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3 *transition*
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17 # Integrated stratigraphy at the Bartonian–Priabonian transition:
18 # Correlation between shallow benthic and calcareous plankton
19 # zones (Varignano section, northern Italy)

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29 **ABSTRACT**

30   The Varignano section (Trento province, northern Italy) provides an exceptional
31 opportunity for a direct correlation between shallow benthic (SB) zones and standard calcareous
32 plankton zones at the Bartonian–Priabonian transition (middle–late Eocene). This transition has
33 attracted great attention by biostratigraphers in the last decades in searching for a boundary
34 stratotype section. The Alano di Piave section (NE Italy) is the leading candidate for the base
35 Priabonian Global Stratotype Section and Point (GSSP). However, at Alano, larger foraminifera-
36 bearing resedimented levels occur exclusively well below the critical interval. Conversely, the
37 Varignano section, located ~80 km west of the Alano section, preserves several coarse bioclastic
38 levels rich in larger foraminifera throughout the section. These levels are intercalated with
39 basinal marlstones, crystal tuff layers, and an organic-rich interval. The Varignano section spans
40 planktic foraminiferal ~~Zones E10–11~~ zones E10 and E11 to lower E14, calcareous nannofossil
41 zones MNP16Bc to MNP18 and chrons 18n to 17n.2n. The main calcareous plankton events
42 recently proposed as primary base-Priabonian correlation tools, i.e., the last occurrence of the
43 genus *Morozovelloides* and the base common (= acme beginning) of *Cribrocentrum erbae* occur,
44 respectively, within C17n.3n and C17n.2n. We correlate prominent crystal tuff layers exposed at
45 Varignano with those outcropping at Alano, ~~included~~ including the Tiziano bed, ~~which~~ whose

46   base has also been proposed as the GSSP level.**[[Please review this sentence.]]** The Varignano
47   section spans the upper SB17 and the lower SB18 zones, with the zonal boundary marked by the
48   first occurrence of the genus *Pellatispira*. This event occurs in the lower part of zones E13 and
49   MNP17A within C18n, well below all the potential criteria to identify the GSSP that also
50   includes Chron C17n.1n base. We point out that the usage of shallow-water biostratigraphers in
51   placing the base of the Priabonian at the base of Zone SB19 is inconsistent with the proposed
52   plankton events.
53   **INTRODUCTION**
54   Correlation between biotic events from shallow-water and deep-water paleoenvironments
55   is one of the main challenges of biostratigraphy. The Bartonian–Priabonian transition (middle–
56   late Eocene) has attracted in the last decades great attention by stratigraphers searching for a
57   Global Stratotype Section and Point (GSSP) for base Priabonian that is so far not yet ratified.
58   The original stratotype section near the village of Priabona (Munier-Chalmas and de Lapparent,
59   1893) in the eastern Lessini Mountains of northeastern Italy is composed of shallow-water
60   sediments. This hinders the correlation with the pelagic realm, making it difficult to define a
61   chronostratigraphic unit (Roveda, 1961; Hardenbol, 1968). In addition, the base of the type
62   section is marked by a hiatus and overlies volcanic rocks (Piccoli and Massari Degasperi, 1968;
63   Setiawan, 1983). Since the Eocene colloquium held in Paris in 1968 (Cita, 1969) the
64   International Commission on Stratigraphy has been searching for a new, more reliable stratotype.
65   To establish the correct correlations between larger foraminifera (LF hereafter) and calcareous
66   plankton zonal schemes is therefore especially critical across this interval.
67   In absence of a newly defined GSSP, stratigraphers have adopted diverse criteria on the
68   basis of calcareous plankton and LF events to place the Bartonian–Priabonian boundary. In deep-
69   water successions, the first appearance of the calcareous nannofossil *Chiasmolithus oamaruensis*
70   that defines the NP17–NP18 zonal boundary (Martini, 1971) has been used for a long time to
71   approximate the base of the Priabonian Stage (e.g., Berggren et al., 1995). The discontinuous and
72   sporadic occurrences of *C. oamaruensis* and demonstrated diachrony of its first appearance over
73   latitudinal distance (Wei and Wise, 1992; Marino and Flores, 2002a, 2002b; Villa et al., 2008;
74   Fornaciari et al., 2010) indicate that this biohorizon is a poor guiding criterion for definition of a
75   chronostratigraphic stage boundary. As for the planktic foraminiferal criteria, the main events
76   close to the middle–upper Eocene boundary are the nearly simultaneous extinction of the
77   murico-keeled (from muricae, i.e., typical pointed/conical pustules of the test wall) planktic
78   foraminiferal genus *Morozovelloides* and *Acarinina mcgowrani*, the latter being characterized by
79   relatively large size (>125 μm) and well-developed muricae (Berggren and Pearson, 2005; Wade
80   et al., 2011, 2012).

81   The Alano di Piave section (Veneto region, northeastern Italy, hereafter referred to as
82   Alano) that is located in the type area of the "historical" Priabonian stratotype is the favored
83   GSSP candidate of the base of Priabonian (Agnini et al., 2011; Vandenberghe et al., 2012; Ogg
84   et al., 2016). Most of the documentation needed has been presented in Agnini et al. (2011,
85   2014b) and Spofforth et al. (2010), such as lithostratigraphy, calcareous plankton
86   biostratigraphy, magnetostratigraphy, and chemostratigraphy. The Alano section meets indeed
87   the prerequisites for being a suitable GSSP, such as continuous outcrop, completeness, lacking
88   deformation, richness in calcareous plankton, good magnetic properties, and easy accessibility.
89   Agnini et al. (2011) listed alternative reliable calcareous plankton criteria across the Bartonian–
90   Priabonian transition. They include the top of planktic foraminiferal *Morozovelloides* (E13–E14
91   boundary of the Wade et al. 2011 zonal scheme) that occurs within C17n.3n and the acme

92   beginning of the calcareous nannofossil *Cribrocentrum erbae* occurring in the lowermost part of
93   C17n.2n. The *Morozovelloides* extinction is a robust event as it is synchronous in Tethyan and
94   Atlantic sites and it closely follows (<~11 k.y.) the extinction of *Acarinina mcgowrani* (Wade et
95   al., 2012; Ogg et al., 2016; Coccioni et al., 2016). Moreover, the *Morozovelloides* extinction
96   coincides with a large turnover in radiolarian assemblages (Wade et al., 2012). The calcareous
97   nannofossil *C. erbae* revealed to be as well a reliable event as it is synchronous over the Tethyan
98   and Atlantic Ocean realm (e.g., Fornaciari et al., 2010; Fioroni et al., 2015) and it occurs very
99   close to the C17n.2n-C17n.2r boundary. The two potential calcareous plankton events and the
100   base of Chron C17n.1n, also proposed to correlate the base of the Priabonian by Vandenberghe
101   et al. (2012), are located at Alano close to a crystal tuff layer named as Tiziano bed. The base of
102   this bed (age 37.814–37.521 Ma, depending on the scale used) has been suggested as the GSSP
103   level for the Bartonian–Priabonian boundary by Agnini et al. (2011, 2014 a, 2014c).
104   Unfortunately, at Alano a direct correlation with shallow benthic zones is hampered
105   because bioclastic levels containing LF are scarce and all occur well below the critical interval
106   for defining the boundary (Agnini et al., 2011).
107   Larger foraminifera experienced several extinctions through the middle–late Eocene. An
108   important turnover event has been traditionally considered to represent the Bartonian–Priabonian
109   boundary in LF biostratigraphy (e.g., Hallock et al., 1991; Papazzoni and Sirotti, 1995; Serra-
110   Kiel et al., 1998; Bassi et al., 2000; Luciani et al., 2002; Less et al., 2008; Less and Özcan,
111   2012). Specifically, the Bartonian/Priabonian transition interval is usually defined by the last
112   occurrence of the larger-sized species of *Nummulites* (*N. maximus, N. biedai,* and *N. lyelli* among
113   others) along with the first occurrence of the genus *Spiroclypeus* and of the species *N. fabianii*,
114   the latter being the descendant of the chronospecies *N. hormoensis* (= *N. ptukhiani* sensu Schaub
115   1981, *N. "ptukhiani"* in Papazzoni 1998) within the reticulate *Nummulites* lineage (Papazzoni
116   and Sirotti, 1995; Serra-Kiel et al., 1998; Less et al., 2008; Less and Özcan, 2008**[[Not listed.**
117   **Should this be Less and Özcan, 2012, or Less et al., 2008?]]**; 2012). These events identify the
118   boundary between ~~the~~ zones SB18 and SB19 (Serra-Kiel et al., 1998). However, the
119   synchronism of calcareous plankton events with LF turnover has never been precisely
120   established. Hallock et al. (1991) hypothesized that main**[[major?]]** planktic and LF
121   evolutionary trends were synchronous with the major paleoceanographic variations, ~~included~~
122   including the middle to late Eocene changes, such as climate cooling and related modifications in
123   trophic sources and paleoceanography. Specifically, these authors correlate extinction of K-
124   strategist planktic foraminifera such as the muricate forms to the disappearance of the K-
125   strategist large *Nummulites*. The rationale behind this hypothesis is that the oligotrophic K-
126   strategists are more sensitive to environmental stress being characterized by long individual life
127   and low reproductive potential with respect to the eutrophic opportunist r-strategists which are
128   able to rapidly increase their population densities by faster reproduction (e.g., Hallock, 1985).
129   Therefore, large *Nummulites* and muricate forms may have shared low resilience to the major
130   paleoceanographic and climatic changes that occurred during the middle-late Eocene transition.
131   However, in the Mossano section (Colli Berici, Vicenza, Italy), which has been proposed
132   as a possible "parastratotype" for the Priabonian ("Colloque sur l'Éocène," Paris, 1968), the
133   SB18 correlates with the uppermost part of zones E14 and NP17-18, thus suggesting that the
134   extinction of *Morozovellioides* and *Acarinina mcgowrani* as well as the first occurrence of *C.*
135   *oamaruensis*, occurred earlier (Luciani et al., 2002). These data are in agreement with the record
136   from northern Egypt where the first occurrence of *N. fabianii* corresponds to the upper part of the
137   foraminiferal *Globigerinatheka semiinvoluta* (E15) and the nannofossil NP18 zones (Strougo,

138   1992). More recently, other records suggest similar inconsistencies between the SB, calcareous
139   plankton zonal schemes, and chronostratigraphy. Specifically, the record from eastern Ebro
140   Basin (NE Spain) (Costa et al., 2013) highlights a correlation of SB18 with calcareous
141   nannofossil zones "confidently" placed within the Priabonian (NP19-20, Martini, 1971; polarity
142   chrons C17–C16). Other data from Armenia and eastern Turkey document a correlation of
143   SB17–SB18 boundary with polarity chrons C16 and C17, respectively (Cotton et al., 2017;
144   Rodelli et al., 2018). However, most of the aforementioned sections do not encompass the entire
145   Bartonian–Priabonian transition. Therefore, to date, the correlation between deep- and shallow-
146   water settings is largely indirect thus the exact correspondence between the SB18–SB19
147   boundary and the calcareous plankton zones and chronostratigraphy remains uncertain.
148   The Varignano section (Trentino region, northern Italy; Fig. 1) crops out ~80 km to the
149   west of the Alano section and provides an exceptional opportunity for attaining a direct
150   correlation between the SB and the standard calcareous plankton zonal schemes across the
151   crucial Bartonian–Priabonian boundary in the Tethyan area. The hemipelagic marlstones of
152   Varignano contain indeed, besides rich calcareous plankton assemblages and levels with
153   volcanoclastic material, several coarse bioclastic levels rich in LF throughout the entire section
154   (Luciani and Lucchi Garavello, 1986). The Eocene Varignano succession was deposited in a
155   bathyal setting bordered to the east by the shallow carbonate platform of the Lessini Shelf, the
156   likely source of the calciturbidites (Doglioni and Bosellini, 1987; Luciani, 1989).
157   Here we present new data on planktic foraminiferal, calcareous nannofossil, LF
158   biostratigraphy, magnetostratigraphy, and layers bearing volcanoclastic material from Varignano
159   with the main aim to document the direct correlation between shallow benthic and calcareous
160   plankton zonal schemes across the Bartonian–Priabonian interval. Our analysis allows us to
161   validate middle-late Eocene calcareous plankton events and to accurately compare bio-
162   magnetostratigraphy and layers with volcanoclastic material with the Alano GSSP candidate
163   section.
164   We demonstrate that the primary and secondary calcareous plankton bioevents are
165   recorded at Varignano in the same order and stratigraphic position as at Alano, especially those
166   across the Bartonian–Priabonian interval. We highlight, however, that there is inconsistency with
167   the common usage of shallow-water biostratigraphers in positioning the base of the Priabonian
168   thus demonstrating that correlations with SB zones need to be revised.
169   **GEOLOGICAL AND HISTORICAL BACKGROUND**
170   The Varignano section (latitude 45° 55′ 17.06″ N, longitude 10° 51′ 15.93″ E) is located
171   in the southern Sarca River Valley north of the Garda Lake, in the southwestern Trento Province
172   of the Trentino-Alto Adige region, NE Italy (Figs. 1A–1C). The study area is located in the
173   southern portion of the NNE-SSW–trending system of the Giudicarie belt within the post-
174   collisional south-vergent thrust system of the Southern Alps of northern Italy (e.g., Massironi et
175   al., 2009). The Southern Alps (Fig. 1A), a major structural element of the Alpine chain, are
176   considered to be a significantly preserved portion of the southern continental margin of the
177   Mesozoic Tethyan Ocean (Castellarin et al., 2006). This area was less severely affected by
178   tectonic deformation than elsewhere in the Alps and Apennines (e.g., Channell and Medizza,
179   1981), making the pre-Alps suited for studies of the lower Paleogene pelagic record as exposed
180   in well-preserved on-land sections especially in the Belluno area (e.g., Dallanave et al., 2009,
181   2012; Agnini et al., 2011; D'Onofrio et al., 2016; Giusberti et al., 2016; Luciani et al., 2016).
182   On the whole, the southern Giudicarie belt developed along the transition between the
183   basinal (Lombardian Basin) and platform (Trento Platform) Jurassic domains. The

184 paleogeography inherited since the Jurassic strongly influenced the evolution of the area during
185 the following Cretaceous and Paleogene.
186   The Eocene Varignano sedimentary succession deposited in a bathyal setting within the
187 still persisting Lombardian Basin, bordered by the shallow carbonate platform of the Lessini
188 Shelf, that represents, albeit reduced in size, a Paleogene renewed Trento Platform (Bosellini,
189 1989; Luciani, 1989; Fig. 1C).
190   The Paleogene succession of Varignano was an object of interest since the middle of the
191 twentieth century, when Hagn (1956) investigated both benthic and planktic foraminifera from
192 the marlstones outcropping in the area, ascribed by him to the upper Eocene. Later on, Luciani
193 and Lucchi Garavello (1986) sampled and investigated the foraminifera on a 217-m-thick profile
194 spanning the Maastrichtian to lower Oligocene, located in a large now inactive quarry (Cava
195 Cementi Riva). The authors detected the presence of a wide hiatus corresponding to most of the
196 Paleocene, evidencing at the same time an expanded and continuous transition from the middle
197 Eocene to the lower Oligocene. In the same study, Luciani and Lucchi Garavello (1986, p. 27)
198 recognized that the resedimented LF occurring in the section were contemporaneous of the
199 planktonic foraminifera contained in the marlstones across the Bartonian–Priabonian interval
200 (see also Luciani, 1989).

THE VARIGNANO SECTION

202   The section object of this work corresponds with the lower-middle portion of the profile
203 originally investigated near the Varignano village by Luciani and Lucchi Garavello (1986) (Fig.
204 1B) and partly still exposed near the Bordellino Creek (Fig. 1D). The section measured and
205 logged, spanning the middle–upper Eocene transition, is ~43 m thick (Fig. 2) and it is mainly
206 constituted by grayish hemipelagic marlstones with 13 intercalated coarse LF-bearing
207 calciturbidites and 12 sandy-silty layers mostly interpreted as crystal tuff layers (upper part of
208 lithologic unit "D" and unit "E" of Luciani and Lucchi Garavello (1986). These levels are quite
209 evenly distributed from base to top and can generally be traced well laterally and allowed to
210 overcome a minor fault in the lower 10 m of the section during the sampling. Such
211 calciturbidites, which vary in thickness from 5 to 20 cm, originated from the adjacent Lessini
212 Shelf (Luciani, 1989) and sometimes contain centimetric intraclasts. The silty-sandy layers,
213 previously detected by Luciani and Lucchi Garavello (1986) vary in thickness from <1–25 cm
214 and are generally well recognized as they are prominent with respect to the pure marlstones. In
215 some cases, they show lateral variation in thickness. In the lower part of the section, the
216 marlstones contain several centimeter-thick beds with sand-sized crystals.
217   In Figure 2 the level 0 m corresponds to the top of a ~200-cm-thick organic-rich interval
218 (= sapropel-like interval in Alano section), consisting of laminated blackish to dark marlstones.
219 From the level 0 upward the silty-sandy levels show an abrupt increase of the crystal content up
220 to become (crystal tuff layers s.s.).[[Please review the last part of this sentence.]]
221   The hemipelagic marlstones of Varignano contain calcareous nannofossils, planktic
222 foraminifera, smaller benthic foraminifera, and ostracods. Macrofossils are conspicuously
223 absent, with the exception of scattered plant debris throughout the section already detected by
224 Luciani and Lucchi Garavello (1986). The marlstones show common bioturbation and sporadic
225 ichnofossils such as *Zoophycos*. Based on the dominance of planktic over benthic foraminifera
226 (from 80% to 90%) and the composition of the benthic assemblages throughout the section, the
227 Priabonian portion of the Varignano section was deposited at middle bathyal depth (~700–800
228 m) (Luciani and Lucchi Garavello, 1986). From a lithostratigraphic point of view, the section
229 here investigated belongs to the Ponte Pià Formation (previously known as "Scaglia Cinerea" or

230 "Scaglia grigia"; Castellarin et al., 2005), deposited during the depositional sequence E2
231 recognized by Luciani (1989) in the nearby Monte Baldo area. The Ponte Pià Formation is
232 heteropic with the slope deposits of Lessini Shelf known as Malcesine Limestone (Fig. DR1[1])
233 (Luciani, 1989).

234 **MATERIALS AND METHODS**
235 **Sampling Strategy**
236   Samples collected for the integrated analysis are shown in Figure 2. An average sampling
237 interval of 25 cm was used for the hemipelagic marlstones, with the exception of the organic-rich
238 interval for which a sampling interval of 5 cm was adopted. A total of 133 samples of marlstones
239 were collected for the calcareous plankton analysis. All of the 13 large foraminiferal
240 calciturbidites were sampled. Nine levels with volcanoclastic material were sampled for
241 evaluating their petrographic-geochemical composition.

