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

7 CESARE ANDREA PAPAZZONI,¹ ELIANA FORNACIARI,² LUCA GIUSBERTI,²

8 ALESSANDRO VESCOGNI,¹ and BEATRICE FORNACIARI¹

9 ¹University of Modena and Reggio Emilia, Department of Chemical and Geological Sciences, Via
10 Campi 103, 41125 Modena, Italy

11 ²University of Padova, Department of Geosciences, Via Gradenigo 6, 35131 Padova, Italy
12 email: papazzoni@unimore.it

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

22 INTRODUCTION

23 The Eocene Lagerstätten of Bolca (northern Italy) are known worldwide for the exceptional
24 preservation and diversity of their faunas, including soft-bodied organisms (e.g., Sorbini 1972
25 1999), and especially for their rich ichthyofauna, represented by more than 240 taxa (Carnevale et

26 al. 2014). Often referred to as “Monte Bolca”, the locality is actually represented by two sites: the
27 Pesciara di Bolca and the Monte Postale (Fig. 1). These sites are geographically close each other,
28 but no direct, physical correlation is possible because they are separated by a narrow valley,
29 volcanic rocks, and possibly a fault. Moreover, the thickness of sedimentary rocks exposed varies
30 considerably, being less than 20 m for the Pesciara limestone (Papazzoni and Trevisani 2006) and
31 more than 130 m for the Eocene limestones in the Monte Postale (this work).

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

37 The age of the Monte Postale section has long been debated. Munier-Chalmas (1891) recognized in
38 the Monte Postale the “Tufs et calcaire de Spilecco”, attributed to the lower Eocene, lying on the
39 Cretaceous Scaglia Rossa and overlain by the volcanic breccia with “*Lithothamnium Bolcense*”
40 (*nomen nudum*) representing the base of the middle Eocene. Fabiani (1914, 1915) later reported the
41 same age for the main body of limestones that constitutes the Monte Postale. Malaroda (1954)
42 provided the same age, but in a footnote (p. 6) remarked that Arni (1939) determined the
43 nummulites from the nearby Brusaferrì locality were Cuisian age (= late Ypresian), suggesting that
44 the alveolines from the Monte Postale could also be from the Ypresian. Hottinger (1960) recognized
45 larger foraminiferal assemblages from the Bolca area not younger than the “middle Cuisian”,
46 therefore definitely older than the Lutetian. Unfortunately, in the comprehensive geological and
47 stratigraphic survey of the Bolca area by Barbieri and Medizza (1969) the Monte Postale was not
48 taken into consideration. Trevisani (2015), based on preliminary data by Papazzoni and Trevisani
49 (2009), ascribed the 60 m of “Nummulitic limestone” of his M. Postale 1 succession to the SBZ 10-
50 11. However, the study does not report the distribution of fossils in the section, and determined the

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

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

63 GEOLOGICAL AND STRATIGRAPHICAL SETTING

64 The Monte Postale section is renowned not only for its vertebrate and mollusk fossil faunas (e.g.,
65 Sorbini 1972; Papazzoni et al. 2014a), but also because it is one of the few shallow-water
66 successions showing the establishment of the first nuclei of what later became the Lessini Shelf
67 (Bosellini 1989). The Lessini Shelf was one of the main paleogeographic features of Southern Alps
68 during the Eocene (e.g., Bosellini 1989; Luciani 1989), representing at that time the northernmost
69 margin of the Adriatic Plate (Carminati et al. 2012). It was the result of uplift of a pre-existing
70 structural high, the “Trento Plateau” (Middle Jurassic–Paleocene), which formed with the drowning
71 of the Early Jurassic Trento Platform (Bosellini et al. 1981; Winterer and Bosellini 1981). The
72 Paleogene uplift was not uniform, due to the Alpine tectonics acting in this area with block-faulting
73 (Márton et al. 2011). The tectonic activity resulted in deposition of volcanic and volcanoclastic
74 material, mainly basaltic in composition. Beginning in the early Eocene, in shallower areas in the
75 photic zone, these volcanic and volcanoclastic deposits are commonly intercalated with limestones

