Calcareous Nannofossil Biostratigraphy and Stage Boundaries of the Santonian-Eocene Successions in Wadi El Mizeira Northeastern Sinai, Egypt

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Abstract

The stratigraphic successions exposed in Wadi El Mizeira have been dated through the analysis of the calcareous nannofossil assemblages. The results of this study indicate that the successions comprise the Santonian-Late Maastrichtian (Sudr Formation), the Paleocene (Esna Formation) and the Early Eocene (Thebes Formation). The following biozones were recognized: Late Santonian, CC16 Zone; Late Santonian/Early Campanian, CC17 Zone; Early Campanian, *Aspidolithus parcus* Zone (CC18) Zone; Late Maastrichtian, CC25c Zone; Early Paleocene (Late Danian), NP3 Zone and NP4 Zone; Late Paleocene (Thanetian-Selandian), NP5 Zone; Early Eocene, NP9b Zone, NP10a Zone, NP11 Zone, NP12 Zone and NP14 Zone. Several stratigraphic hiatus were recorded in the studied interval including the absence of Cretaceous nannofossil Zones CC19 to CC25b and CC26 as well as the early Paleocene Zones NP1 and NP2 and probably the basal part of Zone NP3, in addition to the absence of the Zones NP6 and NP7/8. These hiatus may be attributed to environmental conditions, structural activity and/or post depositional processes. This work represents the first attempt to evaluate the nannofossil taxa of the Wadi El Mizeira, Northeastern Sinai.

Keywords

Calcareous Nannofossil, Biostratigraphy, Santonian, Eocene, Sinai, Egypt

1. Introduction

The Upper Cretaceous-Lower Paleogene sediments are well developed in the stratigraphic successions of Sinai.

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A relatively thick Santonian-Eocene sequence was measured and sampled from Wadi El Mizeira, Northeastern Sinai (Figure 1). Wadi El Mizeira (about 35 km south of El Qussaima) extends to the north and west around Gabal Araif El-Naqa. The Upper Cretaceous Sudr Chalk is exposed forming the floor of the wadi and the footslope of Senaf El Mizeira ridge, while, the Thebes Formation forming the prominent cliff of Senaf El Mizeira Ridge.

The paleontological aspects of the Upper Cretaceous-Lower Paleogene in north east Sinai have been the subject of several studies [1]-[31] because of its relative richness in microfossils and expanded stratigraphic records. The published data on the calcareous nannofossil biostratigraphy in northeastern Sinai are scarce. The purpose of the present study is to establish a calcareous nannofossil biostratigraphic framework and define the stage boundaries and biostratigraphic hiatus for the Santonian-Early Eocene sediments at Wadi El Mizeira.

2. Material and Methods

Calcareous nannofossil analyses have been performed for 129 samples taken on average every 1 m; with high resolution sampling adopted close to key biohorizons. Calcareous nannofossils are generally abundant and well diversified in the studied sequence, with a good degree of preservation.

Samples were processed by smear slide preparation from raw sediment samples [32]. All samples were prepared similarly to insure uniformity in the distribution and to minimize bias. Relative species abundances were determined by counting a population of at least 300 specimens along a random traverse with a light microscope at a magnification of about 1250×. Rare species were searched in two additional traverses across the slide to assure that no stratigraphic marker was overlooked. Total nannofossil abundance was calculated as the total number of specimens counted per number of fields of view (FOV) traversed.

Preservation was estimated as Good (G) for nannofossil specimens exhibiting little or no dissolution; Moderate (M) for moderate dissolution and/or overgrowth and Poor (P) for strong dissolution and/or overgrowth. A fully referenced taxonomic listing appears in [33]. The stratigraphic distribution, preservation and abundance of the nannofossils are provided in a distribution charts (Figures 3-5).

3. Lithostratigraphy

The Santonian-Eocene succession exposed at Wadi Mizeira is generally composed of carbonate sediments. Lithostratigraphically, the succession is subdivided from base to top into; the Sudr, the Esna and the Thebes Formations (Figure 2).
3.1. Sudr Formation

The term Sudr Chalk was originally introduced by [34] for the chalky limestone succession exposed at Wadi Sudr, west central Sinai. In the present study the Sudr Formation is exposed along the floor of Wadi El Mizeira and the foot-slope of Senaf El Mizeira Ridge. It is predominantly composed of chalk, chalky limestone with shale intercalations, siliceous limestone, chert and bioclastics. The Sudr Chalk could be subdivided into; the Lower Chalk Member, the Chert Member and the Upper Chalk Member.

