



# Sequence stratigraphic framework of the Upper Eocene–Oligocene succession, northwest Birket Qarun, Fayum-Egypt

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## Abstract

The Upper Eocene–Oligocene sequence exposed northwest Birket Qarun; Fayum district covers two rock units, Qasr El-Sagha (Temple and Dir Abu Lifa members) and Gebel Qatrani formations were re-evaluated by sequence stratigraphy. Six depositional sequences were recognized based on facies geometry, and sedimentological aspects. The first sequence (Temple Member) was accumulated under marginal intertidal flat environment indicating highstand deposits. The second (the lower Dir Abu Lifa Member) displays a regressive sedimentary facies starting with progradational delta front environment reflecting lowstand deposits followed upward by a lagoonal environment indicating transgressive/highstand deposits. The third (the top of the Dir Abu Lifa Member) was accumulated under a low sinuosity stream reflecting lowstand deposits. The fourth which constitutes the topmost of Dir Abu Lifa Member initiating near-shore shallow marine points to transgressive sediments, followed upward by fluvial sediments reflecting highstand deposits. The fifth (the Lower of Gebel Qatrani Formation) accumulated as point-bar deposits demonstrating lowstand deposits. The last occupies the main of Gebel Qatrani Formation initiates with restricted riverine marking lowstand deposits, followed upward by several fining upward cycles that were accumulated in fluvial and flood plain conditions with evidence of tidal influence on sedimentation near its top denoting transgressive deposits. Several minor transgressive episodes accompanied by tidal influence on sedimentation are noticed near the top, which may reflect gradual subsidence of the Oligocene alluvial plain. The area is subjected to relative sea-level changes that show a similarity with the global sea level. The base-level fluctuations are mainly controlled by the regional tectonic setting.

**Keywords** Sequence stratigraphy · Systems tracts · Facies analysis · Depositional environments · Sea-level fluctuations

## Introduction and geologic setting

The geology of the Fayum province has attracted the attention of many geologists since the discovery of vertebrate fossils association by Dames (1883) from the strata exposed to the north and northwest of Birket Qarun. It is characterized by pronounced facies changes, distinct depositional variations, and sedimentation discontinuities owing to the interaction between relative fluctuations in sea level and tectonic events. Generally, the surface structural setting of the area is affected by several tectonic events initiated during

the early and late Paleozoic represented by regional uplifts (Said 1990).

The Fayum Basin was established during the events associated with the spread of tectonics and slip movements between the Afro / Arabian plates and Eurasia (Smith 1971; Guiraud et al. 2005) (Fig. 1). The basin was originally uplifted after a complex tectonic history and the development of deep structures of Syrian-arc activity, as early as Late Cretaceous, during which the basin was uplifting and subdivided to two main basins, namely the northern Tiba Basin and the southern Gindi Basin (Coleman 1981; El Zarka 1983). Since the Middle Eocene, the physiographic margins of Egypt, including the Faiyum basin, have been dominated by vertical movements, associating the gradual subsidence of the Mediterranean Sea and the Red Sea Rift (Sestini 1984). By the advent of the Late Eocene, a span marked by a continuous lowering of relative sea level, resulting in the progressive emergence and erosion of the

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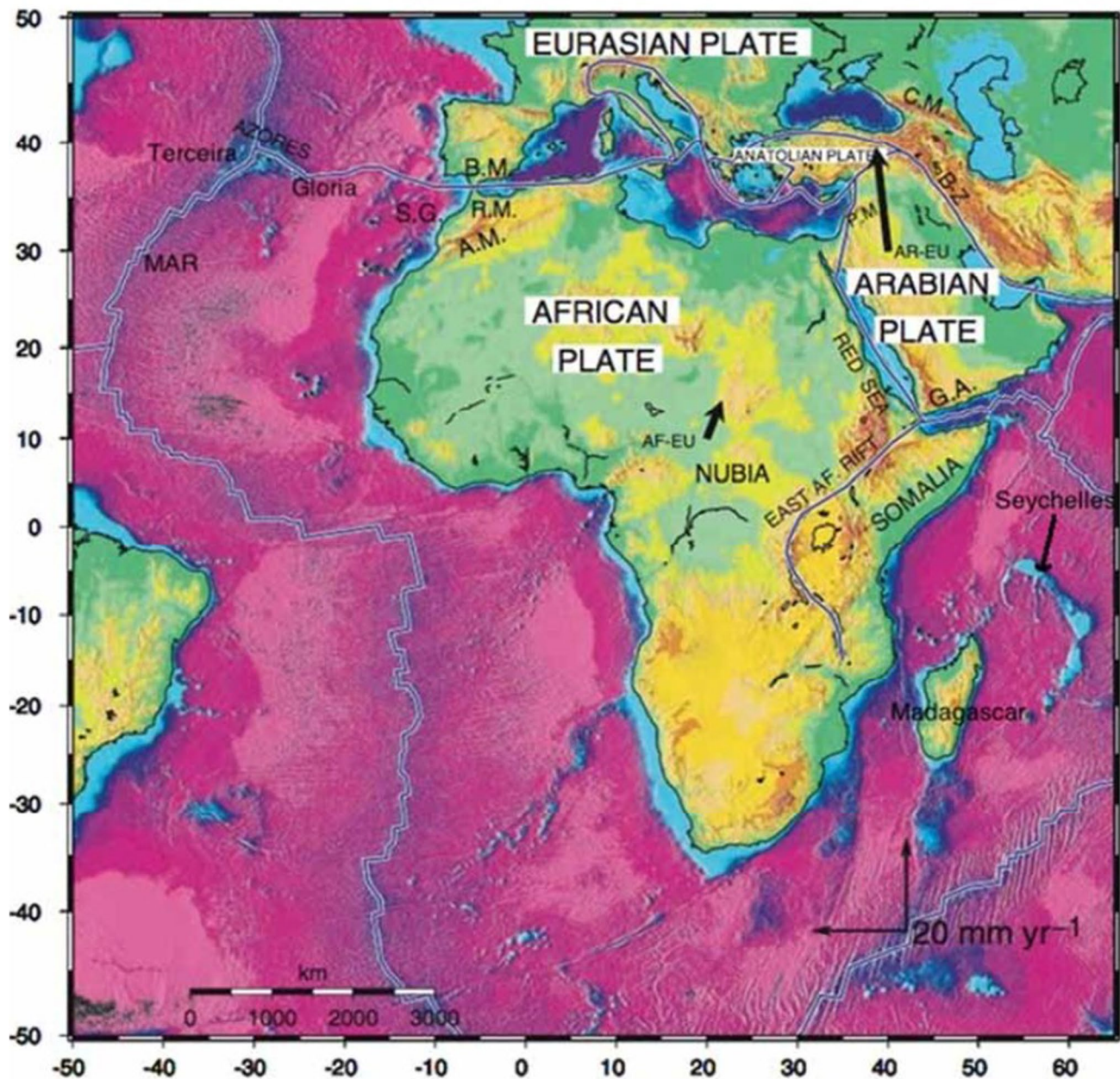


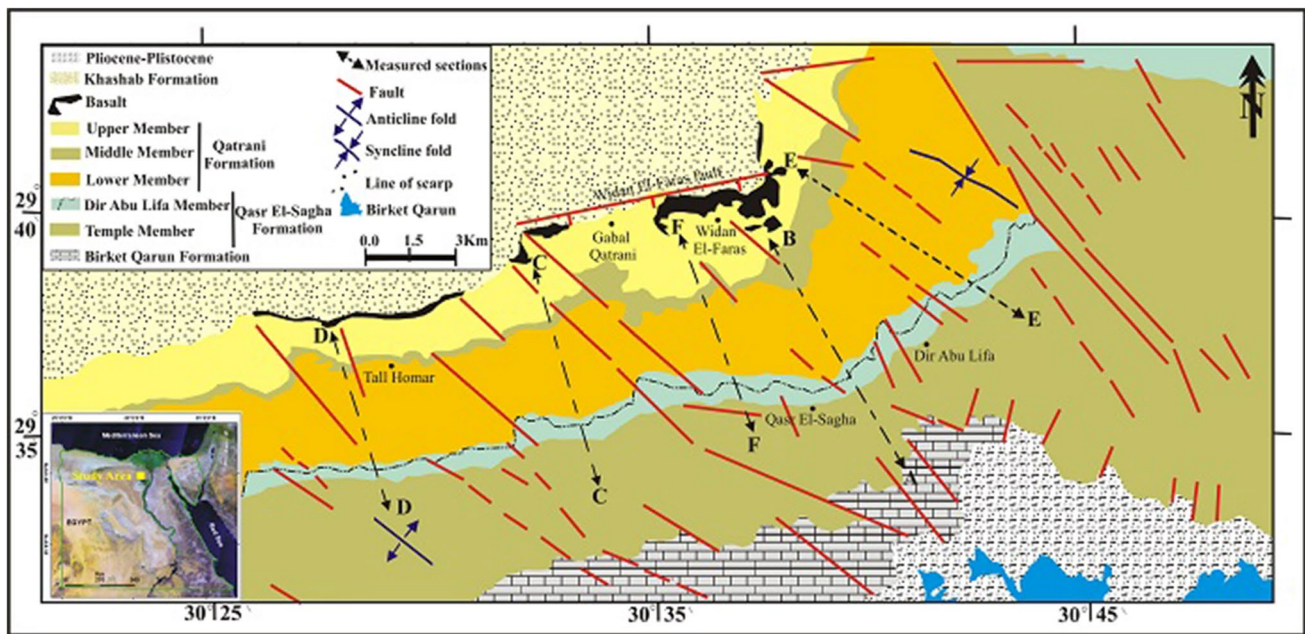
Fig. 1 Outline of the African/Arabian and Eurasian tectonic plates region (Modified after Mc Clusky et al. 2003)

pre-existing structural highs provided the Late Eocene basins of northern Egypt with clastic sediments (Salem 1976). Notably, the post-Eocene events have resulted in the accumulation of the distinct and variable Oligocene sediments that denoted a time of marked uplift, sea regression, continental sediments and volcanic activity (Cherif and El Afifi 1983; Said 1990).