76 and marls derived from thriving larger foraminifera, mollusks, corals, algae, and other biotic
77 carbonate producers (Doglioni and Bosellini 1987; Bosellini 1989; Luciani 1989; Bassi et al. 2008).
78 The main structural element influencing the Lessini area is the Castelvero Fault (Barbieri 1972),
79 which runs a few kilometers west of the Monte Postale. This fault is on the border between two
80 sectors. In particular, the eastern area was characterized by a graben (or semi-graben) known as
81 Alpone-Chiampo graben (Barbieri et al. 1982) or Alpone-Agno half-graben (Barbieri et al. 1991), or
82 Alpone-Agno graben (Zampieri 1995), where subsidence and volcanic activity were more
83 pronounced than in the western part. Barbieri et al. (1991) recognized six volcanic stages from the
84 late Paleocene up to the Bartonian (see also Barbieri and Zampieri 1992; Zampieri 1995). The
85 volcanic rocks of the Monte Postale have traditionally been ascribed to the third stage, but this
86 attribution was not supported by radiometric dating.

87 The lithostratigraphy of the Lessini area suffers from a lack of formal names and from the poor
88 biostratigraphic constrains of the most commonly used units. For example, in the past the name
89 “Spileccian” or “Calcari di Spilecco” (Spilecco limestones) was used as a synonym of the rocks
90 ascribed to the lower Eocene (e.g., Malaroda 1967a; Ungaro 2001). Currently, it is assumed that
91 only the uppermost part of the Thanetian and the lowermost part of the Ypresian are represented in
92 Spilecco (NP 9-10 calcareous nannofossil Zones; Barbieri and Medizza 1969; Papazzoni et al.
93 2014b), whereas the lower Eocene deposits are generally ascribed to the Chiusole Formation (*sensu*
94 Luciani 1989). This formation was deposited in a basinal-slope setting, heteropically passing to the
95 Malcesine Limestones, deposited on the ramp margins (Luciani 1989), and to the neritic facies. The
96 latter has been usually named “Calcari nummulitici” (Nummulitic limestones) (Malaroda 1967b;
97 Carraro et al. 1969; De Zanche et al. 1977; Sarti 1980; Ungaro 2001), but the litho-
98 chronostratigraphy of this unit in the Lessinian area still needs revision (e.g., Papazzoni et al.
99 2014c).

100 The Paleogene limestones at the Monte Postale are usually ascribed to the “Calcari nummulitici”

101 (e.g., Malaroda 1967), even if nummulites in them are very rare. More recently, Dal Degan and
102 Barbieri (2005) ascribed the entire succession to the informal “Monte Postale formation” (also
103 described in the text as “Formazione del Monte Postale-Pesciara”) and dated it as early-middle
104 Eocene.

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

109 MATERIALS AND METHODS

110 Fieldwork and Sampling

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

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

124 A synthesis of the stratigraphic succession of the Monte Postale including the positions of the 85
125 samples analyzed is provided (Fig. 3). The total thickness of the sampled sections reaches about 135

126 m, with some uncertainties due to the cover intermissions. Some tens of meters below the base of
127 section E (Fig. 2), the contact between the Paleogene limestones and the underlying Cretaceous
128 Scaglia Rossa can be observed. However, this portion of the succession was not investigated, as the
129 relatively few outcrops did not allow a reliable reconstruction of the stratigraphic architecture.

130 Larger Foraminifera

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

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

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

141 Calcareous Nannofossils

142 Forty-five samples were collected and prepared from unprocessed material as smear slides and
143 examined using a light microscope at $1250\times$ magnification. Because most samples contain rare to
144 few calcareous nannofossils a semi-quantitative counting of the number of specimens in a prefixed
145 area of about $8\text{--}7\text{ mm}^2$ (roughly equivalent to three vertical traverses; modified after Gardin and
146 Monechi 1998) was performed. This kind of count allowed an evaluation of the presence or absence
147 of index species. The counting of biostratigraphically useful species within a prefixed number of
148 taxonomically related forms (e.g., 20–40 *Discoaster*; Rio et al. 1990) was performed in the samples
149 where the number of the selected taxon was statistically significant (at least 25–30 specimens).

