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# Cyclo-Stratigraphy of the Lower Cretaceous Succession in Jade field, North Western Desert, Egypt

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***Abstract:*** *The lower Cretaceous Alam Elbueib (AEB) Formation acts as a hydrocarbon reservoir in the subsurface of the Western Desert, Egypt. The objective of this paper is to investigate changes in the depositional settings of the early Cretaceous; mainly for Alam Elbueib Formation in Jade field using lithofacies characteristics and electrofacies analysis. It is subdivided into six units (AEB-1, 2, 3, 4, 5 and 6) and is composed mainly of sandstone with shale and siltstone interbeds at base while carbonate increases at top. AEB-3 unit consists of a succession of massive fluvial sand bodies separated by marine shale incursions and is divided into six subunits (AEB-3A, 3C, 3D, 3E, 3F and 3G).*

*Ditch samples and well logs of six wells (Jade-1X, Jade-2X, Jade-3X, Jade-8, Jade-12 and Jade N-1X) were utilized in this study. The description of samples and logs revealed strata packages with a progradation to retrogradation timeline which defines two regressive to transgressive trends forming the lower Cretaceous succession in Jade field. The first cycle commences with a transgressed phase started during Tithonian at the base of AEB-6 and continued during Valangian (AEB-5) to early Hauterivian (AEB-4) with mainly shallow marine setting with a terrestrial input. This transgression came after a period of non-deposition and/or erosion which is regional in the North Western Desert of Egypt. A regressive phase started with the thick fluvial sand sequence of AEB-3G of early Hauterivian, culminating in non-deposition during the late Hauterivian. These sands occasionally interbedded with thin shale and siltstone layers. Also, it contains some recognized shale intervals in AEB-3C and AEB-3F subunits, which may represent shallow marine setting. The second cycle begins with the end of AEB Formation during Barremian by another transgressive phase that is reached its peak in the Aptian Alamien marine shelf dolomites. It is represented by the increase of dolomites and marine dinocysts enrichment which referee to increase of marine influence. Dahab shallow marine claystones represents the regressive phase and it marks the end of this cycle by a subaerial unconformity that separates it from the above sands of Kharita Formation.*

*The results of lithofacies analysis were correlated with the wire line log response to perform electrofacies investigation. Four main facies associations could be recognized in the studied lower Cretaceous sequence in Jade field.*

*The obtained results indicate that interested horizon within the lower Cretaceous succession in Jade field in general represents two 3$^{rd}$ order cycles of shallow marine to fluvial environments.*

***Keywords:*** Lower Cretaceous, Cyclo-Stratigraphy, Lithofacies analysis, electrofacies analysis, Jade field, Western Desert, Egypt.

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## I. Introduction

The Jade field that forms the scope of this study lies in the Matrouh Basin, North Western Desert, Egypt (Fig.1). The study area lies between latitudes 21° 53` 05`` – 21° 56` 21`` N and longitudes 27° 06` 00`` – 27° 09` 15`` E.

Various geological studies are dealing with the tectonic framework and stratigraphy of sedimentary succession in the Western Desert of Egypt; e.g. Said (1962), Norton (1967), Meshref (1982), RRI (1986), Barakat et al. (1987), Kelly (1989), Hantar (1990), El Shaarawy et al. (1996), Abu Shady et al. (2001), Moustafa et. al. (2003) and Abd El Kader (2012). Moreover, studies concerned with the distribution and evolution of the sedimentary basins in the North Western Desert were carried out by many authors such as**;** Abu El Naga (1984), Moussa (1986), Shalaby et al. (2000), Moustafa (2008), Afify (2012), Nassar (2013) and El Bastawesy (2016).

During the early Cretaceous, the Tethys transgressed the North Western Desert of Egypt resulting in deposition of Alam Elbueib section. In order to investigate changes in the depositional settings for the studied Alam Elbueib Formation, lithofacies supported with electrofacies analysis were investigated following the general classification of Serra and Abbot (1980), which defines depositional systems and therefor, the hierarchy of depositional cycle would be identified.

