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Facies Analysis and Depositional Environments of the Lower Cenomanian Bahariya Formation, North Western Desert, Egypt

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Abstract: This study focuses on the lithofacies and depositional environments of the Lower Cenomanian Bahariya Formation in the Western Desert, Egypt. The formation is composed mainly of clastic sedimentary deposits. Thirteen facies and six facies associations were identified based on their lithological and paleontological characteristics. The facies types suggest deposition in fluvio-deltaic, coastal plain, lagoonal, estuarine, and shallow marine environments. The lithofacies include fine-grained sandstone, laminated siltstone and claystone, grey mudstone, grayish-green mudstone, variegated shale, cross-bedded sandstone, shell bed, ferricretes, thin-laminated sandstone, and massive sandstone. The presence of certain sedimentary structures and fossils within the lithofacies suggest specific depositional processes and environments. The Bahariya Formation was deposited in a fluvio-deltaic to shallow marine environment with a mix of marine organic matter and high terrestrial/fresh-water input. These depositional environments indicate variation in tectonic setting, sea level oscillation and sediment supply.

keywords: Lithofacies; Cenomanian; Bahariya; Egypt

1.Introduction

Bahariya Oasis is located approximately 350 kilometers southwest of Cairo and is the most northern of a series of oases in Egypt's Western Desert (Fig. 1.1) [1]. The Central African Rift System includes these oases, which are located in depressions in the Cenozoic plateaus of the Western Desert [2]. The Bahariya Oasis is 95 kilometers long and 45 kilometers wide. Its floor is 110m below the surrounding desert's surface [3]. The Oasis is situated in a breached anticline [4].

Scientist Ernst Stromer, who led a series of expeditions to the Western Desert in the early twentieth century, named the Bahariya Formation [5]. Dominik [6] classified the formation into three members: the Gebel Ghorabi Member, the Gebel Dist Member, and the uppermost El Heiz Member. The beds of El Heiz Member have been treated as a distinct formation that lies beneath the Bahariya Formation ([3], [7], [8] and [9]). The fossils discussed are from the Bahariya Formation's Gebel Dist Member.

The Bahariya Formation forms the floor of Bahariya Oasis as well as much of the surrounding escarpment [3] and [10].

Gebel El Dist and Gebel Ghorabi as two isolated hills in the northern Bahariya Oasis, are dominated by Bahariya Formation. According to Dominik [6], the Bahariya Formation exposed in the Oasis is up to 360m thick. Removal of the El Heiz beds reduces the thickness of the Bahariya Formation to a maximum of 170m ([3], [7a] and [10]).

The Bahariya Formation, which extends north and west in the subsurface ([2], [4], [11], [12] and [13]), is an important reservoir rock in Egyptian oilfields. The petrophysical properties of the Baharyia Formation reflect the ability of the formation to store and produce oil [14]. According to Issawi et al [15], the Upper Cretaceous succession is subdivided into three lithostratigraphic units from the oldest Bahariya to the Abu Roash and the Khoman Formations. There are many producing formations. The Upper Cretaceous Bahariya Formation is one of the most promising reservoirs in the northwestern Desert, in addition to its reservoir potential, it is a hydrocarbon source rock within the basin [16]. The present work aims at interpreting the depositional environments of the Lower Cenomanian Bahariya Formation via investigating the facies analysis through using some sedimentological aspects and comparing them with other investigations.

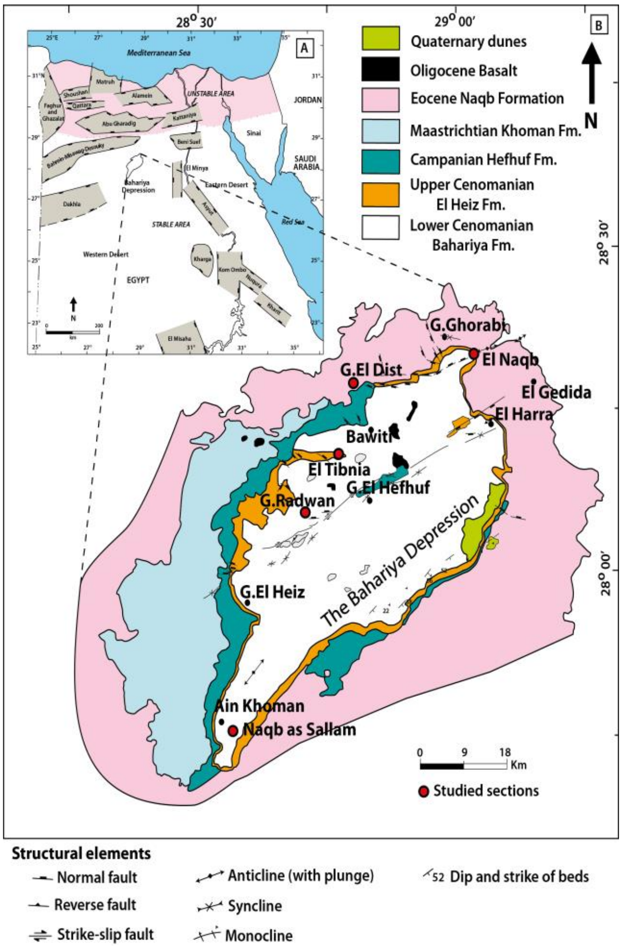

Fig. 1: (A) The main Paleozoic- Mesozoic basins of the Western Desert and Nile Valley after [17]; (B) Geological map of the Bahariya Oasis (modified after Egyptian Mineral Resources Authority [18]).

2. Geologic setting

2.1 Tectonics

The northern tectonically unstable area in the northwestern Desert underwent three main phases of extension and shortening. These were a Jurassic to Early Cretaceous rifting phase, Late Cretaceous to Early Tertiary basin inversion, and Miocene to post-Miocene extension [17]. The rifting that took place during the Jurassic and Early Cretaceous during the opening of the NeoTethys resulted in ENE-oriented basins bounded by major normal faults of the same orientation in the northern Western Desert [19]. The northern tectonically unstable area contains ENE-oriented basins in the form of NNW-tilted fault blocks, such as the Kattaniya, Abu Gharadig, Alamein, Qattara, and Shoushan basins (Fig. 1) ([20], [21], [22], [23] and [24]). Meanwhile, in the 'stable shelf', Mesozoic rift basins such as Dakhla, Asyut, Nuqura, and El Misaha occur [25].

2.2 Stratigraphy

The Bahariya Formation is made up of clastic sedimentary deposits such as sandstones, siltstones, claystones, and shales, with minor carbonates. These deposits mainly represent fluvio-marine facies, meaning they were formed in a setting that was a mix of river and marine environments [26]. The formation is divided into three units, each with distinct features: the lower, middle, and upper units [27]. Interestingly, the lower and upper units contain a high concentration of ironstone crusts and concretions [26]. The Bahariya formation outcrops in the Bahariya Depression; that is unconformably overlain by the Lower Eocene Naqb Formation, and is conformably overlain with the Upper Cenomanian El Heiz Formation at the northern and southern parts of the depression, respectively.

