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Stratigraphical studies on the Matulla/Sudr formational boundary, western Sinai, Egypt

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Detailed field, litho-, and bio-stratigraphical analyses are carried out on the Matulla-Sudr formational boundary interval in five sedimentary stratigraphic sections along north-south profile (Sadr Al-Hitan, Wadi Sudr, Abu Qada, Ain-Markha and Wadi Feiran) at southwestern Sinai, Egypt. Vertical lithologic variation from the Matulla Formation (siliciclastic facies) to Sudr Formation (carbonate facies) refers to a sedimentary tectonic event within the advent of the carbonate sediments of Sudr formational basin especially toward the south at Abu Qada, Ain-Markha and Wadi Feiran sections. This event has led to form a hiatus at Matulla/Sudr formational boundary. It is documented by the occurrence of an erosional surface with pebbles and phosphatic materials at the base of Sudr Formation. The missing of the Early Campanian planktonic foraminiferal *Globotruncanita elevata*/*Dicarinella asymetrica* Subzone and *Globotruncanita elevata* Zone documented this event. The Syrian Arc tectonic event which took place at the Late Cretaceous may be the main reason for this event.

***Keywords*:** Matulla Formation, Sudr Formation, Santonian, Campanian, Syrian Arc tectonic event, Sinai, Egypt.

1. INTRODUCTION

Geographically, Sinai Peninsula lies in the northeastern corner of Egypt, which is considered as a part of the African plate. It is bounded by the Arabian Plate in the east and the Mediterranean Sea in the north. Sinai is affected by the compressional stresses of the Syrian Arc tectonic event as a result of the convergence of the Afro-Arabian plate in the south with the Eurasian Plate in the north during the Late Cretaceous time [1]. The Syrian Arc system is belonging to the Alpine Orogeny. The Syrian Arc tectonic event has led to the formation of double plunging anticlinal mountains in northern Sinai such as Maghara, Halal, Arif El Naqa, Yellag, Menshera mountains. Moreover, it disturbed the Late Cretaceous-

Paleogene sedimentary basins all over the geographic provinces of Egypt [2]–[8].

The Sudr Formation (a carbonate facies) is widely distributed in the northern Eastern Desert and Sinai, Egypt. It is deposited during a major transgression phase following directly a regression cycle which has led to the deposition of Matulla Formation (a siliciclastic facies). During the Late Cretaceous, the transgression cycle was attributed to the global sea-level [9], [10]. However, there are some local changes in the eustatic sea level which are also caused by tectonic event (subsidence or uplift). The stratigraphy of the Late Cretaceous successions in Sinai was carried out based on micropaleontological studies by several authors (e.g. [11]–[19]. These studies did not concern the control of the Syrian Arc tectonic event on the evolution of the sedimentary basins. Therefore, the present study focuses on the stratigraphic nature of the Matulla-Sudr formational transition interval and the causes of the changes in the facies of the sedimentary basin.

Fig.1. location map of the study sections, western Sinai, Egypt.

2. MATERIAL AND METHODS

The successions of the Matulla-Sudr formational transition interval at five sedimentary stratigraphic sections (Sadr Al-Hitan, Wadi Sudr, Abu Qada, Ain-Markha and Wadi Feiran) at southwestern Sinai, Egypt (Fig 1), are measured, collected and described. The sample intervals vary from 10-100cm in this interval. About 200 grams of the rock samples were disaggregated in water and washed through a 63μm sieve until clean surface of foraminiferal individuals were distinguished. After drying the residues, the planktonic and benthonic foraminiferal taxa were picked out and identified. Also, the important taxa are photographed (Plate 1) using the Scanning Electron Microscope (JSM 5400 LD), at Assiut University. The abundance of total foraminiferal number, planktonic/benthonic percentage, species richness and agglutinated/calcareous percentage are calculated. Finally, paleorelief profiles are constructed using the calibration of the planktonic foraminiferal zones within the Matulla-Sudr formational transition interval. These paleorelief profiles and the stratigraphic criteria are used to demonstrate the effect of Syrian Arc tectonic event on the evolution of Matulla and Sudr sedimentary basins during the Late Cretaceous time.

3. LITHOSTRATIGRAPHY

The Matulla and Sudr formations constitute an important exposure of the Late Cretaceous sequence in Sinai, Egypt. They are well distributed and characterized by distinguishing in the change of sedimentary facies from Matulla siliciclastic facies at base to Sudr carbonate facies at top.

3.1 Matulla Formation

[20] introduced the Matulla Formation to describe a succession of sandstone, shale with limestone and marl intercalations at Wadi Matulla, southwest Sinai, Egypt. In the present study, the uppermost part of the Matulla Formation is only concerned. It is composed of brown shale which changes upward into organic-rich black shale (Figs. 2).

At Sadr Al-Hitan section, the uppermost part of Matulla Formation attains ~9.75m thick. It is subdivided into two beds (from base to top); 1) ~2.35m thick of brown shale, 2) ~7.40m thick of organic-rich black shale.

At Wadi Sudr section the uppermost part of Matulla Formation attains ~11.5m thick. It is subdivided into two beds (from base to top); 1) ~2.75m thick of brown shale, 2) ~8.75m thick of organic-rich black shale.

At Abu Qada section, it is ~6.5m thick and subdivided into three beds (from base to top); 1) ~1.7m thick of brown shale, 2) ~3.80m thick of organic-rich black shale intercalated by ~30cm thick of siltstone band at the middle part, and 3) ~1m thick of glauconitic dark grey shale rich with phosphatic materials.