The Lower Chalk Member attains a thickness of about 35 m and consists mainly of hemipelagic soft snow-white massive chalk. The middle Chert Member exhibits distinctive lithologic characters and is composed of dark chert, siliceous limestone, siliceous sandstone and bioclasts. It attains about 10 m thick and contains few phosphatic beds and oyster banks. The Upper Chalk Member (about 18 m thick) is composed of chalk and chalky limestone grads into argillaceous chalk at the top. The calcareous nanofossil content assigned the Lower Chalk Member to Santonian-Early Campanian age and the Upper Chalk Member to Late Maastrichtian age. The stratigraphic position of the Middle Chert Member points to Late Campanian - Early Maastrichtian age.
Figure 3. Distribution, abundance, preservation and biozones of the Santonian-Maastrichtian calcareous nannofossils in Wadi El Mizeira, Sinai.
3.2. Esna Shale

The term Esna Shale was first introduced by [35]. In the study area the Esna Formation (24 m thick) overlies the Upper Cretaceous Sudr Chalk and underlies the Lower Eocene Thebes Formation. At Wadi El Mizeira, the Esna Shale is predominantly composed of greenish gray shale, along Senaf El Mizeira Ridge the formation displays significant change in lithology and is made up of greenish hemipelagic marls, chalky with few grayish green shale intercalations in the middle part. The calcareous nannofossil content points to Late Maastrichtian to Early Eocene age for the Esna Shale.

3.3. Thebes Formation

The term Thebes Formation has been introduced by [36] to describe the limestone unit with chert bands overlying the Esna Shale in many parts of Egypt. At Wadi El Mizeira the Thebes Formation is well exposed forming the prominent cliff of Senaf El Mizeira Ridge. It is 65 m thick and composes of marls, marly chalk, and chalky limestone with chert bands and nodules. The formation exhibits lateral lithologic change and dominates with white chalk, siliceous limestone and some shale. The nannofossils content indicates an Early Eocene age for the Thebes Formation.

4. Biostratigraphy

In the present study, nannofossil biostratigraphic framework is applied according to the biozonation scheme of [37].
Figure 5. Distribution, abundance, preservation and biozones of the Eocene calcareous nannofossils in Wadi El Mizeira, Sinai.

| Early Eocene | Age | Rock units |
|--------------|-----|------------|
|              |     |            |

| Biozone | NP10a | NP11 | NP12 | NP14 |
|---------|-------|------|------|------|
|         | R     | R    | R    | R    |
|         | R     | R    | R    | R    |
|         | R     | R    | R    | R    |
|         | R     | R    | R    | R    |
|         | R     | R    | R    | R    |

5. Late Cretaceous Biozones

5.1. *Luctanorhabdus cayeuxii* Zone (CC16)

**Definition:** Interval from the FO of *L. cayeuxii* Deflandre to the FO of *Calculites obscurus* (Deflandre).

**Author:** [37].

**Age:** Late Santonian.

**Thickness:** 10 m; equivalent to the lower part of the Lower Chalk Member.
Table 1. Correlation of Santonian-Maastrichtian calcareous nannofossil biostratigraphy of Wadi El Mizeira section with other biostratigraphic schemes in Sinai and Western Desert.

| Age          | Biozones   | [74] Western Desert | [28] East Central Sinai | [75] North East Sinai | [29] West Central Sinai | [76] West Central Sinai | Present Study |
|--------------|------------|----------------------|-------------------------|-----------------------|-------------------------|-------------------------|---------------|
| Santonian    | CC26       | Hiatus               | CC26                    | CC26                  | Hiatus                  | Hiatus                  | Hiatus        |
| Maastrichtian| CC25       | Hiatus               | CC25                    | CC25                  | Hiatus                  | Hiatus                  | Hiatus        |
|              | a          | CC24                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |
|              | b          | CC23                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |
|              |            | CC22                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |
|              |            | CC21                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |
|              |            | CC20                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |
|              |            | CC19                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |
|              |            | CC18                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |
|              |            | CC17                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |
|              |            | CC16                 | Hiatus                  |                       | Hiatus                  | Hiatus                  |               |