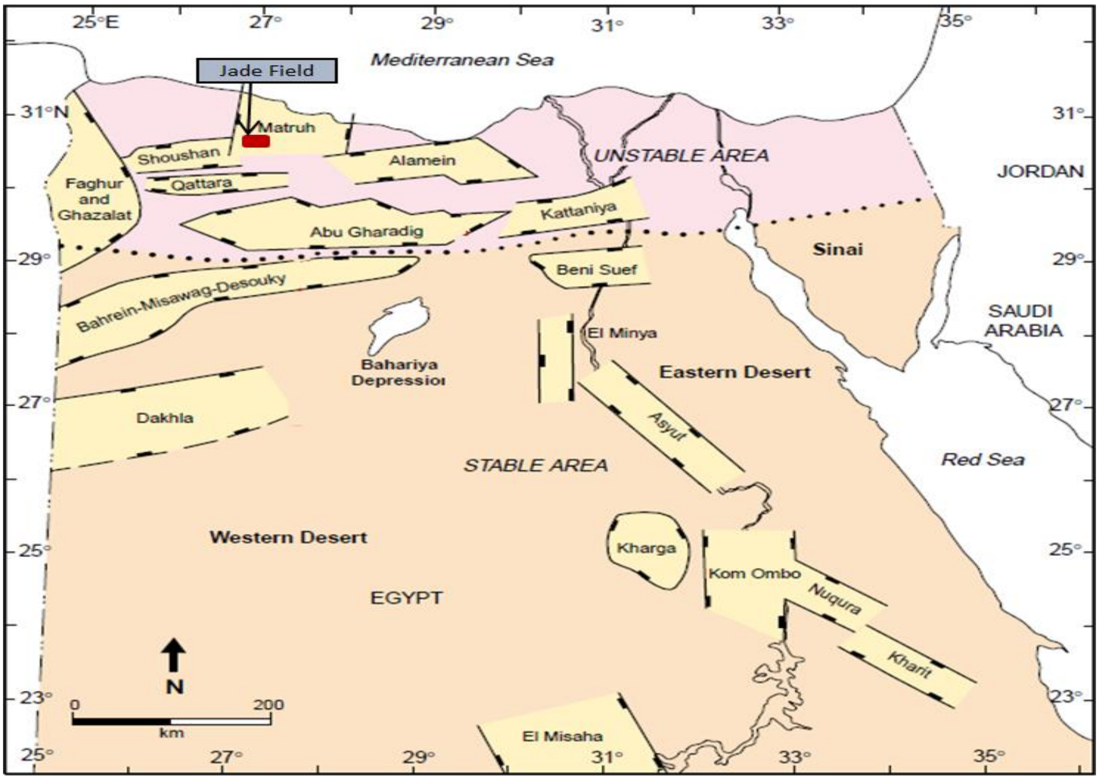

**Fig.1:** Basins and major fault trends pattern of the Western Desert of Egypt (modified after Taha, 1992; Dolson et al., 2001; and Moustafa et. al., 2003).

## II. Stratigraphic Setting

The northern part of the Western Desert comprises a number of sedimentary basins such as Matruh, Shushan, Alamein and Natrun, that received a thick succession of the Mesozoic sediments. Matruh basin was inverted in late Cretaceous-early Tertiary time leading to the development of NNE-oriented fault propagation folds dissected by NW-oriented normal faults (Moustafa, 2008).

The stratigraphic section of the Jade field follows the North Western Desert regime (Fig.2) and it ranges in age from the Paleozoic to the Cenozoic (Neogene). The post-Paleozoic succession in this area comprises four sedimentary cycles; lower to upper Jurassic, lower Cretaceous, upper Cretaceous, and Eocene to Miocene (Sultan and Abd El Halim, 1988).

The Cretaceous is divided into a lower unit made up primarily of clastics and an upper unit that is made up mainly of carbonates (Fig.2). The lower unit includes an important carbonate bed of great areal extent (the Alamein Dolomite). The North Western Desert formed as a platform of uniform sedimentation with little facies or isopachous variations (Said, 1990). This study focuses on the lower Cretaceous Alam Elbueib Formation, which represents the main pay zone in Jade field.