At Ain-Markha section, the uppermost part of Matulla Formation attains ~6.65m thick. It is subdivided into four beds (from base to top); 1) ~1.75m thick of brown shale, 2) ~3.15m thick of organic-rich black shale 3) ~50cm thick of sandy fossiliferous (bivalves and gastropods) limestone and 4) ~1.25m thick of glauconitic dark grey shale rich with phosphatic materials.

Fig. 2. Field photographs showing: A) phosphatic materials at contact of the Matulla/Sudr formational boundary at Wadi Sudr section, B) Matulla/Sudr formational boundary at Abu Qada section, C) Matulla/Sudr formational boundary at Ain-Markha section, D) bioturbated surface at Matulla-Sudr transition at Ain-Markha section.

At Wadi Feiran section, it attains ~5.20m thick. It is subdivided into three beds (from base to top); 1) ~2.40m thick of brown shale 2) ~1.7m thick of organic-rich black shale and 3) ~1.10m thick of glauconitic dark grey shale rich with phosphatic materials.

3.2 Sudr Formation

The Sudr Formation was originally proposed by [20] to describe a chalky limestone sequence at Wadi Sudr, southwestern Sinai, Egypt. In the study area, a thick succession of chalky limestone (Sudr Formation) is exposed overlying the Matulla Formation. The lower part of Sudr Formation is only studied and described (Fig 2). It is composed of chalky limestone rich in phosphatic materials at the basal part. At Sadr Al-Hitan and Wadi Sudr sections, the Matulla/Sudr formational boundary is characterized by sharp contact, but at Abu Qada, Ain-Markha and Wadi Feiran sections is marked by the occurrence of erosive, bioturbation surface contains glauconitic and phosphatic materials. The measured sections of Sudr Formation attain ~10.25m; ~12m, 2.7m, 2.6m and 4.15m thick at Sadr Al-Hitan, Wadi Sudr, Abu Qada, Ain-Markha and Wadi Feiran sections respectively.

4. BIOSTRATIGRAPHY

Several planktonic foraminiferal zonal schemes for the Late Cretaceous time interval were introduced by different authors e.g. [21]–[24]. In the present study, a detailed study of the planktonic foraminiferal assemblages has been carried out to establish the zonal scheme which covers the Santonian-Campanian interval. Three zonal intervals are recorded (Figs. 3-7); *Dicarinella asymetrica* Zone of Santonian-Early Campanian age, *Globotruncanita elevata* Zone and *Globotruncana ventricosa* Zone of Early Campanian age. *Dicarinella asymetrica* Zone is subdivided into three subzones *Dicarinella asymetrica/Marginotruncana sinousa* (latest Santonian age), Barren intersubzone interval and *Globotruncanita elevata/Dicarinella asymetrica* (earliest Campanian age).

4.1. *Dicarinella asymetrica* Zone

Dicarinella asymetrica Zone was originally defined by [21]as a total range zone to cover the stratigraphic interval of the nominate taxon within the Santonian Stage. In the present study, the range of the *Dicarinella asymetrica* (Sigal) extends to cover the Santonian-earliest Campanian age. This zone is here subdivided into:

