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Facies analysis and sequence stratigraphy of the Upper Cretaceous- Lower Paleogene of the Hammam Faraoun, Gulf of Suez, Egypt.

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Abstract

The lithofacies types and associations of the Hammam Faraoun section in the eastern side of the Gulf of Suez, Egypt, have been examined and described in detail and used in sequence stratigraphy of the Upper Cretaceous- Lower Paleogene rocks. Lithostratigraphy, three rock units have been noted: the Sudr Formation (Maastrichtian); Southern Galala Formation (Paleocene) and the Wasit Formation (Lower Eocene). The studied section is composed of carbonate rocks with intercalations of clastic rocks with skeletal and nonskeletal components. Five lithofacies associations range from tidalites to deep subtidal have been noticed. Two third order depositional sequences separated by three sequence boundaries have been detected in the studied area. The sequences are built up of two system tracts: the transgressive system tracts (TST) and the highstand system tract (HST). The TSTs were recorded mainly in the limestones and marlstones while the HSTs were recorded in the sandstone, shale, dolostone, and limestones. The first sequence boundary separated between the Maastrichtian Sudr and the Early Paleocene Southern Galala formations (K-P boundary). The second sequence boundary is separated between the lower and the upper Paleocene while the last sequence boundary is determined between the upper Paleocene southern Galala Formation and the lower Eocene Wasit Formation. These boundaries are related mainly to tectonics and partly to eustatic sea level.

Key words: Hammam Faraoun, sequence stratigraphy, Upper Cretaceous, Lower Paleogene

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Introduction

The Hammam Faraun studied section (Fig. 1) which located in the Suez Rift is the region most likely to be affected by the tectonic activity (Bosworth et al. 2005). The Suez rift includes many faults and grabens surrounded by non-compressional faults (Khalil and McClay, 2001). The K-P is recorded in the studied section and is represented by various marine lithofacies. According to Korneva et al. (2018), two general rifts have been detected in the Suez Rift, pre-rift and syn-rift. The pre-rift overlying the Precambrian basement rocks is extended from Cambrian to Eocene stages and we can follow it regionally in the North Africa while the syn-rift is extended from Oligocene to Quaternary stages and consists mainly of marine clastics and local non-clastic rocks. The studied section belongs to the pre-rift and consists mainly of Paleocene rocks which overlies the upper Cretaceous rocks and underlies the lower Eocene rocks. Most of fault trends in the studied area as well as the Gulf of Suez are north to north west and related to the Miocene rifting (Kuss et al. 2000). Generally the Paleocene rocks in Egypt have been considered as a portion of the southern Tethys epicontinental shelf and the tectonic effects have been responsible for the configuration of Egypt during this period (Aubry and Salem, 2013). Most of the Paleocene rocks in Egypt has a deeper marine facies with lateral variations related to epirogenic movement (Farouk 2016). Few previous stratigraphic studies were dealing with the studied area and focus mainly on litho- and biostratigraphy (Faris and Strougo 1992; Hamza et al. 1997; Lüning et al. 1998,; El-Deeb et al. 2000; Abu-zeid et al. 2001; El-Nady and Shahin 2001; Dakroury 2002; Faris and Zahran 2002; Strougo et al. 2003; Abu Shama and Faris 2005; Faris and Farouk 2012). The aim of this paper is threefold: (1) investigate in details the lithofacies types, (2) determine the main lithofacies

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associations and construct the depositional model, and (3) explain the depositional sequences and their boundaries.

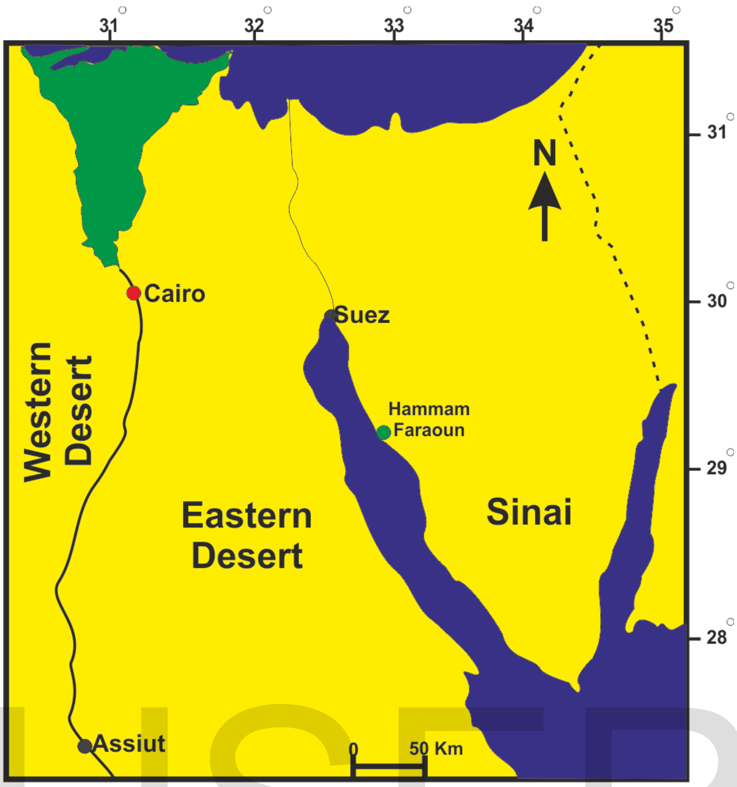

Fig. 1: The location map of the studied area

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General Stratigraphy

The studied section is located on the Sinai Peninsula and considered as the main fault blocks in the central dip area of the Suez rift (Gawthorpe et al. 2003). It is 70 km southeast of Suez city. The entire succession of the studied Hammam Faraoun Mountain range exposes late Cretaceous to lower Eocene (Fig. 2). It is represented by The Sudr, Southern Galala, and Wasit formations as the following:

Sudr Formation: It represents the oldest rock units in the studied section and the first one who has described this formation at Wadi surd in Central Sinai was Ghorab (1961). The surd Formation (Maastrichtian) in the studied section consists of massive chalky limestone (8 m thick) interbedded with thin lamina of grey shale and marl (20-40 cm thick). The macrofossils are relatively low and includes some taxa of *Pecten* and Pychnodonte. Planktonic foraminifers are recorded in the limestone beds. The lower contact is unexposed and the upper contact of the studied formation with the overlying Southern Galala Formation is a universal unconformity (K-P boundary).

