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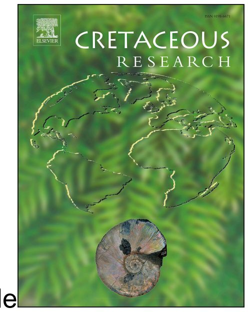

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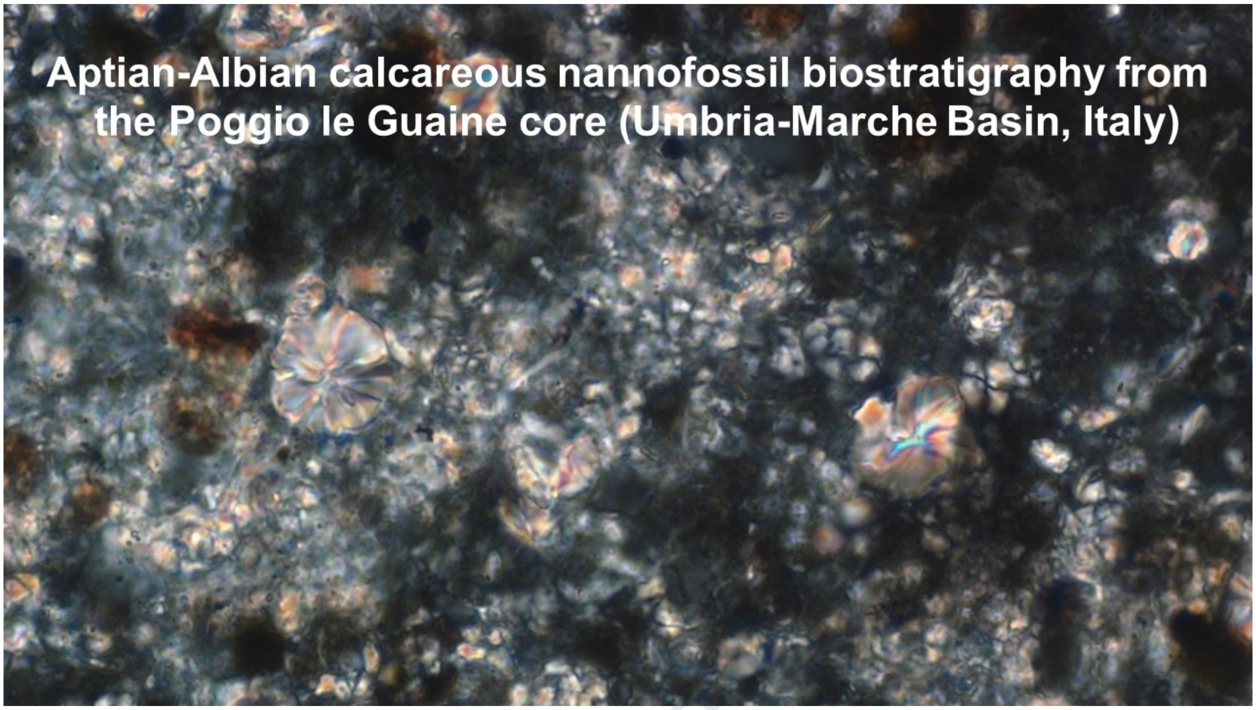
Aptian-Albian calcareous nannofossil biostratigraphy from the Poggio le Guaine core (Umbria-Marche Basin, Italy)

Calcareous nannofossils from the Poggio le Guaine core (Umbria-Marche Basin, central Italy): biostratigraphy and discussions on the bioevents of the Aptian–Albian interval

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Abstract

The calcareous nannofossil biostratigraphy of the Aptian–Albian interval has been continuously applied and developed along the last decades. The shortage of complete and continuous outcropping marine sections and even marine subsurface sections is one of the challenges of the stratigraphic studies of this interval. Taxonomic ambiguities, diachronism and reworking are constantly pointed as challenging aspects for the calcareous nannofossil biostratigraphic studies of this interval. Amid this scenario, the Poggio le Guaine section of the Umbria-Marche Basin (central Italy) stands out by presenting a complete and undisturbed pelagic to hemipelagic marine sedimentary succession of the Aptian–Albian interval. The present work is aimed to provide a detailed biostratigraphic zonation based on calcareous nannofossils, to calibrate the results to other stratigraphic tools of previous published works and to discuss some important bioevents of the Aptian–Albian interval along the PLG core. The following biozones of the calcareous nannofossil reference zonation for the Aptian–Albian interval were recognized: the *Chiastozygus litterarius* Zone (NC6 Zone), the *Rhagodiscus angustus* Zone (NC7 Zone), the *Prediscosphaera columnata* Zone (NC8* and NC8 zones), the *Axopodorhabdus albianus* Zone (NC9 Zone) and the *Eiffellithus turriseiffelii* Zone (NC10 Zone). The PLG core encompasses the chronostratigraphic interval from the Barremian/Aptian through the Albian/Cenomanian boundaries. Finally, detailed discussions on some important calcareous nannofossil bioevents of this interval were performed, among them: the first occurrence (FO) of *Hayesites irregularis,* the FO of *Hayesites albiensis*, the last occurrence (LO) of *Conusphaera rothii*, the LO of *Micrantholithus hoschulzii/Micrantholithus obtusus*, the FO of *Rhagodiscus achlyostaurion*, the FO of *Prediscosphaera columnata*, the FO of *Tranolithus orionatus* and the LOs of *Assipetra* spp.

Keywords: biostratigraphy, calcareous nannofossils, Aptian–Albian

1. Introduction

The calcareous nannofossil biostratigraphy of the Aptian-Albian interval has been continuously applied and developed along the last two decades, especially regarding the taxonomy, paleoecology and the stratigraphic positioning calibration of the main biohorizons (Aguado et al., 2014; Alves et al., 2017; Bellanca et al., 2002; Bottini et al., 2015; Bottini and Erba, 2018; Bown, 2005; Browning and Watkins, 2008; Bruno et al., 2020; Channell et al., 2000; Coccioni et al., 2012, 2014; Erba, 2004; Erba et al., 2019, 2015, 2010; Erba and Tremolada, 2004; Fernando et al., 2011; Frau et al., 2018; Gale et al., 2011; Gholamifard et al., 2016; Grippo et al., 2004; Herrle, 2003; Herrle et al., 2004; Herrle et al., 2003a,b; Herrle and Mutterlose, 2003; Hoffmann et al., 2019; Huber and Leckie, 2011; Jeremiah, 2001; Kanungo et al., 2021, 2018; Karpuk et al., 2018; Kennedy et al., 2017, 2014, 2000; Kulhanek and Wise, 2006; Leandro et al., 2022; Lees et al., 2005; Luber et al., 2019; Luciani et al., 2004; Mahanipour et al., 2018, 2011; McAnena et al., 2013; Mutterlose et al., 2009, 2003; Pedrosa et al., 2019; Sabatino et al., 2018, 2015; Shamrock and Watkins, 2009; Sikora and Bergen, 2004; Silva et al., 2020; Švábenická, 2008; Szives et al., 2018; Tiraboschi et al., 2009; Tremolada, 2002; Tremolada et al., 2006; Tremolada and Erba, 2002; Urquhart et al., 2007; Watkins and Bergen, 2003).

The base of the Aptian Stage proposed (not yet ratified) to be equated to the base of the Reversed-Polarity Zone M0r (M0r Polarity Zone) primary marker by Erba et al. (1996, 1999) from the Umbria-Marche Basin, Italy, is characterized below, by the first occurrences (FOs) of *Hayesites irregularis* and *Nannoconus truittii* (Erba et al., 1999) and, right above, by the nannoconid crisis, followed by the FO of *Eprolithus floralis* (Erba, 2004, 1994; Erba et al., 1996).

The base of the Albian Stage as proposed and ratified by Kennedy et al. (2000, 2014, 2017) from the Vocontian Basin, France, is characterized by the FO of the *Microhedbergella renilaevis* planktonic foraminifera species as a primary marker. The FO of *Prediscosphaera columnata* (subcircular) and the FO of *Prediscosphaera columnata* (circular) were placed by Kennedy et al. (2000, 2014, 2017) right below the base of the Albian Stage in the Vocontian Basin (France), between the Jacob and Kilian levels. Besides that, Kennedy et al. (2000, 2014, 2017) proposed new informal biostratigraphic units (NC8* and CC8* zones) defined at their base by the FO of

Prediscosphaera columnata (subcircular) and at their top by the FO of *Prediscosphaera columnata* (circular), which are questioned in the present work.

The present work is aimed: (1) to provide a detailed biostratigraphic scheme, based on calcareous nannofossils; (2) to calibrate the results to other stratigraphic tools of previous published works; (3) to discuss some important bioevents of the calcareous nannofossil zonations, recorded along the core; and finally (4) to evaluate the calcareous nannofossil bioevents by comparing them to sections from other regions of the world.

2. Location and Geological Setting

The Poggio le Guaine section (Umbria-Marche Basin, central Italy) stands out by presenting a continuous, complete and undisturbed record of pelagic to hemipelagic deposits, along the Aptian–Albian interval, besides having already been object of a wide range of litho-, bio-, chemo-, magneto and cyclostratigraphic studies (Baudin et al., 1998; Coccioni et al., 2014, 2012, 2006, 1990, 1989, 1987; Coccioni and Galeotti, 1993; Ferraro et al., 2020; Leandro et al., 2022; Matsumoto et al., 2020; Sabatino et al., 2018, 2015; Satolli et al., 2008; Savian et al., 2016).

The Poggio le Guaine core (PLG) drill site (Fig. 1) is located adjacent to its homonymous outcrop, in the Umbria-Marche Basin, in the Monte Nerone ridge (lat. 43°32'42.72" N; long. 12°32'40.92" E), 888 m above the sea level, 6 km West from the city of Cagli, in the east limb of the Monte Nerone anticline. The core is 98.72 m length, 8 cm of diameter and it had a recovery of 100 % (Coccioni et al., 2012, 2006). The basin is located in the Northern Apennines fold-thrust belt between the Trasimeno-Falterona-Cervarola nappe and the Pliocene Adriatic foredeep (Cresta et al., 1989).

The tectono-stratigraphic evolution of the Umbria-Marche Basin is a result of the differential movements between the plates of Africa and Europe from the Late Triassic–Early Jurassic as a part of the peri-Mediterranean system of the Alpine chains (Menichetti, 2016). The Umbria-Marche Basin was developed in a margin of a continental promontory from the African Plate, the Adriatic Promontory “Adria”, in the Western Tethys Ocean (Cresta et al., 1989).

From the Late Jurassic through the Paleogene a thick sedimentary succession was deposited on a passive continental margin reaching thicknesses of platform and pelagic carbonate rocks around 1,300 to 2,000 m (Cresta et al., 1989).

The stratigraphic record of the Aptian–Albian interval of the basin comprises the Maiolica Formation (upper Tithonian–lower Aptian), the Marne (or Scisti) a Fucoidi Formation (lower Aptian–upper Albian) and the Scaglia Bianca Formation (upper Albian to lower Turonian) (Menichetti, 2016).

The Maiolica Formation is characterized by micritic, uniform, white to gray limestones with 10 to 150 cm thick layers as well as black to gray nodules and chert layers. Centimetric intercalations of claystones and organic-rich black marly shales are also typical. The black shales increase their thickness and frequency toward the overlying formation, the Marne a Fucoid Formation (Menichetti, 2016).