The Bahariya Formation's shallow marine and transitional facies represent a gradual transgression that followed the initial period of sedimentation of the Kharita Formation during the Cretaceous. This means that the environment slowly shifted from a mostly terrestrial environment to a more marine one. Therefore, the Bahariya Formation is a fascinating geological formation that offers insights into the geological history of the study area.

Catuneanu et al [28], Ramadan et al [29] and Khalifa and Catuneanu [30] mentioned that the Bahariya Formation is composed mainly of sandstones, siltstones and mudstones deposited in fluvio-deltaic, coastal plain, lagoonal, estuarine and shallow marine environments. Khalifa and Catuneanu [30] mentioned that the Lower Cenomanian Bahariya Formation was deposited under two coeval environmental conditions. A fully fluvial system occurs in the southern portion of the Bahariya Oasis, including depositional products of meandering and braided streams, and a coeval fluvio-marine setting is dominant to the north. These deposits are organized into four unconformity-bounded depositional sequences.

3. Materials and methods

The research for this project was done in outcrop exposures using the standard methods of lithofacies analysis and architectural element analysis. Five measured sections (Table 1; Fig. 2) were measured and described according to their variations in color, lithology, grain size, texture, sedimentary structures, fossil content and diagenetic features.

Table .1: Location, code, thickness and upper boundary of the studied sections**.**

Lithologic section	Code	Location	Thickness (m)	Upper boundary
West of Naqb El-Bahariya	(N)	28° 23′ 27.4’’N 29°06′49.9’’E	65	El-Naqb Fm.
Gabal El-Dist	(D)	28° 25′ 39.2’’N 28° 55′ 39.5’’E	165	El-Naqb Fm.
Gabal El Tibnia	(T)	28° 18′ 59.7’’N 28° 46′ 49.7’’E	50	El-Heiz Fm.
Gabal Radwan	(R)	28°12′ 34.6’’N 28° 45′ 53’’E	115	El-Heiz Fm.
Naqb as sallam	(S)	27° 46′ 46.3’’N 28° 31′ 50.5’’E	100	El-Heiz and El-Hufuf Fms.

4. Results and Discussion

4.1 Lithofacies

From north to south, these outcrops are West of Naqb El-Bahariya (Fig. 2), the measured section (65 m thick) is composed of dark-colored to black shale, siltstones and laminated sandstones as intercalations, with red ferricrete crusts, capped by Eocene limestones and dolostones. Gabal El-Dist (Fig. 2), the exposed section (165 m thick) is composed of moderately to poorly-sorted silty sandstones and sandy siltstones with intercalations of sandstones, siltstones and clayey siltstones. It contains red ferruginous bands, iron oxide concretions, gypsum, glauconite and charcoal, capped by Eocene limestones and dolostones. Gabal El Tibnia (Fig. 2), the exposed section (50 m thick) is composed of shale, siltstones and cross-bedded sandstones, with bands of ferricrete, capped by Eocene limestones and dolostones. Iron concretions recorded in this section. Gabal Radwan (Fig. 2), the exposed section (115 m thick) is composed of sandstones; highly laminated and massive in parts, fissile shale with bands of ferricrete in the upper parts, Iron concretions, hard walls of sandstone recorded in this section. Naqb as Sallam (Fig. 2), the exposed section (100 m thick) is composed of laminated sandstones; that interbedded with shale, and shows trough cross-bedded and fractured in its the lower parts. Crusts of ferricrete, gypsum, plant roots and leaves are recorded in this section.

The Lower Cenomanian Bahariya Formation has been divided into thirteen facies and six facies’ associations based on lithological and biological characteristics.

4.1.1 Fine grained sandstone facies (F1):

This lithofacies shows well bedding and load casts (Fig. 3a) at the base of the mudstone layer. It acts as a sand filled channel. The presence of load structures at the base of the finning-upward cyclothems reflects high sedimentation rates and soft sediment deformation [33].

4.1.2 Laminated siltstone and claystone facies (F2):

This lithofacies shows horizontal lamination, including plant remains and bone fragments. The presence of laminated siltstones and claystone suggests deposition in floodplain areas (Fig. 3b) [34].

4.1.3 Grey mudstone facies (F3):

This lithofacies contains plant remains and load casts, which occur directly below the sandstone facies of the overlying cycle. The presence of deformational structure (load casts) suggests that the deformation occurs as a result of differential compaction and water escape (Fig. 3a). Such structures are common in deltaic and fluvial systems [35].

4.1.4 Grayish-green mudstone facies (F4):

This lithofacies grades upward into reddish brown siltstone containing charcoal and gypsum thin layers and greensand. These facies (Fig.4a) are capped by layers of ferricrete in the top of each cyclothem. The mudstone at the base of the coarsening-upward cyclothems shows that the sedimentation started with a flooding surface and ended with subaerial exposure [28].