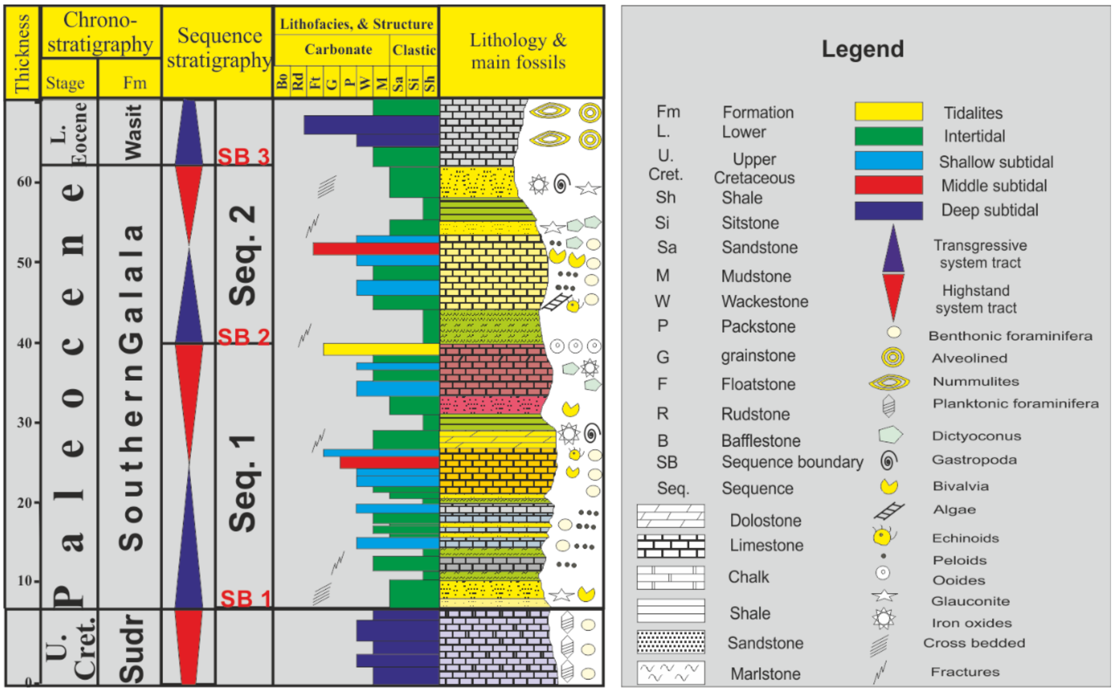

Fig. 2: Texture, facies and interpreted sequence stratigraphy of the studied formations in the Hammam Faroun section.

Southern Galala Formation: It represents the main rock units in the studied section and was first introduced at Gebel Thelmest in the western side of the Gulf of Suez by Abdallah et al. (1970). The term southern Galala has been used to describe the Paleocene rocks in this area which has been affected by many tectonic activities related to the Syrian acr system. The terminology of Southern Galala may represent a kind of missy because Strougo et al. (2003) named the "Paleocene- Eocene" succession in the north east Gulf of Suez as Southern Galala Formation. The Southern Galala differs from the other Paleocene formations in the lithology, fossils and facies association. It consists mainly of 55 meters of argillaceous limestone, shale and marl intercalated with sandstone layers towards the upper part. Benthic foraminifers, bivalve and gastropod shells are the essential bio component in the Hammam Faraoun Paleocene beds without any true recording to the planktonic foraminifers and this indicates a shallower condition in the studied area than the others Paleocene rocks in Egypt. Glauconitic and ferruginous minerals have been considered the main non skeletal grains in these beds. The Southern Galala Formation is overlain by the Lower Eocene **Wasit Formation**. These lower Eocene rocks have been referred as Thebes Formation in several studies. The Thebes Formation consists mainly of nodular limestone and chert and the studied lower Eocene beds are massive and laminated without nodular limestone and chert. So, it was concluded that it is closer to Wasit Formation than Thebes Formation. It attains 8m in the studied section and consists mainly of alveolinid and nummulite layers.

Study area and methods

The Hammam Faraun studied section lies in the northeastern side of the Suez Rift between the coastal plain of the Gulf of Suez and the Gebel Nukhul in southern Sinai at latitude 29°11'50", longitude 32°57'55" E (Fig. 1). A total of 44 thin sections were fabricated from the examined section. The fabricated thin sections have been studied under petrographic microscope. The collected samples allowed us to analyze and understand the lithofacies types, and their associations. The lithofacies associations were arranged in the vertical facies succession to determine the sequences and the

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sequence boundaries depending on the process-sedimentology approach of Kerans and Tinker 1997; and Catuneanu, 2006. The field studies were based on observations of cycles and sequences, boundaries, sedimentary structures and fossils. The definition of these sequences was depend on rock color, texture, grain size, fossil contents and other lithological characteristics.