The upper boundary of the Maiolica Formation is placed in the uppermost layer containing black chert (Coccioni et al., 1990, 1987; Cresta et al., 1989). The thickness of this unit varies between 20 and 40 m in the structural highs and 450 m in the structural lows (Cresta et al., 1989).

The Marne a Fucoidi Formation is characterized by 10 to 20 cm-thick varicolored layers that encompass reddish to pale olive, brown and grayish layers. The lithologies consist of marlstones, calcareous marlstones, marly claystones in a rhythmical alternation with dark gray to black organic carbon-rich bituminous shales usually with low carbonate contents, and marly limestones and limestones (Cresta et al., 1989; Menichetti, 2016).

The varicolored rock intervals of the Marne a Fucoid Formation are remarkable and well known along several sections in the basin, both in outcrops and cores, which allow a reliable stratigraphic correlation (Coccioni et al., 2012; Cresta et al., 1989; Erba, 1988, 1992). The thickness of this unit is around 90 m. The marlstones progressively decrease in frequency towards the top of the Marne a Fucoidi Formation being replaced by the whitish pelagic limestones of the Scaglia Bianca Formation (Cresta et al., 1989; Menichetti, 2016).

The Scaglia Bianca Formation is characterized by thin to medium thick white micritic limestones with nodules and lenses of grey to black chert. This unit ranges in thickness from 50 to 70 m (Cresta et al., 1989).

Throughout the Marne a Fucoid and the Scaglia Bianca formations several levels of organic-rich black shales are recognized as the regional sedimentary expressions of the Oceanic Anoxic Events 1a to 1d (OAE1a to OAE 1d) represented by the Selli Level (OAE1a), the 113 or the Jacob, the Killian, the Urbino or the Paquier and the Leenhardt levels (OAE1b), the Amadeus Segment (OAE1c) and the Pialli Level (OAE1d) (Coccioni et al., 2014, 2012, 2006; Coccioni and Galeotti, 1993; Erba, 1988, 1992; Menichetti, 2016).

3. Material and Methods

The operational proceedings of the core drilling, sampling and storage can be seen in details in Coccioni et al. (2012) and Savian et al. (2016).

The stratigraphic thickness calculated for the PLG core is 96.02 m from which 3.51 m correspond to the Maiolica Formation, 82.53 m to the Marne a Fucoid Formation and 9.98 m to the Scaglia Bianca Formation (Coccioni et al., 2012).

The table of depths conversion from the measured depths to the adjusted depths is available in the Appendix A (Supplementary material).

A total of 135 samples with a sampling resolution of 1.0 m through the core were processed. The sampling resolution was increased to 0.5 m across the Barremian/Aptian and the Aptian/Albian boundaries, previously defined by Coccioni et al. (2012) for the PLG core.

The samples were processed by the smear slide technique, according to Bown and Young (1998). The biostratigraphic analyses were performed under a Zeiss Axio Imager.A2 optical microscope with a 1,600x magnification (objective lens 100x and ocular lens 16x). Each slide was analyzed along four to five longitudinal traverses (~ 800 to 1,000 fields of view – FOV) from which the species occurrences were recorded. Semiquantitative calcareous nannofossil abundance and species abundance were estimated for each sample as well.

The semiquantitative calcareous nannofossil and species abundances parameters are detailed in the caption of the stratigraphic range chart (Appendix B - Supplementary Material).

The preservation of the specimens were classified as good, moderate or poor according to the classes of Bown and Young (1998).

Photomicrographs of the main taxa were taken with a Zeiss AxioCam MRc camera (resolution of 1.3 MP) coupled to the microscope with an aid of the Zeiss AxioVision software (SE64 Rel. 4.9.1).

The widely applied and well established calcareous nannofossil zonation of the Aptian–Albian interval (NC zonation) was the reference for the present work (Bralower et al., 1993, 1997; Roth, 1978). The NC8* zone and the NC8a* subzone are informal biostratigraphic units proposed by Kennedy et al. (2000, 2014, 2017) after detailed studies of the *Prediscosphaera columnata* morphotypes in sections of the Vocontian Basin (France), including the Global Boundary Stratotype Section and Point (GSSP) of the base of the Albian Stage (Col de Pré-Guittard). According to Kennedy et al. (2000, 2014, 2017) the NC8* zone is delimited at the base by the FO of *P. columnata* (subcircular) and at the top by the FO of *P.columnata* (circular).

The chronostratigraphy and the numerical ages were based on Gradstein et al. (2020) and the taxonomic concepts are in agreement to those reported by Perch-Nielsen (1985), Bown et al. (1998), Kennedy et al. (2017, 2014, 2000) and the electronic catalog *Nannotax* (Young et al., 2022). All the taxa recorded in the present work are listed in the Appendix C (Supplementary Material).

All the studied material is stored in the micropaleontological repository of the Petrobras Research Centre (CENPES), Rio de Janeiro, Brazil.

4. Results

Eighty-eight taxa were recognized in the core and, in general, the calcareous nannofossil abundance varied from poor to common in the interval of the Maiolica and the Scaglia Bianca formations, and from abundant to very abundant in the Marne a Fucoidi Formation.

In the Maiolica Formation, the low calcareous nannofossil abundance can be related either to the extraction difficulty of the calcareous nannofossils from the matrix or the disaggregation of the specimens during the sample processing (especially regarding the nannoconids). Both possibilities were previously reported by Bralower (1987) and Erba (1994) for the well lithified rocks and with high abundance of nannoconids in the Maiolica Formation. The preservation of the specimens was predominantly moderate along the entire core.

On the basis of the bioevents recorded throughout the core (Table 1), six biostratigraphic intervals were recognized, that correspond to a part of the *Chiastozygus litterarius* Zone (NC6 Zone), the *Rhagodiscus angustus* Zone (NC7 Zone), the *Prediscosphaera columnata* zone (informal unit of Kennedy et al., 2000, 2014, 2017 - NC8* zone), the *Prediscosphaera columnata* Zone (NC8 Zone), the *Axopodorhabdus albianus* Zone (NC9 Zone) and the *Eiffellithus turriseiffelii* Zone (NC10 Zone) (Bralower et al., 1993, 1997; Roth, 1978)

The Figure 2 presents the litho-, bio- (planktonic foraminifera and calcareous nannofossils) and magnetostratigraphic data for the PLG core, the black shale levels related to the oceanic anoxic events, as well as the stratigraphic range and bioevents of important species of calcareous nannofossils (marker species and species considered reworked).

The NC zonation was chosen as the reference zonation for the description of the biostratigraphic intervals delimited in the PLG core (Fig. 3), as follow, in stratigraphic order:

The NC6 Zone was the lowermost biozone recognized in this core, from the occurrences of *Hayesites irregularis* in the lowermost sample (95.96 m) to the sample 88.67 m, where it was observed the FO of *Eprolithus floralis*. The last occurrence (LO) of *Conusphaera rothii* was not detected in the core and, therefore, the boundary between the NC6a and the NC6b subzones was not recognized. Such interval was referred as NC6a-b.

The interval of the NC6a-b Zone yielded a poor assemblage, with low specific richness, which can reflect the impact of the OAE 1a (Selli Event) on the nannoplankton assemblages (Erba, 2004, 1994, 1988) as well as the difficulty in the calcareous nannofossil extraction from the matrix, particularly from the well lithified calcareous lithologies of the Maiolica Formation (Bralower, 1987; Erba, 1994). The FO of *Nannoconus truittii* (95.47 m) was placed below the base of the M0r Polarity Zone. Such bioevent is in agreement to Erba et al. (1999) and Tremolada and Erba (2002), who placed it right below the base of the M0r Polarity Zone, and slightly different of its positioning in Erba (1994, 2004) and Erba et al. (1996), who placed it immediately above the base of the M0r Polarity Zone. In the NC6a-b Biozone, between the samples 90.65 and 89.61 m, calcareous nannofossils are absent in the central part of the Selli Level defined by Coccioni et al.

(2012). A similar barren interval was documented by Erba et al. (2010) in the central part of the Selli Level of the Cismon core (Belluno Basin, Southern Alps - Italy) and also in other sections as documented by Erba (1994). Between the samples 91.43 and 91.15 as well as between the samples 89.38 and 88.67 m, near the lower and the upper boundaries of the Selli Level, respectively, an increase in abundance of the large morphotypes of *Assipetra* spp. (*Assipetra infracretacea larsonii* and *Assipetra terebrodentarius youngii*) was observed. This is in agreement with previous studies by Tremolada and Erba (2002) and Erba (2004) in other sections. *Rhagodiscus gallagheri* and *Eiffellithus hancockii* were recorded from the lowermost sample of the core (95.96 m), below the base of the M0r Polarity Zone, i.e., from the upper Barremian. The NC6a-b Zone is assigned to the upper Barremian–lower Aptian (Gradstein et al., 2020).

The NC7 Zone was recognized by the FO of *E. floralis* (88.67 m) at the base and by the FO of *P. columnata* (subcircular) (66.34 m) at the top. The LO of *M. hoschulzii/M. obtusus* (grouped taxa – see taxonomic discussion on topic 5.1) and the FO of *Rhagodiscus achlyostaurion* were observed at much higher levels than expected, according to the NC Zonation of Bralower et al. (1993, 1995), beyond the upper boundary of the NC7 Biozone and, therefore, it was not possible to place the boundaries between the NC7a/NC7b and NC7b/NC7c subzones, respectively. In general, the calcareous nannofossil abundance varies from abundant to very abundant in this interval. The FO of *Radiolithus planus* lies in sample 87.97 m and the FO of *Braarudosphaera africana* occurs in sample 74.25 m. Between the samples 77.19 and 72.18 m it was observed an increase in the abundance of *N. truittii*, corresponding to the *N. truittii* acme, as defined by Erba (1994). The top of the *N. truitti* acme can be correlated to the nannoconid crisis II of Herrle and Mutterlose (2003). The NC7a-b-c Zone is assigned to the lower–upper Aptian (Gradstein et al., 2020).

In the PLG core, the NC8* informal biozone (and the NC8a* informal subzone) corresponds to only one sample, which was characterized by the FO of *P. columnata* (subcircular) at the base (66.34 m) and by the FO of *P. columnata* (circular) at the top (65.78 m). The base of the NC8* zone (66.34 m) is located about 1 m above of the 113 or Jacob Level delimited by Coccioni et al. (2012). This interval is assigned to the upper Aptian (Gradstein et al., 2020).

The NC8 Zone was recognized at the base by the FO of *P. columnata* (circular) (65.78 m) and by the FO of *Axopodorhabdus albianus* at the top (39.37 m). The NC8a, NC8b and NC8c subzones were identified. The calcareous nannofossil abundance varies predominantly from abundant to very abundant along this interval.

The NC8a Subzone was recognized at the base by the FO of *P. columnata* (circular) (65.78 m) and at the top by the FO of *H. albiensis* (55.79 m). The FO of *R. achlyostaurion* was recorded in sample 61.80 m. The occurrences of *P. columnata* (subcircular) and *P. columnata* (circular) became consistent from the sample 57.34 m upwards, between the Kilian and the Urbino/Paquier levels. This interval is assigned to the upper Aptian–lower Albian (Gradstein et al., 2020).

The NC8b Subzone was recognized at the base by the FO of *H. albiensis* (55.79 m) and by the FO of *Tranolithus orionatus* at the top (41.37 m). The FO of *Helicolithus trabeculatus* was observed at 54.77 m. In sample 44.32 m the LOs of *Nannoconus steinmannii steinmannii* and *Nannoconus circularis* were observed and once both species have their extinctions in the Aptian (Deres and Achéritéguy, 1980; Ogg et al., 2021), they are herein considered reworked. This interval is assigned to the lower Albian (Gradstein et al., 2020).

