Lithostratigraphic characterization of the phosphate bearing sedimentary sequence of some occurrences in Dakhla Oasis, Western Desert, Egypt

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Abstract

The south of the Western Desert of Egypt exhibits well exposures of Late Cretaceous successions, represented by the fluvio-marine (Nubian sandstone group) and shallow marine deposits. The phosphate bearing horizons of Abu-Tartur plateau and Dakhala Oasis are concentrated in the base of Duwi Formation, Campanian age. Duwi Formation uncomfortably overlies Quseir variegated shale and conformably and partially uncomfortably overlain by Maastrichtian Dakhla shale. The phosphate layer of Duwi Formation at Abu-Tartur and Dakhla Oasis regarded as the main sources of the phosphorites of Egypt. This research aims to provide a comprehensive understanding of the geological framework and lithostratigraphic characteristics of the phosphate bearing sedimentary sequences of Dakhla Oasis, which extends from west Abu-Tartur to Gabal-Edmonston in the Dakhla Oasis, with a special focus on phosphorite deposits and the associated non-phosphate interlayers. The study combines regional stratigraphic and lithological investigations to elucidate the vertical and lateral distribution patterns of phosphorite layers. The results will contribute to knowledge of phosphorite formation processes and evaluation of potential resources in the study area.

Keywords: Western Desert; Dakhla; Egypt; phosphate.

Introduction

The Abu-Tartur and Dakhla Oasis region of Egypt is renowned for its geological significance and abundant mineral resources [**1**, **3**]. The exposed rock formations in this area span from the Upper Cretaceous to Lower Eocene and Quaternary periods [**16**], (Fig. 1). The geological structures in this region are relatively simple and have experienced minimal tectonic forces, which have preserved them in a relatively undisturbed state [**11**].

Dakhla Oasis is situated in the heart of the Western Desert, approximately 500 km away from the Nile Valley [**2**]. It occupies a structural basin that lies about 90-140 meters above sea level, covering an area of around 1400 km² [**8**]. The exposed rock units in the region, ranging from the Teneida to Abu-Minqar, include the Taref and Quseir formations of the Nubian Sandstone Group (Pre-Maestrichtian age), Duwi (Lower Maastrichtian), and Dakhla (Maastrichtian-Paleocene) formations. Additionally, there are Quaternary deposits composed of aeolian, fluviatile, and lacustrine sediments that have been influenced by wet and dry phases [**15**, **17**]. The lithological characteristics of Duwi Formation consist of alternating phosphatic and non-phosphatic beds. The phosphatic beds primarily comprise phosphatic mudstone, wackstone, packstone, and grainstone [**1**, **14**], (Fig. 2C). The area is particularly renowned for its phosphate deposits, which hold economic significance. These deposits form a nearly continuous phosphate bed, with minor clay intercalations, reaching a thickness of 4.5 to 6.6 m in certain parts of the southeastern sector of the Abu-Tartur plateau. These phosphate layers represent the eastern extension of the Eocene Tethyan phosphogenic province, which also includes the substantial reserves found in North Africa, particularly in Morocco and Tunisia [**6**, **9**].

Duwi Formation, which is exposed in the Abu-Tartur Plateau and the Dakhla Oasis area, is the primary host for phosphorite deposits in the region. Within the lower member of the Duwi Formation, there is a productive phosphorite bed that displays varying thickness, ranging from 0.7 to 10 meters. On average, the economically viable phosphorite beds are around one meter thick [**5**]. While the average thickness of phosphorite layer is approximately one meter, there are occurrences within the Abu Tartur Plateau where the phosphorite beds can exceed nine meters in thickness. These thicker deposits represent notable concentrations of phosphorite resources in the area. The presence of such significant phosphorite beds highlights the economic importance of this region in terms of phosphate mining and production [**7**, **13**].

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The extensive presence of phosphorite deposits in the Abu Tartur and Dakhla Oasis region underscores their economic significance. These deposits offer potential opportunities for mining operations that can support various sectors reliant on phosphorus-based resources.

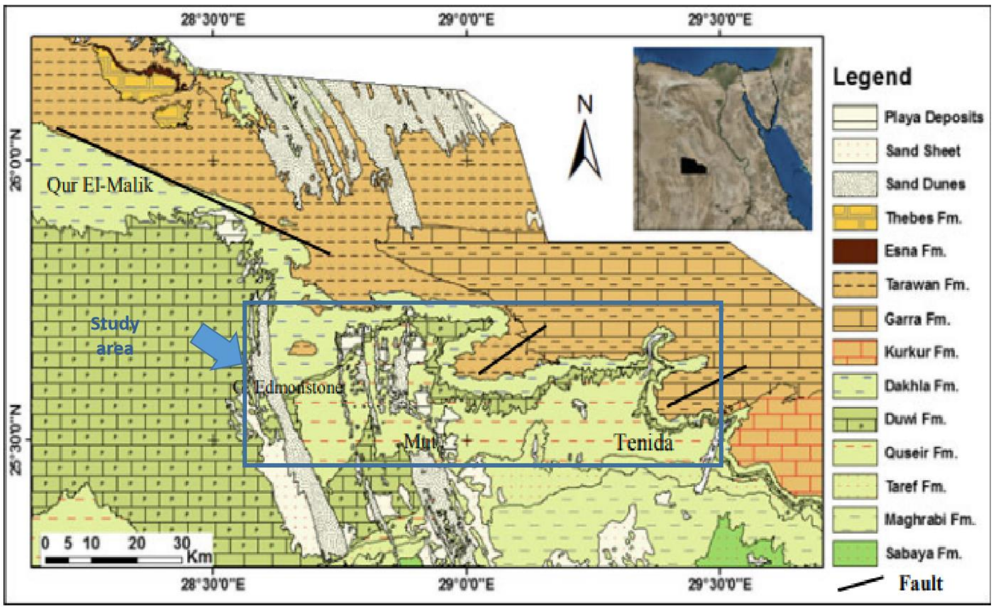

Fig. 1: Geological map of Dakhla Oasis, showing the study area (blue rectangle) (modified after **10, 11, 16**)

The aims and objectives of the study are as follows

1. Review the regional geological setting of the study area and its surroundings to understand the lithostratigraphic characteristics of the unexploited phosphorite ore deposits within the study outcrops. This will involve examining the geological context and determining the geological formations and structures present in the area.
2. Demonstrate the lateral and vertical variations in lithology, composition, texture, and sedimentary structure of the phosphorite sequences and associated rocks. This will enable the correlation of the different study sections with each other and with the Abu-Tartur composite section, which serves as a reference for comparison.

Materials and Methods

Field works

Fieldwork was conducted to investigate the geological characteristics of the unexploited phosphorite deposits in the study area. Each site within the Duwi composite stratigraphic section was thoroughly examined from the top of the Quseir variegated shale to the base of the Dakhla shale. The fieldwork involved lithological description, measurements, and sampling, with a focus on the phosphorite intervals and associated non-phosphatic beds. The thickness of the study sections and their individual beds was measured, and photographs were taken using a digital camera Nikon D780 (AF-S Nikkor 70-200 mm 1:28 E.F / 28 LE DVR) to document the field observations. The field descriptions encompassed the identification of lithological changes, sedimentary structures, bioturbation and erosion surfaces, as well as megascopic compositional features, karst formations, and fracture intensity. Approximately fifty samples were collected to represent each stratigraphic unit of the Duwi Formation, particularly the phosphorite intervals. Whenever a significant change in lithological character was observed, detailed descriptions and sampling were carried out for each interbed.

