



## Contribution to the lithostratigraphy of the Middle Miocene Marmarica Formation at Siwa Oasis, Egypt

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**Abstract:** The lithostratigraphy of the Marmarica Formation at Siwa Oasis was examined; following the classification of [1]. For a proper characterization of the different rock types, the contents of dolomite and calcite were determined in one hundred and three carbonate samples collected from the area under study. Also, carbonate-sand-mud composition was obtained from seventy-eight shale and argillaceous carbonate samples. Comparison with the previous studies indicated that the thickness of the dolostone strata was underestimated. The abundance of dolostones suggests that dolomitization represents the major diagenetic process in the carbonate sediments of the Marmarica Formation at Siwa Oasis.

The Oasis Member is relatively rich in shale, limestone, dolostone, in addition to cross-bedded coquina and local shell banks with abundant bivalves. The attribute of the Oasis Member refers to deposition in shallow marine and high energy environment. The Siwa Escarpment and El Diffa Plateau members consist mainly of thick bedded, chalky dolostones in addition to some limestones and dolomitic limestones.

The remarkable decrease in clastic sediments and current induced structures in the carbonate dominated sequence of the Siwa Escarpment and El Diffa Plateau members, compared with the Oasis Member suggests relative deepening of the original marine conditions.

**keywords** Lithostratigraphy, Marmarica Formation, Middle Miocene, Siwa Oasis

### 1. Introduction:

The northern part of the Western Desert of Egypt is dominated by the Middle Miocene Marmarica Formation; which unconformably overlies the fluviomarine Lower Miocene Moghra Formation. The northern escarpment of the Siwa Oasis, about 5 km to the north of Siwa village (Latitude 29° 16' N and Longitude 25° 31' E), is the type locality of the Marmarica Formation with a thickness of 78 m. [2] divided the Marmarica Formation in the Siwa area to an upper white limestone member and a lower member of gray calcarenites with some shale intercalations. [1] divided the Marmarica Formation into three members from base to top; the Oasis, Siwa Escarpment, and El Diffa Plateau. The subdivision of the Marmarica Formation into three members was followed in several studies (e.g., [3], [4], [5], [6], [7] and [8]). According to [9], the Marmarica Formation at Siwa Oasis is subdivided into two

units; the lower unit is coeval to the Oasis Member and the Siwa Escarpment Member while the upper unit is equivalent to the El Diffa Plateau Member (sensu [1]). According to [1], the finding of *Borelis melo* in the lower Oasis Member places this unit as Middle Miocene and not Lower Miocene as was suggested by [2]. [6] recorded *Borelis melo* and *Borelis melo curdica* in the Oasis Member of Siwa Oasis which imply a Late Burdigalian to Langhian (Early to Middle Miocene). A Langhian to Serravallian (Middle Miocene) age was suggested for the Siwa Escarpment and El Diffa Plateau members; based on the abundant *Borelis melo melo* as well as the associated micro- and macro-fauna [6].

### 2. Material and methods

The present work is based on three stratigraphic sections (**Fig. 1**). From west to east, these

sections are Girba Oasis (Lat. 29° 18' 27.5" N and Long 25° 21' 3.8" E, **Fig. 2a**) Naqb El-Migahhiz (Lat. 29° 16' 30.5" N and Long. 25° 31' 35.8" E, **Fig. 2b**) and Umm Hiyus (Lat. 29° 16' 0.8" N and Long. 25° 41' 28.1"E, **Fig. 2c**). The three members of the Marmarica Formation were recorded in both the Naqb El-Migahhiz and Girba Oasis sections, whereas in the Umm Hiyus section there are only two members; the Oasis and the Siwa Escarpment. The apparent lack of the El Diffa Plateau Member at Umm Hiyus was observed by [1] and [6].