Table 2. Correlation of Paleocene-Eocene calcareous nannofossil biostratigraphy of Wadi El Mizeira section with other biostratigraphic schemes in Sinai.

| Age          | Biozones   | [77] North Central Sinai | [75] North East Sinai | [78] West Central Sinai | [79] North Sinai | [80] North Central Sinai | Present Study |
|--------------|------------|-------------------------|-----------------------|-------------------------|-----------------|--------------------------|---------------|
| Paleocene    | NP14       | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP13       | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP12       | Hiatus                  |                       | NP12                    | Hiatus          | Hiatus                   | Hiatus        |
|              | NP11       | Hiatus                  |                       | NP11                    | Hiatus          | Hiatus                   | Hiatus        |
|              | NP10       | Hiatus                  |                       | NP10                    | Hiatus          | Hiatus                   | Hiatus        |
|              | NP9        | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP7/8      | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP6        | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP5        | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP4        | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP3        | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP2        | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |
|              | NP1        | Hiatus                  | Hiatus                | Hiatus                  | Hiatus          | Hiatus                   | Hiatus        |

Assemblage: In general, the identified taxa in this zone are rare, but diversity is relatively high. In addition to the nominate taxon, this interval includes *W. béarnaise* and *Q. Gartner* among many other species.

Remarks: The first occurrence of *L. cayeuxii* is a very reliable event. Zone CC16 is equivalent to the upper
part of Zone UC11 and the UC12-13 zones of [39].

5.2. *Calculites obscurus* Zone (CC17)

**Definition:** This zone covers the interval from the FO of *Calculites obscurus* to the FO of *Aspidolithus parcus*.

- **Author:** [37].
- **Age:** Late Santonian/Early Campanian.
- **Thickness:** 10 m; equivalent to the middle part of the Lower Chalk Member.
- **Assemblage:** The assemblage of this interval is similar to that of the underlying CC16 Zone, with the addition of rare occurrences of the nominate taxon.

**Remarks:** According to [39], the first occurrence of *Arkhangelskiella cymbiformis* defines the base of Subzone UC13a of Early Campanian age. In the present study, rare specimens of *A. cymbiformis* have been observed in the Late Santonian (CC17), indicating that the range of the *A. cymbiformis* extends down into the Santonian. The FO of *Aspidolithus parcus* is an event that has been used for zonation and coincides reasonably well with the Santonian/Campanian boundary.

5.3. *Aspidolithus parcus* Zone (CC18)

**Definition:** Interval from the FO of *Aspidolithus parcus* to the LO of *Marthasterites furactus*.

- **Author:** [37].
- **Age:** Early Campanian.
- **Thickness:** 15 m; equivalent to the upper part of the Lower Chalk Member.
- **Assemblage:** Similar to the nannofossil assemblage from the CC17 Zone, with the addition of the nominate taxon *Aspidolithus parcus*.

**Remarks:** The upper boundary of the CC18 not well defined due to the absence of *M. furactus*. The first occurrence of *B. parcaparca* is a reliable global stratigraphic datum. Numerous workers have indicated that this datum marks the base of the CC18 Zone and serves as an approximation to the Santonian/Campanian boundary [16] [39]-[46]. The current study maintains this approximation because it can be correlated globally at all palaeolatitudes and in all palaeobiogeographical provinces [39] [46].

5.4. *Micula murus* Zone (CC25c)

**Definition:** It is defined as the interval from the FO of *Micula murus* to the FO of *N. frequens*.

- **Authors:** [47], emended [48].
- **Age:** Late Maastrichtian.
- **Thickness:** 18 m; equivalent to the upper part of the Lower Chalk Member and the lower most part of the Esna Formation.

- **Assemblage:** Besides the marker species, this zone is dominated by *Micula decussata, Watznaueria barnesae, Thoracosphaera operculata, Prediscosphaera cretacea, Eiffellithus gorkae, Arkhangelskiella cymbiformis, Eiffellithus turrisiefellii and Cyclagelosphaera reinhardtii*.

