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INTEGRATING SHALLOW BENTHIC AND CALCAREOUS NANNOFOSSIL ZONES: THE LOWER EOCENE OF THE MONTE POSTALE SECTION (NORTHERN ITALY)

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ABSTRACT: The Monte Postale section (Bolca, northern Italy), one of the most famous Lagerstätten of the Eocene, has been investigated to reconstruct the sedimentary succession and to determine both the larger foraminiferal and the calcareous nannofossil biozones. The results allowed us to ascribe the Monte Postale limestones to the Shallow Benthic Zone 11 and to the calcareous nannofossil Zone CNE 5-?6 (= NP 13-?14a). The direct correlation of the SB and CNE Zones is consistent with the current biostratigraphic schemes and allows assignment of the deposition of the succession to the interval between 50.7 and 48.9 Ma, in the late Ypresian (early Eocene). According to the available biostratigraphic data, the uppermost portion of the Monte Postale section should correlate with the Pesciara limestones.

INTRODUCTION

The Eocene Lagerstätten of Bolca (northern Italy) are known worldwide for the exceptional preservation and diversity of their faunas, including soft-bodied organisms (e.g., Sorbini 1972 1999), and especially for their rich ichthyofauna, represented by more than 240 taxa (Carnevale et al. 2014). Often referred to as "Monte Bolca", the locality is actually represented by two sites: the Pesciara di Bolca and the Monte Postale (Fig. 1). These sites are geographically close each other, but no direct, physical correlation is possible because they are separated by a narrow valley, volcanic rocks, and possibly a fault. Moreover, the thickness of sedimentary rocks exposed varies considerably, being less than 20 m for the Pesciara limestone (Papazzoni and Trevisani 2006) and more than 130 m for the Eocene limestones in the Monte Postale (this work).

The Pesciara limestones have been ascribed by Medizza (1975) to the *Discoaster sublodoensis* Zone (= NP 14 Zone of Martini 1971) based on calcareous nannofossils. More recently, a study of the *Alveolina* assemblages by Papazzoni and Trevisani (2006) identified the SBZ 11 (Serra- Kiel et al. 1998; middle Cuisian or upper part of the Ypresian). Accordingly, the Pesciara succession was restricted to the uppermost part of the SBZ 11.

The age of the Monte Postale section has long been debated. Munier-Chalmas (1891) recognized in the Monte Postale the "Tufs et calcaire de Spilecco", attributed to the lower Eocene, lying on the Cretaceous Scaglia Rossa and overlain by the volcanic breccia with "*Lithothamnium Bolcense*" (*nomen nudum*) representing the base of the middle Eocene. Fabiani (1914, 1915) later reported the same age for the main body of limestones that constitutes the Monte Postale. Malaroda (1954) provided the same age, but in a footnote (p. 6) remarked that Arni (1939) determined the nummulites from the nearby Brusaferri locality were Cuisian age (= late Ypresian), suggesting that the alveolines from the Monte Postale could also be from the Ypresian. Hottinger (1960) recognized larger foraminiferal assemblages from the Bolca area not younger than the "middle Cuisian", therefore definitely older than the Lutetian. Unfortunately, in the comprehensive geological and stratigraphic survey of the Bolca area by Barbieri and Medizza (1969) the Monte Postale was not taken into consideration. Trevisani (2015), based on preliminary data by Papazzoni and Trevisani (2009), ascribed the 60 m of "Nummulitic limestone" of his M. Postale 1 succession to the SBZ 10-11. However, the study does not report the distribution of fossils in the section, and determined the

SBZ 10 on the presence of *Nummulites partschi*, which indeed spans through the SBZ 10 and 11 (see Serra-Kiel et al. 1998).

With the aim of obtaining a robust biostratigraphic framework for the Monte Postale, possibly with a direct correlation between shallow-water zonation and planktonic faunas, a detailed revision of the Monte Postale section was completed. A series of detailed field surveys were integrated with the study of a core sample drilled in 2000 and of field data collected during the quarrying campaigns directed by the Verona Museum of Natural History (2000–2004). More than 80 samples spanning the 135-m thick succession were examined for larger foraminifera (especially alveolines) and calcareous nannofossils (Figs. 2, 3). This dataset allows both the correlation between the Shallow Benthic (SB) Zones and the Calcareous Nannofossil Eocene (CNE) Zones and precise dating, thus clarifying the relationships between the laminites with fish and plants of the Monte Postale and those of the Pesciara.