Geologically, the studied area is distinguished by a relatively low-lying monotonous plain directly overlooking the northern corner of Birket Qarun Lake, mainly covered by Late Eocene clay interbedded with yellowish-brown

sandstone, calcareous in parts, together with marls and limestone. Followed to the north by a stratigraphical succession composed of carbonate and terrigenous sedimentary rocks forming a series of Questa escarpments (Fig. 2). Several sedimentological and stratigraphical workers were carried out on the geology of the Fayum area, western desert, Egypt, such as Beadnell (1901, 1905), Cuvillier (1930), Iskandar (1943), Said (1962, 1990), Ismail and Abdel-Kareem (1971), Salem (1976), Cherif and El-Afifi (1983), Bassiouni et al. (1984), Swedan (1986, 1992), Bown and Kraus (1988), Saber (1988), Wanas (1992), Gingerich (1993), Mahmoud





**Fig. 2** Geological map of the studied area northwest of Birket Qarun, Fayum Region, Egypt (Modified after EGPC/CONOCO 1987; Makram 1998; EL-Younsy et al. 1999)

(1993), Zalat (1995), Makram (1998), EL-Younsy et al. (1999), Ahmed (2001), Abdallah et al. (2002, 2003), Youssef et al. (2006), Abdel-Fattah et al. (2011), El-Fawal et al. (2013); Legler et al. (2013), Strougo et al. (2013) and King et al. (2014).

In spite of this, only some studies concerning sequence stratigraphy have been published in the studied area (Abdel-Fattah 2009; Peters et al. 2009; Abdel-Fattah et al. 2010; Abu El Ghar 2012) regarding the Upper Eocene deposits. For that reason, the current work aims to achieve a reasonable sequence stratigraphic framework and the sea-level fluctuations of the Upper Eocene–Oligocene succession exposed to the northwest of Birket Qarun (Fig. 2). Moreover, this can provide a basis for significant information to correlate the Faiyum sediments in a regional/interregional context.

## Methodology

Five stratigraphic sections of the Upper Eocene–Oligocene succession exposed to the north of Birket Qarun Lake, Fayum area, Egypt (latitudes 29° 31′–29° 42′ N and longitudes 30° 25′–30° 50′ E) were measured and sampled in detail during field studies for recognizing and interpreting the lithological aspects, facies varieties, faunal content and nature of surface contacts (Fig. 2).

About sixty thin sections representing the different studied rock units were prepared and subjected to different

laboratory analyses to study their depositional texture and microfacies assemblages following Pettijohn et al. (1973) for the siliciclastic sediments and Dunham (1962); Embry and Klovan (1972) for the carbonate rocks. The distribution of lithofacies as well as recognition of stratigraphic surfaces allowed the presentation of the data within a sequence stratigraphic framework.

The sequence stratigraphic analysis in the studied succession was carried out using detailed field diagnostics and sedimentological features represented by different types of primary structures followed by the terminology given by Vail et al. (1977, 1991), Van Wagoner et al. (1990), Emery and Myers (1996), Posamentier and Allen (1999) and Catuneanu et al. (2004, 2006, 2009).

## Stratigraphy

Generally, the exposed stratigraphic succession northwest of Birket Qarun ranges in age from Upper Eocene to Miocene and is covered unconformably by the Pliocene and Pleistocene sediments (Beadnell 1905; Cuvillier 1930; Said 1962; Bown and Kraus 1988; Makram 1998; EL-Younsy et al. 1999). The current investigation devoted on the Upper Eocene Qasr El-Sagha Formation, in addition to the unconformably overlain the Oligocene succession of Gebel Qatrani Formation (Figs. 3, 4).

Author Age	Beadnell (1905)	Cuviller (1930)	Iskandar (1943)	Said (1962)	Ismail & Abdel-kareem (1971)	Bassiouni et al. (1984)	Bown & Kraus (1988)	Said (1990)	Swedan (1992)	El-Younsy et al. (1999)	Abdel-Fattah et al. (2010)	Present work
Oligocene	Fluviomarine Series	Gebel Qatrani Beds	Gebel Qatrani Formation	Qatrani Formation	Gebel Qatrani Formation	El Qatrani Formation	Gebel Qatrani Formation	Gebel Qatrani Formation	Gebel Qatrani Formation	Gebel Qatrani Fm	Gebel Qatrani Formation	Gebel Qatrani Fm
										Upper Member		Middle Member
Late Eocene	Qasr El Sagha Series	Qasr El Sagha Series	Gehannam Formation	Qasr El Sagha Formation	Qasr El Sagha Formation	Qasr El Sagha Formation	Qasr El Sagha Fm	Qasr El Sagha Formation	Qasr El Sagha Formation	Qasr El Sagha Fm	Qasr El Sagha Fm	Qasr El Sagha Fm

Fig. 3 Lithostratigraphic correlation of the studied Upper Eocene—Oligocene rock units northwest of Birket Qarun, Fayum Region, Egypt

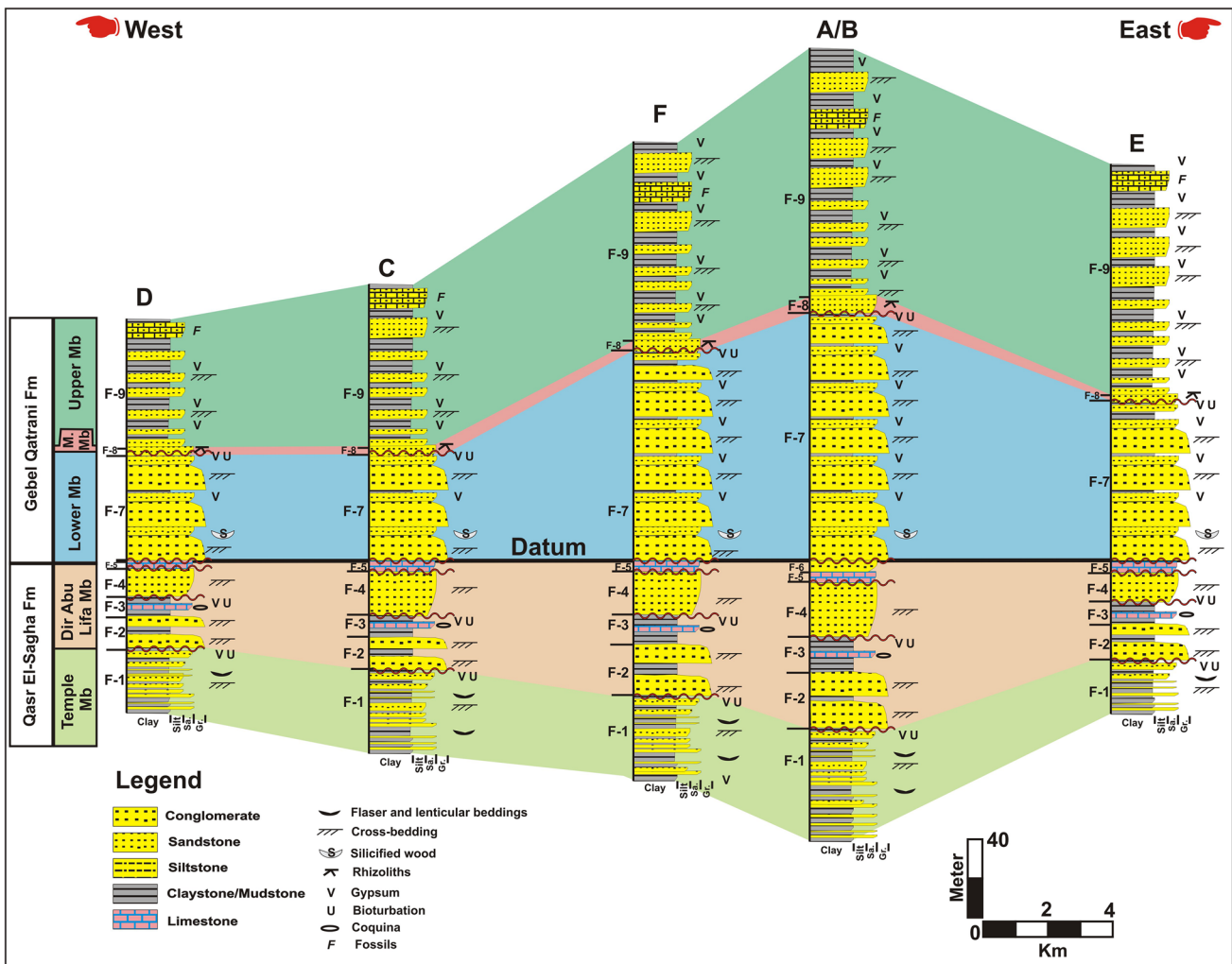


Fig. 4 Measured stratigraphic sections of the studied lithostratigraphic units at the studied area