Side geology

The research aimed to update the understanding of the geological characteristics of the unexploited phosphorite deposits located west of the Abu-Tartur plateau in the Dakhla depression. This included analyzing the geomorphological setting of the study area as part of the larger Dakhla plateau, as well as describing the stratigraphic sections and establishing correlations based on the fieldwork findings.

The study area

The study area is situated approximately 600 km southwest of Cairo and 50 km west of El-Kharga Oasis in the Western Desert. It lies along the western margin of the plateau and is positioned between the Abu Tartur and

Gabal Edmonston areas. The study area is bounded by latitudes 25° 20'N to 25° 50'N and longitudes 28° 54'E to 29° 25'E, (Fig. 3)

The Duwi Formation, which represents phosphorite deposits from the Late Campanian to early Maastrichtian period, is extensively distributed in the study area along the northern escarpment of Dakhla Oasis and Gabal Edmonstone. This region holds significant potential for unexploited phosphorite deposits within the Dakhla Oasis. The exposed phosphorite deposits are covered by relatively thin overburden shale layers. In order to investigate the stratigraphy of the area, six sections were surveyed and sampled. These sections were selected to cover the uncomfortable contact between the underlying Quseir Formation and the overlying Dakhla shale. The sections, arranged from east to west, are as follows:

Teneida Composite Section- labeled as (A), North Teneida Section - labeled as (F), Eweina Section - labeled as (E), Hindaw Section - labeled as (D), Qasr Section - labeled as (B), North Qasr Section - labeled as (C). These sections were studied in the field to gather information about the stratigraphy and obtain samples for further analysis (Fig. 2).

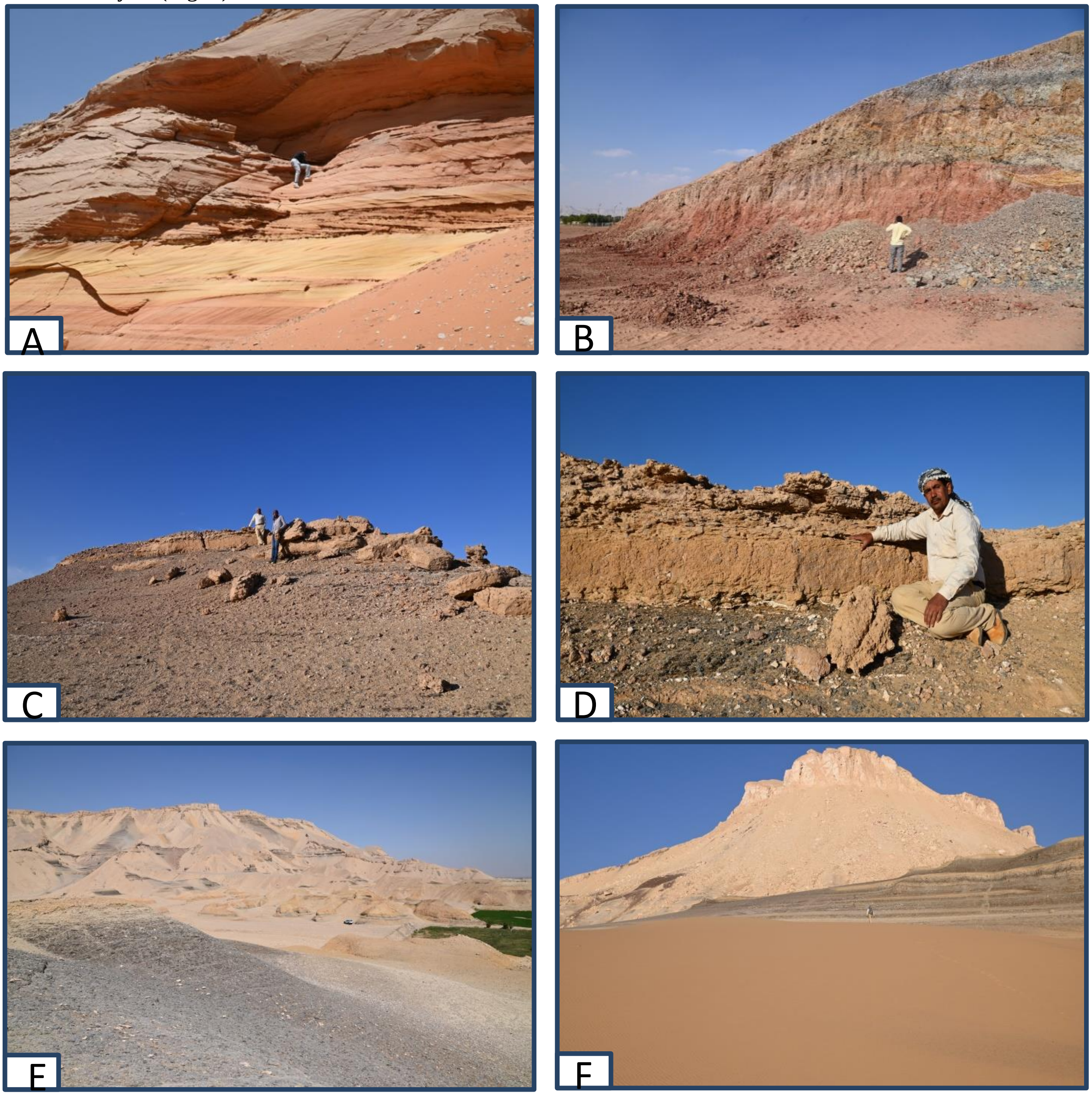

Fig. 2. Stratigraphic successions of the study area. **A**: ferruginous, cross bedded sandstone of Taref Formation, **B**: variegated shale of Quseir Formation, **C**: dark laminated shale, intercalated by phosphatic layers of Duwi Formation. **D**: fossiliferous, phosphate bearing layer at the top of Duwi Formation, **E**: General view of Dakhla Formation, northwest Dakhla, **F**: Grayish white limestone of Tarawn Formation, at the top of Dakhla Formation.

Stratigraphic sections

Six stratigraphic sections are measured and described in the field; these are from east to west: Teneida (A), North-Teneida (F), Eweina (E), Hindaw (D), Qasr (B), and North-Qasr (C) sections. Each section is subdivided into three units: lower, middle and upper units where each unit start by phosphorite beds followed by up word by dark colored shale and topped by hard carbonates beds (figs.4-9 inclusive). The measure stratigraphic sections are briefly described as follows.

The Teneida section A (Fig. 4)

The lower unit of the Duwi Formation in the Teneida section exhibits distinct layers of different rock types. The base of the formation is marked by a clear boundary between lower shale and a 1 m thick layer of white to yellow, hard silt-sized detrital quartz grains. This layer also contains fossiliferous phosphatic limestone, alternating with shale. Above this layer, there is a 0.75 m thick layer of yellow fossiliferous phosphate. This contains skeletal remains such as fish debris and bone fragments. Many of the sand-sized grains in this layer have oval shaped resembling phosphatized fecal pellets and exhibit poor sorting and angularity.

On top of the phosphate layer, there is about 6 m layer of laminated shale. This shale has a black to gray color and consists of fine layers that easily split apart (fissile). It is abundant in organic matter and displays thalassinoidal structure at the top. Finally, the uppermost layer of this unit is composed of yellow fossilferous dolostone with a distinct boundary separating it from the underlying unit.