150 The taxonomy here adopted was outlined by Perch-Nielsen (1985). Taxonomic remarks and the list

151 of the calcareous nannofossil considered are reported in the Appendix. The main marker species are
152 represented in Figure 4.

153 THE MONTE POSTALE SECTION

154 Description and Facies Distribution

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

163 Upwards, again on the road, there are laminated, fine-grained limestones followed by coarser
164 *Alveolina*-bearing strata alternated with thin marly beds. A basaltic dyke interrupts the exposure, but
165 the observation of some key levels in a core drilled in 2000 (samples CMP on the column, section
166 “core”; Natural History Museum of Verona) allowed us to correlate the latter with the underlying
167 strata, and to verify that, despite the dyke, the vertical displacement of the strata is negligible.

168 The situation in the uppermost part of the section is more complex, because there are several
169 outcrops (sections A, A1, A2, B, C, D, D1) showing significant lateral facies changes from quite
170 evenly bedded fine-grained limestones, locally laminated and bearing fish and plants, to massive
171 limestones rich in corals and algae, representing a bioconstructed facies (sections A1, A, B, C, D1,
172 D) interpreted as the raised threshold separating the open sea from a protected area (“lagoon”)
173 (Vescogni et al. 2016).

174 The contact between these lateral facies is locally sharp and was interpreted as a probable tectonic
175 contact by Munier Chalmas (1891) and Trevisani (2015). During field observations we did not find

176 any evidence of tectonic activity in this portion of the succession; instead, we observed a gradual,
177 continuous transition between the bedded limestones and the massive limestones some tens of
178 meters far. Therefore, we are inclined to interpret the sharp contact as a local sedimentary onlap.

179 *The Alveolina Assemblages*

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

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

194 *Alveolina frumentiformis* has been observed only at the top of the investigated section (sample PST
195 1318). This species is characteristic/indicative of the SBZ 12, but the co-occurrence of *A. cremae*,
196 *A. decastroi*, and *A. distefanoi* shall instead confirm the attribution to the SBZ 11, extending its
197 range downward to include the upper part of the SBZ 11.

198 On the other hand, the sample MPO 0301 at base section (Fig. 5D) contains *A. cf. schwageri*, which
199 together with *A. rugosa* should indicate the SBZ 10. However, this sample was taken from a slump,
200 so it could contain reworked material. We consider this *A. cf. schwageri* as an indication that the

201 lower portion of Mt. Postale section probably was deposited close to the base of SBZ 11.

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

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

207 The Calcareous Nannofossil Assemblages

208 Analytical calcareous nannofossil data are reported in Table 1. The results are reported in Figure 3
209 together with the biostratigraphic classification according to the “standard” zonation of Martini
210 (1971) and the zonal scheme of Agnini et al. (2014). Out of 45 samples studied, only 24 of them
211 contain a calcareous nannofossil assemblage useful for biostratigraphic interpretation while 18 are
212 barren or almost barren (< 10 specimens per 8–7mm²). Calcareous nannofossils are generally rare or
213 scarce in the investigated material, with the exception of four samples (> 100 specimens per 8–7
214 mm²) containing common nannofossils. Preservation of calcareous nannofossil assemblage is
215 moderate to poor. Assemblages are usually dominated by placoliths (mainly *Coccolithus pelagicus*,
216 *Dictyococcites*, and *Reticulofenestra*) and sphenoliths (mainly *Sphenolithus moriformis* group and
217 *Sphenolithus radians*). Among placoliths, *Cyclicargolithus floridanus* and *Ericsonia* are generally
218 scarce while *Toweius* is rare. The genus *Discoaster* is poorly represented, except for the samples
219 CMP 1422, CMP 800, PST 15105, PST 15102, and PST 1594 (Table 1).