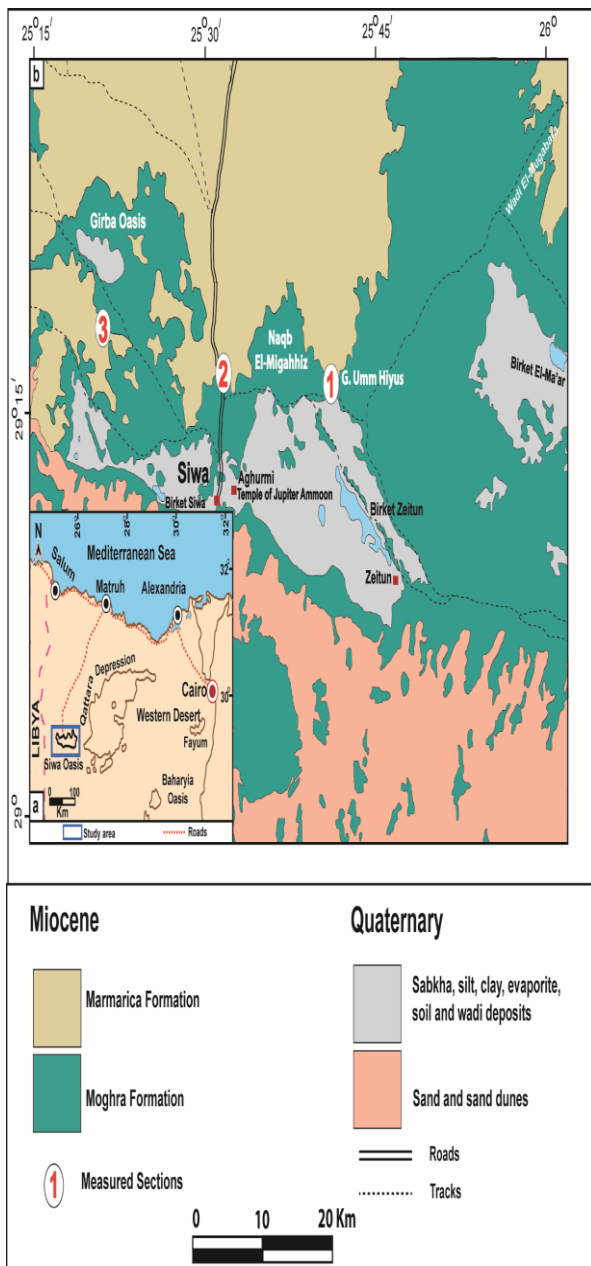


Fig. 1: (a) Location map of the northern part of the Western Desert and the study area, (b) Geological map of Siwa Oasis (compiled and modified after [10]).

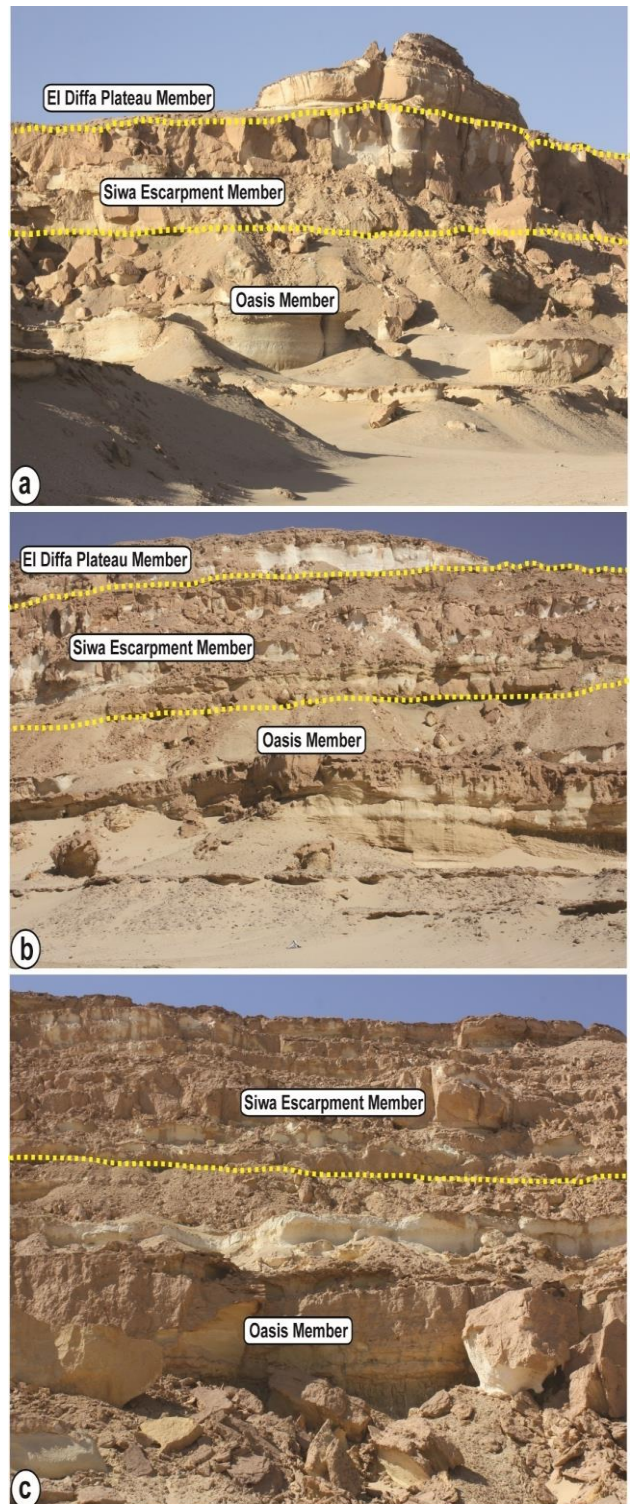


Fig. 2:(a, b) Slope-forming strata of the Oasis Member which underlies the cliff-forming beds of the Siwa Escarpment and El Diffa Plateau members at Girba Oasis (section relief is~63 m) and Naqb El-Migahhiz (section relief is~61m), (c) Field photograph showing the Oasis and Siwa Escarpment members at Umm Hiyus (section relief is~111m).

For a proper characterization of the different rock types, the contents of dolomite and calcite were determined in the measured

sections. One hundred and three rock samples were chemically analyzed for the contents of Ca and Mg by the titration method using EDTA. The chemical data were used to calculate the amounts of dolomite and calcite. Due to the presence of several shale and argillaceous carbonate units especially in the Oasis Member, the contents of carbonate-sand-mud were determined in seventy-eight samples using dilute HCl. The present chemical analysis indicates that the distribution of dolostone units within the Marmarica Formation at Siwa Oasis was underestimated in the previous studies (e.g., [5], [6], [7], [8] and [9]).