The NC8c Subzone was recognized at the base by the FO of *Tranolithus orionatus* (41.37 m) and by the FO of *Axopodorhabdus albianus* at the top (39.37 m). This interval is assigned to the lower–middle Albian (Gradstein et al., 2020).

The NC9 Zone was recognized at the base by the FO of *A. albianus* (39.37 m) and by the FO of *Eiffellithus turriseiffelii* at the top (15.09 m). The NC9a and the NC9b subzones were identified and the calcareous nannofossil abundance varies, mainly, from abundant to very abundant along this interval.

The base of the NC9a Subzone was placed at the FO of *A. albianus* (39.37 m) while its top was placed at the FO of *Eiffellithus monechiae* (18.05 m).

The consistent LO of *M. hoschulzii/M. obtusus* was observed from sample 39.37 m and a further isolated occurrence was recorded at 20.53 m. Such occurrences of *M. hoschulzii/M. obtusus* were considered reworked in the PLG core given that the uppermost occurrence of this grouped taxa is calibrated to the lower part of the upper Aptian according to Bralower et al. (1993, 1995), Gradstein et al. (2020) and Ogg et al. (2021). The LOs of *A. i. youngii* and *A. t. larsonii* were observed in samples 39.37 m and 37.43 m, respectively. The FO of *Gartnerago stenostaurion* was placed at 32.34 m. This interval is assigned to the middle Albian (Gradstein et al., 2020).

The base of the NC9b Subzone was placed at the FO of *Eiffellithus monechiae* (18.05 m) and its top was placed at the FO of *E. turriseiffelii* (15.09 m). The LO of *H. albiensis* was detected at 16.13 m, right below the FO of *E. turriseiffelii*. This interval is assigned to the upper Albian (Gradstein et al. 2020).

The NC10 Zone (NC10a Subzone) was the uppermost biozone recognized in the PLG core. Its base was placed at the FO of *E. turriseiffelii* (15.09 m). and its top was not detected. The sample 12.26 m contains the LO of *Assipetra infracretacea infracretacea* and *Assipetra terebrodentarius terebrodentarius*.

The stratigraphic calibration for the PLG core was based on the previously published literature data (lithostratigraphy, chronostratigraphy, planktonic foraminifera zones and magnetostratigraphy) (Coccioni et al., 2012; Leandro et al., 2022; Savian et al., 2016) as well as the new data of the present work (calcareous nannofossil biostratigraphy). The stage boundaries were set based on the criteria of the above-mentioned literature and they were described in detail below.

The base of the Aptian Stage was placed at the base of the M0r Polarity Zone, according to the magnetostratigraphy of Savian et al. (2016) and Leandro et al. (2022). Such boundary coincided with a point between the FO of *Hayesites irregularis* and the base of the Selli Level.

The base of the Albian Stage was placed at the base of the planktonic foraminifera *Microhedbergella renilaevis* Zone, delimited by Coccioni et al. (2012) and Leandro et al. (2022). Such boundary coincided with a point between the FOs of *P. columnata* (subcircular), *P. columnata* (circular) and the Kilian Level.

Finally, the base of the Cenomanian Stage was inferred at the base of the planktonic foraminifera *Thalmanninella globotruncanoides* Zone, according to Coccioni et al. (2012). Such boundary was placed above the FO of *Eiffellithus turriseiffelii*.

5. Discussions

5.1. Bioevents and taxonomic remarks

Some important calcareous nannofossil bioevents of the reference zonations for the Aptian-Albian interval have been assessed regarding their reliability, either for being rare in the geological record, or by presenting a possible diachronism, or even due to taxonomic ambiguities. Discussions on some of these bioevents are presented below whilst additional ones are available in the Appendix D (Supplementary material).

- FO of *H. irregularis* and FO of *H. albiensis*

The FO of *H. irregularis* is well established right below the base of the M0r Polarity Zone in the upper Barremian (Erba, 2004; Erba et al., 1999; Gradstein et al., 2020) while the FO of *H. albiensis* is calibrated to a point above the FO of *P. columnata* (circular), between the Kilian and Urbino/Paquier levels in the lower Albian (Bralower et al., 1995; Gradstein et al., 2020; Herrle and Mutterlose, 2003).

Kennedy et al. (2000, 2017) and Luber et al. (2019) reported difficulties in classifying morphotypes with nine to eleven imbricated rays and irregular outline [*H. irregularis* (Thierstein in Roth and Thierstein 1972) Applegate et al. in Covington and Wise 1987] apart from morphotypes with six to eight more symmetric, longer, and narrower rays (*H. albiensis* Manivit 1971), and so these authors used the grouped taxa *H. irregularis/H. albiensis* to classify such nannoliths. Coccioni et al. (2014) reported transitional forms between *H. irregularis* and *H. albiensis* besides possible diachronism of the FO of *H. albiensis*, raising doubts on the reliability of the FO of *H. albiensis* as a marker for the lower Albian.

In the PLG core we observed the FO of *H. irregularis* in sample 95.96 m (below the M0r Polarity Zone, upper Barremian) and the FO of *H. albiensis* in sample 55.79 m (above the FO of *P. columnata* (circular) and between Kilian and Urbino levels, lower Albian) and, therefore, in agreement to the literature (Bralower et al., 1995; Erba, 2004; Erba et al., 1999; Gradstein et al., 2020; Herrle and Mutterlose, 2003).

Apparently, when observing small specimens of *Hayesites* under the optical microscope, the rays seem overlapped, or even, the adjacent rays show an optical continuity, so it appears that two or more rays are just one. This feature can lead to difficulties in classifying some specimens of *H. irregularis*. However, in most of them is possible to solve this difficulty by counting the minute elements in the serrate outline of the specimens. Such morphotypes with apparently less than nine elements do not have the long and narrow rays of the *H. albiensis* diagnosis and can be separated from them. Furthermore, the long and narrow rays of *H. albiensis* can be broken or etched in poorly preserved specimens but they have marked less elements than the *H. irregularis* morphotypes.

With respect to the possible diachronism of the FO of *H. albiensis* argued by Coccioni et al. (2014) based on the ODP 1049C (Browning and Watkins, 2008) and the DSDP 545 (Huber and Leckie, 2011), the following arguments should be considered:

a) After the work of Browning and Watkins (2008), Huber and Leckie (2011) replaced the Aptian/Albian boundary at the ODP 1049C, based on planktonic foraminifera, exactly at the hardground level that marks a hiatus between the planktonic foraminifera *Paraticinella rohri* Zone and the *Microhedbergella rischi* Zone and coincides with the FO of *H. albiensis*. Since then, the FO of *H. albiensis* is assigned to a stratigraphic position as that defined originally by Manivit (1971) (lower Albian) and no longer represent the diachronism related by Coccioni et al. (2014).

b) At the DSDP Site 545, the Aptian/Albian boundary was recognized, from planktonic foraminifera, based on the LO of *Paraticinella rohri* (= *P. eubejaouaensis* (Huber and Leckie, 2011). By considering the calcareous nannofossil data, the FO of *H. albiensis* was assigned to the upper Aptian in that section (Bralower et al., 1993; Herrle et al., 2004; McAnena et al., 2013). Based on that evidence, Coccioni et al. (2014) questioned the accuracy of *H. albiensis* as a marker for the Albian. However, one intriguing characteristic of the Site 545 section is the position of the LO of *P. eubejaouaensis* which was placed well above the Kilian Level equivalent black shale, as interpreted by Coccioni et al. (2014), in disagreement to its positioning at the Col de Pré-Guittard (Vocontian Basin – France) and at the Poggio le Guaine (Umbria-Marche Basin – Italy) sections. Other particularities of the DSDP Site 545 are detailed in the *P. columnata* topic – Appendix D (Supplementary material). Because of these particularities it is not possible to evaluate the stratigraphic position of the FO of *H. albiensis* at the Site 545.

Given the above considerations, we conclude that the FO of *H. albiensis* is a valid taxon to be used as a marker for the Albian as originally defined by Manivit (1971).

- LO of *Micrantholithus hoschulzii/Micrantholithus obtusus*

Both *M. hoschulzii* (Reinhardt 1966) Thierstein 1971 and *M. obtusus* Stradner 1963 are characterized as pentaliths with five triangular elements and sutures that goes from the center to the vertex of the specimens. The original diagnoses are broad and the photomicrographs illustrate a differentiation of these two species based on the deepening of the triangular elements indentations (Perch-Nielsen, 1985; Young et al., 2022), which is absent in the first species but pronounced in the second one. Due to the lack of more precise diagnoses and the use of a qualitative criterion for the distinction of both species, as the deepening of the indentation, besides there are transitional morphotypes between the two end members, some authors have classified them as a grouped taxon, or even, have included the *M. obtusus* morphotypes as *M. hoschulzii,* or vice-versa (Applegate and Bergen, 1988; Bown et al., 1998; Bralower et al., 1993; Sissingh, 1977; Thierstein, 1976). In the present work, by considering the above-mentioned taxonomic ambiguities we also opted by the grouped taxon classification for *M. hoschulzii*/*M. obtusus*. Furthermore, some works have used the LO of *Micrantholithus* spp. instead of the LO of *M. hoschulzii*, in order to delimit the top of NC7a Subzone (Bown et al., 1998; Herrle and Mutterlose, 2003).

As far as the stratigraphic range is concerned (Fig. 4), the LO of *M. hoschulzii*/*M. obtusus* is calibrated with the lower part of the upper Aptian (Applegate and Bergen, 1988; Bown et al., 1998; Bralower et al., 1993, 1995, 1997, 1999; Herrle and Mutterlose, 2003; Mahanipour et al., 2018; Perch-Nielsen, 1979, 1985; Roth and Thierstein, 1972; Roth, 1978; Sissingh, 1977; Thierstein, 1971, 1973, 1976). See additional information in the Appendix D (Supplementary material).

Nevertheless, there are sporadic records of these species in the upper part of the upper Aptian and in the Albian in some areas. These younger occurrences were interpreted as reworking (Bralower et al., 1993; Thierstein, 1973, 1971) and others are not discussed in detail (Coccioni et al., 2014; Erba, 1988; Jeremiah, 2001; Kennedy et al., 2017). Moreover, Luber et al. (2019) stated that the range of *M. hoschulzii* substantially extends its conventional LO.

In the present work (in the PLG core) occurrences of *M. hoschulzii*/*M. obtusus* were observed from the lower Aptian, below the Selli Level, up to the middle Albian, above the FO of *A. albianus*. Such occurrences are consistent, i.e., they occur in consecutive samples, even though they are very rare (in general, less than four specimens in 800 to 1,000 FOV or four to five longitudinal traverses). The fact of: (1) the occurrences in the PLG core are very rare; (2) the LO of *M. hoschulzii*/*M. obtusus* is calibrated with the lower part of the upper Aptian by several authors; (3) among other criteria described in the topic 5.2 – Reworking, suggest to consider that such occurrences, at least in the strata located above the *N. truittii* acme and the planktonic foraminifera *Globigerinelloides algerianus* Zone and the *Hedbergella trocoidea* Zone (where the LO of *M. hoschulzii/M. obtusus* is calibrated), are a result of reworking in the PLG core.