**Remarks:** In this study, this zone is identified from the first occurrence (FO) of *Miculamurus* to the FO of *N. frequens*. This zone correlates with the lower part of the *Nephrolithus frequens* Zone [49] modified by [50]. The *M. murus* Zone is probably restricted to low latitudes [50]. The top of CC25c is not defined accurately due to the absence of *M. prinsii*.

6. Paleocene and Eocene Biozones

6.1. *Chiasmolithus danicus* Zone (NP3)

**Definition:** FO of *Chiasmolithus danicus* to FO of *Ellipsolithus macellus*.

- **Author:** [51].
- **Age:** Early Paleocene (Late Danian).
- **Thickness:** 2 m; equivalent to the lower part of the Esna Formation.
- **Assemblage:** It is dominated besides the marker species by *Ericsonia cava* and relatively rare to very rare
occurrences of Cruciplacolithus primus, Coccolithus pelagicus and Thoracosphaera oculata.

Remarks: The upper boundary is defined by the FO of Ellipsolithus macellus, which is easy to recognize in well preserved material. In poorly preserved assemblages and/or in high latitudes, this species is missing but the zonal boundary can be identified by substitute evidence such as the absence of species of Neochiastozygus (N. saepes, N. perfectus), Chiasmolithus bidens and Prinsius martini, all forms which are used to subdivide the high latitude Danian sections. Chiasmolithus danicus Zone is correlated to CP2 of [52].

6.2. Ellipsolithus macellus Zone (NP4)

Definition: FO of Ellipsolithus macellus to FO of Fasciculithus tympaniformis.

Author: [51].

Age: Early Paleocene (Late Danian).

Thickness: 5 m; equivalent to the lower part of the Esna Formation.

Assemblage: The calcareous nannofossil assemblage’s characteristic of this zone contains Chiasmolithus danicus, Cruciplacolithus primus. Cr. tenuous, Placozygus sigmoidesand Ellipsolithus spp. are occurred rarely in this zone. The first representatives of Fasciculithus (F. billii, F. uliiand, F. janii); Sphenolithus (Sphenolithus primus) were also observed in this zone.

Remarks: Instead of the FO of E. macellus, the FO of E. distichus, another species of Ellipsolithus, appearing slightly after E. macellus where the two are consistently found together, has been used as a marker by some authors. Ellipsolithus is present from the lowermost studied sample upwards, thus indicating the presence of NP4. Ellipsolithus macellus Zone is equivalent to Zone CP3 of [52].

6.3. Fasciculithus tympaniformis Zone (NP5)

Definition: FO of Fasciculithus tympaniformis to FO of Heliolithus kleinpellii.

Authors: [53].

Age: Late Paleocene (Thanetian, Selandian).

Thickness: 4 m; equivalent to the middle part of the Esna Formation.

Assemblage: Nannofossil assemblages are similar to those recorded in NP4 but are distinguished by the presence of F. tympaniformis and F. bitectus.

Remarks: The lower boundary of NP5 was discussed above. Several new species such as Heliolithus and Bomolithus evolved before the FO of H. kleinpellii [50] [54]. H. kleinpellii was chosen as a zonal marker due to its wide distribution and easy recognition. The base of this zone is only recognized in the studied sequence. It is equivalent to Fasciculithus tympaniformis Zone, CP4 of [52].

6.4. Discoaster multiradiatus Zone (NP9b)

Definition: FO of Discoaster multiradiatus to FO of Tribrachiatus bramlettei or Discoaster diastypus.

Authors: [55] emended [56] [47].

Age: Early Eocene (Ypresian).

Thickness: 6 m; equivalent to the upper part of the Esna Formation.

Assemblage: The calcareous nannofossil assemblages; Ericsonia cava, Ericsonia subpertusa, Coccolithus pelagicus, Chiasmolithus danicus, Fasciculithus involutus and Sphenolithus primus occurred frequent to rarely in this zone.

