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Research paper

Palynological, palaeoenvironmental and sequence stratigraphical analyses of a Turonian-Coniacian sequence, Beni Suef Basin, Eastern Desert, Egypt: Implication of *Pediastrum* rhythmic signature

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ABSTRACT

Sixteen samples from the "E" to "B" members of the Abu Roash Formation encountered in the Beni Suef Basin, Eastern Desert of Egypt were palynologically analyzed for palaeoenvironmental and sequence stratigraphic investigations. The integrated palynofacies and lithofacies analysis of the studied section indicates deposition of five alternating regressive and transgressive sequences in well-oxygenated, proximal shelf settings. The Abu Roash "E" and the upper "D" to the lower "C" members were deposited during pronounced regressive phases in oxic, shallow marginal marine settings. The upper "B" Member was deposited during a recurring regressive phase but of a lower magnitude in oxic, shallow inner neritic conditions. The lower "D" Member was deposited during a minor transgression phase in dysoxic, shallow inner neritic settings. While the upper "C" to the lower "B" section was deposited during a stronger transgressive episode in a relatively deep, inner neritic environment of prominent dysoxic conditions. This interchange in the depositional setting was documented by the pronounced and concurrent, cyclic nature of the freshwater algae, peridinioid dinoflagellate cysts, pteridophyte spores, and reworked sporomorphs with variable intensities. Their increasing and conversely their diminishing trends clearly reflect alternating regressive-transgressive periods of reduced and relatively normal salinity conditions, respectively. Overall, sedimentation of the studied Abu Roash section indicates a recurring rise in sea level, which accentuated during the earliest Santonian time.

The analogous peaking in the *Pediastrum* signals with those of the pteridophyte spores and reworked taxa indicate a good connection between these *Pediastrum* signals and the pronounced fluviatile influxes of terrigenous sediments during regressive phases. Accordingly, this can be used to identify regressive sequence boundaries and hence the clastic reservoirs. Even with the small counts recorded herein, we believe high ratios of peridinioid/gonyalulacoid dinocysts are significantly paralleled by peaking signals of freshwater algae and regressive sedimentation phases. This must be preliminary documented here. Probably future palynological studies will be able to fully interpret and address this important *Pediastrum* rhythmic event in different sequence stratigraphic settings.

The palynological parameters, age controlled sporomorph marker taxa, lithology, and gamma ray data were used to differentiate the Abu Roash members into three distinctive 3rd order depositional sequences (AR SQ1, AR SQ2, and AR SQ3). These sequences match well with the global stratigraphic sequences Tu 3, Tu 4, and Co 1 and connect the local rise in sea level to the global eustatic sea level rise.

1. Introduction

Several palynological works have been issued on the biostratigraphic and palaeoenvironmental settings of the Abu Roash Formation in the north Western Desert of Egypt (e.g. El Beialy et al., 2010, 2011; Tahoun, 2012; Aboul Ela et al., 2013; Tahoun et al., 2013; Deaf et al., 2014; Tahoun and Deaf, 2016; Mahmoud et al., 2017). However, a very limited number of publications gave attention to the Eastern Desert of Egypt (e.g. Ibrahim et al., 2001, 2008, 2002; Mahmoud et al., 2007) with no interest at all for the Beni Suef

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Basin. Thus, the present study represents up to our knowledge a pilot palynological study of the upper Cretaceous Abu Roash Formation in the Beni Suef Basin, in the Eastern Desert of Egypt. Recently, this basin is seen nationally and internationally as a key area with future successful hydrocarbon expulsions in Upper Egypt (Zahran et al., 2011). Further detailed studies on more samples from other wells in this basin are highly recommended to obtain a complete picture of its lithologic and petroliferous characteristics.

On the other hand, almost all of the old and recent Egyptian palynological studies dealt principally with the sporomorphs and dinoflagellate cysts as the only imperative elements used in stratigraphic studies. Yet, acritarchs, microforaminiferal test linings, and freshwater algae were conventionally considered by most of the Egyptian palynologists as secondary ingredients in any palynological sample. Consequently, any details regarding freshwater algae are absolutely missing. Some of the previous palynological studies carried out in the Western Desert of Egypt (e.g. Abdel-Kireem et al., 1993; El Beialy, 1994; Schrank and Ibrahim, 1995; Ibrahim, 1996; Mahmoud and Deaf, 2007; Ibrahim et al., 2009; El Beialy et al., 2011) just used the presence of the freshwater algae as a freshwater indicators. Most of the previous studies limited their common presence to the upper Cenomanian and the lower Turonian rocks of the Western Desert of Egypt. El Beialy (1994) recorded a late Cenomanian assemblage with a dominant *Pediastrum* frequency in Abu Gharadig-9 (AG-9) well, Abu Gharadig Oil Field, the north Western Desert. Later, Schrank and Ibrahim (1995) erected the Chlorococcalean green algae interregnum Zone 4 (late Cenomanian-early Turonian) in Abu Gharadig-18 (AG-18) based on the common presence of *Pediastrum*, *Botryococcus* and *Scenedesmus*. Ibrahim (1996) identified a Chlorococcalean-dominated Zone 5 and discussed its promising hydrocarbon potential. However, such mentioned studies lacked highlighting its potential sequence stratigraphic significance.