242 **Planktic Foraminifera**
243   Planktic foraminifera were analyzed from 101 samples (Table DR1; see footnote 1).
244 Foraminifera were extracted by treating 50–100 g of dry sediment, crushed into small fragments
245 of ~5 mm in diameter using different methods depending on lithology. Most of the samples were
246 treated with a solution of hydrogen peroxide (H_2O_2) diluted to 35% or with a solution of acetic
247 acid (CH_3COOH) diluted to 80%, the so-called "cold acetolyse" technique of Lirer (2000; Table
248 DR1). In several cases samples were successively immersed within a pure surface-tension-active
249 chemical product (alkyldimethylbenzylammonium chloride, 10%) to obtain a complete
250 disaggregation. A gentle ultrasonic bath (e.g., low-frequency at 40 kHz for less than 15 seconds)
251 further improved the cleaning of the tests where necessary (Table DR1). All the samples were
252 washed and sieved using a 63 μm mesh. Sieves were immerged in a methylene blue bath after
253 each washing in order to color planktic foraminifera potentially trapped in the sieve mesh (e.g.,
254 Green, 2001). This is an easy method to exclude possible contamination amongst successive
255 samples.
256   Planktic foraminifera have been qualitatively analyzed to identify bioevents useful for the
257 zonal attribution of the section according to the zonal scheme of Wade et al. (2011).
258   Quantitative analyses were performed across the organic-rich interval cropping out in the
259 lower part of the section. Specifically, the relative abundance of genera was counted on a
260 population of ~300 specimens in the ≥63 μm size fraction on representative splits of washed
261 residues. Counts, expressed in percentage, concern the genus *Morozovelloides*, the forms
262 belonging to genus *Acarinina* with well-developed muricae and test size >125 μm, and the
263 "small acarininids" (medium size <125 μm). Large acarininids that include *A. bullbrooki, A.*
264 *mcgowrani, A. pretopilensis, A. primitiva, A. rohri, A. topilensis*) show at Alano a marked
265 decline in abundance before their final extinction whereas acarininids such as *A. collactea, A.*
266 *echinata*, and *A. medizzai* that retain small sized test also in adult stage, range up to the late
267 Eocene and Oligocene (Agnini et al., 2011; Wade and Hernitz Kucenjak, 2018). Therefore we
268 decided to quantify the abundances of these groups to compare our results with the Alano data.
269   Foraminiferal taxonomy adopted in this study follows Pearson et al. (2006).

270 **Calcareous Nannofossils**
271   Ninety-six samples, of 133 samples collected for calcareous nannofossils analysis (Table
272 DR2; see footnote 1), were prepared from unprocessed material as smear slides and examined
273 using a light microscope at ~1250× magnification. All samples were firstly examined with
274 qualitative methods to evaluate the abundance and state of preservation of calcareous nannofossil
275 assemblages. The presence or absence of index species was assessed by mean of quantitative and

276   semiquantitative counting following the methods developed by Thierstein et al. (1977), Rio et al.
277   (1990), and Gardin and Monechi (1998). Specifically: (1) the abundance of selected species was
278   calculated taking into account at least 300–500 specimens, (2) the abundance of the marker
279   species was established by counting the number of the species marker over 50–100 specimens
280   belonging to the correspondent genus, and[[Please review this sentence.]] (3) specimens of rare
281   but biostratigraphically useful species were counted in an area of ~6–7 mm^2, which is roughly
282   equivalent to three vertical traverses. The last method is very time consuming and it was adopted
283   only for checking the presence-absence of key index species that are particularly rare
284   (*Chiasmolithus grandis, Chiasmolithus oamaruenis,* and *Istmolithus recurvus*). Taxonomic
285   concepts mainly follow Perch-Nielsen (1985) and Fornaciari et al. (2010). For the purposes of
286   this work, we applied zonal schemes by Fornaciari et al. (2010) and Agnini et al. (2014b).
287   Although the calcareous nannofossil standard zonations of Martini (1971) and Okada and Bukry
288   (1980) still represent a fundamental biostratigraphic tool, some adopted markers cannot be
289   considered fully reliable in view of the large amount of new information that has been
290   accumulated over the past four decades. The zonations here adopted are more functional for
291   dating the marlstones of the studied area.
292   **Larger Foraminifera**
293   　　　Thirteen turbiditic layers have been sampled to identify LF assemblages (Table DR3; see
294   footnote 1). From these samples both thin sections and washed residues were obtained.
295   Specifically, eleven of these turbidites that present a portion of consolidated limestones were
296   analyzed on 32 petrological thin sections. For 12 turbidites it was possible to extract isolated
297   specimens, either by directly washing the unconsolidated sediments or (for two samples) by
298   applying the cold acetolyse method as described by Lirer (2000). The individual specimens were
299   prepared as oriented individual sections (equatorial or axial) or by splitting with pliers and
300   observed for their external size, shape, and ornamentation and for the internal characters of the
301   sections. Whenever possible, some biometrical parameters were measured directly under the
302   optical microscope or on photomicrographs. A number of equatorial sections of orthophragmines
303   were observed on random thin sections and the species were determined accordingly.
304   　　　The preservation state of LF is much variable: the tests are commonly infilled by calcite,
305   sometimes recrystallization obliterated the inner structures and a few individuals are strongly
306   deformed. The presence-absence of the LF is reported on DRS3. Taxonomy mainly follows
307   Hottinger (1977), Less (1987), Schaub (1981), and Hottinger et al. (2001).
308   **Shaw Diagram**
309   　　　The Shaw diagram is a simple graphic technique developed by Shaw (1964) to compare
310   sequences of biohorizons or other geological events observed in two or more stratigraphic
311   sections. It allows testing the ranking and the spacing among the events, to observe changes in
312   the sedimentation rates and the stratigraphic completeness and expansion of the sections
313   analyzed. Specifically, the Shaw diagram is a scatter graph in which the scale units are the depth
314   or thickness of successions and in which the sequence of events in one section is paralleled to the
315   same sequence of events documented in a section considered a standard reference. In this
316   instance, the "master" section is the Alano section, which is located in the same geographic area
317   of Varignano, spans the same stratigraphic interval, and records a good magnetostratigraphy
318   (Agnini et al., 2011).
319   　　　The main control points considered here are the base of magnetic polarity Chron C17r,
320   the base and top of Chron C17n.2r and two prominent lithological beds well identifiable in the
321   outcrops. These are two layers with a volcanoclastic material (VL+3, VL+4) that, by means of a

322 bundle of calcareous plankton biohorizons and petrographic analysis, revealed to be equivalent
323 between the two sections.
324   The best fit of the resulting separated homologous points is called "line of correlation."
325 The events that intercept or coarsely fall in close proximity to the line of correlation can be
326 considered as reasonably synchronous. Changes in the slope of the line suggest variations of
327 rock-accumulation rates.
328 **Magnetostratigraphy**
329   A total of 64 rock cores (2.54 cm diameter) were drilled along ~29 stratigraphic meters of
330 section (except between ~8 and 13 m, where the section was not accessible for drilling) and
331 oriented with a magnetic compass. From these cores we obtained 96 oriented standard (~11 cm^3)
332 specimens for paleomagnetic analysis. A representative set of 10 specimens from the trimmed
333 ends of the cores was subjected to stepwise isothermal remanent magnetization (IRM)
334 acquisition up to 2.4 T. The coercivity components of the IRM curves have been isolated by
335 means of cumulative log-Gaussian function analysis (Kruiver et al., 2001). Thermomagnetic
336 curves were obtained from two representative specimens of this set by progressive heating to 700
337 °C in an inducing field of 500 mT using a variable field translation balance (~~VFTB;~~ Petersen
338 Instruments). The curves were processed with the RockMag~~netic~~Analyzer version 1.1**[[O.K.?]]**
339 software of Leonhardt (2006).
340   To resolve the vector components of the natural remanent magnetization (NRM), we
341 performed stepwise thermal demagnetization on 64 oriented specimens (one from each core
342 sample), adopting steps of 50 °C up to 250 °C, reduced then to 25 °C up to a maximum of 425
343 °C. Since these data are generally characterized by high noise, we attempted to get more stable
344 signal treating the remaining 32 sister specimens with stepwise 3-axes alternating field (AF)
345 demagnetization up to 90 mT. This procedure, however, was not successful, and all AF
346 demagnetized specimens have been discarded. All remanence magnetization measurements were
347 performed with a 2-G Enterprises superconducting magnetometer placed in a shielded room.
348 Directional data were analyzed through inspection of vector end-point demagnetization diagrams
349 (Zijderveld, 1967) using the Paleomag software of Jones (2002). Linear vector components of
350 the NRM were estimated with the principal component analysis (PCA) of Kirschvink (1980),
351 while characteristic remanent magnetization (ChRM) directions failing to trend linearly to the
352 origin of the demagnetization axes were averaged using the spherical statistic of Fisher (1953).
353 The mean paleomagnetic directions and associated 95% confidence boundary have also been
354 estimated by means of Fisher (1953) statistic. Laboratory analyses have been conducted in the
355 paleomagnetic laboratory of the Ludwig Maximilians Universität (Munich, Germany).
356 **Layers with Volcanoclastic Material**
357   Nine samples were investigated under an optical microscope. From the samples collected
358 in the lower part of the section (VL-4 to VL-1) we obtained normal thin sections, while the
359 poorly cemented samples from the VL0A level upwards (Fig. 2) were washed and their sandy
360 fraction has been split and impregnated in an epoxy resin according to the methodology
361 described by Gazzi et al. (1973), in order to obtain thin sections.
362   In addition, we have chemically analyzed six samples from the Varignano section and
363 four from Alano in order to compare them. Unfortunately, for a seventh sample (VL-3) the
364 analyses were hampered due to bad preservation.
365   Chemical analyses were carried out using a CAMECA SX50 electron microprobe
366 (wavelength dispersive spectroscopy mode, 20 kV, 20 nA, 2 μm beam diameter) installed at
367 ~~CNR-IGG~~ the National Research Council of Italy Geosciences and Earth Resources Institute

368   (hosted by the Department of Geosciences of University of Padova, Italy). Standards (analyzer
369   crystal, element, emission line) used were Kakanui pyrope (New Zealand) from the Smithsonian
370   Museum (TAP[[Should these three highlighted acronyms be defined?]], MgKα); Amelia
371   albite (Virginia) (TAP, NaKα); diopside (TAP, SiKα; PET, CaKα); Al$_2$O$_3$ (TAP, AlKα);
372   MnTiO$_3$ (PET, TiKα; LIF, MnKα); Fe$_2$O$_3$ (LIF, FeKα). Zn, Cr, Ni, and Ba were below the
373   detection limits.

374   **DATA AND RESULTS**
375   We illustrate below calcareous plankton biostratigraphy, LF events and
376   magnetostratigraphy from the Varignano section in order to establish an accurate
377   chronostratigraphy and chronology. A taxonomic list of species, cited in text and figures, is
378   shown in supplementary Appendix A (see footnote 1). In addition, petrographic and geochemical
379   characters of layers with volcanoclastic material are described to allow us a reliable comparison
380   with similar levels from the Alano section.

381   **Planktic Foraminifera**
382   Planktic foraminifera are continuously present in the Varignano section, abundant and
383   diverse throughout the section. Infilling of tests commonly occurs. The species are generally well
384   recognizable even though recrystallized. The assemblage composition at Varignano is typical of
385   subtropical to temperate climate and shows variations in the relative abundance of different taxa
386   throughout the section. Subbotinids and globigerinathekids are among the more frequent and
387   common groups. The large acarininids are abundant in the basal part of the section, but they
388   markedly decrease concomitantly with the organic-rich interval similarly to the record from the
389   Alano section (Luciani et al., 2010; Agnini et al., 2011), where it corresponds to the post middle
390   Eocene climatic optimum (post-MECO) interval (Spofforth et al., 2010) (Fig. 3). The post-
391   MECO is the interval following the δ^{18}O negative shift, interpreted as representing the MECO
392   warming, when the δ^{18}O curve recoveries[[Please review this sentence.]] the pre-event values
393   (Luciani et al., 2010; Spofforth et al., 2010; Boscolo Galazzo et al., 2013).
394   The middle–late Eocene genus *Hantkenina* displays an uneven distribution and, where
395   present, constitutes a minor component of the assemblages, as already documented at Varignano
396   by Luciani and Lucchi Garavello (1986) and in other northeastern Italian sections (e.g.,
397   Toumarkine and Luterbacher, 1985; Agnini et al., 2011).
398   We refer here to the Wade et al. (2011) zonal scheme. We have also taken into account
399   the bioevents of the *Turborotalia cerroazulensis* lineage, on which is based the Toumarkine and
400   Bolli (1970) scheme, later updated in Toumarkine and Luterbacher (1985), which was proposed
401   for mid-latitude areas as complementary to the standard schemes, with specific reference to
402   sections located in the Veneto region.
403   The basal part of the section, up to −2.95 m level, is assigned to the upper part of the
404   combined Zone E10-E11 due of the absence of *Morozovella aragonensis* and *Orbulinoides*
405   *beckmanni*. We have combined zones E10 and E11 because the *Gumbelitriodes nuttalli* top, that
406   should identify the E10-E11 zonal boundary, occurs above the *O. beckmanni* top (Fig. 3), the
407   marker of the total range Zone E13. Indeed, small specimens of *G. nuttalli* (Fig. 3), though very
408   rare and unevenly distributed, are present up to the top of the section (Zone E14).
409   The 2.48-m-thick interval from −2.93 to −0.45 m levels is assigned to Zone E12 based on
410   the total range of *Orbulinoides beckmanni*. The top of this species is, however, difficult to be
411   precisely located at Varignano due to the scarcity of this marker especially within the organic-
412   rich intervals.
413   The base of the planktic foraminiferal species *Turborotalia cerroazulensis* coincides at

414   Varignano with the *O. beckmanni* base. However, *T. cerroazulensis* is rare and unevenly
415   distributed in the earlier part of its range and presents small size.**[[Please review this sentence.]]**
416   At Varignano, small and rare specimens of *Turborotalia cocoaensis*, distinguishable from
417   its ancestor *T. cerroazulensis* by an acute profile, occur within Zone E12 (−2.23 m). The
418   abundance of *T. cocoaensis* is highly variable throughout the section, alternating intervals of
419   extreme scarcity with others of relatively common presence. The top of the earlier
420   representatives of the *cerroazulensis* lineage *T. frontosa,* the appearance of which occurs in the
421   lowermost part of the Lutetian Stage (Molina et al., 2011) occurs at Varignano at −2.68 m, i.e.,
422   between the *O. beckmanni* and *T. cerroazulensis* bases and the *T. cocoaensis* top (Fig. 3). At the
423   same level, we record the *T. possagnoensis* top. The species *Turborotalia pomeroli,* the
424   intermediate species between *T. possagnoensis* and *T. cerroazulensis,* occurs throughout the
425   section.
426   The 16.28-m-thick interval, from the *O. beckmanni* top (−0.45 m) to the genus
427   *Morozovelloides* top, represented by the species *M. crassatus* (sample BRD3, 15.83 m) is
428   referable to Zone E13. The extinction level of *A. mcgowrani* occurs at sample BR2 (15.79 m)
429   and is immediately followed (25 cm above, according to our sampling resolution) by the
430   disappearance of *M. crassatus*.
431   We assigned the upper part of the investigated section, above the 15.83 m level, to Zone
432   E14 because *Globigerinatheka semiinvoluta*, which disappearance marks the E14-E15 zonal
433   boundary, is present up to the top of the Varignano section (Fig. 3). This species first appears at
434   sample 26.45 m level, i.e., 22.25 m above the top of *Morozovelloides*.
435   Just below the *G. semiinvoluta* base we record the top of the small-sized species
436   *Planorotalites capdevilensis* (26.525 m) that is a minor constituent of the foraminiferal
437   assemblages.
438   The top of the small acarininids A. collactea, *A. echinata* and *A. medizzai* is not recorded
439   at Varignano as they occur within Zone E14 up to the top section. These species are a minor but
440   characteristic component of the planktic foraminiferal assemblages.

441 **Calcareous Nannofossils**
442   The Varignano sediments contain common to abundant calcareous nannofossils with rich
443   and well diversified assemblages. The preservation varies from moderate to good throughout the
444   section. The reworking is rare except for the organic-rich interval dominated by reworked
445   *Sphenolithus furcatolithoides* specimens.
446   Assemblages are largely dominated by placoliths belonging to genera *Reticulofenestra,*
447   *Cribrocentrum,* and *Dictyococcites.* Sphenoliths are also well represented and provide first order
448   biostratigraphic information. On the contrary, *Discoaster* and *Chiasmolithus* are exceedingly rare
449   or missing. Furthermore, identification of *Chiasmolithus* and *Discoaster* specimens at specific
450   level is sometimes difficult due to etching and overgrowth. *Isthmolithus recurvus* generally
451   represents a negligible component of the total assemblage. In Figure 4, we report the quantitative
452   distribution patterns of index species from the Varignano section that allow us to define the
453   following types of biohorizons according to Backman et al. (2012) and Agnini et al. (2014b):
454   Base and top to describe, respectively, the stratigraphic lowest and highest occurrences of taxa
455   and base common (Bc) and top common (Tc) to define the first or last continuous and relatively
456   common occurrence of a taxon. An exception is represented by the Bc and Tc of *Cribrocentrum*
457   *erbae* that we label in the Figure 4 also as acme beginning (AB) and acme end (AE) as in
458   Fornaciari et al. (2010) and Agnini et al. (2011). However, we use hereafter in the text for the *C.*
459   *erbae* acme Bc and Tc to be consistent with Agnini et al. (2014b). We recognized across the