Based on the above-mentioned arguments, the LO of *M. hoschulzii/M. obtusus* as a marker for the lower part of the upper Aptian should be applied very carefully, especially where there is any possibility of reworking.

- FO of *Prediscosphaera columnata*

Kennedy et al. (2017, 2014, 2000) applied a morphometric criterion, the length (L)/width (W) ratio, to classify the different types of the *P. columnata* specimens, as follow: *P. columnata* specimens with a L/W ratio > 1.1 were classified as subcircular forms and referred as *P. columnata* (subcircular), on the other hand, *P. columnata* specimens with a L/W ratio ≤ 1.1 were classified as near circular to circular, at a first moment, and then just referred as *P. columnata* (circular). According to those authors, both bioevents, the FO of *P. columnata* (subcircular) and the FO of *P. columnata* (circular), were recorded in the upper Aptian of the Col de Pré-Guittard section (Vocontian Basin – France) between the Jacob and the Kilian levels. According to Kennedy et al. (2017, 2014, 2000), *P. columnata* (subcircular) was rare and consistent (i.e., it occurred continuously in subsequent samples) from its first occurrence upwards, while *P. columnata* (circular) was rare and sporadic between the Jacob and the Kilian levels (upper Aptian) and it became consistent just near the Paquier Level (lower Albian) upwards, at the Col de Pré-Guittard section. Despite of the advances related to the taxonomy of *P. columnata*, Kennedy et al. (2000) highlighted that it was surprisingly difficult to determine the circularity by eye, which was just achieved confidently based on high resolution images computer-aided morphometrics.

Such morphometric measurements were performed herein (PLG core) as an attempt to evaluate this method. See additional information in the Appendix D (Supplementary material).

In the present work, despite the difficulty in distinguishing *P. columnata* (subcircular) and *P. columnata* (circular), such task was done with an aid of morphometry on photomicrographs in several specimens. However, the accuracy in the distinction of the varieties was compromised by the preservation of the specimens, which frequently presented etching in the edges of their distal shields. For this reason, the measurements were taken in the central area of the specimens instead of the edges of the distal shields, where the diameter was still shorter, in turn, increasing the difficulty and the measurements imprecisions even more. Even so, the L/W ratio limit was the same as that defined by Kennedy et al. (2000).

In the present work, the occurrences of *P. columnata* (subcircular) and *P. columnata* (circular) are extremely rare and the specimens are very small (< 5 μm). It was necessary to analyze a high number of FOV to record these taxa (800 to 1000 FOVs = 4 to 5 longitudinal traverses), particularly along the interval near the Aptian/Albian boundary. Such need demanded much more time than the average and it can lead to an imprecision when correlating these FOs among different sections.

To minimize any imprecision and by considering the difficulties related to the above-mentioned characteristics in regard of using *P. columnata* as a reliable marker, we recommend using just the FO of *P. columnata* (*lato sensu*), i.e., including in this taxon the varieties of *P. columnata* (subcircular) and *P. columnata* (circular), rather than separating them. Thus, the stratigraphic positioning of the FO of *P. columnata* (*lato sensu*), in the upper Aptian, between the 113 (Jacob) and the Kilian levels, could be used to delimit the base of NC8 Zone (and the NC8a Subzone). Finally, the informal NC8* (NC8a* subzone) and CC8* (CC8a* subzone) of Kennedy et al. (2017, 2014, 2000) would no longer be applicable.

Photomicrographs of the main taxa recorded along the PLG core are presented below (Fig. 5, Fig. 6, Fig. 7, Fig. 8).

5.2 Reworking

Calcareous nannofossil reworking is a common phenomenon but its identification is often difficult (Applegate and Bergen, 1988; Bergen, 1986; Bramlette and Martini, 1964; Bramlette and Sullivan, 1961; Perch-Nielsen, 1985). This is due to the high abundance of the calcareous nannofossils in the geological record as well as because of their tiny size (as particles of silt and clay size). For this reason, calcareous nannofossils are, in theory, more susceptible to reworking than other microfossils groups, of larger size and lower abundance (Bramlette and Martini, 1964; Bramlette and Sullivan, 1961).

To minimize the effects of reworking in any section, is more reliable to use the FOs of the microfossils rather than the LOs. In such cases, the confidence of the LOs can be somewhat compromised, being reworked to an upward stratigraphical position compared to the original one. On the other hand, by using only the FOs any misinterpretation is avoided in regard of reworking (Applegate and Bergen, 1988; Bramlette and Sullivan, 1961; Perch-Nielsen, 1985).

In the PLG core (this work), some species presented stratigraphic ranges that differ from those of the literature. The outstanding cases are those regarding the *M. hoschulzii/M. obtusus*, *N. steinmannii steinmannii* and *N. circularis*, which their LOs occurrences are recorded consistently in intervals younger than those calibrated in the literature. Also remarkable is an occurrence of *Cruciellipsis cuvillieri*, in the upper Aptian of the PLG core, a species whose extinction is dated as Hauterivian.

The reworked specimens were observed in the middle part of the Marne a Fucoidi Formation (83.24 to 39.37 m). Such interval is characterized, in its lower part, mainly by reddish marlstones, and in its upper part, by the rhythmically interbedding of organic-rich black shales, limestones and marlstones.

Although it is not the scope of the present work, overall microfacies analyses were performed in thin sections through the core (sampling resolution ~ 1.0 m) to investigate potential reworking: no evidence of reworking was observed (e.g., intraclasts), rather the microfacies suggest sedimentation by settling (Fig. 9).

The organic matter of the majority of the black shales and marlstones from the Marne a Fucoidi Formation in the PLG outcrop, are of the types III and IV, related to debris of higher terrestrial plants and highly oxidated organic matter, respectively (Sabatino et al., 2015). The exceptions are the 113 (Jacob) and the Urbino (Paquier) levels, which contain organic matter of the Type II (algae or bacteria derivation) (Sabatino et al., 2015).

Even though the occurrences of some calcareous nannofossil reworked specimens in the PLG core are intriguing there are arguments that support the reworking hypothesis, among them:

(1) most of the LOs of such species are calibrated to a stratigraphic level older than those where they were recorded: *M. hoschulzii/M. obtusus* – in the lower part of the upper Aptian; *Nannoconus s. steinmannii* – in the lower Aptian and *Nannoconus circularis* – in the lower part of the upper Aptian; all of them were recorded through the lower-middle Albian in the PLG core.

(2) although they are consistent, the occurrences are extremely rare (e.g., *M. hoschulzii/M. obtusus* occurs from 1 to 4 specimens in 800 to 1,000 FOV or 4 to 5 longitudinal traverses);

(3) in sample 66.84 m (upper Aptian) was recorded the only specimen of *Cruciellipsis cuvillieri* of the core, whose LO is dated as Hauterivian (Thierstein, 1971), herein interpreted as reworked;

(4) Tornaghi et al. (1989) recorded planktonic foraminifera (*Globigerinelloides algerianus*), interpreted as reworked, in the lower-middle Albian of the Piobbico core (Umbria-Marche Basin);

(5) there is evidence of tectonism in the basin during the Aptian–Albian interval: the PLG core as well as the PLG outcrop shows different dip angle bedding along their sections (Coccioni et al., 2014, 2012), which can be related to the tectonic movements in the region; Menichetti (2016) reported evidences of tectonic activity in the basin, as well as in the surrounding regions along this interval;

(6) there is prevalence of the organic matter of the types III and IV in the rhythmic interval of the Marne a Fucoidi Formation, which indicates extrabasinal material input.

6. Concluding remarks

The detailed calcareous nannofossil biostratigraphy performed on the Poggio le Guaine core provided a precise positioning of the bioevents and biozones which encompasses the chronostratigraphic intervals from the Barremian/Aptian boundary throughout the Albian/Cenomanian boundary.

The calcareous nannofossil biostratigraphy was calibrated with other stratigraphic tools that were used for placing the stage boundaries and some important taxonomic discussions were made regarding some remarkable calcareous nannofossil bioevents.

The first occurrences of the *Hayesites irregularis*, *Eprolithus floralis*, *Prediscosphaera columnata* (subcircular), *Prediscosphaera columnata* (circular), *Hayesites albiensis, Tranolithus orionatus, Axopodorhabdus albianus, Eiffellithus monechiae* and *Eiffellithus turriseiffelii*, supported the recognition of the biozones and subzones NC6 (NC6a-b), NC7 (NC7a-b-c), NC8* (NC8a*), NC8 (NC8a, NC8b and NC8c), NC9 (NC9a and NC9b) and NC10 (NC10a). Moreover, the *Nannoconus truittii* acme was detected in the upper Aptian.

The subdivision of *Prediscosphaera columnata* based on their subcircular and circular forms as well as the NC8* (NC8a*) and CC8* (CC8a*) informal biostratigraphic units were questioned and recommended to not be applicable.

Supported by several arguments, reworking was considered the cause of the occurrences of *Micrantholithus hoschulzii/Micrantholithus obtusus*, *Nannoconus steinmannii steinmannii*, *Nannoconus circularis* and *Cruciellipsis cuvillieri* in the upper part of the upper Aptian as well as in the lower-middle Albian.

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Author statement

Fábio Lamm, conceived and designed the research; performed the analysis; interpreted obtained data; wrote the manuscript.

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Declarations Conflict of Interest

The authors declare no competing interests.

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Captions

Fig. 1. Poggio le Guaine (PLG) drill site location map (Umbria-Marche Basin, central Italy). Modified from Coccioni and Galeotti (1993) and Ferraro et al. (2020).

Fig. 2. Stratigraphic scheme for the PLG core.

Fig. 3. Biostratigraphic zonations for the upper Barremian to the lower Cenomanian, comprising all the Aptian-Albian interval, and the recognized biozones in this work (PLG core). *pars* = partial. Figure produced with the *Time Scale Creator* 8.0 (Ogg et al., 2021).

Fig. 4. Stratigraphic range of *M. hoschulzii*/*M. obtusus* according to several works. (A): France; (B): North Atlantic; (C): Central Atlantic; (D): mainly Europe and North Africa; (E): Global; (F): Italy; (G): Boreal Realm (North Sea); (H): Tethyan Realm; (I): Mexico; (J) Iran; (K) Marroco.

Fig. 5. Calcareous nannofossil species from the PLG core. A, *Hayesites irregularis,* 95.96 m, XPL. B-C, *Hayesites irregularis,* 95.47 m, XPL and XPL+GP. D-E, *Hayesites irregularis*, 94.57 m, XPL and XPL+GP. F-G, *Eprolithus floralis*, 88.67 m, XPL and XPL+GP. H-I, *Eprolithus floralis*, 87.97 m, XPL and side view (I). J-L, *Prediscosphaera columnata* (subcircular), 39.37 m, XPL. M-N, *Prediscosphaera columnata* (circular), 38.38 m, XPL. O, *Prediscosphaera columnata* (circular), 28.44 m, XPL. P, *Hayesites albiensis*, 51.36 m, XPL. Q-R, *Hayesites albiensis*, 39.37 m, XPL and XPL+GP. S, *Hayesites albiensis*, 33.37 m, XPL. T, *Tranolithus orionatus*, 31.42 m, XPL. XPL = cross-polarized light. GP = gypsum plate. Scale bar = 5 µm.

