

Permo-Triassic Qiseib Formation, Western Side of the Gulf of Suez, Egypt: A Link of Fluvial Facies with Sequence Stratigraphy

Wanas HA* and Soliman HE

Geology Department, Faculty of Science, Menoufiya University, Shebin El-Kom, Egypt

Abstract

Facies analysis of the studied Permo-Triassic Qiseib Formation indicates the presence of five lithofacies. These lithofacies are: matrix-supported conglomerates facies (facies A), coarse-to medium-grained sandstone facies (facies B), heterolithic facies (interbedded sandstone and siltstone) (facies C), interbedded siltstone and claystone facies (facies D), and mixed clastic-carbonate facies (facies E). These facies were deposited in two fluvial environments: low sinuosity braided and high sinuosity meandering. The braided stream deposits dominate the southern portion of the studied area, whereas the meandering stream deposits prevailed in the northern portion. The fine-grained meandering stream deposits grade laterally to the northern part of the study area into tidally-influenced fine-grained meandering strata (estuarine mud).

In terms of its sequence stratigraphy, the Qiseib Formation represents a fluvial depositional sequence bounded by two sequence boundaries. This fluvial sequence comprises lowstand-, transgressive- and highstand systems tracts. The lowstand systems tract (LST) is predominantly characterized by braided coarse-grained sandstone deposits (Braided stream facies) with limited fine-grained clastics (floodplain facies). TST includes the coeval tidally-influenced fine-grained meandering strata that occur in the extreme north of the study area. The highstand systems tract (HST) is assigned to the sand bodies of the crevasse splay that encased within the floodplain mudstones, where base level rise slows down. Architectures of deposition of the studied Qiseib Formation were mainly controlled by tectonics and climate change. Influence of sea-level control could be developed during deposition in the northern part of the study area, where the tidally-influenced downstream deposits (estuarine mudstone and siltstone) dominated. Also, the relative proportion of fluvial channel sand bodies and fine over bank deposits of the Qiseib Formation were a result of changes in the balance between accommodation space (A) and sediment supply (S).

Keywords: Fluvial facies; Sequence stratigraphy; Permo-Triassic; Qiseib Formation; Egypt

Introduction

Fluvial sequences and facies are mainly controlled by tectonics, climate change and topography [1-6]. However, early studies in fluvial sequence stratigraphy emphasized that the sea-level may control in the downstream environments near the coastal to marine systems [1,7,8]. The identification of sequences and systems tracts within fluvial systems are based mainly on the relative proportion of fluvial channel sand bodies and fine over bank deposits which are a result of changes in the balance between accommodation space (A) and sediment supply (S) [1,3,6,9].

In Egypt, no detailed synthesis on the sedimentology and sequence stratigraphy of the Permo-Triassic Qiseib Formation exists, although the lithological description of the succession has been presented by few authors [10-16] who declared that the Permo-Triassic Qiseib Formation is represented by non-fossiliferous brown and red sandstones and claystones. Therefore, the present study aims to study lithofacies of the Permo-Triassic Qiseib Formation in terms of their sequence stratigraphic characteristics. In addition, this lithofacies study offers an opportunity to link fluvial facies and sequence stratigraphy. To achieve these targets, three stratigraphic sections (Figures 1 and 2) were measured, described and sampled in the field, along the western side of the Gulf of Suez-Egypt.

Geological Setting

Permo-Triassic deposition was followed the Upper Paleozoic Hercynian tectonic movement. After this tectonic movement, the northeast Egypt (northern Sinai) was lowland area, whereas the southern Sinai and Gulf of Suez region were highland areas [15]. During

this period, the marine transgression was developed in northern Sinai (Gebel Arif El-Naga) where the lowlands were developed. On the other hand, the southern Sinai and Gulf of Suez region seem to have been the site of the continental fluvial deposits, where the highlands were dominated. During Triassic, an arm of the sea advanced to south of the northeast Egypt covering the central Sinai and Gulf of Suez region [11].

Methodology

Three lithostratigraphic sections were described and measured bed-by-bed from outcrops of the Permo-Triassic strata in the northern Galala and Wadi Araba (western side of the Gulf of Suez), Egypt, in order to obtain a complete vertical lithologic succession. This was obtained during two field trips. During the fieldwork, special attention was paid to the different lithofacies varieties; bed geometry, nature of contact, faunal content, sedimentary structures, and lateral/vertical variations in lithologies and thicknesses. The collected sandstone samples were analyzed by sieving technique to classify their grain-sizes. The measured sections are located as the following: Section I (29° 04' 98" N and 32° 4' 92" E), Section II (29° 24' 24" N and 32° 18' 51.75" E), and Section III (29° 25' 98" N and 32° 17' 92" E) (Figure 1).