Lithofacies analysis and interpretation

1. Tidalites lithofacies association

Ferruginous ooidal pack- to grainstone (Fig. 3a): it is recorded in the lower upper part of the Southern Galala. The facies made of ooid grains packed in a mosaic matrix. These ooids have tangential structure with average size is nearly 0.5mm and partial micritization. Detrital quartz grains and, peloids are encountered in this facies. Granular spar and iron oxides are acts as a cement between ooid grains.

Interpretation: According to Flugel (2010), the sample comes from restricted near-coast marine parts of a carbonate platform and beaches. The rare of fossils, presence of quartz grains and the prevailing of the iron oxides minerals indicate tidalites setting.

2. Intertidal lithofacies association

Ferruginous quartz arenite (Figs. 3b, c)**:** It recorded in the most parts of the Southern Galala Formation as a massive sandstone bed. This facies consists mainly of a coarse to medium grained, well sorted, and rare fossils quartz arenite. The quartz grains are cemented together by ferroan calcitic and dolomitic cement. The maturity of sand grains is high and sometimes coated with ferruginous and mud materials. Few green, medium sized, and ovoidal to spherical glauconite-rich sediment are recorded.

Interpretation: The well sorted quartz arenite indicates near shore intertidal or tidal flat setting. The ferruginous and mud cements refer to near shore setting with subaerial exposure (Wanas 2008). The paucity of fossils and the absence of primary structure indicate shoreface environment and peritidal setting (Khalifa et al. 2014). The presence of glauconite grains refer to tidal flat to inner platform with normal marine salinity during the transgressive tract (Anan 2014). The scarcity of glauconite grains exhibits that these grains are transported and aren't in their original place.

Shale-mudstone (Fig. 3d)**:** It consists of thin- to medium-thick beds of grey shale alternated to marl or sandstone in some beds in the Southern Galala Formation. The facies is generally mudstone with rare fossils such as bivalve shells.

Interpretation: the rare fossiliferous shale beds with bivalvian shells and without any indication to terrestrial or deep sutidal refer to restricted inner lagoon or tidal flat setting.

Lime-mudstone (Fig. 3e)**:** This microfacies is noticed in the upper part of the Sudr Formation and in the lower and upper parts of the southern Galala Formation. The fossils are very limited distriebution in this facies. Mud peloids and traces of iron oxides are encountered within the micrite matrix. The main diagenetic feature is the fractures which are filled by sparry caclites.

Interpretation: The low diversity fauna associated with muddy facies and without any indications to the deep stubtidal mean subtidal to shallow lagoon environment in the low energy setting (Heckel 1972, Flügel 2010). The high amount of mud grains and the absence of wave sedimentary structure evidence indicate a low energy environment (Tawfik et al. 2017). The fractures mean physical compaction and indicate the effect of the tectonic activity during this period.

Ferruginous dolo mudstone (Fig. 3f)**:** In the Southern Galala Formation, this lithofacies is represented in the middle and upper parts with an average thickness of 2.5

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m. Rocks in this lithofacies are grey to yellowish grey, massive and very hard. The rocks consist mainly of hypidiotopic to xenotopic dolomite rhombs with the average size 10µm without zonation. The pore space between rhombs filled with iron-oxides. Some scattered quartz grains are present and no fossils recorded in this facies.

Interpretation: This type of fine-grained dolostone suggests early phase of dolomitization in the intertidal flat setting (Shinn 1983). The facies may refer to the lowering in sea level during sedimentation and this a strong evidence to the tectonic effects during this period (Coe 2003). The small dolomite crystal size, and the scattered quartz grains and the absence of fossils refer to low energy conditions in a tidal flat setting (Adabi and Mehmandosti 2008). According to Flugel (2010), this dolomite type is recorded in supratidal to intertidal zone.

3. **Shallow subtidal lithofacies association**

Biclastic peloidal grainstone (Fig. 3g): It is recorded in the lower and upper part of the Southern Galala Formation. It consists mainly of angular to rounded mud peloids and aggregate grains. The skeletal grains are minor such as parts of bivalve shells, echinoids and foraminifers, and the skeletal grain size is small to medium. In the field the facies is characterized by thin to thick bedded and light gray color. Micrite envelops have been recorded on the most skeletal grains and other non-skeletal component.

Interpretation: The mud peloids indicate restricted inner platform lagoon (Flugel 2010). The minor fossils with peloid grains indicate (Rivandi et al. 2013). The plenty of micrite envelopes suggest restricted conditions rather than an open-marine conditions.

Bioclastic bivalve shells wackestone (Fig. 3h)**:** the facies forms many beds in the Galala Formation with a thickness 0.4m to 3m. The bivalve shells constitute the bulk skeletal grains in the carbonate mud matrix. Other skeletal components such as foraminifers and algae are recorded. Micrite clasts and bioturbation are common and the main diagenetic feature in this microfacies is a neomorphism.

Interpretation: The bivalvian shells corresponding to mud clasts indicate a shallow platform in a shallow inner lagoon with open circulation (Bauer et al., 2003). The prevalence of mud calsts and bioturbation indicate the low energy calm water conditions ((Nichols, 2009, Khalifa et al. 2016).

Bioclastic foraminieral wackestone (Fig. 4a, b)**:** the facies has a wide distribution throughout the southern Galala Formation with average thickness 2-4 m. In the field, these beds are yellowish gray to brown, hard and massive. The facies consists mainly of bioclastics floated in a micrite matrix. These bioclastics are represented by biserial benthic foraminiferal tests, echinoids spines, algae and molluscan shells. In some beds in the regressive parts as describes later, the main foraminiferal tests are *Dictyoconus* sp. with micritization, and ferrugination. Other bioclastics exhibit a neomorphism. Non skeletal grains such as peloids are encountered in this facies.