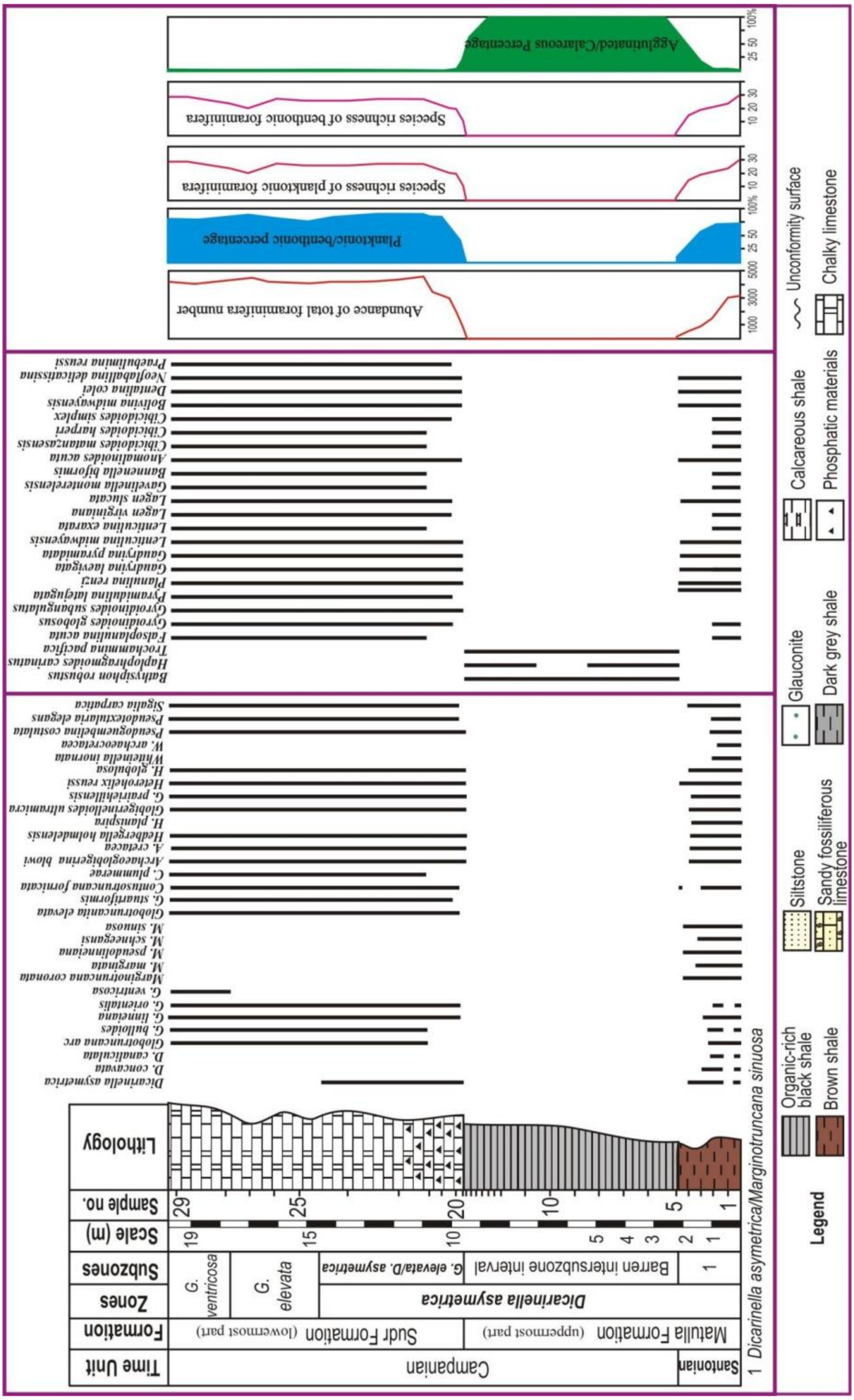

Fig. 3. Biostratigraphic distribution chart of the foraminiferal species (planktonic and benthonic) and some foraminiferal indices at Sadr Al-Hitan section.

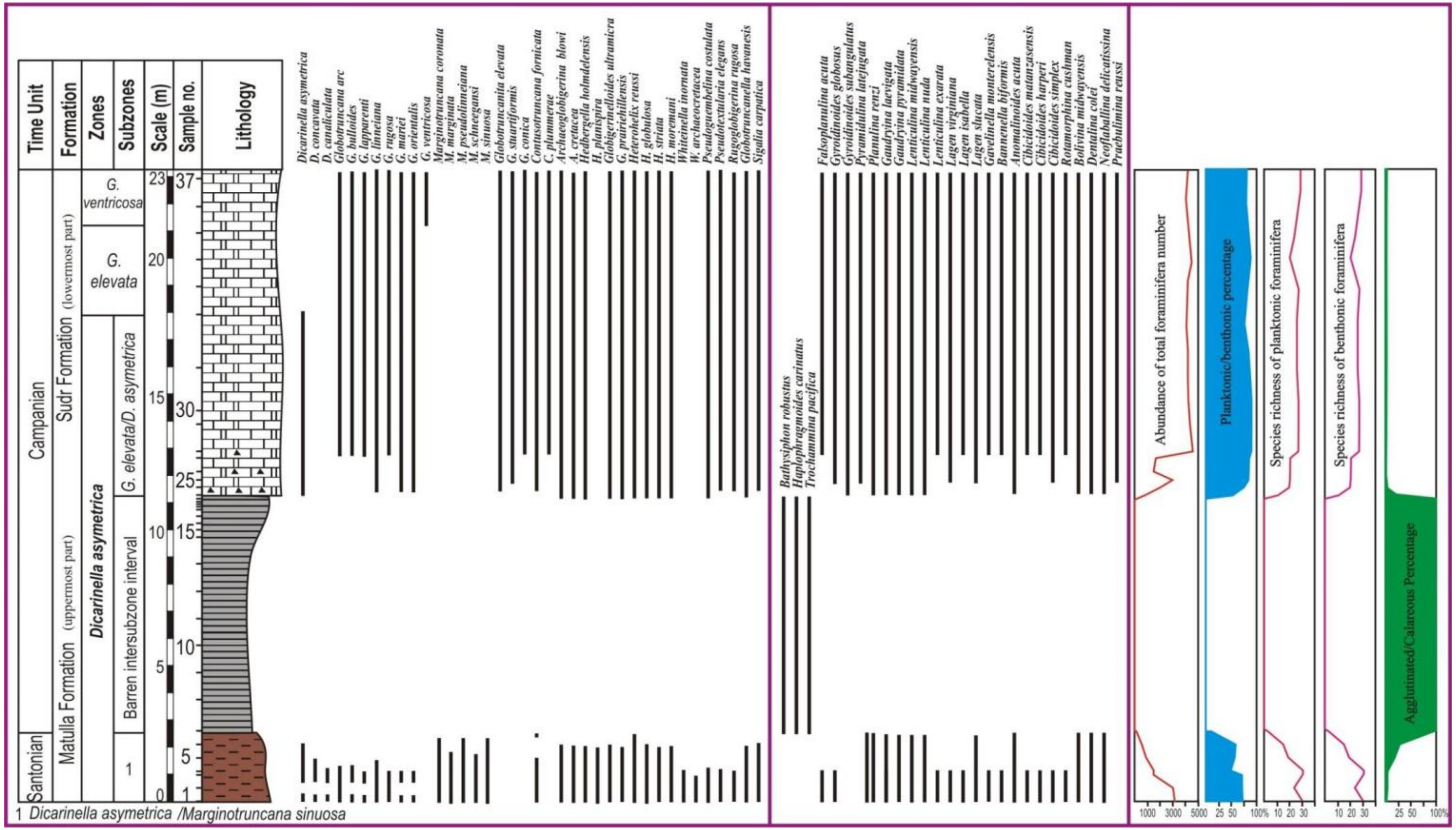

Fig. 4. Biostratigraphic distribution chart of the foraminiferal species (planktonic and benthonic) and some foraminiferal indices at Wadi Sudr section.

