widely in the north Western Desert of Egypt with a considerable thickness of about 220 m and attains a maximum thickness of about 1000 m in the depocentre of the Abu Gharadig Basin (e.g. Khaled, 1999; Maky and Saad, 2009). Its alternating coarse- and fine-clastic dominated intervals show a dual importance as potential sources and/or reservoirs in several oil fields in the north Western Desert. This made the Abu Roash "G" one of the main targets of many national and international oil operating companies. Recently, Tahoun and Deaf (2016) highlighted the significant potential of the Abu Roash "G" Member as a source of hydrocarbons in the extreme northern part of the Western Desert. However, a complete picture of the hydrocarbon potential of this member across the north Western Desert is not clear yet. This raised an immense demand to better understand its vertical and lateral lithologic variations for a practical delimiting of the coarsening and fining trends and their associated depositional trends of the sedimentary organic matter. Moreover, the "G" Member exhibits an obvious diachroneity and has different depositional palaeoenvironmental settings across the north Western Desert. This calls for a further assessment of its age and depositional setting in different areas of northwestern Egypt.

Therefore, integrated palaeoenvironmental, organic geochemical, and sequence stratigraphic analyses of the "G" Member were carried out. In addition, results of work completed on equivalent sections of this member in the north Western Desert were compiled and integrated with our data to present a depositional model of the "G" Member and reveal its hydrocarbon potential in this vast area of northwestern Egypt (Fig. 1).

2. Lithostratigraphy

The "G" rock unit represents the last member at the base of the Abu Roash Formation (Norton, 1967) and extends widely in the north Western Desert of Egypt (Hantar, 1990). Stratigraphically, the "G" Member overlies conformably the Bahariya Formation and underlies the "F" Member of the Abu Roash Formation. The "G" Member shows subtle to notable vertical and lateral lithologic variations in different basins of the north Western Desert. These changes parallel the shallowing and deepening trends from an area to another. In the deep settings, shale and limestone are the dominant lithologies (e.g. Nest-1A and Abu Tunis 1X wells in the extreme northwest). In the shallower settings in the south, shale, siltstone and fine sandstone are the dominant lithologies (e.g. BED 2-4, BED 14-1 wells in the north Western Desert). In BED 2-4 and BED 14-1, the "G" Member attains a thickness of about 126 m and 120 m, respectively. This rock unit shows a diachronism, where several palaeontological studies dated the "G" unit as being of middle to late Cenomanian age in northern Egypt (e.g. Schrank and Ibrahim, 1995; Ibrahim, 1996; El Beialy et al., 2010), while others (e.g. Ibrahim et al., 2009) dated the member as being of late Cenomanian age. The recent palynological work of El Beialy et al. (2011), Tahoun (2012), and Tahoun and Deaf (2016) assigned this member to the late Cenomanian in the northern part of the Western Desert. Integrated sedimentological and micropalaeontological analyses of the member suggested shallow marine depositional settings (e.g. Dominick, 1985; Hantar, 1990; Kerdany and Cherif, 1990). On the other hand, palynology suggested shallow to deep marine depositional settings for the "G" Member in different areas of the north Western Desert (e.g. Ibrahim, 1996; Ibrahim et al., 2009; El Beialy et al., 2010; Tahoun and Deaf, 2016; Mahmoud et al., 2017).

3. Materials and methods

Twenty-six cutting samples of the Abu Roash "G" Member were palynologically investigated from BED 2-4 (15 samples, Lat. 29° 53′ 20.40″ N; Long. 27° 43′ 10.35″ E) and BED 14-1 wells (11 samples, Lat. 29° 50′ 51.06″ N; Long. 27° 38′ 57.3″ E). Badr Petroleum Company (BAPETCO) drilled these wells in the north Western Desert of Egypt (Abu Gharadig Basin) in 1991 and 1988, respectively. Furthermore, twenty-one samples of the same member were palynologically investigated from the Abu Tunis 1X well (8 samples, Lat. 31° 16′ 08″ N; Long. 26° 50′ 41″ E) and from the Nest-1A well (13 samples, Lat. 31° 33′ 18.22″ N; Long. 25° 47′ 21.73″ E) in the Matruh Basin. For additional details on the last two wells, the readers are referred to Deaf (2009), Deaf et al. (2014), and Tahoun and Deaf (2016). A standard HCl/HF extracting technique was employed (Wood et al., 1996). The oxidation step was avoided in order to keep the AOM intact for a detailed palynofacies analysis. Two palynological slides were prepared for each sample. The particulate organic matter and the palynomorphs were examined qualitatively and quantitatively using an Olympus (BX41) transmitted-light microscope (LM) equipped with an Infinity-1 digital camera for microphotographing, at the Geology Department, Faculty of Science, Assiut University. For a consistent approach in studying the Abu Roash "G" Member, the same 500 particles of organic matter and 200 separate counts of palynomorphs (Tyson, 1995; Tahoun and Deaf, 2016) were employed for each sample. Slides of BED 2-4, BED 14-1, and Abu Tunis wells are stored in the Geological Museum of the Geology Department, Faculty of Science, Assiut University.

An independently calibrated palynostratigraphic framework of BED 2-4 well was carried out using the vertical stratigraphic distributions of the recovered palynomorphs next to the recorded foraminifera and ostracodes assemblages (BAPETCO, 1991; M. Abdel-Kader, personal communication, May 2016). The palynomorphs of stratigraphic and/or palaeoenvironmental significance were photomicrographed.

For the current palynofacies analysis and subsequent palaeoenvironmental interpretations, the classification of the palynofacies constituents used by Tahoun and Deaf (2016) was applied, by following the classifications of Whitaker (1984), Tyson (1993, 1995) and Pittet and Gorin (1997) with some modifications. Five palynofacies parameters (brown wood, black wood, terrestrial palynomorphs, marine palynomorphs, and AOM) were used. Abundance and species diversity of dinoflagellate cysts (Simpson diversity index $1/D_S$) as well as cyst morphotypes (cavate, proximate, and skolochorate) were also used. Palynomorphs and particulate organic matter were categorized as very abundant (> 50%), abundant (36–50%), frequent (16–35%), common (5–15%), and rare (< 5%). More details on these parameters can be found in Tahoun and Deaf (2016). We followed Tyson (1984, 1995, p. 438–439) in quantifying the palynological and TOC percentage data in terms of minimum, maximum, and average.

Organic petrography analyses of the particulate organic matter of BED 2-4, BED 14-1, and Abu Tunis 1X wells were carried out using the light microscope and the incident blue light fluorescence. For the UV fluorescence of the BED wells, a 450–490 (560) nm excitation filter (green light) with a 510 nm reflector (dichroic mirror) and a 520–529 nm long pass barrier filter at 200× magnification was carried out at the Zewail City of Science and Technology, Egypt. The UV analysis of the Abu Tunis 1X organic matter was carried out using the same light parameters and filters at the Faculty of Medicine, Assiut University, Egypt.