GEOLOGICAL AND STRATIGRAPHICAL SETTING

The Monte Postale section is renowned not only for its vertebrate and mollusk fossil faunas (e.g., Sorbini 1972; Papazzoni et al. 2014a), but also because it is one of the few shallow-water successions showing the establishment of the first nuclei of what later became the Lessini Shelf (Bosellini 1989). The Lessini Shelf was one of the main paleogeographic features of Southern Alps during the Eocene (e.g., Bosellini 1989; Luciani 1989), representing at that time the northernmost margin of the Adriatic Plate (Carminati et al. 2012). It was the result of uplift of a pre-existing structural high, the “Trento Plateau” (Middle Jurassic–Paleocene), which formed with the drowning of the Early Jurassic Trento Platform (Bosellini et al. 1981; Winterer and Bosellini 1981). The Paleogene uplift was not uniform, due to the Alpine tectonics acting in this area with block-faulting (Márton et al. 2011). The tectonic activity resulted in deposition of volcanic and volcaniclastic material, mainly basaltic in composition. Beginning in the early Eocene, in shallower areas in the photic zone, these volcanic and volcaniclastic deposits are commonly intercalated with limestones and marls derived from thriving larger foraminifera, mollusks, corals, algae, and other biotic carbonate producers (Doglioni and Bosellini 1987; Bosellini 1989; Luciani 1989; Bassi et al. 2008). The main structural element influencing the Lessini area is the Castelvero Fault (Barbieri 1972), which runs a few kilometers west of the Monte Postale. This fault is on the border between two sectors. In particular, the eastern area was characterized by a graben (or semi-graben) known as Alpone-Chiampo graben (Barbieri et al. 1982) or Alpone-Agno half-graben (Barbieri et al. 1991), or Alpone-Agno graben (Zampieri 1995), where subsidence and volcanic activity were more pronounced than in the western part. Barbieri et al. (1991) recognized six volcanic stages from the late Paleocene up to the Bartonian (see also Barbieri and Zampieri 1992; Zampieri 1995). The volcanic rocks of the Monte Postale have traditionally been ascribed to the third stage, but this attribution was not supported by radiometric dating.

The lithostratigraphy of the Lessini area suffers from a lack of formal names and from the poor biostratigraphic constrains of the most commonly used units. For example, in the past the name "Spileccian" or "Calcari di Spilecco" (Spilecco limestones) was used as a synonym of the rocks ascribed to the lower Eocene (e.g., Malaroda 1967a; Ungaro 2001). Currently, it is assumed that only the uppermost part of the Thanetian and the lowermost part of the Ypresian are represented in Spilecco (NP 9-10 calcareous nannofossil Zones; Barbieri and Medizza 1969; Papazzoni et al. 2014b), whereas the lower Eocene deposits are generally ascribed to the Chiusole Formation (*sensu* Luciani 1989). This formation was deposited in a basinal-slope setting, heteropically passing to the Malcesine Limestones, deposited on the ramp margins (Luciani 1989), and to the neritic facies. The latter has been usually named "Calcari nummulitici" (Nummulitic limestones) (Malaroda 1967b; Carraro et al. 1969; De Zanche et al. 1977; Sarti 1980; Ungaro 2001), but the litho-chronostratigraphy of this unit in the Lessinian area still needs revision (e.g., Papazzoni et al. 2014c).

The Paleogene limestones at the Monte Postale are usually ascribed to the "Calcari nummulitici" (e.g., Malaroda 1967), even if nummulites in them are very rare. More recently, Dal Degan and Barbieri (2005) ascribed the entire succession to the informal “Monte Postale formation” (also described in the text as “Formazione del Monte Postale-Pesciara”) and dated it as early-middle Eocene.