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

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

233 The high-resolution sampling from approximately 60 to 102 m allows a sound biostratigraphic
234 constraint of this part of the M. Postale composite section. In particular, the segment between 60
235 and 87 m is characterized by the presence of *Reticulofenestra*, *Dictyococcites*, and *C. crassus*, while
236 the discoasterids which provide important biostratigraphic biohorizons are very rare except in three
237 samples (Fig. 3, Table 1). The count within the genus *Discoaster* highlights the presence of
238 *Discoaster lodoensis* (10–30%) and of rare specimens of 6-rayed *Discoaster* (6-rayed *Discoaster* cf.
239 *sublodoensis* in Table 1; 0–3%) with intermediate morphologies between *D. sublodoensis* and *D.*
240 *lodoensis*. In order to overcome this taxonomic problem, we considered as *D. sublodoensis* only the
241 5-rayed morphotypes, in agreement with Agnini et al (2006, 2014). The sporadic presence of *T.*
242 *orthostylus* has been attributed to reworking. In fact, the species becomes extinct in correspondence
243 of the base common occurrence of Noelaerhabdaceae (Agnini et al. 2006, 2014) which, in the
244 investigated section, are common from the base. The concomitant occurrence of specimens
245 belonging to Noelaerhabdaceae, the virtual absence of *Tribrachiatus orthostylus* and the absence of
246 *Discoaster sublodoensis* allow to ascribe the segment to the Biozone CNE 5 of Agnini et al. (2014;
247 = Zone NP 13 of Martini 1971; Fig. 3). The segment between 87–102 m contains a few nannofossils
248 except in the sample at the top of this interval (PST 1594), where we registered the sporadic
249 presence of ambiguous specimens of *D. sublodoensis* (11%; Table 1) which could represents the
250 first rare and discontinuous occurrence of the species in the upper part of Zone CNE 5 as observed

251 by Agnini et al. (2006, 2014). On this basis, we suggests to assign the top of this interval to the
252 uppermost part of the calcareous nannofossil Zone CNE 5, according to Agnini et al. (2014; Fig. 3).
253 The segment from 102 m to the top of the M. Postale composite section is represented by lithologies
254 not suitable for calcareous nannofossil analysis (massive limestone, biocalciruditic limestone, etc.).
255 The investigated samples are barren/almost barren and so not useful for biostratigraphic
256 interpretation. However, we suggest that this segment could be ascribed to the transition CNE
257 5/CNE 6 Zones of Agnini et al. (2014) (NP13/NP14 Zones of Martini 1971) or to the lowermost
258 part of the CNE 6 Zone based on its stratigraphic position (Fig. 3). The biostratigraphic assignment
259 of the entire M. Postale composite section (lower CNE 5- uppermost CNE 5 or basal CN6) indicates
260 the age of the section is to be late Ypresian, spanning the interval between ~ 50.5 and 48.96 Ma
261 according to Vandenberghe et al. (2012) and Agnini et al. (2014; Fig. 3).

262 INTEGRATED BIOZONATION (SB-CNE ZONES)

263 To date, a firm and integrated calcareous nannofossil and larger foraminifera biostratigraphic
264 scheme for the Paleogene is not established, even if some correlation schemes (Serra-Kiel et al.
265 1998, fig. 1; Vandenberghe et al. 2012, fig. 28.1) are published and widely used. The different envi-
266 ronmental settings (basinal and shallow-water, respectively) of these groups often hinder their direct
267 correlation, there are therefore relatively few successions suitable for a straightforward correlation
268 between calcareous nannofossils and larger foraminifera biozones.

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

273 Up to now, the larger foraminiferal assemblages from the Monte Postale were studied either as
274 single samples from unresolved stratigraphic levels (e.g., Hottinger, 1960) or as the bulk fossil
275 content of the stratigraphic succession (Trevisani 2015). Regarding calcareous nannofossils, no

276 studies have concerned Monte Postale before now. In the present paper we show for the first time
277 the complete distribution of both alveolines and calcareous nannofossils throughout the succession
278 (Fig. 3).