Alam Elbueib Formation rests unconformably on the late Jurassic Masajid Limestone. The Alam Elbueib Formation is mainly dominated by sandstone with siltstone and shale interbedded with some carbonate laminae in its lower and upper parts. In the studied field, Alam Elbueib Formation has a huge thickness reaches up to 4800 ft. Lithologically, it is subdivided into six units from bottom to the top: Alam Elbueib-6 (AEB-6), Alam Elbueib-5 (AEB-5), Alam Elbueib-4 (AEB-4), Alam Elbueib-3 (AEB-3), Alam Elbueib-2 (AEB-2) and Alam Elbueib-1 (AEB-1), whereas, the AEB-3 unit itself was subdivided into six subunits: G, F, E, D, C and A (Fig.3).

The Alam Elbueib Formation is conformably overlain by Alamein Formation, which is the most famous dolomitic formation in the Western Desert. According to EGPC (1992), this is a carbonate unit, mostly dolomite, separates the Alam Elbueib Formation from the overlying Dahab Formation.

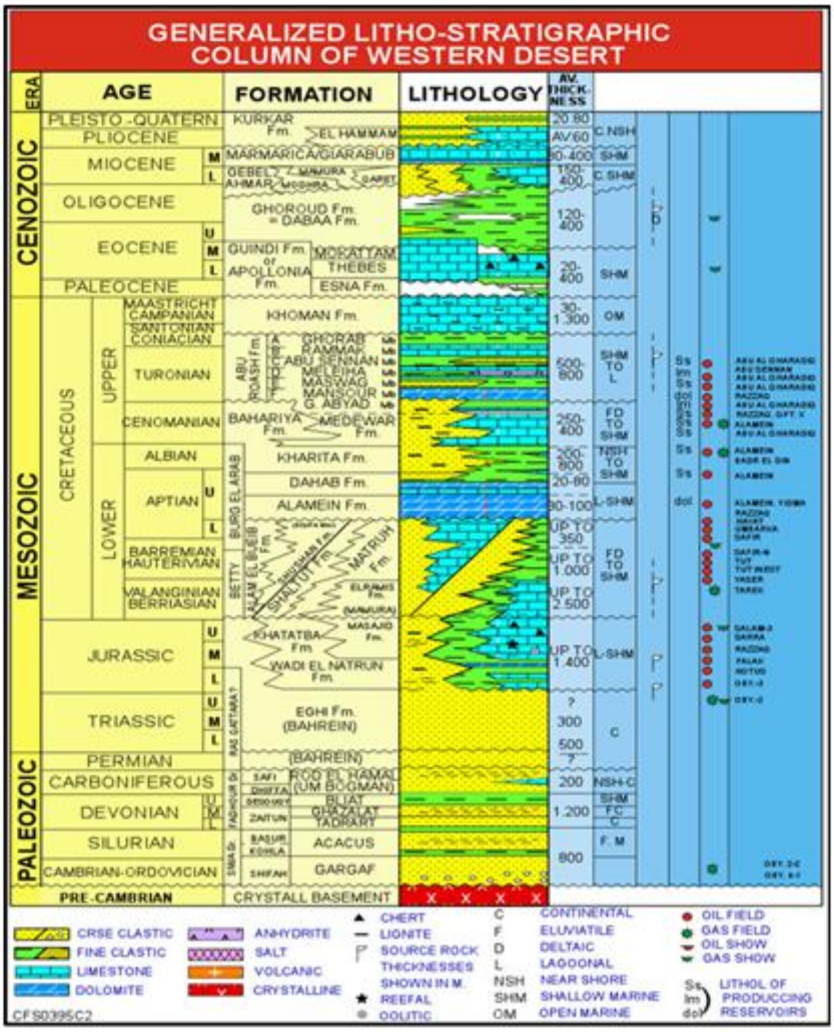


**Fig.2:** Generalized stratigraphic column of the North Western Desert (Schlumberger, 1995).

Dahab Formation conformably rests on Alamein Formation and is overlain unconformably by Kharita Formation. It is Aptian to early Albian (Hantar, 1990) and is made up of greenish gray pyritic shale with interbedded siltstone, sandstone, and limestone.