The alleged “Monte Postale fault” theory reported by Trevisani (2015) is discarded herein (see below) based on field observations (see Vescogni et al. 2016). Therefore, even if the volcanic neck and dykes are cutting the sedimentary succession, we can affirm that the Monte Postale succession is relatively undisturbed and represents a quite continuous stratigraphic record.

MATERIALS AND METHODS

Fieldwork and Sampling

Monte Postale Hill was the object of intensive field activity (beginning 2003, focused 2013–2015) aimed to detect outcrops, reconstruct the stratigraphic succession, and collect a large number of samples for paleoenvironmental and biostratigraphic purposes.

Unfortunately, outcrops in the study area are typically small and discontinuous due to dense vegetative cover. Moreover, the current strike and dip of the strata does not necessarily reflect original depositional geometries as volcanic intrusions caused localized displacements of the sedimentary beds. Despite this, eight partial stratigraphic sections (Fig. 2) were measured and sampled; all are located on the eastern and northern sides of the hill that, unlike the western side, are absent volcanic intrusion. The relatively short distances among the outcrops usually allows straightforward correlations. The resulting stratigraphic framework was developed further by correlation with a 20-m core drilled in 2000 by the Natural History Museum of Verona (samples CMP on the column in Fig. 3). The core site (shown on Fig. 2) was below active quarry operations for the years 1999–2011.

A synthesis of the stratigraphic succession of the Monte Postale including the positions of the 85 samples analyzed is provided (Fig. 3). The total thickness of the sampled sections reaches about 135 m, with some uncertainties due to the cover intermissions. Some tens of meters below the base of section E (Fig. 2), the contact between the Paleogene limestones and the underlying Cretaceous Scaglia Rossa can be observed. However, this portion of the succession was not investigated, as the relatively few outcrops did not allow a reliable reconstruction of the stratigraphic architecture.

Larger Foraminifera

Forty-four samples were studied for their larger foraminiferal content with particular attention given to the species of the genus *Alveolina*, a genus with high biostratigraphic potential and the most abundant in the Monte Postale limestones.

On random thin sections (4.5 × 6.0 cm) true axial sections of *Alveolina* were selected for taxonomic identification, then digitally photographed under optical microscope. All the features useful for species identification were measured using the image analysis software JMicroVision 1.2.7. The species of *Alveolina* were determined following mainly Hottinger (1960, 1974), Drobne (1977), and Scotto di Carlo (1966).

The Shallow Benthic Zones (SBZ) were determined according to the species ranges reported in Serra-Kiel et al. (1998).

Calcareous Nannofossils

Forty-five samples were collected and prepared from unprocessed material as smear slides and examined using a light microscope at 1250× magnification. Because most samples contain rare to few calcareous nannofossils a semi-quantitative counting of the number of specimens in a prefixed area of about 8–7 mm^2 (roughly equivalent to three vertical traverses; modified after Gardin and Monechi 1998) was performed. This kind of count allowed an evaluation of the presence or absence of index species. The counting of biostratigraphically useful species within a prefixed number of taxonomically related forms (e.g., 20–40 *Discoaster*; Rio et al. 1990) was performed in the samples where the number of the selected taxon was statistically significant (at least 25–30 specimens). The taxonomy here adopted was outlined by Perch-Nielsen (1985). Taxonomic remarks and the list of the calcareous nannofossil considered are reported in the Appendix. The main marker species are represented in Figure 4.

THE MONTE POSTALE SECTION

Description and Facies Distribution

The section begins at one of the major hairpins turns of the Monte Postale trail (Fig. 2, section E), where massive limestones with coral rubble and encrusting biota crop out. Stratification is clearly visible ascending the sidehill (across the woods) for the first 25 m of thickness, then vegetation covers the next ~ 15 m, with a few small outcrops allowing confirmation that the bedding continues upwards with the same orientation. The outcrop is visible for another ~ 8 m and is then obscured by vegetative cover for another 10 m (to the road). The strata are mostly *Alveolina* grainstones/packstones that are alternated with laminated limestones with fish and plants and very few, thin marly levels.