*Corresponding author: Wanas HA, Geology Department, Faculty of Science, Menoufiya University, Shebin El-Kom, Egypt, Tel: +2 01007902156; E-mail: hamdallawanas@yahoo.com

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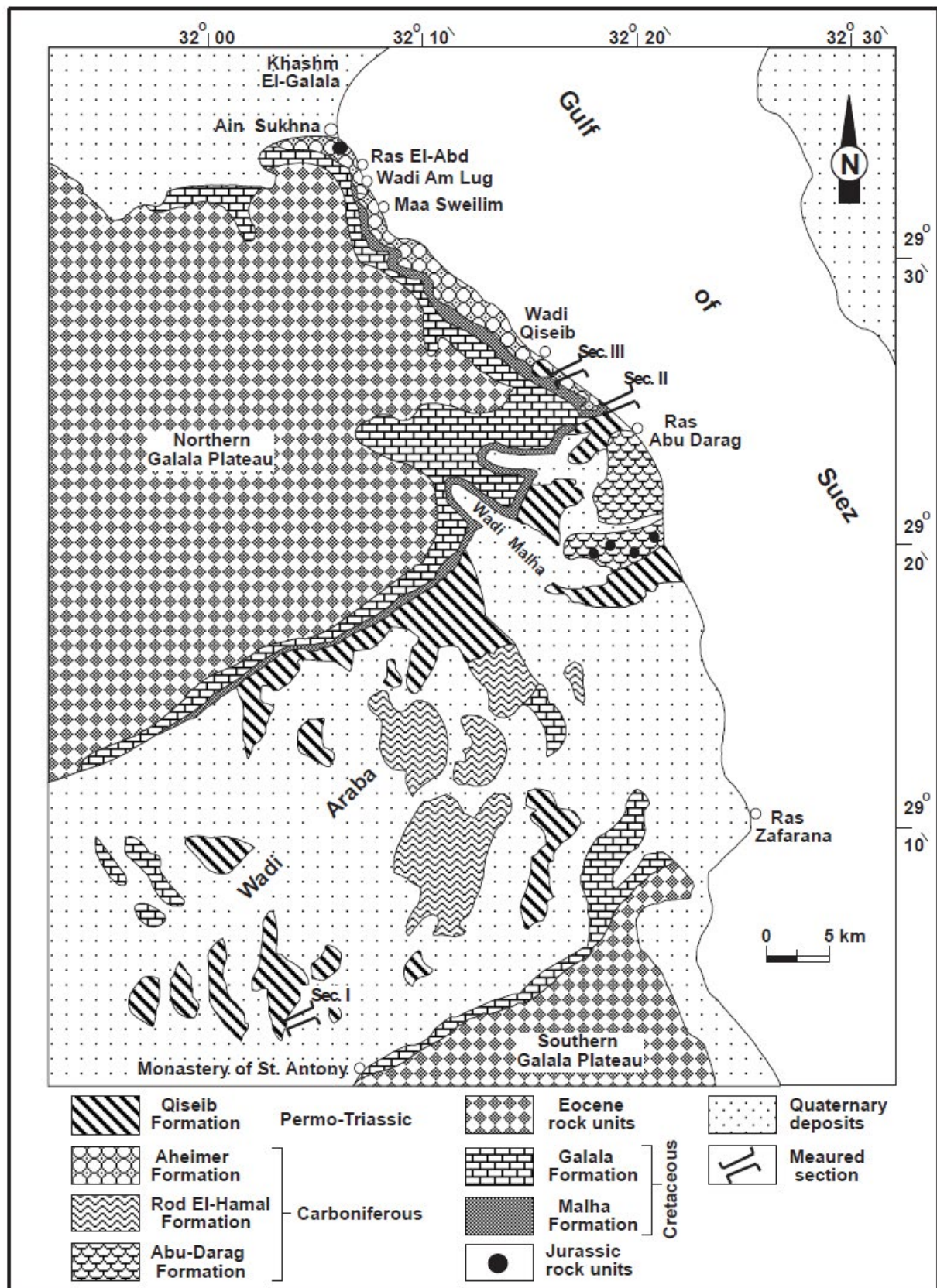


Figure 1: Geologic map of the area of study.

The Qiseib Formation

The term "Qiseib Formation" was introduced by Abdallah and El-Adindani [10] and Abdallah [11] for the Permo-Triassic non-fossiliferous brown and red sandstones and claystones exposed along the western side of the Gulf of Suez, at the Northern Galala Plateau and Wadi Araba. The Qiseib Formation is well exposed in Wadi Qiseib area, type locality, (Figure 1). At its type locality, the Qiseib Formation attains a thickness of 43.5 m. It is unconformably underlain by the Upper Paleozoic rocks (Abu Darag, Aheimer, and Rod El Hamal formations) and is unconformably overlain by the Lower Cretaceous Malha Formation. The age of the Qiseib Formation is still matter of debate, varying according to different authors. For instance, Abdallah and El-Adindani [10], Barakat [12] and Darwish [16] consider a Permo-Triassic age for the deposition of the Qiseib Formation, whereas other author considers a Triassic age [13,15]. On the other hand, Abd El-Shafy [17] attributed the Qiseib Formation exposed along the western side of the Gulf of Suez to an Abtian age.

