

## EARLY TO LATE OLIGOCENE CALCAREOUS NANNOFOSSIL BIOEVENTS IN THE MEDITERRANEAN (UMBRIA-MARCHE BASIN, CENTRAL ITALY)

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**Key words:** Calcareous nannofossils, Biostratigraphy, Oligocene, Mediterranean, Italy.

**Abstract.** Calcareous nannofossil assemblages have been investigated by means of quantitative analyses in three Oligocene pelagic sections located in the Umbria-Marche Apennines (Central Italy). The studied sections mainly consist of marly limestones and marls belonging to the Scaglia Cinerea Formation, and include the interval between NP23 and NP25 representing a time interval of about 3.5 Ma. Biostratigraphic resolution is extremely low and only two standard bioevents are known, which are the FO of *Sphenolithus ciperoensis* and the LO of *Sphenolithus distentus*. The distribution patterns of poorly known or recently described calcareous nannofossils provided a valuable tool for improving the current biostratigraphic framework. The studied interval is characterized by significant changes in the calcareous nannofossil assemblages and by several extinction events. The last occurrence (LO) and/or the last common occurrence (LCO) here proposed are: the LO of *Sphenolithus akropodus*, the LO of *Reticulofenestra circus*, the LCO of *Helicosphaera ethologa*, the LCO of *Helicosphaera compacta* and the LO of *Discoaster tani nodifer*. The reversal in abundance between *Sphenolithus predistentus* and *S. distentus* provided an additional biostratigraphic constraint at the NP23-NP24 transition. In addition biometric criteria enabled the recognition of the first common occurrence (FCO) of *Cyclicargolithus abisectus* > 12 µm as potential bioevent within NP24. The quantitative distribution of *Sphenolithus distentus* suggests to rely on the LCO of the species rather than on the LO, for the identification of NP24-NP25 boundary. The identified bioevents is a first step towards the improvement of the present Mediterranean biostratigraphic framework of the Oligocene geological record. A preliminary correlation of the bioevents to the Geomagnetic Polarity Time Scale is presented.

**Riassunto.** In questo lavoro vengono presentati i risultati di uno studio biostratigrafico quantitativo sulle associazioni a nannofossili calcarei svolto in tre successioni pelagiche oligoceniche ubicate in Italia centrale, nell'Appennino umbro-marchigiano. Le successioni analizzate sono costituite principalmente da calcari marnosi e marne della Formazione Scaglia Cinerea e corrispondono all'intervallo stratigrafico compreso tra le biozone NP23-NP25. In questo intervallo la risoluzione biostratigrafica fornita dalle zonazioni standard è estremamente bassa

e solo due limiti biozonali, rappresentati dalla comparsa di *Sphenolithus ciperoensis* e dalla estinzione di *Sphenolithus distentus*, vengono definiti in un intervallo di tempo di circa 3.5 Ma. La distribuzione quantitativa di alcuni taxa poco noti e/o di recente istituzione ha consentito il riconoscimento di variazioni nelle associazioni a nannofossili e l'individuazione di eventi biostratigrafici nuovi. L'intervallo studiato è caratterizzato da importanti cambiamenti nelle associazioni e da numerosi eventi di estinzione. Gli eventi di scomparsa (LO) e/o le ultime comuni presenze (LCO) sono: LO di *Sphenolithus akropodus*, LO di *Reticulofenestra circus*, LCO di *Helicosphaera ethologa*, LCO di *Helicosphaera compacta*, LO di *Discoaster tani nodifer*. Inoltre, l'inversione di abbondanza tra *Sphenolithus predistentus* e *S. distentus* può essere utilizzata come ulteriore marker biostratigrafico alla transizione NP23-NP24 e l'utilizzo di criteri biometrici consente di proporre la prima comune comparsa (FCO) di *Cyclicargolithus abisectus* > 12 µm, come evento utile nella Zona NP24. La distribuzione quantitativa di *Sphenolithus distentus* suggerisce di utilizzare la LCO della specie, per l'individuazione del limite biozonale NP24-25, piuttosto che la LO. Gli eventi proposti rappresentano un punto di partenza per migliorare il quadro biostratigrafico dell'Oligocene nel Mediterraneo. È inoltre proposta una preliminare correlazione dei bioeventi riconosciuti con la Scala Cronostratigrafica Standard.

### Introduction

During the Early Oligocene calcareous nannofossil assemblages have experienced the lowest evolutionary rate of the entire Paleogene, which may reflect times of global climatic deterioration (Haq 1973). The low specific diversity due to the numerous Early Oligocene extinctions has also been related to a step in the eutrophication of the euphotic zone (Aubry 1992). Independently of the reasons for the low turnover in the Oligocene calcareous nannofossil assemblage, it is well known that a very low number of non-repetitive bioevents through time is observed in the Oligocene record

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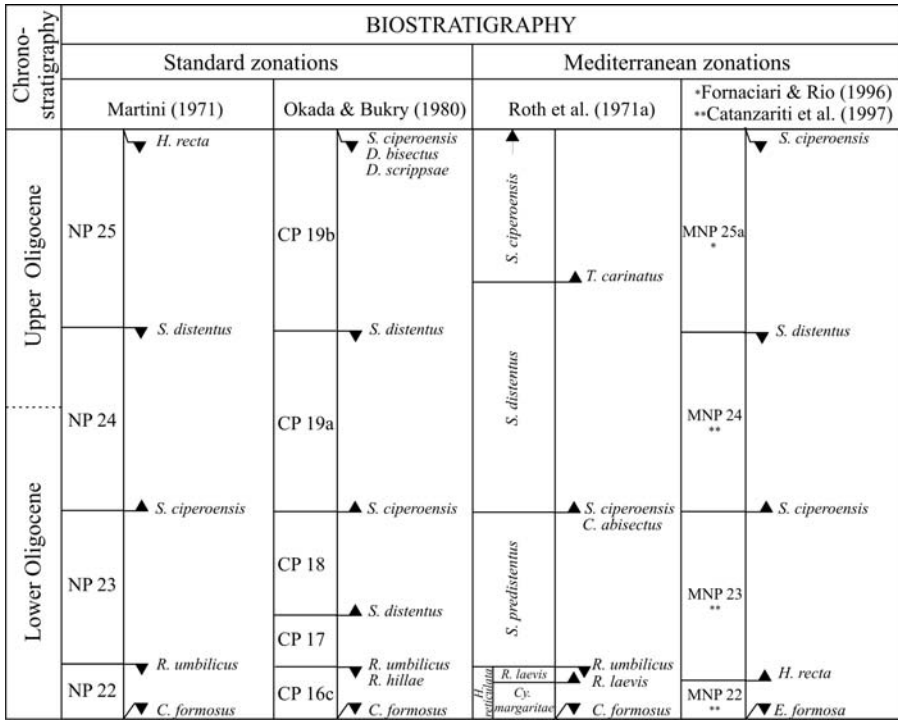


Fig. 1 - Summary of Oligocene calcareous nannofossil biostratigraphy.

and a rather low resolution characterizes both Standard and Mediterranean Oligocene biostratigraphic zonations (Fig. 1). In the about 9 Ma, covered by the Oligocene Epoch, only 5 standard biohorizons are available and their reliability and quantitative pattern has not been investigated in detail so far. Actually, during the last decade, most of the calcareous nannofossil studies in the Cenozoic have mainly focused on major changes in the assemblages at the Paleogene Series boundaries (P/E, E/O, O/M) and on the Neogene and Quaternary biostratigraphic record. Only a few quantitative studies from both the Mediterranean and extra-Mediterranean region (Fornaciari et al. 1990; Olafsson & Villa 1992; de Kaenel & Villa 1996; Catanzariti et al. 1997) have been performed on Oligocene calcareous nannofossil biostratigraphy. Consequently a detailed nannofossil biostratigraphic framework of the Oligocene record and direct correlation of most of the biohorizons to the Geomagnetic Polarity Time Scale are not available yet neither in the land sections nor in the deep-sea cores.