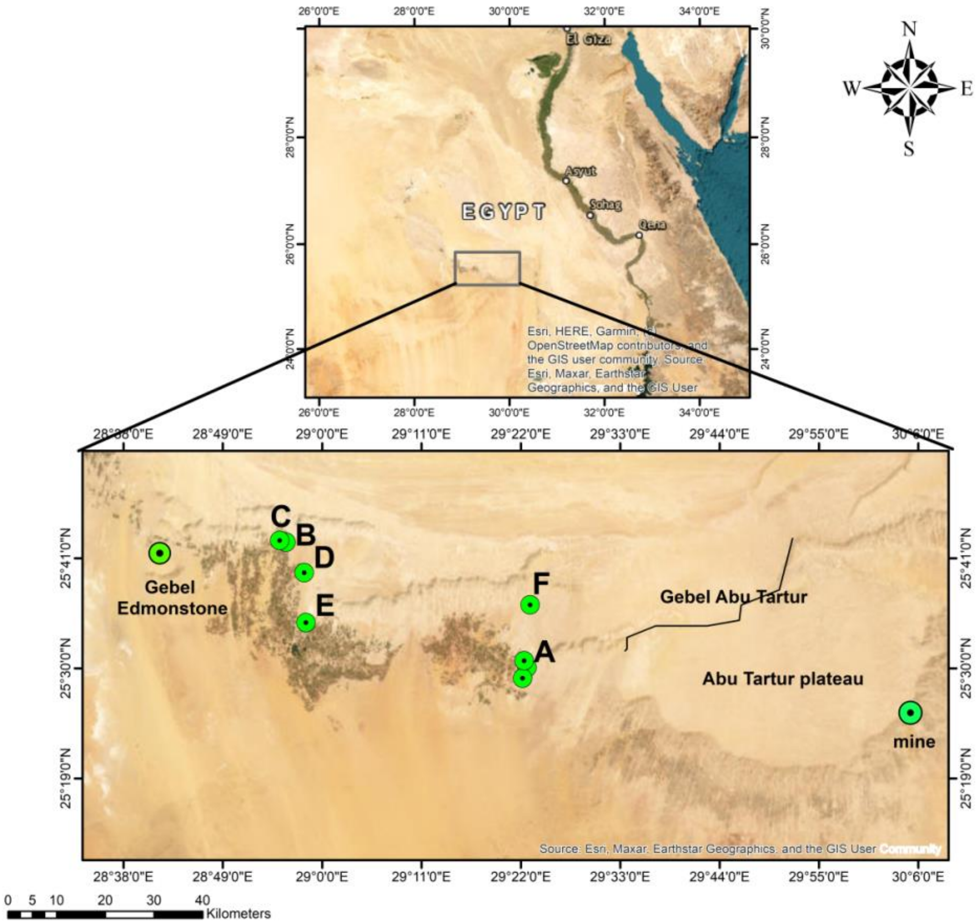

Fig. 3. Satellite image of the study area, showing the location of the studied stratigraphic section, (**A**) Teneida composite section, (**B**) North Qasr section, (**C**) Qasr section, (**D**) Hindaw section, (**E**) Ewiena section, (**F**) North Teneida section.

The middle unit of the Teneida section begins with a 0.75 m thick layer of yellow phosphate rock containing fossils, shark teeth, and grains of similar sizes. This is followed by a 1.5 m thick layer of dark shale with thin layers and a hard top. Next is another 0.75 m thick layer of yellow phosphate rock with fossils, pebbles, and oval-shaped grains of similar sizes. This is followed by 2 m thick layer of brown-gray shale with thin layers and burrows on the top. The sequence includes a 0.5 m thick layer of hard, cliff-forming yellow limestone. **The upper unit of the Teneida section** is composed of a 0.5 m layer of yellow phosphate conglomeratic fossiliferous rock contains skeletal remains and oval grains that are moderately sorted. This layer is overlain by 30 cm thick brown gray laminated shale with thalasinoidal structures at the top. This shale bed is covered by pale yellow sandy, fossiliferous limestone.

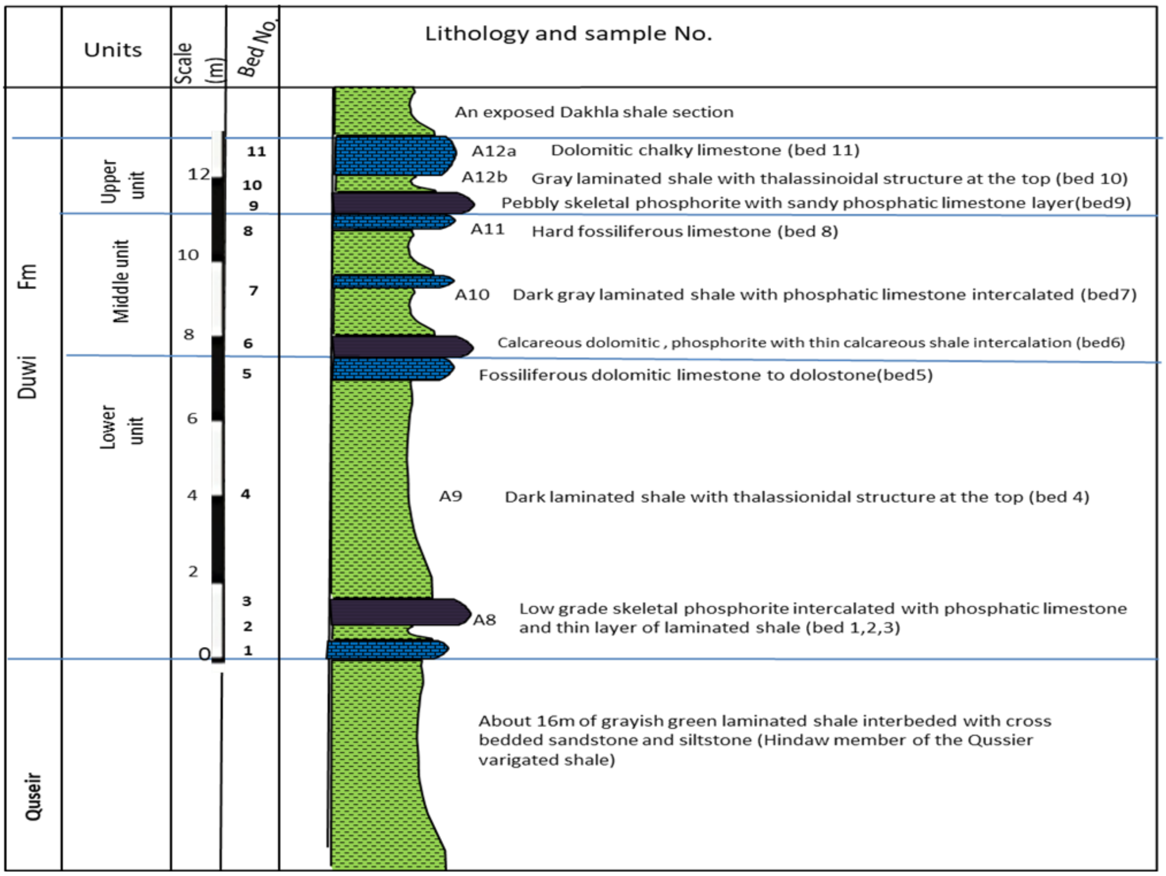

Fig. 4. schematic lithostratigraphic section of Teneida (section A)

The North Teneida section F (Fig. 5)

The lower unit of the north Teneida section starts with 1.5 m thick layer of yellow phosphate rock with fossils and pebbles, interspersed with thin shale layer, followed by 2 m thick layer of pale gray shale with thin layer. Finally there is 0.5 m thick layer of hard yellow limestone with fossils, (Fig. 10a).