Upwards, again on the road, there are laminated, fine-grained limestones followed by coarser *Alveolina*-bearing strata alternated with thin marly beds.A basaltic dyke interrupts the exposure, but the observation of some key levels in a core drilled in 2000 (samples CMP on the column, section "core"; Natural History Museum of Verona) allowed us to correlate the latter with the underlying strata, and to verify that, despite the dyke, the vertical displacement of the strata is negligible. The situation in the uppermost part of the section is more complex, because there are several outcrops (sections A, A1, A2, B, C, D, D1) showing significant lateral facies changes from quite evenly bedded fine-grained limestones, locally laminated and bearing fish and plants, to massive limestones rich in corals and algae, representing a bioconstructed facies (sections A1, A, B, C, D1, D) interpreted as the raised threshold separating the open sea from a protected area ("lagoon") (Vescogni et al. 2016).

The contact between these lateral facies is locally sharp and was interpreted as a probable tectonic contact by Munier Chalmas (1891) and Trevisani (2015). During field observations we did not find any evidence of tectonic activity in this portion of the succession; instead, we observed a gradual, continuous transition between the bedded limestones and the massive limestones some tens of meters far. Therefore, we are inclined to interpret the sharp contact as a local sedimentary onlap.

The *Alveolina* Assemblages

The faunal composition of the larger foraminiferal (LF) assemblages at Monte Postale is fairly constant (Fig. 3) and, according to the SB zonation of Serra-Kiel et al. (1998), it allows us to ascribe the entire section to the SB 11 Zone (middle Cuisian, or upper part of the Ypresian) since *Alveolina cremae* (Fig. 5A), *A. dainellii*, and *A. decastroi* (Fig. 5B) are limited to this biozone. *Alveolina distefanoi, A. fornasinii*, and *A. rutimeyeri* (SBZ 10-11), and *A. rugosa* (upper SBZ 10-lower 12) are also fully consistent with the SBZ 11.

Some elements of larger foraminiferal assemblages deserve further discussion. *Alveolina* aff. *croatica*, previously recorded from the Pesciara limestones by Papazzoni and Trevisani (2006), differs from *Alveolina croatica* Drobne 1977 for the size of the proloculus, closer to the one of *A. levantina*, and for its smaller overall size, with a lower number of whorls. A comprehensive description of this taxon goes beyond the aims of this paper, therefore we simply suggest that it could be a transitional form between *A. levantina* (upper SBZ 11-SBZ 12) and *A. croatica* (upper SBZ 12-SBZ 13). According to data presented herein, *A.* aff. *croatica* ranges through the whole SBZ 11.

Alveolina frumentiformis has been observed only at the top of the investigated section (sample PST 1318). This species is characteristic/indicative of the SBZ 12, but the co-occurrence of *A. cremae*, *A. decastroi*, and *A. distefanoi* shall instead confirm the attribution to the SBZ 11, extending its range downward to include the upper part of the SBZ 11.

On the other hand, the sample MPO 0301 at base section (Fig. 5D) contains *A.* cf. *schwageri*, which together with *A. rugosa* should indicate the SBZ 10. However, this sample was taken from a slump, so it could contain reworked material. We consider this *A.* cf. *schwageri* as an indication that the lower portion of Mt. Postale section probably was deposited close to the base of SBZ 11.

In summary, the Monte Postale section is totally included in the SBZ 11 and probably spans through most of it.

The *Alveolina* assemblage contains species that were recorded from the same biozone throughout the Paleogene Adriatic Carbonate Platform (including southern Italy; see Hottinger 1960; Scotto di Carlo 1966) as well as in Spain, France, Greece, and Turkey (Drobne et al. 2011).