In the present study, the results of quantitative analyses on calcareous nannofossils are reported through the Oligocene Zones NP23/25 of Martini (1971), from three Mediterranean on-land pelagic sections belonging to the Scaglia Cinerea Unit, located in the Umbria-Marche region (Fig. 2). Abundance patterns of conventional markers allow an evaluation of the mode of originations and extinctions, and provide an indication of reliability of biostratigraphic boundaries especially for short distance correlation. Moreover, quantitative distributions of poorly known taxa have

been considered, in order to provide additional biohorizons that may improve the Oligocene biostratigraphic framework within the Mediterranean region. This study is part of a multidisciplinary stratigraphic program (OLIS working group, Coccioni et al. submitted), which focused on the reconstruction of the events occurring at the Rupelian/Chatian boundary.



Fig. 2 - Location of the studied sections. CBR: Contessa Barbeti Road section MCA: Monte Cagnero section; PAC: Pieve d'Accinelli section.

## Materials

The biostratigraphic data have been obtained from three continuous pelagic successions cropping out in the northeastern Apennines of Italy, in the Umbria-Marche basin and belonging to the Scaglia Cinerea Formation. They are characterized by a fairly regular alternation of grey marly limestones, calcareous marls and marl beds, of 10-20 cm in thickness, with some intercalations of biotite-rich volcanoclastic layers. Magnetostratigraphy and radiometric calibration of biotite-rich layers in all studied sections is presented in Coccioni et al. (submitted).

### The Contessa section (CBR)

The section is located near Gubbio and has been sampled along a new road cut in the Barbetti quarries, Contessa Barbetti Road (CBR). Stratigraphic correlation between the new exposure (CBR) and the nearby Contessa Quarry section (CQ), studied by Lowrie et al. (1982) and dated by Montanari et al. (1985), are reported in Coccioni et al. (submitted).

Previous biostratigraphic studies on the Contessa section have been carried out on the Late Oligocene-Early Miocene sequence by Montanari et al. (1991), Coccioni & Monechi (1992), Montanari et al. (1997), and at the Eocene-Oligocene transition (Nocchi et al. 1986; Premoli Silva et al. 1988). In the previous works no quantitative data on the Oligocene portion were reported and only the marker species have been used. The CBR section is about 50 m thick and a total of 60 samples were studied, collected at a mean interval of about 1 meter or rarely of 50 cm, allowing a sample resolution of about 1 sample/100ky.

### The Monte Cagnero section (MCA)

The Monte Cagnero section is a continuous sedimentary succession spanning from the middle Eocene to the upper Oligocene and located near the town of Urbania (Marche, Central Italy). Previous biostratigraphic studies of the Lower Oligocene interval (up to NP22) of the Monte Cagnero section were performed by Baumann & Roth (1969), Roth (1970), Parisi et al. (1988). Tori (2005) re-investigated the Eocene-Oligocene transition. In this study an interval of 80 meters has been sampled spanning the NP23-NP25 interval, and a total of 80 samples (one sample per meter) has been investigated, with a sample resolution of approximately every 60-70ky.

### The Pieve d'Accinelli section (PAC)

The Pieve d'Accinelli section is located near Piobico and is about 58 meters thick. It recovers the middle part of the Scaglia Cinerea Formation. A total of 90 samples has been studied, collected mostly at a mean

distance of 50 cm (about 1 sample/40ky), or rarely of 1 meter in the lowermost and uppermost parts of the section, where no significant biohorizons were detected. The calcareous nannofossil content of the Pieve d'Accinelli section was not previously studied.

## Methods

Smear slides were prepared from unprocessed samples using standard methodology (Bown & Young 1998) and analysed under a polarized light microscope at 1000x magnification. Quantitative analyses have been performed in order to evaluate distribution patterns of index species and distinguish between first occurrence (FO) or first common occurrence (FCO) and last occurrences (LO) or last common occurrences (LCO). In the studied sections most of the events are represented by LCOs or LOs. The LCO event has been indicated at the end of a consistent distribution pattern, followed by rare and scattered occurrences of the taxon which prevented the recognition of a reliable LO event. The LO event has been recognized at the highest occurrence of the species whose final distribution is characterized by a fairly consistent and homogeneous pattern. Only selected taxa have been counted: *Cyclicargolithus abisectus* and reticulofenestrads were counted on 300 specimens of the total assemblages and a counting of 100 sphenoliths has been performed on this genus (Backman & Shackleton 1983; Rio et al. 1990); abundances are plotted as percentage. Helicolithids and discoasterids are often rare in the assemblages and their abundance patterns were collected counting the index species in an area of 150 views containing about 1500-2000 nannofossils and plotted as N°/mm<sup>2</sup>.

## Results

In all sections the interval between the upper part of NP23 and the lower part of NP25 has been examined. Calcareous nannofossil assemblages are generally abundant and moderately overgrown. On the basis of the quantitative distribution of selected taxa observed in the studied sections (Figs. 3-5) and of those shown by different authors both in Mediterranean and extra-Mediterranean sections, the reliability of standard and supplementary bioevents is discussed from the oldest to the youngest.

### LO of *Sphenolithus akropodus*

This species was first recorded in the equatorial Indian Ocean (Okada 1990; Fornaciari et al. 1990) within Zones CP16 and CP17; subsequently it was formally described from the Iberia abyssal plain by de Kaenel & Villa (1996), where the LO of *S. akropodus* was proposed as a reliable event in the upper part of NP23. The species has not been previously documented from the Mediterranean region. In this study the uppermost range of *S. akropodus* has been recorded in the CBR and MCA sections (Figs. 3-4); the species is never abundant and only in the MCA section exceeds 5% of all sphenoliths. The LO of *S. akropodus* has been observed in both sections and occurs within Zone NP23. However, the entire distribution of the taxon needs to be docu-