Interpretation: The presence of benthic foraminifers, especially biserial tests indicate the lagoon lithofacies associations (Koehrer et al.2010). The existing of mud-supported texture and the disappearance of current witness refer to low energy in an open marine environment. The faunal assemblage points to low to moderate depth below normal wave base (Tucker and Wright, 1990). The abundance of *Dictyoconus* sp. In some beds indicates low energy shallow subtidal in inner platform (Tawfik et al. 2016).

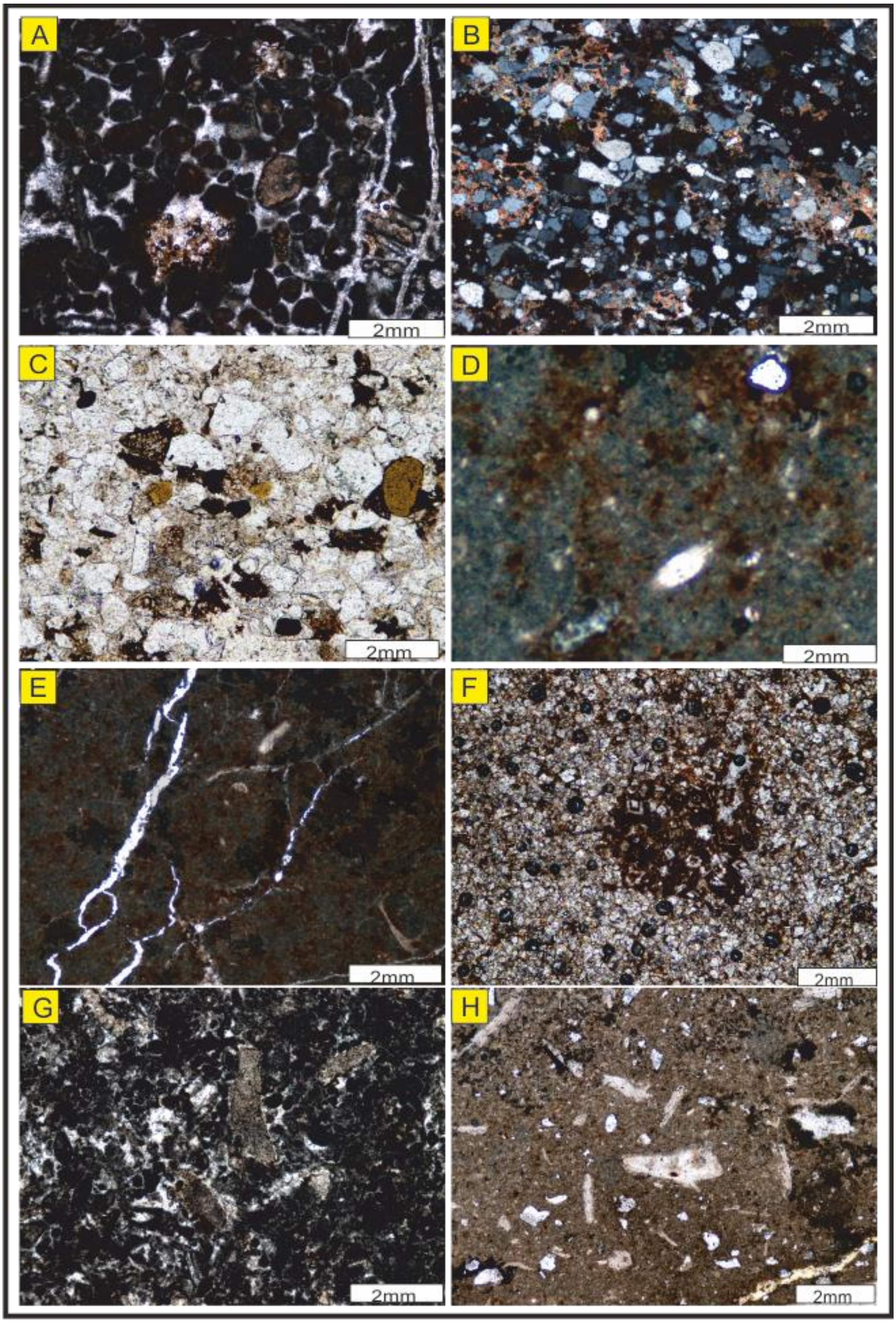

Fig. 3: Photomonographs of: A. Ferruginous ooidal pack- to grainstone consists of ooid grains, and peloids. B. Ferruginous quartz arenite dominated by quartz grains coated with ferruginous material and cemented by calcite. C. Green sands; composed of glauconite grains and other clasts. D. shale-mudstone with few bioclasts. E. Lime-mudstone with few bioclasts, and peloids. F. Ferruginous dolo mudstone consists mainly of dolomite rhombs. G. Bioclastic peloidal grainstone dominated by micritized peloids and bioclasts. H. Bioclastic bivalve shells wackestone that comprises bivalve shells and other bioclasts.