## III. Samples And Methods

Ditch samples and well logs of six wells (Jade-1X, Jade-2X, Jade-3X, Jade-8, Jade-12 and Jade N-1X) were utilized in this study. Samples description accompanied with electrofacies interpretation were used to support the lithofacies analysis within the lower Cretaceous rocks. Serra and Abbot (1980) extended the concepts of lithofacies to geophysical logs and defined electrofacies as a set of log responses that characterize the drilled sediments and differentiate it from the other sediments.

## IV. Results

### *4.1 Lithofacies Analysis*

Lithofacies is a rock unit with a distinctive set of characteristics, such as coloure, grain size, sorting, crystallinity and associated minerals, and is generally produced by a particular process or depositional environment. Based on Walker (2006) facies is a term that can be used in both as a descriptive and interpretive sense. Basically, it may highlight either a specific distinguishing feature of the deposits of a given facies, or may include an interpretation of the depositional environment from which the deposits originate.

The Alam Elbueib Formation is assigned to Tithonian to Barremian (RRI, 1986). It is subdivided into six units (AEB-1, 2, 3, 4, 5 and 6) and is composed mainly of sandstone with shale and siltstone interbeds at base while carbonate increases at top. The following is a brief note about the lithostratigraphy of these units from the bottom to top:

***Alam Elbueib-6 (Tithonian-Berriasian):***

The base of AEB-6 unit is marked by a major unconformity surface that separates it from the underlying Masajid Formation. Dinocysts are observed in AEB-6 and moderately diverse upward in AEB-5 and AEB-4 suggesting shallow marine conditions of these units (RRI, 1986). It consists mainly of sandstone, siltstone, shale and traces of dolomite. Sands at the base are colorless, fine grained, sub-angular to sub-rounded, slightly dolomitic and well sorted. Sands turned upward to white, grayish white, medium to fine sandstone with traces of pyrite which indicates an intertidal regime. The siltstones are brownish gray, light to medium gray, while shales are greenish gray to brownish gray and silty with traces of pyrite associated with dolomite that indicates a lagoonal regime. AEB-6 unit represents the basal transgressive part of the Alam Elbueib Formation. The lithologic composition of this unit is pointing to a deposition in shallow marine environment.

***Alam Elbueib-5 (Valanginian):***

AEB-5 unit measures about 260 ft. in average. It is made up of interbedded sand and siltstone with traces of shale. Sands are colorless, medium to fine grained, sub-rounded, moderately sorted, with traces of pyrite and clay fragment which points to a fluvio-marine environment. It is occasionally consolidated to white, grayish white and tannish white sandstone with brownish gray siltstones. These facies sported deposition in shallow marine environment with high terrestrial input.

***Alam Elbueib-4 (Hauterivian):***

AEB-4 unit is represented mainly by shale, siltstone and fine sandstone with some dolomite layers. The thickness of this unit is around 620 ft. Siltstone and shale predominate and form about 70% of this unit. Siltstones are brownish gray and brickish red, with traces of pyrite and carbonate thin layers. These characters refer to a lagoonal or intertidal regime. The colour of siltstones turns sporadically to greenish gray that refers to a sub-tidal regime. Sandstone are white, grayish white, off white and tannish white, fine to medium grained, well to moderately sorted, with traces of pyrite, occasionally with dolomitic cement. These facies supported deposition in shallow marine environment.

***Alam Elbueib-3 (Hauterivian):***

AEB-3 unit consists of a succession of massive fluvial sand bodies separated by marine shale incursions (Moustafa, 2008). It is relatively thick attaining about 1850 ft and is divided into six subunits (AEB-3A, 3C, 3D, 3E, 3F and 3G). This unit consists mainly of clastics with some traces of dolomites, which rise in the most upper part to reach about 10% in AEB-3A. A brief description about AEB-3 subunits from base to top is given below:

AEB-3G subunit attains about 746 ft. thick in well Jade-1X and consists mainly of poorly consolidated sands, occasionally consolidated to sandstone with minor occurrence of siltstone, shale and traces of dolomite. The sands are medium to coarse grained, sub-rounded, moderately sorted, while the sandstones are light gray, rarely dark gray, very fine to fine grained, occasionally medium, moderately to well sorted, non to slightly argillaceous, with traces of pyrite and clay fragments. Siltstone is brownish gray to brownish white, with traces of pyrite and occasionally graded to very fine sandstone with medium to dark gray non-calcareous shale. The facies refers mainly to a fluvial environment. Minor thin supra-tidal dolomite strikes are found within this fluvial system.