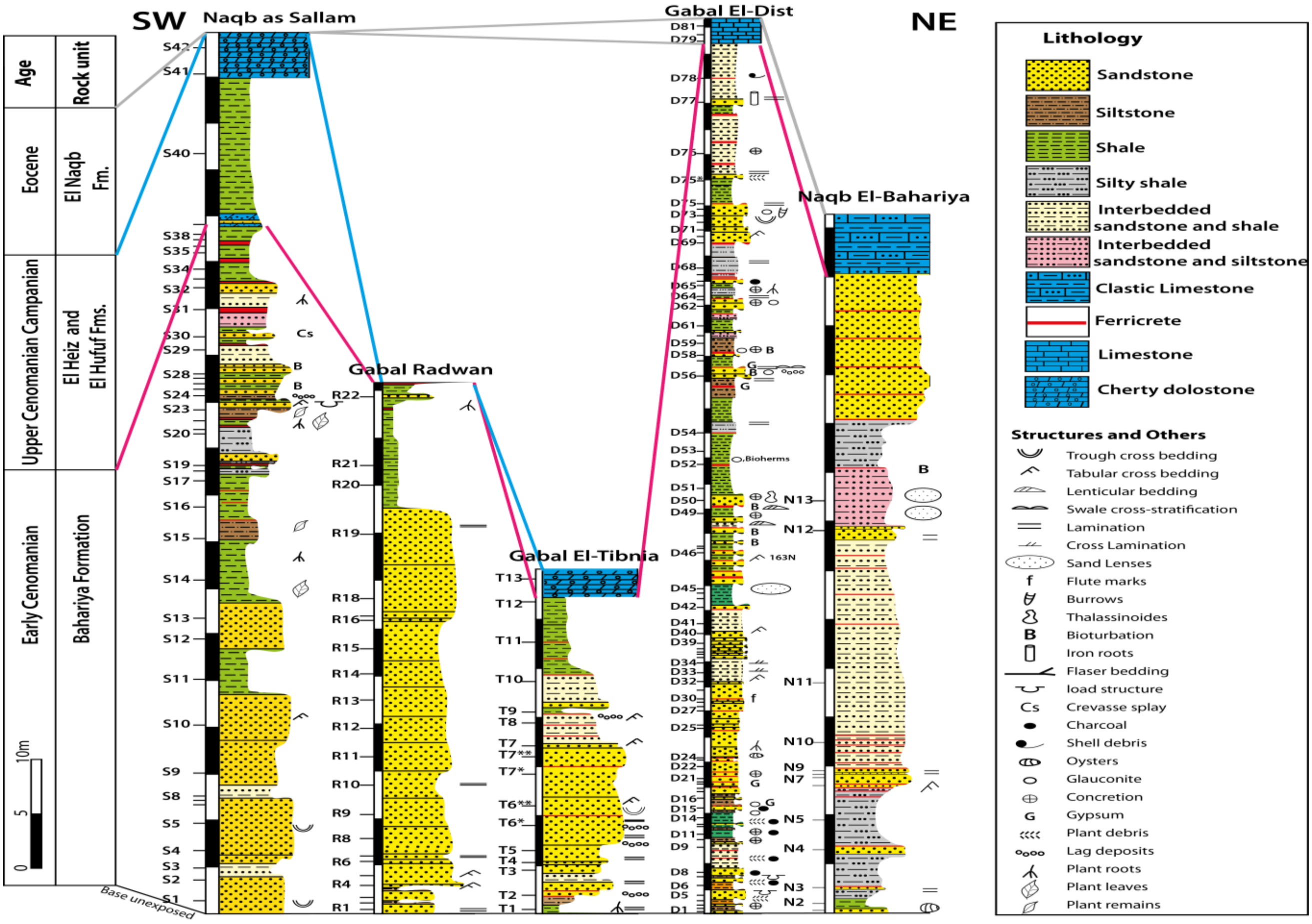

Fig. 2: Lithostratigraphic correlation chart between the studied five sections

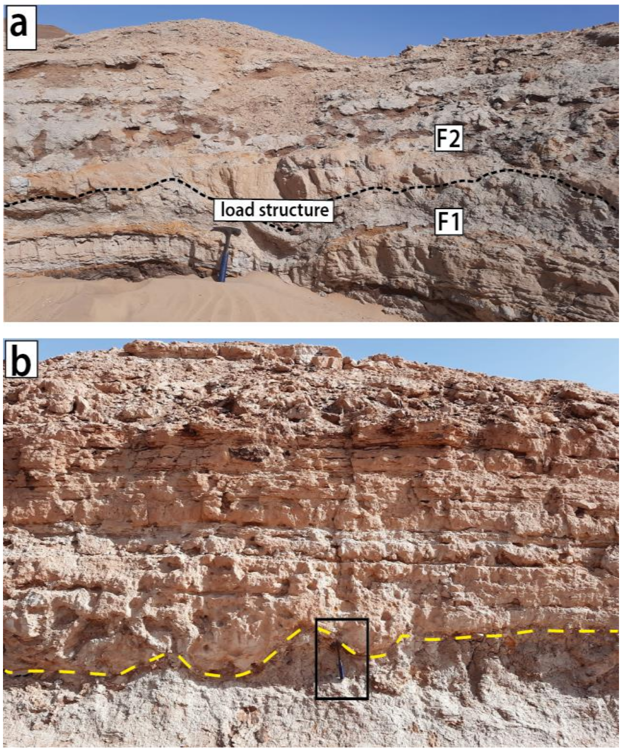

Fig. 3. (a): Field photograph shows fine-grained sandstone (F1) and grey mudstone facies (F2) at the lower part of Gabal El-Dist. b): Cliff forming beds of the lower part of Gabal El-Dist showing load structure (dashed line) between claystone below and laminated siltstone and claystone facies (F2) above. Geologic hammer for scale is 25cm.

4.1.5 Shell bed (F5):

It is interbedded with ferruginous sandstone. It contains bioclasts in fine-grained sandstone, including marine bivalves (Fig. 4b) (e.g., *Ostrea* sp. and *Exogyra* sp.; [36]), which are concentrated as lag deposits at the top of each ferricrete layer. The presence of the Oyster *Exogyra* [37] suggests a shallow marine depositional setting.

4.1.6 Ferricretes (iron crusts) (F6):

This lithofacies consists of nodular (Fig. 5a), colloform structures associated with lag deposits of molluscan pelecypod shells. It usually forms the top of parasequences (Fig. 5b). These parasequences are subaerially exposed during regression of the coastline. It may show nodular

4.1.7 Thin-laminated sandstone facies (F7):

It consists of fine-grained sandstone intercalated with massive and planar cross-bedded sandstone. It shows horizontal lamination. It contains iron roots (Fig. 5c). The thin-laminated sandstone facies suggest formation under oscillatory unidirectional currents [33] and [38].

Fig. 4. (a): Field photograph at Naqb as Sallam section showing the grayish green mudstone facies (F4); (b) Field photograph at the Naqb El Bahariya section showing the shell bed facies (F5) which interbedded with the ferruginous sandstone.

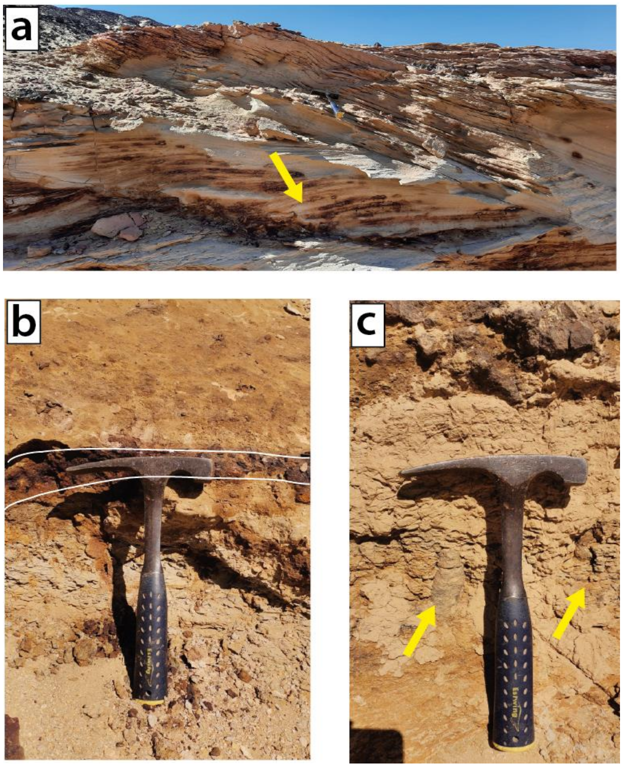

Fig. 5. (a): large scale planar cross bedding. The arrow points to concretions from ironstone in the base of the Naqb as Sallam section. Geologic hammer for scale is 25cm; (b) Field photograph at Gabal El-Dist showing the ferricretes (iron crusts) (F6) which cap the thin laminated sandstone facies; (c) Field photograph at Gabal El-Dist showing the thin-laminated sandstone facies (F7) with plant roots (Yellow arrows)