### 3. Lithostratigraphy

The thickness distribution of the different rock types encountered in the Marmarica Formation at Siwa Oasis is given in **Tables (1-3)**. Limestone, dolostone and shale represent the dominant rock types. The sand fraction in the majority of rock types rarely exceeds 5%. This indicates that sandstones or sandy beds are nearly absent from all the three members of the Marmarica Formation. The scarcity of sand rich detrital sediments throughout the Marmarica Formation at Siwa suggests mature topography and low relief of land adjoining the depositional basin of the Marmarica Formation [1].

Shale units are common in the Oasis Member. The thickness ratio of shale/carbonate is presented in **Tables (1-3)**. Most of the shale units are calcareous. Recorded microfossils include pectinids, *Placuna* sp and gastropods. The Siwa Escarpment and El Diffa Plateau members are almost devoid of shale. When present, shale occurs as thin parting between thick chalky carbonate rocks.

Dolostone units are encountered in the Oasis Member. At Girba, dolostone beds represent about 24% of the total thickness of the Oasis Member. The corresponding dolostone values at Naqb El-Migahhiz and Umm Hiyus sections drop to 14% and 7%, respectively (**Tables 1-3**). Dolostone is a major rock in both the Siwa Escarpment and El Diffa Plateau members. This indicates that dolomitization represents the major diagenetic process that affected the carbonate sediments of the Marmarica Formation at Siwa Oasis

**Table 1:** Thickness distribution (in m.) of limestone, dolostone and shale in the members

of the Marmarica Formation at Girba, Siwa Oasis.

Member	Limestone	Dolostone	Shale	Shale/Carbonate
El Diffa Plateau Member	4	16.5	0.0	0.0
Siwa Escarpment Member	3	14.5	0.0	0.0
Oasis Member	11.5	6.1	8.0	0.45

**Table 2:** Thickness distribution (in m.) of limestone, dolostone and shale in the members of the Marmarica Formation at Naqb El-Migahhiz, Siwa Oasis.

Member	Limestone	Dolostone	Shale	Shale/Carbonate
El Diffa Plateau Member	0.0	12.5	0.0	0.0
Siwa Escarpment Member	5.5	15.7	0.0	0.0
Oasis Member	15.5	3.7	8.5	0.31

**Table 3:** Thickness distribution (in m.) of limestone, dolostone and shale in the members of the Marmarica Formation at Umm Hiyus, Siwa Oasis

Member*	Limestone	Dolostone	Shale	Shale/Carbonate
Siwa Escarpment Member	12	29.1	0.0	0.0
Oasis Member	37.6	5.2	27	0.39

El Diffa Plateau Member is missing in Umm Hiyus section.

The thickness of the different members of the Marmarica Formation at Siwa Oasis is given in **Table 4**. The thickness of the Marmarica Formation at Girba is very close to the corresponding thickness at Naqb El-Migahhiz; 63.6 m and 61.1 m, respectively (**Table 4**). Although the El Diffa Plateau Member is missing in Umm Hiyus section, the total recorded thickness of the Oasis and Siwa Escarpment members was 110.9 m. [6] stated that the El Diffa Plateau Member is mostly absent at Umm Hiyus section. The Oasis

Member has a thickness of 63 m and the Siwa Escarpment Member has a thickness of 34 m. The relatively high thickness at Umm Hiyus is not clearly understood. In spite of the variations in thickness, the similarities in lithology and sedimentary structures among the measured section of the Marmarica Formation at Siwa Oasis suggest uniform depositional conditions over extensive marine shelf. Description of the different members of the Marmarica Formation at Siwa Oasis will be given below in detail.