The middle unit begins with a layer of yellow phosphate rock, containing fossils, pebbles and grains of different sizes and shapes. This is followed by 2.5 m thick layer of pale gray shale with thin layers of phosphorites. Finally, there is 1 m thick layer of hard yellow limestone with fossils.

The upper unit of the north Teneida section is composed of several distinct layers, based by 0.5 m layer of yellow fossiliferous dolomitic phosphate, characterized by angular and rounded grains. This layer is then overlied by 2.5 m layer of gray laminated shale. Lastly, the uppermost layer consists of 1.5 m yellow fossiliferous limestone.

The Eweina section E (Fig. 6)

The lower unit of the Ewiena section begins with 1 m thick layer of yellow phosphate, containing fossils. This is followed by 3.5 m thick layer of gray shale with numerous burrows. The unit ends with hard dolomitic fossiliferous limestone layer, (Fig. 10b).

The middle unit starts with 0.75 m thick layer of yellow phosphate rock containing fossils and grains of different sizes. This is followed by 4 m thick layer of gray shale with thin layer of phosphorite. This unit ends with 1 m thick layer of limestone containing fossils.

The upper unit of Eweina section is based by yellow fossiliferous phosphate which contains skeletal grains (shark teeth and fish bones) and poorly sorted. This layer overlay by 3 m gray laminated shale with thalasinoidal structures at the top. Above this layer is a hard yellow fossiliferous limestone that sharp contact with shale.

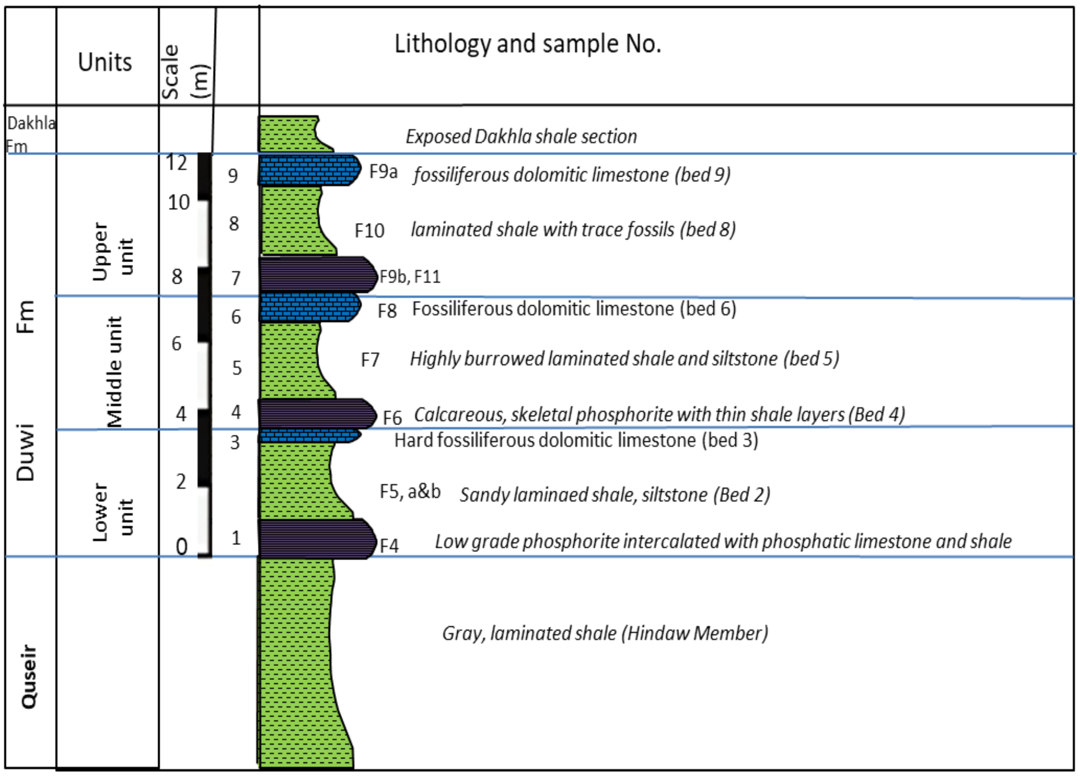

Fig.5. schematic lithostratigraphic section of North Teneida (section F)

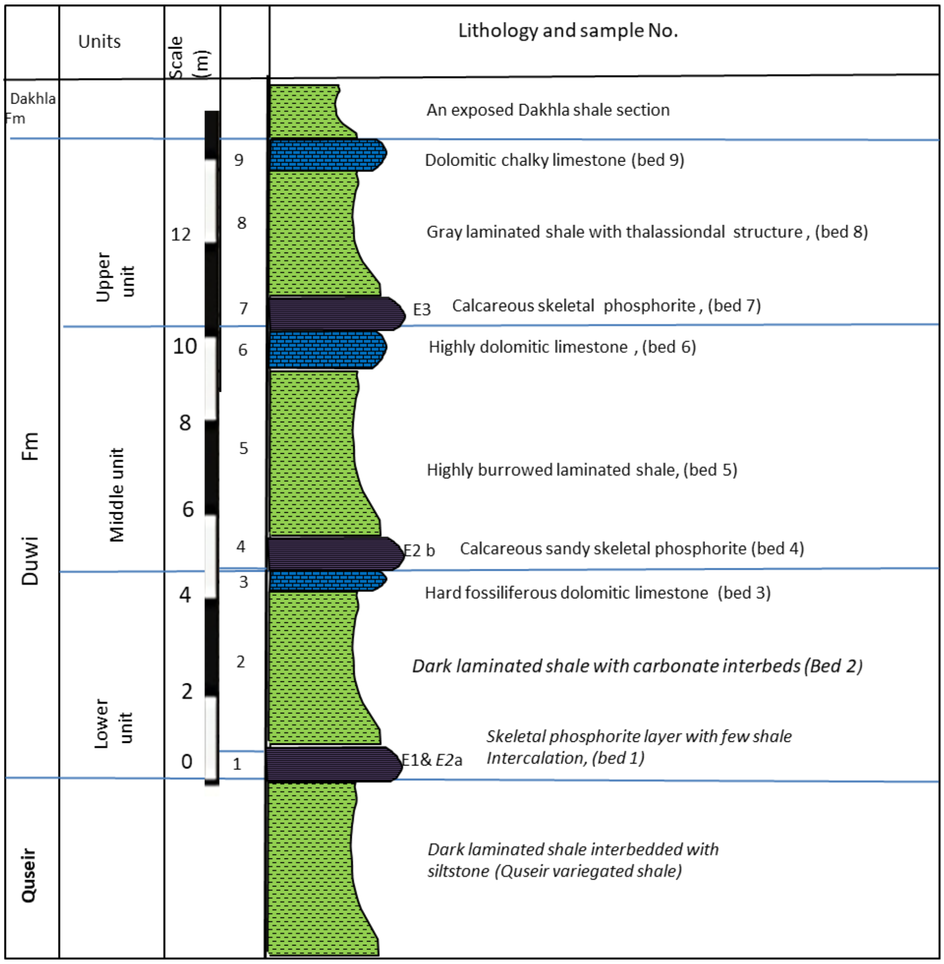

Fig. 6. schematic lithostratigraphic section of Eweina (section E)

The Hindaw section D (Fig. 7)

The Hindaw section, **the lower unit** begins with a 1 m thick layer of yellow phosphate sand with fossils and grains of different sizes. This is followed by 3 m thick layer of dark shale. Finally the unit ends with a 30 cm thick layer of dolostone that contains fossils, (figs. 10c, d & e)

The middle unit is characterized by a 0.5 m layer of yellow fossiliferous skeletal phosphate, consisting of moderately sorted and oval grains. This layer is followed by 7 m thick dark laminated shale intercalated with yellow marl. The unit is topped by a 1 m thick layer of yellow hard fossiliferous dolomitic limestone.