4.1.8 Massive sandstone facies (F8):

The massive yellow sandstone (Fig. 6a,b) grades upward into yellowish-brown ferruginous sandstone facies. It includes flaser bedding or abundant fine mud laminae. These facies show many cycles having an increasing thickness of ferruginous sandstone upward. The last cycle shows a high thickness of cross-bedded ferruginous sandstone. The massive appearance of sandstone may be related to the weathering effect [30] due to it high concentration of FeO.

4.1.9 Cross bedded sandstone facies (F9):

It contains planar cross-bedded fine to medium-grained sandstone and trough cross-bedded coarse-grained sandstone (Fig. 5a and Fig. 6). It grades upward into cross-laminated sandstone intercalated with variegated shale. Low-angle cross-beds suggest deposition under high energy conditions in particular channel locations, such as at the base of longitudinal bars or the intersection of channels [34].

4.1.10 Varigated shale facies (F10):

It intercalated with sandstone facies. It includes lenticular bedding, iron concretion and capped by crusts of ferricrete. Fine-grained sediments suggest deposition in floodplain areas under seasonally dry and oxidizing environmental conditions due to red paleosols [39] and [40].

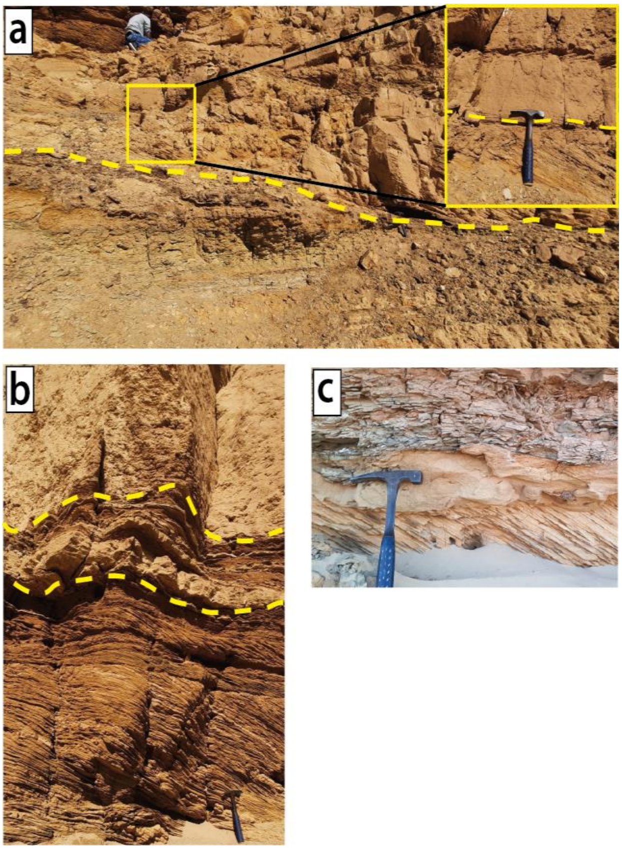

Fig. 6. Field photographs (a, b) at Gabal El Dist showing cross bedded sandstone underlies massive sandstone; (c): Close-up view of cross bedded sandstone at El Tibnia section.

4.1.11 Bioturbated shale and siltstone facies (F11):

They are laminated and include a high percentage of burrowing, rootlets and lenticular bedding. The latter consists of isolated ripples of sandstones in shale (Fig. 7a). The degree of bioturbation varies from rare to common and is represents with *Thalassinoides*.

4.1.12 Black shale facies (F12):

Dark grey fissile black shale intercalated with thin-bedded ferricrete layers with bioherms. This facies grades upward into lamination of shale, siltstones and claystone lithofacies which are variably colored (red, grey, greenish grey, yellow) (Fig. 7b). The siltstone in this facies contains gypsum as vertical strikes.

4.1.13 Glauconite sand facies (F13):

Glauconitic sand facies usually occur above the siltstone or shale and below the ferricrete. It contains:

a) Laminated swaley cross-bedding glauconitic sandstone with gypsum and lag deposits (Fig. 8a, b).

b) Massive bioturbated glauconitic sandstone with iron concretions (Fig. 8c).

c) Trough cross-bedding and planar cross-bedding glauconitic sandstones.

d) Inter-bedding glauconitic and ferruginous sandstones.

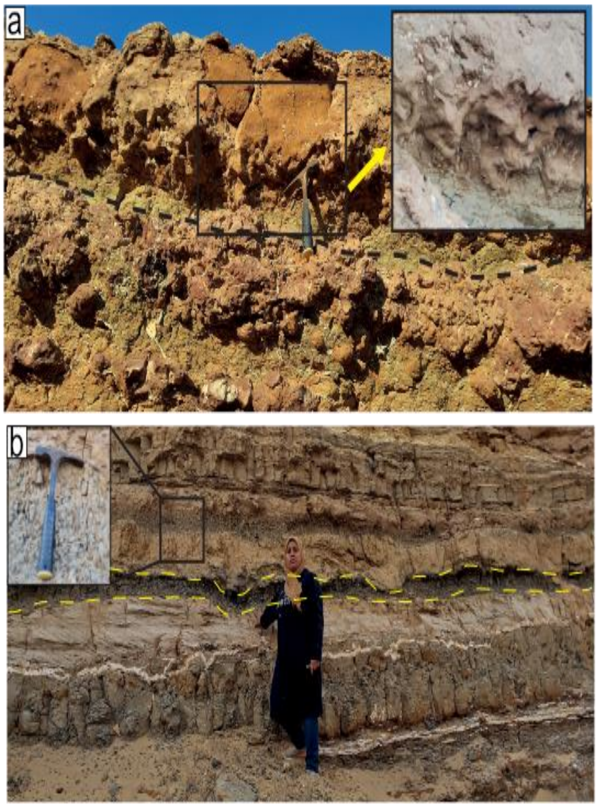

Fig. 7. Field photographs at Gabal El-Dist showing (a) the bioturbated shale and siltstone facies which have the Thalassinoides-rich bed at Gabal El Dist section; (b) The bioturbated shale and siltstone facies, the black shale facies (yellow dashed) and the enlargement box refers to the plant roots at Naqb as Sallam section.