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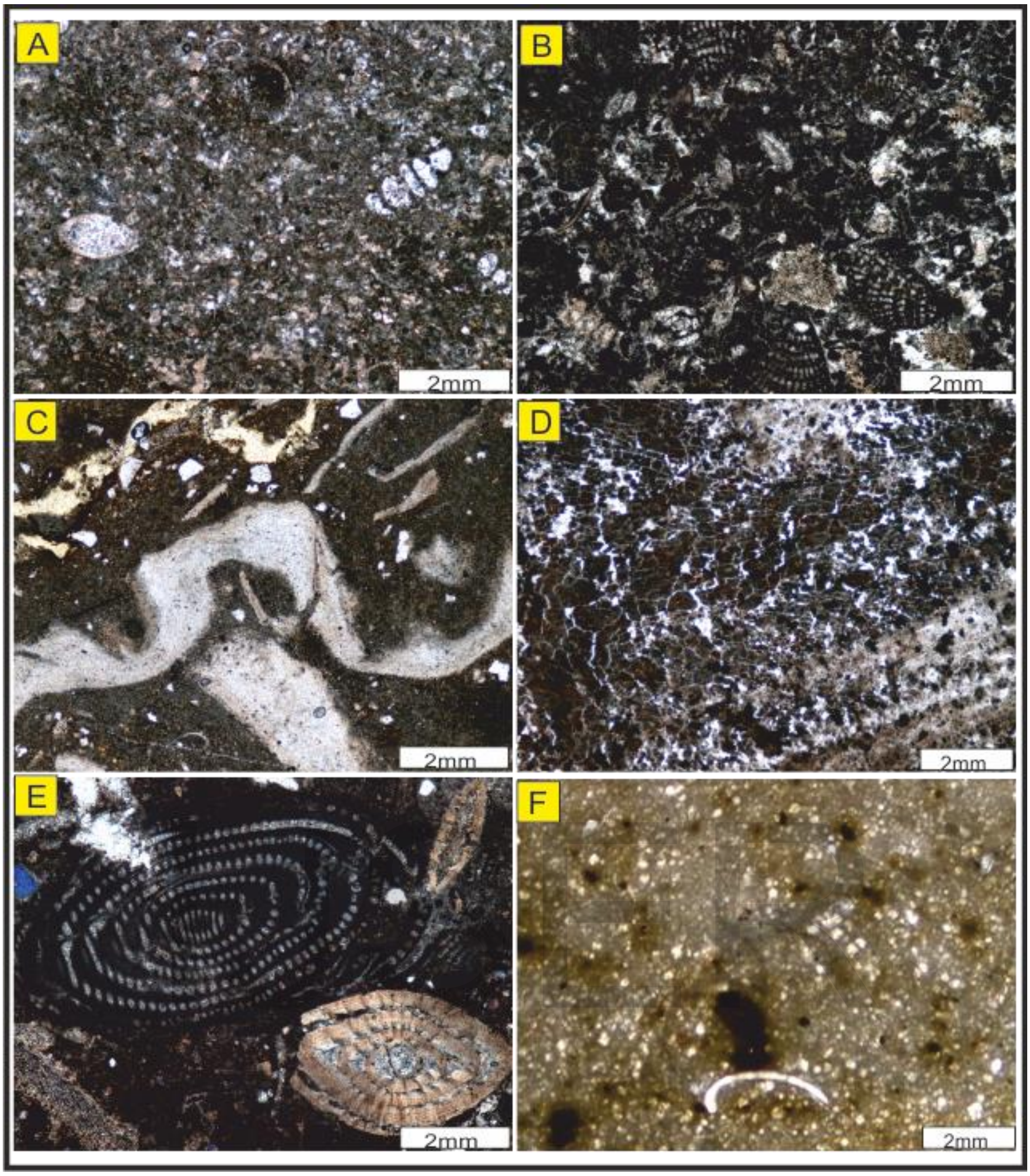

Fig. 4: Photomonographs of: A. Bioclastic froaminiferal wackestone consists mainly of biserial foraminifers and other bioclasts. **B.** Dictyoconus wackestone dominated by *Dictyoconus* sp. and other foraminifers. **C.** Skeletal Floatstone contains mainly bivalve shells **D.** Recrystallized foraminiferal peloid packstone that comprises rounded recrystallized foraminiferal tests and peloids. **E.** Alveolinid nummulite wacke- to floatstone consists mainly of alveolinid sp., *Nummulites* spp. and other foraminiferal grains. **F.** Bioclastic planktonic foraminiferal wackestone with main benthic foraminifers and planktonic foraminifers.

4. Middle subtidal lithofacies association

Skeletal Floatstone (Fig. 4c)***:*** The facies is recorded in the middle part of the lower and upper parts of the Southern Galala Formation. These decimeters to meter thick skeletal floatstone beds are grey to yellowish white limestone containing abundant bivalvian shells, undifferentiated foraminiferal tests and echinoids float in a muddy matrix. The grain size in these beds are rudite and the sorting is moderate to poor.

Interpretation: The muddy matrix, poor to moderate sorting of this facies, and the fossil assemblages indicate relatively low-energy setting in the open marine shallow subtidal setting. Insalaco et al. (2006). Abundant bivalve shells suggest low oxygenation and nutrient-rich waters (Gertsch et al., 2010).

Recrystallized foraminiferal peloid packstone (Fig. 4d): this facies is recorded in the middle lower part of the Southern Galala Formation. It contains abundant peloids, foraminifers, bivalve shells, micrite intraclasts and scarce ooids in a sparry matrix. Peloids are subangular to subrounded, moderately sorting and have been created through micritization of small bioclasts. The foraminiferal tests are recrystallized and show similar degree of sorting. Some coated grains are encountered in this facies.
Interpretation: The moderately sorting of peloids in the sparry matrix indicates the transition between an inner to middle or outer platform in the deep subtidal setting (Chatalov et al. 2015). The prevailing of micritization in the most grains indicate low energy setting in the subtidal zone.