Fig. 6. Calcareous nannofossil species from the PLG core. A, *Tranolithus orionatus,* 25.48 m, XPL. B, *Tranolithus orionatus,* 17.14 m, XPL. C, *Tranolithus orionatus,* 10.18 m, XPL. D, *Axopodorhabdus albianus,* 39.37 m, XPL. E, *Axopodorhabdus albianus,* 35.38 m, XPL. F, *Axopodorhabdus albianus,* 29.27 m, XPL. G, *Eiffellithus monechiae*, 18.05 m, XPL. H, *Eiffellithus monechiae*, 15.09 m, XPL. I, *Eiffellithus turriseiffelii*, 15.09 m, XPL. J, *Eiffellithus turriseiffelli*, 13.28 m, XPL. K, *Assipetra terebrodentarius terebrodentarius*, 92.02 m, XPL. L, *Assipetra terebrodentarius youngii*, 88.67 m, XPL. M, *Assipetra infracretacea infracretacea*, 91.15 m, XPL. N, *Assipetra infracretacea larsonii*, 61.80 m, XPL. O, *Micrantholithus hoschulzii*, 80.23 m, XPL. P, *Micrantholithus hoschulzii*, 50.32 m, XPL. Q, *Cruciellipsis cuvillieri*, 66.84 m, XPL. R, *Nannoconus steinmannii steinmannii*, 47.37 m, XPL. S, *Nannoconus circularis*, 56.83 m, XPL. T, *Nannoconus kamptneri*, 95.02 m, XPL. XPL = cross-polarized light. Scale bar = 5 µm.

Fig. 7. Calcareous nannofossil species from the PLG core. A, *Biscutum constans,* 0.39 m, XPL. B, *Biscutum constans,* 87.97 m, XPL. C, *Rhagodiscus achlyostaurion*, 0.95 m, XPL. D, *Rhagodiscus achlyostaurion*, 1.41 m, XPL. E-F, *Nannoconus truittii*, 64.78 m, NL and XPL. G-H,

Nannoconus truittii, 74.25 m, NL and XPL. I, *Rhagodiscus asper*, 32.34 m, XPL. J, *Rhagodiscus asper*, 95.93 m, XPL. K-L, *Rhagodiscus asper*, 53.81 m, XPL. M-O, *Braarudosphaera pseudobatilliformis*, 64.36 m, XPL. P, *Braarudosphaera africana*, 0.95 m, XPL. Q, *Braarudosphaera africana*, 66.86 m, XPL. R, *Watznaueria biporta*, 80.23 m, XPL. S, *Watznaueria britannica*, 87.36 m, XPL. T, *Rhagodiscus gallagheri*, 95.93 m, XPL. NL = Natural light. XPL = cross-polarized light. Scale bar = 5 µm.

Fig. 8. Calcareous nannofossil species from the PLG core. A, *Tegumentum stradneri*, 49.37 m, XPL. B, *Helicolithus trabeculatus*, 48.34 m, XPL. C, *Helicolithus trabeculatus*, 37.43 m, XPL. D, *Lithraphidites carniolensis*, 55.79 m, XPL. E, *Zeugrhabdotus diplogrammus*, 21.53 m, XPL. F, *Zeugrhabdotus diplogrammus*, 38.38 m, XPL. G, *Eiffellithus? hancockii*, 52.88 m, XPL. H, *Eiffellithus? hancockii*, 95.96 m, XPL. I, *Gartnerago stenostaurion*, 29.26 m, XPL. J, *Haqius circumradiatus*, 29.26 m, XPL. K, *Haqius circumradiatus*, 81.21 m, XPL. L, *Tranolithus gabalus*, 52.88 m, XPL. M-N, *Radiolithus planus*, 87.97 m, XPL and XPL+GP. O, *Flabellites oblongus*, 83.24 m, XPL. P, *Zeugrhabdotus howei*, 81.21 m, XPL. Q-R, *Zeugrhabdotus embergeri*, 92.38 m, XPL. S, *Zeugrhabdotus xenotus*, 35.38 m, XPL. T, *Zeugrhabdotus xenotus*, 60.76 m, XPL. XPL = cross-polarized light. GP = gypsum plate. Scale bar = 5 µm.

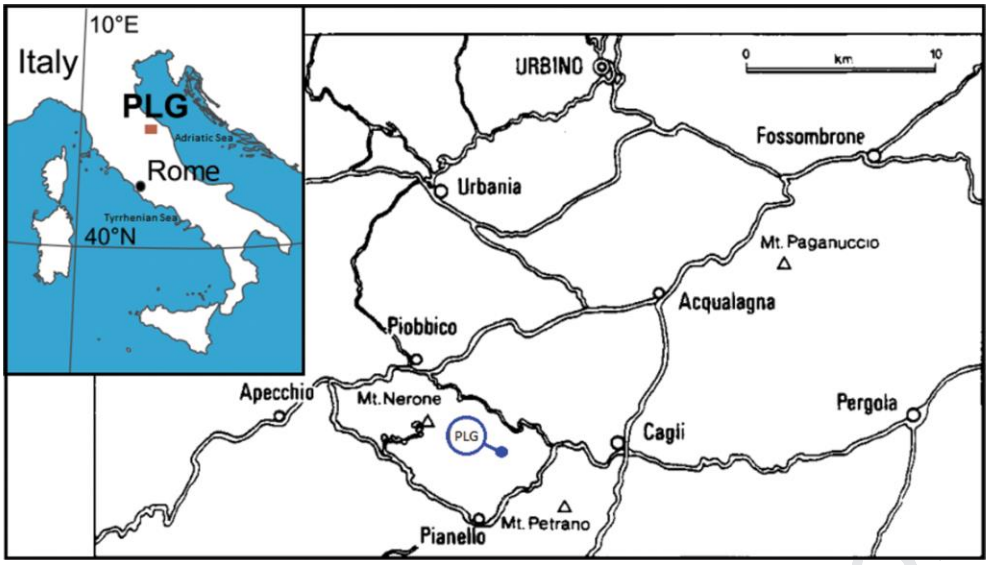
Fig. 9. Illustrative photomicrographs of the observed microfacies. A, Mudstone with foraminifera and radiolaria, 2.5x, NL, 0.48 m. B, Wackestone with foraminifera and radiolaria, 2.5x, NL, 3.97 m. C, Mudstone with foraminifera and radiolaria, bioturbated, 2.5x, NL, 5.32 m. D, Laminated Mudstone, 2.5x, NL, 89.99 m. NL = natural light. Microfacies according to Dunham (1962). Scale bar = 500 µm.

Table 1. Calcareous nannofossil bioevents applied to the Poggio le Guaine core (this work), magnetic-polarity zones (Savian et al., 2016) and selected stratigraphic levels (Coccioni et al., 2012).

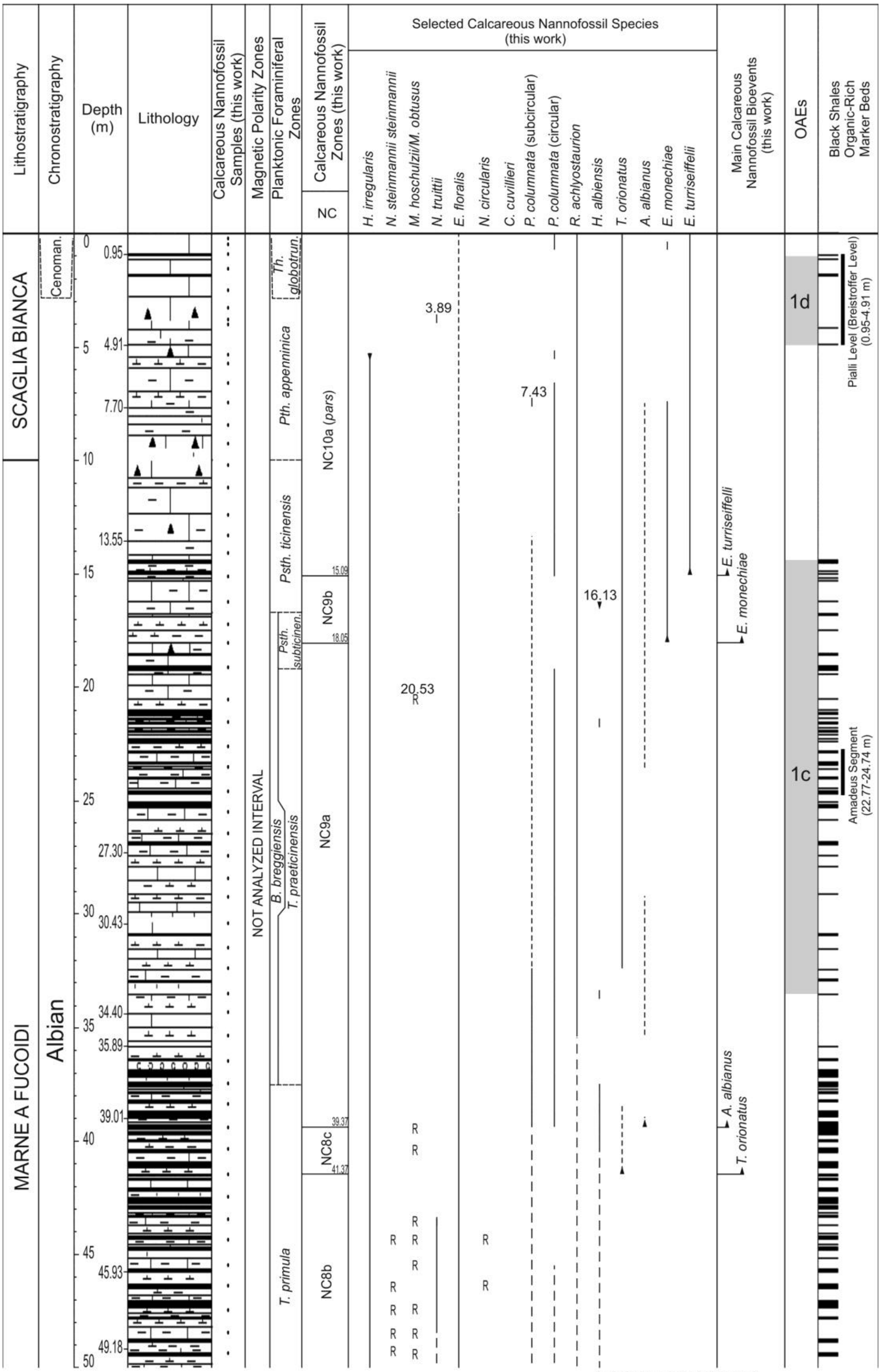
Calcareous nannofossil bioevents (this work)	Depth (m)	NC zones	Remarks
FO *Eiffellithus turriseiffelii*	15.09	NC10a base	between the Amadeus Segment and the Pialli Level
FO *Eiffellithus monechiae*	18.05	NC9b base	between the Amadeus Segment and the Pialli Level
FO *Axopodorhabdus albianus*	39.37	NC9a base	between the Urbino Level and the Amadeus Segment
FO *Tranolithus orionatus*	41.37	NC8c base	between the Urbino Level and the Amadeus Segment
FO *Hayesites albiensis*	55.79	NC8b base	between the Kilian and the Urbino levels
FO *Prediscosphaera columnata* (circular)	65.78	NC8a base	between the Jacob and the Kilian levels
FO *Prediscosphaera columnata* (subcircular)	66.34	NC8a* base	between the Jacob and the Kilian levels
FO *Eprolithus floralis*	88.67	NC7a-b-c base	right above the Selli Level
FO *Hayesites irregularis*	95.96	NC6a-b base	right below the base of the M0r Polarity Zone

Magnetic-polarity zones (Savian et al., 2016)	Depth (m)
C34n Base	92.7
M0r Base	95.1