AEB-3F subunit attains about 110 ft. thick and consists of gray shale with strikes of brownish gray and brickish red siltstone at the upper part.

The subunit AEB-3E consists of poorly consolidated sands with few streaks of siltstone measuring about 450 ft. in average. Sands are medium to coarse grained with pyrite and clay fragments. These characteristics represent a fluvial environment.

AEB-3D is the thinnest subunit of AEB-3 with a minor thickness of only 40 ft. It consists mainly of sandstone with some shale streaks. Sandstone is medium to fine grained, moderately sorted with pyrite and scarce clay fragments. These descriptions reflect the fluvial system regime that was persisted throughout deposition of AEB-3 unit.

AEB-3C attains about 70 ft. thick. The lower part is composed mainly of shale with few carbonate streaks. Shale is dark gray, brownish to greenish gray, sub-flaky to flaky, partially silty. The upper part consists of brownish gray siltstone and off white, fine to medium, sub-rounded sandstone. These lithologic compositions echo the shallow marine incursion of the AEB-3C.

AEB-3A subunit attains about 440 ft. thick and is composed of sandstone interbedded with siltstone and dolomite. Sandstones are off white, tannish white, medium to fine grained, sub-angular to sub-rounded, moderately to poorly sorted and occasionally unconsolidated. The lower part experience more presence of the dolomite thin layers. These characteristics refer to a fluvial environment.

***Alam Elbueib-2 (Barremian):***

AEB-2 unit attains about 320 ft. in average. This unit is composed predominately of dolomite with subordinate sand, shale and siltstone. Dolomites reach about 60% of the total thickness. Dolomites are tannish white, off white, creamy white, locally light gray, micro to fine crystalline, hard to moderately hard, showing a sucrosic texture and sandy with scattered pyrite. Shale is greenish gray, medium gray, sub-flaky to sub-blocky, moderately firm to soft and partially silty with traces of pyrite. Sandstone is off white, grayish white, fine to medium grained and moderately sorted, with pyrite and traces of clay fragment.

***Alam Elbueib-1 (Barremian):***

This unit represents the topmost unit of Alam Elbueib Formation with average thickness of 190 ft. It consists of a sequence of dolomitic sandstones interbedded with shales and dolomites. Sandstones are off white, tannish white, very fine to fine grained, locally medium grained, moderately sorted, sub-rounded to sub-angular, moderately consolidated to semi-friable, occasionally with dolomitic cement, and traces of pyrite. Shale is greenish gray, olive green, brownish gray, sub-flaky to sub-blocky, moderately firm, with traces of pyrite, slightly calcareous. Dolomites are light brown, honey brown or smoky white in colour, microcrystalline and hard to fairly hard. Siltstones are brownish white, off white, sub-blocky, soft, and partially grading to very fine sandstone. During Middle to Late Barremian, the marine dinocyst assemblages tend to be of high abundance and diversity (Khalda Petroleum Company, 2008) that indicates an increase in the marine influence.

***Alamein Formation (Aptian):***

This formation overlies Alam Elbueib Formation with a thickness of about 250 ft. It is composed entirely of dolomites. Dolomites are honey brown, light brown, tannish white, micro to cryptocrystalline, hard to moderately hard, pyritic and sandy near the base. An increase in dinocyst abundance and diversity is usually apparent in this formation (Khalda Petroleum Company, 2008). The increase of marine dinocyst refers to a more marine invasion during this time.