5. **deep subtidal lithofacies association**

Alveolinid nummulite wacke- to floatstone (Fig. 4e): this facies is recorded overlain the sequence boundary between the Paleocene Southern Galala Formation and the Lower Eocene Wasit Formation. It consists mainly of yellowish white to white massive limestone with abundant medium sized Alveolina spp. and *Nummulites* spp. Other foraminiferal fauna such as *Somalina* sp., bivalve shells, echinoid spines are recorded in the mud matrix.
Interpretation: the combination between alveolina and *Nummulites* indicate open marine outer shelf in the subtidal zone (Moghaddam et al. 2002). The presence of mud matrix indicates a low energy in the middle to upper subtidal zone (Adabi et al. 2008)

Bioclastic planktonic foraminiferal wackestone (Fig. 4f): this facies is recorded only in the upper parts of the Maastrichtian under the SB 1. It consists of yellowish white limestone and chalky limestone which are mainly bioclastic mudstone and wackestone. The main components in this facies is bivalve shells, benthic foraminifers and planktonic foraminifers. Bioturbation is recorded in these beds.
Interpretation: the presence of benthic and planktonic in theses beds in the Hammam Faraoun area reflects the area between middle subtidal and deep subtidal or in the beginning area of the deep subtidal setting. The occurrence of fossiliferous mud- to wackestone indicates a low energy open marine conditions.

Depositional model (Fig. 5)
The 3-D depositional model of the examined formations platform is presented in (Fig. 5). The nature of the facies in this area is characterized by shallow tidal flat and subtidal rather than deep subtidal, although the upper Cretaceous and Paleocene successions in the most regions of Egypt were deep subtidal to basinal facies. This is related to the tectonic activities during that period which was responsible for uplifting this area during the Paleocene stage as discussed later. The studied upper part of the sudr Formation consists mainly of the transition zone between middle and deep subtidal zone. The sudr Formation rocks don't contain much planktonic foraminifers and it is dominated by muddy facies. The Paleocene rocks in the studied outcrop section represent the tidelites, intertidal, shallow and middle subtidal in the platform. Low energy restricted marine conditions are present in large parts of the succession. The studied section is composed mainly of ferruginous quartz grains with few glauconite grains, shales, skeletal grains such as bivalve shells, gastropods, echinoids and foraminifers and non-skeletal grains such as peloids, aggregates with limited occurrence of ooids. The upper part of the studied section consists mainly of foraminiferal limestone beds of Wasit Formation as discussed above. These beds contain nummulite and alveolinid which attributed to the general shallowing to deepening subtidal conditions.

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Sequence boundaries

Three sequence boundaries have been detected in the studied exposure (Fig. 6). These sequence boundaries have been recognized on the basis of field observation and thin section studies as the following:

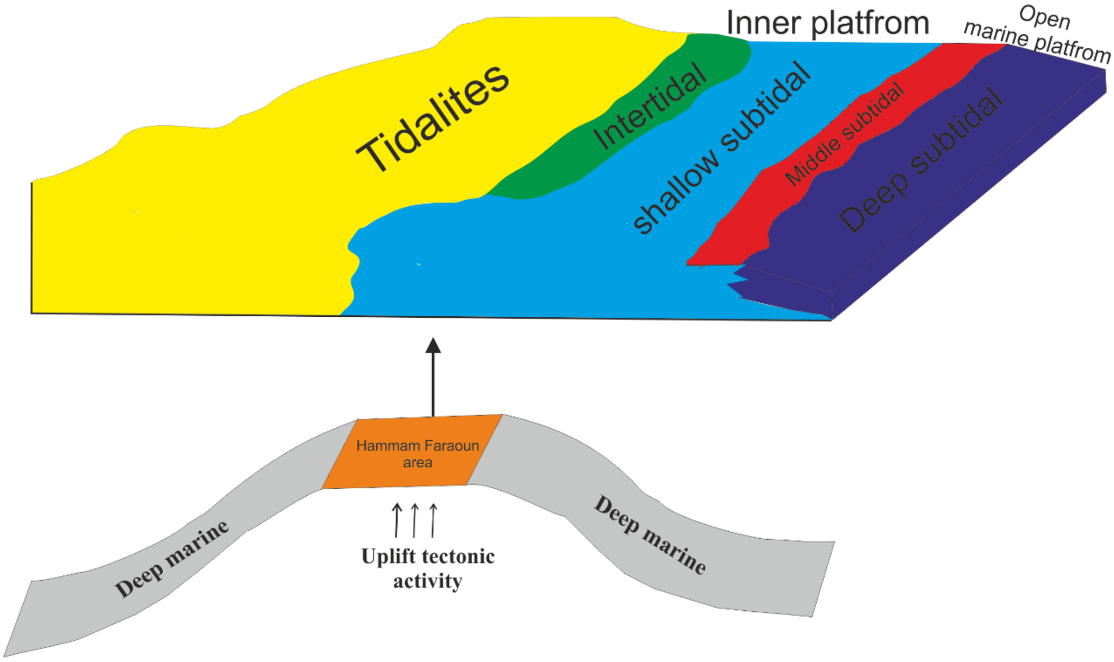

Fig.5. Depositional model of the studied formations lithofacies association from tidalites to deep subtidal in the Hammam Faraoun area.

1. **Sequence boundary 1 (SB 1):** It is represented by an obvious unconformity on the thin conglomerate ferruginous bed with concentrations between the Maastrichtian sudr Formation and the lower Paleocene southern Galala Formation (K/Pg boundary) (Fig. 6). This sequence boundary is noticed throughout the all Egyptian tertiary (Said 1990). The studied area as well as Sinai has been affected by the Syrian Arc System (Scheibner et al. 2003) which has been considered the main factor for the uplifting processes during this period (Farouk et al., 2014). According to Ayyat and Obaidalla (2013) the K/P boundary in Sinai and Eastern Desert is notarized by the obscurity of Late Maastrichtian and Early to Middle Danian. The tectonics may also responsible for the prolonged erosion and the rapid eustatic sea level fall during this period (Vail et al., 1984, Catuneanu et al. 2009). So the type of K/Pg unconformity is a type 1 sequence boundary.