Therefore, based on the data available, the present study is designed to address three main aims. Firstly, we intend to show vertical distribution of different kerogen constituents and to use them along with integrated lithologic and geophysical data (i.e. gamma ray) to understand the palaeoenvironmental and sequence stratigraphic settings of the newly explored Beni Suef Basin. Brenac and Richards (2001) suggested using the opposing trends of the freshwater algae *Pediastrum* and lumped marine microplanktons to recognize regressive systems tracts. Such comparison of total marine microplanktons is very ambiguous, since microforaminiferal test linings (MFTLs) have their own palaeoenvironmental and sequence stratigraphic indications that differ from those of the dinoflagellate cysts. Thus, a special emphasis on the palaeoenvironmental and sequence stratigraphic implications of the freshwater algae is another aim of this study. Finally, we intend to study the stratigraphic distribution pattern of the spores, pollen grains, and dinoflagellate cysts of certain palaeoenvironmental significance to explore their relationships with the *Pediastrum* algae. This in turn will enable us to assess the validity of using such a continental palynomorph (i.e. *Pediastrum*) in tracing out regressive systems tracts.

2. Stratigraphic setting

The Beni Suef Basin lies approximately 150 km south of Cairo and it is bisected by the present-day Nile Valley (Fig. 1). A major part of the Beni Suef Basin is located to the east of the Nile River, i.e. in the Eastern Desert of Egypt. It is considered as one of the important Eastern Desert basins (Zahran et al., 2011). The stratigraphic column of the Beni Suef Basin extends from the Precambrian granitic basement to the major Cretaceous reservoirs and seals and ends up with the Eocene Apollonia carbonates. Some uncertainty exists around the inception age of the Beni Suef Basin and the sedimentation extent within the basin prior to the deposition of the Kharita Formation (Zahran et al., 2011). The stratigraphic column of the Beni Suef Basin in the Eastern Desert is comparable to its counterparts in the Gindi and Abu Gharadig basins in the Western Desert of Egypt. Except that, the inception of the Beni Suef Basin may be controlled by Aptian/Albian NE-SW extension that resulted in the deposition of the Kharita Formation directly on the basement. The Beni Suef Basin is currently producing hydrocarbons, which are believed to be sourced from different sources; one of them is the Turonian carbonate of the Abu Roash "F" Member. The Abu Roash "A", "E", and "G" members are the most important reservoir sections within the Beni Suef Basin (Zahran et al., 2011).

The current study deals with the Late Cretaceous (Turonian-Coniacian) Abu Roash Formation encountered in the TAR-1X well, located in the Beni Suef Basin, Eastern Desert of Egypt (Fig. 1). This section represents the middle part of the Abu Roash Formation (part of the "E" Member, "D" Member, "C" Member, and part of the "B" Member). It is composed mainly of a carbonate unit that is interbded with substantial clastic horizons at its lowermost and middle parts (Fig. 2). The Abu Roash Formation shows a notable growing significance as a potential oil reservoir to the Egyptian and the international oil industries. It contains a large part of the discovered oil reserves (Schlumberger Middle East, 1995). In the closer Gindi Basin, the Abu Roash Formation shows remarkable increases in its clastic content and stronger freshwater influxes comparable to those encountered in the northern basins of the Western Desert. Such enriched clastics and freshwater influxes making the considerable thickness of about 1900 m in the Gindi Basin is attributed to the proximity of the southern Gindi Basin to the flowing rivers. Theses rivers brought the terrigenous sediments derived from the eroded areas in the south into the Gindi Basin (Hantar, 1990; Issawi et al., 1999). Such freshwater influxes may be traced out laterally and recorded in the Beni Suef Basin.

2.1. Abu Roash Formation

The Abu Roash Formation was designated by Norton (1967) to the subsurface rock unit conformably overlies the Bahariya Formation in the north Western Desert of Egypt. It commonly underlies the Khoman Formation. Generally, the Abu Roash is mainly composed of a limestone sequence, which is interbedded with shale and sandstone units. In the north Western Desert, the Abu Roash Formation is subdivided into seven conformable, well-defined, and easily traceable, alternating clastic and carbonate members. These are nominated from the bottom to the top as the "G" = Abyad Mb, "F" = Mansour Mb, "E" = Miswag Mb, "D" = Meleiha Mb, "C" = Abu Sennan Mb, "B" = Rammak Mb, and "A" = Ghorab Mb (Hantar, 1990; Schlumberger Middle East, 1995). However, we used here the conventional naming (i.e. A, B, C, etc …), which are extensively used in the Egyptian literature up to now for a brevity purpose and to make it easier for readers to follow discussion. These members correspond to alternative transgressive and regressive phases. However, to the south of the northern basinal areas (e.g. Matruh and Shushan basins), there is a substantial sand sedimentation and development of shallower deposits, which consist of shales and sandstone alternations. The "B", "D", and "F" members are relatively clean carbonates (Mahmoud et al., 2017). However, the other members exhibit higher clastic contents that are largely comprised of fine clastics and contain variable amount of detrital material. The shales grade into deeper carbonate and shallower sandstone lithologies to the north and south, respectively, where the transgression of the sea comes from the north direction (Said, 1990; Mahmoud et al., 2017). These clastic