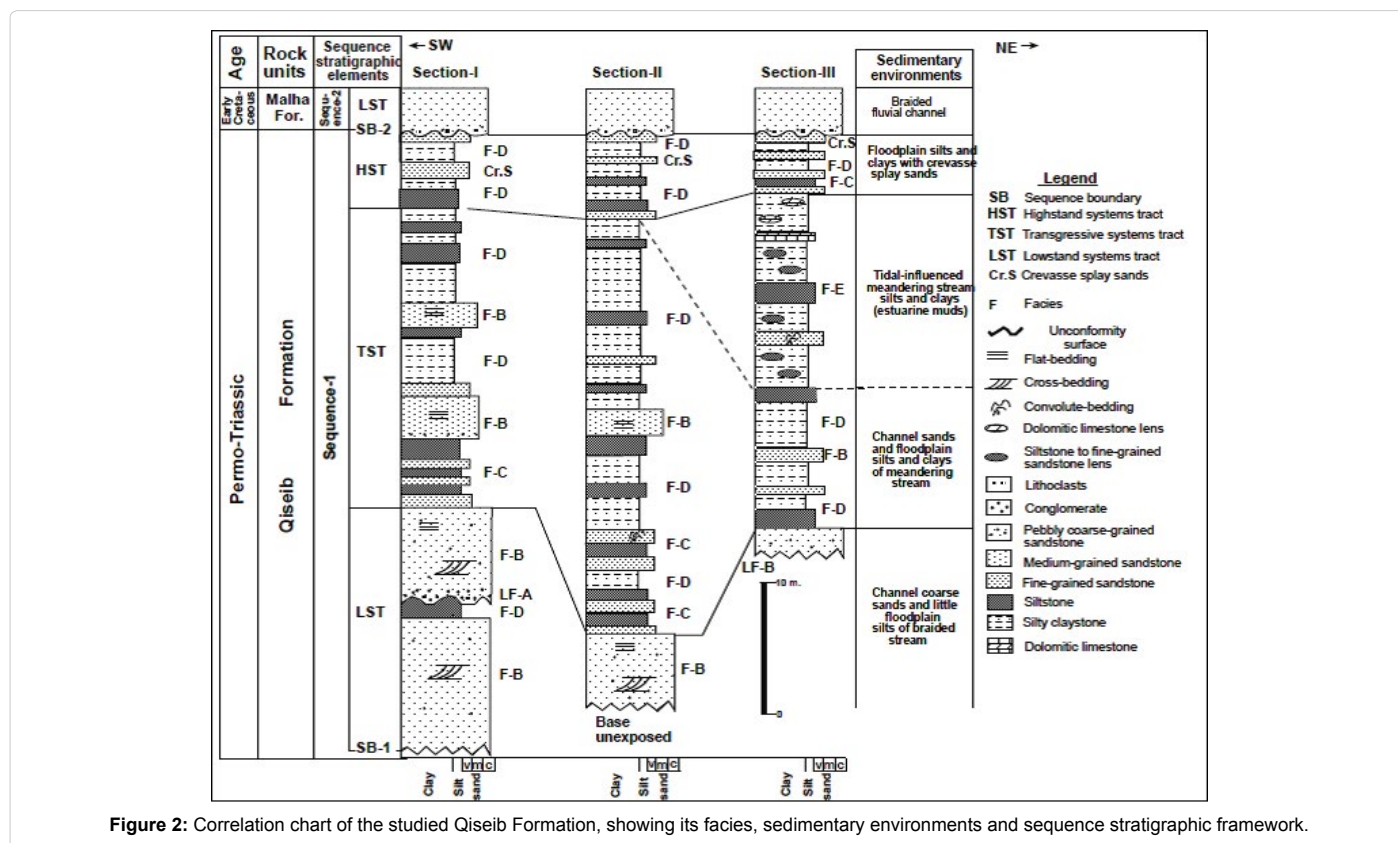
In the studied area, the lower contact between the Qiseib Formation and the underlying Paleozoic rocks is not exposed. However, Abdallah [11] defined this contact as an invisible unconformity. Although this lower contact is not exposed in the study area, it was recorded in the adjacent areas marking unconformable relationship with the underlying Upper Paleozoic rocks [12,16,18]. The Qiseib Formation unconformably overlays the Lower Cretaceous Malha Formation (Figure 3A). The thickness of the Qiseib Formation decreases from south to north where it attains a thickness of 47.75 m in section I in the south, 32.25 m in section III in the north and 43.85 m in section II in between. The Qiseib Formation is mainly made up of alternating multicolored sandstones, siltstones and mudstones. In addition, thin layers of marl, sandy limestone, dolostone and calcareous mudstone