460   interval studied at Varignano all the calcareous nannofossil marker species used to define the
461   zonal boundaries of Fornaciari et al. (2010) and Agnini et al. (2014b).
462   Specifically, the basal part of the section up to −3.8 m level is assigned to Zone CNE14
463   (Agnini et al., 2014b) due to the lowest common and continuous occurrence (>0.4%–0.6%) of
464   *Dictyococcites bisectus*. This interval can be split at −4.85 m level in the zones MNP16A and
465   MNP16Ba on the base of extinction of *S. furcatolithoides,* following Fornaciari et al. (2010; Fig.
466   4).
467   The interval from −3.8 m level to 7.76 m level, is assigned to CNE15 (MNP16Bb-
468   MNP17A) zones because of the common occurrence of *D. bisectus* and of the back to back last
469   common and continuous presence of *Sphenolithus spiniger* and total range of**[[O.K.?]]**
470   *Sphenolithus obtusus.* The top of this last taxon defines the base of CNE16 (MNP17B Zone).
471   This zone extends up to ~21 m level and is characterized by the concomitant absence of *S.*
472   *obtusus* and of common (<5%) *Cribrocentrum erbae*. In the interval between 21 m and 30.95 m
473   levels, we observe a neat increase in abundance, up to 40%, of *C. erbae*. This peculiar abundance
474   pattern is used to identify an acme event defined as the interval characterized by percentages of
475   *C. erbae* greater than 5% (Fornaciari et al., 2010; Agnini et al., 2011, 2014b; Fioroni et al.,
476   2015). The abrupt increase and decrease of this taxon marks the Zone CNE17 (MNP18A).
477   The uppermost part of the Varignano section (from ~31 m to the top) has been assigned
478   to CNE18 (MNP18B) Zone that is the interval below the *Cribrocentrum isabellae* base. It is
479   important to point out that within Zone CNE18 (MNP18B) in the short interval comprised from
480   32.63 to 34.82 m, we record the occurrence of the *I. recurvus* spike as observed at Ocean
481   Drilling Program (ODP) Site 1052, Alano and others Tethyan sections (Fornaciari et al., 2010).
482   The main calcareous nannofossil biohorizons identified are described and commented
483   upon in detail below in stratigraphic order, from the base to the top of the section (Fig. 4; Table
484   1).
485   The top of *Sphenolithus furcatolithoides* occurs at −4.85 m level. At Varignano the
486   distribution pattern of this species displays a distinct extinction that provides a clear and neat
487   biohorizon. This event occurs shortly below the Bc of *Dictyococcites bisectus*. The specimens of
488   *S. furcatolithoides* observed in a short interval (between −0.8 and −0.25 m levels) above its
489   highest occurrence have been attributed to reworking.
490   The Bc of *D. bisectus* occurs at −3.805 m level. We assigned to *D. bisectus* only to those
491   specimens larger than 10 µm in size. This biohorizon, observed just 1 m above the *S.*
492   *furcatolithoides* top, defines the base of Zone CNE15 (MNP16Bb Subzone). *Dictyococcites*
493   *bisectus* shows at Varignano a sharp increase of abundance at its Bc; below this level the species
494   is virtually absent except rare specimens (0.1%) in a single sample (Fig. 4).
495   The Tc of *Sphenolithus spiniger* occurs at −1.93 m level. This biohorizon marks the base
496   of Subzone MNP16Bc (Fornaciari et al., 2010). In the Varignano section, *S. spiniger* shows a
497   marked decrease in abundance followed, slightly above, by a short-lived interval of reentry of
498   this species with frequencies up to 12%. We considered this spike as primarily caused by
499   reworking because it coincidences with the spike of reworked *S. furcatolithoides*. At Varignano,
500   in spite of this complicated record, the Tc of *S. spiniger* provides a neat biohorizon. On the
501   contrary, the final exit of this species is problematic to detect because it is difficult to establish
502   whether its presence above the common occurrence is genuine or due to reworking.
503   The base and top of *Sphenolithus obtusus* occur at −1.03 and 7.76 m level, respectively.
504   At Varignano the initial range of *S. obtusus*, shortly above its appearance, is characterized by an
505   interval of virtual absence of this form that roughly coincides with the spikes of *S.*

506 *furcatolithoides* and *S. spiniger.* This atypical *S. obtusus* absence can be easily explained with
507 the fact that this interval contains mainly reworked specimens. With this exception, this species,
508 easily recognizable with optical microscope, is well distributed and exhibits a distinct base and
509 top.
510   The *Chiasmolithus oamaruensis* base and the *Chiasmolithus grandis* top occur at 19.775
511 and 26.75 m level, respectively, though with some uncertainties, as discussed below. We discuss
512 these biohorizons because they are, together with the *Chiasmolithus solitus* top, the criteria for
513 defining middle–late Eocene zones of classical standard zonations of Martini (1971) and Okada
514 and Bukry (1980), i.e., the base of NP15 (CN18), CP15a, and NP17 (CP14a), respectively.
515 Fornaciari et al. (2010) and Agnini et al. (2011) highlight that the bases of *C. solitus, C.*
516 *oamaruensis,* and the *C. grandis* top are problematic events that should be used with caution for
517 long distance correlation because they are based on index species that are exceedingly rare and
518 discontinuous. Results from the Varignano section confirm these observations. *Chiasmolithus*
519 *solitus* is indeed virtually absent while *C. oamaruensis* and *C. grandis* are rare to very rare and
520 exhibit a discontinuous abundance pattern that makes it difficult to detect accurately their base
521 and top, respectively.
522   The Bc and Tc of *Cribrocentrum erbae* occur at ~21 and 30.95 m level, respectively.
523 These events first highlighted by Fornaciari et al. (2010) as acme beginning (= Bc) and acme end
524 (= Tc) mark the boundaries of Zone CNE17 of Agnini et al. (2014b). The Tc of *C. erbae* marks
525 the return of this species to background abundances. This biohorizon is more difficult to detect at
526 Varignano because the decrease in abundance is gradual, as it occurs in other sections (e.g.,
527 Fornaciari et al., 2010). In the Varignano section we define the Tc of *C. erbae* when its
528 abundance drops from 4%–6% to 0.4%–2% of the total assemblage.
529   A peculiar feature of the *Istmolithus recurvus* distribution is a short interval of its
530 presence, termed *I. recurvus* spike, followed by an interval of absence before its Bc. Spike
531 beginning (SB) and spike end (SE)**[[Delete these two acronyms. SB is already used to define
532 "shallow benthic." SE and SB, in this context, do not seem to be used again in the text. If
533 they are used again please spell them out and fix throughout.]]** of *I. recurvus* occur at 32.635
534 and 34.82 m, respectively. This odd trait has been pointed out recently in sediments from middle
535 and low latitudes (e.g., Fornaciari et al., 2010; Shamrock et al., 2012; Costa et al., 2013).
536 However, the spike of *I. recurvus* apparently occurs at slightly different stratigraphic levels in the
537 various successions (Fornaciari et al., 2010). At Varignano we record as well a spike of ~2% in
538 abundance of *I. recurvus* just above the Tc of *C. erbae*. The Bc of *I. recurvus* was not observed
539 at Varignano up to the top of the section.
540 **Larger Foraminifera**
541   The abundant LF occurring in the Varignano section testifies the productivity of the
542 shallow water carbonate factory of the nearby Lessini Shelf, which is the most probable source
543 of the calciturbiditic levels. All the studied assemblages are of course resedimented but no
544 evidence of reworking were detected as documented by the absences of taxa older than middle
545 Eocene and of platform limestone clasts. We therefore consider them as substantially
546 contemporaneous to the deposition of the in situ pelagic biota (Luciani and Lucchi Garavello,
547 1986; Luciani, 1989).
548   The LF assemblages are quite uniform across the whole Varignano section, with
549 prevailing nummulitids and orthophragminids, consistent with their original deposition on the
550 middle-outer ramp. Distribution of the taxa identified is shown in Table DR3 and Figure 5. The
551 assemblages are more influenced by the size selection due to the mechanical transport downslope

552 than from the stratigraphic position. All the samples contain LF traditionally attributed to the
553 "Bartonian" zones SB17 and SB18, in particular the distinctive larger nummulitids of the
554 *Nummulites millecaput* group. The species *Nummulites dufrenoyi* is one of the terminal members
555 of this group and it is recorded throughout the section from the lowermost sample up to the
556 topmost one. *Nummulites dufrenoyi* is regarded by Schaub (1981) as ranging from the uppermost
557 Lutetian to the "Biarritzian" (= Bartonian). Serra-Kiel et al. (1998) considered it ~~as a~~
558 ~~synonymous of~~ synonymous with *Nummulites maximus* spanning from zones SB16 up to SB18.
559   The constant presence of *Operculina* ex gr. *gomezi* within the Varignano section
560 indicates that the section cannot be older than Zone SB17 (Less et al., 2008; Less and Özcan,
561 2012).
562   Two specimens of orthophragmines were biometrically identified on random thin
563 sections: *Orbitoclypeus varians roberti* was recognized in VAR0, and *Discocyclina discus*
564 *adamsi* in VAR2. The first one is distributed in the orthophragminid zone (OZ) 11–13 (Less,
565 1998[[Less, 1998, is not in the reference list.]]; Less et al., 2011), the second one ranges OZ11–
566 OZ14 (Less et al. 2011). This, in terms of SB zones possibly corresponds to SB15–SB17 and
567 SB15–SB19 (lower part), respectively (Papazzoni et al., 2017). Therefore, the sample VAR0 can
568 be assigned to the Zone SB17, whereas VAR2 should belong to Zone SB18. In the sample VAR2
569 we also recognized the first appearance of *Pellatispira*, together with a possible *Heterostegina*.
570 Unfortunately, all the thin sections analyzed do not show equatorial or nearly equatorial section
571 of the alleged *Heterostegina*; for this reason the identification is reported as uncertain. Moreover,
572 no other *Heterostegina* specimens were recognized in any other sample from the Varignano
573 section, whereas *Pellatispira* has been found throughout the section up to the last sample.
574 According to Less et al. (2008) and Less and Özcan (2012) the appearance of *Heterostegina*
575 marks the Zone SB18 base, whereas the first *Pellatispira* occurs in their Zone SB18B, possibly
576 in SB18A. Here, as already proposed in Papazzoni et al. (2014), we consider the first appearance
577 of *Pellatispira* as defining the Zone SB18 base.
578   In the uppermost part of the section, no new appearances of LF are recorded.
579 Specifically, there are no taxa indicating the base of Zone SB19, which has been traditionally
580 considered as the base of the Priabonian by the LF researchers (e.g., Serra-Kiel et al., 1998).
581 **Rock Magnetism**
582   The IRM curves, plotted on a semi-log diagram, can be divided in two groups with
583 distinct behavior (Fig. 6A). Samples collected from the section base up to 8 m belong to group 1,
584 while sediments from the 13 m up to the section top to group 2. IRM data points of group 1 are
585 successfully interpolated by two coercivity components (Fig. 6B). The lowest possesses a $B_{1/2}$
586 (i.e., the field at which half of the saturation is reached) that ranges from 32 to 39 mT. The
587 estimated $B_{1/2}$ of the higher coercivity component ranges between 269 and 447 mT. The low
588 magnetic coercivity component is interpreted as magnetite, which is the mineral carrying the
589 NRM (see below). The higher $B_{1/2}$ component is interpreted as deriving from minerals of the
590 pyrrhotite group, which typically possess coercivity higher than magnetite (Tauxe et al., 2018).
591 The presence of iron sulfides is also supported by the thermomagnetic remanence curve (Fig.
592 6C), which is characterized by a very low initial magnetization approaching zero only after a
593 transitional increase of magnetization centered at ~500 °C. This "hump" indicates the formation
594 of magnetite from ferriferous minerals like pyrite-pyrrhotite (Passier et al., 2001). Magnetite is
595 indeed the dominant phase during cooling, as determined by the rapid increase of magnetization
596 of the cooling cycle below 575 °C (i.e., approximately the Curie temperature of magnetite;
597 Dunlop and Özdemir, 1997). The small but sharp further increase of magnetization observed

598   during cooling at ~305 °C indicates the presence of pyrrhotite, originated from pyrite during
599   heating. This behavior has been observed in similar thermomagnetic experiment performed on
600   natural crystalline pyrite (Wang et al., 2008) as well as clay-rich marine sedimentary rocks
601   (Dallanave et al., 2018).
602   IRM data points of group 2 are best interpolated by a single coercivity component (Figs.
603   6A and 6B), which possesses a $B_{1/2}$ of ~80 mT. This could be the result of a higher relative
604   content of minerals from the pyrrhotite group, hiding the contribution of magnetite. The
605   thermomagnetic curve is indeed identical to the one from group 1, indicating similar magnetic
606   composition (Fig. 6C).
607   Summarizing, the sediments from the Varignano section contain a mixture of minor
608   magnetite, however, enough to record a primary NRM (see below), and iron sulfides of the
609   pyrite-pyrrhotite group, which turn to magnetite during heating >400 °C. This phenomenon
610   explains the erratic behavior of the vector end-points diagrams after thermal demagnetization
611   above this temperature (Fig. 6D).

Paleomagnetism

613   The NRM of all core specimens has an average value of 0.45 mA/m. It is generally
614   higher in the basal 8 m of a section**[[O.K.?]]**, with an average value of 0.70 mA/m against an
615   average of 0.29 mA/m of the upper part. From all 96 oriented cores only 31 (33%) gave reliable
616   paleomagnetic results. All directions were derived from the thermally demagnetized specimens.
617   A spurious magnetic "A" overprint was removed between room temperature and 150–200 °C
618   (Fig. 7A). Only 23 of these "A" directions have a maximum angular deviation (MAD) of <25°
619   and have been evaluated for statistical significance. They are randomly distributed, as revealed
620   by performing a Watson's (1956) test of randomness (R = 6.4, which is lower than the critical Rc
621   = 7.74, where R is the precision parameter of Fisher, 1953). After removal of the "A" overprint,
622   we isolated a ChRM component up to a maximum unblocking temperature of 400 °C. This
623   temperature suggests magnetite as the ChRM carrier**[[O.K.?]]**, as generally iron sulfides possess
624   a maximum Curie temperature of ~325 °C (Dekkers 1989). Of these 31 ChRM components, nine
625   show a linear trend of the vector end-points (Fig. 6C, vma27) and thus were interpolated linearly
626   by PCA analysis. In all other samples, we averaged the ChRM direction for a Fisher (1953) mean
627   of the vector end-points. Although scattered, ChRM directions are organized in two modes
628   oriented approximately north-south (Fig. 7A; Table 2). After correction for a homoclinal bedding
629   tilt of 55° dipping 170°, the inclination of the two modes increases significantly (Fig. 7A; Table
630   2). The two modes depart from antipodality by 17.4°, passing the reversal test using the
631   statistical approach of Watson (1983; V = 1.8; Vcritical = 6.8; see also Tauxe et al., 2018, for details
632   on the method), with a class "C" of McFadden and McElhinny (1990). We calculated the mean
633   ChRM direction for the entire data set inverting all directions to a common north-pointing
634   polarity (Table 2).
635   From the declination and inclination of each ChRM direction we derived the associated
636   virtual geomagnetic pole (VGP; Fig. 6B). We determined the sequence of polarity reversals by
637   using the latitude of each VGP relative to the mean paleomagnetic north pole (Fig. 7B), whereby
638   positive (negative) latitude represents normal (reverse) geomagnetic polarity.
639   At Varignano we retrieved a total of five magnetic polarity zones, three of which of
640   normal polarity (N1–N3) and two of reverse polarity (R1–R2); the interval between ~8–13 m,
641   where no samples were drilled, is considered of uncertain polarity.

Layers with Volcanoclastic Material

643   Both optical and chemical analyses confirm the field observations that allow us to divide

644 the layers with a volcanoclastic material in two groups: the first one prevailing in the lower part
645 of the section, constituted by fossiliferous marlstones with scattered volcanic material, and the
646 second one prevailing in the upper part of the section that are almost entirely made of volcanic
647 debris (i.e., crystal tuff s.s., Table 3).
648   In all samples the sandy fraction is similar and almost exclusively consisting of angular
649 crystal-shape twinned or zoned feldspars, quartz crystals, biotite flakes, vitric or microlithic
650 volcanic rock fragments and scarce amphiboles commonly chloritified. Scattered green particles
651 are present as transformation of vitric groundmasses and in a few cases are very abundant (e.g.,
652 VL+1). Moreover, the samples from the upper part of the section are slightly cemented by calcite
653 crystals that are present as replacement in some plagioclase cores.
654   Six samples were also processed with microprobe: the first four samples ~~outcrops~~ outcrop
655 in the basal part of the section (VL-4, VL-2, VL-1, VL0A) just below the coarse level VAR0 rich
656 in LF. The last two samples, VL+3 and VL+4, were sampled, respectively, at ~22 and ~34 m
657 (Fig. 2).
658   Results of chemical analyses of the volcanoclastic material are summarized in Table DR4
659 (see footnote 1) and compared with those from Alano section. Table DR4 reports for each
660 sample the mean of each oxide analyzed (the data are reported in oxide wt%) and the standard
661 deviation.
662 **DISCUSSION**
663   In the following sections we discuss the main results obtained and in particular the
664 magnetostratigraphic interpretation and the age model adopted which allow us to evaluate the
665 correlation of calcareous plankton events between the Varignano and Alano section and to
666 compare our main Tethyan events with the established chronology of the same events from the
667 Atlantic Ocean (Edgar et al., 2010; Wade, 2004, Wade et al., 2012; Agnini et al., 2014b).
668   In addition, we discuss the relationship between some volcanic bearing layers
669 outcropping at Varignano and Alano, including the Alano Tiziano bed, in order to verify whether
670 they are the products of the same volcanic activity recognized in the Lessini Shelf area
671 (Beccaluva et al., 2007 and reference therein) and to support the strong correlation between the
672 two sections. Finally, the combined stratigraphic framework deriving from our analyses will
673 provide a solid integration between calcareous plankton and shallow benthic events across the
674 Bartonian–Priabonian transition.
675 **Interpreting Magnetostratigraphy and Correlation with the Alano Section**
676   Several biostratigraphic events allow us to correlate the magnetic polarity stratigraphy at
677 Varignano with the Global Polarity Time Scale (GPTS) (Figs. 2 and 4–8). Among all deep-sea
678 sites recovered over the years, ODP Site 1052 (Leg 171b, Black Nose) has one of the most
679 continuous records across the middle to upper Eocene. It is supported by robust
680 magnetostratigraphy (Ogg and Bardot, 2001), cyclostratigraphic calibration (Pälike et al., 2001),
681 and planktic foraminifera and calcareous nannofossil biostratigraphy (Wade, 2004; Fornaciari et
682 al.,. 2010). At ODP Site 1052, the top of calcareous nannofossil *S. obtusus* and the AB of *C.*
683 *erbae* have been found, respectively, within Chron C17r and close the C17n.2n-C17n.2r
684 boundary, while the *Acarinina mcgowrani* top and the *Morozovelloides crassatus* top are
685 constrained within Chron C17n.3n. Data from ODP Site 1052 are in excellent agreement with the
686 magneto-biostratigraphic record from Alano, where they have been used as reference for
687 correlating the magnetic polarity zones with the GPTS.
688   Within this biostratigraphic framework, the correlation of the magnetic polarity zones at
689 Varignano with the GPTS is straightforward (Figs. 3–8). Specifically, zones N1 and R1

690   correlate, respectively, with chrons C18n and C17r. Upsection, after ~5 m of undetermined
691   polarity (Fig. 7), zones N2, R2, and N3, respectively, correlate with chrons C17n.3n, C17n.2r,
692   and C17n.2n.

Chronology and Rock-Accumulation Rate at Varignano

694   In order to estimate the chronology of the recorded biohorizons and the derived mean
695   rock-accumulation rates at Varignano we firstly evaluate through the Shaw diagram of Figure 9
696   the degree of synchroneity between the Varignano and Alano events.