The upper unit of the Hindaw section is composed of three successive beds of 1 m phosphorite intercalated with dark shale containing skeletal remains and exhibiting moderate sorting. This layer is followed by a 1 m layer of dark laminated shale. Above the shale is another 0.5 m layer of yellow skeletal phosphatic, this is succeeded by a 2 m layer of gray laminated shale. On top of the shale is a 0.5 m layer of yellow fossiliferous phosphate, once again containing skeletal remains and exhibiting moderate sorting. Finally, the uppermost layer consists of a 1 m yellow fossiliferous dolomitic limestone.

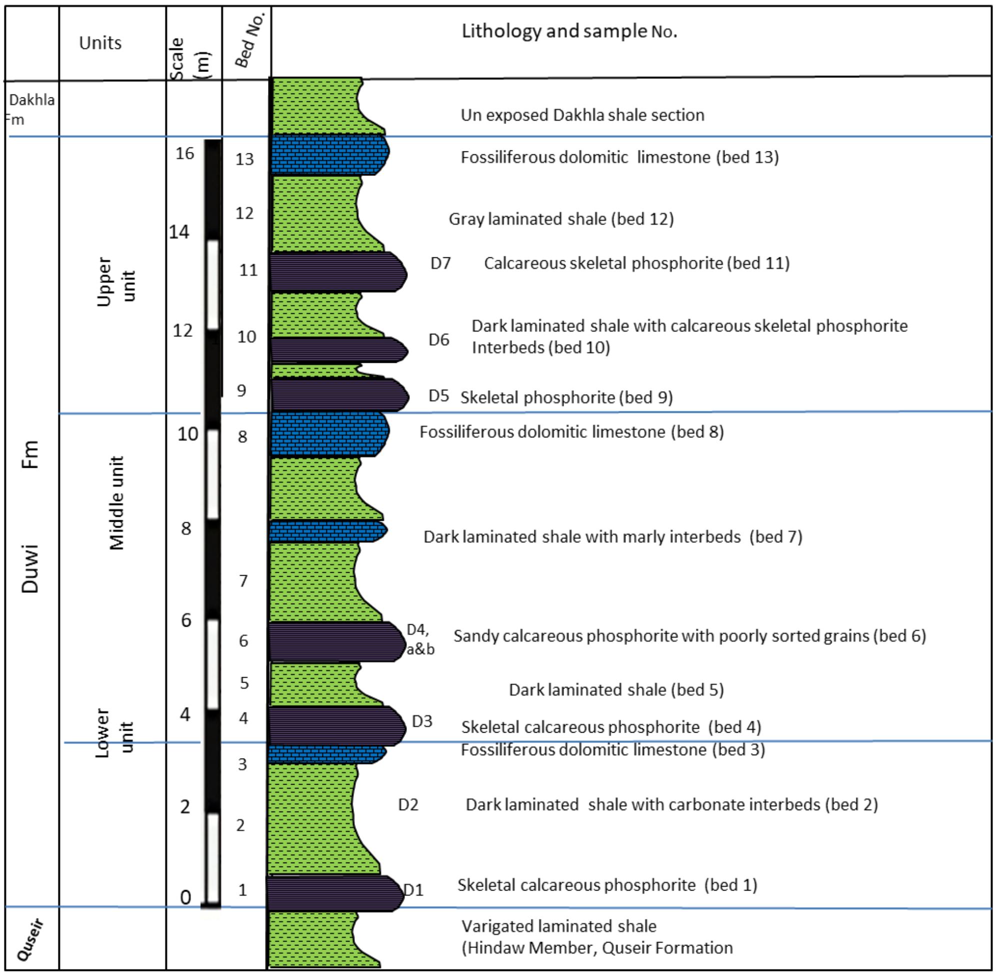

Fig. 7. Schematic lithostratigraphic section of Hindaw section (section D)

The Qasr section B (Fig. 8)

The lower unit of Qasr section starts with 0.5 m thick layer of yellow phosphorite with shark teeth and grains of varying sizes. Next, there is a 3 m thick layer of gray to dark shale, topped by 0.5 m thick layer of yellow dolomitic fossiliferous limestone.

The middle unit begins with a 1.5m-thick layer of gray, hard, calcareous phosphate containing fossils. This is followed by a 3.5 m thick layer of dark shale with laminations, interspersed with yellow dolostone layers that also contain fossils. On top of that, there is a 0.5 m thick layer of fossiliferous dolostone.

The upper unit of the El Qasr section consists of about 4 m thick of alternating layers of dark laminated shale, fossiliferous limestone and calcareous phosphate layers, these layers are topped 0.5 m layer of hard yellow fossiliferous dolomitic limestone.

The North Qasr Section C (Fig. 9)

The North El Qasr section begins with **the lower unit** a 0.5 m thick layer of yellow sandy siltstone and phosphorite. This is followed by 3.5 m thick layer of dark shale with thin layers of dolomitic limestone. The unit is topped by a fossiliferous limestone.

The middle unit starts with 0.5 m thick layer of hard yellow phosphate rock that lacks fossils. This is followed by 5 m thick layer of dark shale with thin layers, interbedded by thins layer of skeletal phosphorite. The unit ends with a 0.5 m thick bed of hard yellow fossiliferous limestone. **The upper unit** is formed of 5 m thick of gray laminated shale, intercalated with thin layers of fossilifrous phosphorites. The unit is topped by fossiliferous dolomitic limestone.