The presence of glauconite may indicates progradation into a marine environment or deposition in the transitional zone between reducing and oxidizing conditions [41].

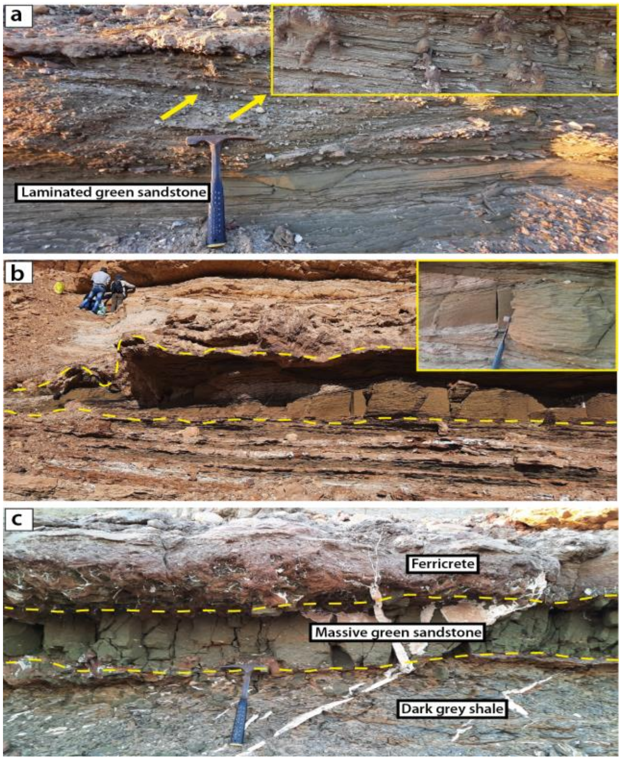

Fig. 8. Field photographs at Gabal El-Dist showing (a) Laminated greensand with bioturbation (arrows); (b) Close-up view of swaley cross lamination of greensand. Geologic hammer for scale is 25cm; (c) Massive greensand topped by ferricrete;

4.2 Delineation of the Facies Associations (FA)

4.2.1 Facies association at Gabal El-Dist:

4.2.1.1 Facies Association (FA1):

It represents the lowermost part of Gabal El-Dist (Fig. 9) as fining-upward cycles containing fine-grained sandstone (F1), laminated siltstone and claystone (F2) and grey mudstone facies (F3). It reflects a shift from sand-filled distributary channels to mud-dominated interdistributary areas [28]. Such facies association are commonly recorded in flood plains or delta plain settings [42].

4.2.1.2 Facies Association (FA2):

It is composed of regressive episodes that include green mudstone facies (F4) at the base (Fig. 9), grading upward into green sandstone facies capped by crusts of ferricrete (F6) and containing shell-rich bed (F5). Many cycles consist of the mudstone facies capped by ferricretes directly. These coarsening-upward cyclothems are considered as coastal-marine facies, which accumulate during transgression of the shoreline.

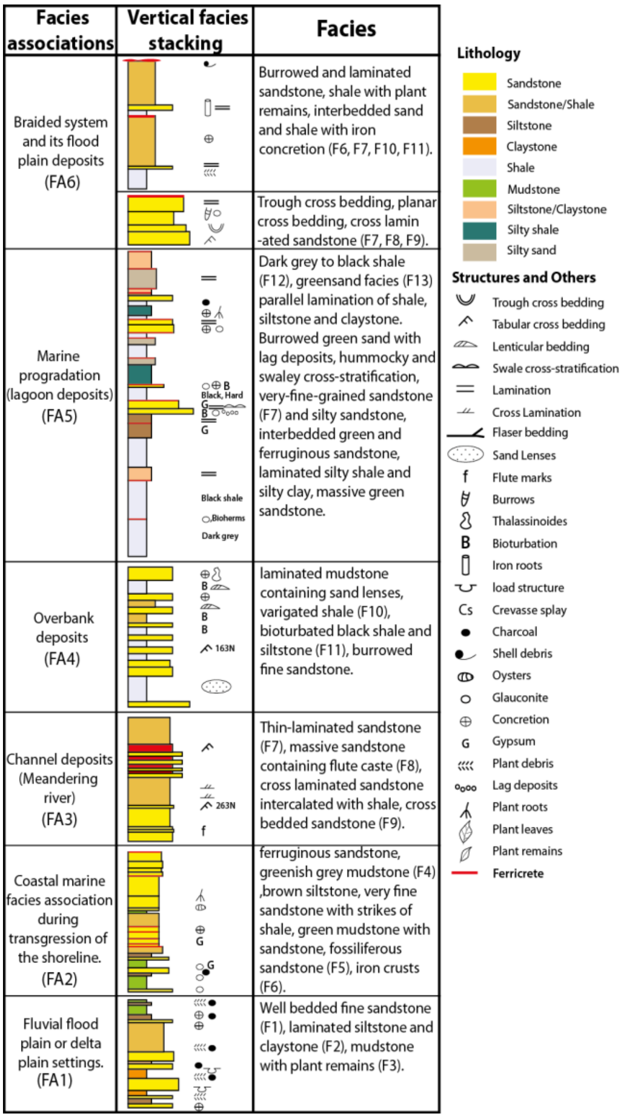

Fig. 9. Lithofacies and facies associations at Gabal El Dist section.

4.2.1.3 Facies Association (FA3):

It includes thin laminated sandstone facies (F7), massive sandstone facies (F8), planar cross bedding sandstone facies (F9) and flaser bedding structure (Fig. 9). The presence of these facies and structure suggests deposition in fluvial channel environment [43] and [44].

4.2.1.4 Facies Association (FA4):

It includes variegated shale facies (F10) with lenticular bedding sandstone and bioturbated shale and siltstone facies (F11; Fig. 9). The presence of burrows and rootlets suggests deposition in overbank areas as a result of periodic flooding [43].

4.2.1.5 Facies Association (FA5):

It includes black shale facies (F12) and glauconitic sand facies (F13; Fig. 9). While representing sedimentation in the marine shoreface. The lower and middle shoreface consist of both swaley and hummocky cross-stratified sandstone and wave ripples [45].

4.2.1.6 Facies Association (FA6):

It includes massive sandstone facies (F8), planar and trough cross bedding sandstone facies (F9; Fig. 9). These amalgamated sandstone bodies are representing sedimentation in braided system.

4.2.2 Facies association at Naqb as Sallam:

4.2.2.1 Facies Association (FAS1):

It is composed of fining upward cyclic sedimentation which contains medium to coarse-grained, whitish-yellow, trough cross-bedded sandstone grades upward into laminated sandstone with thin shale interbeds which shows flaser bedded sandstone (Fig. 10). Sandstones are varicolored from whitish-yellow, yellow and dark yellow with different sedimentary structures like trough cross bedding, tabular cross bedding, flaser bedding and groove marks. The intercalations of sandstone and shale are capped by iron oxide bands (ferricrete). There are some reworked ironstone concretions (Fig. 6d). The presence of these observations and sedimentary structures suggest fluvial origin to this facies association [43] and [44]. These amalgamated sandstone bodies are representing sedimentation in braided system (Fig. 10).