The Calcareous Nannofossil Assemblages

Analytical calcareous nannofossil data are reported in Table 1. The results are reported in Figure 3 together with the biostratigraphic classification according to the "standard" zonation of Martini (1971) and the zonal scheme of Agnini et al. (2014). Out of 45 samples studied, only 24 of them contain a calcareous nannofossil assemblage useful for biostratigraphic interpretation while 18 are barren or almost barren (< 10 specimens per 8–7mm^2). Calcareous nannofossils are generally rare or scarce in the investigated material, with the exception of four samples (> 100 specimens per 8–7 mm^2) containing common nannofossils. Preservation of calcareous nannofossil assemblage is moderate to poor. Assemblages are usually dominated by placoliths (mainly *Coccolithus pelagicus, Dictyococcites,* and *Reticulofenestra*) and sphenoliths (manly *Sphenolithus moriformis* group and *Sphenolithus radians*). Among placoliths, *Cyclicargolithus floridanus* and *Ericsonia* are generally scarce while *Toweius* is rare. The genus *Discoaster* is poorly represented, except for the samples CMP 1422, CMP 800, PST 15105, PST 15102, and PST 1594 (Table 1).

The first 60 m of the Monte Postale composite section is characterized by a limestone facies not suitable for calcareous nannofossil studies, therefore, the nannofossil content of only three marly samples from the interval between 10–20 m has been analyzed, and it provided poor assemblages. However, the presence of rare Noelaerhabdaceae (*Reticulofenestra*, *Dictyococcites*, and *C. floridanus*) and the absence of *Tribrachiatus orthostylus* and *Discoaster sublodoensis* allow the ascription of this part of the section to the Biozone CNE 5 of Agnini et al. (2014; = Zone NP 13 of

Martini 1971; Fig. 3, Table 1). In particular, the presence of very rare specimens belonging to genus *Toweius* (Prinsiaceae) and *Coccolithus crassus* suggests that this part of the investigated section could be assigned to the lower part of the Zone CNE 5 of Agnini et al. (2014; Fig. 3, Table 1). In fact, according to Agnini et al. (2006, 2014), in the uppermost Zone CNE 4 the Prinsiaceae show a sharp decrease in abundance concomitantly with the first and sporadic entry of members of the Noelaerhabdaceae family and *C. crassus* has its first occurrence (Bukry 1971; Agnini et al. 2006; Shamrock and Watkins 2012).

The high-resolution sampling from approximately 60 to 102 m allows a sound biostratigraphic constraint of this part of the M. Postale composite section. In particular, the segment between 60 and 87 m is characterized by the presence of *Reticulofenestra*, *Dictyococcites,* and *C. crassus*, while the discoasterids which provide important biostratigraphic biohorizons are very rare except in three samples (Fig. 3, Table 1). The count within the genus *Discoaster* highlights the presence of *Discoaster lodoensis* (10–30%) and of rare specimens of 6-rayed *Discoaster* (6-rayed *Discoaster* cf. *sublodoensis* in Table 1; 0–3%) with intermediate morphologies between *D. sublodoensis* and *D. lodoensis*. In order to overcome this taxonomic problem, we considered as *D. sublodoensis* only the 5-rayed morphotypes, in agreement with Agnini et al (2006, 2014). The sporadic presence of *T. orthostylus* has been attributed to reworking. In fact, the species becomes extinct in correspondence of the base common occurrence of Noelaerhabdaceae (Agnini et al. 2006, 2014) which, in the investigated section, are common from the base. The concomitant occurrence of specimens belonging to Noelaerhabdaceae, the virtual absence of *Tribrachiatus orthostylus* and the absence of *Discoaster sublodoensis* allow to ascribe the segment to the Biozone CNE 5 of Agnini et al. (2014; = Zone NP 13 of Martini 1971; Fig. 3). The segment between 87–102 m contains a few nannofossils except in the sample at the top of this interval (PST 1594), where we registered the sporadic presence of ambiguous specimens of *D. sublodoensis* (11%; Table 1) which could represents the first rare and discontinuous occurrence of the species in the upper part of Zone CNE 5 as observed by Agnini et al. (2006, 2014). On this basis, we suggests to assign the top of this interval to the uppermost part of the calcareous nannofossil Zone CNE 5, according to Agnini et al. (2014; Fig. 3). The segment from 102 m to the top of the M. Postale composite section is represented by lithologies not suitable for calcareous nannofossil analysis (massive limestone, biocalciruditic limestone, etc.). The investigated samples are barren/almost barren and so not useful for biostratigraphic interpretation. However, we suggest that this segment could be ascribed to the transition CNE 5/CNE 6 Zones of Agnini et al. (2014) (NP13/NP14 Zones of Martini 1971) or to the lowermost part of the CNE 6 Zone based on its stratigraphic position (Fig. 3). The biostratigraphic assignment of the entire M. Postale composite section (lower CNE 5- uppermost CNE 5 or basal CN6) indicates the age of the section is to be late Ypresian, spanning the interval between ~ 50.5 and 48.96 Ma according to Vandenberghe et al. (2012) and Agnini et al. (2014; Fig. 3).