## Qasr El-Sagha formation

The term Qasr El-Sagha Formation was introduced by Said (1962) to designate the enriched stratigraphic sequence of the Upper Eocene rocks. It is assigned to the Late Eocene age (Cuvillier 1930; Said 1962). Remarkable variations in the thickness of this formation exhibit a general decrease in both the eastern (about 70 m) and western (about 85 m) directions with an obvious increase (about 150 m) in between near the Qasr El-Sagha Temple of the study area (Figs. 4, 5a). The vertical variation in the lithological characters of the Qasr El-Sagha Formation permits its differentiation into two members; Temple Member at the base and Dir Abu Lifa at the top:

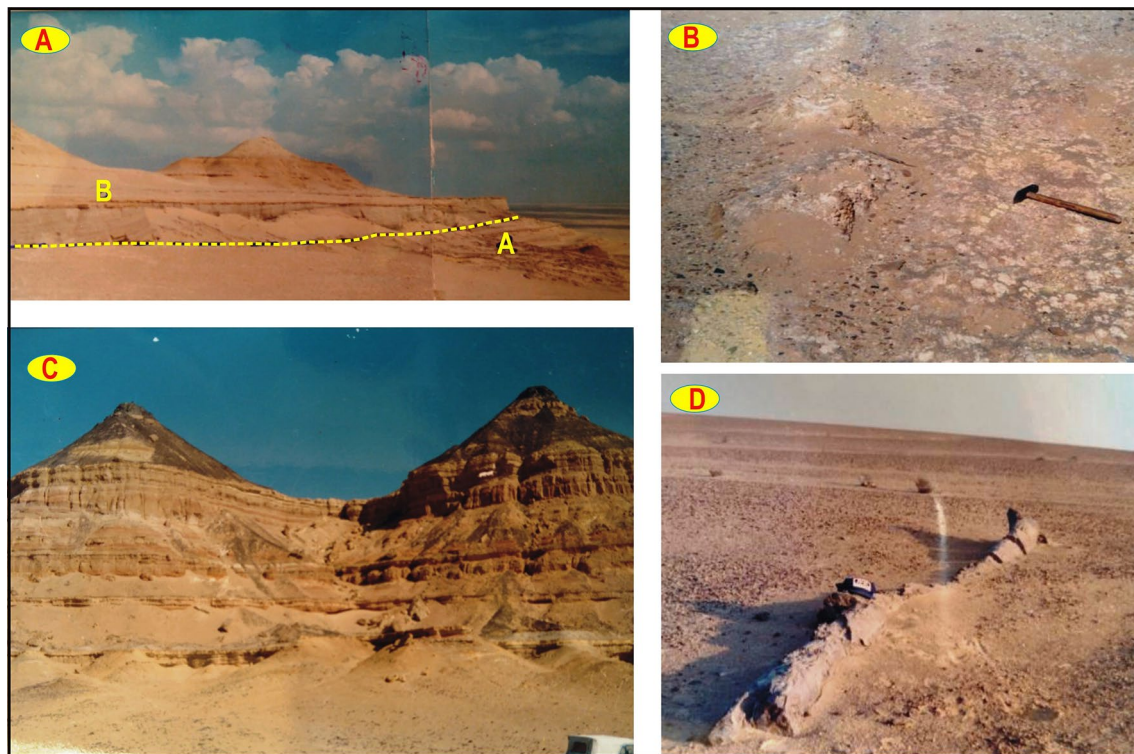
*The Temple Member* is representing the basal part of Qasr El-Sagha Formation. It overlies the Birket Qarun Formation with invisible (ambiguous) contact, whereas it underlies the Dir Abu Lifa Member with an irregular contact in the study area (Fig. 5a). Its thickness reaches about 80 m near the Temple of Qasr El-Sagha with a marked decrease towards both the eastern (35 m) and the western (25 m) parts of the study area (Fig. 4). The Temple Member is generally composed of thin layers of highly fossiliferous, glauconitic and limonitic arenaceous limestones (20–50 cm thick) and fine

rippled, cross-laminated and highly bioturbated siliceous sandstones (35–2.5 m thick) interbedded with thick laminated siltstones and gypsiferous sandy mudstones.

*The Dir Abu Lifa Member* overlies the Temple Member forming the upper part of the Qasr El-Sagha Formation. It is overlain by Gebel Qatrani Formation with an erosional contact. Its thickness ranges between about 50 m and 77 m with a remarkable thinning towards the northeast direction of the study area (Fig. 4). The Dir Abu Lifa Member is generally composed of sequential cycles of varicolored, cross-stratified sandstones, alternating with siltstone, silty claystone and shale and topped by a hard, yellow, fine-to-coarse sandy limestone bed (2–4 m), with many gradational to erosional surfaces in between (Fig. 5a). It is also characterized by the presence of fossils (*Carolia placunoides*), bioturbation, and poorly preserved silicified wood throughout this unit. Gypsum is also encountered and commonly is associated with barite nodules (Fig. 5b).

## Gebel Qatrani formation

The Gebel Qatrani Formation was termed by Said (1962) to define the terrigenous sedimentary sequence previously known as “fluvio-marine series” by Beadnell (1905) which



**Fig. 5** Field photographs showing; **a** General view of the Upper Eocene succession with the two members of the Qasr El-Sagha Formation, A Temple Member and B Dir Abu Lifa Member. **b** Gypsum and barite nodules characterizing Dir Abu Lifa Member. **c** The Upper

Member of Gebel Qatrani Formation, Oligocene, overlain by Widan el-Faras Basalt. **d** Silicified wood characterizing the Lower Member of Gebel Qatrani Formation

lies unconformably between the marine beds of the Upper Eocene Qasr El-Sagha Formation at the base and the basalt flow layers at the top (Figs. 3, 4, 5c). It is assigned to the Oligocene age (Beadnell 1905; Said 1962) due to the occurrence of some plant and vertebrate remains. The thickness of this formation reaches its maximum at Widan el-Faras locality (about 270 m), with a remarkable decrease in both the eastern (about 145 m) and western (about 118 m) parts in the study area (Fig. 4). Generally, the lithological architecture of this formation is characterized by siliciclastic diversities mainly of sandstone (about 80%), siltstone (10%), claystone (4%), and conglomerate (4%) with few bands of carbonate (2%) near its top part. Commonly, the beds of this formation in most parts of the study area are of lenticular shape. The sequence of the Gebel Qatrani Formation is divisible into Lower, Middle and Upper members (Makram 1998; El-Younsy et al. 1999).

*The Lower Member* occupies the basal part of the Gebel Qatrani Formation and rests unconformably on the underlying Dir Abu Lifa Member of the Qasr El-Sagha Formation with a marked erosional surface. It forms a flat bench at the top of the Qasr El-Sagha escarpment. Generally, the maximum thickness of this member reaches about 130 m in the Widan el-Faras area, with a remarkable decrease towards both the east (70 m) and the west (60 m) of the area (Fig. 4). Generally, it is mainly composed of yellow, white and red, coarse- to medium-grained sandstones, gravel and gravelly sandstone interbedded with fine-grained, varicolored sandstones, sandy mudstones, and mudstones forming several fining upward cycles, with lateral and vertical thickness variations. It is characterized by large-scale trough and tabular cross-stratification which grade upwards into sets of small-scale varieties. Abundant fragmented silicified wood (Fig. 5d), fossil vertebrate remains, rhizoliths, and animal bioturbation are also noticed.

*The Middle Member* occurs as massive and cliff-forming in its appearance and rests on the Lower Member of the Gebel Qatrani Formation with a marked erosional surface ranging from 4 to 10 m in thickness (Fig. 4). It is composed of well-indurated green, white and pale pink, medium- to coarse-grained (locally granular) sandstones, which grade upwards into green, fine- to medium-grained mostly cemented by calcium carbonate. Generally, it exhibits poorly preserved, less abundant large-scale trough cross-bedding with numerous rhizoliths at some localities. Chert pebbles, mud interclasts are locally common near its lower parts forming linear bands, while gypsum and barite nodules are met with near the top.

*The Upper Member* forms the main surface of Gebel Qatrani-Widan el-Faras scarp and overlies the Middle member of the Gebel Qatrani Formation with gradational contact while in some localities it exhibits a thin erosional features characterized by lenticular gravelly sandstone. It

attains a thickness of about 130 m in the Widan el-Faras area, with a remarkable decrease towards the east and south-west directions (Fig. 4). It is generally, made up of several cycles of coarse-grained and gravelly sandstones exhibits small- to large-scale trough and tabular cross-stratification, with muddy sandstones and sandy mudstones as well as a minor amount of greenish–grey shale intercalations. In some localities, the topmost part of this member is characterized by thin lenticular bodies (0.5–1.5 m thick) of pale green and buff sandy limestone and calcareous sandstone with numerous fragments of marine mollusks as well as gypsum and carbonate concretions. Fossil vertebrate, poorly preserved fossil wood, bioturbation, rhizoliths are also observed.