697   The Shaw diagram highlights that 16 calcareous plankton bio-horizons out of the 19
698   identified (11 based on calcareous nannofossils and eight on planktic foraminifera) intercept or
699   are in close proximity to the line of correlation suggesting they can be deemed synchronous. The
700   three biohorizons that result located far away from the best-fit correlation line are the *O.*
701   *beckmanni* top, *C. oamaruensis* base, and *C. grandis* top thus suggesting that they are not
702   synchronous. Interestingly, two prominent resedimented layers rich in LF both occurring at the
703   top of the organic-rich deposition (VAR1 at Varignano and Palladio bed at Alano, Agnini et al.,
704   2011) intercept perfectly the best-fit of correlation line. These levels have also the same
705   biostratigraphic constrain in the two sections. Therefore, we can suppose that VAR1 and Palladio
706   bed were deposited roughly synchronously.

707   The slope of the correlation line changes from 0.53 ($y = 0.53x + q$) to 1.91 ($y = 1.91x +$
708   q) across Cn18n/Cn17r reversal, from 1.91 to 1.42 ($y = 1.42x + q$) across Cn17n.3n/Cn17n.2r
709   reversal, and from 1.42 to 1.47 ($y = 1.47x + q$) across Cn17n.2r/Cn17n.2nr reversal. The average
710   sedimentation rate is therefore very low in the basal ~12 m at Varignano, then it markedly
711   increases in the upper part of the section.

712   Successively, we developed the age models on the basis of five chronologic control
713   points (Tables 3–5**[[Does this refer to Tables DR3–DR5?]]**) that allow us to evaluate the
714   derived mean rock-accumulation rates. This is essential to extrapolate the age of the recorded
715   bioevents and to test their synchroneity with respect to other regions. The chronologic control
716   points are magnetic polarity reversals, i.e., the base of Chron C17r and both the base and top of
717   Chron C17n.2r recorded at Varignano and two biohorizons, specifically the *S. furcatolithoides*
718   top and the Tc of *C. erbae* detected near the base and the top of the section, respectively. These
719   calcareous nannofossil events are proved indeed reliable with consistent ages over wide areas
720   (e.g., Fornaciari et al., 2010). In the Shaw diagram (Fig. 9) they intercept the correlation line and
721   hence they can be assumed synchronous between the two compared sections. For these
722   biohorizons we adopted the ages from Agnini et al. (2014b) instead of those derived from Alano
723   section. This is because we consider more reliable the age of *S. furcatolithoides* top from ODP
724   Site 1051 (Agnini et al., 2014b) as it is estimated for straight interpolation within magnetochron
725   C18r. On the contrary, the age of Chron C18r in the Alano section has been indirectly assumed
726   by means of the mean accumulation rate during Chron C18n because the base of C18r is not
727   recorded at Alano. The difference of *C. erbae* Tc age estimation between the ODP Site 1052
728   (Agnini et al. 2014b) and Alano is negligible. Therefore, we used the age calibrated in Agnini et
729   al. (2014b) for consistency. These points are calibrated either at the orbitally tuned time scale of
730   Pälike et al. (2006) or at the geomagnetic polarity time scale of Cande and Kent (1995; CK95).
731   We assumed the rock-accumulation rate constant between each pair of the five tie points. The
732   obtained age model rock-accumulation rates (not corrected for compaction) of ~0.5 cm/k.y.
733   between the *S. furcatolithoides* top and the top of C18n followed up by an increase of
734   sedimentation rates (~2.75–2.3 cm/k.y.). The low sediment accumulation rate in the first 12 m
735   was possibly due, at least in part, to the erosion produced by the thicker bioclastic beds with

736   abundant pelitic intraclasts.

Comparison of Calcareous Plankton Chronology between the Tethyan Varignano and
Alano Sections and Atlantic Ocean Sites

739   Our integrated bio-magnetostratigraphy allows us to accurately compare the age
740   estimation of middle-late Eocene calcareous plankton events from the Tethyan Varignano and
741   Alano sections and to evaluate their equivalence with the bioevents from the northwestern
742   Atlantic Ocean. This is important to validate the reliability of primary biohorizons adopted in
743   calcareous plankton biostratigraphy.

744   Tables 4 and Tables DR5–DR6 (see footnote 1) show the estimated ages and relative
745   positions of bioevents in relation to magnetochrons, calibrated adopting both the chronologies of
746   CK95 and Pälike et al. (2006) for the ~~Varignano, Alano~~ Varignano and Alano sections and
747   Atlantic Ocean (Leg 171B). Our record highlights a general good correspondence between the
748   two sections in the ranking of the planktic foraminiferal and calcareous nannofossils bioevents,
749   especially across the critical Bartonian–Priabonian transition (Fig. 10), as discussed below. This
750   is not surprising because the two paleogeographic units where the Varignano and Alano
751   sediments were deposited, i.e., the Lombardian and Belluno basins bordering, respectively,
752   western and eastern the Lessini Shelf (Fig. 1) were connected to the south (Doglioni e Bosellini,
753   1987).

754   Some chronological attributions, however, display some differences. The causes of
755   discrepancies may have different explanations: (1) uncertainties in both the sections of reversals
756   positioning that are main age-control points, especially C18n-C17r (Fig. 7), (2) presence of small
757   hiatuses not detectable through biostratigraphy, (3) changes of sedimentation rate, (4) different
758   sampling resolution resulting in different positioning of bioevents, (5) different approaches used
759   for age extrapolation. Taking into account all the possible complications in age evaluation, we
760   consider the biohorizons that show a ==difference minor ~60 k.y. as confidentially synchronous== in
761   the two areas.**[[Please review this sentence.]]**

762   We summarize below our results for planktic foraminifera and calcareous nannofossils
763   from the lower to the upper part of the Varignano section and compare them with the data from
764   Alano and other sites from the western North Atlantic where chronology is well established
765   (Edgar et al., 2010; Wade, 2004, Wade et al., 2012; Agnini et al., 2014b) (Fig. 11; Tables 4;
766   Tables DR5 and DR6).

Planktic Foraminiferal Biostratigraphic Events

768   The base of *Orbulinoides beckmanni* occurs in the upper part of C18r both at Varignano
769   and Alano and correlates with the calcareous nannofossil Zone MNP16Bb (Fig. 10). According
770   to Edgar et al. (2010), the origination, subsequent evolutionary development, and extinction of
771   this short-lived species were intimately linked to environmental changes associated with the
772   MECO warming event. The record of Edgar et al. (2010) reveals that the *O. beckmanni* base is
773   distinctly diachronous, appearing ~500 k.y. earlier in the equatorial Atlantic than in the
774   subtropics (41.0 Ma vs 40.5 Ma), according to the warm preferences of this taxon (Fig. 11). The
775   estimated age of the *O. beckmanni* base at Alano (Agnini et al., 2011) and Varignano displays a
776   value of ca. 40.250 Ma (Agnini et al., 2011) and ca. 40.150 Ma, respectively (Table 4), according
777   to the Cande and Kent (1995) calibration. These data further extend the age of the base of this
778   species and they seem compatible with the temperate Tethyan latitude of the two sections. In
779   addition, Edgar et al. (2010) show that the *O. beckmanni* occurred later (39.5 Ma) with respect to
780   the previous calibrations (40.0 Ma, Wade, 2004). The calculated age of *O. beckmanni* top at
781   Alano and Varignano is ca. 39.638 ~~k.y.~~Ma at Varignano and ca. 39.922 ~~k.y.~~Ma at Alano. The

782 difference in the age estimation of *O. beckmanni* top between these two sections can likely be
783 related with the difficulty ~~to precisely identify~~ in precisely identifying this biohorizon due to the
784 scarcity of this marker, especially within the organic-rich layers ~~at both the two~~ found within
785 both sections.**[[Please review the changes suggested in this sentence.]]**
786   The planktic foraminiferal events across the Bartonian–Priabonian transition from the
787 Varignano section, such as *A. mcgowrani* top ~~just~~ immediately**[[O.K.?]]** followed by the
788 *Morozovelloides crassatus* top, correspond precisely with the Alano record (Fig. 10). The
789 estimated age interval between these two events is <11 k.y., in agreement with the Atlantic Ocean
790 and Adriatic Sea data. (Tables 4; Table DR5) (Wade et al., 2012). They occur in all the cited
791 successions within the short Subchron C17n.3n (Fig. 11). Furthermore, the muricate extinctions
792 coincide with a large turnover in radiolarian assemblages (Wade et al., 2012) thus representing
793 one of the best-calibrated and most easily recognizable foraminiferal biohorizon of the entire
794 Cenozoic. Size restricted carbon isotope analyses of *M. crassatus* from the western North
795 Atlantic (ODP Site 1052) document a reduction in the $\delta^{13}C$ trend through ontogeny, suggesting a
796 deterioration of the photosymbiotic relationship (bleaching) prior to extinction (Wade et al.,
797 2008; Wade and Olsson, 2009). At ODP Site 1052 the *M. crassatus* specimens in the ~18 k.y.
798 prior to extinction are smaller in size as a consequence of bleaching, thus reducing from 500 to
799 350 μm. Moreover, they bear a minor number of chambers in the last whorl (Wade and Olsson,
800 2009). A reduction in test size but not in number of chambers in the last whorl of *M. crassatus* is
801 evident also at the Varignano section and at Alano (unpublished data)**[[GSA does not permit**
802 **the citing of work that has not been formally accepted. Can this, and the one other**
803 **highlighted occurrence at line ~848, be cited as a personal communication or "author's**
804 **data?"]]** ~20 k.y. prior to extinction. Specifically, the mean test size moved in both sections
805 from ~410 to ~250 μm. A decrease in size is common to many extinction events in planktic
806 foraminifera (Wade and Olsson, 2009) and suggests an interval of elevated stress prior to their
807 extinction.
808   The large *Acarinina* group displays at Varignano a substantial decline in abundance well
809 below the horizon of their highest occurrence (Fig. 3), precisely within Zone E12, close to the
810 interval of organic-rich deposition. A thicker (~8 m) organic-rich interval in the lower part of the
811 Alano section represents the lithological expression of the post-MECO. A consistent drop in
812 abundance of large *Acarinina* occurs also at Alano across the post-MECO interval (Luciani et al.,
813 2010). Even though large acarininids are not frequent close to their extinction level at Varignano,
814 their disappearance constitutes a significant, easily recognizable event. Stable isotope data are
815 not yet available for the Varignano section but the bio-magnetostratigraphic position of the black
816 levels strongly suggests a correlation with the post-MECO event. Interestingly, at Varignano the
817 planktic foraminiferal assemblages within the organic-rich levels show an increase of opportunist
818 taxa, such as chiloguembelinids, pseudohastigerinids, and *Jenkinsina*. The same changes in
819 assemblages have been recorded at Alano in the organic-rich levels corresponding to the MECO
820 and post-MECO interval. These changes have been related to eutrophication and lowered
821 oxygenation of the upper water column (Luciani et al., 2010).
822   At Varignano the *Globigerinatheka semiinvoluta* base presents the same ranking
823 observed at Alano, i.e., it is located below the Bc *Cribrocentrum erbae* and SB *Isthmolithus*
824 *recurvus* in both the sections (Fig. 10). The difference in age estimation (Tables 4; Table DR5) is
825 <60 k.y. thus we can consider this event virtually synchronous between the two sections. There is
826 a significant stratigraphic interval at Varignano between the *Morozovelloides* top and the *G.*
827 *semiinvoluta* base that was also found at Alano and in several other successions (e.g., Benjamini,

828 1980; Pearson and Chaisson, 1997; Norris et al., 1998; Gonzalvo and Molina, 1996). However,
829 in some areas (western North Atlantic ODP Site 1052; Wade, 2004, Umbria-Marche sections;
830 Nocchi et al., 1986), the *G. semiinvoluta* base occurs just above the top of large acarininids and
831 *M. crassatus* or even below (Berggren et al., 1995).
832   As for the secondary planktic foraminifera events recorded in the two sections, our data
833 reveal significant differences with respect to the literature for most of the species belonging to
834 the *Turborotalia cerroazulensis* lineage. Specifically, the base of the planktic foraminiferal
835 species *Turborotalia cerroazulensis* coincides at Varignano with the *O. beckmanni* base and it
836 occurs slightly below in the Alano section. However, this species is generally reported within
837 Zone E13 or higher up (e.g., Toumarkine and Bolli, 1970; Toumarkine and Luterbacher, 1985;
838 Nocchi et al., 1986; Coccioni et al., 1988; Gonzalvo and Molina, 1992; Berggren et al., 1995;
839 Berggren and Pearson, 2005; Wade et al., 2011). Even for the *Turborotalia cocoaensis* base we
840 record at Varignano an earlier occurrence because this species first occurs within Zone E12 as in
841 the Alano section instead of the late Eocene (above references). Preliminary data from
842 northwestern Atlantic Site 1051 confirms that the first appearance of rare *T. cocoaensis* occurs
843 much earlier in middle Eocene than previously thought (unpublished data). We assume that the
844 earlier occurrence of these species were probably overlooked in part because of lower sampling
845 resolution, and/or because these species are rare, small-sized, and unevenly distributed in the
846 earlier part of their range. Because of the relatively small discrepancy of age estimation (~40 k.y.
847 ca. 40 Ma) for the *T. cerroazulensis* and *T. cocoaensis* bases between the Varignano and Alano
848 sections we can consider these events as synchronous in the two sections (Fig. 9).
849   At Varignano, the top of the earlier representatives of the *cerroazulensis* lineage such as
850 T. *frontosa* and *T. possagnoensis* occurs concurrently between the bases of *O. beckmanni* and *T.*
851 *cerroazulensis* and the *T. cocoaensis* base. The data from Alano record these events at the same
852 stratigraphic position (Fig. 10). The *Turborotalia frontosa* top is reported higher within the Zone
853 E14 at 39.3 Ma by Berggren et al. (1995) and Wade et al. (2011). This discrepancy could be
854 related with the discontinuous presence and abundance of this species or, most probably,
855 suggests significant diachroneity of this event over different areas. The events of the
856 *cerroazulensis* lineage need indeed a revision to be applied as useful biostratigraphic events for
857 supra-regional application.
858   The top of small-sized *Planorotalites capdevilensis* is recorded at Varignano just below
859 the base of *G. semiinvoluta* while at Alano these two events are recorded at the same level. The
860 disappearance of *P. capdevilensis* appears diachronous over different areas, as highlighted by
861 Wade (2004) who records its top in the tropical western North Atlantic (ODP Site 1052) even
862 higher than at Alano and Varignano within Zone P15 (E14 *p.p.*) in C16n.2n. This is in contrast to
863 previous works that suggested an extinction of *P. capdevilensis* within Zone P14 (E13 *p.p.*) at
864 38.5 Ma (Schmidt and Raju, 1973; Toumarkine and Luterbacher, 1985; Nocchi et al., 1986;
865 Mancin and Pirini, 2001). This discrepancy can probably be attributed, at least in part, to
866 *Planorotalites'* size, as this genus generally falls into the 63–125 μm size fraction and it may
867 have been overlooked as to whether the assemblages were analyzed at greater sizes.**[[Please**
868 **review this sentence.]]** Further investigation is needed to detect the possible reliability of the *P.*
869 *capdevilensis* top for regional correlations.
870   Even though the uppermost part of the Varignano section does not intercept the top of
871 small *Acarinina*, our record confirms that this group persists into the upper Eocene, contrary to
872 the larger representatives of this genus. This was noted as well in high latitudes at ODP sites 702
873 and 703 (South Atlantic) by Nocchi et al. (1991), at ODP sites 738 and 744 (Kerguelen Plateau)

874   by Huber (1991), and at ODP Site 1052 (western North Atlantic) by Wade (2004). According to
875   the data so far available the extinction of this group was not a synchronous event over wide
876   areas. Recent data from the Pacific, Indian, and Atlantic oceans document that the small
877   acarininids lineage continued through the Oligocene and perhaps into the Miocene (Wade and
878   Hernitz Kucenjak, 2018).
879   ***Calcareous Nannofossil Events***
880   The lowest calcareous nannofossil biostratigraphic event recorded at Varignano is the
881   *Sphenolithus furcatolithoides* top. This event maintains the same spacing and ranking at
882   Varignano and Alano (Fig. 10) as also shown in Figure 9 where it intercepts the best-fit line of
883   correlation. However, the different approaches used for extrapolating ages have likely influenced
884   the chronological attribution of the *S. furcatolithoides* top ~~that presents at Varignano an age~~
885   ~~younger by ~250 k.y.~~ at Varignano which is ~250 k.y. younger with respect to the Alano
886   sections.**[[O.K.?]]** The Varignano estimation is determined according to the calibration of
887   Agnini et al. (2014b) that takes advantage ~~from~~ of the best magnetostratigraphic record at Site
888   1051 with respect to Alano (Agnini et al., 2011) across this interval (Fig. 11).
889   The Bc of *Dictyococcites bisectus* and Tc of *Sphenolithus spiniger* maintain the same
890   ranking and spacing as shown by the interception of the best-fit correlation line of these events
891   (Fig. 9). The age of Bc of *D. bisectus* calibrated at the ODP Site 1051 differs by only 32 k.y.
892   with respect to the estimated age at Varignano thus suggesting this event as synchronous in
893   central western Tethys and western North Atlantic. However, the chronological attributions of
894   the Bc of *D. bisectus* at Varignano and Alano show a discrepancy of ~220 k.y. (Fig. 11; Table 4).
895   These differences are likely overestimated due to diverse approaches used for the chronological
896   attributions. Nevertheless, we emphasize that the age estimation and stratigraphic position of Bc
897   of *D. bisectus* prove to be quite different over latitudes. Actually, data from the Southern Ocean
898   suggest this event as time transgressive from middle to high latitudes (Wei and Wise, 1990;
899   Persico et al., 2012; Fioroni et al. 2015). It is worth pointing out that these differences could
900   derive, at least in part, from taxonomic issues affecting this taxon that make it difficult
901   ~~unambiguous identification of this species~~ to unambiguously identify this species**[[Please review**
902   **this sentence.]]** (Fornaciari et al., 2010; Persico et al., 2012).
903   The *Sphenolithus obtusus* base occurs at Varignano shortly above the Tc *S. spiniger* as at
904   Alano (Fig. 10) and in other central Tethyan sections (e.g., Fornaciari et al., 2010). However,
905   even though these species ~~retains~~ retain the same ranking, the spacing is slightly out of phase in
906   the Shaw diagram correlation line (Fig. 9). This discrepancy (~160 k.y., Tables 4; Table DR6)
907   could be attributed to a hiatus undetectable by the biostratigraphic resolution, from uncertainties
908   of tie-points or from abrupt changes in the rock accumulation rate.
909   The *S. obtusus* top, which identifies the base of CNE15 (MNP17A) Zone, occurs within
910   basal Chron C17r as in the Alano section (Fig. 10) thus suggesting that the event is reasonably
911   synchronous in spite of the discrepancy of 83 k.y. exhibited by the estimated ages (Fig. 11;
912   Tables 4; Table DR6). This difference is very likely amplified by the large uncertainties in the
913   positioning of the base of magnetochron C17r in both the sections (Fig. 9). At Blake Nose (ODP
914   Site 1052; Fornaciari et al., 2010; Agnini et al., 2014b) the *S. obtusus* top occurs at the
915   C18n.1n/C17r boundary confirming the reliability of this event for supra regional correlation
916   (Fig. 11; Tables 4; Table DR6).
917   The calcareous nannofossil events across the Bartonian–Priabonian transition are: (1) the
918   *Chiasmolithus oamaruensis* base, (2) the Bc of *Cribrocentrum erbae,* and (3) the *Chiasmolithus*
919   *grandi*s top.