INTEGRATED BIOZONATION (SB-CNE ZONES)

To date, a firm and integrated calcareous nannofossil and larger foraminifera biostratigraphic scheme for the Paleogene is not established, even if some correlation schemes (Serra-Kiel et al. 1998, fig. 1; Vandenberghe et al. 2012, fig. 28.1) are published and widely used. The different environmental settings (basinal and shallow-water, respectively) of these groups often hinder their direct correlation, there are therefore relatively few successions suitable for a straightforward correlation between calcareous nannofossils and larger foraminifera biozones.

The presence of calcareous nannofossils in the Monte Postale section offers the opportunity to test the reliability of Serra Kiel et al. (1998) correlation scheme in the Ypresian. In this section the limestones with *Alveolina* are intercalated with marly beds containing a number of calcareous nannofossils sufficient for biostratigraphic interpretation.

Up to now, the larger foraminiferal assemblages from the Monte Postale were studied either as single samples from unresolved stratigraphic levels (e.g., Hottinger, 1960) or as the bulk fossil content of the stratigraphic succession (Trevisani 2015). Regarding calcareous nannofossils, no studies have concerned Monte Postale before now. In the present paper we show for the first time the complete distribution of both alveolines and calcareous nannofossils throughout the succession (Fig. 3).

The integrated biostratigraphic study performed on the Monte Postale composite section suggests that the section encompasses almost all the SBZ 11, up to its top; in terms of calcareous nannofossils we recognize the Zone CNE 5 (= NP 13) and the possible transition to the nannofossil Zone CNE 6 in the uppermost portion of the section. These results indicate the age of the entire section is late Ypresian (middle Cuisian) as also suggested by Hottinger (1960). It is worth pointing out that these results seem consistent with the correlation proposed by Serra-Kiel et al. (1998) and by Vandenberghe et al. (2012) (Fig. 6).

Our findings are in good agreement with the results from the Agost section (Alicante, southeast Spain), where the top of the NP13 (CNE5) Zone occurs within the SBZ11 (Larrasoaña et al. 2008). On the contrary, at Gorrondatxe (Biscay Province, Basque Country, Spain), the top of the NP 13 (CN5) Zone is apparently located within the SBZ 12 (Bernaola et al. 2006; Payros et al. 2007; Molina et al. 2011), but the raw data show that only one sample contains larger foraminifera attributed to the SBZ 12 (see Bernaola et al. 2006, fig. 11; Molina et al. 2011, fig. 7), and this sample correlates with the CP 12a (= NP 14a) (see Bernaola et al. 2006, fig. 4; Molina et al. 2011, fig. 5). No samples with larger foraminifera are reported from below, therefore the extension of the SBZ 12 to the upper part of the NP 13 is not justified by data.

The comparison with the neighboring section of Solane (Giusberti et al. 2014) provides additional information about the lower part of the Monte Postale section. At Solane the SBZ 11 was recognized in the lower part of the section correlated with the CNE 4 (= NP 12) Zone, in good agreement with the schemes by Serra-Kiel et al. (1998) and Vandenberghe et al. (2012). At Monte Postale, the first sample with nannofossils (PST 1435), approximately 10 m from the base section, positively indicates the lower CNE 5 Zone, therefore we can assume that probably the SBZ 11 should continue below the section measured. Hence, the *A.* cf. *schwageri* identified at the very base of the section is most probably reworked.