4.2.2.2 Facies Association (FAS2):

It contains floodplain lithofacies (Fig. 10); shale, siltstone and fine-grained sandstone interbeds (F10, F11). The shale beds are dark grey to black in color and contain plant remains and charcoal. The siltstone beds are laminated and contain plant leaves. These facies are capped by crusts of ferricrete. The shale and sandstone beds sometimes contain plant roots. The presence of these facies reveals periodic flooding of the overbank environment in interfluve areas [43]. Sandstones may enclose gypsum, that suggests that flooding events were separated by periods of evaporation under semi-arid to arid climatic conditions [43]. Small scale channel sandstone (crevasse splay facies) was also recorded, which represents river flooding episodes.

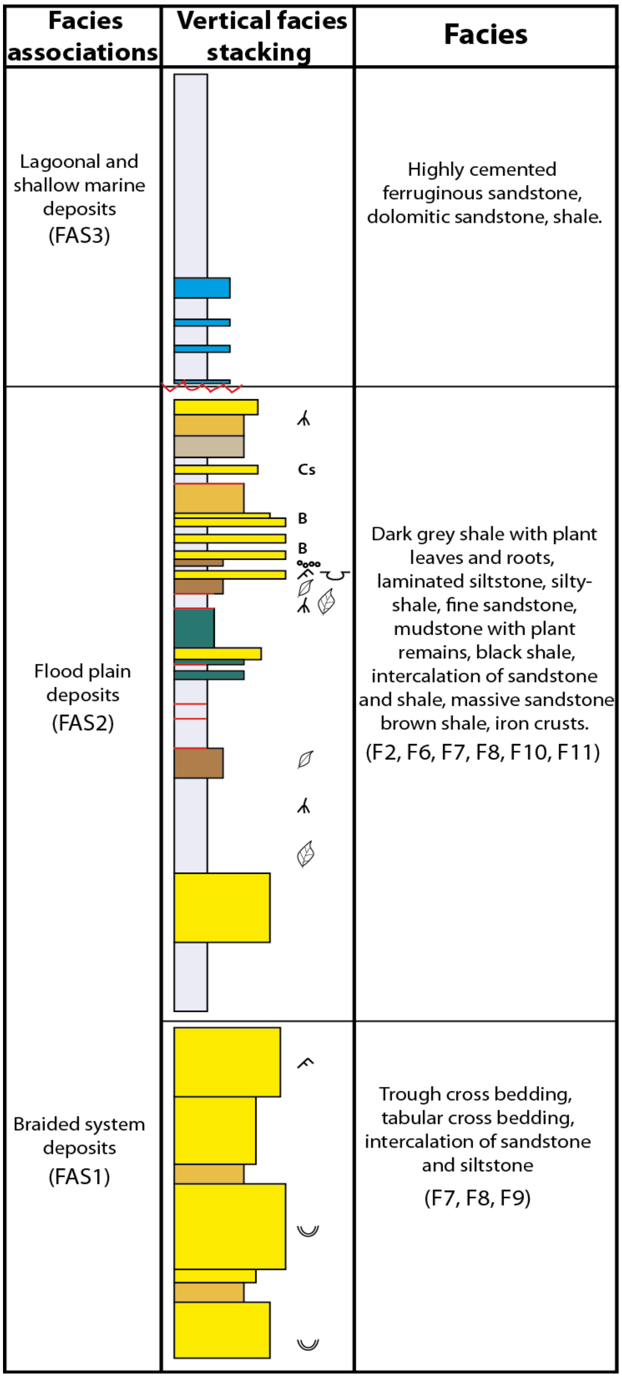

Fig. 10. Lithofacies and facies associations at Naqb as Sallam section (for legend, refer to Fig. 9).

4.2.2.3 Facies Association (FAS3):

It forms the upper part of the section, which contains upward sequence of thick shale, highly cemented ferruginous sandstone and cliff forming dolomitic sandstone bed (Fig. 10). This facies association reflects a lagoonal deposition to shallow marine conditions [6]. These lithofacies are overlain by dolostone interbeds. Dolostone is brown, hard and finely crystalline, which represents El Heiz Formation.

4.2.3 Facies association at Naqb El-Bahariya:

4.2.3.1 Facies Association (FAN1):

It is composed of coarsening-upward cyclothems that include dark grey to black shale at the base, grading upward into silty shale and sandstone facies capped by crusts of ferricrete (Fig. 11). The thickness of sandstone beds increases upward. These coarsening-upward cyclothems are considered as marine progradation facies, which accumulate during transgression of the shoreline.

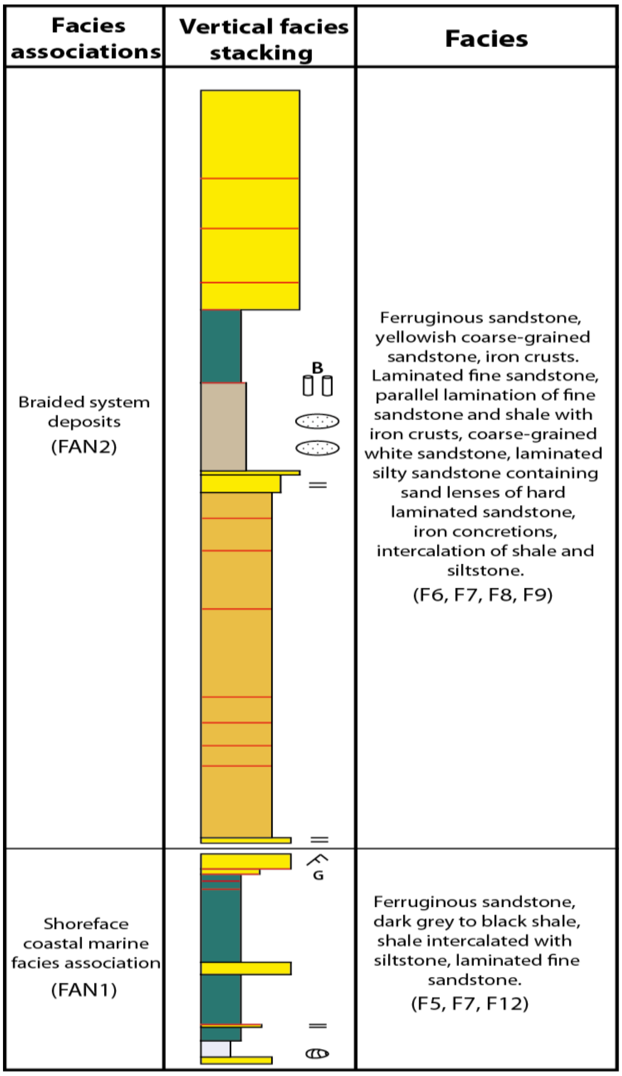

Fig. 11. Lithofacies and facies associations at Naqb El-Bahariya section section (for legend, refer to Fig. 9).