### 3.1 The Oasis Member

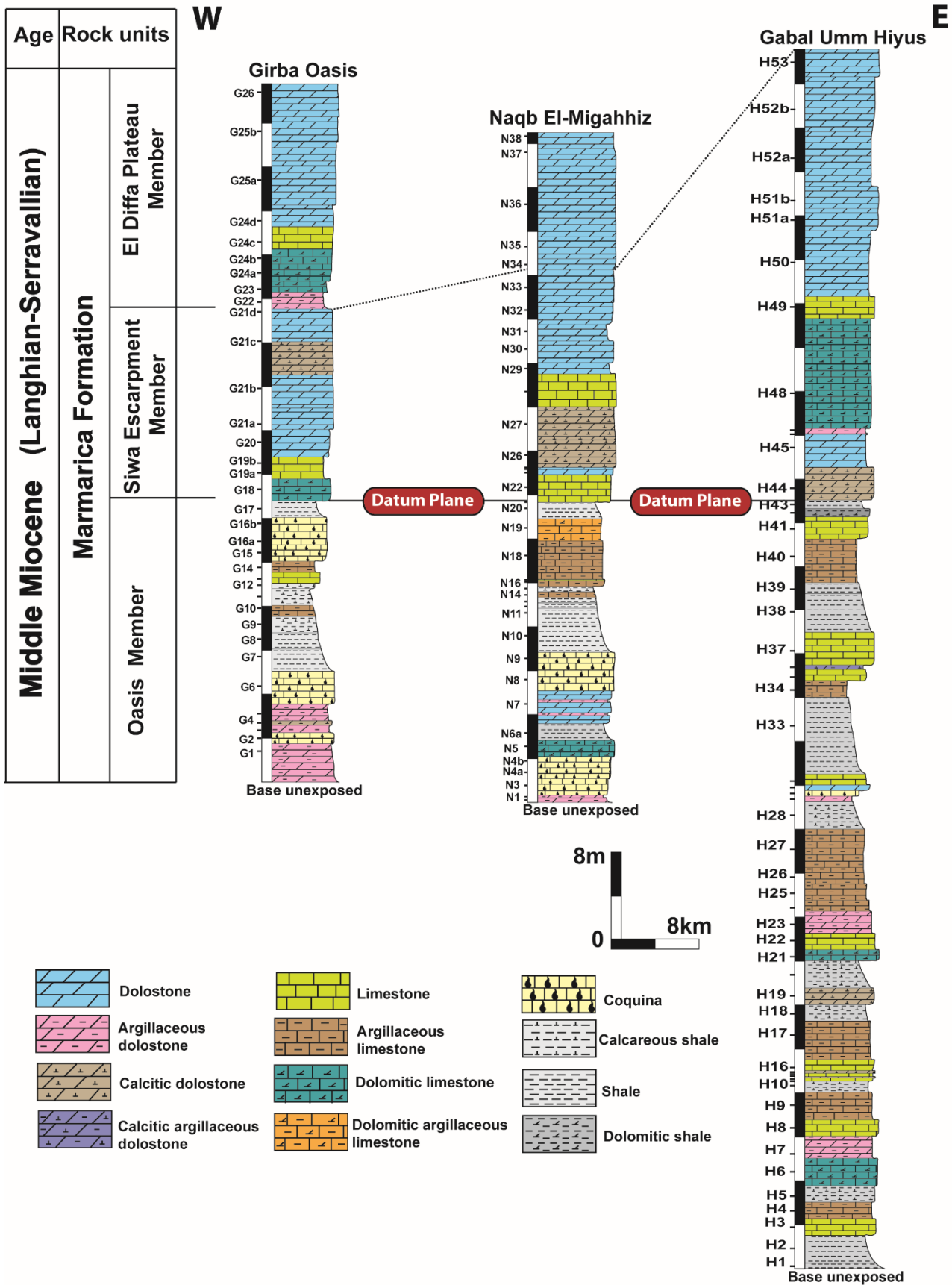
This member is recorded in all the studied sections. It shows an increase in thickness from west to east as it is 25.6 m in the Girba Oasis section, 27.4 m in the Naqb El-Migahhiz section, and 69.8 m in the Umm Hiyus section (**Fig. 3**). The Oasis Member is composed mainly of alternations of carbonate rocks and shale. The main carbonate rocks include limestone, argillaceous limestone, dolostone, argillaceous dolostone and shale. The beds of the Oasis Member show different colors; gray, yellow, grayish green, grayish white, and yellowish white. Cross-bedding is observed only in this member (**Fig. 4a**). It is recorded in the lowermost part of this member. The cross-bedded coquinas are composed largely of mixed fossil debris derived from marine fauna. The paleocurrent which was deduced from cross-bedding is northwest. [1] reported that the northwestern direction of transportation prevailed through the whole vertical profile. They observed that the coquina is well sorted, fine to coarse-grained, and the cross-bedding is well developed. In contrast, the sorting and fabric of the carbonate beds becomes complex, where the cross-bedding is not well developed. Lamination is recorded in the lower part of the Oasis Member in both the Naqb El-Migahhiz and the Girba Oasis sections (**Fig. 4b**). In the

Naqb El-Migahhiz section, some of the long shale lenses (e.g., bed N6a, **Fig. 4c**) inter-finger with a coquina dolostone (bed N6b). The mud content of the shale lenses was probably winnowed out by currents from coquina and deposited in more protected areas. Lag deposits and reworked fossils are observed in the lower part of the Oasis Member in Umm Hiyus section (**Fig. 4d**) as well as rounded clasts which are observed in the other sections. There are cylindrical burrows in the middle and upper parts of the member at Girba Oasis (**Fig. 4e**) and Umm Hiyus sections. A shell bank of *Placuna (Indoplacuna) miocenica* occurs at the upper part of the Oasis Member in the studied sections at Girba Oasis (**Fig. 4f**) and Naqb El-Migahhiz sections. Encrustations by serpulid tubes (**Fig. 5a**) and bryozoans were observed. The frequent shell encrustation points to a low rate of sedimentation. The placunoid shell band may result from repeated colonization events during periods of relatively quiet conditions and negligible sedimentation [9].