occur interbedded in the upper part of the Qiseib Formation in section III (Figure 2). Thin beds of massive and crudely bedded conglomerates occur at the base of the sedimentary successions in the southern section I (Figures 2,3B). The sandstones are coarse- to very fine-grained and exhibit different colours. They exhibit different primary structures such as flat- bedding, cross-bedding and convolute bedding and desiccation cracks. The mudstone and claystone are multicolored (red, gray, brown and green) and exhibit different primary structures (thin bedding, lamination and fissility). Different pedogenic features including red coloration and color mottling are dominant in the whole formation (especially in the sandstones and mudstones). The formation is generally unfossiliferous, except for silicified and ferruginous plant remains in the sandstones and a few badly preserved pelecypods in the thin carbonate interbeds in section III in the northern part of the study area.

Sedimentary Facies and their Interpretation

The studied three lithostratigraphic sections show that the Qiseib Formation is dominantly siliclastic rocks. The lithology ranges from conglomeratic lag deposits to mudstones and claystones. However, carbonate deposits occur at the northern part of the studied area (Figure 2). The facies of the Qiseib Formation exhibit different colors including white, yellow, gray, green, brown, violet, olive, and red mottling with variable sedimentary structures such as flat-bedding, lamination, channeling, scouring, planar cross- bedding, convolute bedding, lenticular bedding, flute casts, and ripple marks. Pedogenic features that include mottling and iron crusts in the silty claystone occur in the silty claystone of the formation. Some of these facies may dominate the succession in one location or repeat themselves in a particular fashion in another locality.