One of the still unresolved questions about the Bolca sites is the relative stratigraphic position of the laminated limestones containing the famous “Monte Bolca” ichthyofauna. This name groups together the Pesciara and the Monte Postale laminites, which are apparently very similar and so presumably correlate to each other. Trevisani (2015) concluded that “the Pesciara stratigraphic section is synchronous with the M. Postale 2 section.” This assumption is to some extent vague and leaves uncertainties about the correlation of the 15-m thick Pesciara section with the 90-m thick M. Postale 2 section. Since the SBZ 11 is a long-lasting zone, the simple identity of the larger foraminiferal assemblage is not sufficient to allow a precise correlation.

Medizza (1975), based on a single sample from the uppermost part of the Pesciara (Level L4 in Papazzoni and Trevisani 2006) ascribed this part of the section to the *Discoaster sublodoensis* (NP 14) calcareous nannofossil Zone. This, together with the recognition of the SBZ 11, allowed Papazzoni and Trevisani (2006) to restrict the age of the Pesciara laminites to the uppermost part of the SBZ 11 and lowermost NP 14 (= CNE 6) based on the correlation given by Serra-Kiel et al. (1998). The results of this study allow us to ascribe confidently most of Monte Postale succession to the SBZ 11 and to the CNE 5 Zone. However, we cannot exclude, for stratigraphic position, the presence of the CNE 6 Zone in the uppermost part of the section (over 105 m; Fig. 3) where the calcareous nannofossil assemblage does not contain biostratigraphically significant taxa. The larger foraminiferal assemblages indicate for this segment the upper part of the SBZ 11. This portion of the M. Postale composite section, which is above the “M. Postale 2” section of Trevisani (2015), still contains alveolines of the SBZ 11 and for the aforementioned reasons is possibly synchronous with the Pesciara section. Consequently, we suggest that the laminites of the Monte Postale could be slightly older than the ones of the Pesciara.

According to the calcareous nannofossils biochronology by Agnini et al. (2014), we can estimate the interval of deposition of the Monte Postale succession between about 50.7 and 48.9 Ma, with a mean depositional rate of at least 6 cm/kyr. This average rate results essentially from two different depositional processes: one very slow and even, accounting for the deposition of the laminated and non-laminated, fine-grained limestones, the other one quite rapid and abrupt, giving rise to the thick coarse-grained *Alveolina* limestones. Given the difficulties in determining quantitatively the relative extent of the two processes, we cannot estimate with confidence their relative importance, therefore the calculated depositional rate has to be considered as purely indicative.

CONCLUSIONS

In this study, we report for the first time the calcareous nannofossil assemblages from the Monte Postale, together with the distribution of the alveolines throughout the section. These data allowed us to obtain a direct correlation of the Shallow Benthic with the Calcareous Nannofossil Zones and therefore to confirm the general validity of the correlation schemes (Serra-Kiel et al. 1998; Vandenberghe et al. 2012) in this time interval. The comparison of the Monte Postale section with other sections in Italy and Spain reinforces the correlation between the SBZ 11 and the nannofossil zones CNE 4 (upper part), 5 and 6 (lower part) (Fig. 6).

These new data are of major importance for the correlation with the Pesciara limestone. For the latter, the attribution to the SBZ 11 and NP 14a (= CNE 6) (Papazzoni and Trevisani 2006) suggests a correlation with the uppermost part of the Monte Postale section.

The famous mollusk faunas described by Malaroda (1954) come from the uppermost levels of the Monte Postale; unfortunately, we do not have nannofossil data from here, but based on the larger foraminiferal assemblages we suggest that they belong to the uppermost part of the SBZ 11 or to the SBZ 12, ruling out the Lutetian age.

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FIGURE CAPTIONS

Fig. 1.—Location map of the Monte Postale section.

Fig. 2.—Position of the sections surveyed and sampled, with the relative stratigraphic columns.

Fig. 3.—Larger foraminifera and calcareous nannofossil biostratigraphy distribution along the composite section. The range of selected calcareous nannofossil and larger foraminifera (alveolinids) taxa is reported. Abundances of calcareous nannofossils are expressed as number of specimens per 7-8 mm^2, corresponding to three vertical traverses. Light gray areas represent barren or almost barren samples for nannofossil assemblages. The presence of larger foraminifera is represented by the black rectangles; the gray triangles represent reworked taxa. The star represents the presence of *D.* cf. *sublodoensis* (11%) within the *Discoaster*. Columns: A = Thickness (m); B = Chronostratigraphy; C = Larger foraminiferal SB Zones (Serra-Kiel et al. 1998); D = Calcareous

nannofossil zones (Martini 1971); E = Calcareous nannofossil zones (Agnini et al., 2014); F = Simplified lithologies and relative position of the samples.