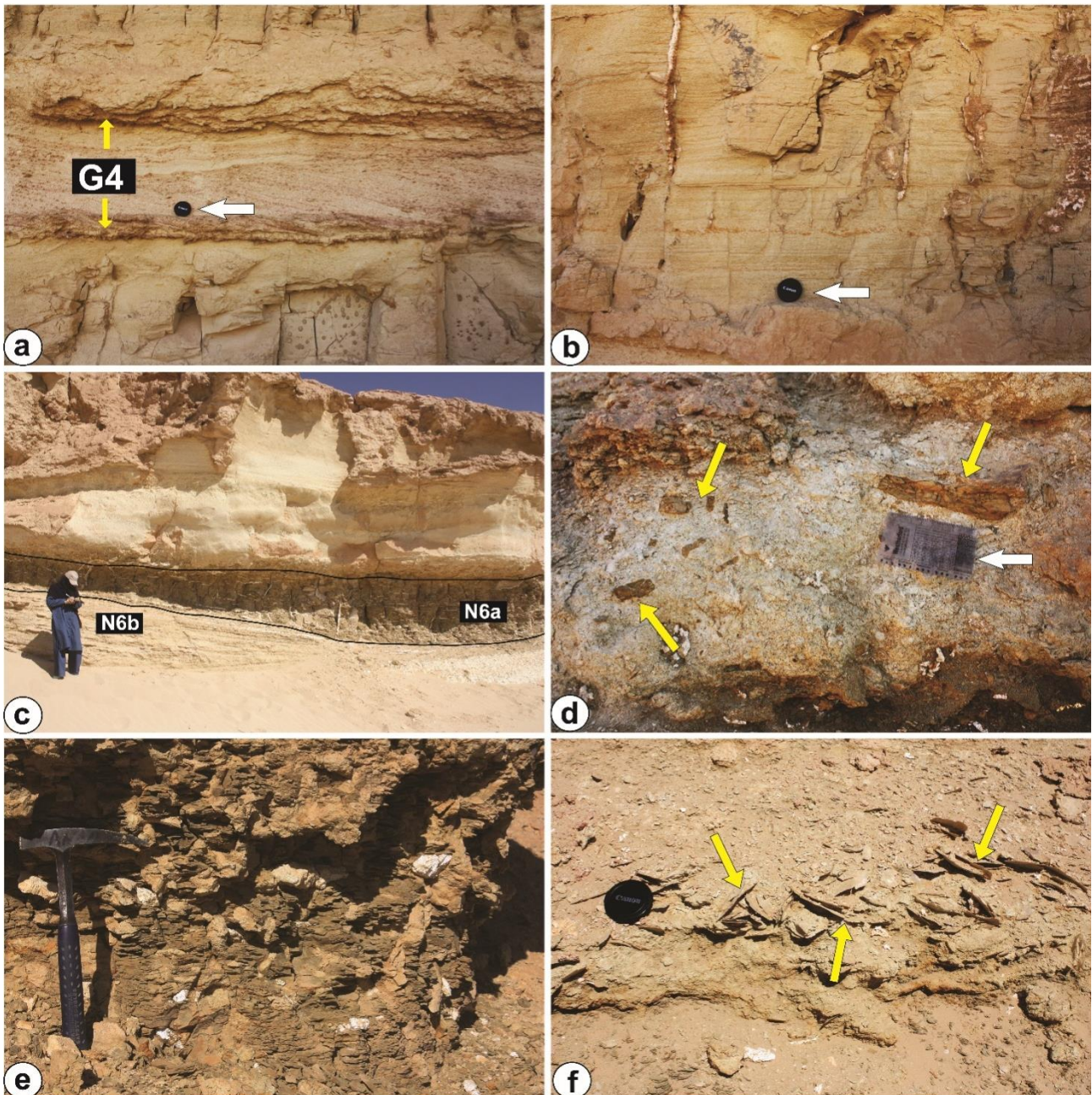
**Table 4:** Thickness (in m.) of the units of the Marmarica Formation at Siwa Oasis

	Oasis Mem ber	Siwa Escarpme nt Member	El Diffa plateau Member	Total
<b>Girba Oasis</b>	25.6	17.5	25.5	63.6
<b>Naqb El- Migah hiz</b>	27.4	21.2	12.5	61.1
<b>Umm Hiyus</b>	69.8	41.1	-	110.9

\* El Diffa Plateau Member is absent in Umm Hiyus section



**Fig. 3:** Correlation chart of the three lithostratigraphic units of the Marmarica Formation outcrops in Siwa Oasis



**Fig. 4:** Close-up views of the Oasis Member. **a)** Cross-bedding in a dolomitized coquina (bed G4), the Oasis Member, Girba Oasis. Lens cap (white arrow) is 4 cm, **b)** Laminated dolomitic limestone (bed G5), the Oasis Member, Girba Oasis. Lens cap (white arrow) is 4 cm, **c)** Pinch out of a shale unit (bed N6a) which grades laterally to coquina dolostone (bed N6b), the Oasis Member, Naqb El-Migahhiz. Person for scale is 1.67m, **d)** Close-up view of subangular to rounded clasts within a grayish yellow fossiliferous limestone (bed H3), the clasts have different sizes (3-16 cm in length), the Oasis Member, Umm Hiyus. Ruler (white arrow) for scale is 8 cm, **e)** Burrows in a grayish green calcareous shale G12 filled with carbonate derived from the

overlying limestone (bed G13), the Oasis Member, Girba Oasis. Geologic hammer length is 32.5 cm, **f)** Accumulation of the bivalve *Placuna (Indoplacuna) miocenica* (arrows) at the base of argillaceous limestone (bed N16), the Oasis Member, Naqb El-Migahhiz. Lens cap is 4 cm

The Oasis Member is characterized by a high diversity in megafossils; echinoderms, oysters, pectinids and other bivalves are commonly recorded. Remains of broken and/or unbroken echinoids (mostly *Scutella*, *Echinolampas* and, less commonly, *Clypeaster* species) are very abundant [1]. The topmost part of the Oasis Member contains a re-sedimented concentration of the oyster

*Crassostrea gryphoides* forming an almost monotypic assemblage [7]. The studied section is located north of the Siwa City at Latitude 29° 16' 0.8" N and Longitude 25° 41' 28.1"E. The oyster concentration is a lens-shaped bank up to 80-100 cm thick and about 220m long. The densely packed, imbricated and randomly oriented shells suggest a moderate to high energy event. The concentration of the oyster bank is interpreted as proximal tempestites assemblage [7]. A lens-shaped bank of the oyster *Crassostrea gryphoides* was observed at the topmost part of Umm Hiyus section. Encrustation and bioerosion are observed on the oyster valves (Fig. 5b and c).