Stratigraphic levels (Coccioni et al., 2012)	Base depth (m)	Top depth (m)
Pialli Level	4.91	0.95
Amadeus Segment	24.74	22.77
Urbino Level	54.88	54.63
Kilian Level	63.02	62.64
Jacob Level	67.52	67.44
Selli Level	91.19	89.24



10°E
Italy
PLG
Adriatic Sea
Rome
Tyrrhenian Sea
40°N
URBINO
0
km
10
Fossombrone
Urbania
Mt. Paganuccio
Acqualagna
Piobbico
Apecchio
Mt. Nerone
PLG
Cagli
Pergola
Pianello
Mt. Petrano



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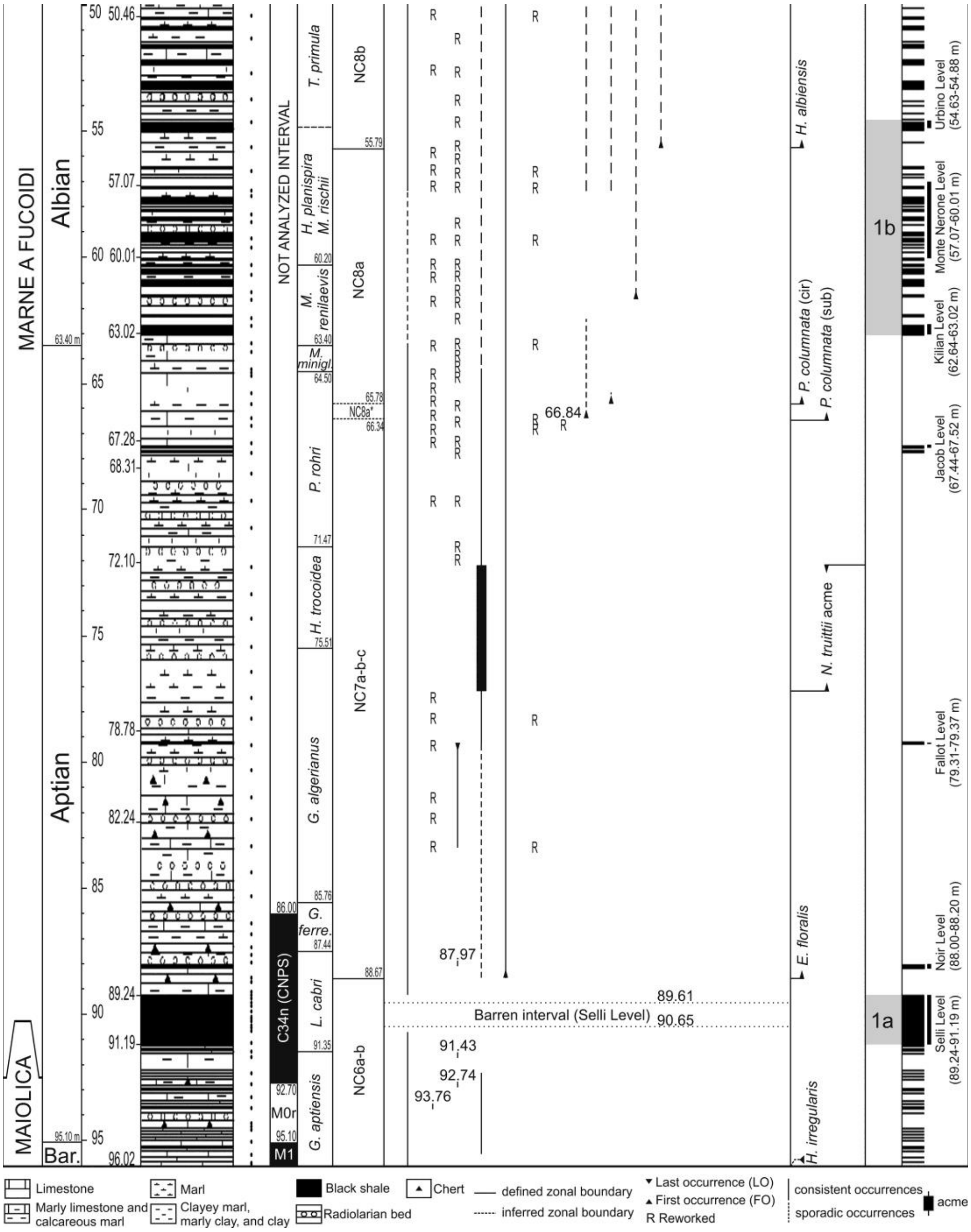
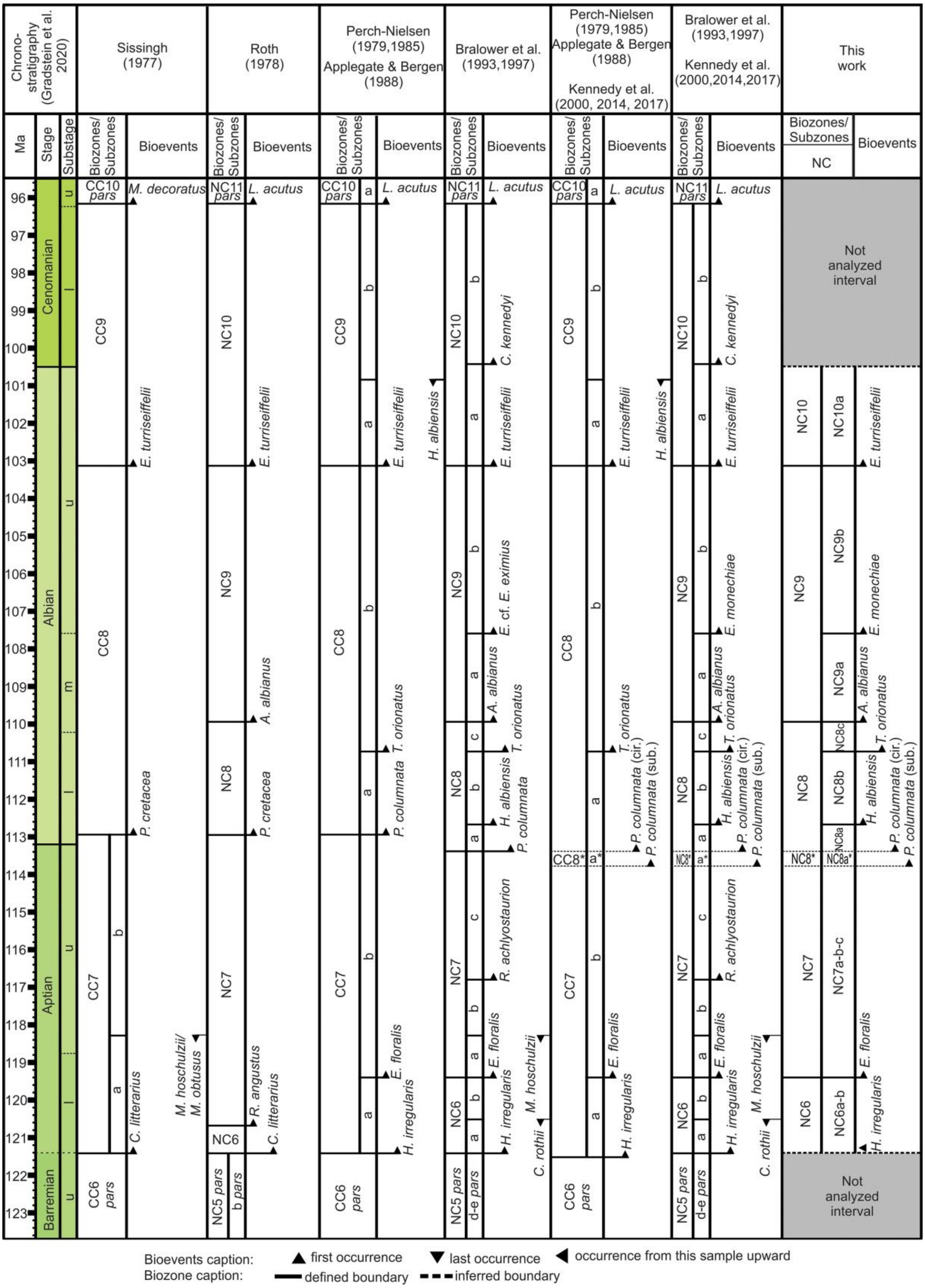
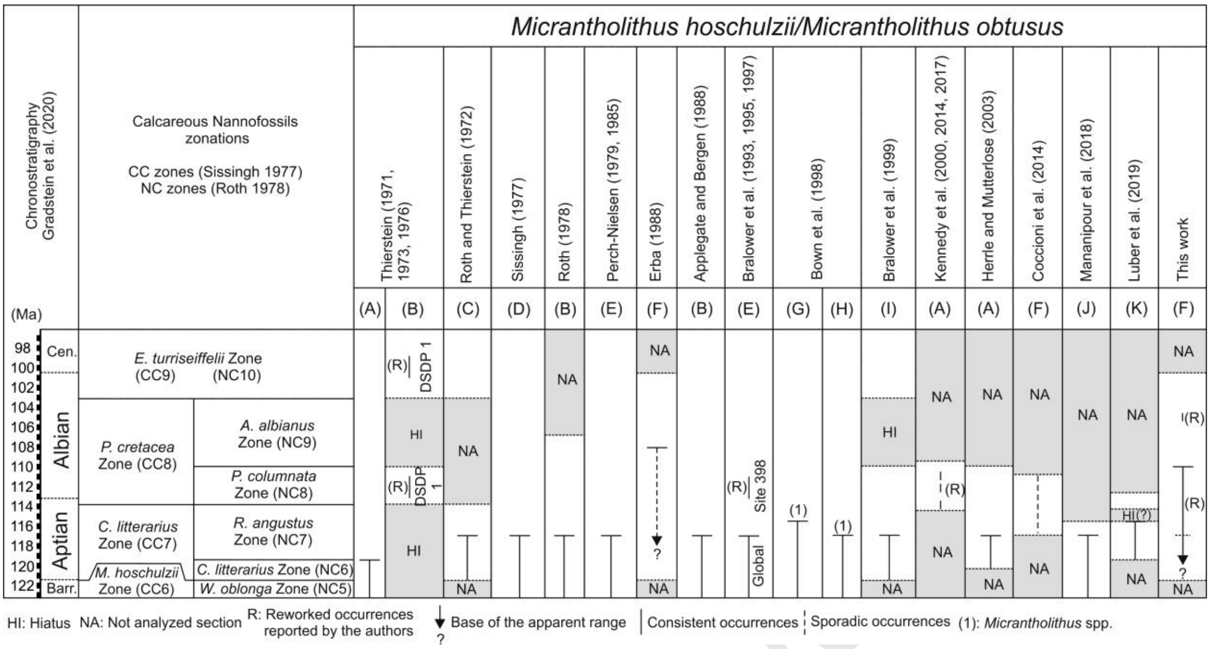
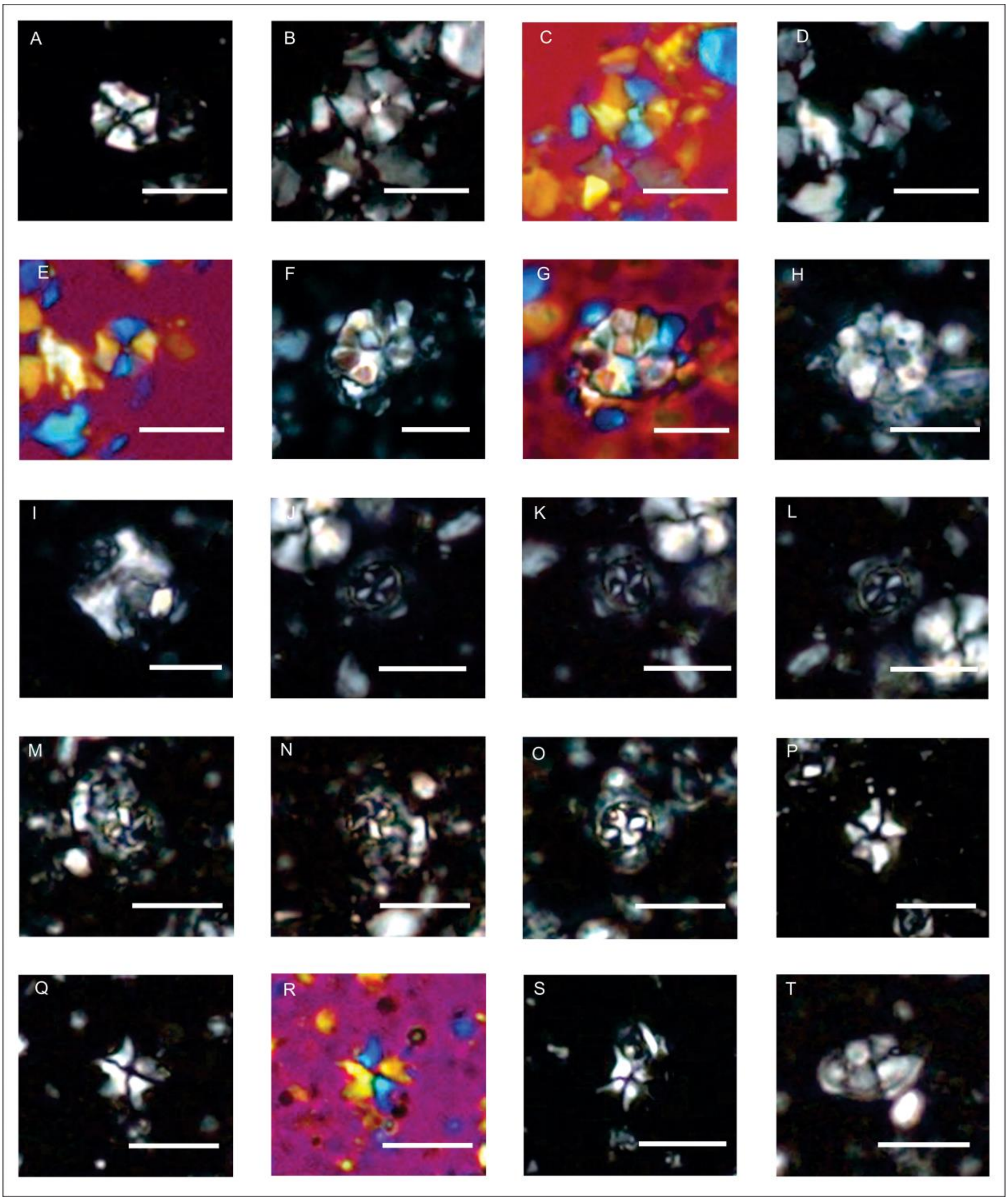