### Sequence stratigraphy

Sequence stratigraphy is often considered a relatively new science that developed in the 1970s from the science of seismic stratigraphy although it had its old roots about the origin of cyclic deposition and the interplay between the eustatic and tectonic controls on sea-level (Emery and Myers 1996). The sequence stratigraphy value is extremely useful as a predictive tool in analyzing clastic shoreline and shallow marine systems across a sedimentary basin (Gharecheloua et al. 2020). Applying sequence stratigraphic concepts to fluvial systems had less success since the role of relative fluctuations in sea level is less clear in creating the fluvial stratigraphic record (Posamentier and Vail 1988; Shanley 1991; Shanley and McCabe 1989, 1990, 1991, 1994; Westcott 1993). Rapid lateral facies changes together with lack of internal features in thick alluvial successions caused a problem in subdividing them into their time stratigraphic units. Thus, the application of sequence stratigraphy to fluvial systems is still in its infancy (Galloway 1981; Miall 1986, 1991; Boyd et al. 1989; Walker 1990; Posamentier and James 1993; Schumm 1993; Westcott 1993; Koss et al. 1994; Shanley and McCabe 1994), except the investigations made by Catuneanu et al. (2006), Peters et al. (2009), Abu El Ghar (2012) and Selim (2017).

Catuneanu et al. (2004) stated that the application of sequence stratigraphic principles can be successfully supposed even in the near absence of precise time lines, where the facies geometry, stacking patterns, and depositional models are well understood. In the present study, the exposed Upper Eocene–Oligocene succession, north-west Birket Qarun, Fayum region is generally represented by a thick sequence of siliciclastic rocks with an insignificant proportion of limestone intercalations. It is difficult to define an accurate precise timelines of the studied Upper Eocene–Oligocene sequence since it is barren of any diagnostic planktonic foraminifera. Thus, the sequence stratigraphic interpretation is constructed based on the identified



facies associations, as well as on the nature of the contacts that separate them to understand the evolution and the history of base-level changes. Six depositional sequences with their boundaries and systems tracts are recognized in the studied stratigraphic succession (Fig. 6; Table 1).

### Depositional sequence-1 (DS-1)

The first depositional sequence DS-1 constitutes the Upper Eocene Temple Member of the Qasr El-Sagha Formation. The base of this sequence is unexposed in the study area and its upper boundary is recognized by the presence of an irregular surface which appeared as channel scours at the top of the Temple Member marked an unconformable sequence boundary SB1 (Fig. 6). It is marked by a major accumulation of numerous mollusks shells forming a conglomeratic coquina layer (Fig. 7a). This sequence reaches its thickness about 60 m near the Temple of Qasr El-Sagha, whereas it displays a marked decrease in thickness towards both the eastern and the western parts of the studied area (Fig. 6).

In general, DS-1 is composed of thin glauconitic and limonitic arenaceous limestones and fine quartz sandstones

interbedded with thick laminated siltstones, claystone, and sandy mudstone.

The arenaceous limestone layers (20–50 cm thick) are highly fossiliferous with numerous molluscan shells (e.g. *Carolia placunoides* and *Exogyra frassi*) that are represented by pelecypodal-nummulitic wackestone microfacies (Fig. 8a). The sandstone beds (35 cm to 2.5 m thick) are markedly rippled and cross-laminated that are mainly represented by quartz wackes with subangular to subrounded, poorly sorted quartz-grains embedded in an argillaceous matrix (Fig. 8b). They are highly bioturbated, mainly cylindrical with irregular and random distributions, especially near their base. Flaser and lenticular bedding as well as planar and trough cross-stratifications are well developed in some horizons. Major accumulation of numerous mollusks shells forming lag deposits and conglomeratic coquina layers are also noted. The clay sediments of this facies may reflect low-energy water sedimentation whereas siltstones and sandstones reflect intermittent high-water agitation probably related to freshwater influx (Reineck and Singh 1973). On the bases of lithofacies, geometry and primary sedimentary structures, it is believed that the

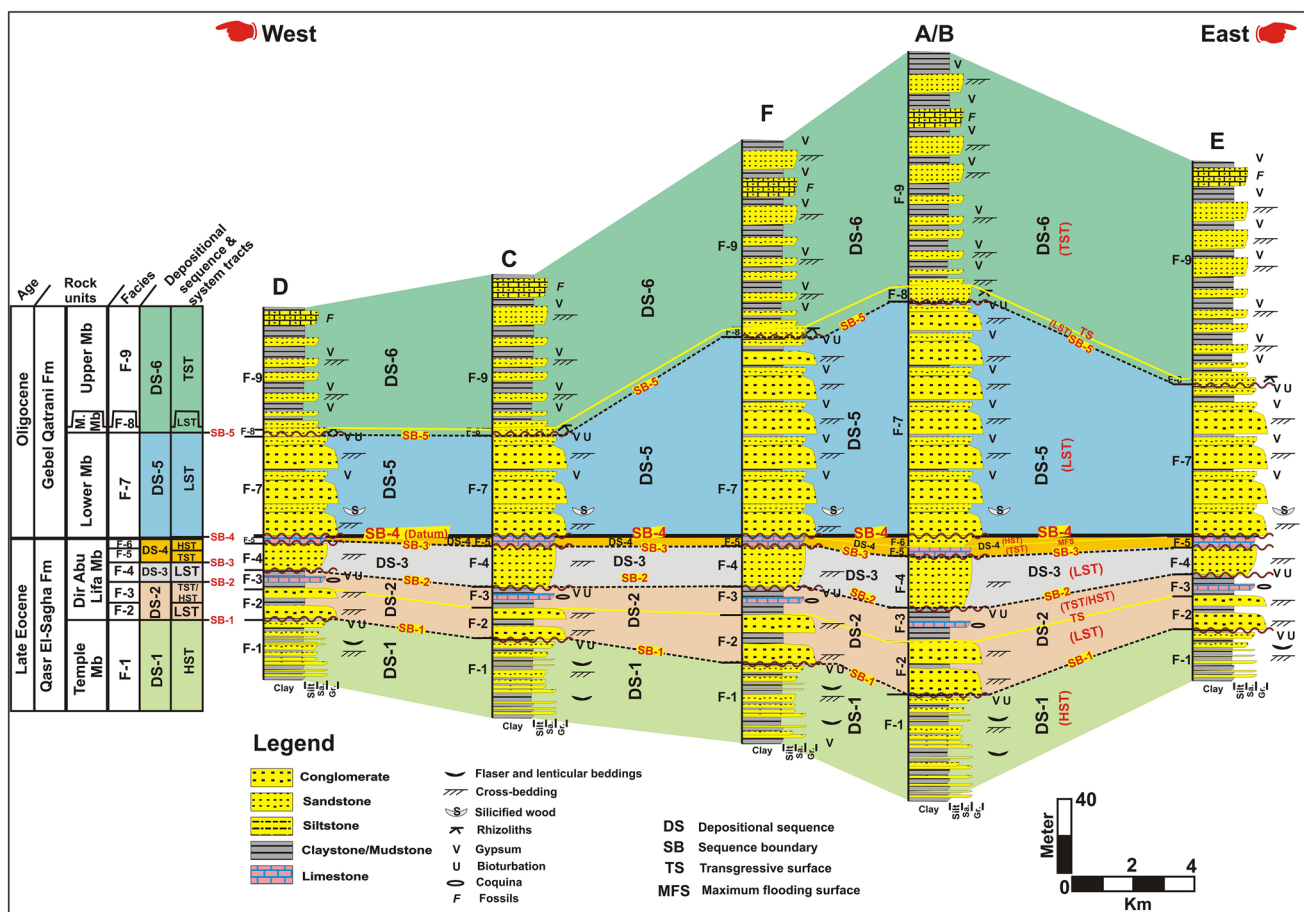


Fig. 6 Correlation of the studied Upper Eocene –Oligocene succession showing the depositional sequences and their surfaces, and systems tracts

**Table 1** Summary of the sedimentary facies, sequence stratigraphy and their distinctive lithological and sedimentological characteristics of the Upper Eocene–Oligocene succession, Northwest Birket Qarun, Fayum-Egypt