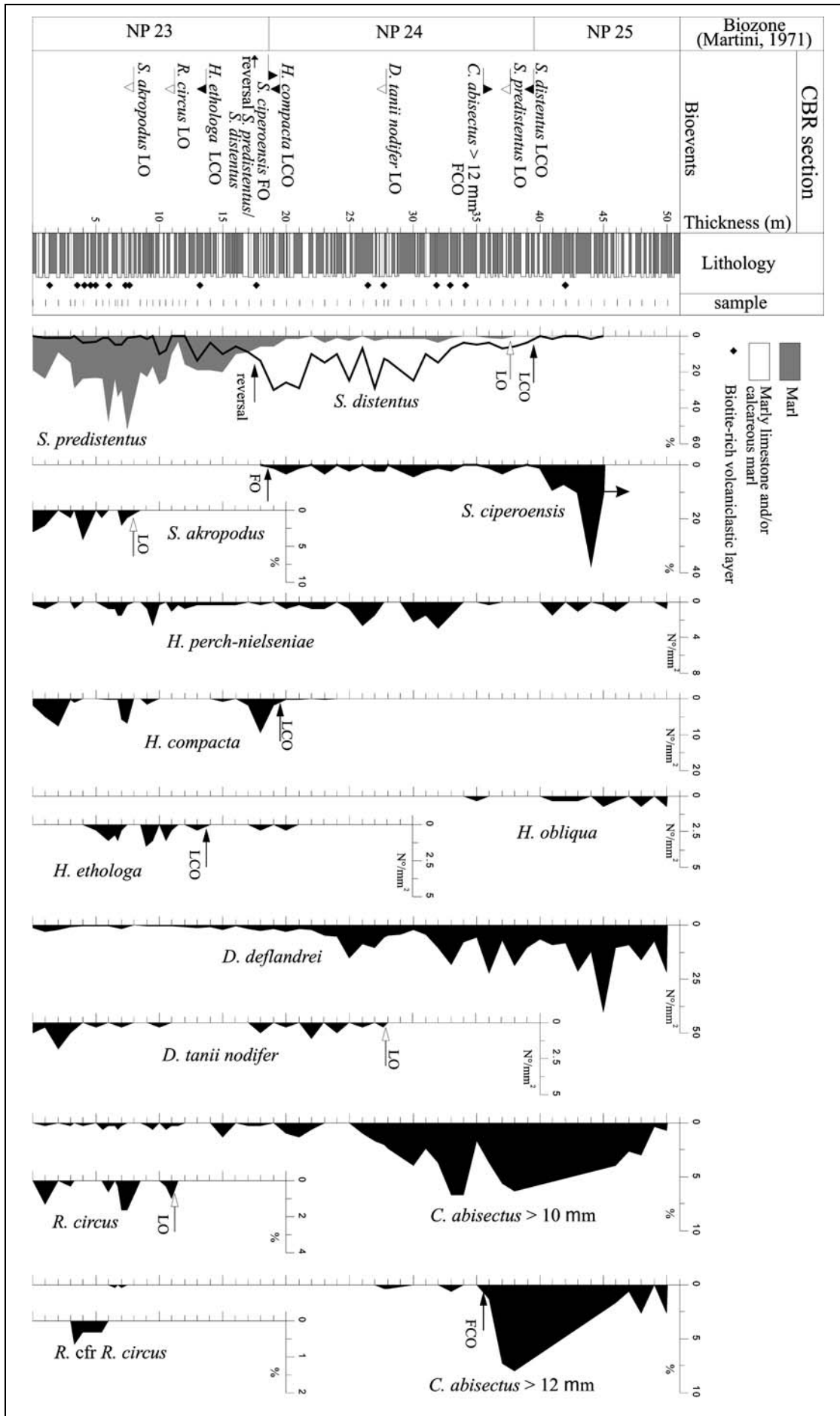


Fig. 3 - Abundance patterns of selected calcareous nannofossils from the Contessa Barberi Road (CBR) section. Lithology from Coccioli et al. (submitted). FO: First occurrence; FCO: First common occurrence; LO: Last occurrence; LCO: Last common occurrence.

mented in more detail in different sections in order to evaluate the reliability of this bioevent.

#### LO of *Reticulofenestra circus*

The extinction pattern of *R. circus* has only been documented from the Iberia abyssal plain (de Kaenel & Villa 1996), within NP23, below the LO of *S. akropodus*. Rare occurrences of *R. circus* are recorded in the lowermost part of the CBR and MCA sections (Figs. 3-4) and therefore only the uppermost range of the species can be shown. According to our results the LO of *R. circus* seems to occur within NP23, above the LO of *S. akropodus*. However, the rarity of the species and the short distribution observed in our sections suggest that the LO of *R. circus* and its mutual position with the LO of *S. akropodus* need further investigations.

#### LCO of *Helicosphaera ethologa*

De Kaenel & Villa (1996) proposed the LO of *Helicosphaera* aff. *carteri* (= *H. ethologa*) as a new bioevent within the lower part of NP24. The species has been recently described by Bown (2005) from NP23. *H. ethologa* has been identified in the CBR and MCA sections (Figs. 3-4), in which it is never abundant, but fairly continuously present within NP23. Very rare and scattered occurrences have been observed up to the lower part of NP24. The distribution of the species is more continuous in the MCA section than in the CBR section, where the species is very rare and discontinuously present. The quantitative pattern observed in both sections suggests that its LCO may be an additional bioevent in the upper part of NP23, although the distribution of the taxon needs to be tested in other sections.

#### FO of *Sphenolithus ciproensis*

The FO of *S. ciproensis* is one of the few biohorizons used in the Oligocene standard zonation and defines the base of NP24 and CP19a; its reliability is still controversial. The early range of the species has been often documented as characterized by scattered and rare occurrences (Fornaciari et al. 1990; Olafsson & Villa 1992; de Kaenel & Villa 1996; Catanzariti et al. 1997). The FO has been considered an unreliable event, because it is inconsistently correlated among different sections (Wei & Wise 1989), and difficult to recognize due to controversial taxonomy (Moran & Watkins 1988). In the Contessa Quarry section the FO of *S. ciproensis* has been recorded only above the LO of *S. distentus* (Lowrie et al. 1982).

On the basis of our results the species results very rare in the lower part of its range; we identify its first rare occurrences, generally represented by 1-2 specimens of 100 sphenoliths, both at CBR and MCA (Figs. 3-4), and recognize the base of Zone NP24, below the LO of *S. distentus*.