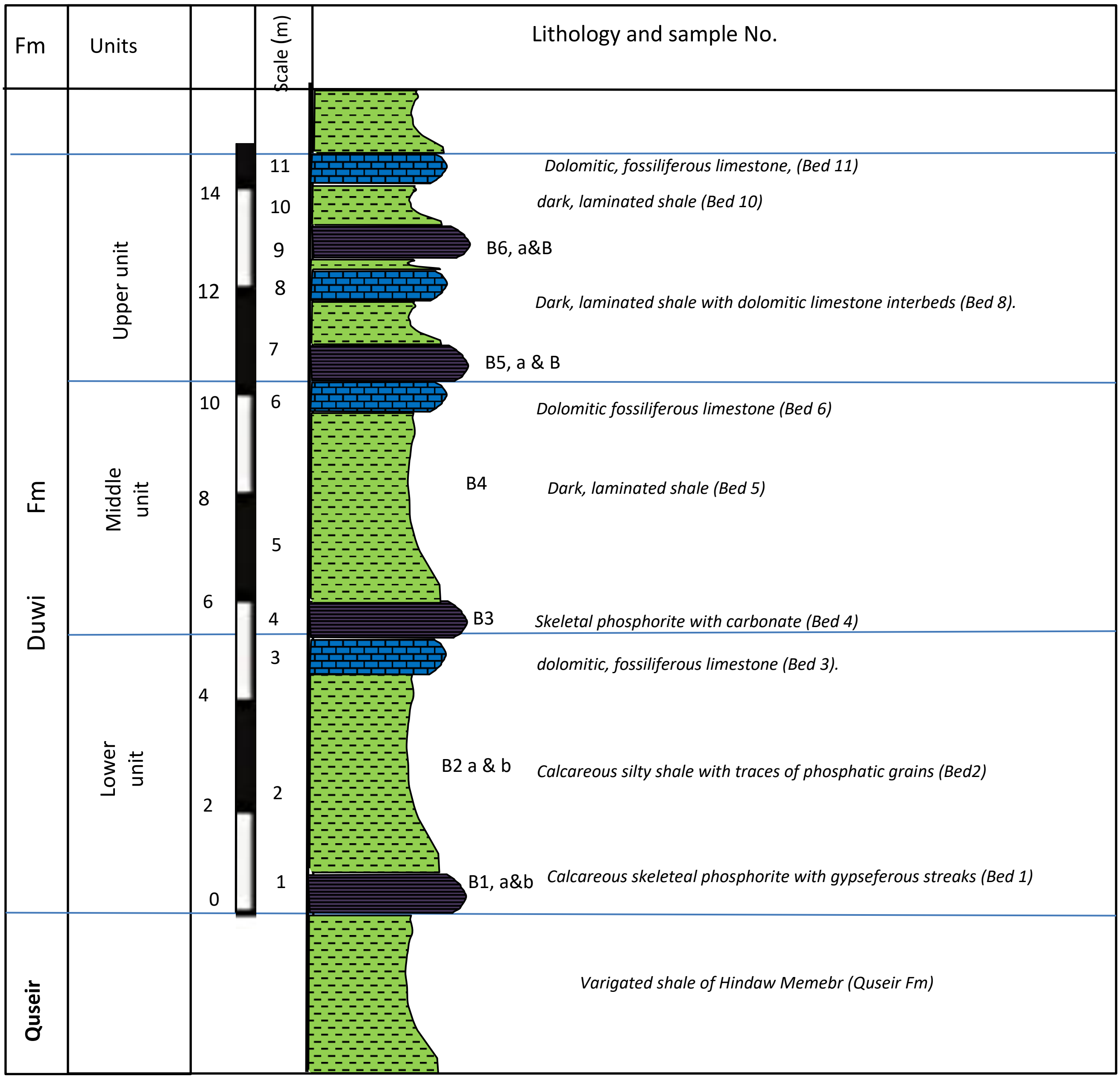

Fig. 8. Schematic lithostratigraphic section of Qasr section (section B)

Lithostratigraphic subdivision and correlation

The Duwi Formation in the study area could be subdivided vertically into three remarkable units (lower, middle, and upper units), which are considered as depositional sequences of beds rather than lithological units. The sequences of the beds represent repeated similar depositional models which may reflect repeat sea level fluctuations during their deposition. They show some variation in the overall thickness, lithology, contacts of interbedded or intercalation and sedimentary structures. Based on these sedimentological characteristics each depositional sequence unit is marked by three lithofacies association: phosphorite lithofacies (P) association that followed upward by mudrock (Sh) and carbonate (Dl) dominated association (Figs.2-15).

Among the study six sections Teneida section (the nearest section to the Abu Tartur plateau) is considered as model section to which all other sections can be correlated (Figs.2-15).

Slight variation in thickness with noticeable lateral changes in bedding shale and lithology are detected in both depositional sequences and lithofacies associations as given in table 2-2.

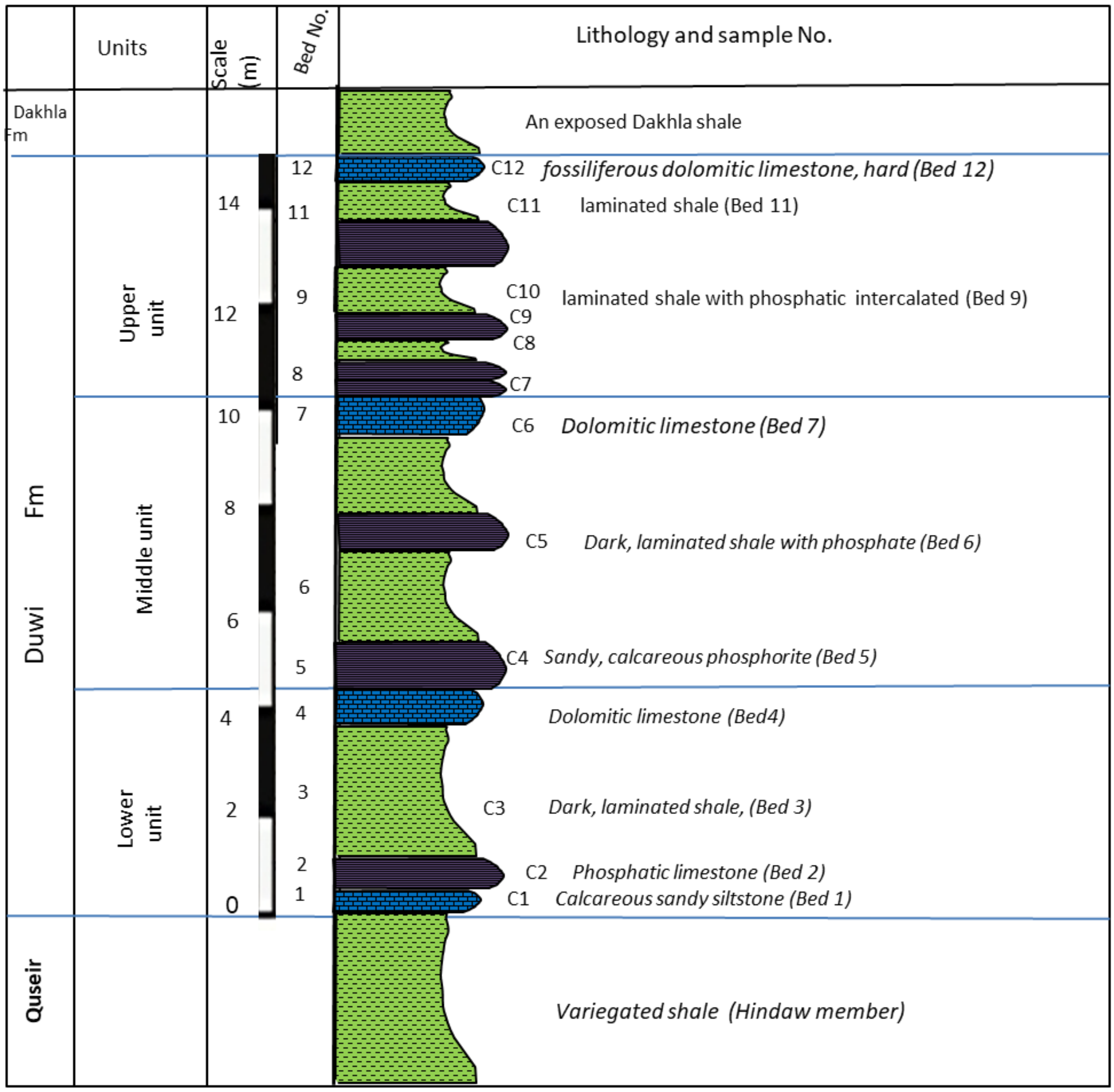

Fig. 9. Schematic lithostratigraphic section of North El-Qasr (section C)

The correlated phosphorite association in the study sections, is characterized by the following properties:

1- The phosphorite association represents the basal beds of each sequence exhibiting lateral changes in facies and thickness. The average thickness is about one meter for individual phosphorite beds or more than 3.5 meter for the interbedded association (e.g the upper unit of Hindaw, Qasr, and North Qasr sections). Laminated shale and phosphatic limestone or very fine grain sandstone are the main types of the interbeds in the phosphorite association in the upper and middle units of some sections (Figs.2-15).
2- The lower surface of phosphorite association is usually irregular, erosive, scour and associated with abundant thalassinoids burrowing networks (figs. 2-16).
3- One common feature of nearly all sections is extensive bioturbation. As a result, most of the phosphatic beds appear massive and internally structurless [5]. The original internal deposional structures could have been destroyed by bioturbation and dewatering [15]. Furthermore the phosphorite beds are commonly associated with black shale or siltstone interstratification indicating phases of intermitted mud sedimentation and soft ground condition.
4- The majority of the phosphorite intervals show moderately to poorly sorting grain size. Fining upward beds (gradual upward decrease in size of the phosphorite grains) are common in the form of graded bedding.