### 3.2 The Siwa Escarpment Member

The Siwa Escarpment member is quite different from the Oasis Member as it consists mainly of carbonates (Fig. 3). The main lithology of the Siwa Escarpment Member is dolostone, argillaceous dolostone, limestone, calcitic dolostone and dolomitic limestone. The thickness of this member increases from west to east. It attains 17.5 m in the Girba Oasis, 21.2 m in the Naqb El-Migahhiz, and 41.1m in the Umm Hiyus section. The color of the beds is dominated by white and there are also gray and yellow colors. Globular bryozoan nodules are recorded from the Siwa Escarpment Member at Girba Oasis section (Fig. 5d). The external surface of the nodules shows mamelon-like structure without perforation. The bryozoan nodules acted as sediment builders and sediment bafflers in a micro-reef buildup [11]. The beds of this member are also fossiliferous with echinoderms, bivalves (e.g., oysters and pectinids), and gastropods. There are rip-up clasts in the yellow fossiliferous limestone (bed N22) at the lower most part of the member. The top of the lower bed N22 is crowded by bivalve shells. Burrows are recorded between dolostone beds at the upper part of the Siwa Escarpment Member in the Naqb El-Migahhiz section

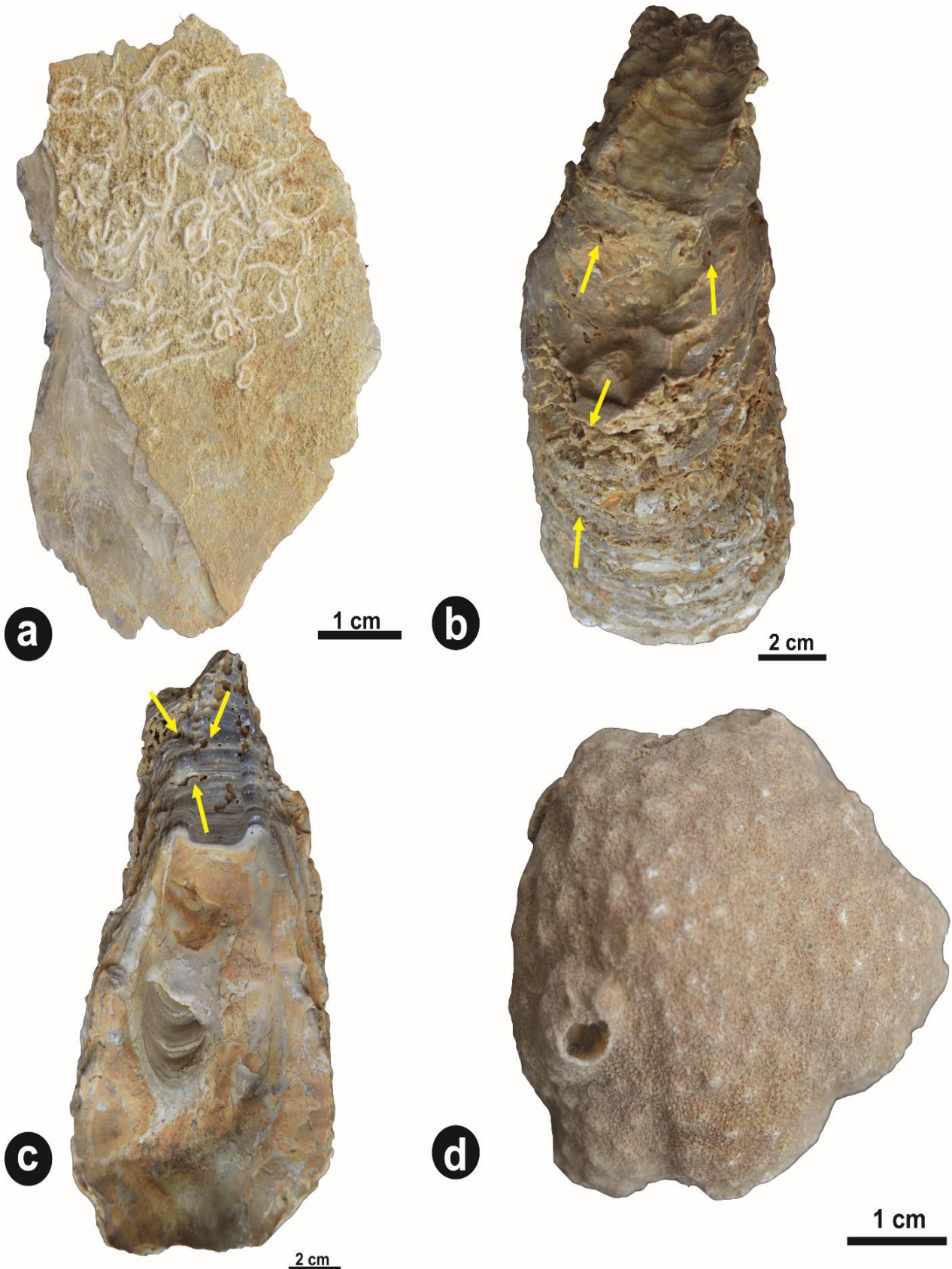
The boundary between the Oasis Member and the overlying Siwa Escarpment Member is placed on the top of the last shale bed of the Oasis Member (*Thalassinoides* horizon). In the present work, *Thalassinoides* was recorded only at the boundary between the first and second members (Fig. 6a and b). However, [9] reported that *Thalassinoides* occurs at several horizons within the Oasis and Siwa Escarpment members. They recorded three ichnospecies of *Thalassinoides* namely; *Th. horizontalis*, *Th. Suevicus* and *Th. paradoxicus*.