Remarks: The definition of the upper boundary of NP9 is different from that of CP8, while the definition of the base is the same. Within NP9 several species of Rhomboaster evolve and can be used for a very fine subdivision of this interval [50] [57]. Several Discoaster species have their FO in NP9. The FO of Discoaster multiradiatus defines the base of Zones NP9 of [56] and CP8 of [52]. The FO of D. multiradiatus is considered a good reliable Paleocene datum in the Atlantic, Pacific and Mediterranean sections (e.g., [50] [53] [55] [58]-[65]). It is correlated with Discoaster multiradiatus Zone, CP8 of [52].

6.5. Tribrachiatus contortus Zone (NP10a)

Definition: FO of Tribrachiatus bramlettei to LO of Tribrachiatus contortus.

Authors: [66] and [67].
Age: Early Eocene (Ypresian).
Thickness: 9 m; equivalent to the lower part of the Thebes Formation.

Assemblage: In addition to the nominate taxon, this interval includes Chiasmolithus consuetus, Discoaster tenticularis, Sphenolithus primus, Coccolithus pelagicus and Zygodiscus bijugatus.

Remarks: NP10a has not been found in several sequences where it might be expected to present, probably due to the absence of the genus Tribrachiatus in certain areas for ecological reasons. When present, however, it is very easy to recognize NP 10 by the presence of T. bramlettei and/or T. contortus. Detailed studies of T. bramlettei, T. contortus and T. orthostylus were published by [50] [68]. In overgrown material both species have a tendency to look like ordinary calcite rhombohedron. Many species continue from the Paleocene into the Eocene, including some species, the FO of which is used as zonal markers in the Paleocene, i.e. Ellipsolithus macellus and Discoaster multiradiatus. Fasciculithus is only found in the lowermost part of NP 10 according to [50] and it’s LO is used by other authors to define the Paleocene/Eocene boundary in sections where Tribrachiatus is very rare. It is correlated with Tribrachiatus contortus Subzone, CP9a of [52].

[69] subdivided the NP10 Zone into four subzones: NP10a (biostratigraphic interval from FO of T. bramlettei to the FO of T. digitalis); NP10b (total range of T. digitalis); NP10c (from LO of T. digitalis to the FO of T. contortus) and NP10d (total range of T. contortus). None of these subdivisions can be differentiated in the current study. This may be attributed to large space of sampling and/or small hiatus.

6.6. Discoaster binodosus Zone (NP11)

Definition: LO of Tribrachiatus contortus to FO of Discoaster lodoensis.

Authors: [53].
Age: Early Eocene (Ypresian).
Thickness: 17 m; equivalent to the middle part of the Thebes Formation.

Assemblage: Discoaster distinctus, Sphenolithus editus, S. radians and S. conspicus appear within NP11.

Remarks: Tribrachiatus orthostylus, a species which evolved from T. contortus appears near the NP10/NP11 boundary and evolves from a form with a slight bifurcation at the end of three arms to a form with three simple arms [50] [68] within NP11.

The top of NP10 is generally defined by the LO of Tribrachiatus contortus [32] [50] [56]. Alternatively, the FO of Tribrachiatus orthostylus takes place shortly before the LO of Tribrachiatus contortus and can be used as an approximation of the NP10/NP11 boundary [32]. We have tentatively placed that boundary at the FO of Tribrachiatus orthostylus so that our Zone NP11 may be a bit more reduced in reality than it appears. In this context, Sphenolithus radians record its FO at the base of NP11. It is correlated with Discoaster binodosus subzone, CP9b of [52].

In the present study, other nannofossil species occur in Zone NP11, such as Zygrahablithus bijugatus, Discoaster barbariensis, Discoaster binodosus, C. pelagicus, E. cava, and Chiasmolithus solitus.

In several sections in Egypt [70]-[72], the T. orthostylus sometimes co-occurs with T. contortus at the extreme top part of zone NP10 or appears directly above the last occurrence of the latter, i.e., at the very base of Zone NP11. T. orthostylus was originally described from the Lower Eocene rocks of California and Austria [73]. In Egypt this species is predominate and characterize the Lower Eocene sediments. The stratigraphic value and occurrence of Tribrachiatus orthostylus as a guide fossil have already been proved [50].

6.7. Tribrachiatus orthostylus Zone (NP12)

Definition: FO of Discoaster lodoensis to LO of Tribrachiatus orthostylus.

Authors: [67] [73].
Age: Early Eocene (Ypresian).
Thickness: 12 m; equivalent to the middle part of the Thebes Formation.