920   At Varignano, the first event was observed just below the Bc of *Cribrocentrum erbae*
921   (within the upper part of C17n.2r). The comparison with the Alano reference section shows that
922   the *C. oamaruensis* base is located at Varignano in a slightly lower stratigraphic position. This is
923   not surprising because Fornaciari et al. (2010) in some ~~Apennines~~ Apennine sections and Villa et
924   al. (2008) at the high latitude Southern Ocean record the *C. oamaruensis* base in an even lower
925   stratigraphic position. In addition, this event at ODP Site 1052 (Blake Nose) occurs in a different
926   stratigraphic position namely just above the Bc of *C. erbae* (Fig. 11; Tables 4; Table DR6).
927   Although it was considered for a long time as one of the events to approximate the Priabonian
928   base (e.g., Berggren et al., 1995), it is now clearly evident its diachroneity and unreliability is
929   also due to the exceedingly ~~rarity~~ rare and discontinuous abundance pattern of this species,
930   especially in the lower part of its range.**[[Please review the suggested changes in this**
931   **paragraph.]]**
932   The second event, the Bc of *C. erbae*, occurs at Varignano as at Alano just below a
933   prominent crystal tuff layer here labeled as VL+3 (Fig. 10). Nevertheless, while at Varignano the
934   Bc of *C. erbae* is recorded in the uppermost part of Chron C17n.2r at Alano and ODP Site 1052
935   it occurs in the early part of Chron C17n.2n. However, this inconsistency ~~could be only~~ may only
936   be apparent due to the slightly different reversal positioning due to different sampling resolution
937   in the two sections. Indeed, the Shaw diagram (Fig. 9) evidences that this biohorizon maintains
938   the same ranking and spacing. Therefore, the Bc of *C. erbae* is proving to be a reliable
939   biohorizon. The Tc of *C. erbae* is recorded in the same relative stratigraphic position in both
940   sections. At Varignano *C. erbae* shows a similar distribution pattern as that observed in the
941   central Tethyan sections, northern and southern Atlantic ODP sites 1052 and 1263, respectively
942   (Fig. 11), and in the western equatorial Indian Ocean Site 711 (Fornaciari et al., 2010; Fioroni et
943   al., 2015).
944   The third event, *C. grandis* top, corresponds in our section to the planktic foraminiferal
945   event *Globigerinatheka semiinvoluta* base and it occurs within the acme of *C. erbae*. This event
946   retains the same ranking with respect to the Alano section but not the spacing as shown in the
947   Shaw diagram where this event is recorded far away from the best-fit correlation line (Fig. 9).
948   This is due to the difficulties in the identification of its true disappearance because this species is
949   rare and discontinuously distributed in the final part of its occurrence.
950   Above the interval across the base Priabonian we record in the Varignano section the SB
951   of *I. recurvus* that is located just above the Tc of *C. erbae* and just below the VL+4 crystal tuff
952   layer, thus showing an exact correspondence with the Alano record (Figs. 9 and 10). The spike
953   end of this species is observed at 2.18 m above the top of the crystal tuff layer and it presents
954   therefore a stratigraphic position broadly consistent with that observed at Alano (Fig. 10).
955   In conclusion, our data show that the estimated ages of all the calcareous plankton
956   biohorizons, from ~8 m up to the top of the Varignano section with the exception of *C. grandis*
957   top, are consistent with ages of the correlative biohorizons from Alano as well as from
958   successions located in the Atlantic (i.e., ODP sites 1051, 1052, and 1263; Fornaciari et al., 2010)
959   (Fig. 11).
960 **Integrating Calcareous Plankton and Shallow Benthic Events at the Bartonian–Priabonian**
961 **Transition**
962   The main goal of this work, to produce the integrated calcareous plankton and shallow
963   benthic biostratigraphy at the Bartonian–Priabonian transition, is here attained thanks to the
964   recurring ~~occurrence of~~ calciturbidites rich in LF at the Varignano section and the well-
965   established calcareous plankton bio-magnetostratigraphy and biochronology (Fig. 12). In this

966   section, there is no evidence of the sub-aerial exposure and erosion of the Lessini Shelf carbonate
967   platform during the Bartonian–Priabonian boundary interval as assumed by Luciani (1989). This
968   is important to underline because it implies that the LF events recorded in the bioclastic beds can
969   be considered virtually contemporaneous to the calcareous plankton events.
970   On the one hand, the relationship between calcareous plankton and SB zones is well
971   established as regards the Zone SB18 base that is identified by the lowest occurrence of
972   *Pellatispira* (Papazzoni et al., 2014). This event occurs slightly above the base of the planktic
973   foraminiferal Zone E13 (Wade et al., 2011) and in the lower part of the calcareous nannofossil
974   Zone MNP17A (Fornaciari et al., 2010). On the other hand, the base of SB19 that is usually
975   considered as the base of the Priabonian Stage in LF literature (e.g., Serra-Kiel et al., 1998) is not
976   recorded in the Varignano section as confirmed by the continuous presence of large nummulites
977   belonging to the *N. millecaput* group. Therefore, the SB18–SB19 boundary results ~~to be~~
978   are[[O.K.?]] significantly higher than the Bartonian–Priabonian transition determined according
979   to calcareous plankton events (Agnini et al., 2011, Wade et al., 2012, Ogg et al., 2016) but also
980   according to the other criteria so far proposed for the GSSP of Priabonian, i.e., base of Tiziano
981   bed, Agnini et al. (2011, 2014a, 2014c) and base of Chron C17n.1n (Vandenberghe et al., 2012).
982   The discrepancy observed at Varignano is consistent with data from the Urtsadzor section
983   in Armenia (Cotton et al., 2017). Even though the Armenian section does not span the entire
984   critical interval, the SB18–SB19 boundary has been observed there much higher than the
985   Bartonian–Priabonian boundary interval as determined by means of both planktonic foraminifera
986   and calcareous nannofossils. According to Cotton et al. (2017) the base of Zone SB19 is indeed
987   close to the CNE18–CNE19 boundary and to the lowermost Zone E15.
988   Less et al. (2008) and Less and Özcan (2012), highlight that the evolutionary degree of
989   the *Heterostegina reticulata* lineage has a great potential to achieve a high-resolution
990   biostratigraphy inside the Zone SB18. Recently, Rodelli et al. (2018) used the appearance of
991   *Heterostegina* as a datum plane to mark the SB17–SB18 boundary from an eastern Turkey
992   succession. Unfortunately, the authors do not indicate the level where *Pellatispira* appeared,
993   although this genus is mentioned in their list of LF occurring in the resedimented beds.
994   According to their correlation with the calcareous plankton zonal schemes, the base of Zone
995   SB18 is recognized within Zone MNP17B and the upper part of Zone E13, whereas at Varignano
996   it is recorded in a significantly lower position, i.e., close to the base of zones MNP17A and E13.
997   Unfortunately, no specimens of *Heterostegina* were confidently identified along the Varignano
998   section, with the exception of an uncertain specimen recorded in the same sample where
999   *Pellatispira* first appears (VAR 2), thus hampering any direct correlation of the *Heterostegina*
1000 *reticulata* lineage with the calcareous plankton events here observed. Investigations from other
1001 shallow-water settings ~~areas~~ will help to clarify the relationship between the *Pellatispira* and
1002 *Heterostegina* ranges.
1003   The aforementioned discrepancies mainly derive from the small numbers of well-
1004 preserved specimens in the turbiditic levels, reflected in the scarcity of ~~good~~ well-oriented
1005 sections useful ~~to identify~~ in identifying the species of LF. Moreover, the discontinuity of the
1006 resedimented layers reduces the resolution power of the SB zones. Lastly, the distance between
1007 northern Italy and eastern Turkey could imply some degree of diachrony in the biohorizons of
1008 appearance-disappearance of LF taxa. Therefore, to correctly establish the
1009 synchronism/diachronism among LF events requires additional records from shallow-water
1010 settings in several localities. The direct correlation of the SB biozones with the calcareous
1011 plankton events and derived chronostratigraphy is therefore essential to reach this goal. The

1012 calibration of the SB zones by searching for synchronous events in the shallow-water
1013 assemblages is indeed part of a much larger research program (e.g., Papazzoni et al., 2017;
1014 Pignatti and Papazzoni, 2017). The results from the Varignano section, supported by the
1015 magnetostratigraphic data, provide an exceptional chance to verify the current biostratigraphic
1016 integrated schemes and support an under way revision of the correlations between calcareous
1017 plankton with SB zones. Unfortunately, no useful LF events occur at Varignano close to the
1018 aforementioned calcareous plankton events across the Bartonian–Priabonian boundary so that
1019 this boundary would correlate with the mid Zone SB18 whatever will be the primary criterion
1020 among the various events so far proposed.[[Please review this sentence.]]
1021 **Correlation of Volcanic Bearing Layers with the Alano Section**
1022   All our lithological, magnetostratigraphic, geochemical-petrographical, and
1023 biostratigraphical data allow us to delineate a correspondence of a number of volcanic prominent
1024 layers outcropping at Varignano with those from the Alano section. In the lower part of the
1025 section, level VL-4, VL-3 from Varignano, and the Mantegna bed from Alano outcrop just below
1026 the T of the calcareous nannofossil *S. furcatulithoides* (Fig. 10). The geochemical analyses of
1027 VL-2, outcropping just above the top of *S. furcatulithoides,* and VL-4, located at the base of the
1028 Varignano section, (Table DR4) suggest close similarity with the Mantegna bed. However, the
1029 biostratigraphic contrains[[constraints?]] and the Shaw diagram support the hypothesis that VL-
1030 3 probably represents the best equivalent of the Mantegna bed. Unfortunately, the bad
1031 preservation of VL-3 hampered optical and chemical investigation useful for precise correlation.
1032 The level VL-4 could correspond to one of the levels outcropping at Alano below the Mantegna
1033 bed (Fig. 10). Our data reveal that during this interval of the middle Eocene the volcanic activity
1034 was characterized by similar composition.
1035   At Alano, the Giorgione level outcrops above the Mantegna bed within the interval
1036 comprised from the B *D. bisectus* to the T *S. spiniger* (Fig. 10). In the corresponding
1037 biostratigraphic interval at Varignano, two closely spaced levels bearing volcanoclastic material
1038 are recorded (VL-1, VL 0A, Figs. 2 and 10). Both the Varignano levels were geochemically and
1039 petrographically analyzed (Table DR4). Results demonstrate a good equivalence of VL0A and
1040 the Giorgione bed. Minor differences among the positon of these levels in the two sections with
1041 respect to planktic foraminifera horizons, i.e., the *T. cerroazulensis* and *O. beckmanni* bases may
1042 derive from different sampling resolution or from the rarity of these species at both ~~the~~ sections,
1043 as previously discussed. However, it is worth pointing out that unlike the Alano section, the
1044 samples from the lower part of the Varignano section differ from the upper ones because the
1045 volcanic debris is diluted thus suggesting a synsedimentary reworking.
1046   In the middle-upper part of the Varignano the VL+3 and VL+4 crystal tuffs show an
1047 impressive correspondence with Tiziano and Tintoretto levels from the Alano section on the
1048 basis of both petrographic and geochemical analyses (Fig. 10; Table~~s~~ 3; Table DR4). These
1049 analyses confirm the bio-magnetostratigraphic correlation and indicate that these levels are
1050 equivalents.
1051   All the evidences described definitely support the connection between the two sections
1052 that are located in the western (Varignano) and eastern (Alano) basins bordering the Lessini
1053 Shelf (Fig. 1). The tuff composition supports a common origin for this type of beds[[this type of
1054 bed *or* these types of beds?]], related to the significant mafic to ultramafic volcanic activity that
1055 characterized the area between the Garda Lake and the Brenta River since the Paleocene (e.g.,
1056 Beccaluva et al. 2007 and reference therein).
1057 **SUMMARY AND CONCLUSIONS**

1058   The Varignano section (Trento province, northern Italy) provides an exceptional
1059   opportunity for a direct correlation between shallow benthic zones and standard calcareous
1060   plankton zonal schemes at the Bartonian–Priabonian transition (middle–late Eocene). Differently
1061   from the Alano di Piave section (NE Italy) that is the leading candidate for the base of
1062   Priabonian GSSP, the Varignano section preserves several coarse bioclastic levels rich in LF that
1063   are quite evenly distributed throughout the section. Our integrated analysis of the Varignano
1064   sediments reveals the following main results:
1065   (1) The Varignano section spans planktic foraminiferal zones E10–E11 to lower E14,
1066   calcareous nannofossil zones MNP16Bc to MNP18 and chrons 18n to 17n.2n. Our results show a
1067   good correspondence with the most recent integrated scheme presented by Ogg et al. (2016).
1068   Most of the calcareous plankton primary and secondary bioevents are recorded at Varignano in
1069   the same order and stratigraphic position as at Alano and allow us to compare them with the
1070   well-calibrated corresponding events from the Atlantic Ocean. The main planktic foraminiferal
1071   event across the Bartonian–Priabonian boundary is the genus *Morozovelloides* top slightly
1072   preceded (<~11 k.y.) by the *Acarinina mcgowrani* top. This event occurs within the short
1073   Subchron C17n.3n and precisely corresponds with the Alano record. In addition, the double
1074   closely spaced planktic foraminiferal extinctions are also synchronous across the Atlantic Ocean
1075   and Adriatic Sea (Wade et al., 2012) and they coincide with a large turnover in radiolarian
1076   assemblages (Wade et al., 2012) thus representing one of the most robust and easily recognizable
1077   foraminiferal biohorizon of the entire Cenozoic.
1078   (2) The Bc of the calcareous nannofossil *C. erbae* is recorded at Varignano in the
1079   uppermost part of Chron C17n.2r while at Alano and ODP Site 1052 this event occurs in the
1080   early part of Chron C17n.2n. However, this inconsistency is ~~probably only apparent as~~ likely due
1081   to different sampling resolution in the two sections that resulted in slightly different reversal
1082   positioning. Our Shaw diagram evidences indeed support that this biohorizon maintains the same
1083   ranking and spacing thus proving that the Bc of *C. erbae* ~~proves~~ is a reliable biohorizon. The Bc
1084   of *C. erbae* is synchronous across the Atlantic and Indian oceans and Tethyan basin (Fornaciari
1085   et al., 2010; Fioroni et al., 2015). We confirm that the first appearance of *C. oamaruensis* ~~that~~
1086   ~~marks~~ marking the base of nannofossil biozone NP18 and formerly considered the main criterion
1087   to identify the base Priabonian (e.g., Berggren et al., 1995) is an inadequate event.**[[Please**
1088   **review the changes in this paragraph.]]**
1089   (3) We attained the main goal of this paper, to correlate SB zones with calcareous
1090   plankton zonal schemes on the basis of our solid integrated bio-magnetostratigraphy. The direct
1091   correlation is needed for calibrating the shallow benthic zonation by means of selected, well-
1092   recognizable biohorizons, possibly the appearance of distinctive species or genera (e.g.,
1093   Papazzoni and Pignatti, 2017**[[Papazzoni and Pignatti, 2017, is not in the reference list.]]**;
1094   Papazzoni et al., 2017). The relationship with the planktic zonations is crucial to test the
1095   synchroneity of the shallow benthic biohorizons and consequently to better define the boundaries
1096   between contiguous SB zones. Data from different paleogeographical areas are required to
1097   determine the extension of the synchronous events. The analysis of the Varignano section
1098   allowed us the opportunity to precisely calibrate one of these events, namely the appearance of
1099   the distinctive genus *Pellatispira* that we consider as the marker for the base of Zone SB18,
1100   according to Papazzoni et al. (2014). The advantages in biostratigraphic use of this taxon are its
1101   easy identification, even on thin sections, and the evidence that *Pellatispira* appearance has
1102   never been signaled before the SB18. The first appearance of *Pellatispira* occurs at Varignano
1103   within the upper C18n, a few meters above the E12–E13 boundary, in the lower part of Zone

MNP17A. The base of Zone SB19, usually considered as the base of the Priabonian Stage in the LF literature, is not recorded in the Varignano section thus demonstrating to be significantly higher that the Bartonian–Priabonian transition. On the basis of our results, this boundary would correlate with the mid Zone SB18. We demonstrate that there is inconsistency with the common usage of shallow-water biostratigraphers in placing the base of the Priabonian as corresponding to the base of Zone SB19. Unfortunately, no other useful LF events occur at Varignano close to the potential events to identify the Bartonian–Priabonian boundary in shallow-water settings.

(4) Bio-magnetostratigraphy and petrographical-mineralogical analyses allows us to correlate prominent layers with volcanoclastic material exposed at Varignano with the Mantegna, Giorgione, Tiziano, and Tintoretto beds from the Alano section. The equivalence of these levels further strengthens the relationship between Varignano and the leading candidate for the Bartonian–Priabonian boundary, the Alano section. The recognition of the Tiziano bed equivalent at Varignano (VL+3) is particularly significant because the base of this level has been proposed as GSSP for the base Priabonian, as aforementioned (Agnini et al., 2011, 2014a, 2014c). Our study highlights the regional occurrence of this bed as resulting from the significant mafic to ultramafic volcanic activity that characterized the Lessini Shelf since the Paleocene (e.g., Beccaluva et al., 2007 and reference therein).

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REFERENCES CITED

Agnini, C., Fornaciari, E., Giusberti, L., Grandesso, P., Lanci, L., Luciani, V., Muttoni, G., Pälike, H., Rio, D., Spofforth, D.J.A., and Stefani, C., 2011, Integrated biomagnetostratigraphy of the Alano section (NE Italy): A proposal for defining the middle-late Eocene boundary: Geological Society of America Bulletin, v. 123, p. 841–872, https://doi.org/10.1130/B30158.1.

Agnini, C., Backman, J., Fornaciari, E., Galeotti, S., Giusberti, L., Grandesso, P., Lanci, L., Monechi, S., Muttoni, G., Pälike, H., Pampaloni, M.L., Pignatti, J., Premoli Silva, I., Raffi, I., Rio, D., Rook, L., and Stefani, C., 2014a, The Alano section: The candidate GSSP for the Priabonian Stage, *in* Rocha, R., Pais, J., Kullberg, J.C., and Finney, S., eds., STRATI 2013 First International Congress on Stratigraphy: At the Cutting Edge of Stratigraphy: Berlin, Germany, Springer Geology, p. 55–59.