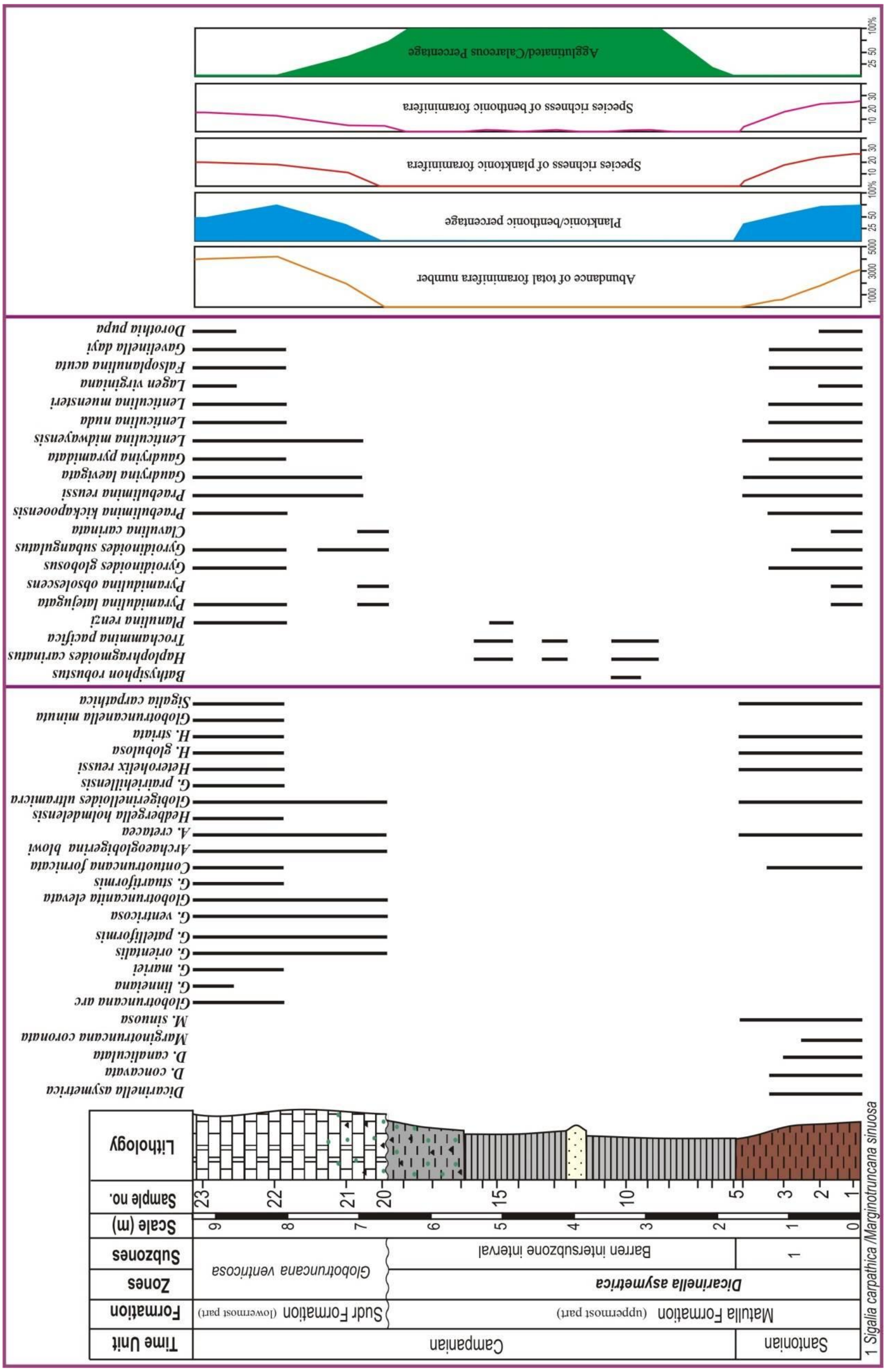

Fig. 5. Biostratigraphic distribution chart of the foraminiferal species (planktonic and benthonic) and some foraminiferal indices at Abu Qada section.