MARNE A FUCOIDI
MAIOLICA
Albian
Aptian
Bar.
63.40 m
95.10 m
NOT ANALYZED INTERVAL
C34n (CNPS)
M0r
M1
T. primula
H. planispira
M. rischii
M. renilaevis
M. minigl.
P. rohri
H. trocoidea
G. algerianus
G. ferre.
L. cabri
G. aptiensis
NC8b
NC8a
NC8a*
NC7a-b-c
NC6a-b
Barren interval (Selli Level)
89.61
90.65
66.84
87.97
91.43
92.74
93.76
H. albiensis
P. columnata (cir)
P. columnata (sub)
N. truittii acme
E. floralis
H. irregularis
1a
1b
Urbino Level (54.63-54.88 m)
Monte Nerone Level (57.07-60.01 m)
Kilian Level (62.64-63.02 m)
Jacob Level (67.44-67.52 m)
Fallot Level (79.31-79.37 m)
Noir Level (88.00-88.20 m)
Selli Level (89.24-91.19 m)
Limestone
Marly limestone and calcareous marl
Marl
Clayey marl, marly clay, and clay
Black shale
Radiolarian bed
Chert
defined zonal boundary
inferred zonal boundary
Last occurrence (LO)
First occurrence (FO)
R Reworked
consistent occurrences
sporadic occurrences
acme


Chrono-stratigraphy (Gradstein et al. 2020)
Sissingh (1977)
Roth (1978)
Perch-Nielsen (1979,1985) Applegate & Bergen (1988)
Bralower et al. (1993,1997)
Perch-Nielsen (1979,1985) Applegate & Bergen (1988) Kennedy et al. (2000, 2014, 2017)
Bralower et al. (1993,1997) Kennedy et al. (2000,2014,2017)
This work
Ma
Stage
Substage
Biozones/ Subzones
Bioevents
NC
Cenomanian
Albian
Aptian
Barremian
Not analyzed interval
Bioevents caption: first occurrence
last occurrence
occurrence from this sample upward
Biozone caption: defined boundary
inferred boundary