Agnini, C., Fornaciari, E., Raffi, I., Catanzariti, R., Pälike, H., Backman, J., and Rio, D., 2014b, Biozonation and biochronology of Paleogene calcareous nannofossils from low and middle

1150   latitudes: Newsletters on Stratigraphy, v. 47, p. 131–181, https://doi.org/10.1127/0078-
1151   0421/2014/0042.
1152 Agnini, C., Capraro, L., Giusberti, L., Boscolo Galazzo, F., Fornaciari, E., Luciani, V.,
1153   Papazzoni, C., and Rio, D., 2014c, Post conference field trip guidebook: The Paleogene of
1154   the central-eastern Veneto region (northeastern Italy): Climatic and Biotic Events of the
1155   Paleogene, Ferrara, Italy, July 5–6.
1156 Backman, J., Raffi, I., Rio, D., Fornaciari, E., and Palike, H., 2012, Biozonation and
1157   biochronology of Miocene through Pleistocene calcareous nannofossils from low and
1158   middle latitudes: Newsletters on Stratigraphy, v. 45, p. 221–244,
1159   https://doi.org/10.1127/0078-0421/2012/0022.
1160 Bassi, D., Cosovic, C., Papazzoni, C.A., and Ungaro, S., 2000, The Colli Berici, *in* Bassi, D., ed.,
1161   Field Trip Guidebook: Shallow Water Benthic Communities at the Middle–Upper Eocene
1162   Boundary, Southern and North-Eastern Italy, Slovenia, Croatia, Hungary: Ferrara, Italy, 5th
1163   Meeting of the International Geoscience Program: Annali dell'Università di Ferrara,
1164   Supplement 8, p. 43–57.
1165 Beccaluva, L., Bianchini, G., and Wilson, M., eds., 2007, Cenozoic Volcanism in the
1166   Mediterranean Area: Geological Society of America Special Paper 418, 335 p.
1167 Benjamini, C., 1980, Stratigraphy and foraminifera of the Qezi'ot and Har'Aqrav formations
1168   (latest middle to late Eocene) of the western Negev, Israel: Israel Journal of Earth Sciences,
1169   v. 29, p. 227–244.
1170 Berggren, W.A., and Pearson, P.N., 2005, A revised tropical to subtropical Paleogene planktonic
1171   foraminiferal zonation: Journal of Foraminiferal Research, v. 35, p. 279–298,
1172   https://doi.org/10.2113/35.4.279.
1173 Berggren, W.A., Kent, D.V., Swisher, C.C., III, and Aubry, M.-P., 1995, A revised Cenozoic
1174   geochronology and chronostratigraphy, *in* Berggren, W.A., Kent, D.V., Aubry, M.-P., and
1175   Hardenbol, J., eds., Geochronology, Time Scales and Global Stratigraphic Correlation: A
1176   Unified Temporal Framework for an Historical Geology: Tulsa, Oklahoma, USA, Society of
1177   Economic Paleontologists and Mineralogists Special Publication 54, p. 129–212.
1178 Boscolo Galazzo, F., Giusberti, L., Luciani, V., and Thomas, E., 2013, Paleoenvironmental
1179   changes during the Middle Eocene Climatic Optimum (MECO) and its aftermath: The
1180   benthic foraminiferal record from the Alano section (NE Italy): Palaeogeography,
1181   Palaeoclimatology, Palaeoecology, v. 378, p. 22–35,
1182   https://doi.org/10.1016/j.palaeo.2013.03.018.
1183 Bosellini, A., 1989, Dynamics of Tethyan carbonate platforms, *in* Cravello, P.D., Wilson, J.L.,
1184   Sarg, J.F., and Read, J.F., eds., Controls on Carbonate Platform and Basin Platform: Tulsa,
1185   Oklahoma, USA, Society of Economic Paleontologists and Mineralogists Special
1186   Publication 44, p. 3–13.
1187 Bosellini, F.R., and Papazzoni, C.A., 2003, Palaeoecological significance of coral-encrusting
1188   foraminifera associations: A case-study from the Upper Eocene of northern Italy: Acta
1189   Palaeontologica Polonica, v. 48, no. 2, p. 279–292.
1190 Cande, S.C., and Kent, D.V., 1995, Revised calibration of the geomagnetic polarity time scale
1191   for the Late Cretaceous and Cenozoic: Journal of Geophysical Research. Solid Earth, v. 100,
1192   no. B4, p. 6093–6096, https://doi.org/10.1029/94JB03098.
1193 Castellarin, A., Picotti, V., Cantelli, L., Claps, M., Trombetta, L., Selli, L., Carton, A., Borsato,
1194   A., Daminato, F., Nardin, M., Santuliana, E., Veronese, L., and Bollettinari, G., 2005, Note
1195   illustrative della Carta Geologica D'Italia alla scala 1:50.000, Foglio 80, Riva del Garda,

1196   Dipartimento difesa del suolo: Servizio Geologico d'Italia, organo cartografico dello Stato,
1197   Provincia Autonoma di Trento, 145 p.
1198 Castellarin, A., Vai, G.B., and Cantelli, L., 2006, The Alpine evolution of the Southern Alps
1199   around the Giudicarie faults: A Late Cretaceous to Early Eocene transfer zone:
1200   Tectonophysics, v. 414, no. 1–4, p. 203–223, https://doi.org/10.1016/j.tecto.2005.10.019.
1201 Channell, J.E.T., and Medizza, F., 1981, Upper Cretaceous and Palaeogene magnetic
1202   stratigraphy and biostratigraphy from the Venetian (southern) Alps: Earth and Planetary
1203   Science Letters, v. 55, p. 419–432, https://doi.org/10.1016/0012-821X(81)90169-2.
1204 Cita, M.B., 1969, Le Paléocène et l'Éocène de l'Italie du Nord: Mémoires du Bureau des
1205   Recherches géologiques et Minières, v. 69, p. 417–429.
1206 Coccioni, R., Monaco, P., Monechi, S., Nocchi, M., and Parisi, G., 1988, Biostratigraphy of the
1207   Eocene–Oligocene boundary at Massignano (Ancona, Italy), *in* Premoli Silva, I., Coccioni,
1208   R., Montanari, A., and Jenkins, D.G., eds., The Eocene–Oligocene Boundary in the Marche-
1209   Umbria Basin (Italy): Ancona, Italy, Fratelli Anniballi, International Union of Geological
1210   Sciences Special Publication, International Subcommission on Paleogene Stratigraphy
1211   Report, p. 59–80.
1212 Coccioni, R., Catanzariti, R., Frontalini, F., Galbrun, B., Jovane, L., Montanari, A., Savian, J.,
1213   and Sideri, M., 2016, Integrated magnetostratigraphy, biostratigraphy, and
1214   chronostratigraphy of the Paleogene pelagic succession at Gubbio (central Italy), *in*
1215   Menichetti, M., Coccioni, R., and Montanari, A., eds., The Stratigrahic Record of Gubbio:
1216   Integrated Stratigraphy of the Late Cretaceous–Paleocene Umbria-Marche Pelagic Basin:
1217   Geological Society of America Special Paper 524, p. 139–160,
1218   https://doi.org/10.1130/2016.2524(10).
1219 Costa, E., Garcés, M., López-Blanco, M., Serra-Kiel, J., Bernaola, G., Cabrera, L., and Beamn,
1220   E., 2013, The Bartonian-Priabonian marine record of the eastern south Pyrenean foreland
1221   basin (NE Spain): A new calibration of the larger foraminifers and calcareous nannofossil
1222   biozonation: Geologica Acta, v. 11, p. 177–193, https://doi.org/10.1344/105.000001779.
1223 Cotton, L., Zakrevskaya, E.Y., van der Boon, A., Asatryan, G., Hayrapetyan, F., Israelyan, A.,
1224   Krijgsman, W., Less, G., Monechi, S., Papazzoni, C.A., Pearson, P.N., Razumovskiy, A.,
1225   Renema, W., Shcherbinina, E., and Wade, B.S., 2017, Integrated stratigraphy of the
1226   Priabonian (upper Eocene) Urtsadzor section, Armenia: Newsletters on Stratigraphy, v. 50,
1227   no. 3, p. 269–295, https://doi.org/10.1127/nos/2016/0313.
1228 Dallanave, E., Agnini, C., Muttoni, G., and Rio, D., 2009, Magnetobiostratigraphy of the
1229   Cicogna section (Italy): Implications for the late Paleocene–early Eocene time scale: Earth
1230   and Planetary Science Letters, v. 85, 1–2, p. 39–51.
1231 Dallanave, E., Muttoni, G., Agnini, C., Tauxe, L., and Rio, D., 2012, Is there a normal magnetic-
1232   polarity event during the Palaeocene–Eocene thermal maximum (55Ma)? Insights from the
1233   palaeomagnetic record from the Belluno Basin (Italy): Geophysical Journal International,
1234   v. 191, no. 2, p. 517–529, https://doi.org/10.1111/j.1365-246X.2012.05627.x.
1235 Dallanave, E., Kirscher, U., Hesse, R., Bachtadse, V., and Wortmann, U.G., 2018,
1236   Palaeomagnetic time and space constraints of the Early Cretaceous Rhenodanubian Flysch
1237   zone (Eastern Alps): Geophysical Journal International, v. 213, p. 1804–1817,
1238   https://doi.org/10.1093/gji/ggy077.
1239 Dekkers, M.J., 1989, Magnetic properties of natural pyrrhotite. II. High and low temperature
1240   behaviors of Jrs and TRM as a function of grain size: Physics of the Earth and Planetary
1241   Interiors, v. 57, p. 266–283, https://doi.org/10.1016/0031-9201(89)90116-7.

1242 Doglioni, C., and Bosellini, A., 1987, Eoalpine and Mesoalpine tectonics in the southern Alps:
1243   Geologische Rundschau, v. 76, no. 3, p. 735–754, https://doi.org/10.1007/BF01821061.
1244 D'Onofrio, R., Luciani, V., Fornaciari, E., Giusberti, L., Boscolo Galazzo, F., Dallanave, E.,
1245   Westerhold, T., Sprovieri, M., and Telch, S., 2016, Environmental perturbations at the early
1246   Eocene ETM2, H2, and 11 events as inferred by Tethyan calcareous plankton (Terche
1247   section, northeastern Italy): Paleoceanography and Paleoclimatology, v. 31, p. 1225–1247,
1248   https://doi.org/10.1002/2016PA002940.
1249 Dunlop, D.J., and Özdemir, Ö., 1997, Rock Magnetism: Fundamentals and Frontiers:
1250   Cambridge, UK, Cambridge University Press, 596 p.,
1251   https://doi.org/10.1017/CBO9780511612794.
1252 Edgar, K.M., Wilson, P.A., Sexton, P.F., Gibbs, S.J., Roberts, A.P., Norris, R.D., and Fisher, R.,
1253   2010, New biostratigraphic, magnetostratigraphic and isotopic insights into the Middle
1254   Eocene Climatic Optimum in low latitudes: Palaeogeography, Palaeoclimatology,
1255   Palaeoecology, v. 297, p. 670–682, https://doi.org/10.1016/j.palaeo.2010.09.016.
1256 Fioroni, C., Villa, G., Persico, D., and Jovane, L., 2015, Middle Eocene-Lower Oligocene
1257   calcareous nannofossil biostratigraphy and paleoceanographic implications from Site 711
1258   (equatorial Indian Ocean): Marine Micropaleontology, v. 118, p. 50–62,
1259   https://doi.org/10.1016/j.marmicro.2015.06.001.
1260 Fisher, R.A., 1953, Dispersion on a sphere: Proceedings of the Royal Society A, Mathematical,
1261   Physical and Engineering Sciences, v. 217, p. 295–305,
1262   https://doi.org/10.1098/rspa.1953.0064.
1263 Fornaciari, E., Agnini, C., Catanzariti, R., Rio, D., Bolla, E.M., and Valvasoni, E., 2010, Mid
1264   latitude calcareous nannofossil biostratigraphy and biochronology across the middle to late
1265   Eocene transition: Stratigraphy, v. 7, p. 229–264.
1266 Gardin, S., and Monechi, S., 1998, Palaeoecological change in the middle to low latitude
1267   calcareous nannoplankton at the Cretaceous/Tertiary boundary: Bulletin de la Société
1268   Géologique de France, v. 5, p. 709–723.
1269 Gazzi, P., Zuffa, G.G., Gandolfi, G., and Paganelli, L., 1973, Provenienza e dispersione litoranea
1270   delle sabbie delle spiagge adriatiche tra le foci dell'Isonzo e del Foglia: Inquadramento
1271   regionale: Memorie della Societa Geologica Italiana, v. 12, p. 1–37.
1272 Giusberti, L., Boscolo Galazzo, F., and Thomas, E., 2016, Variability in climate and productivity
1273   during the Paleocene–Eocene Thermal Maximum in the western Tethys (Forada section):
1274   Climate of the Past, v. 12, p. 213–240, https://doi.org/10.5194/cp-12-213-2016.
1275 Gonzalvo, C., and Molina, E., 1992, Bioestratigrafía y cronoestratigrafía del tránsito Eoceno–
1276   Oligoceno en Torre Cardela y Massignano (Italia): Revista Espanola de Paleontologia, v. 7,
1277   no. 2, p. 109–126.
1278 Gonzalvo, C., and Molina, E., 1996, Bioestratigrafía y cronoestratigrafía del tránsito Eoceno
1279   medio-Eoceno superior en la Cordillera Bética: Revista Española de Micropaleontología,
1280   v. 28, no. 2, p. 25–44.
1281 Green, O.R., 2001, A Manual of Practical Laboratory and Field Techniques in Palaeobiology:
1282   Dordrecht, The Netherlands, Springer, https://doi.org/10.1007/978-94-017-0581-3.
1283 Hagn, H., 1956, Geologische und Paläontologische untersuchungen im Tertiär des Monte Brione
1284   und seiner umgebung (Gardasee, Ober-Italien): Palaeontographica. Abteilung A,
1285   Paläozoologie, Stratigraphie, v. 107, p. 67–210.
1286 Hallock, P., 1985, Why are larger foraminifera large?: Paleobiology, v. 11, p. 195–208,
1287   https://doi.org/10.1017/S0094837300011507.

1288 Hallock, P., Premoli Silva, I., and Boersma, A., 1991, Similarities between planktonic and larger
1289   foraminiferal evolutionary trends through Paleogene paleoceanographic changes:
1290   Palaeogeography, Palaeoclimatology, Palaeoecology, v. 83, p. 49–64,
1291   https://doi.org/10.1016/0031-0182(91)90075-3.
1292 Hardenbol, J., 1968, The "Priabonian" type section (a preliminary note): Mémoires du Bureau
1293   des Récherches Géologique et Minières, v. 58, p. 629–635.
1294 Hottinger, L., 1977, Foraminifères operculiniformes: Mémoires du Muséum National d'Histoire
1295   Naturelle, v. 40, p. 1–159.
1296 Hottinger, L., Romero, J., and Caus, E., 2001, Architecture and revision of the Pellatispirines,
1297   planispiral canaliferous foraminifera from the late Eocene Tethys: Micropaleontology, v. 47,
1298   p. 35–77.
1299 Huber, B.T., 1991, Paleogene and early Neogene planktonic foraminifer biostratigraphy of Sites
1300   738 and 744, Kerguelen Plateau (southern Indian Ocean), *in* Barron, J., Larsen, B., et al.,
1301   Proceedings of the Ocean Drilling Program, Scientific Results, Volume 119: College
1302   Station, Texas, USA, Ocean Drilling Program, p. 427–449,
1303   https://doi.org/10.2973/odp.proc.sr.119.142.1991.
1304 Jones, C.H., 2002, User-driven integrated software lives: "Paleomag" paleomagnetics analysis
1305   on the Macintosh: Computational Geosciences, v. 28, p. 1145–1151,
1306   https://doi.org/10.1016/S0098-3004(02)00032-8.
1307 Kirschvink, J.L., 1980, The least-squares line and plane and the analysis of palaeomagnetic data:
1308   Geophysical Journal International, v. 62, no. 3, p. 699–718, https://doi.org/10.1111/j.1365-
1309   246X.1980.tb02601.x.
1310 Kruiver, P.P., Dekkers, M.J., and Heslop, D., 2001, Quantification of magnetic coercivity
1311   components by the analysis of acquisition curves of isothermal remanent magnetization:
1312   Earth and Planetary Science Letters, v. 189, p. 269–276, https://doi.org/10.1016/S0012-
1313   821X(01)00367-3.
1314 Leonhardt, R., 2006, Analyzing rock magnetic measurements: The RockMagAnalyzer 1.0
1315   software: Computational Geosciences, v. 32, p. 1420–1431,
1316   https://doi.org/10.1016/j.cageo.2006.01.006.
1317 Less, G., 1987, Paleontology and stratigraphy of the European orthophragminae: Geologica
1318   Hungarica series Paleontologica, v. 51, p. 1–373.
1319 Less, G., and Özcan, E., 2012, Bartonian-Priabonian larger benthic foraminiferal events in the
1320   Western Tethys: Mitteilungen der Österreichischen Geologischen Gesellschaft, v. 105,
1321   p. 129–140.
1322 Less, G., Özcan, E., Papazzoni, C.A., and Stockar, R., 2008, The middle to late Eocene evolution
1323   of nummulitid foraminifer *Heterostegina* in the Western Tethys: Acta Palaeontologica
1324   Polonica, v. 53, p. 317–350, https://doi.org/10.4202/app.2008.0212.
1325 Less, G., Özcan, E., and Okay, A.I., 2011, Stratigraphy and larger foraminifera of the middle
1326   Eocene to lower Oligocene shallow-marine units in the northern and eastern parts of the
1327   Thrace Basin, NW Turkey: Turkish Journal of Earth Sciences, v. 20, p. 793–845.
1328 Lirer, F., 2000, A new technique for retrieving calcareous microfossils from lithified lime
1329   deposits: Micropaleontology, v. 46, p. 365–369.
1330 **[[Not cited?]]**Luciani, V., 1988, La Dorsale Paleogenica M. Baldo-M. Bondone (Trentino
1331   meridionale): Significato paleogeografico e paleotettonico: Rivista Italiana di Paleontologia
1332   e Stratigrafia, v. 93, p. 507–520.
1333 Luciani, V., 1989, Stratigrafia sequenziale del Terziario nella Catena del Monte Baldo (Provincie

1334   di Verona e Trento): Memorie di Scienze Geologiche, v. 41, p. 263–351.