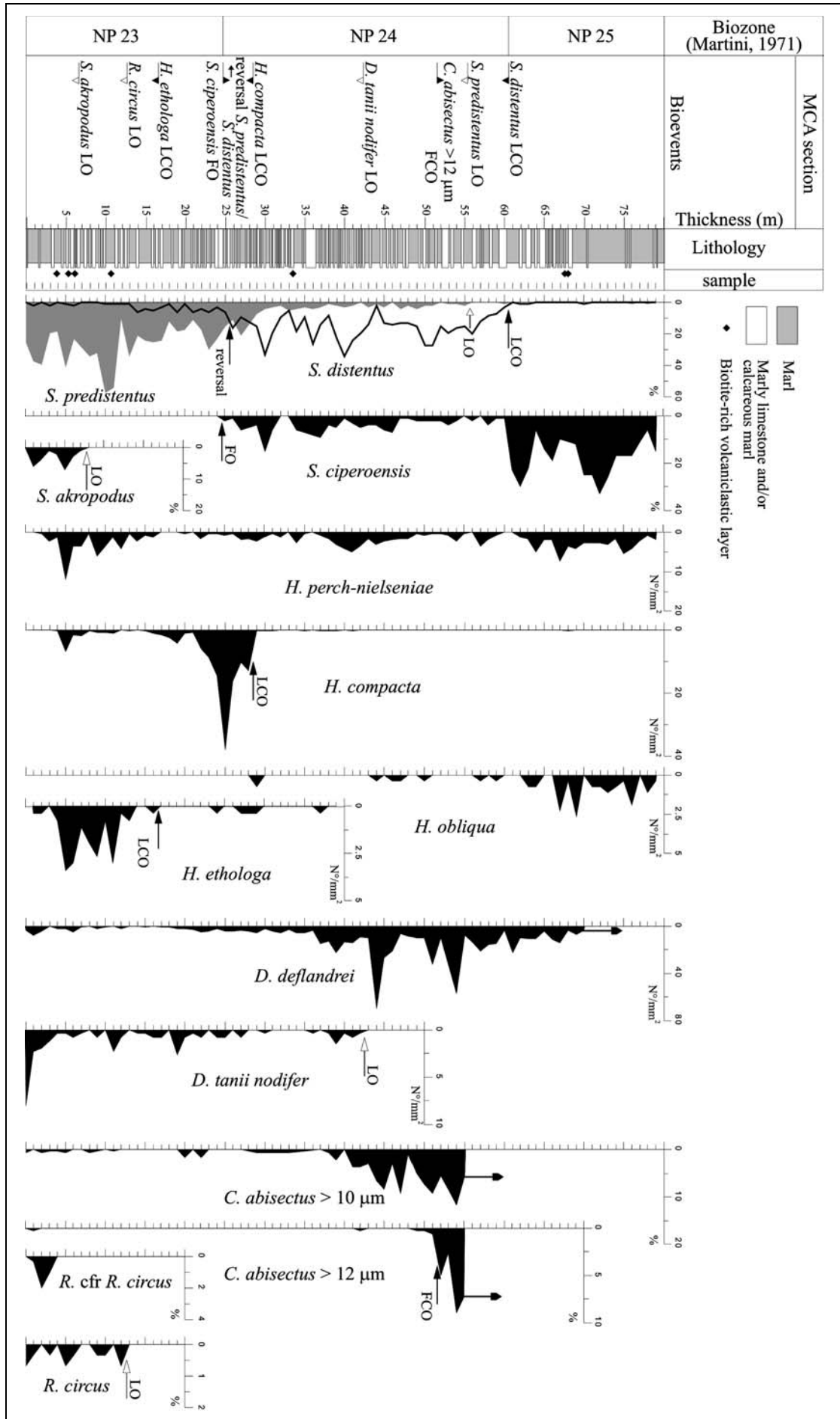
Reversal in abundance between *Sphenolithus predistentus* and *Sphenolithus distentus*.

The succession of *Sphenolithus predistentus*, *S. distentus* and *S. ciproensis* is well known to represent a distinctive evolutionary lineage. Their respective changes in abundance through time have been already noted within NP23/25 interval. For a biostratigraphic purpose, the abundance transition from the dominant *Sphenolithus predistentus* to the dominant *S. distentus* has been proposed for the subdivision of the interval between the LO of *R. umbilicus* and the FO of *S. ciproensis* (Fornaciari et al. 1990) in replacement of the FO of *S. distentus*. In the investigated sections, the reliability of the FO of *S. distentus* cannot be tested, since the species occurs as rare and scattered from the lowermost samples. However, at the CBR and MCA sections, a significant increase in abundance of *S. distentus* from 1-8% to above 10% and a concomitant decrease of *Sphenolithus predistentus* (*S. predistentus*/*S. distentus* reversal) is observed (Figs. 3-4). It occurs slightly above and slightly below the FO of *S. ciproensis* at the MCA and CBR sections respectively. Although the reversal in abundance between the two species reflects their phylogenetical relation and can be useful for biostratigraphical purposes, a palaeoenvironmental control on the frequency variations of these taxa cannot be excluded. Therefore the reliability and consistency of this signal need to be tested in additional sections.

#### LCO of *Helicosphaera compacta*

The LO of *H. compacta* was recorded within NP23 in the equatorial Indian Ocean (Fornaciari et al. 1990) or within NP24 from the Iberia margin (de Kaenel & Villa 1996). However, the LCO of the species has been considered a more easily detectable event than its LO in the uppermost part of NP23 (de Kaenel & Villa 1996), close to the FO of *S. ciproensis*. Quantitative data are not available on the final distribution of *H. compacta* within the Mediterranean region. The abundance patterns obtained at the CBR and MCA sections (Figs. 3-4) indicate that the species has very low and scattered abundances during its final range. This suggests that the sharp decline in abundance of the species (LCO), occurring in the lowermost part of NP24, is a more distinct event than its LO. The LCO of *H. compacta* is characterized by a sharp drop in abundance of the species from more than 10 specimens/mm<sup>2</sup>, to generally less than 1 specimens/mm<sup>2</sup>, above the FO of *S. ciproensis*. The slight discrepancies in the mutual position between the LCO of *H. compacta* and the FO of *S. ciproensis* with respect to previous findings can be due to the rarity of *S. ciproensis* in the lower part of its range. In our opinion the LCO of *H. compacta* in the Mediterranean can be a useful event to approximate the

Fig. 4 - Abundance patterns of selected calcareous nannofossils from Monte Cagnero section. For legend see Fig. 3.



FO of *S. ciproensis* due to the distinctive pattern of the species and unambiguous taxonomy.

LO of *Discoaster tanii nodifer*

Aubry (1992) indicated the LO of *D. tanii nodifer* within NP23, whereas de Kaenel & Villa (1996) recorded the same event within NP24. Although *D. tanii nodifer* is never abundant in the sections studied, our data collected in all three sections (Figs. 3-5) are consistent with the latter authors and indicate that the LO of the species may be an additional event within NP24. The rarity of species and the only few data on the quantitative distribution of this taxon suggest that the biostratigraphic value of the event need to be further investigated.

FCO of *Cyclicargolithus abisectus* > 12  $\mu\text{m}$

The distribution of *C. abisectus* > 10  $\mu\text{m}$  has been used in the Oligocene record for biostratigraphic purpose and occurrences of this morphotype are reported from NP23 (Fornaciari et al. 1990; de Kaenel & Villa 1996). Olafsson (1992) indicated that the distribution of

specimens of the *Cyclicargolithus* group > 11  $\mu\text{m}$  is limited to CP19. In this work, specimens of *C. abisectus* > 10 and 11  $\mu\text{m}$  in size have been observed throughout the three sections from the lowermost samples and their lowest occurrences could not be monitored. However, *Cyclicargolithus abisectus* seems to increase in size through NP24. A sharp increase in abundance of morphotypes > 12  $\mu\text{m}$  (FCO), within the upper part of NP24, signals a distinct change in the assemblage in all investigated sections (Figs. 3-5), suggesting that it may be a useful supplementary bioevent, at least on a regional scale, within NP24.