### 3.3 The El Diffa Plateau Member

The El Diffa Plateau Member forms the cap rocks of the escarpment in the Siwa depression (Fig. 3). [1] described this member as it consists mainly of cyclically fossiliferous and poorly fossiliferous chalky carbonate beds. The carbonate beds are dominated by chalky-looking dolostone and dolomitic limestone (Fig. 6c and d). These beds alternate with very thin calcareous shale, up to few centimeters thick. This member decreases in thickness from west to east and disappears in Umm Hiyus section. It attains 20.5m in the Girba Oasis section and 12.5m in the Naqb El-Migahhiz section. The apparent lack of the member at Umm Hiyus was observed by [1] and [6]. In the Girba Oasis section, there is an erosional surface; contains rounded clasts and reworked fossils, at the top of grayish white dolomitic limestone bed (G24b) in the upper part of this member. Burrows (Fig. 6e and f) are recorded at the top of a creamy white dolostone bed (G24c) above the erosional surface recorded in bed (G24b).

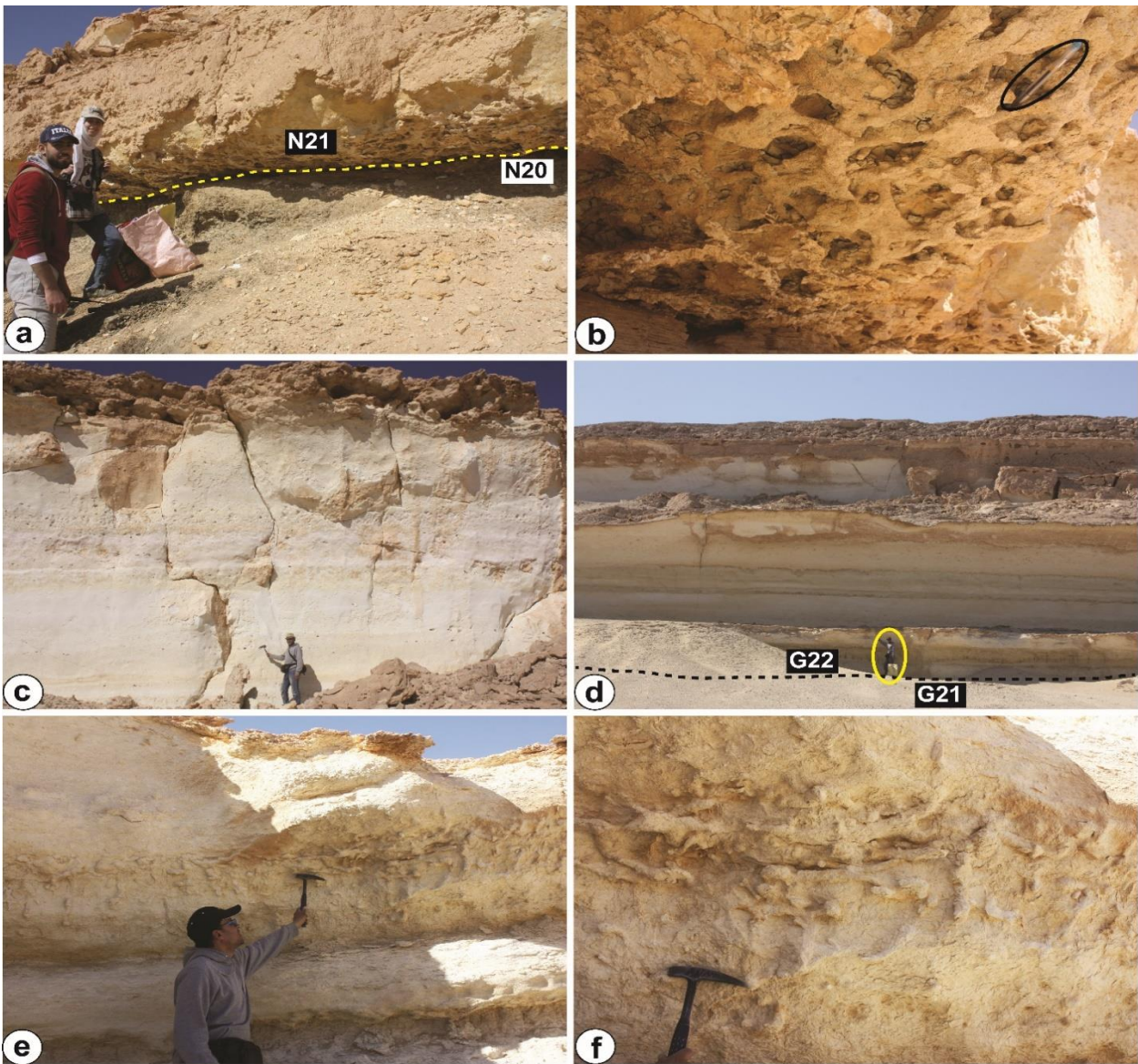
## 4. Discussion

The lithology of the Marmarica Formation in the Siwa Oasis is dominated by dolostone, limestone and shale. The chemical analysis shows that dolostones are the most common carbonate rocks in the studied Marmarica Formation. This indicates that dolomitization