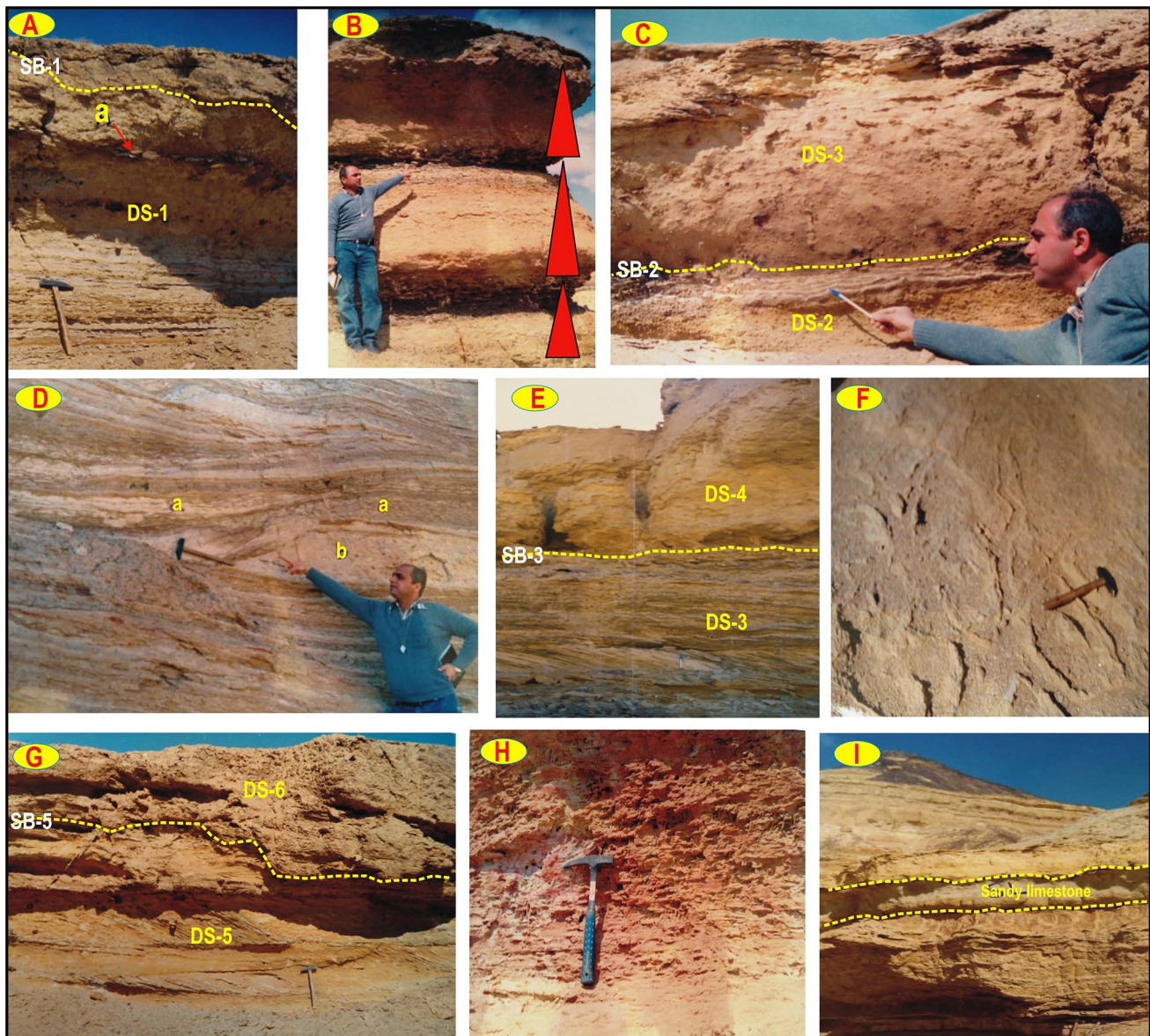
Rock units	Sedimentary facies	Lithological aspects and Sedimentological features	Dep sequences	Systems tracts
Gebel Qatrani Fm (~70–150 m)				
Upper Member	F-9 Flood plain	Several fining upward cycles start with large-scale trough and tabular cross-stratified coarse-grained and /or gravelly sandstones that gradually pass upward into small-scale trough and tabular cross-stratified medium to fine-grained sandstones and terminated by laminated green shale and mudstones	DS-6	TST
Middle Member	F-8 Marshes	Well-indurate green, medium to coarse-grained sandstones with chert pebbles and granular sandstone in its lower part, grades upward into green, fine to medium-grained sandstones with numerous rhizoliths at some localities and less abundant trough cross-bedding		LST
Lower Member	F-7 Point bar-meandering stream	Coarse to medium-grained sandstones, gravel and gravelly sandstone interbedded with fine -grained, varicolored sandstones, sandy mudstones and mudstones developing generally in several fining upward cycles	DS-5	LST
Qasr El-Sagha Fm (~118–270 m)				
Dir Abu Lifa Member	F-6 Fluvial	Fine to medium-grained quartz sandstones interbedded with sandy mudstones exhibiting fining upward cycles. Generally, it shows medium-scale trough cross-stratification at the base, ripple marks at the top	DS-4	HST
	F-5 Shallow marine	Fine to coarse sandy fossiliferous limestone facies, mainly foraminiferal wackestone, enriched with marine mollusks together with fragments of bones, silicified wood and bioturbated		TST
	F-4 Low sinuosity stream	Large-scale planar cross-bedded sandstones, interbedded with green sandy claystone and siltstones	DS-3	LST
	F-3 Lagoonal	Massive glauconitic siltstone, silty sandstone, green shale and it terminates with massive sandstone at the top. Few fossils, such as <i>Carolia</i> and <i>Exogyra</i> , with fragments of molluscan shells, fossil wood with iron nodules are observed	DS-2	TST/ HST
	F-2 Progradational delta front	Sets of cross-stratified, pale yellow sandstones interlaminated with pale yellowish-brown and dark grey siltstone, silty claystone, and shale which exhibit fining upward cycles		LST
Temple Member	F-1 Intertidal flat	Fine rippled, cross-laminated and highly bioturbated sandstones interbedded with thick laminated siltstones, claystone, and sandy mudstone. Flaser and lenticular bedding as well as planar and trough cross-stratifications are well developed in some horizons	DS-1	HST

facies association constituting this depositional sequence has accumulated under a marginal, intertidal flat (F-1) environment (Reineck and Singh 1973; Bown and Kraus 1988; El-Younsy et al. 1999). This set is assigned to the highstand systems tract (HST). It consists of several shallowing-upward parasequence (cycles), each of which consists of sandstone beds at the base and claystone beds at the top (Fig. 7b).

### Depositional sequence-2 (DS-2)

The second depositional sequence DS-2 coincides with the Upper Eocene Dir Abu Lifa Member (lower part) of the Qasr El-Sagha Formation. This sequence is delimited at its base by the previous remarkable unconformable sequence boundary SB1 and terminated by the occurrence of an erosional surface with fragmented iron nodules (up to 10–30 cm)





**Fig. 7** Field photographs showing the depositional sequence diagnostics including; **a** Sequence boundary SB1 marked by an irregular surface with channel scours at the top of the Temple Member. Note the major accumulation of numerous mollusks shells forming conglomeratic coquina layer (**a**). **b** Several shallowing- upward cycles, each one consists of sandstone beds at the base and claystone beds at the top, characterizing the highstand systems tract (HST) at DS-1. **c** Sequence boundary SB2 marked by an erosional surface with fragmented iron nodules. **d** Superimposed channel deposits characterizing the progradational delta front (F-2), characterizing the lowstand systems tract (LST) at DS-2. Note the ripple cross lamination (**a**) and sand dune (**b**). **e** An unconformable sequence boundary SB3 marked

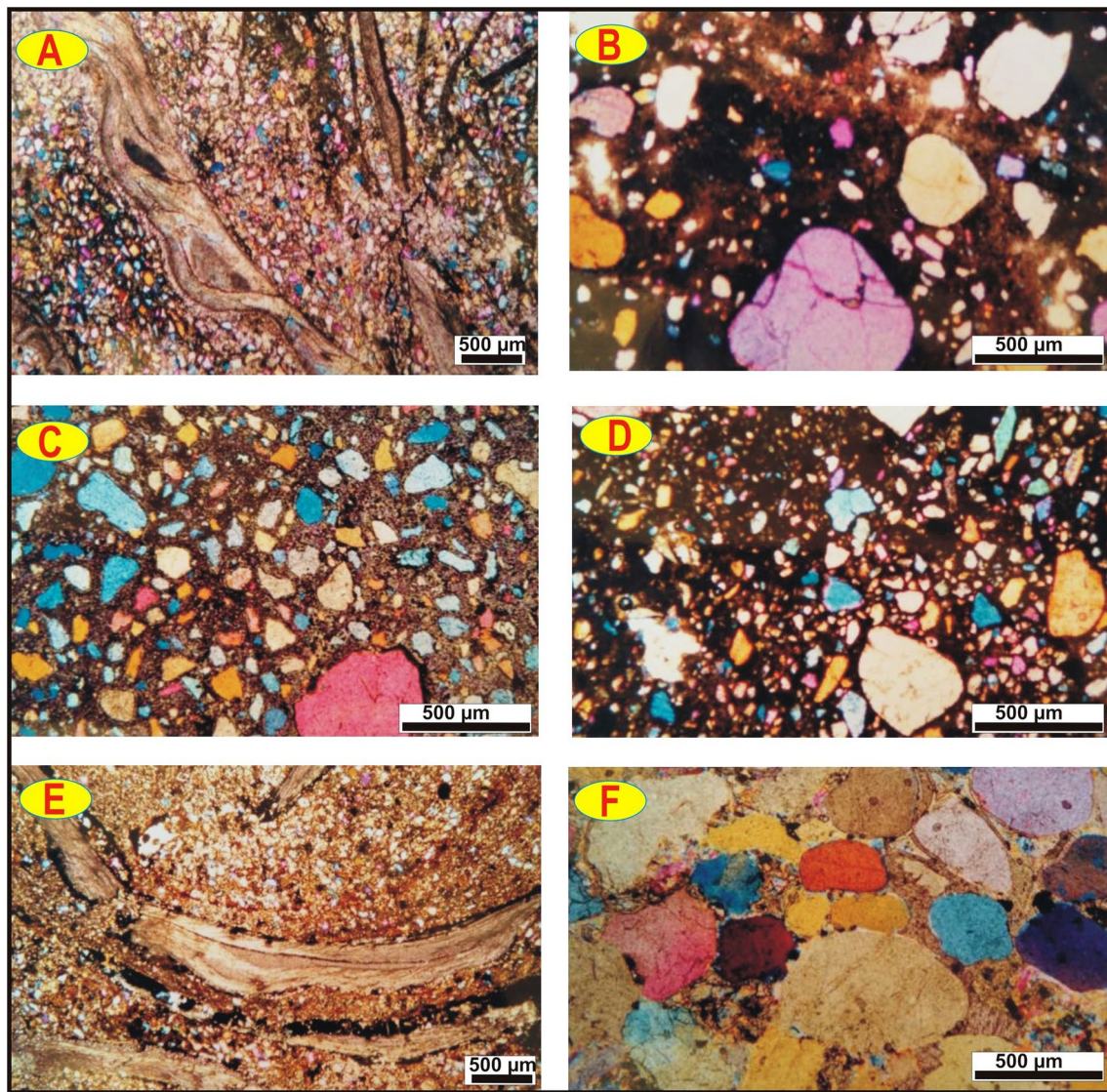
by an erosional contact within Dir Abu Lifa Member. **f** Bioturbation (inclined and the horizontal) characterizing the upper surface of the sandy limestone of near-shore marine facies (F-5), characterizing the transgressive systems tract (TST) at DS-4. **g** Sequence boundary SB5 marked by an irregular surface separating DS-5 (the Lower Member of Gebel Qatrani Formation below) from the DS-6 (Middle Member) at top. **h** Rhizoliths in the point-bar-meandering stream facies (F-7), characterizing the lowstand systems tract (LST) at DS-5. **i** Sandy limestone band intercalating near the top of the Upper Member of Gebel Qatrani Formation denoting the transgressive systems tract (F-9 of DS-6)

within Dir Abu Lifa Member, marking an unconformable sequence boundary SB2 (Figs. 6, 7c).