LO of *Sphenolithus predistentus*

The LO of *S. predistentus* has been considered a reliable event in order to increase Oligocene biostratigraphic resolution (Olafsson & Villa 1992) and an alternative biohorizon for the identification of the NP24/25 zonal boundary (Fornaciari et al. 1990; de Kaenel & Villa 1996). In the investigated sections it is clear that *S. predistentus* remains only a minor component among sphenoliths above the FO of *S. cipro-*

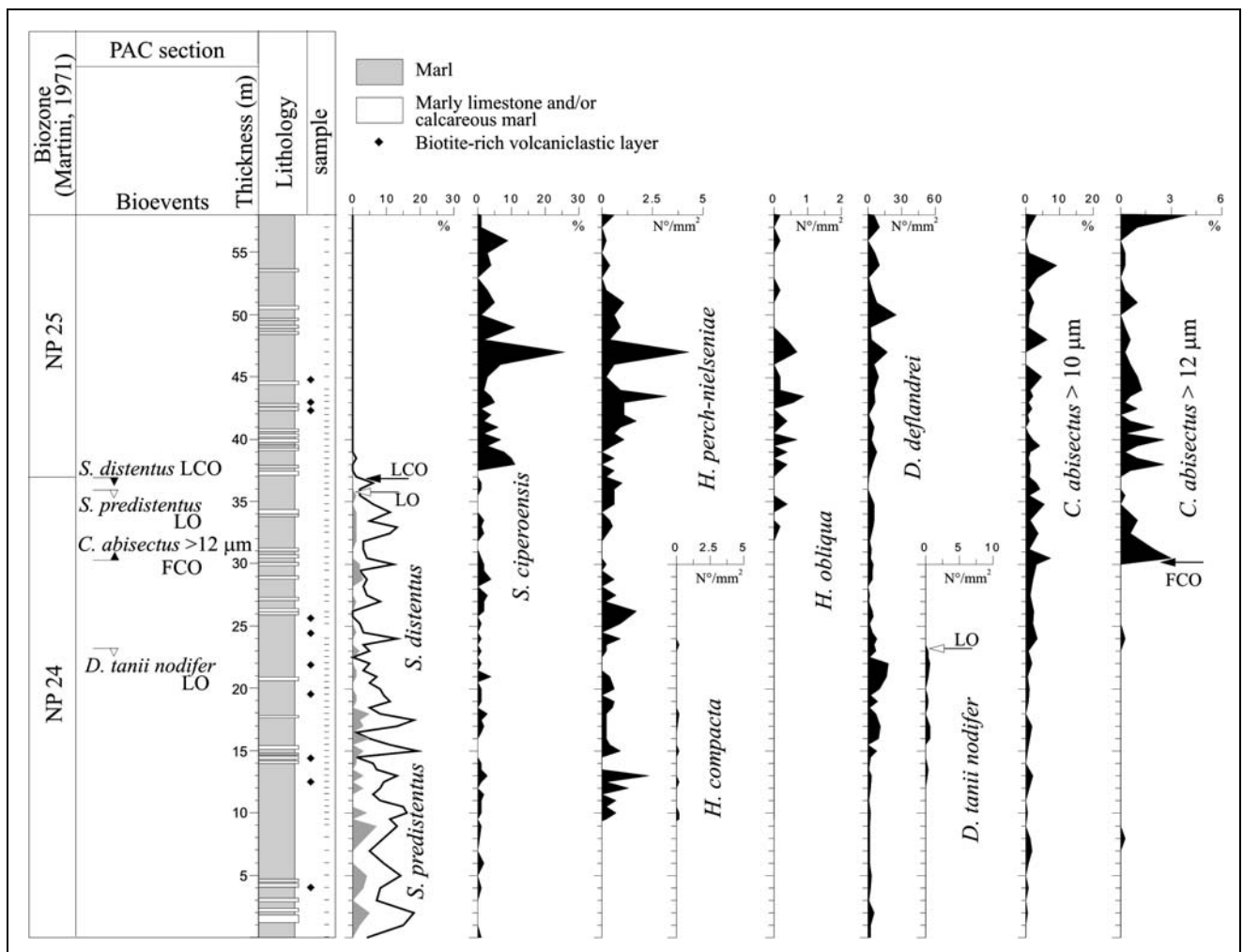


Fig. 5 - Abundance patterns of selected calcareous nannofossils from Pieve d'Accinelli section. For legend see Fig. 3.

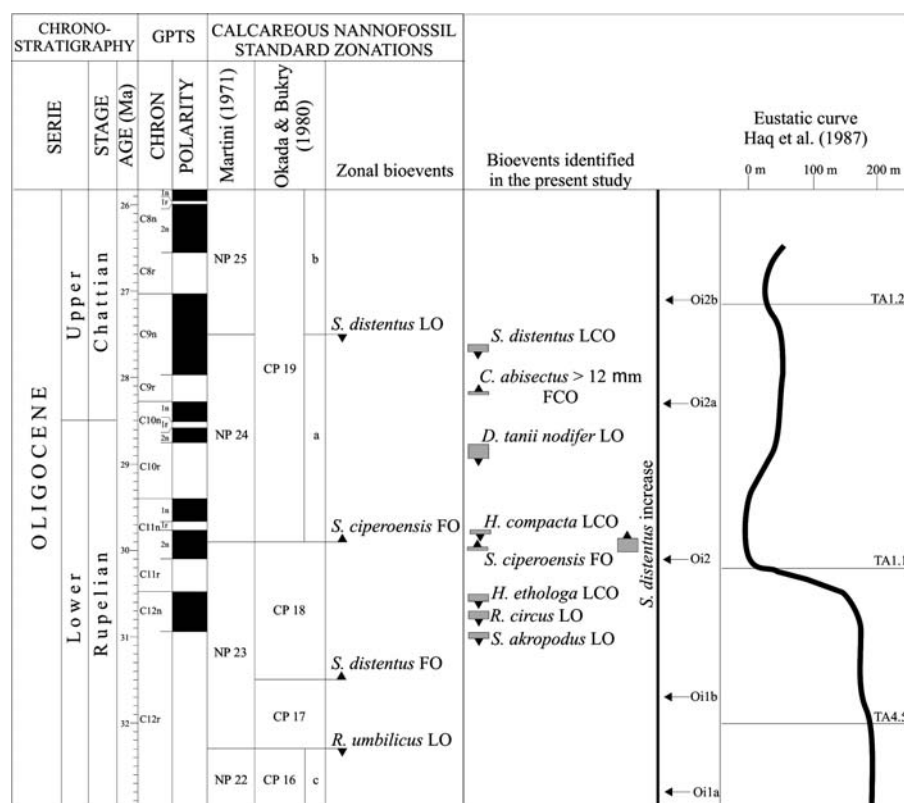


Fig. 6 - Correlation of the bioevents to the GPTS of Berggren et al. (1995) and Cande & Kent (1995), oxygen isotope maxima (Oi) of Miller et al. (1998) and eustatic curve of Haq et al. (1987) whose chronology is adapted to Berggren et al. (1995) and follows Miller et al. (1998). Calibration of the zonal bioevents refer to Berggren et al. (1995); correlation of the bioevents identified in the present study to the GPTS follows Coccioni et al. (submitted); shaded boxes testify uncertainty in biochronology. TA refers to sequence boundaries in Haq et al. (1987).