**Dahab Formation (Aptian):**

Dahab Formation overlies Alamein Formation. It attains about 120 ft. and consists of brownish gray and dark brown shales with pyrite interbedded with brownish gray siltstone and thin laminations of fine to very fine grained sands and dolomite. The top is marked by a dark brown to dark reddish brown glauconitic shale. The oxidizing regime that is reflected by the dark reddish colour with the increase concentration of oxidized glauconite are evidence for the known unconformity that separated Dahab Formation from the overlying Kharita Formation. Dahab Formation contains a moderately diverse dinocyst assemblage and abundant terrestrial miospores indicating that a terrigenous influx recommended into the shallow marine setting (RRI, 1986).

***4.2 Electrofacies Analysis***

The results of lithofacies analysis were correlated with the wire line log response to perform electrofacies investigation. Four main facies associations could be recognized in the studied lower Cretaceous sequence based on this correlation applying the concepts of Serra and Abbot (1980). These facies as shown below are represented in (Table 1).

1. Very low Gamma Ray and blocky.
2. Low Gamma Ray and blocky.
3. Moderate Gamma Ray and Spiky.
4. High Gamma Ray and erratic.

| GR LOG RESPONSE (Gamma ray 0.00 gAPI 150.00) | LOG SIGNATURE | FACIES ELEMENT | CYCLO-STRATIGRAPHIC FRAMEWORK | FORMATION |
|---|---|---|---|---|
| | Very low GR and Blocky | Carbonates (Shallow marine to Marine) | Transgression/ Retrograding | Alamein/ part of AEB-1 and AEB-2 |
| | Low GR and Blocky | Fluvial / distributary channels | Regression/ Prograding | Most of AEB-3 |
| | Moderate GR and Spiky | Shelf / Shallow marine | Transgression/ Retrograding | Most of AEB-4, AEB-5 and AEB-6 |
| | High GR, Erratic | Shallow marine | Transgression/ Retrograding | Most of AEB-6, AEB-5, AEB-4 and Dahab |

**Table 1:** Main facies association of the studied lower Cretaceous sequence based on well log response applying the concepts of Serra and Abbot (1980).

The recognized facies associations represent diverse environments ranging from fluvial to shallow marine influenced environments in the Jade area.

The first facies association is represented by Very Low Gamma Ray facies that reflect the main carbonate units in the upper part of Alam Elbueib Formation (AEB-1 and AEB-2), Alamein Formation and the Jurassic Masajid Formation. This facies is related to a retrogradational pattern and records the marine influx dominated with shallow marine.