The Qiseib Formation comprises five lithofacies, each of which is



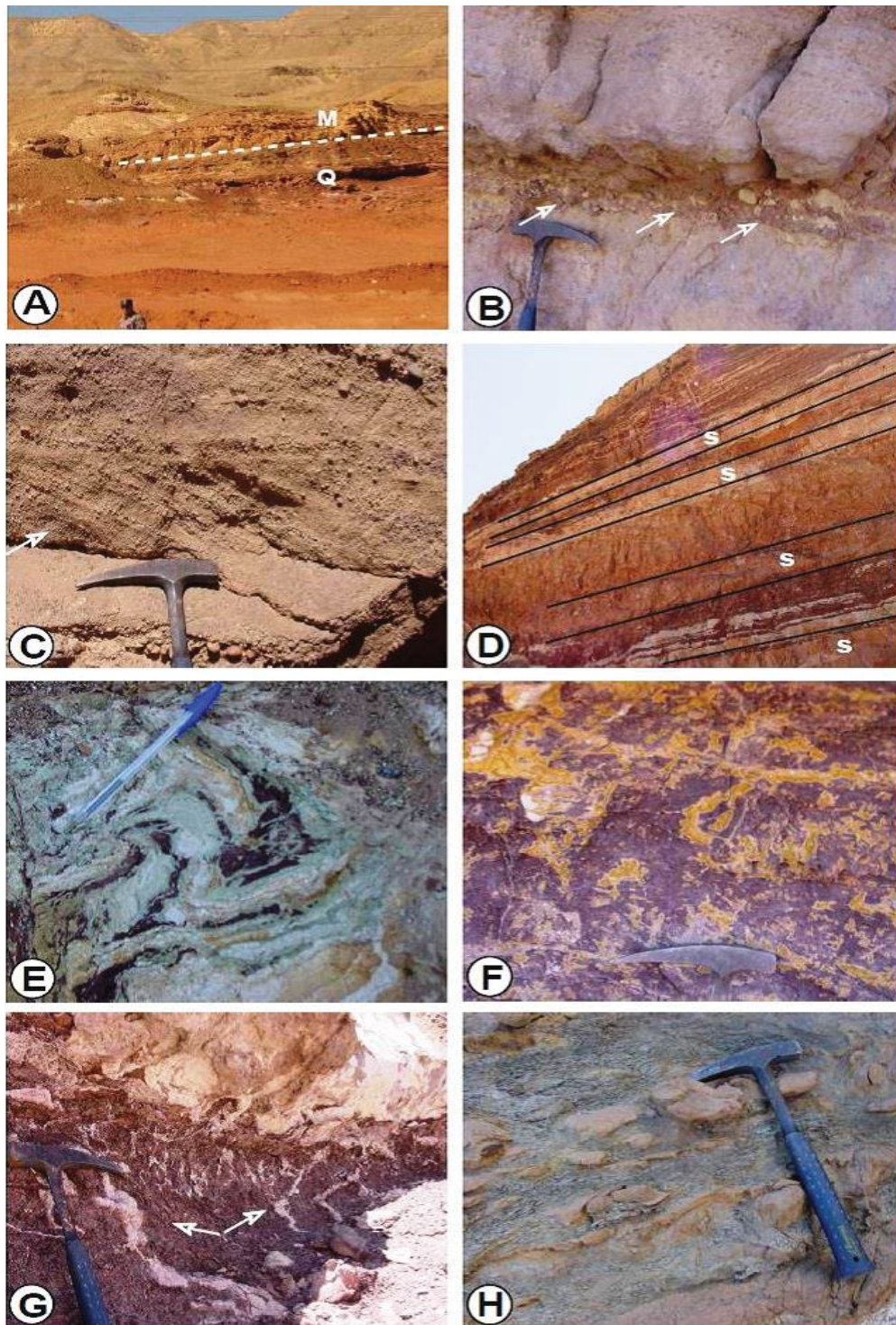


Figure 3: Field photographs showing

- A)** The Malha Formation (M) overlying the Qiseib Formation (Q) in section III.
- B)** The conglomerates (see arrows) of lithofacies A in section I.
- C)** The cross-bedded pebbly sandstone (see arrow) of lithofacies B in section I.
- D)** The flat bedding characterizes the medium-grained sandstones (S) in section II, Notice: and upward gradation from thick to thin sandstone beds (S) that occur between the siltstones and claystones.
- E)** Convolute bedding in the fine-grained sandstone of lithofacies C in section II.
- F)** Pedogenic features (mottling, reddening and yellow and white patches) in the silty claystone of lithofacies D in section III.
- G)** Desiccation cracks (see arrows) filled by gypsum in the silty claystones of lithofacies D in section I.
- H)** Lenticular bedding in lithofacies E (lenses of yellowish white sandstone in greenish grey silty claystone, and siltstone).

characterized by specific lithology and primary sedimentary structures. These lithofacies are: conglomerates facies (facies A), coarse-to medium-grained sandstone facies (facies B), heterolithic facies (interbedded sandstone and siltstone) (facies C), interbedded siltstone and claystone facies (facies D), and mixed clastic-carbonate rocks (facies E).

Lithofacies A: Matrix-supported conglomerates

Description: Facies A occurs only at section (I) in the southern portion of the studied area. This facies generally occurs as thin beds of conglomerates and pebbly sandstone at the base of the sedimentary succession (Figs. 2; 3B). It overlies the finer rocks (siltstone and silty claystone) of facies D and underlies the facies B. The conglomerates of this facies are yellowish white and brown in colour. This facies is matrix-supported conglomerate, and is made up of poorly sorted and sub angular to sub-rounded polymictic pebbles in a matrix of sand and silt. The conglomerates are massive or crudely bedded and exhibit irregular erosional bases (Figure 3B).

Interpretation: Facies A (conglomerates) is similar to the Gm facies of Miall [19] and is interpreted as lag and longitudinal bar deposits [19,20]. These lag deposits are associated with the repeated scour surfaces produced by repeated floods within a stream valley [21]. They are formed by the removal of portions of the pre-existing sediments and accumulation of coarse clasts at the bottom of fluvial channels [22]. The lag gravel is commonly trapped in the scour pools and covers the basal scoured surfaces [22,23]. Therefore, the conglomerates of facies A represent channel lag deposits that were formed from the pre-existing sediments and accumulated as coarse clasts at the bottom of the fluvial channels.

Facies B: Coarse- to medium-grained sandstone

Description: Facies B is made up of multicolored (white, gray, pink, red, yellow, greenish, pale brown to yellowish brown, and mottled) coarse- to medium-grained, moderately- to poorly sorted sandstones. In some cases, the sandstone facies contains quartz and mudstone pebbles. In addition, it contains brownish lithoclasts. These sandstone bodies occur in the form of elongate and tabular in geometries and are 0.50 to 12.5 m. thick. The coarse-grained sandstone facies has its largest thickness in the southern area and its thickness decreases northwards. The medium-grained sandstone is distributed in all the studied sections. The base of this lithofacies is sharp, erosional and scoured. In most cases, this facies occurs above the channel lags of facies A. Sometimes, it occurs above either the heterolithic facies C or the silty claystone and siltstone of facies D. This facies grades upward into the heterolithic facies (facies C) (Figure 2). The dominant primary structures in facies B include cross-bedding and flat-bedding. The low angle trough- and tabular cross-bedding dominate in the coarse-grained sandstones of facies B (Figure 3C). This cross-bedding frequency decreases upward and in the northern part of the study area. The flat- bedding characterizes the medium-grained sandstones in all the studied sections and thinning-upward pattern (Figures 2, 3D). Massive sandstone bodies occur locally in the southern area.