Micrantholithus hoschulzii/Micrantholithus obtusus
Chronostratigraphy Gradstein et al. (2020)
Calcareous Nannofossils zonations
CC zones (Sissingh 1977)
NC zones (Roth 1978)
Thierstein (1971, 1973, 1976)
Roth and Thierstein (1972)
Sissingh (1977)
Roth (1978)
Perch-Nielsen (1979, 1985)
Erba (1988)
Applegate and Bergen (1988)
Bralower et al. (1993, 1995, 1997)
Bown et al. (1998)
Bralower et al. (1999)
Kennedy et al. (2000, 2014, 2017)
Herrle and Mutterlose (2003)
Coccioni et al. (2014)
Mananipour et al. (2018)
Luber et al. (2019)
This work
(Ma)
Cen.
Albian
Aptian
Barr.
E. turriseiffelii Zone (CC9) (NC10)
P. cretacea Zone (CC8)
A. albianus Zone (NC9)
P. columnata Zone (NC8)
C. litterarius Zone (CC7)
R. angustus Zone (NC7)
M. hoschulzii Zone (CC6)
C. litterarius Zone (NC6)
W. oblonga Zone (NC5)
DSDP 1
Site 398
Global
HI: Hiatus
NA: Not analyzed section
R: Reworked occurrences reported by the authors
Base of the apparent range
Consistent occurrences
Sporadic occurrences
(1): Micrantholithus spp.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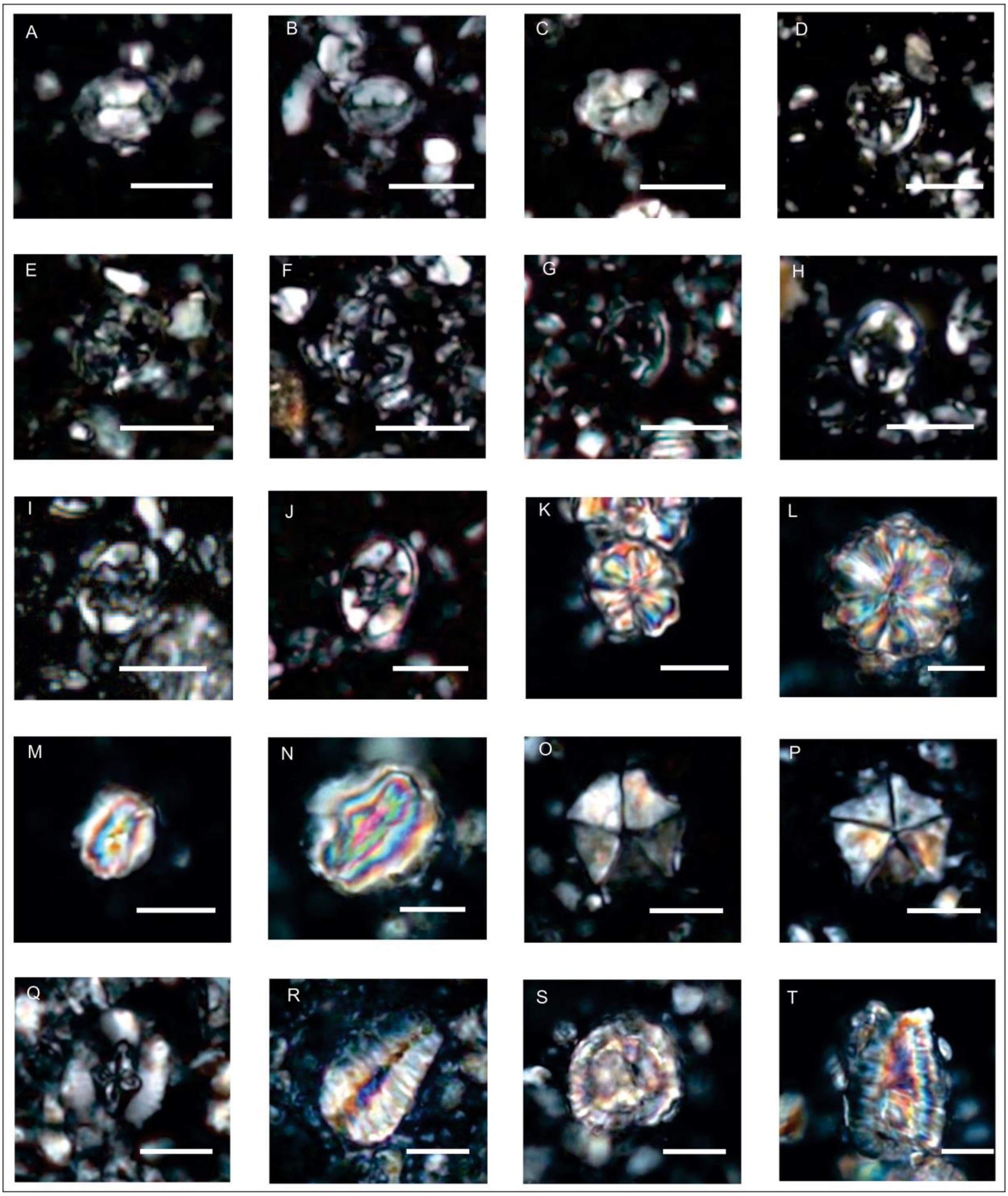
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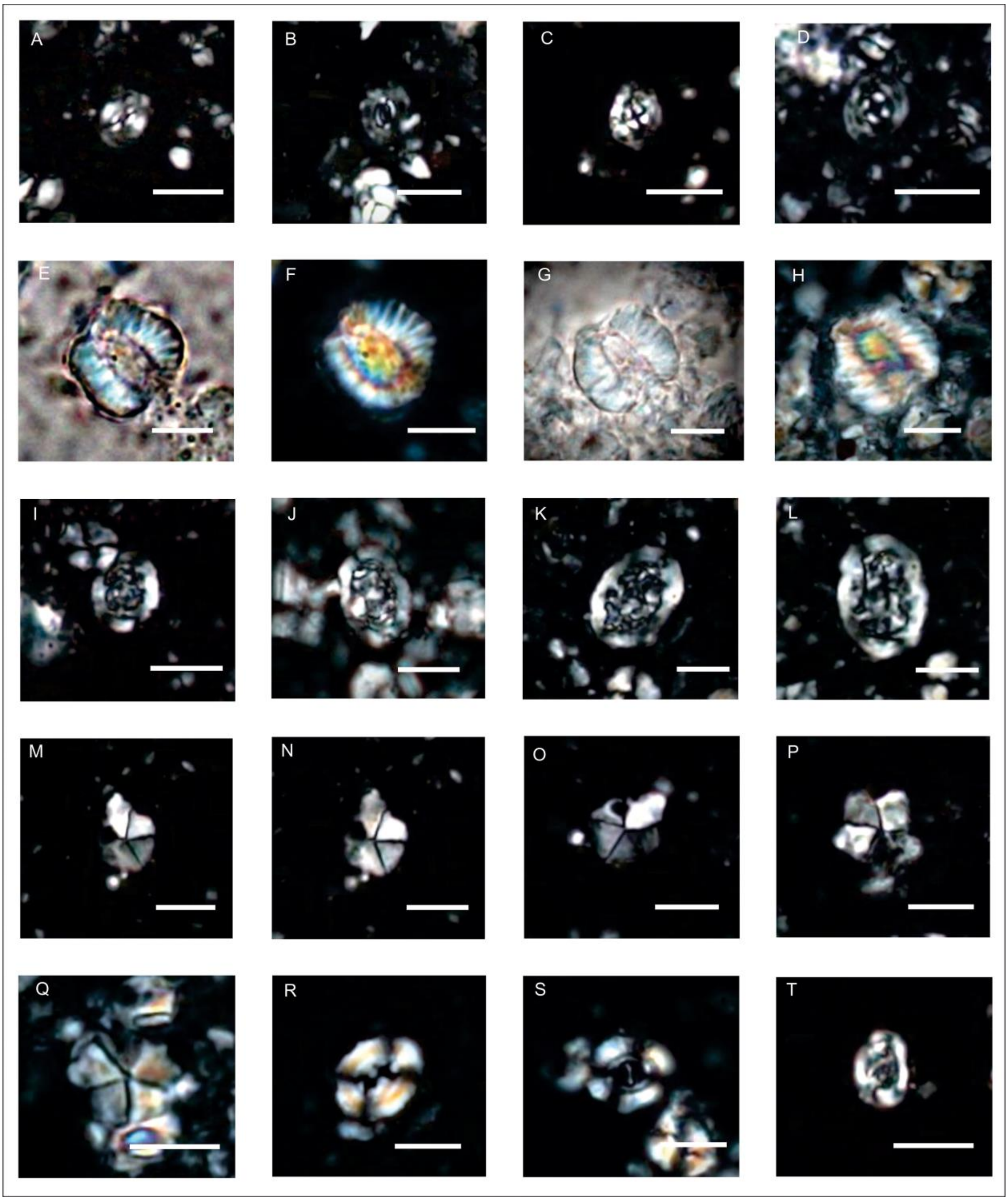
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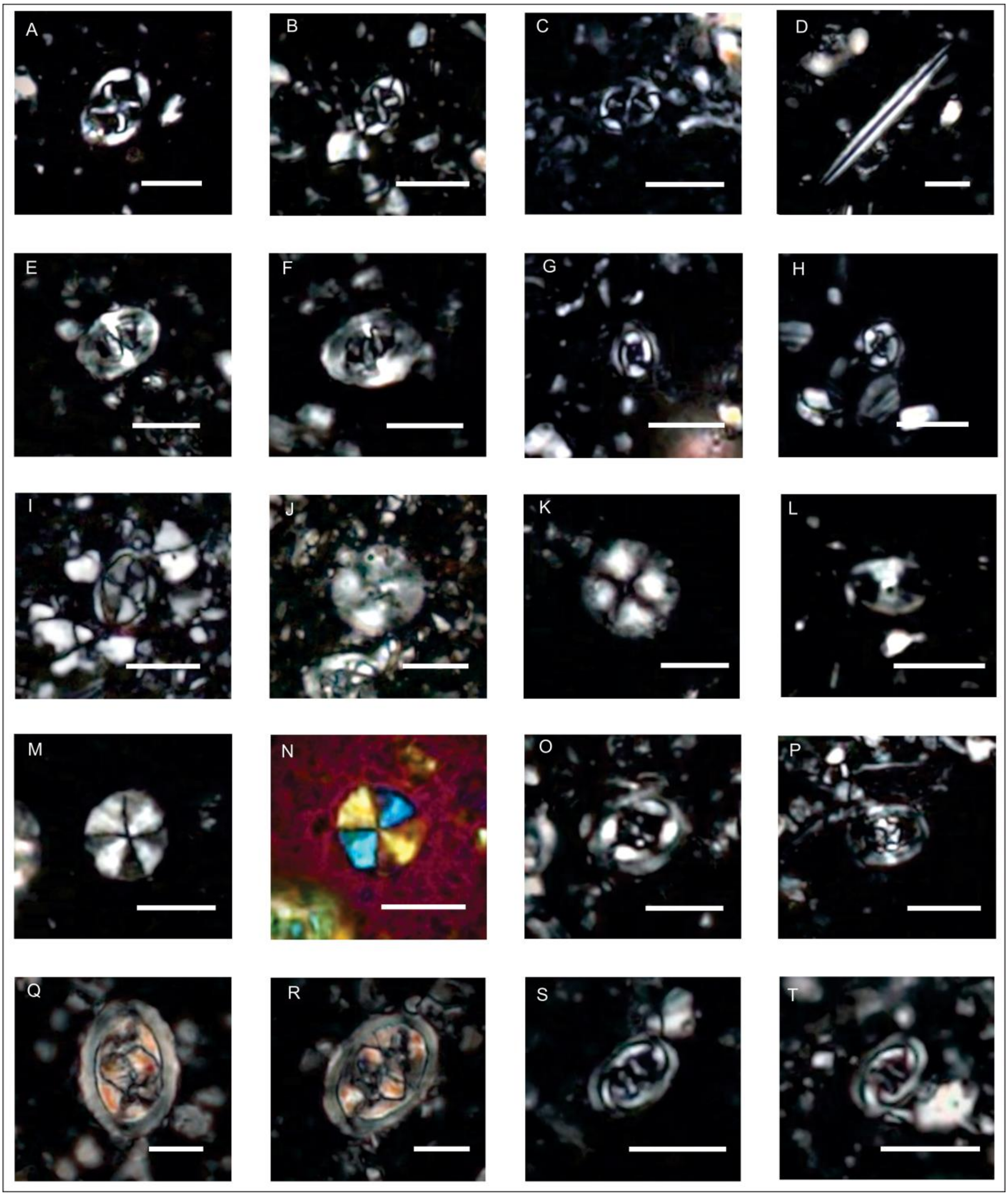
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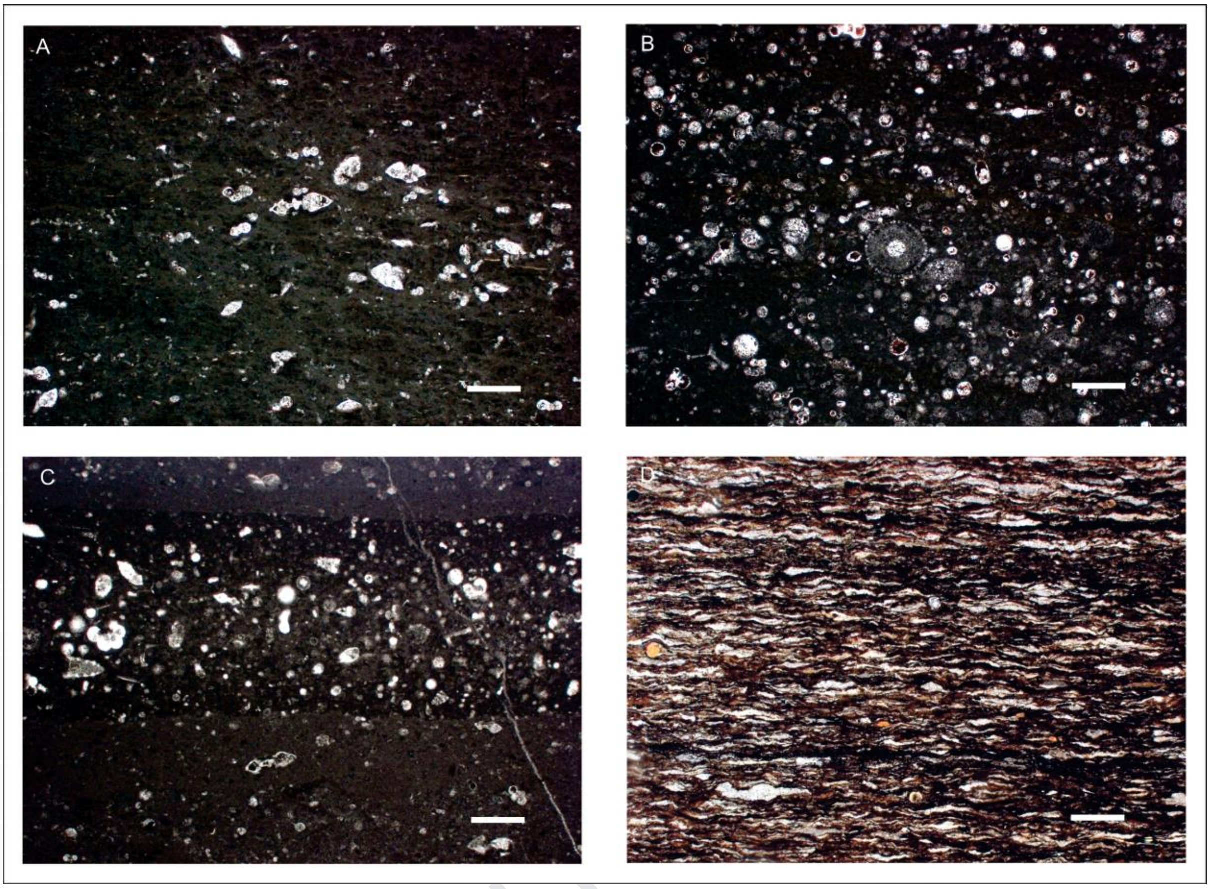
A
B
C
D

- The Poggio le Guaine core (PLG) (Italy) represents a complete Aptian-Albian stratigraphic interval
- The calcareous nannofossil biostratigraphy was performed for the PLG core
- The Aptian-Albian calcareous nannofossil NC6 to NC10 zones were recognized in the PLG core
- Some important calcareous nannofossil bioevents recognized in the PLG core were discussed
- The calcareous nannofossil results were calibrated to other stratigraphic tools of previous published works

Declaration of interests

☐The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Fabio Lamm reports financial support, administrative support, and equipment, drugs, or supplies were provided by Petrobras. Francisco Henrique de Oliveira Lima reports financial support, administrative support, and equipment, drugs, or supplies were provided by Petrobras. Ismar de Souza Carvalho reports financial support was provided by National Council for Scientific and Technological Development. Ismar de Souza Carvalho reports financial support was provided by Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro. Fabio Lamm reports a relationship with Petrobras that includes: employment. Francisco Henrique de Oliveira Lima reports a relationship with Petrobras that includes: employment. Ismar de Souza Carvalho reports a relationship with National Council for Scientific and Technological Development that includes: funding grants. Ismar de Souza Carvalho reports a relationship with Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro that includes: funding grants.