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

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

295 The comparison with the neighboring section of Solane (Giusberti et al. 2014) provides additional
296 information about the lower part of the Monte Postale section. At Solane the SBZ 11 was
297 recognized in the lower part of the section correlated with the CNE 4 (= NP 12) Zone, in good
298 agreement with the schemes by Serra-Kiel et al. (1998) and Vandenberghe et al. (2012). At Monte
299 Postale, the first sample with nannofossils (PST 1435), approximately 10 m from the base section,
300 positively indicates the lower CNE 5 Zone, therefore we can assume that probably the SBZ 11

301 should continue below the section measured. Hence, the *A. cf. schwageri* identified at the very base
302 of the section is most probably reworked.

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

311 Medizza (1975), based on a single sample from the uppermost part of the Pesciara (Level L4 in
312 Papazzoni and Trevisani 2006) ascribed this part of the section to the *Discoaster subladoensis* (NP
313 14) calcareous nannofossil Zone. This, together with the recognition of the SBZ 11, allowed
314 Papazzoni and Trevisani (2006) to restrict the age of the Pesciara laminites to the uppermost part of
315 the SBZ 11 and lowermost NP 14 (= CNE 6) based on the correlation given by Serra-Kiel et al.
316 (1998). The results of this study allow us to ascribe confidently most of Monte Postale succession to
317 the SBZ 11 and to the CNE 5 Zone. However, we cannot exclude, for stratigraphic position, the
318 presence of the CNE 6 Zone in the uppermost part of the section (over 105 m; Fig. 3) where the
319 calcareous nannofossil assemblage does not contain biostratigraphically significant taxa. The larger
320 foraminiferal assemblages indicate for this segment the upper part of the SBZ 11. This portion of
321 the M. Postale composite section, which is above the “M. Postale 2” section of Trevisani (2015),
322 still contains alveolines of the SBZ 11 and for the aforementioned reasons is possibly synchronous
323 with the Pesciara section. Consequently, we suggest that the laminites of the Monte Postale could be
324 slightly older than the ones of the Pesciara.

325 According to the calcareous nannofossils biochronology by Agnini et al. (2014), we can estimate

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

333 CONCLUSIONS

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

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

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

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615 FIGURE CAPTIONS

616 FIG. 1.—Location map of the Monte Postale section.

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

618 FIG. 3.—Larger foraminifera and calcareous nannofossil biostratigraphy distribution along the
619 composite section. The range of selected calcareous nannofossil and larger foraminifera
620 (alveolinids) taxa is reported. Abundances of calcareous nannofossils are expressed as number of
621 specimens per 7–8 mm², corresponding to three vertical traverses. Light gray areas represent barren
622 or almost barren samples for nannofossil assemblages. The presence of larger foraminifera is
623 represented by the black rectangles; the gray triangles represent reworked taxa. The star represents
624 the presence of *D. cf. subbloensis* (11%) within the *Discoaster*. Columns: A = Thickness (m); B =
625 Chronostratigraphy; C = Larger foraminiferal SB Zones (Serra-Kiel et al. 1998); D = Calcareous

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

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

647 FIG. 5.—Photomicrographs of selected species of alveolines from the Monte Postale section. **A)**
648 *Alveolina cremae* Checchia-Rispoli 1905. Sample CMP 1970. **B)** *Alveolina decastroi* Scotto di
649 Carlo 1966. Sample CMP 1970. **C)** *Alveolina fornasinii* Checchia-Rispoli 1909. Sample MPO
650 0306. **D)** *Alveolina cf. schwageri* Checchia-Rispoli 1905. Sample MPO 0301. **E)** *Glomalveolina*

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

653 FIG. 6.—Biomagnetostratigraphy of the Ypresian–Lutetian interval. Geomagnetic polarity scale
654 after Cande and Kent (1995). Tethyan zonation of larger benthic foraminifera from Serra-Kiel et al.
655 (1998). Calcareous nannofossil zonations from Martini (1971; NP Zones) and Agnini et al (2014;
656 CNE zones). The stratigraphic positions of Monte Postale section is indicated by the gray bar.

657 TABLE CAPTION

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