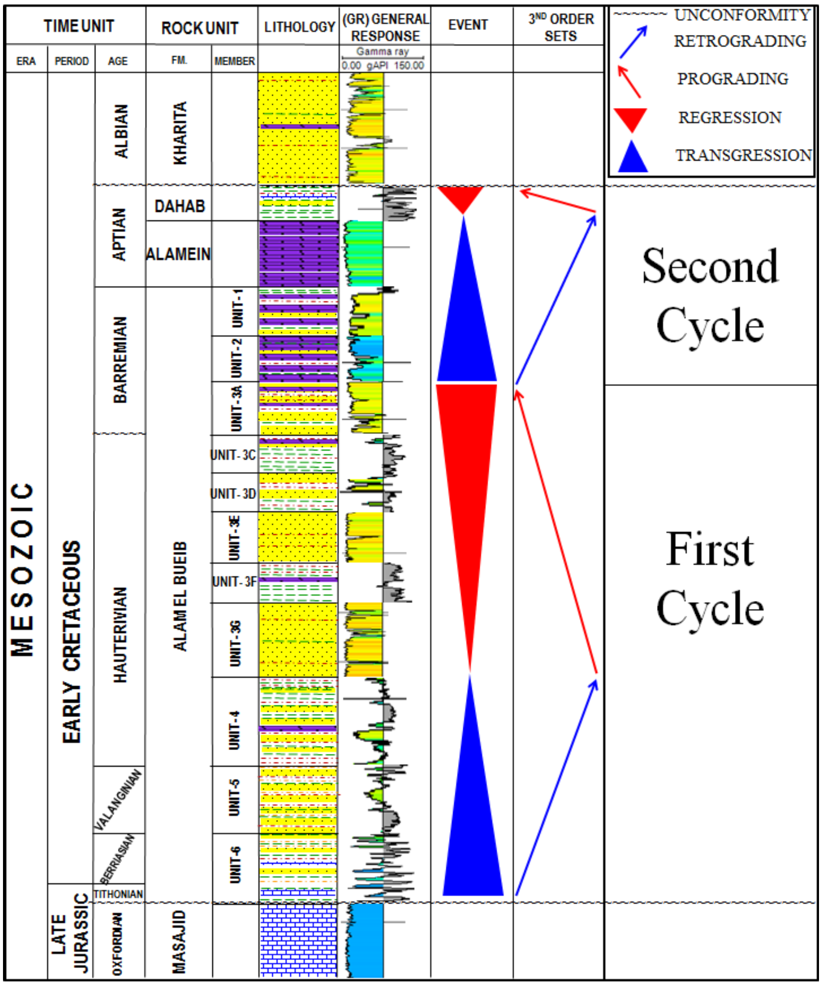


**Fig.3:** Cycling analysis of Alam Elbueib Formation based on major events, using lithofacies and electrofacies

The second investigated Low Gamma Ray, blocky coarsening upward trend facies is mostly obvious in the middle part of Alam Elbueib Formation (AEB-3), which is associated with amalgamated fluvial channel. This facies trend could be related either to a progradation in regression event or in a transgression event.

The other two Moderate to high GR and spiky to erratic facies associations are controlled by deposits that may be related with shelf to shallow marine facies. This profile is associated with the transgression event that mostly appears in the lower part of Alam ELbueib Formation (AEB-4, AEB-5 and AEB-6). The unconformity that separated Dahab Formation from the overlying Kharita Formation is clear in Gamma Ray response, where Gamma Ray readings was turned suddenly from high to low which means a subaerial unconformity.

### *4.3 Cyclicity of Lower Cretaceous Sequence*

Depending on lithofacies and electric logs of the studied wells, two major $3^{rd}$ order cycles have been detected during the early Cretaceous in the area under investigation of Jade field. These two cycles are shown in (Fig.3) and supposed to be as following:

*First cycle:* This cycle began with a transgressed phase started during Tithonian at the base of AEB-6 and continued during Valangian (AEB-5) to early Hauterivian (AEB-4) with mainly shallow marine setting with a terrestrial input. This transgression came after a period of non-deposition or erosion which is regional in the North Western Desert of Egypt.

A regressive phase started with the thick fluvial sand sequence of AEB-3G of early Hauterivian, culminating in non-deposition during the late Hauterivian. These sands occasionally interbedded with thin shale and siltstone layers. Also, it contains some recognized shale intervals in AEB-3C and AEB-3F subunits, which may represent shallow marine setting.

*Second cycle:* By the end of Alam Elbueib Formation during Barremian, another transgressive phase started and reached its peak in the Aptian Alamien marine shelf dolomites. It represented by the increase of dolomites and marine dinocysts abundance which referee to increased marine influence. Dahab shallow marine claystones represents the regressive phase and it marks the end of this cycle by a subaerial unconformity that separates it from the above sands of Kharita Formation.

## V. Conclousions

Alam Elbueib Formation in general represents shallow marine to fluvial environments. AEB-6 unit represents the start of early Cretaceous first marine transgression with a shallow marine situation. The basal units (AEB-6 and AEB-5) probably represent shallow marine conditions with high terrestrial input. AEB-4 is more silty and shaly and still shallow marine conditions were performed. AEB-3 is a thick fluvial sand body interbedded with shallow marine shales especially in AEB-3F and AEB-3C subunits. The uppermost part of the Alam El Bueib Formation (AEB-1 and AEB-2) is representing by the shallow marine environment. Alamein Formation represents the maximum marine transgression, whereas Dahab Formation was recommended to be a shallow marine setting with terrigenous influx.

Correlating the lithofacies with electric logs resulting in identification of two major $3^{rd}$ order cycles during the deposition of lower Cretaceous succession in the studied area of Jade field.

The resulting strata packages are all have a progradation-to-retrogradation timeline which defines a regressive-to-transgressive trend during the deposition of the Alam Elbueib Formation. These transgressive and regressive trends are related to the balance between accommodation creation and sediment supply, which in turn controls relative sea-level changes.

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