This sequence comprises two distinct sedimentary facies. The lower facies (F-2) initiates at the basal part of the Dir Abu-Lifa Member by major and thick sets of cross-stratified,

pale yellow sandstones interlaminated with pale yellowish–brown and dark grey siltstone, silty claystone, and shale which exhibit fining upward cycles. The thickness of this facies reaches up to 30 m near Qasr El-Sagha Temple whereas it thins out towards both the eastern and the





**Fig. 8** Photomicrographs showing the sedimentological features within the depositional sequences including; **a** Pelecypodal calcareous fine sandstone (F1), within Temple Member (F-1 of HST within DS-1, XPL). **b** Quartz graywacke showing poorly sorted subangular to subrounded quartz grains in lime-mud matrix within Temple Member (F-1 of HST within DS-1, XPL). **c** Argillaceous quartz graywacke of the Lower of Gebel Qatrani Formation showing angular to sub-angular quartz grains embedded in an argillaceous matrix

(F-7 of LST within DS-5, XPL). **d** Ferruginated quartz graywacke of the Middle of Gebel Qatrani Formation showing poorly sorted quartz grains embedded in a ferruginated lime-mud matrix (F-8 of LST within DS-6, XPL). **e** Fossiliferous calcareous fine sandstone, characterized the thin lenticular bodies near the top of TST within DS-6, XPL. **f** Quartz arenite showing poorly sorted subangular to subrounded quartz grains (F-9 of DS-6, XPL)

western parts of the studied area (Fig. 6). The sandstones are mainly sublithic arenite with angular to subrounded, moderately sorted grains, embedded in muddy matrix. Large-scale planar cross-stratification more than 3 m thick (giant cross-bedding) is common with smaller intrasets of medium- and small-scale troughs and tabular cross-stratification (20–90 cm thick) on the foresets of the giant cross-bedding. Ripple marks are also characterizing some interlaminated siltstone horizons. Fossils are rare in this facies. However, *Carolia* valves, pieces of fossil wood and plant remains are

found locally. Vertical and inclined burrows as well as rhizoliths are common, especially near the top. Several superimposed channel deposits are also well developed. Numerous sand-bars are also developed as elongated sand bodies or as bar finger sand (Fig. 7d). This facies with its features is, therefore, believed to have accumulated under a progradation delta front subenvironment, with distributary channels and bar finger sand bodies (Reineck and Singh 1973; Davis 1983; Galloway and Hobday 1996; EL-Younsy et al. 1999) reflecting a lowstand systems tract (LST), which is bounded



below by the sequence boundary (SB1) and above by a significant transgressive surface (TS), points to the beginning of sea-level rise during the late Eocene at the studied area (Fig. 6).

Upwards, it changes into massive sandy gypsum, glauconitic siltstone, silty sandstone, green shale and it terminates with massive sandstone at the top. The sandstones are mainly of quartz wackes, with subangular to subrounded grains forming the above facies (F-3). Few fossils, such as *Carolia* and *Exogyra*, with fragments of molluscan shells, fossil wood with iron nodules are observed forming a conglomeratic coquina band (10–15 cm thick) near the top of this facies. Few ripple marks and poorly developed mud cracks, as well as poorly preserved, vertical, and inclined branched burrows are abundant especially in the glauconitic green siltstone beds. The characteristic features of this facies (F-3) designate their accretion on low-energy marginal system as a tidal flat lagoonal environment (Reineck and Singh 1973; EL-Younsy et al. 1999). This denotes the transgressive/highstand systems tracts (TST/HST) consequently it is difficult to delineate the maximum flooding surface (MFS) separating between them (Fig. 6).

### Depositional sequence-3 (DS-3)

The third depositional sequence DS-3 comprises the Upper Eocene succession at the top of the Dir Abu Lifa Member of the Qasr El-Sagha Formation ranging in its thickness from 19 to 21 m. It is demarcated at its base by the preceding remarkable unconformable sequence boundary SB2 and ended by the occurrence of an erosional contact with an abrupt facies changes within Dir Abu Lifa Member, marking an unconformable sequence boundary SB3 (Figs. 6, 7e).

This sequence starts with large-scale planar cross-bedded sandstones, interbedded with green sandy claystone and siltstones (F-4). Generally, the sequence is distinct at its base by erosional surface exhibiting thin, planar cross-bedded sandstone with fragmented iron nodules (10–30 cm across) and silicified, limonitized fossil wood and rhizoliths beneath the boundaries of some sets. This points to their accumulation under a low sinuosity stream system of fluvial environment (Moody-Stuart 1966; Reineck and Singh 1973; Galloway and Hobday 1996; EL-Younsy et al. 1999) reflecting a lowstand systems tract (LST).

### Depositional sequence-4 (DS-4)

The fourth depositional sequence DS-4 constitutes the Upper Eocene at the topmost parts of Dir Abu Lifa Member of the Qasr El-Sagha Formation attaining a thickness up to 5 to 11 m. It is delineated at its base by the previous unconformable sequence boundary SB3, and ended at its top with the appearance of an erosional contact, separating the

Eocene Qasr El-Sagha Formation from the overlying Oligocene Gebel Qatrani Formation, marking an unconformable sequence boundary SB4 (Fig. 6).

This sequence starts with hard, yellow fine to coarse sandy fossiliferous limestone facies (F-5), mainly foraminiferal wackestone (~ 2–4 m thick), enriched with marine mollusks together with fragments of bones, silicified wood and bioturbated (inclined and the horizontal) near its top (Fig. 7f) pointing their accumulation in a near-shore shallow marine environment (Reineck and Singh 1973; Davis 1983, 1992; Galloway and Hobday 1996; EL-Younsy et al. 1999). These features point to the transgressive systems tract (TST) sediments. The lowstand deposits are lack in this sequence owing to the combining surface of both the transgressive surface (TS) and the sequence boundary SB3. This erosive surface (SB3) with its demarcated features reflects wave and tidal ravinement accompanying the beginning of the transgressive facies during the latest Eocene marine invasion across the studied area.

This facies is locally overlain at Widan el-Faras area (section A/B) by fine- to medium-grained quartz sandstones interbedded with sandy mudstones (~ 3–7 m thick) exhibiting fining upward cycles facies (F-6). Generally, it shows medium-scale trough cross-stratification at the base, ripple marks at the top as well as rhizoliths and mud drops pointing to their accumulation under fluvial environment (Reineck and Singh 1973; Davis 1992; Galloway and Hobday 1996 and EL-Younsy et al. 1999). These features reflect the highstand systems tract (HST). Since, this facies is not well represented throughout the study area that was attributed to its removal from other parts of the area. This may be due to the subsequent erosion of the active channels coupled with the local tectonic effect that prevailed during the Oligocene time (Fig. 6).

### Depositional sequence-5 (DS-5)

The fifth depositional sequence DS-5 comprises the Oligocene succession of the Lower Member of Gebel Qatrani Formation. It achieves a maximum thickness of about 130 m in the Widan el-Faras area where it generally decreases towards both the east and the west of the area 60 m (Fig. 6). This sequence is delimited at its base by the previous described unconformable sequence boundary SB4, and terminated by the occurrence of an irregular surface separating the Lower Member of Gebel Qatrani Formation below from the Middle Member at the top, delineating an unconformable sequence boundary SB5 (Fig. 7g).

This sequence (DS-5) is mainly composed of coarse- to medium-grained sandstones, gravel and gravelly sandstone interbedded with fine-grained, varicolored sandstones, sandy mudstones and mudstones developing generally in several fining upward cycles (F-7), with marked lateral and

vertical thickness variations. Each cycle starts with gravelly, sometimes pebbly sandstones (5–15 m thick) exhibiting an erosional contact with the underlying one and showing large-scale trough and tabular cross-stratification, mostly with large silicified tree trunks accumulation, rhizoliths, burrows and in some cases showing reworked limonitic nodules. Gradually grade upward into small-scale trough and tabular cross-stratified coarse- to medium-grained sandstones and terminated with fine sandstones, sandy mudstones and / or mudstones, rich in rhizoliths (Fig. 7h). The sandstones are mainly quartz wackes with subangular to moderately rounded, poorly sorted quartz grains (Fig. 8c). Accordingly, this facies (F-7), seem to accumulate as point-bar deposits in several distinct meandering streams (Mc Gowen and Garner 1970; Davis 1983, 1992; El-Younsy et al. 1999) demonstrating the lowstand systems tract (LST).