2. **Sequence boundary 2 (SB 2):** SB 2 can be recognized in the beginning of the upper part of the Southern Galala and separated between Sequence 1 and Sequence 2 as discussed later. The boundary is placed at the ferruginous ooidal limestone bed (0.5-1m) on the top of sequence 1. This boundary is local in spite of the recording of this hiatus in dispersal areas in Egypt and neighboring countries (Farouk 2016). This SB 2 can be primarily linked to the sea level regression and secondly to the local tectonic activities which are related to remaining impact of the Syrian arc deformation.

3. **Sequence boundary 3 (SB 3):** This sequence boundary separated between the Paleocene upper Southern Galala Formation and the Lower Eocene Wasit Formation (P/E boundary). SB 3 is marked by a vertical facies change from the clastic rocks on the top of Southern Galala Formation to foraminiferal limestone in the lower part of the

Wasit Formation. This hiatus is documented in Egypt by many authors such as (Hewaidy and Strougo, 2001, Alegret and Ortiz, 2013, El-Dawy et al. 2016, Obaidalla et al. 2017). According to Zachos et al. (1993), this hiatus is related to the global warming event known as late Paleocene thermal maximum. On the other hand Moustafa and Khalil (1989) related this hiatus to the continuity of the Syrian Arc system activates in northern Egypt. As the SB 1, this sequence boundary is belonged to a type 1 sequence boundary.

Depositional sequences and system tracts

Based on field observations, facies analysis, and the arrangement of the lithofacies types and associations, two complete studied 3rd order sequences are described and interpreted in the Hammam Faraoun section (figs. 2, 6). The two sequences were examined over the SB 1, and each sequence contains one transgressive system tract (TST) and one highstand system tract (HST) bound by the maximum flooding surface (MFS).

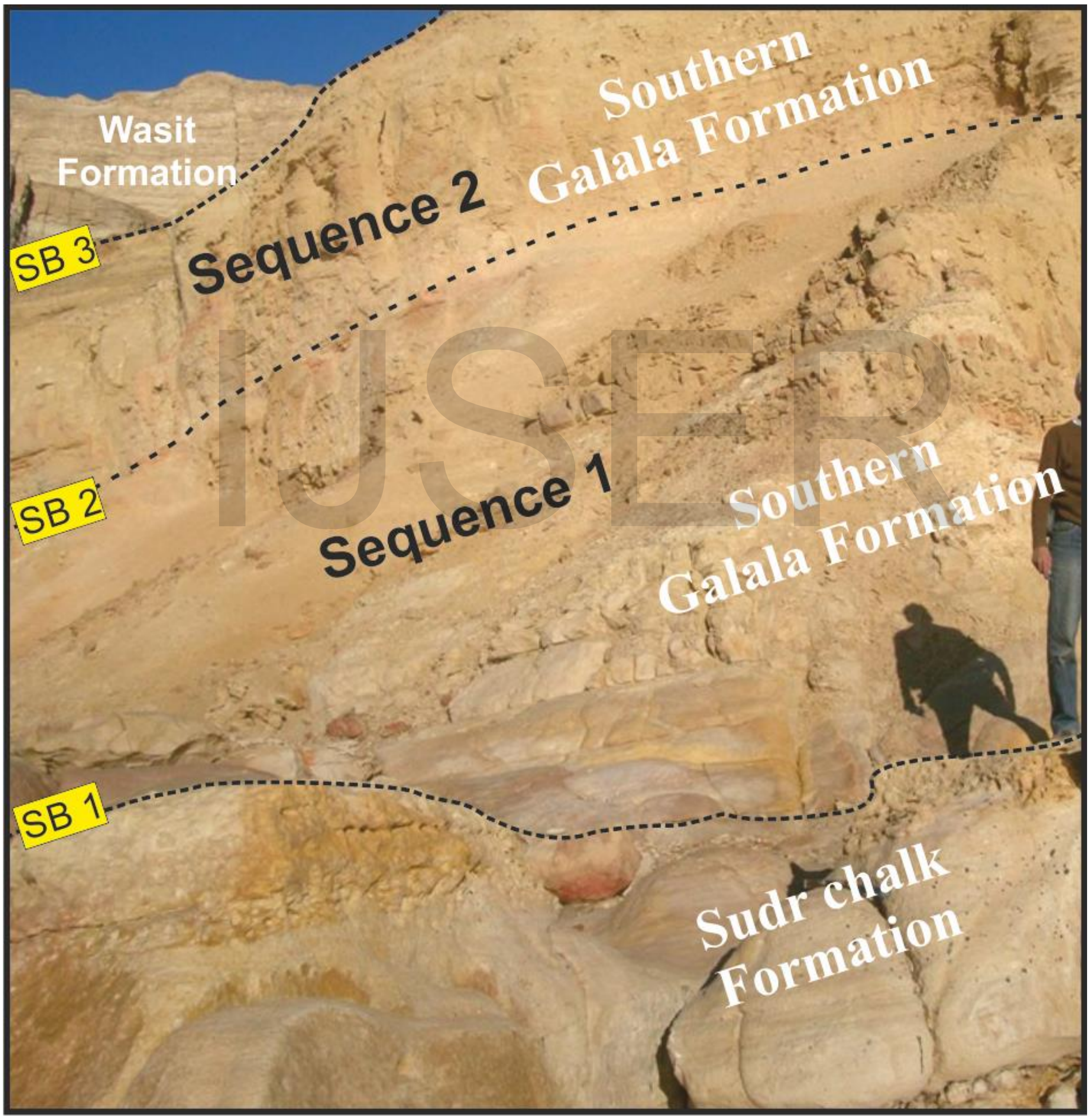

Fig. 6. The studied formations, sequences and sequence boundaries in the Hammam Faraoun area.