Such sedimentological structure may be due to change in flow conditions during sedimentation. In agreement more or less with [15]) conclusion, the phosphorite beds like carbonate romps and graded beds, may be deposited from waning storm currents as turbidities and clastic continental shelves.

5- On the other hand, the mudrocks lithofacies association consists mainly of relatively thick intervals of dark laminated gypsiferous shale or siltstone showing considerable changes laterally in thickness. The shale association is commonly fissile, organic rich and dark in color. Occasionally, it is partially changed to siltstone or calcareous mudstone with fine grained sandstone as detected in Qasr (B) and North Qasr (C) sections. The dark shale association in the middle unit is interbedded with thin slightly phosphatic limestone beds (e.g. in Teneida (A), Hindaw (H), and North Qasr (C) sections). The shale association of the upper unit is further characterized by occurrence of microfauna (e.g foraminiferal tests) and gypsum veinlets of digenetic origin. The lower and upper contacts of mudrocks intervals with phosphorite and carbonate association respectively are sharp and conformable, (Fig. 11).

6- The carbonate lithofacies association is mainly represented by dolomitic limestone or/and dolostone. At the top of mudrocks association in the lower, middle, and upper units of the all sections (Fig. 11). It is variable in thickness, dolomite and fossil contents, and sedimentary structure. Occasionally, it grades laterally into coarse grained dolomite or into fossiliferous calcareous shale or chalky limestone. The upper unit (the upper unit depositional sequences) is commonly capped by thick phosphatic limestone with chondrites burrows in the basal 10 cm. the top of this unit terminate the deposition of the Duwi Formation which conformably overlain by open marine shales of the Dakhla Formation. However, the basal part of the Dakhla Formation is not exposed at the top of some sections.

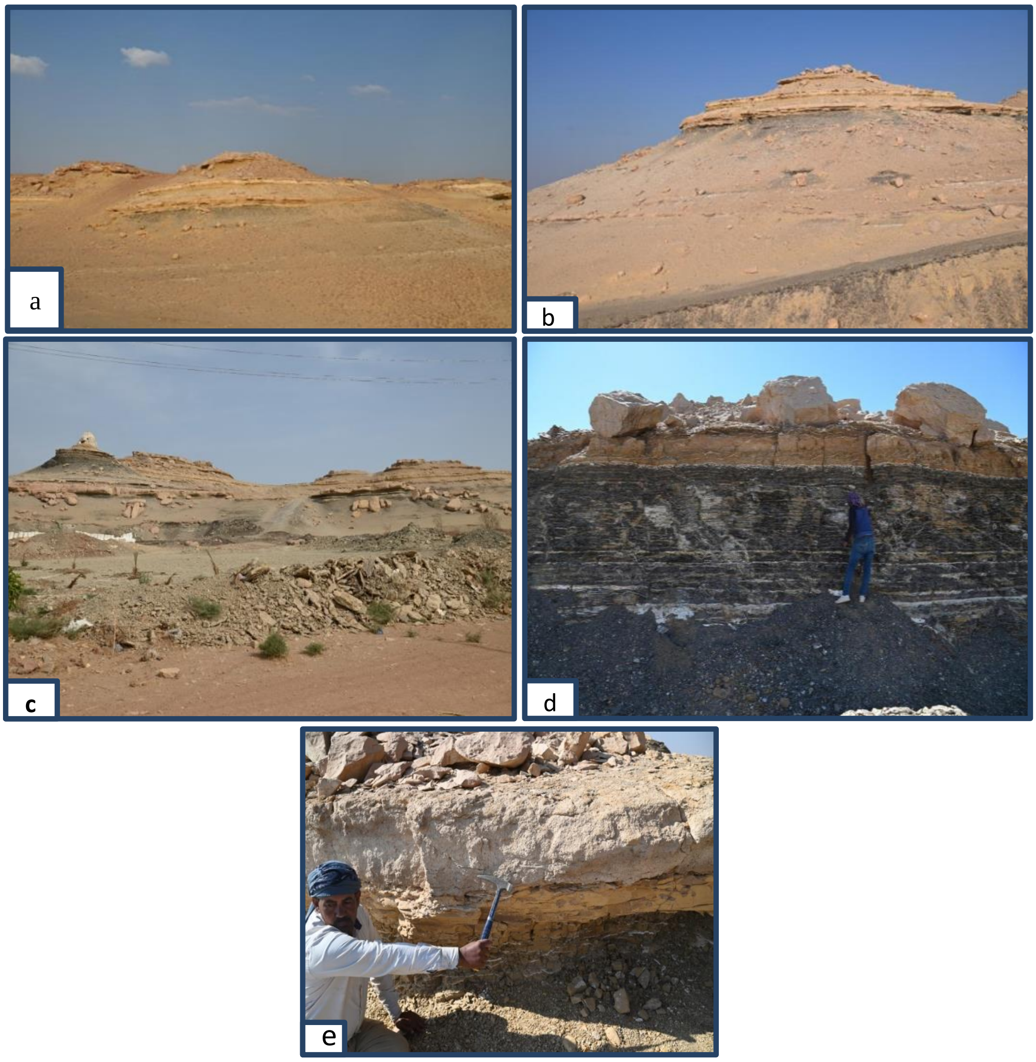

Fig. 10. a) General view of Duwi Formation at North-Teneida section (F), northeast Teneida. b) General view of Duwi Formation at Eweina section, west Mut (E, C) General view of Duwi Formation at Hindaw section, west Mut (D)