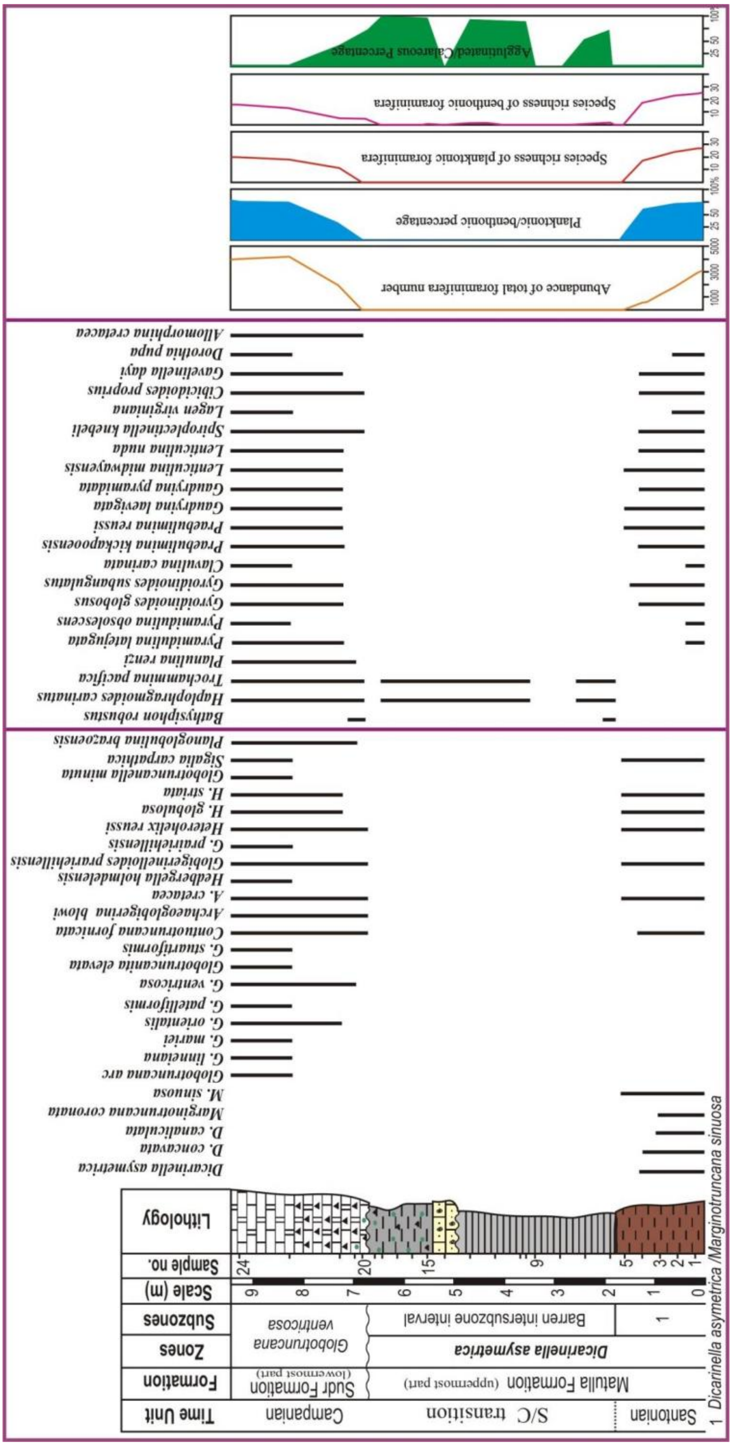

Fig. 6. Biostratigraphic distribution chart of the foraminiferal species (planktonic and benthonic) and some foraminiferal indices at Ain-Markha section.

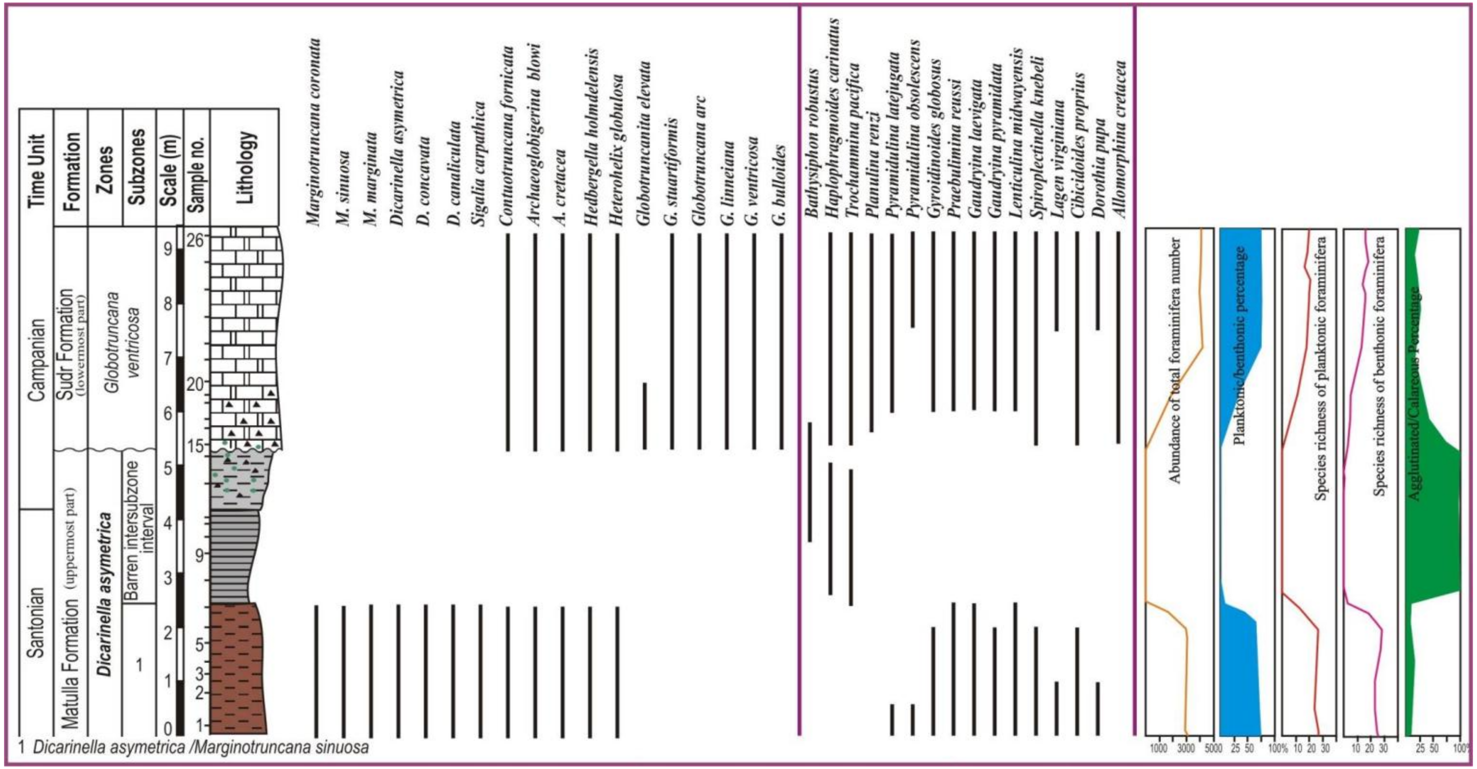

Fig. 7. Biostratigraphic distribution chart of the foraminiferal species (planktonic and benthonic) and some foraminiferal indices at Wadi Ferian section.