Interpretation: The sandstones of facies B are devoid of marine fauna as well as any evidence of tidal processes, like mud drapes, flaser bedding and bi-directional cross-beds. These features following Allen and Posamentier [24] strongly suggest that these sands were deposited in fluvial environments landward of the bayline. These deposits are also documented to refer to meandering-channel deposits on the basis of the following characteristics of these sandstone beds: elongate and tabular geometry; finning-upward cycles of grain size; irregular erosional bases; and vertical and lateral association with levee or flood

basin facies [25]. The fluvial deposits are composed of a succession of fining-upward cycles of which each cycle begins at the base by a scoured surface with common occurrence of conglomerate followed by sandstone that grades upward into siltstone [26-28]. Erosive-based cycles that show upward progressive decrease in grain size and decrease in scale of sedimentary structures accompanied by the abundance of fines in the upper parts of the cycles agree with deposition in a meandering stream environment [26,27,29]. An additional evidence for the meandering nature of the fluvial system is the high ratio between the mud-siltstone and the sandstone [30]. Flat-bedding can be the dominant structure in fine-grained sandstone of channel deposits and it is a predictable structure in low-sinuosity streams [27]. According to McKee ED [31], major floods can form sand deposits characterized by flat-bedding. "The cross-bedded sandstone represents channel and point-bar deposits of lower flow conditions" [32]. Reineck and Singh [33] recorded convolute bedding within point-bar tops and overbank environments. Selley [34] reported that the lithology of braided fluvial deposits consists almost entirely of cross-bedded, coarse-grained and pebbly sandstones with only minor amount of silts and clays. He also added that the meandering channel consists of about equal parts channel flat-bedded medium-grained sands and floodplain silts and clays. From the above discussion, we can conclude that the cross-bedded, coarse-grained pebbly sandstones that are dominated in the southern part of the study area form the channel deposits of low sinuosity braided stream. On the other hand, the flat-bedded, medium-grained sandstones, which are predominated in the northern part of the study area, represent the channel point bar of meandering stream (Figure 2).

Facies C: Heterolithic facies

Description: Facies C is made up of interbedded fine-grained sandstone and siltstone. It overlies and underlies the sandstones of facies B in the middle part of section I at the south. This facies represents most of the succession in section II in the central part of the studied area, where it overlies and underlies either the sandstone of facies B or the silty claystone and siltstone of facies D. In section III in the north, it occurs mainly at the top of the succession above the mudstone of facies E. This facies varies in thickness from one place to another as well as in different portions of the succession. It attains a thickness of 7 m in section I in the south, 1 to 5 m in section II, and 1 to 3 m in section III in the north (Figure 2).

The sandstones of facies C are white, brownish, reddish, fine- to very fine-grained. The siltstones are yellow, red and violet in colour. Pockets of silty claystones occur within the siltstones. The fine-grained sandstones and siltstones are thinly bedded and laminated. Flaser-, wavy-, and convolute bedding (Figure 3E) are the most prominent primary structures, beside the flat lamination and bedding, in this facies.

Interpretation: The interbedded fine-grained sandstones and siltstones of facies C represent a succession of overbank fines with episodic deposition of unconfined and unchanneled flows [35]. The thinly interbedded fine-grained sandstone and siltstone of facies C resemble the coarse-grained overbank deposits of Facies 1 of Fielding [36]. These channel overbank (levee) deposits are mostly associated with major tributary channels [37]. Bhattacharya [38] recognized flaser bedding on upper point bars of a perennial river. Moreover, Martin [39] demonstrated that flaser- and wavy bedding can form and be preserved in ephemeral streams. Therefore, the most probable depositional environment of facies C is channel overbank deposits in ephemeral stream.

Facies D: Interbedded siltstone and claystone

Description: This facies is composed of siltstone and silty claystone. It exhibits different colors (e.g., green, olive, gray, violet, red, yellow, brown, and white) with irregular patches of sandstones. Mottling is the dominant feature in this lithofacies (Figure 3F). Thickness of facies D ranges between 0.5 m and 6 m with the increasing of claystones from south to north. In some places, the silty claystone encloses sandstone sheets with sharp contacts. Thinly flat-bedding, lamination and convolute bedding are the dominant primary structures in the siltstones. Desiccation cracks filled with gypsum are dominant in the clay stones (Figure 3G). The contact with the overlying or underlying heterolithic facies is gradational whereas its contact with the sandstone facies is sharp and sometimes erosional.

Interpretation: The siltstones, with regularly spaced, thin claystone bands of facies D are similar to the siltstone-dominated overbank (floodplain) deposits of Facies 2 of Fielding [36]. This facies is developed at the margins of minor distributary channels [37]. The sandstone sheets of a sharp lower boundary within claystone can be interpreted to represent crevasse splay deposits [40]. According to Turner [41], most overbank sediments are red or reddish brown with irregular diffuse patches and lenses. Red coloration, desiccation cracks and color mottling are among the diagnostic features of pedogenesis and soil formation. Consequently, the siltstones and claystones of facies D were deposited as floodplain, whereas the enclosed sandstone sheets were developed by encased crevasse splays. In conclusion, facies D represents floodplain silts and clays with crevasse splay sands, Cr.s (Figure 2). Also, these floodplain deposits were subjected to pedogenesis and soil formation as is evidenced by their colour mottling and desiccation cracks (Figure 3F, G).