### Depositional sequence-6 (DS-6)

The sixth depositional sequence DS-6 which represents the uppermost sequence in the studied stratigraphic sections (~ 140 m maximum thick) occupies both the middle Member (~ 4–10 m thick) and the Upper Member (~ 130 m maximum thick) of the Oligocene Gebel Qatrani Formation (Fig. 6). This sequence is delineated at its base by the sequence boundary SB5 (Fig. 7g) while its upper limit is not recognized. This sequence (DS-6) comprises two distinct sedimentary facies (F-8 and F-9).

The lower facies (F-8) constructs the Middle member of the Gebel Qatrani Formation all over the study area (ranges from 4 to 10 m thick). It initiates with a marked erosional surface and generally is composed of well-indurate green, medium- to coarse-grained sandstones, mostly cemented by calcium carbonate with chert pebbles and granular sandstone in its lower part. It grades upward into green, fine- to medium-grained sandstones with numerous rhizoliths at some localities and less abundant trough cross-bedding. The sandstones are mainly quartz wacke characterized by poorly sorted quartz grains embedded in the lime-mud matrix (Fig. 8d). Also, abundant gypsum, as well as barite nodules, are observed near its top. The characteristic features of this facies points to that these sediments were accumulated in mangrove swamps overlain by channel sandstone. Thus, this facies suggests stream sedimentation in swamps at a coastal plain (Davis 1992; El-Younsy et al. 1999) marking a lowstand systems tract. It is bounded above by a significant transgressive surface (TS), which points to the beginning of base-level rise during the Oligocene time at the studied area.

The preceding facies (F-8) is gradually overlain by varicolored, gravelly sandstones and sandy mudstones with a minor amount of greenish-grey shale facies (F-9), which occupies the upper part of the Gebel Qatrani Formation all over the study area. It is well represented at Widan el-Faras

area (~ 140 m thick) but generally decreases towards the west and the east directions (Fig. 6). This facies discloses several fining upward sedimentation cycles in a regular pattern; each single cycle starts with large-scale trough and tabular cross-stratified coarse-grained and /or gravelly sandstones that gradually pass upward into small-scale trough and tabular cross-stratified medium- to fine-grained sandstones and terminated by laminated green shale and mudstones. The topmost part of this facies, in some localities, exhibits thin lenticular bodies (0.5 and 1.5 m thick) of pale green and buff sandy limestone and calcareous sandstone with numerous fragments of marine mollusks (Figs. 7i, 8e). The sandstones are represented by Quartz arenite and litharenite with subangular to subrounded, poorly sorted quartz grains embedded in a lime-mud matrix (Fig. 8f). On the bases of the aforesaid attributes, these facies have probably accumulated in a meandering fluvial system terminated by overbank, levee and flood plain conditions with evidence of a tidal influence on stream sedimentation near the top (Allen 1965; Davis 1992; Mader 1985; Davis 1992; Gallogway and Hobday 1996; El-Younsy et al. 1999) denoting the transgressive systems tract (TST).

### Sea-level changes and discussion

The construction of a sedimentary succession is dependent on the changes in relative sea-level and sediment supply. Sea-level changes are either attributed to true eustatic sea-level variation (Vail et al. 1991) or to the changing morphology of the basin due to tectonics (Cloetingh 1988).

It is worth noting that northern Egypt was characterized by a passive margin dominated by the carbonate deposition during the Eocene (El-Younsy et al. 2015, 2017; Obaidalla et al. 2017). By the early Oligocene, a major eustatic sea-level falls due to the climatic cooling that subsequently followed by heavily incision, carving, and karstification of the Eocene carbonates through the development of a fluvial system in northwest of Birket Qarun, Fayum province (Dolson et al. 2005).

Based on field observations, detailed and integrated investigations of the facies association, primary sedimentary structures and the depositional environments, the sequence stratigraphic interpretation is constructed to understand the evolution and the history of base-level changes. Six depositional sequences (DS-1, DS-2, DS-3, DS-4, DS-5, and DS-6) with their associated surfaces and systems tracts are recognized in the studied Upper Eocene and Oligocene stratigraphic succession, northwest of Birket Qarun, Fayum province are postulated. A distinct history for each studied depositional sequence is clearly noticed from the sea-level fluctuation curves deduced from the sedimentary facies

analysis in the studied succession (Fig. 9), compared with the global sea-level curve given by Haq et al. (1987).

The Upper Eocene sedimentation conditions northwest Birket Qarun is differentiated into four depositional sequences (DS-1, DS-2, DS-3 and DS-4). The first

depositional sequence (DS-1) constitutes the Temple Member of the Qasr El-Sagha Formation northwest Birket Qarun reflects alternating regressive and minor transgressive sedimentation conditions (gradual and sporadic in nature). A thick intertidal sequence (F-1) was accumulated under

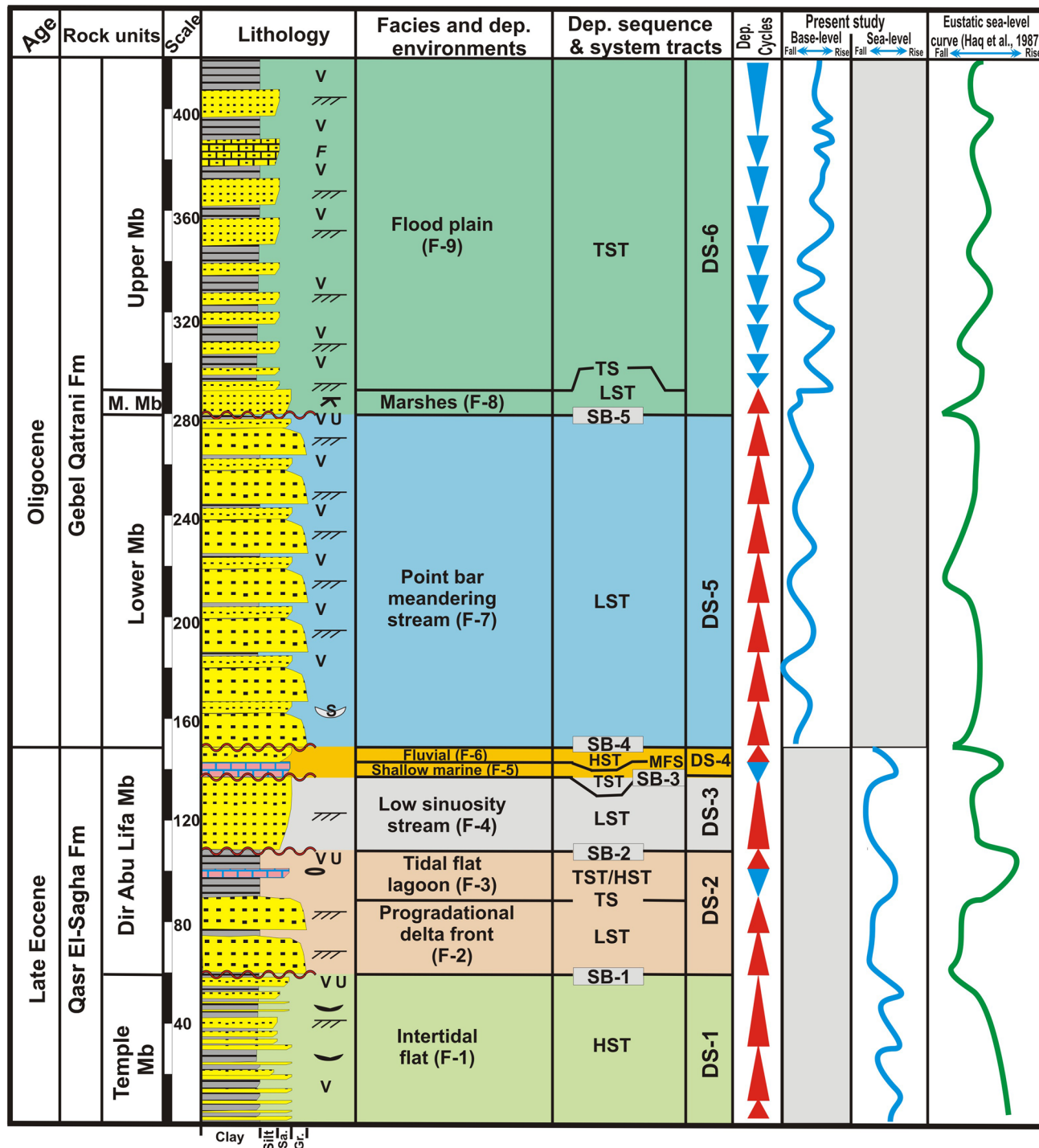


Fig. 9 The sea level as well as base-level changes of the studied Upper Eocene–Oligocene sequence at the studied area compared with the eustatic sea-level curve given by Haq et al. (1987)



marginal, intertidal flat environment involving the highstand systems tract (HST) with its three shallowing-upward parasequence (cycles) that is capped with sequence boundary (SB1) at the top of the Temple Member (Fig. 9). Sea-level fluctuations show a general coincidence to the global sea-level curve of Haq et al. (1987). The other three depositional sequences (DS-2, DS-3 and DS-4) comprise the Dir Abu-Lifa Member of the Qasr El-Sagha Formation northwest Birket Qarun.