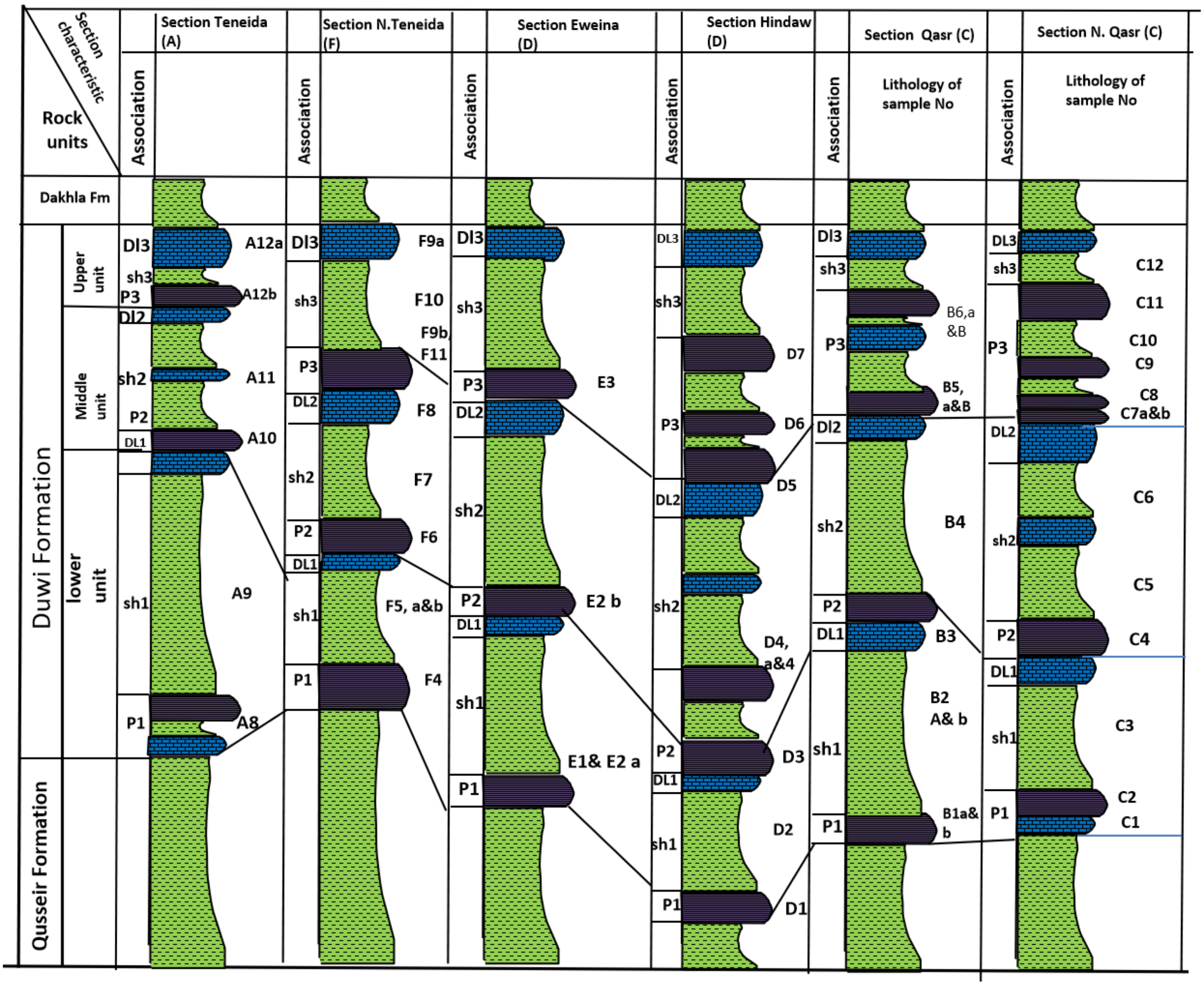

Fig. 11. Correlation chart for the study stratigraphic sections, P: phosphate, sh. Mudrock association, D. carbonate lithofacies association

Conclusion

The Dakhla depression in the southern Egypt including the study area is characterized by several geological Formations Taref Formation, Quseir Formation, Duwi Formation, Tarawan Formation. And the region also contains Quaternary deposits that including thin layers of playa, tufa and lake deposits.

1- the tectonic history of the Dakhla region involved a complex interplay of various tectonic events, including compression, rifting, extension, deformation, and transgressions, which contributed to the geological formations and phosphorite sedimentation in the Western Desert of Egypt.
2- There are six stratigraphic sections measured and described in the field, from east to west: Teneida (A), North-Teneida (F), Eweina (E), Hindaw (D), Qasr (B), and North-Qasr (C) sections. Each section is subdivided into three units: lower, middle, and upper units, characterized by phosphorite beds at the base, followed by dark shale layers, and topped by hard carbonate beds.
3- The Duwi Formation in the study area can be divided into three distinct units: lower, middle, and upper units. These units represent depositional sequences of beds rather than individual lithological units. The bed sequences reflect repeated similar depositional patterns, which may indicate fluctuations in sea level during their formation. There are variations in thickness, lithology, interbedding, and sedimentary structures within each depositional sequence.
4- Based on these sedimentological characteristics, each depositional sequence unit is characterized by three lithofacies associations. The first association is the phosphorite lithofacies (P), which is followed upward by the mudrock (Sh) association, and finally, the carbonate (Dl) dominated association. These lithofacies associations provide insights into the predominant sediment types and environments of deposition within each sequence unit.

References

[1] - Abou El-Anwar, Esmat A. "Lithologic characterization of the phosphorite-bearing Duwi Formation (Campanian), South Esna, West Nile Valley, Egypt." Carbonates and Evaporites 34 (2019): 793-805.

[2] - Belal, A. B., Mohamed, E. S. S., Abdellatif, M. A., & Abdel-Rahman, M. A. (2021). Soil Conditions of Dakhla Oasis, Western Desert, Egypt. Sustainable Water Solutions in the Western Desert, Egypt: Dakhla Oasis, 123-144.

[3] - Brookes, Ian A. "Geomorphology and Quaternary geology of the Dakhla Oasis region, Egypt." Quaternary Science Reviews 12.7 (1993): 529-552.

[4] - Continental Oil Company (CONOCO) (1987) Stratigraphic map of Egypt 1: 500,000. In Maurice Hermina E, Franz K List (Eds).

[5] - El Ayyat, Abdalla M. "Lithostratigraphy, sedimentology, and cyclicity of the Duwi Formation (late Cretaceous) at Abu Tartur plateau, Western Desert of Egypt: evidences for reworking and redeposition." Arabian Journal of Geosciences 8.1 (2015): 99-124.

[6] - El Maghraby, Ashraf. "Phosphate mining wastes at Abu Tartur mine area, Western Desert of Egypt." Australian Journal of basic and Applied Sciences 10.6 (2012).

[7] - Geissler, Bernhard, Gerald Steiner, and Michael C. Mew. "Clearing the fog on phosphate rock data–Uncertainties, fuzziness, and misunderstandings." Science of the total environment 642 (2018): 250-263.

[8] - Giddy, Lisa L. "Egyptian oases: Baḥariya, Dakhla, Farafra, and Kharga during pharaonic times." (No Title) (1987).

[9] - Hellal, F., El-Sayed, S., Zewainy, R., & Amer, A. (2019). Importance of phosphate pock application for sustaining agricultural production in Egypt. Bulletin of the National Research Centre, 43, 1-11.

[10] - Hewaidy, Abdel Galil A., Sherif Farouk, and Youssef S. Bazeen. "Sequence stratigraphy of the Maastrichtian-paleocene succession at the Dakhla oasis, western desert, Egypt." Journal of African Earth Sciences 136 (2017)

[11] - Mansour, H. H., B. Issawi, and M. M. Askalany. "Contribution to the geology of West Dakhla oasis area, Western Desert, Egypt." Annals of the Geological Survey of Egypt 12 (1982): 255-281.

[12] - Ruban, D. A., Tiess, G., Sallam, E. S., Ponedelnik, A. A., & Yashalova, N. N. Combined mineral and geoheritage resources related to kaolin, phosphate, and cement production in Egypt: Conceptualization, assessment, and policy implications. Sustainable Environment Research, (2018). 28(6), 454-461.

[13] - Schwennicke, Tobias, Hendrik Siegmund, and Caroline Jehl. "Marine phosphogenesis in shallow-water environments: Cambrian, Tertiary, and recent examples." (2000).

[14] - Tantawy, A. A., Keller, G., Adatte, T., Stinnesbeck, W., Kassab, A., & Schulte, P. Maastrichtian to Paleocene depositional environment of the Dakhla Formation, Western Desert, Egypt: sedimentology, mineralogy, and integrated micro-and macrofossil biostratigraphies. Cretaceous Research, (2001). 22(6), 795-827.

[15] - Tucker, Maurice E., and Stuart J. Jones. Sedimentary petrology. John Wiley & Sons, 2023.

[16] - Zaghloul, Elsayed A. "Geology of Dakhla Oasis, Western Desert, Egypt." Sustainable Water Solutions in the Western Desert, Egypt: Dakhla Oasis (2021): 29-44.