Facies E: Mixed clastic-carbonate rocks

Description: Mixed clastic-carbonate facies occurs in the uppermost part of the studied formation at the extreme north of the study area (at measured section III). It consists of thin beds of yellow and green marl, sandy limestone and dolomite within varicolored calcareous claystone and siltstone (Figure 2). The carbonate beds have a few fossils of gastropods and pelecypods. The clastic deposits are characterized by lenticular- (Figure 3H) and convolute bedding.

Interpretation: The gastropod and pelecypod fossils in the carbonate beds were interpreted as an indication to a marginal or coastal marine environment [42]. Therefore, the carbonate deposits could be a result of post-Carboniferous encroachment of an arm of the sea on the Gulf of Suez area [11]. The associated fine-grained siliciclastic facies (claystones and siltstones) are characterized by lenticular bedding indicating deposition in tidally-influenced fluvial environments [43]. Such alternated marginal marine carbonate facies and tidally-influenced fine-grained fluvial (meandering) siliciclastic facies refer to estuarine mud environment of deposition. The existence of these estuarine sediments overlying fluvial deposits indicates the onset of marine transgression [44].

Sequence Stratigraphy

Sequence stratigraphy has been applied widely and successfully to predict the spatial distribution of paralic and shallow-marine siliciclastic depositional facies since twenty years ago [7,45]. These transitional to shallow marine settings are sensitive to changes in relative sea level. In contrast, the application of sequence stratigraphy techniques to non-marine clastic deposits, especially fluvial deposits, is still limited and controversial [46, 47]. However, changes of fluvial styles

have been suggested to occur as consequence of changes in the rate of base level, rate of sediment supply and accommodation spaces [1-6,8,9,48-51]. The application of sequence stratigraphy of fluvial systems in response to base level change can be successfully performed in the lack of tectonic tilt and the preservation of the original horizontality of the stratal units [52]. Consequently, the non-tilted and horizontally nature of the studied fluvial deposits can provide a good reference to discuss the sequence stratigraphy in terms of river response to base level change [1,52]. This also provides additional hints to constrain the correlation of the studied sections, and supports the relatively conformable character of the depositional sequences, as well as the genetically related nature of their strata [46,52]. In the present study, the sequence stratigraphic models for fluvial styles proposed by Wright and Marriott [8] and Shanley and McCabe [1] have been applied. Sequence stratigraphy of the studied Qiseib Formation has been studied only by Darwish [16]. The present study introduces new concepts regarding the sequence stratigraphy of the Qiseib Formation.

Sequence boundaries

Recognition of sequence boundaries in predominantly fluvial strata is difficult because basinward shift in facies and related incision can be confused with more local channel scour. Therefore, in fluvial strata, sequence boundaries can be identified by the abrupt increase in vertical amalgamation and mean grain size of sandstones. Such criteria can only be used to identify sequence boundaries if the changes are of regional (mappable) extent accompanied by incision in many places at the same stratigraphic level [1].

The studied Qiseib Formation is bounded by two distinctive erosional surfaces (see lithostratigraphy) [16]. Each of them lies under coarse-grained sandstone. These two erosional surfaces and the overlying coarse-grained sandstones are widely distributed and can be correlated among the outcrops in the study area. Therefore, these two erosional surfaces of regional (mappable) extent are considered as two sequence boundaries. The regional extent of these erosional surfaces refers to a basinward shift and a remarkable fall in the regional base level [1]. Also, the abrupt transition from predominantly fine-grained strata to coarse-grained strata across the erosional surfaces indicates a change in the rate of fluvial aggradation [53] and/or a change in accommodation space [7]. No other major erosional surfaces were recorded within the Qiseib Formation, except for some local and minor erosion or scour at the bottom of the sandstone channels in the high sinuosity meandering stream strata (Figure 2).