1335 Luciani, V., and Lucchi Garavello, A.M., 1986, Biostratigrafia del Paleogene pelagico del

1336   Bacino del Sarca (Trentino meridionale): Studi Trentini di Scienze Naturali: Acta

1337   Geologica, v. 62, p. 19–70.

1338 Luciani, V., Negri, A., and Bassi, D., 2002, The Bartonian–Priabonian transition in the Mossano

1339   section (Colli Berici, north-eastern Italy): A tentative correlation between calcareous

1340   plankton and shallow-water benthic zonations: Geobios, Supplement 1, v. 35, p. 140–149,

1341   https://doi.org/10.1016/S0016-6995(02)00055-4.

1342 Luciani, V., Giusberti, L., Agnini, C., Fornaciari, E., Rio, D., Spofforth, D.J.A., and Pälike, H.,

1343   2010, Ecological and evolutionary response of Tethyan planktonic foraminifera to the

1344   middle Eocene climatic optimum (MECO) from the Alano section (NE Italy):

1345   Palaeogeography, Palaeoclimatology, Palaeoecology, v. 292, p. 82–95,

1346   https://doi.org/10.1016/j.palaeo.2010.03.029.

1347 Luciani, V., Dickens, G.R., Backman, J., Fornaciari, E., Giusberti, L., Agnini, C., and

1348   D'Onofrio, R., 2016, Major perturbations in the global carbon cycle and photosymbiont-

1349   bearing planktic foraminifera during the early Eocene: Climate of the Past, v. 12, p. 981–

1350   1007, https://doi.org/10.5194/cp-12-981-2016.

1351 Mancin, N., and Pirini, C., 2001, Middle Eocene to early Miocene planktonic foraminiferal

1352   biostratigraphy in the Epiligurian Succession (Northern Apennines, Italy): Rivista Italiana di

1353   Paleontologia e Stratigrafia, v. 107, p. 371–393.

1354 Marino, M., and Flores, J.A., 2002a, Middle Eocene to early Oligocene calcareous nannofossil

1355   stratigraphy at Leg 177 Site 1090: Marine Micropaleontology, v. 45, p. 383–398,

1356   https://doi.org/10.1016/S0377-8398(02)00036-1.

1357 Marino, M., and Flores, J.A., 2002b, Data report: Calcareous nannofossil data from the Eocene

1358   to Oligocene, Leg 177, Hole 1090B, *in* Gersonde, R., Hodell, D.A., and Blum, P., eds.,

1359   Proceedings of Oceanic Drilling Program, Scientific Results 177: College Station, Texas,

1360   USA, Ocean Drilling Program, 9 p., https://doi.org/10.2973/odp.proc.sr.177.115.2002.

1361 Martini, E., 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation *in*

1362   Farinacci, A. ed., Proceedings of the 2nd Planktonic Conference, Rome, volume 2: Rome,

1363   Italy, Edizioni Tecnoscienza, p. 739–785.

1364 Massironi, M., Zampieri, D., Bianchi, M., Schiavo, A., and Franceschini, A., 2009, Use of

1365   PSInSAR™ data to infer active tectonics: Clues on the differential uplift across the

1366   Giudicarie belt (Central-Eastern Alps, Italy): Tectonophysics, v. 476, p. 297–303,

1367   https://doi.org/10.1016/j.tecto.2009.05.025.

1368 McFadden, P.L., and McElhinny, M.W., 1990, Classification of the reversal test in

1369   palaeomagnetism: Geophysical Journal International, v. 103, p. 725–729,

1370   https://doi.org/10.1111/j.1365-246X.1990.tb05683.x.

1371 Molina, E., Alegret, L., Apellaniz, E., Bernaola, G., Caballero, F., Dinares-Turell, J., Hardenbol,

1372   J., Heilmann-Clausen, C., Larrasoana, J.C., Luterbacher, H., Monechi, S., Ortiz, S., Orue-

1373   Etxebarria, X., Payros, A., Pujalte, V., Rodrıguez-Tovar, F.J., Tori, F., Tosquella, J., and

1374   Uchman, A., 2011, The Global Stratotype Section and Point (GSSP) for the base of the

1375   Lutetian Stage at the Gorrondatxe section, Spain: Episodes, v. 34, p. 86–108.

1376 Munier-Chalmas, E., and de Lapparent, A., 1893, Note sur la nomenclature des terrains

1377   sédimentaires: Bulletin de la Société Géologique de France, v. 3, p. 479–480.

1378 Nocchi, M., Parisi, G., Monaco, P., Monechi, S., Madile, M., Napoleone, G., Ripepe, M.,

1379   Orlando, M., Premoli Silva, I., and Bice, D.M., 1986, The Eocene-Oligocene boundary in

1380   the Umbrian pelagic sequences, Italy, *in* Pomerol, C., and Premoli Silva, I., eds., Terminal
1381   Eocene Events: Amsterdam, The Netherlands, Elsevier, p. 25–40,
1382   https://doi.org/10.1016/S0920-5446(08)70091-8.
1383   Nocchi, M., Amici, E., and Premoli Silva, I., 1991, Planktonic foraminiferal biostratigraphy and
1384   paleoenvironmental interpretation on Paleogene faunas from the subantarctic transect, Leg
1385   114, *in* Ciesielski, P.F., Kristoffersen, Y., et al., eds., Proceedings of the Ocean Drilling
1386   Program, Scientific Results, 114: College Station, Texas, USA, Ocean Drilling Program, p.
1387   233–279, https://doi.org/10.2973/odp.proc.sr.114.127.1991.
1388   Norris, R.D., Kroon, D., Klaus, A., et al., 1998, Proceedings of the Ocean Drilling Program,
1389   Initial Reports, Volume 171B: College Station, Texas, USA, Ocean Drilling Program,
1390   https://doi.org/10.2973/odp.proc.ir.171b.1998.
1391   Ogg, J.G., and Bardot, L., 2001, Aptian through Eocene magnetostratigraphic correlation of the
1392   Blake Nose transect (Leg 171B), Florida continental margin, *in* Kroon, D., Norris, R.D., and
1393   Klaus, A., eds., Proceedings of the Ocean Drilling Program, Scientific Results, Volume
1394   171B: College Station, Texas, USA, Ocean Drilling Program, p. 1–58,
1395   https://doi.org/10.2973/odp.proc.sr.171b.104.2001.
1396   Ogg, J.G., Ogg, G., and Gradstein, F.M., 2016, A Concise Geologic Time Scale, 1st Edition:
1397   Elsevier, 240 p.
1398   Okada, H., and Bukry, D., 1980, Supplementary modifications and introduction of code numbers
1399   to the low-latitude coccolith biostratigraphic zonation: Marine Micropaleontology, v. 5,
1400   p. 321–325, https://doi.org/10.1016/0377-8398(80)90016-X.
1401   Pälike, H., Shackleton, N.J., and Röhl, U., 2001, Astronomical forcing in late Eocene marine
1402   sediments: Earth and Planetary Science Letters, v. 193, p. 589–602,
1403   https://doi.org/10.1016/S0012-821X (01)00501–5.
1404   Pälike, H., Norris, R.D., Herrle, J.O., Wilson, P.A., Coxall, H.K., Lear, C.H., Shackleton, N.J.,
1405   Tripati, A.K., and Wade, B.S., 2006, The heartbeat of the Oligocene climate system:
1406   Science, v. 314, p. 1894–1898, https://doi.org/10.1126/science.1133822.
1407   Papazzoni, C.A., 1998, Biometric analyses of *Nummulites "ptukhiani"* Z.D. Kacharava, 1969
1408   and *Nummulites fabianii* (Prever in Fabiani, 1905): Journal of Foraminiferal Research, v. 28,
1409   no. 3, p. 161–176.
1410   Papazzoni, C.A., and Sirotti, A., 1995, Nummulite biostratigraphy at the middle/upper Eocene
1411   boundary in the Northern Mediterranean area: Rivista Italiana di Paleontologia e
1412   Stratigrafia, v. 101, p. 63–80.
1413   Papazzoni, C.A., Moretti, A., Luciani, V., Fornaciari, E., and Giusberti, L., 2014, Correlation
1414   between shallow benthic zones and calcareous plankton zones at the Bartonian–Priabonian
1415   transition: Preliminary results from the Varignano section (Trento Province, northern Italy),
1416   *in* Rocha, R., Pais, J., Kullberg, J.C., and Finney, S., eds., STRATI 2013 First International
1417   Congress on Stratigraphy: At the Cutting Edge of Stratigraphy: Switzerland, Springer
1418   International Publishing, p. 127–130, https://doi.org/10.1007/978-3-319-04364-7_26.
1419   Papazzoni, C.A., Ćosović, V., Briguglio, A., and Drobne, K., 2017, Towards a calibrated Larger
1420   Foraminifera Biostratigraphic Zonation: Celebrating 18 years of the application of Shallow
1421   Benthic Zones: Palaios, v. 32, no. 1–2, p. 1–5, https://doi.org/10.2110/palo.2016.043.
1422   Passier, H.F., de Lange, G.J., and Dekkers, M.J., 2001, Magnetic properties and geochemistry of
1423   the active oxidation front and the youngest sapropel in the eastern Mediterranean Sea:
1424   Geophysical Journal International, v. 145, p. 604–614, https://doi.org/10.1046/j.0956-
1425   540x.2001.01394.x.

Pearson, P.N., and Chaisson, W.P., 1997, Late Paleocene to middle Miocene planktonic foraminifer biostratigraphy of the Ceara Rise, *in* Curry, W.B., Shackleton, N.J., Richter, C., et al., Proceedings of the Ocean Drilling Program, Scientific Results, Volume 154: College Station, Texas, Ocean Drilling Program, p. 33–68.

Pearson, P.N., Olsson, R.K., Hemblen, C., Huber, B.T., and Berggren, W.A., eds., 2006, Atlas of Eocene Planktonic Foraminifera: Lawrence, Kansas, USA, Cushman Foundation Special Publication 41, 513 p.

Perch-Nielsen, K., 1985, Cenozoic calcareous nannoplankton, *in* Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K., eds., Plankton Stratigraphy: Cambridge, UK, Cambridge University Press, p. 427–554.

Persico, D., Fioroni, C., and Villa, G., 2012, A refined calcareous nannofossil biostratigraphy for the middle Eocene-early Oligocene Southern ODP sites: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 335–336, p. 12–23, https://doi.org/10.1016/j.palaeo.2011.05.017.

Piccoli, G., and Massari Degasperi, G., 1968, I molluschi dello stratotipo del Priaboniano e il loro significato paleoecologico: Mémoires du Bureau des Recherches géologiques et Minières, v. 58, p. 242–252.

Pignatti, J., and Papazzoni, C.A., 2017, Oppelzones and their heritage in current larger foraminiferal biostratigraphy: Lethaia, v. 50, no. 3, p. 369–380, https://doi.org/10.1111/let.12210.

~~Raffi, I., Backman, J., Fornaciari, E., Pälike, H., Rio, D., Lou~~**[[maybe this was left in by mistake?]]**

Rio, D., Raffi, I., and Villa, G., 1990, Pliocene–Pleistocene calcareous nannofossil distribution, patterns in the western Mediterranean, *in* Kasten, K.A., Mascle, J., et al., Proceedings of the Ocean Drilling Program, Scientific Results, Volume 107: College Station, Texas, USA, Ocean Drilling Program, p. 513–533, http://www-odp.tamu.edu/publications/107_SR/VOLUME/CHAPTERS/sr107_32.pdf.

Rodelli, D., Jovane, L., Özcan, E., Giorgioni, M., Coccioni, R., Frontalini, F., Rego, E.R., Brogi, A., Catanzariti, R., Less, Gy., and Rostami, M.A., 2018, High-resolution integrated magnetobiostratigraphy of a new middle Eocene section from the Neotethys (Elazig Basin, eastern Turkey): Geological Society of America Bulletin, v. 130, no. 1–2, p. 193–207, https://doi.org/10.1130/B31704.1.

Roveda, V., 1961, Contributo allo studio di alcuni macroforaminiferi di Priabona: Rivista Italiana di Paleontologia, v. 67, p. 153–224.

Schaub, H., 1981, Nummulites et Assilines de la Téthys Paléogène: Taxonomie, phylogenèse et biostratigraphie: Basel, Switzerland, Birkhäuser, Schweizerische Paläontologische Abhandlungen, v. 104–106, p. 1–236.

Schmidt, R.R., and Raju, D.S.N., 1973, *Globorotalia palmerae* Cushman and Bermudez and closely related species from the lower Eocene, Cauvery Basin, south India: Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen. Series B, Palaeontology, Geology, Physics and Chemistry, v. 76, p. 167–184.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferrandez, C., Jauhri, A.K., Less, G., Pavlovec, R., Pignatti, J., Samso, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J., and Zakrevskaya, E., 1998, Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene: Bulletin de la Société Géologique de France, v. 169, p. 281–299.

1472 Setiawan, J.R., 1983, Foraminifers and microfacies of the type Priabonian: Utrecht
1473   Micropaleontological Bulletins, v. 29, p. 1–161.
1474 Shamrock, J.L., Watkins, D.K., and Johnston, K.W., 2012, Eocene biogeochronology and
1475   magnetostratigraphic revision of ODP Hole 762C, Exmouth Plateau (northwest Australian
1476   Shelf): Stratigraphy, v. 9, no. 1, p. 55–75.
1477 Shaw, A.B., 1964, Time in Stratigraphy: New York, USA, McGraw-Hill, 365 p.
1478 Spofforth, D.J.A., Agnini, C., Pälike, H., Rio, D., Bohaty, S., Fornaciari, E., Giusberti, L., Lanci,
1479   L., Luciani, V., and Muttoni, G., 2010, Organic carbon burial following the middle Eocene
1480   climatic optimum in the central western Tethys: Paleoceanography and Paleoclimatology, v.
1481   25, no. 3, https://doi.org/10.1029/2009PA001738.
1482 Strougo, A., 1992, The middle Eocene/upper Eocene transition in Egypt reconsidered: Neue
1483   Jahrbuch Paläontologische Abhandlungen, v. 186, p. 71–89.
1484 Tauxe, L., Banerjee, S.K., Butler, R.F., and van der Voo, R., 2018, Essentials of
1485   Paleomagnetism: 5th Web Edition: https://earthref.org/MagIC/books/Tauxe/Essentials/
1486 Thierstein, H., Geitzenauer, K.R., Molfino, B., and Shackleton, N.J., 1977, Global synchroneity
1487   of late Quaternary coccolith datum levels: Validation by oxygen isotopes: Geology, v. 5,
1488   p. 400–404, https://doi.org/10.1130/0091-7613(1977)5<400:GSOLQC>2.0.CO;2.
1489 Toumarkine, M., and Bolli, H.M., 1970, Evolution de *Globorotalia cerroazulensis* (Cole) dans
1490   l'Eocene moyen et supérieur de Possagno (Italie): Revue de Micropaleontologie, v. 13,
1491   p. 131–145.
1492 Toumarkine, M., and Luterbacher, H.P., 1985, Paleocene and Eocene planktonic foraminifera, *in*
1493   Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K., eds., Plankton Stratigraphy: Cambridge,
1494   UK, Cambridge University Press, p. 87–154.
1495 Vandenberghe, N., Hilgen, F.J., and Speijer, R.P., 2012, The Paleogene Period, *in* Gradstein,
1496   F.M., Ogg, J.G., Smith, A.G., and Ogg, G.M., eds., The Geologic Time Scale 2012: Oxford,
1497   UK, Elsevier, p. 855–921, https://doi.org/10.1016/B978-0-444-59425-9.00028-7.
1498 Villa, G., Fioroni, C., Pea, L., Bohaty, S.M., and Persico, D., 2008, Middle Eocene–late
1499   Oligocene climate variability: Calcareous nannofossil response at Kerguelen Plateau, Site
1500   748: Marine Micropaleontology, v. 69, p. 173–192,
1501   https://doi.org/10.1016/j.marmicro.2008.07.006.
1502 Wade, B.S., 2004, Planktonic foraminiferal biostratigraphy and mechanisms in the extinction of
1503   *Morozovella* in the late middle Eocene: Marine Micropaleontology, v. 51, p. 23–38,
1504   https://doi.org/10.1016/j.marmicro.2003.09.001.
1505 Wade, B.S., and Hernitz Kucenjak, M., 2018, Taxonomy, biostratigraphy and phylogeny of
1506   Oligocene *Acarinina, in* Wade, B.S., Olsson, R.K., Pearson, P.N., Huber, B.T., and
1507   Berggren, W.A., eds., Atlas of Oligocene Planktonic Foraminifera: Lawrence, Kansas, USA,
1508   Cushman Foundation Special Publication 46, p. 393–402.
1509 Wade, B.S., and Olsson, R.K., 2009, Investigation of pre-extinction dwarfing in Cenozoic
1510   planktonic foraminifera: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 284, p. 39–
1511   46, https://doi.org/10.1016/j.palaeo.2009.08.026.
1512 Wade, B.S., Al-Sabouni, N., Hemleben, C., and Kroon, D., 2008, Symbiont bleaching in fossil
1513   planktonic foraminifera: Evolutionary Ecology, v. 22, p. 253–265,
1514   https://doi.org/10.1007/s10682-007-9176-6.
1515 Wade, B.S., Pearson, P.N., Berggren, W.A., and Pälike, H., 2011, Review and revision of
1516   Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the
1517   geomagnetic polarity and astronomical time scale: Earth-Science Reviews, v. 104, p. 111–