4.2.3.2 Facies Association (FAN2):

It includes coarse-grained sandstone facies. Sandstones are reddish yellow and capped by ferricrete (Fig. 11). These amalgamated sandstone bodies are representing sedimentation in braided system.

It includes laminated fine-grained sandstone and shale facies, lenticular hard laminated and bioturbated sandstones (Fig. 11). The presence of burrows and rootlets suggests deposition in overbank areas as a result of periodic flooding [43].

4.2.4 Facies association at El-Tibnia:

It is composed of fining upward cyclic sedimentation which contains medium to coarse-grained, varicolored whitish-yellow, whitish-grey and dark yellowish brown sandstone grades upward into laminated medium to fine sandstone, siltstone with thin shale interbeds (Fig. 12). Sandstones are bedded with different sedimentary structures like trough cross bedding, tabular cross bedding and flaser bedding. The intercalations of sandstone and shale are capped by iron oxide bands (ferricrete). There are some reworked ironstone concretions like pebbles. The presence of these observations and sedimentary structures suggest fluvial origin (braided system) to this facies association [43] and [44].

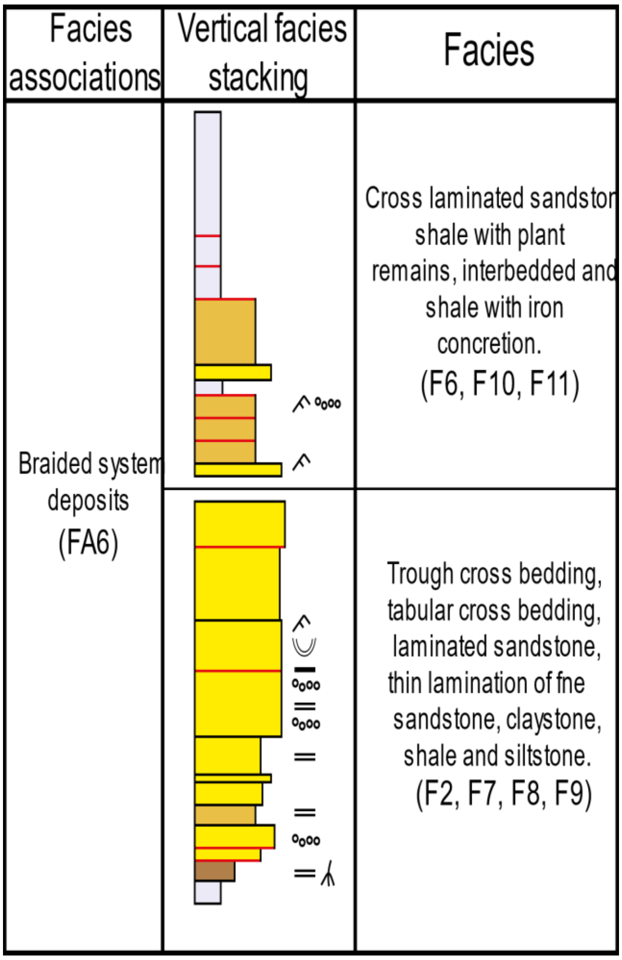

Fig. 12. Lithofacies and facies associations at El-Tibnia section (for legend, refer to Fig. 9).

4.2.5 Facies association at Gabal Radwan:

It is composed of fining upward cyclic sedimentation which contains medium to coarse cross laminated sandstone with vertical fractures. Sometimes, sandstones are pebbly with cross bedding (Fig. 13). Sandstones are varicolored from white, yellow, reddish yellow and violet with thickness increased upward. There are some reworked ironstone concretions. Sandstones are massive, laminated, cross laminated, thin bedded and cross bedded. Sandstones grade upward into shale. The shale beds are capped by ferricrete, grey to brown in color and contain plant roots The presence of these observations and sedimentary structures suggest fluvial origin (braided system) to this facies association [43] and [44].

4.3 Depositional Environment

The Bahariya paleoenvironment has been the subject of extensive research, with numerous studies providing new insights into its unique features. According to Sisi et al [4], Dominik [6] and Werner [46], the area was a forested wetland characterized by low energy paralic sediments. However, recent studies have suggested that the paleoenvironment may have been even more complex than previously thought. For example, some researchers have proposed that the area may have been home to a diverse array of plant and animal species, including those that are not typically associated with wetland ecosystems [47] and [48].

El Atfy et al [48] interpreted the combination of the recorded palynoflora, macroflora as well as charcoal as evidence of deposition in fluvial, coastal to nearshore environments affected by warm and arid climates. Furthermore, palynofacies and geochemistry data indicated that the Bahariya Formation was deposited in a proximal suboxic to oxic shallow marine to fluvio-deltaic environment, where high terrestrial/fresh-water input was mixed with marine organic matter. The evidence that they have gathered from the recorded palynoflora, macroflora, and charcoal suggests that the deposition of the Bahariya Formation occurred in a variety of environments.