The second depositional sequence (DS-2) reflects a terrestrial sedimentation episode of fluvial origin (F-2), mainly prograding delta front, characterizing sedimentation of the lower part of the Dir Abu-Lifa Member reflecting a lowstand systems tract (LST). This event was followed by a relatively minor transgressive sequence (F-3) where tidal flat and lagoonal conditions had prevailed designating the transgressive/highstand system tract (TST/HST). Thus, the maximum flood surface (MFS) separating them is difficult to determine. The third depositional sequence (DS-3) reflects accumulation under a low sinuosity stream system of fluvial environment (F-4) suggesting a lowstand systems tract (LST). The fourth depositional sequence (DS-4) constitutes the top most parts of Dir Abu Lifa Member of the Qasr El-Sagha Formation. Its lower parts are characterized by a near-shore shallow marine environment (F-5) that points to the transgressive systems tract (TST) sediments that records the beginning of the transgressive facies during the latest Eocene marine invasion across the studied area. Its upper parts are characterized by the accretion of fluvial sediments (F-6) reflecting the highstand systems tract (HST). In many parts of the area, this facies is removal by subsequent erosion of the active channels linked with the local tectonic effect that prevailed during the Oligocene time. It is worth noting that the presence of several near-shore marine rocks (F-3 and F-5) through the Upper Eocene terrestrial (fluvial) sedimentation (F-4 and F-6) reflects minor transgressive episodes accompanied by an increase in tidal influence on stream sedimentation (Fig. 9).

By the end of the Upper Eocene time, the fluvial conditions have continued and dominated (F-7, F-8 and F-9) throughout the Oligocene sedimentation of Gebel Qatrani Formation with short shallow marine (tidal influence) episodes near the top (Fig. 9). The fifth depositional sequence (DS-5) comprises the Lower Member of Gebel Qatrani Formation (F-7) seem to accumulate as point-bar deposits in several distinct meandering streams demonstrating the lowstand systems tract (LST). The sixth depositional sequence (DS-6) occupies both the Middle (F-8) and the Upper Member (F-9) of the Oligocene Gebel Qatrani Formation. The lower facies (F-8) refers to stream sedimentation in swamps at a coastal plain marking a lowstand systems tract (LST) that bounded above by a significant transgressive surface (TS) denote to the beginning of base-level rise during the

Oligocene time at the studied area. The preceding facies (F-8) accumulated in a meandering fluvial system terminated by overbank, levee and flood plain conditions (F-9) with evidence of tidal influence on stream sedimentation near the top denoting the transgressive systems tract (TST).

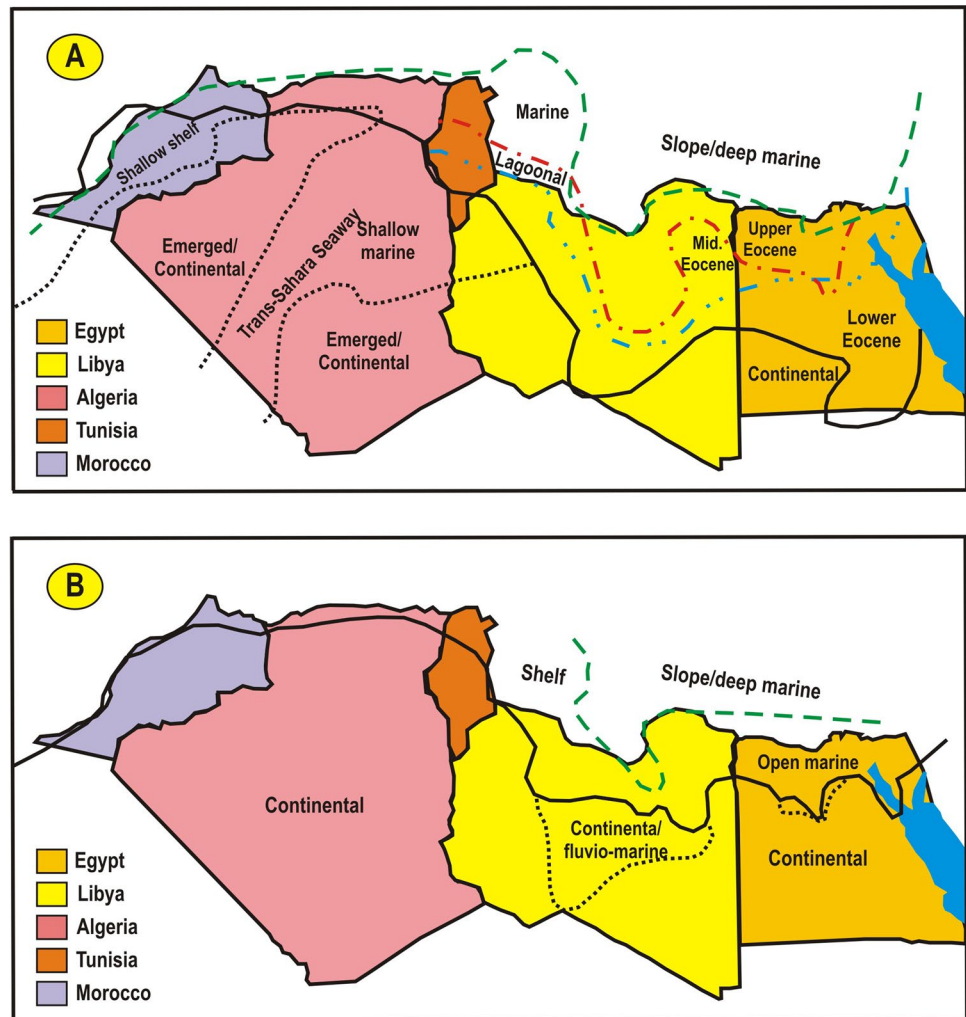
It is worth mentioning that the development of these short shallow marine conditions may have resulted from the gradual subsidence of the alluvial plain, accompanied by tidal influence on stream sedimentation. These short episodes were perhaps associated with tilting or down faulting of the northern part of Egypt (Salem 1976). Generally, it is believed that the considerable variations in the thickness of the Upper Eocene and Oligocene sedimentary facies, particularly in the studied area and generally in the rest of the Western Desert of Egypt, were controlled by the underlying sporadically rising tectonic structures (Shata 1953; Kostandi 1963; Salem 1976; Bown and Kraus 1988; Fawzy and Dahi 1992; Makram 1998; El-Younsy et al. 1999).

A detailed comparison of the study area at el Fayum (Egypt) with the sedimentary basins of North Africa in general (Fig. 10a, b) sheds light on the similarity of the paleogeography and development of the Paleogene basins in North Africa (Tawadros 2011). During the latest Eocene time, a great regression prevailed in both Egypt (Upper Egypt, and Western Sinai) and Libya (the western Sirte Basin, the southern Cyrenaica Shelf) and larger areas became emergent in this territory. Consequently, the upper boundary that separating the Eocene from the Oligocene successions is marked by a regional unconformity related to the global sea-level fall at the end of the Eocene that led to a major change in the depositional domain from carbonate to mainly clastics (Tawadros 2011). Therefore, the studied rock sequence of the Fayum basin (Egypt) which is contemporaneous with the one of the adjacent rocks succession at Dur at Talah (Sirt Basin, Libya; Ashour et al. 2012) indicates similar changes in the facies, sedimentation conditions and sea-level changes (Fig. 10a, b).

## Conclusion

A reasonable sequence stratigraphic framework and sea-level fluctuations during the Upper Eocene–Oligocene succession of the area northwest of Bir Qarun, Fayum district, Egypt have been achieved. The studied sequence covers two rock units, Upper Eocene Qasr El-Sagha (Temple and Dir Abu Lifa members) and Oligocene Gebel Qatrani formations. Based on the field criteria, lateral and vertical facies changes, stratigraphic surveys, and the depositional environments, six depositional sequences with their associated surfaces and systems tracts were realized. The lateral and vertical distribution of the sedimentary facies together with the development of the depositional sequences are controlled by

**Fig. 10** North Africa paleogeographic maps during the Eocene (a) and the Oligocene (b) times (Compiled by Tawadros 2011)



both regional and local subsidence/uplift tectonics in combination with the eustatic sea-level changes, resulting in the adjustment of accommodation space during the deposition of the studied succession.

The Upper Eocene Qasr El-Sagha Formation is differentiated into four depositional sequences (DS-1, DS-2, DS-3, and DS-4), which reflect transgressive/ regressive episodes expressive in various depositional environments (marginal, intertidal flat, prograding deltaic front, lagoon and sinuosity streams), that match with the global sea-level oscillations curve. The Oligocene Gebel Qatrani Formation is differentiated into two depositional sequences (DS-5 and DS-6), which show repeated fining upward cycles (rise/fall) of fluvial regime reflecting the base-level fluctuations controlled by the regional tectonic setting. Evidence of short shallow marine (tidal influence) on stream sedimentation near the top, reflects a gradual subsidence of the Oligocene alluvial plain associated with local tectonism. Evaluation of the study area with the other sedimentary basins of North Africa elucidates the similarity conditions of the Paleogene

basins in North Africa that related to the collision of African/Arabian and Eurasia plates at these times.

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## Declarations

**Conflict of interest** The authors declare that they have no known competing financial interests.

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