1518   142, https://doi.org/10.1016/j.earscirev.2010.09.003.
1519 Wade, B.S., Premec Fucek, V., Kamikuri, S., Bartol, M., Luciani, V., and Pearson, P.N., 2012,
1520   Successive extinctions of muricate planktonic foraminifera (*Morozovelloides* and *Acarinina*)
1521   as a candidate for marking the base Priabonian: Newsletters on Stratigraphy, v. 45, no. 3,
1522   p. 245–262, https://doi.org/10.1127/0078-0421/2012/0023.
1523 **[[Not cited?]]**Walsh, S.L., Gradstein, F.M., and Ogg, J.G., 2004, History, philosophy, and
1524   application of the Global Stratotype Section and Point (GSSP): Lethaia, v. 37, p. 201–218,
1525   https://doi.org/10.1080/00241160410006500.
1526 Wang, L., Pan, Y., Li, J., and Qin, H., 2008, Magnetic properties related to thermal treatment of
1527   pyrite: Science in China. Series D, Earth Sciences, v. 51, p. 1144–1153,
1528   https://doi.org/10.1007/s11430-008-0083-7.
1529 Watson, G.S., 1956, A test for randomness of directions: Geophysical Journal International, v. 7,
1530   p. 160–161, https://doi.org/10.1111/j.1365-246X.1956.tb05561.x.
1531 Watson, G.S., 1983, Large sample theory of the Langevin distribution: Journal of Statistical
1532   Planning and Inference, v. 8, p. 245–256, https://doi.org/10.1016/0378-3758(83)90043-5.
1533 Wei, W., and Wise, S.W., Jr., 1990, Biogeographic gradients of middle Eocene–Oligocene
1534   calcareous nannoplankton in the South Atlantic Ocean: Palaeogeography,
1535   Palaeoclimatology, Palaeoecology, v. 79, p. 29–61, https://doi.org/10.1016/0031-
1536   0182(90)90104-F.
1537 Wei, W., and Wise, S.W., Jr., 1992, Eocene–Oligocene calcareous nannofossil
1538   magnetobiochronology of the Southern Ocean: Newsletters on Stratigraphy, v. 26, p. 119–
1539   132, https://doi.org/10.1127/nos/26/1992/119.
1540 Zijderveld, J.D.A., 1967, A.C. demagnetization of rocks: Analysis of results, *in* Collinson, D.
1541   W., Creer, K. M., and Runcorn, S. K., eds., Methods in Paleomagnetism: Elsevier
1542   Publishing Company, Jan Van Galenstraat, v. 3, p. 211–335.
1543
1544 Figure 1. Geographic and geological context of the Varignano section. (A) Simplified geological
1545 scheme of the Southern Alps. The dotted areas indicate recent alluvial sediments (adapted from
1546 Doglioni and Bosellini, 1987). (B) Location map of the study area with indication of the
1547 Varignano section (red arrow). (C) Paleogeographic reconstruction of the main paleogeographic
1548 elements of the Southern Alps during the Paleogene with indication of the Varignano and Alano
1549 sections; (1) deep water mudstones, (2) Paleogene lagoon and shelf-edge reefs, (3) former
1550 extension of the Jurassic Trento Platform evolved to deep-sea setting during the Paleogene as
1551 characterized by pelagic claystones and marlstones (adapted from Bosellini and Papazzoni,
1552 2003). (D) View of the sampled outcrop with indications of some turbiditic levels rich in larger
1553 foraminifera and the Tiziano bed equivalent (VL+3).
1554
1555 Figure 2. Lithostratigraphy and lithology of the Varignano section (northern Italy)**[[O.K.?]]** with
1556 indication of the set of samples collected for the integrated stratigraphic analyses of this study.
1557 Only levels containing volcanoclastic material with a thickness >5 cm are plotted. Nine of these
1558 outcropping levels have been petrologically analyzed. **[[In Figure 2, consider spelling out or
1559 defining within this figure caption the words "Paleomag" and "Plank."]]**
1560
1561 Figure 3. Planktic foraminiferal data and resulting biostratigraphic attribution of the Varignano
1562 section (northern Italy)**[[O.K.?]]** according to the zonal scheme of Wade et al. (2011). The
1563 relative abundance of the genus *Morozovelloides*, large (>125 μm) and small acarininids is

1564 reported in terms of percentage with respect to the entire assemblage. Positions of the
1565 biohorizons are shown in Table 1. Lithological symbols are consistent with Figure 2. **[[In Figure**
1566 **3, should the two occurrences of the word acarinini**dis **be spelled as acarininids?]]**
1567
1568 Figure 4. Quantitative distribution pattern of selected calcareous nannofossils and resulting
1569 biostratigraphic classification of the Varignano section (northern Italy)**[[O.K.?]]** according to the
1570 zonal scheme of Agnini et al. (2014b) and Fornaciari et al. (2010). The position of the
1571 biohorizons is reported in Table 1. T—top; Tc—top common; B—base; Bc—base common;
1572 AB—acme beginning; AE—acme end. Lithological symbols are consistent with Figure
1573 2.**[[Change Agnini et al., (2014) to 2014b in figure?]]**
1574
1575 Figure 5. Large foraminiferal occurrences at the Varignano section (northern Italy)**[[O.K.?]]** and
1576 resulting biostratigraphic attribution according to the zonal schemes of Papazzoni et al. (2014).
1577 Lithological symbols are consistent with Figure 2.
1578
1579 Figure 6. **[[Please include a geographic description.]]** Rock- and paleomagnetic analyses. (A)
1580 Normalized isothermal remanence magnetization (IRM) acquisition curves of 10 rock
1581 specimens; the inducing field as plotted on a logarithmic scale to highlight the behavior at lower
1582 fields. (B) Examples of cumulative log-Gaussian analyses (Kruiver et al., 2001) of two e.g.,
1583 specimens from group 1 and 2 of panel A; dotted vertical lines indicate the half-saturation field
1584 $B_{1/2}$. (C) Thermomagnetic remanence curves of the same specimens shown in panel B. (D)
1585 Examples of vector end-point demagnetization diagrams as described in the main text; open
1586 (closed) squares are projections on the vertical (horizontal) plane; steps are expressed in degree
1587 Celsius (°C). SIRM—saturation isothermal remanence**[[OK?]]**;W,Up—**[[define?]]**; NRM—
1588 natural remanent magnetization.
1589
1590 Figure 7. **[[Please include a geographic description.]]** Paleomagnetic results. (A) Equal-area
1591 projections of (from high to low) the low temperature overprint ("A") of the natural remanent
1592 magnetization (NRM), the characteristic remanent magnetization (ChRM) in geographic
1593 coordinates and after correction of bedding tilt. (B) Paleomagnetic declination and inclination of
1594 the ChRM directions plotted against the lithological and calcareous nannofossil zones log; the
1595 virtual geomagnetic poles (VGP) latitude calculated from the ChRM directions and the derived
1596 magnetic polarity zonation are shown on the right hand panel.
1597
1598 Figure 8. Main planktic foraminiferal, large foraminiferal (bold character) (on the right),
1599 calcareous nannofossils (in the middle), and magnetostratigraphic events (black diamonds)
1600 recorded from the Varignano section (northern Italy)**[[O.K.?]]** plotted against
1601 magnetostratigraphy and zonal schemes. Layers bearing volcanoclastic material that we have
1602 geochemically analyzed are also indicated (black spades). The shaded light gray band highlights
1603 the critical interval encompassing the events recently proposed for defining the base of the
1604 Priabonian Stage. Lithological symbols are consistent with Figure 2.
1605
1606 Figure 9. Correlation between the Varignano and Alano sections (northern Italy)**[[O.K.?]]**
1607 through the Shaw diagram (Shaw, 1964). Tie points are magnetic polarity reversals. Crystal tuff
1608 layers VL+3, VL+4, the Tiziano and Tintoretto beds are indicated by crosses to highlight their
1609 correlation between the two sections. Note that the events that intercept or coarsely fall in close

1610 proximity to the line of correlation can be considered as reasonably synchronous. Changes in the
1611 slope of the line suggest variations of sedimentation accumulation rates. Lithological symbols
1612 are consistent with Figure 2.**[[Check that the upper right part of Figure 9 isn't cut off in the**
1613 **file.]]**
1614
1615 Figure 10. Correlation of main and secondary calcareous plankton events and layers with
1616 volcanoclastic material (dashed line) recorded in the Varignano and Alano sections, northern
1617 Italy **[[O.K.?]]**. Bioevents are the same as shown in Figure 8 and Tables 2 and 3. The shaded
1618 light gray band highlights the critical interval encompassing the events recently proposed for
1619 defining the base of the Priabonian Stage. The pointed lines refer to the tentative correlations.
1620 The Lithological symbols are consistent with Figure 2.
1621
1622 Figure 11. **[[Please include a geographic description.]]** Chrono-biocorrelation of main planktic
1623 foraminifera and calcareous nannofossil events among the central western Tethyan Varignano
1624 (plain character) and Alano (bold character) sections and the western North Atlantic. The
1625 biohorizons in bold character and underlined are the adopted tie points as being well-calibrated
1626 events, in addition to magnetochron reversals. Time scale is according to Pälike et al. (2006).
1627 Note that the major discrepancies are recorded by the *O. beckmanni* base and top (see discussion
1628 in the text). Across the Bartonian–Priabonian interval only the *G. semiinivoluta* base and the *C.*
1629 *oamaruensis* Br show some inconsistencies. GPTS—geomagnetic polarity time scale **[[OK?]]**.
1630 **[[Change Agnini et al. (2014) to 2014a, 2014b, or 2014c in figure.]]**
1631
1632 Figure 12. **[[Please include a geographic description.]]** Biostratigraphic scheme integrating the
1633 calcareous nannofossils, planktic foraminifera, and LF (bold character) across the interval
1634 Bartonian–Priabonian based on the Varignano results. (1) Martini (1971); (2) Okada and Bukry
1635 (1980); (3) Fornaciari et al. (2010); (4) Agnini et al. (2014b); (5) Berggren et al. (1995); (6)
1636 Wade et al. (2011); (7) Papazzoni et al. (2014). Time scale according to Pälike et al. (2006).
1637 GPTS—geomagnetic polarity time scale **[[OK?]]**.
1638
1639 **[[Move the following to Data Repository]]**
1640 Figure DR1.Paleogeographic-palinspastic sketch map of the study area during the lower
1641 Priabonian showing the location of the Varignano section. 1. Basinal emipelagic marls ("Ponte
1642 Pià Formation"), 2. Slope deposits ("Malcesine Limestone"), 3. Platform carbonates ("Nago
1643 Limestone"). Modified from Luciani (1989).

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TABLE 1. POSITION OF SELECTED CALCAREOUS NANNOFOSSIL AND
PLANKTIC FORAMINIFERAL BIOHORIZONS AT THE VARIGNANO SECTION. NORTHERN ITALY

Biohorizon	Sample	Thickness (m)
Calcareous nannofossils		
I. recurvus spike end	BRD58-BRD60	34.820 ± 0.500
I. recurvus spike beginning	BRD54-BRD55	32.635 ± 0.185
Tc *C. erbae*	BRD50-BRD52	30.950 ± 0.500
T *C. grandis*	BRD45-BRD46A	26.750 ± 0.250
Bc *C. erbae*	BRD22-BRD23	21.005 ± 0.125
Br *C. oamaruensis*	BRD17-BRD18	19.775 ± 0.125
T *S. obtusus*	BRD95-BRD96	7.760 ± 0.090
B *S. obtusus*	FBC-83-FGB-123	−1.030 ± 0.200
Tc *H. spiniger*	RBD1-FGB-203	−1.930 ± 0.100
Bc *D. bisectus*	BDR68-BDR69	−3.805 ± 0.125
T *S. furcatolithoides*	BDR72-RBD2	−4.850 ± 0.120
Planktic foraminifera		
B *G. semiinvoluta*	BRD45-BRD46	26.625 ± 0.125
T *P. capdevilensis*	BRD44-BRD45	26.375 ± 0.125
T M . crassatus	BRD3-BRD4	16.165 ± 0.125
T *large acarininids*	BRD2-BRD3	15.915 ± 0.125
T *O. beckmanni*	FBC-45-FGB-38	−0.415 ± 0.035
B *T. cocoaensis*	BRD63-FGB-223	−2.330 ± 0.100
T *T. possagnoensis*	BRD64-BRD63	−2.555 ± 0.125
T *T. frontosa*	BRD64-BRD63	−2.555 ± 0.125
B *O. beckmanni*	BRD66-BRD65	−3.055 ± 0.125
B *T. cerroazulensis*	BRD66-BRD65	−3.055 ± 0.125
Larger foraminifera		
B *Pellatispira*	VAR1-VAR2	1.625 ± 1.7

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TABLE 2. AVERAGE PALEOMAGNETIC DIRECTIONS FROM VARIGNANO SECTION, NORTHERN ITALY

Group	N	Geographic coordinates				Tilt-corrected coordinates			
		k	α95	Dec	Inc	k	α95	Dec	Inc
A	23	1.32	50.7	240.4	18.5	1.33	50.6	233.6	−4.7
Nr	25	6.25	12.6	5.2	15.4	6.08	12.8	29.4	66.2
Rv	8	4.16	27.8	181.2	0.6	4.25	27.4	189.1	−52.2
Nr+Rv	33	5.83	11.4	4.2	11.6	5.67	11.6	22.9	63.2

Note: A—paleomagnetic low-temperature "A" overprint; Nr—normal paleomagnetic polarity directions; Rv—reverse paleomagnetic polarity directions; N—number of directions; k—precision parameter of Fisher (1953); α95 = 95% confidence angle of Fisher (1953); Dec and Inc—declination and inclination of the average paleomagnetic direction.

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Bed name (thickness)	Field observations	Optical analyses	Rock classification
VL -4 (10 cm)	Fine-grained rock with abundant clay content and scattered bioturbations	Clayed-micritic rock with planktic forams with scattered coarse-grained quartz, angular twinned and zoned feldspars, green particles, volcanic-ground mass, and biotite flakes	Sandy marlstone
VL -2 (5 cm)	Fine-grained rock with abundant clay content	Clayed-micritic rock with very diluted planktic forams and scattered feldspar crystals	Poorly [[sorted?]] sandy marlstone
VL -1 (5 cm)	Slightly laminated rock with abundant clay content and coarse crystals at the base	Clayed-micritic rock with planktic forams, twinned and zoned feldspars, quartz crystals with embayments, glauconitized ground masses, debris of macroforams, intraclasts of lime-mudstones with scattered planktic forams, scattered polycrystalline dolomite grains, biotite flakes, and hornblende	Sandy marlstone
VL 0A (20 cm)	Laminated rock with abundant clay content	Clayed-micritic-grain supported rock with abundant planktic forams and scattered feldspars, quartz, ground mass grains, and biotite flakes	Sandy marlstone
VL 0B (10–15 cm)	Fine-grained sand	Twinned and zoned feldspars, quartz, biotite, and abundant green particles; scattered planktic forams	Crystal tuff
VL +1 (10 cm)	Medium-fine grained sand	Twinned and zoned feldspars, biotite, rare quartz, calcite spars, rare green hornblende, volcanic ground mass, and debris of benthic forams	Crystal tuff
VL +2 (25 cm)	Coarse-medium grained sand with normal gradation	Twinned and zoned feldspars and abundant green ground masses	Crystal tuff
VL +3 (20–25 cm)	Medium- to fine-grained sand	Twinned and zoned feldspars, biotite, rare quartz, calcite spars, rare green hornblende, volcanic ground mass with microlithic texture, opaque grains, and debris of benthic forams	Crystal tuff
VL +4 (10 cm)	Fine-grained sand	Twinned and zoned feldspars, biotite, rare quartz, calcite spars, rare heavy minerals, volcanic ground mass, debris of benthic forams	Crystal tuff

TABLE 4. AGE ESTIMATION OF CALCAREOUS PLANKTON BIOHORIZONS
FROM VARIGNANO AND ALANO SECTIONS, NORTHERN ITALY,
COMPARED WITH DATA FROM LEG 171B

Biohorizon	Central western Tethys				North Atlantic
	Varignano		Alano		Leg 171B
	Age (Ma)*,†	Age (Ma)§	Age (Ma)*,#	Age (Ma)§,†	Age (Ma)§,**
T *A. medizzai–A. echinata*	/	/	**37.272**	**37.32**	/
I. recurvus spike end	37.239 ± 0.023	37.276 ± 0.024	37.288 ± 0.003	37.336 ± 0.003	/
I. recurvus spike beginning	37.34 ± 0.008	37.38 ± 0.009	37.347 ± 0.003	37.395 ± 0.003	/
Tc *C. erbae*	37.417 ± 0.023	37.46 ± 0.024	37.449 ± 0.019	37.496 ± 0.020	37.46
B *G. semiinvoluta*	**37.615 ± 0.006**	**37.665 ± 0.006**	**37.665**	**37.719**	**38.00**
T *P. capdevilensis*	**37.627 ± 0.006**	**37.677 ± 0.006**	**37.665**	**37.719**	/
T *C. grandis*	37.61 ± 0.011	37.66 ± 0.012	37.724 ± 0.003	37.78 ± 0.003	37.77
Bc *C. erbae*	37.866 ± 0.004	37.907 ± 0.003	37.833 ± 0.019	37.892 ± 0.019	37.88
Br *C. oamaruensis*	37.907 ± 0.004	37.947 ± 0.003	37.837 ± 0.003	37.895 ± 0.003	37.84
T *M . crassatus*	**38.04 ± 0.005**	**38.073 ± 0.005**	**37.996**	**38.036**	**38.077**
T *A. mcgowrani*	**38.049 ± 0.005**	**38.082 ± 0.005**	**38.001**	**38.041**	**38.087**
T *S. predistentus*	/	/	38.195 ± 0.031	38.235 ± 0.029	/
T *S. obtusus*	38.353 ± 0.003	38.378 ± 0.003	38.253 ± 0.028	38.289 ± 0.026	38.47
T *C. solitus*	/	/	38.49 ± 0.037	38.511 ± 0.036	/
Tc *C. grandis*	/	/	38.971 ± 0.033	38.984 ± 0.033	/
B. *Pellatispira*	**39.24 ± 0.331**	**39.257 ± 0.328**	/	/	/
Tc *C. solitus*	/	/	39.437 ± 0.033	39.441 ± 0.033	/
B *S. obtusus*	39.758 ± 0.039	39.771 ± 0.039	39.633 ± 0.009	39.604 ± 0.009	/
T *H. spiniger*	/	/	39.633 ± 0.028	39.604 ± 0.027	/
T *O. beckmanni*	**39.638 ± 0.007**	**39.652 ± 0.007**	**39.922**	**39.883**	**39.50**
Tc *H. spiniger*	39.933 ± 0.019	39.945 ± 0.019	40.1 ± 0.009	40.055 ± 0.009	/
B *T. cocoaensis*	**40.011 ± 0.019**	**40.023 ± 0.019**	**40.227**	**40.177**	/
T *T. possagnoensis*	**40.055 ± 0.024**	**40.066 ± 0.024**	**40.274**	**40.222**	/
T *T. frontosa*	**40.055 ± 0.024**	**40.066 ± 0.024**	**40.274**	**40.222**	/
B *O. beckmanni*	**40.152 ± 0.024**	**40.163 ± 0.024**	**40.298**	**40.245**	**40.50**
B *T. cerroazulensis*	**40.152 ± 0.024**	**40.163 ± 0.024**	**40.366**	**40.314**	/
Bc *D. bisectus*	40.298 ± 0.024	40.308 ± 0.024	40.59 ± 0.005	40.525 ± 0.006	40.34
Bc *D. scrippsae*	/	/	40.601 ± 0.006	40.536 ± 0.006	/
B *S. predistentus*	/	/	40.78 ± 0.018	40.708 ± 0.017	/
T *S. furcatolithoides*	40.502 ± 0.023	40.51 ± 0.023	40.78 ± 0.018	40.708 ± 0.017	40.51
Bc ? *C. reticulatum*	/	/	41.119 ± 0.036	41.033 ± 0.034	/

*Age (Ma) CK95.
†This study.
§Age (Ma) Pälike et al. (2006)
#Fornaciari et al (2010); Agnini et al. (2011).
Wade et al (2011, 2012); Agnini et al (2014).[[2014a, 2014b, or 2014c?]]

[[References were moved from headers to notes at bottom. OK?]]

[[Also moved "Central western Tethys" from bottom to top. OK?]]

[[As noted in Table 1, changed commas to periods.]]