4.1.1. *Dicarinella asymetrica/ Marginotruncana sinousa* Subzone

This subzone is firstly introduced in the present study as a concurrent-range subzone to cover the stratigraphic interval from the Lowest Occurrence (LO) of *Dicarinella asymetrica* (Sigal) to the Highest Occurrence (HO) of the *Marginotruncana sinousa* Porthault. This subzone is herein proposed to cover the latest Santonian age. During this interval, the gradually extinction of all marginotruncanid taxa is recorded. These taxa are completely extinct at the end of this interval. This zone is represented by the lower measured part (brown shale) of Matulla Formation at the study area. This zone is characterized by high planktonic/benthonic percentage (~75%) and diversity (~25 species). On the other hand, it is characterized by very low agglutinated/calcareous percentage (~10%).

4.1.2. Barren intersubzone interval

This interval is here defined as a barren intersubzone to cover the stratigraphic interval between the *Dicarinella asymetrica/Marginotruncana sinousa* Subzone and *Globotruncanita elevata/Dicarinella asymetrica* Subzone. It is barren of any calcareous foraminiferal assemblage. This interval is represented by the uppermost part of Matulla Formation which characterized by organic-rich black shale. It is here proposed to cover the earliest Campanian age. This interval is marked by the exclusively occurrence of agglutinated foraminiferal taxa with high abundance and low diversity.

4.1.3. *Globotruncanita elevata/Dicarinella asymetrica* Subzone

This subzone is introduced in the present study as a concurrent-range subzone to cover the stratigraphic interval from the LO of *Globotruncanita elevata* (Brotzen) to the HO of the *Dicarinella asymetrica* (Sigal). It is represented by the lowermost part of Sudr Formation of the earliest Campanian age. This subzone is only represented at Sadr Al-Hitan and Wadi Sudr sections. On the other hand, it is absent at the remainder sections. This zone is characterized by the recovery of calcareous foraminiferal fauna. It is marked by the occurrence of high planktonic/benthonic percentage (~85%) and diversity (~27 species). At the same time, the agglutinated/calcareous percentage is very low (~9%).

4.2 *Globotruncanita elevata* Zone

This zone was originally defined by [21] as partial-range zone of the nominate taxon from it's LO to the LO of *Globotruncanita calcarata* (Cushman). [22] modified the definition of this zone to cover the stratigraphic interval from the HO of *Dicarinella asymetrica* (Sigal) to the LO of *Globotruncana ventricosa* White. In the present study, The definition of [22] is applied. The age of this zone is Early Campanian age. The *Globotruncanita elevata* Zone is represented by the lower part of Sudr Formation at Sadr Al-Hitan and Wadi Sudr sections. While this zone is absent at Abu Qada, Ain-Markha and Wadi Feiran sections due to the occurrence of a hiatus. The foraminiferal indices within this zone resemble the previous one.

4.3 *Globotruncana ventricosa* Zone

This zone was originally defined by [25], to cover the stratigraphic interval from the LO of *Globotruncana ventricosa* White to the LO of *Globotruncanita calcarata* (Cushman). This zone is conformably rest on the *Globotruncanita elevata* Zone at Sadr Al-Hitan and Wadi Sudr sections. At the remainder sections (Abu Qada, Ain-Markha and Wadi Feiran), this zone is represented by the lowermost part of Sudr Formation which unconformably rest on the Matulla Formation. The age of this zone is Early Campanian age. Also, this zone has the same indices of foraminiferal of the previous one.

5. THE EVOLUTION OF THE MATULLA-SUDR TRANSITION INTERVAL

To understand the sedimentary basin evolutions, two paleorelief profiles are erected. Each profile represents the sediments of the same time interval using the calibration of the Matulla-Sudr sediments with the planktonic foraminiferal zones. The geometry and distribution of these sediments of the paleorelief profile used to recognize the magnitude of the tectonic events on the evolution of the sedimentary basin. This paleorelief profiles with other criteria (such as field observations, litho-and bio-stratigraphic results) used to interpret the evolution of the sedimentary basin throughout this interval (Fig 8).

As indicate from figure 8A, the sedimentary basin is received silisiclastic facies (brown shale and organic-rich black shale) of Matulla Formation (uppermost part) which is covered by the *Dicarinella asymetrica/Marginotruncana sinousa* Subzone and Barren intersubzone interval of latest Santonian and earliest Campanian age respectively. The sedimentary basin during this interval is relatively stable at the study area.