Assemblage: The most dominant species in addition to the marker species are Coccolithus pelagicus, S. moriformis, Ericsonia Formosa and T. orthostylus.

Remarks: The overlap of D. lodoensis and T. orthostylus is easily recognized in well preserved assemblages or in assemblages affected by dissolution. It is more difficult to recognize in assemblages affected by heavy overgrowth, where T. orthostylus and D. lodoensis are difficult to identify. It is equivalent to Tribrachiatus orthostylus Zone, CP10 of [52].
6.8. *Discoaster sublodoensis* Zone (NP14)

**Definition:** FO of *Discoaster sublodoensis* to FO of *Nannotetris fulgens*.

**Authors:** [66] [67].

**Age:** Early Eocene.

**Thickness:** 38 m; equivalent to the upper part of the Thebes Formation.

**Assemblage:** It is dominated besides the marker species by *Coccolithus pelagicus*, *Ericsonia Formosa* and *D. lodoensis*.

**Remarks:** *D. lodoensis* overlaps with *D. sublodoensis* in the lower part of the zone and the FO of *R. inflata* is used to subdivide the zone into subzones CP12a and CP12b. The top of the zone has sometimes been approximated by using the FO of any species of *Nannotetris* instead of *N. fulgens*, which can be very rare in some sections where other species of *Nannotetris* are found consistently to be present. In these cases, *R. inflata* has been found overlap with *Nannotetris*, *Sphenolithus furcatolithoides* and *S. spiniger* appear in the upper part of NP14. It is equivalent to *Discoaster sublodoensis* Zone, CP12 of [52], with a different definition for the top of the zone, when the LO of *R. inflata* is used as a substitute marker.

7. Stage Boundaries

The boundaries between stages are delineated based on the calcareous nannofossil datum events as follow:

1) Santonian/Campanian boundary

In the present samples the Santonian-Campanian boundary is marked by the last occurrences of *Calculites obscurus* and the first occurrences of *Aspidolithus parcus*.

2) Campanian/Maastrichtian boundary

The Campanian/Maastrichtian boundary is not clear due to the absence of nannofossil assemblages as a result of post depositional changes.

3) The Cretaceous/Paleogene (K/Pg) boundary

The Cretaceous/Tertiary boundary is marked by the absence of the Late Cretaceous nannofossil Zone; CC26, as well as the Early Paleocene nannofossil biozones, NP1 and NP2 and probably the lower part of NP3.

4) Selandian/Thanethian boundary

A major hiatus is suggested at the Selandian/Thanethian boundary as indicated by absence of the nannofossil biozones; NP6, NP7 and NP8. On the other hand, the latest Paleocene calcareous nannofossil subzone NP9a is missed.

5) Paleocene/Eocene boundary

The Paleocene/Eocene boundary in the studied area is correlative to the base of the *Discoaster multiradiatus* NP9b Subzone. On the other hand, the latest Paleocene calcareous nannofossil subzone NP9a is missed, suggesting a minor hiatus at the P/E boundary.

8. Summary and Conclusions

The Santonian-Eocene carbonate succession of Wadi Mizeira, Northeastern Sinai, is subdivided from base to top into the Sudr, the Esna and the Thebes Formations. Eleven nannofossil zones are identified, based on the first and last occurrences (FOs, LOs) of the marker species. The Upper Cretaceous rocks comprise: 1—*Lucianorhabdus cayeuxii* Zone, CC16 (Late Santonian), 2—*Calculites obscurus* Zone, CC17 (Late Santonian-Early Campanian), 3—*Aspidolithus parcus* Zone, CC18 (Early Campanian) and 4—*Micula murus* Zone, CC25c (Late Maastrichtian). The Paleocene rocks comprise, 1—*Chiasmolithus danicus* Zone, NP3 (Late Danian), 2—*Ellipsolithus macellus* Zone, NP4 (Late Danian), 3—*Fasciculithus tympaniformis* Zone, NP5 (Thanethian-Selandian). The Eocene rocks comprise 1—*Discoaster multiradiatus* Zone, NP9b, 2—*Tricharhiatus contortus* Zone, NP10a, 3—*Discoaster binodosus* Zone, NP11, 4—*Tricharhiatus orthostylus* Zone, NP12, and 5—*Discoaster sublodoensis* Zone, NP14 (Ypresian).