*ensis* and throughout NP24 (Figs. 3-5). Abundance patterns indicate that the LO of *S. predistentus* can be identified, in all three sections, in the uppermost part of NP24. Unfortunately the species is discontinuously present during the final distribution when its abundance rarely exceeds 2% of the sphenoliths. This datum suggests that the event may be of low reliability for stratigraphic correlation especially without a high sampling resolution. We retain that the PAC section (Fig. 5) offers the most reliable final distribution pattern of the species, due to the highest sampling resolution available in this section.

#### LCO of *Sphenolithus distentus*

The LO of *S. distentus* defines the NP24/NP25 zonal boundary in the standard zonation. Fornaciari et al. (1990) have already pointed out that the LO of *S. distentus* can be difficult to identify due to the rarity of the species in the final range. Moreover, Olafsson & Villa (1992) define the “final decline in abundance” of *S. distentus* as a high reliable event. In the three studied sections (Figs. 3-5), *S. distentus* is often very rare in the uppermost part of its range, and consequently reworked occurrences cannot be easily discriminated from rare “normal” occurrences of the species during its final range. The sharp decrease in abundance of the species enables an easy detection of the LCO event and this is used in the present study for the recognition of the NP24/25 zonal boundary. A concomitant increase of *S. ciproensis* is recorded at the same level.

#### Conclusions

The quantitative distribution patterns of calcareous nannofossils in three Oligocene sections located in the Umbria-Marche basin have been presented. A set of ten additional biohorizons, which maintain the same relative positions in the sections, has been identified in the examined 3.5 Ma, through Zones NP23-NP25 of Martini (1971), thus improving the biostratigraphic resolution of the standard zonation (Fig. 6). Calibration of each bioevents to the GPTS is object of current research and still need to be refined. Most of the identified bioevents are LOs or LCOs; others are defined on biometric criteria, or on a reversal in abundance among the Oligocene *Sphenolithus* lineage. The distribution patterns of few taxa such as *S. akropodus*, *R. circus* or *H. ethologa* seems to provide additional biostratigraphic events in the Mediterranean region; however, the data set on these events is still poor and needs to be extended in order to evaluate their biostratigraphic reliability for regional and supraregional correlations.

The numerous Early Oligocene extinctions seem unrelated to significant cooling if compared to the oxygen isotope maximum of Miller et al. (1998) or to sea level curve of Haq et al. (1987). These data may support the hypothesis of Aubry (1992) that suggests that the Early Oligocene extinctions in the calcareous nannofossil record may reflect a step towards eutrophication, as a result of increased mixing following the Early Oligo-



cene ice build-up, rather than a sharp drop in the sea temperatures. Although the degree of evolutionary turnover is confirmed to be minor during the Oligocene, the present study represents an improvement of the bio-chronostratigraphic framework within the Mediterranean area.

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## Taxonomic Appendix

### Genus *Cyclicargolithus* Bukry, 1971

#### *Cyclicargolithus abisectus* (Müller, 1970) Wise, 1983

Pl. 1, figs 1-4, 7-8

**Remarks.** Circular to subcircular birefringent placoliths, with a small central opening and  $> 10 \mu\text{m}$  in size are here assigned to *C. abisectus*. Smaller placoliths similar to *C. abisectus* but  $< 10 \mu\text{m}$  in size have been referred to *C. floridanus*. Specimens of *Cyclicargolithus*  $> 12 \mu\text{m}$  in size have been differentiated for a biostratigraphic purpose, but no taxonomic subdivision is here inferred. They are easily distinguishable from specimens of *Reticulofenestra* cfr *R. circus* (Pl. 1, figs. 13-16) for the much smaller central opening.

### Genus *Reticulofenestra* Hay, Mohler & Wade, 1966

#### *Reticulofenestra circus* de Kaenel & Villa, 1996

Pl. 1, figs 9-12

**Remarks.** According to the original description, this medium-sized reticulofenestrid is 8-9  $\mu\text{m}$  in diameter and is characterized by a subcircular outline, thin collar and wide and quadrate central opening. The taxon can be easily recognized in the studied samples and its LO is recorded within NP23.

#### *Reticulofenestra* cfr *R. circus* de Kaenel & Villa, 1996

Pl. 1, figs 13-16

**Remarks.** Specimens here referred to *Reticulofenestra* cfr *R. circus* have the outline of the placolith and the shape of the central area well comparable to those of *R. circus*. However, they are much larger in size, generally  $> 12 \mu\text{m}$ . They have a very short stratigraphic range in the lowermost part of the studied sections, within NP23 (Figs. 3-4). Although size variation of placoliths can be imputed to an environmental factor such

as nutrient content, temperature and/or salinity, we distinguished *Reticulofenestra* cfr *R. circus* due to its distinctiveness and limited stratigraphic range.

### Genus *Sphenolithus* Deflandre, 1952

Several authors have discussed taxonomic features of the Oligocene sphenoliths as well as their biostratigraphic utility and agree to consider *S. predistentus*, *S. distentus*, *S. ciproensis* as members of a distinctive evolutionary lineage (Bramlette & Wilcoxon 1967; Roth et al. 1971b; Perch-Nielsen 1985; Moran & Watkins 1988; Okada 1990; Fornaciari et al. 1990; Olafsson & Villa 1992). Their gradual evolution, testified by a progressive increase in height and width of the proximal shield, provide difficulties to separate these species using the light microscope. Therefore the taxonomic criteria for the recognition of the Oligocene sphenoliths are still not consistently adopted among nannofossil paleontologists. We report here the diagnostic features adopted in this study for the recognition of *S. predistentus*, *S. distentus* and *S. ciproensis*.

#### *Sphenolithus predistentus* Bramlette & Wilcoxon, 1967

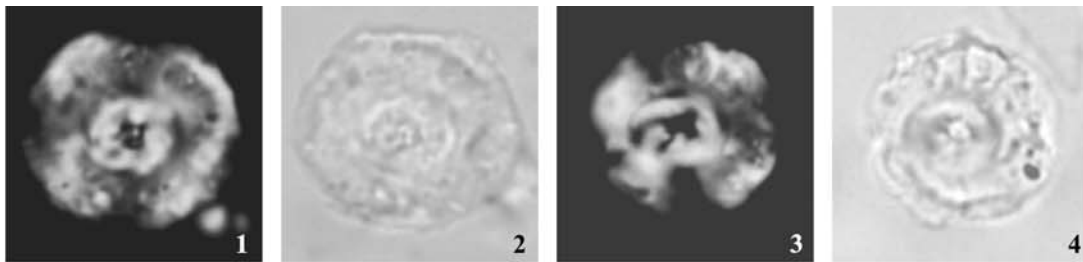
Pl. 2, figs 4-6

**Remarks.** This species has a large, extended and generally pointed apical spine and a low or very low proximal shield. Following Roth et al. (1971b) we as-

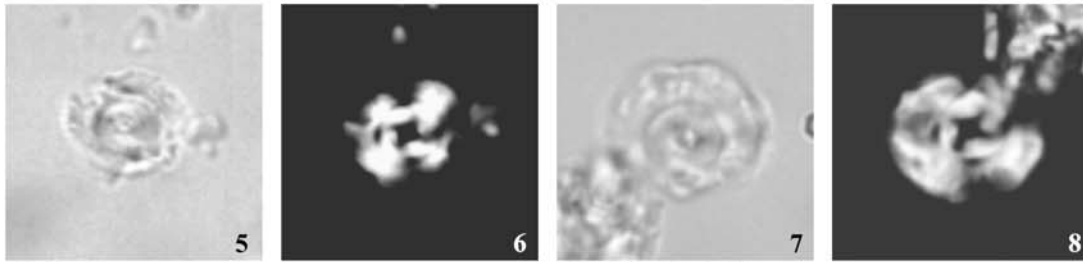
## PLATE 1

Light microscope photographs of selected calcareous nannofossil species. XP - crossed polarized light, PL - parallel light.