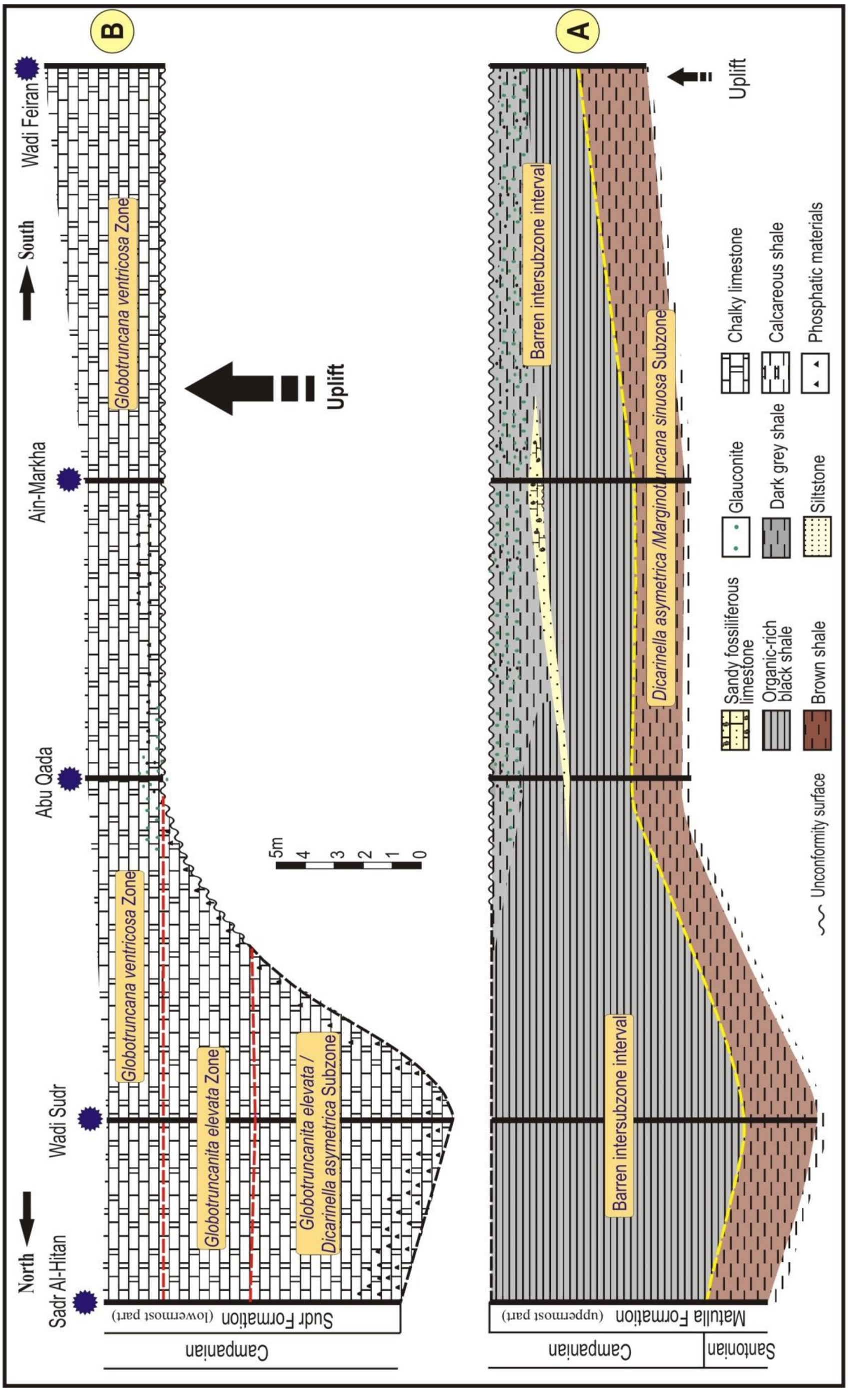

Fig. 8. Paleorelief profiles showing the evolution of sedimentary basin during the sedimentation of the uppermost part of Matulla and lowermost part of Sudr Formation.

The geometry and distribution of the Matulla sediments indicate that the depocenter during this interval lies northward throughout the sedimentary basin at Sadr Al-Hitan and Wadi Sudr sections. Otherwise, the marginal basin lies southward (Abu Qada, Ain-Markha and Wadi Feiran sections).

Upward, the Sudr Formation (carbonate facies) rests on the Matulla Formation (Fig. 8B). The basal part of the Sudr Formation rich by phosphatic materials at Sadr Al-Hitan and Wadi Sudr sections. On the other hand, it is characterized by the occurrence of erosive, bioturbated surface, which contains phosphatic materials and glauconitic sediments indicating the occurrence of a hiatus at Abu Qada, Ain-Markha and Wadi Feiran sections. This is documented by the absence of the Early Campanian *Globotruncanita elevata/Dicarinella asymetrica* Subzone and *Globotruncanita elevata* Zone. Also, the geometry and distribution of the Sudr sediments (Fig. 8B) indicate that the sedimentary basin at Abu Qada, Ain-Markha and Wadi Feiran sections was paleohigh. This paleohigh related to tectonic event uplift the southern part of the study area. This event may be related to the Syrian Arc tectonic event.