Several stratigraphic hiatus were recorded in the studied section. The Cretaceous/Paleogene boundary is marked by the absence of the Late Cretaceous nannofossil Zone; CC26, as well as the Early Paleocene nannofossil biozones, NP1 and NP2 and probably the lower part of NP3. A major hiatus is suggested at the Selandian/Thanethian boundary as indicated by absence of the nannofossil biozones; NP6, NP7 and NP8. On the other hand, the latest Paleocene calcareous nannofossil subzone NP9a is missed, suggesting a minor hiatus at the P/E boundary.
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Plate 1. All figures ×1250. 1-3. Arkhangelskiella cymbiformis Vekshina, 1—sample no. 1, 2—sample no. 28, 3—sample no. 38. 4, 5. Aspidolithus parcus (Stradner), 4—sample no. 46, 5—sample no. 53. 6. Prolatipatella multicarinata (Gartner), sample no. 26. 7. Prediscosphaera cretacea (Arkhangelsky), sample no. 25. 8. Eiffellithus turrisellifolii (Deflandre in Deflandre & Fert), sample no. 24. 9, 13, 14. Micula murus (Martini), 9—sample no. 51, 13—sample no. 54, 14—sample no. 57. 10-12. Micula decussata Vekshina, 10—sample no. 8, 11—sample no. 13, 12—sample no. 22. 15, 20. Placozygus sigmoides (Bramlette & Sullivan), 15—sample no. 65, 20—sample no. 71. 16, 17. Reinhardtites anthophorus (Deflandre), 16—sample no. 6, 17—sample no. 14. 18. Cribrosphaerella ehrenbergii (Arkhangelsky), sample no. 2. 19. Calculites obscures (Deflandre), sample no. 15.
Plate 2. All figures ×1250. 1-3, 4. Watznaueria barnesae (Black in Black & Barnes), 1—sample no. 11, 2—sample no. 36, 3—sample no. 39, 4—sample no. 40. 5-6. Zygodiscus plectopons (Bramlette & Sullivan), 5—sample no. 75, 6—sample no. 80. 7. Neococcolithes protenus (Bramlette & Sullivan), sample no. 92. 8. Lucanorhahdus cuyeurii Deffandre, sample no. 29. 9. Chiasmolithus danicus (Brotzen), sample no. 76. 10. Ellipsolithus macellus (Bramlette & Sullivan), sample no. 94. 11. Ericsonia formosa (Kamptner), sample no. 113. 12. Neococcolithes dubius (Deffandre), sample no. 114. 13, 15. Fasciculithus clinatus Bukry, 13—sample no. 83, 15—sample no. 85. 14-16. Fasciculithus tympaniformis (Hay & Mohler), 14—sample no. 78, 16—sample no. 81. 17. Discoaster barbadiensis Tan, sample no. 87. 18. Discoaster multiradiatus Bramlette & Reidel, sample no. 86. 19. Discoaster araneus Bukry, sample no. 88. 20. Chiasmolithus solitus (Bramlette & Sullivan), sample no. 118.
Plate 3. All figures ×1250. 1, 3. *Reticulofenestra dictyoda* (Deflandre), 1—sample no. 109, 3—sample no. 113. 2. *Reticulofenestra umbilica* (Levin), sample no. 102, 4—*Zeugrhabdotus pseudanthophorus* (Bramlette & Martini), sample no. 46. 5, 8, 9, 10, 12. *Sphenolithus moriformis* (Bronnimann & Stradner), 5—sample no. 91, 8—sample no. 101, 9—sample no. 105, 10—sample no. 106, 12—sample no. 113. 6. *Sphenolithus obtusus* Bukry, sample no. 118. 7, 11. *Sphenolithus radians* Deflandre, 7—sample no. 97, 11—sample no. 99. 13-16. *Tribrachiatus orthostylus* Shamrai, 13—sample no. 102, 14—sample no. 105, 15—sample no. 106, 16—sample no. 108. 17-20. *Zygrhablithus bijugatus* (Deflandre), 17—sample no. 87, 18—sample no. 90, 19—sample no. 93.