- 1-2. - *Cyclicargolithus abisectus* (Müller)  $> 12 \mu\text{m}$ . 1 XP, 2 PL, MCA section, 61 m.
- 3-4. - *Cyclicargolithus abisectus* (Müller)  $> 12 \mu\text{m}$ . 3 XP, 4 PL, CBR section, 38 m.
- 5-6. - *Cyclicargolithus floridanus* (Roth & Hay). 5 PL, 6 XP, MCA section 20 m.
- 7-8. - *Cyclicargolithus abisectus* (Müller)  $> 10 \mu\text{m}$ . 7 PL, 8 XP, MCA section 20 m.
- 9-12. - *Reticulofenestra circus* de Kaenel & Villa. 9, 11 XP, 10, 12 PL, MCA section 10 m.
- 13-16. - *Reticulofenestra* cfr. *R. circus*. 13, 15 PL, 14, 16 XP, MCA section 2 m.
- 17-18. - *Helicosphaera perch-nielseniae* Haq. 17 XP, 18 PL, MCA section 22 m.
- 19-20. - *Helicosphaera compacta* Bramlette & Wilcoxon. 19 XP, 20 PL, MCA section 25 m.
- 21-22. - *Helicosphaera ethologa* Bown. 21 PL, 22 XP, MCA section 29 m.
- 23-24. - *Helicosphaera obliqua* Bramlette & Wilcoxon. 23 PL, 24 XP, MCA section 75 m.