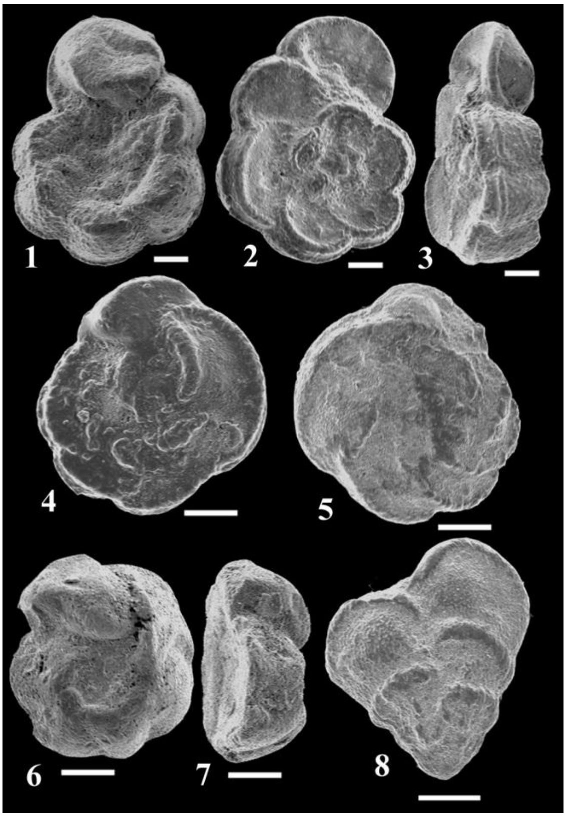

Plate (1) Scale bar is 100 µm: 1-3. *Dicarinella asymetrica* (Sigal), sample no. 30, Wadi Sudr; 4-5. *Marginotruncana sinousa* Porthault, sample no. 3, Wadi Sudr; 6-7. *Globotruncanita elevata* (Brotzen), sample no. 25, Wadi Sudr; 8. *Sigalia carpathica* Salaj &Samuel, sample no. 5, Wadi Sudr.

Accordingly, the sedimentation in the northern part of the study area (Sadr Al-Hitan and Wadi Sudr sections) is mostly complete and representing the depocenter for the Late Santonian-Early Campanian sedimentary basin. At the same time, the sedimentation toward the south (Abu Qada, Ain-Markha and Wadi Feiran sections) is characterized by unconformity at Matulla-Sudr transition interval.

6. CONCLUSION

The present work deals with the stratigraphic studies on the Matulla-Sudr formational boundary interval. Five stratigraphic sections are studied (along north-south profile) namely; Sadr Al-Hitan, Wadi Sudr, Abu Qada, Ain-Markha and Wadi Feiran sections. The Matulla-Sudr transition interval is characterized by a distinctive lithologic variation, from siliciclastic facies (brown shale and organic-rich black shale) lying within the uppermost part of Matulla Formation to a carbonate facies (chalky limestone) of lowermost part of Sudr Formation. This indicates a distinctive lithologic change in the sedimentary basin during this interval.

The brown shale of Matulla Formation which is rich with calcareous foraminiferal assemblages refers to *Dicarinella asymetrica/Marginotruncana sinousa* Subzone of latest Santonian age. Upward, the organic-rich black shale of the Matulla Formation is barren of calcareous foraminiferal fauna. On the other hand, agglutinated foraminiferal taxa are occurred within this interval. These taxa are characterized by high abundance and low diversity. The organic-rich black shale indicates a deposition in dysoxic-anoxic oceanic event during the earliest Campanian age. This part of Matulla Formation is overlain by chalk limestone Sudr Formation which is rich with phosphatic materials at the basal part. At Sadr Al-Hitan and Wadi Sudr sections, the lowermost part of Sudr Formation is represented by the *Globotruncanita elevata/Dicarinella asymetrica* Subzone, *Globotruncanita elevata* Zone and *Globotruncana ventricosa* Zone of Early Campanian age. However, southward (at Abu Qada, Ain-Markha and Wadi Feiran sections), the *Globotruncanita elevata/Dicarinella asymetrica* Subzone and *Globotruncanita elevata* Zone are missing and the lowermost part of Sudr Formation is marked by an erosive surface, bioturbated chalky limestone rich with glauconitic grains and phosphatic materials, indicating the occurrence of a hiatus at Matulla/Sudr formational boundary.

The sedimentary basin during the deposition of the Matulla-Sudr transition interval is affected by tectonic event which is related to the

Syrian Arc compressional movement. This tectonic event is limited at the northward at Sadr Al-Hitan and Wadi Sudr sections while becoming increased southward at Abu Qada, Ain-Markha and Wadi Feiran sections.

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دراسات طباقية على الحد الفاصل بين متكونى الماتلا والصدر ، غرب سيناء ، مصر

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تم دراسة الفترة الترسيبية الانتقالية بين متكونى الماتلا والصدر فى عدد خمس قطاعات (صدر الحيطان ، وادى صدر ، ابو قعدة ، عين مارخا ، وادى فيران). وتتميز هذه الفترة باختلاف واضح فى السحنات الرسوبية بين الجزء العلوى من متكون الماتلا (طفلة بنية اللون يعلوها طفلة سوداء غنية بالمواد العضوية) والجزء السفلى من متكون الصدر (صخور جيرية). وذلك يؤكد تعرض حوض الترسيب أثناء تلك الفترة بين المتكونيين محل الدراسة لحركة تكتونية. كما يظهر تأثيرها بوضوح فى قطاعات ابو قعدة ، عين مارخا ، وادى فيران فى الجزء الجنوبى من منطقة الدراسة. ويؤكد ذلك تواجد رسوبيات غنية بمعدن الجلوكونايت فى الجزء العلوى من متكون الماتلا والجزء السفلى من متكون الصدر. وعلاوة على ذلك يظهر السطح السفلى من متكون الصدر بسطح متعرج نتيجة لعمليات التجوية. ويدعم هذه النتائج غياب بعض النطاقات الحيوية للفورامنيفرا الهائمة (*Globotruncanita elevata*/*Dicarinella asymetrica* Subzone and *Globotruncanita elevata* Zone). وتعتبر حركة الأقواس السورية (Syrian Arc tectoniv event) هى السبب المؤدى لهذا الحدث التكتونى.