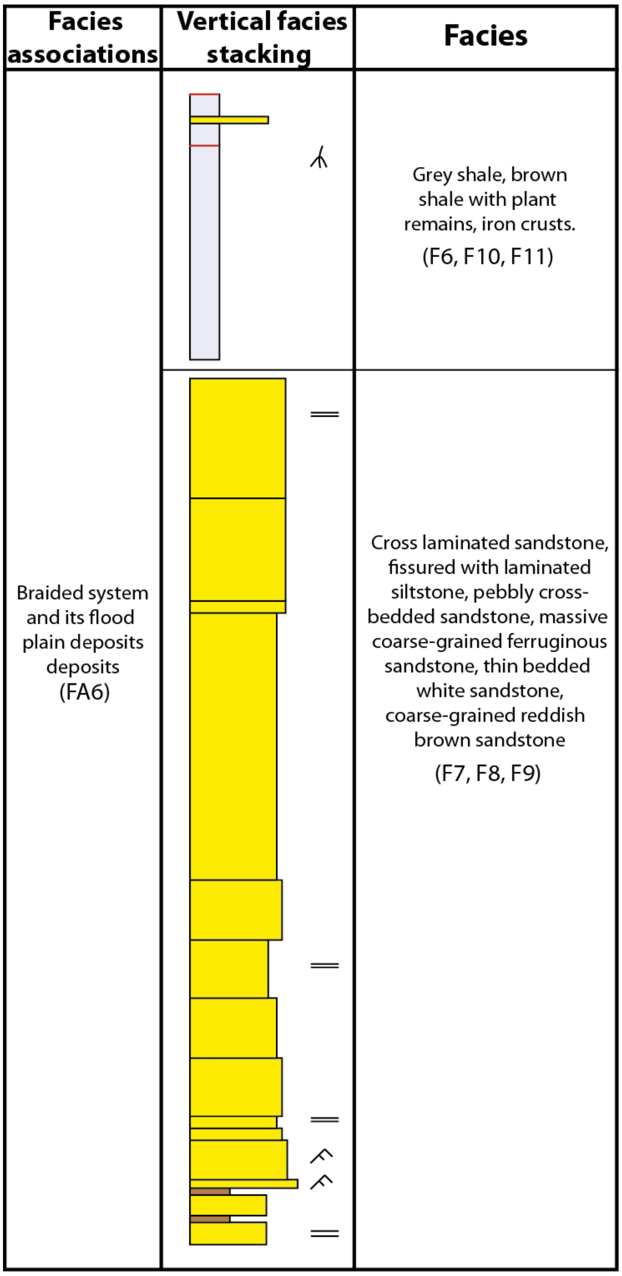

Fig. 13. Lithofacies and facies associations at Gabal Radwan section (for legend, refer to Fig. 9).

Their interpretation is that it was deposited in fluvial, coastal, and nearshore environments that were all affected by warm and arid climates. In addition to the aforementioned evidence, they also analyzed palynofacies and geochemistry data. These data indicate that the Bahariya Formation was deposited in a proximal suboxic to oxic shallow marine to fluvio-deltaic environment. This environment was characterized by a high terrestrial/fresh-water input that was mixed with marine organic matter. Overall, their findings suggest that multiple factors contributed to the formation of the Bahariya Formation. The combination of these factors ultimately led to the unique characteristics of the formation that we observe today.

In the studied sections, the lower Bahariya Formation appears to have been overlain by estuarine or marginal marine sediments, as noted by Dominik [6] and Werner [46]. The estuarine sediments, in turn, are overlain by crossbedded fluvial sands, before a return to marine conditions in the upper Bahariya Formation. This suggests that the area experienced significant changes in environmental conditions over time, which likely had a profound impact on the plant and animal species that called the Bahariya paleoenvironment home.

In the case of the studied Bahariya Formation, the lithofacies types that have been identified suggest deposition in a range of environments, including fluvial deltaic, coastal plain, lagoonal, estuarine, and shallow marine environments (Fig. 14). These environments reflect the complex geological history of the region, which has been shaped by tectonic forces, sea level fluctuations, and climatic changes over millions of years.

As outlined by by El Atfy et al [47], the proposed depositional model suggests that these sediments were accumulated along the shoreline of a broad, shallow epicontinental sea with exceptionally low gradients, which has resulted in the formation of a vast back-barrier region that comprises tidal flats, lagoons, mangrove forests, and tidal channels across the gently sloping coastal plain. The sedimentological and paleontological evidence supports this interpretation of the depositional mosaic. Sedimentary structures are influenced by tidal currents and episodic fluvial inflow. Trough cross-bedding indicates deposition within tidally influenced channels, while laminated shales with ripples reflect low-energy tidal flat settings. The presence of channel deposits interspersed with tidal flat facies suggests lateral migration of channels across the coastal plain.

Fossil assemblages found in the formation exhibit a spectrum of coastal, marine, and terrestrial environments, as evidenced by the presence of marine fauna such as ammonites, bivalves, and gastropods, as well as terrestrial and freshwater organisms like dinosaurs and crocodyliforms. Plant debris found in some deposits suggests inputs from coastal swamps and forests. The formation's vertical sequences provide evidence of regional transgression over time, with the transition from cross-bedded channel sands to more marine carbonates and shales reflecting the landward migration of shoreline environments. Deposits also provide insights into sediment accumulation processes, with tidal couplets and fine grain size indicating intermittent low-energy conditions with slow sedimentation rates, but event beds with rip-up clasts recording periodic storms and flood events. The preservation of some fossils implies rapid burial events. These findings support the proposed transgressive Systems Tract interpretation and offer additional insights into the depositional environment and processe (El Atfy et al., 2023).

In summary, the depositional model, utilizing lithological, paleontological, and sedimentological data, effectively reconstructed the intricate arrangement of depositional settings, lateral relationships, vertical sequences, and sedimentary processes that gave rise to the diverse strata of the Bahariya Formation. The model showcases how a gently sloping seaward transition, characterized by a mix of fluvial, tidal, and shallow marine influences, led to the development of a varied coastal system over an extended period.

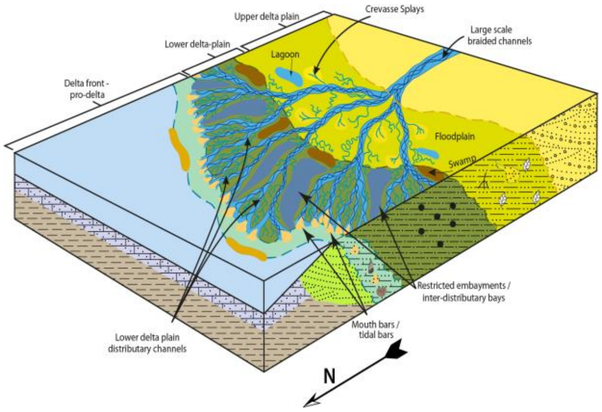

Fig. 14. Simplified geological model for the different depositional environments of the Bahariya Formation (modified after, Heldreich et al [49]).

6. Conclusions

This paper provides a detailed account of the lithofacies of the Lower Cenomanian Bahariya Formation in Egypt's Western Desert. This formation is composed mainly of clastic deposits, which have been studied extensively to understand the depositional environments of the area. Based on lithological and paleontological characteristics, the formation has been divided into thirteen facies, further classified into six facies associations. Each of these facies associations provides valuable insights into the geological processes that shaped the area and the factors that influenced the sedimentation.

The facies types observed in the Bahariya Formation suggest deposition in a range of environments, such as fluvio-deltaic, coastal plain, lagoonal, estuarine, and shallow marine environments. This variety of environments reflects the complex geological history of the region, which tectonic forces, sea level fluctuations, and climatic changes over millions of years have shaped.

Some of the most common lithofacies observed in the Bahariya Formation include fine-grained sandstone, laminated siltstone and claystone, grey mudstone, grayish-green mudstone, variegated shale, cross-bedded sandstone, shell-rich bed, ferricretes, thin-laminated sandstone, and massive sandstone. Each of these lithofacies provides valuable insights into the depositional environment and the geological history of the area.

Overall, The Bahariya paleoenvironment has been extensively researched, revealing its unique features. The area was a forested wetland with low-energy paralic sediments and may have been home to various plant and animal species.

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