FIG. 4.—Photomicrographs of selected calcareous nannofossil taxa from the Monte Postale section. Scale bar 5 µm. **A**–**Db**) *Coccolithus crassus* Bramlette and Sullivan 1961. Crossed nicols. A) Sample CMP 1422. B) Sample MPO P1. C) Sample PST 1594. Db) Sample CMP 1422. **Da**) *Coccolithus pelagicus* (Wallich 1877) Schiller 1930. Crossed nicols. Sample CMP 1422. **E**) *Ericsonia* Black 1964. Crossed nicols. Sample PST 15105. **F**, **G**) *Reticulofenestra* Hay et al. 1966. F) Sample MPO P1. G) Sample PST 15105. **H**, **I**) *Dictyococcites* Black 1967. Sample PST 15105. **J**) *Ericsonia formosa* (Kamptner 1963) Haq 1971. Crossed nicols. Sample PST 15105. **K**) *Cyclicargolithus floridanus* (Roth and Hay *in* Hay et al. 1967) Bukry 1971. Sample MPO P1. **L**) *Girgisia gammation* (Bramlette and Sullivan 1961) Varol 1989. Crossed nicols. Sample PST 15105. **M**) *Zygrhablithus bijugatus* (Deflandre *in* Deflandre and Fert 1954) Deflandre 1959. Crossed nicols. Sample PST 15105. **N**, **O**) *Sphenolithus radians* Deflandre *in* Grassé 1952. N) Crossed nicols 0°. O) nicols 45°. Sample PST 15105. **P**–**R**) *Discoaster lodoensis* Bramlette and Riedel 1954. Parallel light. P, Q) Sample CMP 1422, same specimen different focus. R) Sample CMP 1422. **S**) *Discoaster* cf. *sublodoensis* Bramlette and Sullivan 1961. Parallel light. Sample PST 1594. **T**) *Discoaster kuepperi* Stradner 1959. Parallel light. Sample PST 15105. **U**) *Discoaster nodifer* (Bramlette and Riedel 1954) Bukry 1973. Parallel light. Sample PST 15105. **V**) *Discoaster barbadiensis* Tan 1927. Parallel light. Sample PST 15105. **W**) *Braarudosphaera* Deflandre 1947. Crossed nicols. Sample PST 15105. **X**, **Y**) *Blackites* Hay and Towe 1962. Crossed nicols. Y) Base of *Blackites*. Sample PST 15105.

FIG. 5.—Photomicrographs of selected species of alveolines from the Monte Postale section. **A**) *Alveolina cremae* Checchia-Rispoli 1905. Sample CMP 1970. **B**) *Alveolina decastroi* Scotto di Carlo 1966. Sample CMP 1970. **C**) *Alveolina fornasinii* Checchia-Rispoli 1909. Sample MPO 0306. **D**) *Alveolina* cf. *schwageri* Checchia-Rispoli 1905. Sample MPO 0301. **E**) *Glomalveolina*

minutula (Reichel *in* Renz 1936). Sample PST 1434. **F**) *Alveolina rugosa* Hottinger 1960. Sample MPO 0307. Scale bar = 1 mm.

FIG. 6.—Biomagnetostratigraphy of the Ypresian–Lutetian interval. Geomagnetic polarity scale after Cande and Kent (1995). Tethyan zonation of larger benthic foraminifera from Serra-Kiel et al. (1998). Calcareous nannofossil zonations from Martini (1971; NP Zones) and Agnini et al (2014; CNE zones). The stratigraphic positions of Monte Postale section is indicated by the gray bar.

TABLE CAPTION

TABLE 1.—Distribution of the calcareous nannofossils in the Monte Postale composite section.