1. **Sequence 1**

Description: Sequence 1 (32 m) clarifies the intertidal and shallow subtidal deposition of the lower Southern Galala Formation. The base of this sequence is rested on the upper

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beds of the Sudr Formation which consist mainly of chalk and chalky limestone with benthic and planktonic foraminifers and other bioclastic such as echinoids. The lower beds (14 m) in the sequence 1 begin with repeated small cycles of reddish yellow sandstone, grey marl, and yellowish white, fractured, and moderately hard lime-mudstone rocks with rare fossils. The sandstone beds are calcareous, partly ferruginous, and glauconitic with few bivalvian shells. The lower beds are followed by bioclatic foraminiferal wackestone beds (3m) contain biserial foraminifers, molluscan shells, algae, peloids and echinoids. These wackestones are capped by recrystallized froaminiferal peloidal packstone (1m) with echinoids and bivalve shells. The upper part of the sequence 1 (14m) is massive and consists of ferruginous dolostone and shale beds with rare fossils in their lower beds which is followed by peloidal and *Dictyoconus* wackestones with gastropoda an bivalvian shells. The sequence is capped by reddish yellow ferruginous ooidal grainstone of 0.5-1m thickness with concretions.

Interpretation: The base of this sequence represents the sequence boundary (SB 1) between the middle to deep subtidal carbonate rocks in the lower portion and the intertidal marine marl, sandstone, and limemudstones in the upper portion. These rocks in the lower part of the sequence 1 indicate an intertidal related facies and could be explained as an initial TST. During the sea level rise, the change from proximal intertidal beds to distal foraminiferal and other bioclastic wackestone beds occurred and the MFS is represented on the middle to deep subtidal recrystallized foraminiferal peloidal packstone. The upper part, which is interpreted as a HST consists of dolostones, shales, and muddy facies and indicates a depositional shift toward the intertidal setting again during a sea-level fall. The ferruginous ooidal grainstone bed on the top of this section represents the SB 3 between Sequence 1 and Sequence 2.

2. **Sequence 2**: It is 22 m thick, and starts with 4m of greyish green marlstone beds. The lower part 8m thickness, consists mainly of wackestones and packstones with peloids, bivalve shells, foraminifers, echinoids and intraclasts or detrital particles. Peloids are originated from the mud which are moderately sorted, subangular to subrounded. Above these wackestone beds, there are 2m of yellowish white massive floatstone bed containing bivalve shells, foraminifers and algae. The upper 9 m are poorly to moderate sorted foraminiferal bivalvian wackestones, mudstones, glauconitic sandstones and shales. The upper most part of this sequence, about 1-2 m, consists mainly of ferruginous sandstone bed with rare fossils.

Interpretation: The marlstone in the lower part of this sequence indicates intertidal related facies that are interpreted as an initial TST. During sea level rise more distal shallow subtidal related facies types retrograded over the marlstone beds. The interval with the highest amount of bivalve debris and the high diversity of bioclastics represents middle to deep subtidal and can be interpreted as a MFS. The upper part of this sequence is interpreted as a HST; it consists of muddy facies and indicates a depositional shift again towards an intertidal setting. The ferruginous sandstone bed on the top of this sequence marks the sequence boundary (SB 3) between the Southern Galala Formation and overlaying foraminiferal limestone of the Wasit Formation.

Summary and conclusions

The Hammam Faraoun studied section in the eastern side of the Gulf of Suez is dominated by clastic and non-clastic deposits and the tectonic activities are mainly responsible for the configuration of the area during this period. Three rock units have been detected in the area: Maastrichtian Sudr Formation in the lower part, Paleocene Southern Galala in the middle part and Lower Eocene Wasit Formation in the upper part. 12 lithofacies types have been identified based on field observations and laboratory works. These lithofacies types were assembled into 5 lithofacies associations: peritidal, intertidal, shallow subtidal, middle subtidal and deep subtidal. The studied succession comprises two depositional sequences bounded by three sequence boundaries. SB 1 is related to the tectonic activities of the Syrian arc system and is identified on the ferruginous concretions at the top part of the Sudr

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Formation. It is marked by vertical facies changes between the middle and deep marine Sudr and the intertidal Southern Galala formations. SB 2 seems to be related to sea level regression and is detected in the ferruginous oolitic grainstone layer between the middle and the upper parts of the Southern Galala Formation. SB 3 exists between the Paleocene Southern Galala Formation and the Lower Eocene Wasit Formation. It is characterized by abrupt facies changes from intertidal clastic facies to middle and deep subtidal nummultic and alveolinid carbonate facies. Sequence 1 of the two studied depositional sequences was detected in the lower Southern Galala Formation rocks (Lower Paleocene). The TST of this sequence is represented by marlstone and sandstone in the lower part. The MFS is detected on the recrystallized foraminiferal peloidal packstone bed. The HST of this sequence is represented by shale and dolomite beds in the upper part. Sequence 2 was determined in the Upper Southern Galala Formation rocks (Upper Paleocene) where the marlstone and limestone beds in the lower part were interpreted as TST. During sea level rise, the bivalvian skeletal floatstone retrograde over the TST beds and was interpreted as a MFS. The clastic rocks in the upper part indicate shift towards intertidal conditions and therefore, interpreted as a HST.

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