**Fig.: 5a)** *Placuna (Indoplacuna) miocenica*, heavily encrusted by serpulid worms, the abundant shell encrustations point to slow rate of sedimentation, the Oasis Member, Naqb El-Migahhiz. **b&c)** Left valves of thick-shelled *Crassostreagryphoides*; moderately affected by bioerosion (arrows), the Oasis Member, Umm Hiyus. **d)** Mamelon-like structure of the outer surface of a bryozoan nodule, the Siwa Escarpment Member, Girba Oasis.





**Fig. 6:** General and close-up views of the Siwa Escarpment and El Diffa Plateau members. **a)** Field photograph showing the position of the *Thalassinoides* bearing bed (N21) above the shale unit (N20) of the Oasis Member. The dashed line refers to the boundary between the Oasis Member and the Siwa Escarpment Member, Naqb El-Migahhiz. Person for scale is 1.7m, **b)** Close-up view showing the base of burrowing system of the *Thalassinoides*, the Siwa Escarpment Member, Naqb El-Migahhiz. Pen length is 15 Cm, **c)** The upper part of El Diffa Plateau Member (beds N36-N38) showing chalky looking cliff forming dolostone, Naqb El-Migahhiz. Person for scale is 1.7m, **d)** General view of the El Diffa Plateau Member (beds G22-G26) showing a cliff forming sequence dominated by dolostone and dolomitic limestone, Girba Oasis. The dashed line refers to the boundary between the El Diffa Plateau and Siwa Escarpment members. Person

for scale is 1.7m, **e)** Burrows in a thick bedded dolostone bed G24c, the El Diffa Plateau Member, Girba Oasis. Geologic hammer length is 32.5 cm, **f)** Close-up view of (e) showing the details of the burrows within bed G24c, the El Diffa Plateau Member, Girba Oasis. Geologic hammer length is 32.5 cm represents the major diagenetic process that affected the carbonate sediments of the Marmarica Formation at Siwa Oasis. The shale occurs mainly as beds intercalated with carbonate rocks in the Oasis Member and rarely observed in the other two members. The recorded primary sedimentary structures are dominated by cross-bedding and lamination; most common in the Oasis Member. The remarkable decrease in clastic sediments and current induced structures in the carbonate dominated sequence of the Siwa Escarpment and El Diffa Plateau members in comparison with the Oasis Member suggest

relative deepening of the original marine conditions.

The trace fossil *Thalassinoides* is recorded in all the studied sections at the base of the Siwa Escarpment Member. [9] provided several criteria which suggest that *Thalassinoides* in the Marmarica Formation at Siwa Oasis is mostly a common firm ground indicator. *Thalassinoides* bearing substrates are unlined, uncompacted and display sharp erosional contact. These features suggest several firm grounds across the boundary between the Oasis and Siwa Escarpment members, as well as within these two members. The firm grounds mostly reflect early cementation and extremely low or nearly nil rate of sedimentation [9]. The presence of firm grounds implies either subaerial exposure or burial and exhumation [12]. The frequent occurrence of *Thalassinoides* at different levels within the Oasis Member as well as the lower part of the Siwa Escarpment Member at Siwa Oasis may suggest rapid and frequent oscillation of sea level. The lack of *Thalassinoides* in the upper part of the Siwa Escarpment Member and El Diffa Plateau Member may be related to a deepening upward trend in the depositional environment.

### Conclusions

The lithostratigraphy of the Middle Miocene Marmarica Formation at Siwa Oasis has been examined in Girba, Naqb El-Migahhiz and Umm Hiyus localities. The three members of the Marmarica Formation at Siwa Oasis; introduced by [1], are recognized. The main points are outlined below.

1. Dolostone is the dominant rock type in the Marmarica Formation and its abundance suggests major dolomitization process.
2. The Oasis Member is relatively rich in shale, limestone, dolostone in addition to cross-bedded coquinas and local shell banks of *Crassostrea gryphoides* and *Placuna (Indoplacuna) miocenica*. The sediments of the Oasis Member were mostly deposited under high energy conditions in shallow marine environment.
3. The Siwa Escarpment and El Diffa Plateau members consist mainly of thick bedded chalky dolostone in addition to some dolomitic limestone and limestone.

4. The remarkable decrease in clastic sediments and current induced structures in the Siwa Escarpment and El Diffa Plateau members, compared with the Oasis Member suggest relative deepening of the original marine conditions.
5. The distribution of the trace fossil *Thalassinoides* suggests frequent sea level oscillations during the deposition of the Oasis Member and the lower part of the Siwa Escarpment Member.

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