Depositional systems tracts

The studied deposits show lateral and upward changes in the depositional environments from low sinuosity (braided) to high sinuosity (meandering) river systems and estuarine deposits. The low sinuosity river system (braided style) is prevailed in lower part of section I in the southern area, in which the lithology is dominated by sand and gravel (bed-load) with relatively little amount of siltstone-mudstone floodplain deposits (suspended-load). The high sinuosity river system (meandering style) dominates the upper part of the studied sections and increases in the northern area, where the lithology is exclusively build by mudstones and siltstones with isolated channel sands. The estuarine muddy facies occurs only in the extreme north of the studied area, where the influence of tidal processes is observed. A rather clear pattern of facies change from low sinuosity braided stream deposits in the lower part to meandering stream deposits in the upper part of the Qiseib Formation are also found. Based on our results, and following the sequence stratigraphic model for fluvial systems proposed

by Wright and Marriott [8] and Shanley and McCabe [1], the studied sections provide adequate data for recognition of a fluvial succession consisting of low-stand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST). The LST comprises sand-dominated low sinuosity braided, limited at the base by an erosional surface and showing wide distribution and have lateral continuity. This interval characterized by amalgamated fluvial channel sand bodies interlayered with rare over bank deposits which indicate a succession accumulated with low rates of accommodation creation (A) relative to sediment supply (S) [1]. On the other hand, the high sinuosity fine-grained meandering deposits associated with the tidally-influenced meandering fluvial deposits (estuarine muds) indicates a TST. This is because the meandering and tidally-influenced fluvial systems commonly develop in fluvial styles takes place by the influence of sea in the downstream environments near the coastal to marine systems [1,44]. The HST comprises crevasse splay sandstones within the floodplain deposits of high sinuosity meandering river system. The floodplain proportion of the HST is less and has more crevasse splay strata in a comparison with those of TST. This HST package is characterized by lenticular and isolated channels sand bodies, encased within fine-grained over bank deposits that were formed during periods of higher rates of accommodation creation (A) relative to sediment supply (S) [1,3,6]. These fluvial HST deposits were formed when the base level rise started to slow down after TST (Figure 2).

History of base-level changes

The term “depositional base level” was originally used to describe the equilibrium surface between sedimentation and erosion. A particle cannot come to rest above base level, but deposition is possible below it [54]. Based on the above discussions of facies analysis and sequence stratigraphic framework of the Qiseib Formation, as well as on the models of fluvial sedimentary systems and their development in response to base level changes suggested by Schumm [47], Wright and Marriott [8] and Shanley and McCabe [1], we propose the following evolution:

The basal sequence boundary of the studied sequence marked the rapid stage of base-level fall where the river was characterized by higher energy and morphological gradients and bed-load sediment transport. During the successive slow rise of base-level, the fluvial LST deposits dominated, and lowering of gradient in fluvial system took place. These LST deposits that consist mainly of coarse-grained bed-load materials deposited in low sinuosity braided river system. During the successive rapid rise of base-level, the fluvial TST deposits are developed. In this stage of base level rise, there is a speedup of accommodation space associated with high rates of aggradation and lowering of gradient in fluvial system. These TST deposits comprise fine-grained high sinuosity meandering fluvial deposits and estuarine mud-dominated strata. When the base-level rise comes back to slow down after the TST, the high stand systems tract took place [55]. The isolated sandstones within mud-rich deposition of high sinuosity meandering river system characterizes the HST. The subsequent rapid base-level fall led to the formation of the subaerial unconformity at the top of the Qiseib Formation, forming the upper sequence boundary that occurs below the coarse-grained braided fluvial deposits of the basal Lower Cretaceous Malha Formation (Figure 2).

Conclusions

The studied Qiseib Formation consists mainly of sandstones, siltstones, and claystones and occasionally carbonates with subordinate conglomerates. It shows gradual thinning from south (47.75m thick)

to north (32.25m thick), and is distinguished by the abundance of red beds with pedogenic features. The lateral and vertical variations of the Qiseib Formation show a relative increase of sandstones in the southern part of the study area. Northward, the fine-grained deposits (siltstones, claystones and mudstones) are abundant and associated with subordinate thin carbonate beds. The Qiseib Formation deposited under continental fluvial environment showing different characteristics (low sinuosity braided to high sinuosity meandering streams).

The Qiseib Formation forms a complete fluvial depositional sequence bounded by two (subaerial) erosional surfaces. This sequence includes lowstand-, transgressive- and highstand systems tracts. The lowstand systems tract comprises coarse-grained braided river deposits. The transgressive systems tract consists mainly of fine-grained meandering river deposits as well as their coeval tidally-influenced fine-grained meandering deposits (estuarine mud). The highstand systems tract is devoted to isolated sheets of sandstones and that form crevasse splays in the floodplain-dominated deposits of high sinuosity meandering river. The lowstand-, transgressive- and highstand systems tracts were interpreted to be controlled by three episodes of base level changes: base-level fall, rapid base-level rise and subsequent slow down of base-level rise, respectively. These were mainly controlled by tectonics (accommodation space control) and climate change (discharge or sediment supply control). Sea-level influence could be controlled during deposition in the northern part of the study area, where the tidally-influenced downstream deposits were developed. In general, the relative proportion of fluvial channel sand bodies and fine over bank deposits were a result of changes in the balance between accommodation space (A) and sediment supply (S).

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