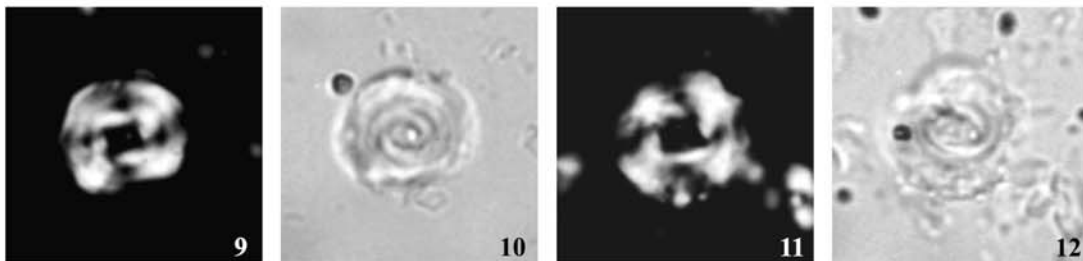


*C. abisectus* > 12  $\mu\text{m}$

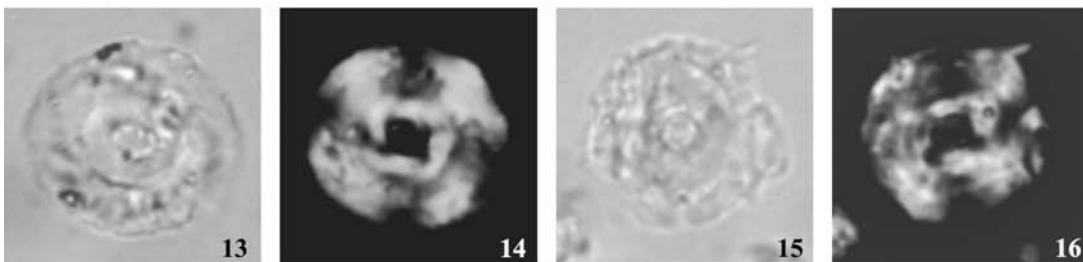


*C. floridanus*

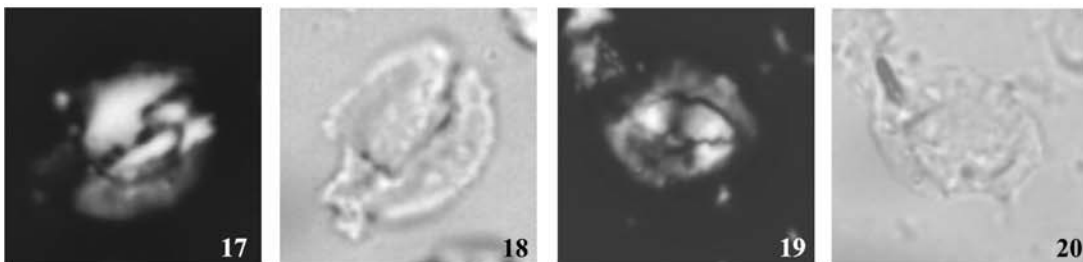
*C. abisectus* > 10  $\mu\text{m}$



*R. circus*

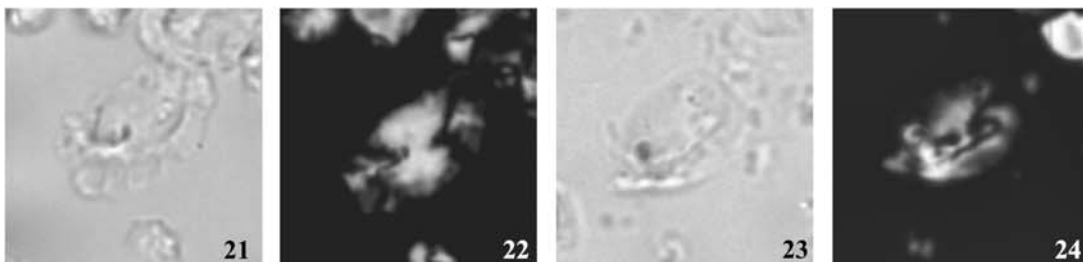


*Reticulofenestra* cfr. *R. circus*



*H. perch-nielseniae*

*H. compacta*



*H. ethologa*

*H. obliqua*

5  $\mu\text{m}$

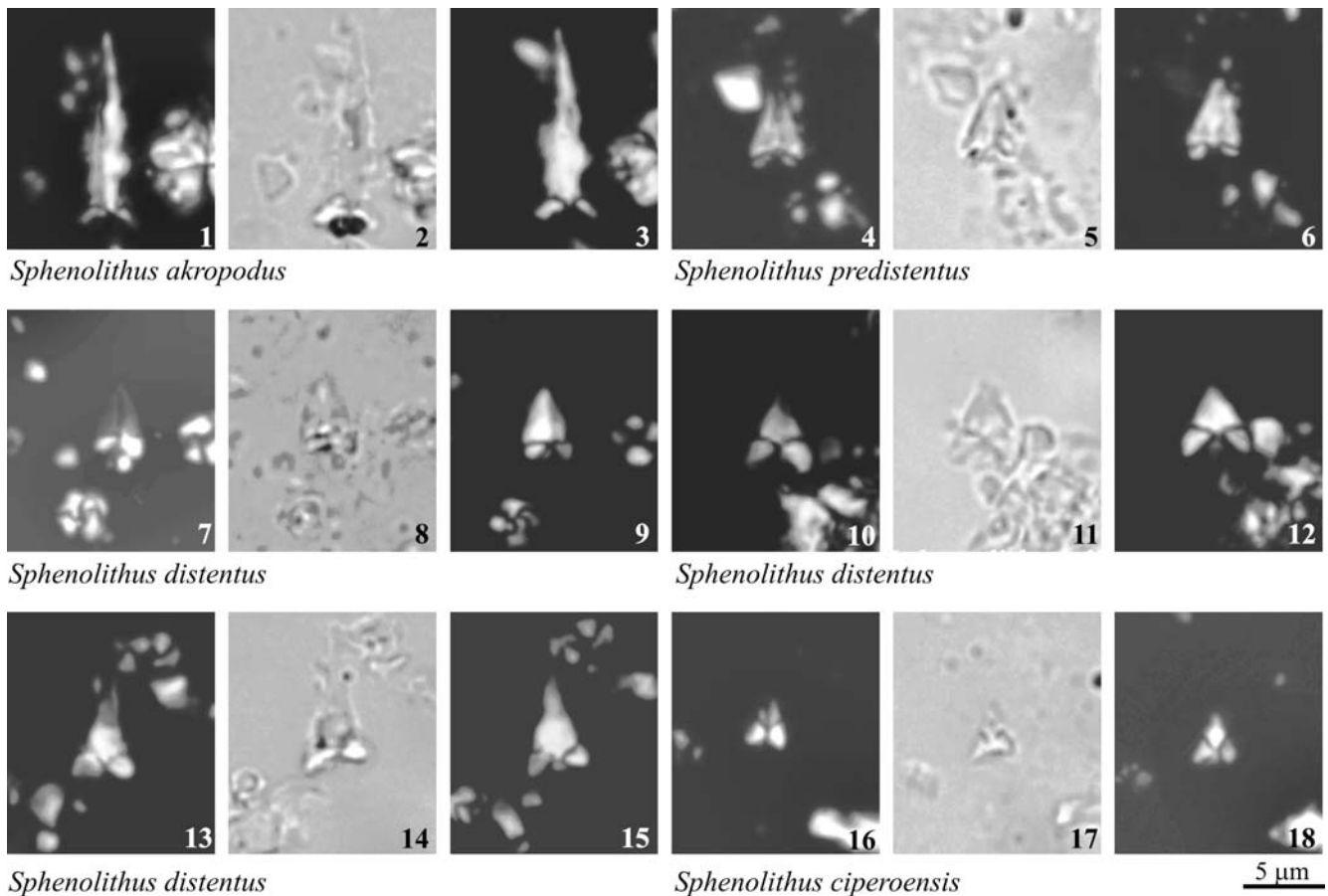


PLATE 2

Light microscope photographs of selected calcareous nannofossil species. XP - crossed polarized light, PL - parallel light.

- 1-3. - *Sphenolithus akropodus* de Kaenel & Villa. 1 XP 0°, 2 PL 0°, 3 XP 45°, MCA section 5 m.  
 4-6. - *Sphenolithus predistentus* Bramlette & Wilcoxon. 4 XP 0°, 5 PL 0°, 6 XP 45°, MCA section 5 m.  
 7-9. - *Sphenolithus distentus* (Martini). 7 XP 0°, 8 PL 0°, 9 PL 45°, MCA section 26 m.  
 10-12. - *Sphenolithus distentus* (Martini). 10 XP 0°, 11 PL 0°, 12 PL 45°, MCA section 29 m.  
 13-15. - *Sphenolithus distentus* (Martini). 13 XP 0°, 14 PL 0°, 15 PL 45°, MCA section 30 m.  
 16-18. - *Sphenolithus ciperoensis* Bramlette & Wilcoxon. 16 XP 0°, 17 PL 0°, 18 PL 45°, MCA section 73 m.

signed to *S. predistentus* sphenoliths whose extinction lines at the base of the apical spine form an angle of 90° or less with the median axis of the sphenolith, when oriented in the 45° position. In addition we point out that *S. predistentus* has a proximal shield slightly narrower than the base of its apical spine.

***Sphenolithus distentus*** (Martini, 1965) Bramlette & Wilcoxon, 1967  
 Pl. 2, figs 7-15

**Remarks.** Sphenoliths here assigned to *S. distentus* have a proximal cycle which is equal in width or slightly larger than the width of the base of the apical

spine (Roth et al. 1971b; Moran & Watkins 1988). The apical spine is wide and generally long. Extinction lines of the proximal shield are “V” shaped and generally cross when apical spine is at the 45° position. Few specimens in which the “V” shaped extinction lines do not cross at 45° to the nicols have also been noted and are here assigned to *S. distentus* since the proximal cycle is not as wide neither as high as in *S. ciperoensis*.

In the light microscope, between crossed nicols and in the 45° position, it differs from *S. predistentus* by having the angle between the extinction lines at the base of the apical spine and the median axis of the sphenolith of more than 90° (Roth et al. 1971b) as well as a relatively higher and wider proximal shield.

**Sphenolithus ciperensis** Bramlette & Wilcoxon, 1967

Pl. 2, figs 16-18

The species has a short apical spine and a proximal cycle, which is always wider than the maximum width of the apical spine. The extinction lines of the proximal shield do not cross when oriented at 45° to the nicols. It differs from *S. distentus* by having a higher proximal shield, always wider than the apical spine, and “chevronlike” extinction lines; moreover, with respect to *S. distentus*, the extinction lines between the proximal shield and the apical spine, extend significantly upwards.

**List of the taxa**

Calcareous nannofossils considered in the text are listed in alphabetical order of generic epithets. Biometric criteria adopted in this study are reported when necessary.

*Cyclicargolithus* Bukry, 1971*Cyclicargolithus abisectus* (Müller, 1970) Wise, 1973 (> 10 µm)*Cyclicargolithus abisectus* (Müller, 1970) Wise, 1973 (> 12 µm)*Cyclicargolithus floridanus* (Roth & Hay, in Hay et al. 1967)

Bukry, 1971 (&lt; 10 µm)

*Discoaster* Tan 1927*Discoaster tani nodifer* Bramlette & Riedel, 1954*Helicosphaera compacta* Bramlette & Wilcoxon, 1967*Helicosphaera ethologa* Bown, 2005*Helicosphaera obliqua* Bramlette & Wilcoxon, 1967*Helicosphaera perch-nielseniae* Haq, 1971*Reticulofenestra* Hay, Mohler & Wade, 1966*Reticulofenestra circus* de Kaenel & Villa, 1996*Reticulofenestra* cfr *R. circus**Sphenolithus akropodus* de Kaenel & Villa, 1996*Sphenolithus ciperensis* Bramlette & Wilcoxon, 1967*Sphenolithus distentus* (Martini 1965) Bramlette & Wilcoxon, 1967*Sphenolithus predistentus* Bramlette & Wilcoxon, 1967

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