Integrated biomagnetostratigraphy of the Alano section (NE Italy):
A proposal for defining the middle-late Eocene boundary

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ABSTRACT

The Alano section has been presented at the International Subcommission on Paleogene Stratigraphy (ISPS) as a potential candidate for defining the global boundary stratotype section and point (GSSP) of the late Eocene Priabonian Stage. The section is located in the Venetian Southern Alps of the Veneto region (NE Italy), which is the type area of the Priabonian, being exposed along the banks of the Calcino torrent, near the village of Alano di Piave. It consists of ~120–130 m of bathyal gray marls interrupted in the lower part by an 8-m-thick package of laminated dark to black marlstones. Intercalated in the section, there are eight prominent marker beds, six of which are crystal tuff layers, whereas the other two are bioclastic rudites. These distinctive layers are useful for regional correlation and for an easy recognition of the various intervals of the section. The section is easily accessible, crops out continuously, is unaffected by any structural deformation, is rich in calcareous plankton, and contains an expanded record of the critical interval for defining the GSSP of the Priabonian. In order to further check the stratigraphic completeness of the section and constrain in time the critical interval for defining the Priabonian Stage, we performed a high-resolution study of integrated calcareous plankton biostratigraphy and a detailed magnetostratigraphic analysis. Here, we present the results of these studies to open a discussion on the criteria for driving the “golden spike” that should define the middle Eocene–late Eocene boundary.

INTRODUCTION

Chronostratigraphy, the subdivision and classification of Earth’s geologic record on the base of time (Hedberg, 1976), represents the most widely used “common language” of communication in the earth sciences. The development of a standard global chronostratigraphic scale (GCS), based on rigorous agreement upon stratigraphic principles, terminology, and classification procedure, is one of the long-standing objectives of the International Commission on Stratigraphy (ICS).

A fundamental step toward this goal is the elaboration of a standard series and stage division of each system, together with precise definition of boundaries between them (Bassett, 1985). With regard to the latter effort, the principle has become firmly accepted that the base of each division be defined at a unique point in a rock sequence, representing a unique point in time, to serve as standard against which other sequences can be correlated by the different available time correlation tools. The standard section and point of the definition are referred to as the global boundary stratotype section and point (GSSP) of the designated stratigraphic boundary.

During the last decades, significant progress has been made in establishing the standard GCS, which, integrated with other tools for “geologic time telling,” was synthesized in 2004 in an updated geologic time scale (GTS04; Gradstein et al., 2004). In the GTS04, the Paleogene System, that is the Paleocene, Eocene, and Oligocene Series, remains in a state of major flux (Berggren and Pearson, 2005; Hilgen, 2008) for multiple reasons: (1) existing age models of the geologic time scale (in pre-Oligocene times) are not yet well established, (2) in some intervals, the biomagnetostratigraphic framework is confused because it is based on a limited database, and (3) only the GSSPs of the basal stages of the series (i.e., Danian, Ypresian, and Rupelian) have been defined to date (Premoli Silva and Jenkins, 1993; Molina et al., 2006c; Aubry et al., 2007). As a result, the practice of recognizing intraseries stages and subdivisions is highly contradictory. For example, as reported in Figure 1, the recognition of the base of the Priabonian, i.e., the middle Eocene–late Eocene boundary, varies by more than 1.5 m.y. among various authors. In order to rapidly overcome the current situation, the International Subcommission on Paleogene Stratigraphy (ISPS) has promoted working groups for defining all the Paleogene stages, and proposals are expected soon for all of them (Hilgen, 2008). Within this activity of the ISPS, we were asked to explore the possibility of defining the Priabonian Stage in the Veneto region, NE Italy, where a classical record of early Paleogene stratigraphy is preserved that has served as reference for introducing the Priabonian Stage for over a century (Munier Chalmas and de Lapparent, 1893). All the sections indicated by Munier Chalmas and de Lapparent, located in the Lessini Mountains and Berici Hills (western Veneto; Fig. 2), and in particular, the stratotype section near the village of Priabona, in the eastern Lessini Mountains (Roveda, 1961; Hardenbol, 1968; Fig. 2), were deposited in shallow-water sediments that are difficult to precisely frame in time and, hence, are unsuitable for usefully defining a chronostratigraphic unit. Therefore, at the Eocene Colloquium held in Paris in 1968 (Cita, 1969), several parastratotypes sections were proposed, among which the deep-water section of Possagno (Treviso Province; Fig. 2), where...
Figure 1. Time frame of the middle to late Eocene. The chronology is based on the geomagnetic polarity time scale (GPTS) of Cande and Kent (1995). Planktic foraminiferal zones are from Berggren and Pearson (2005). Calcareous nannofossil standard zones are those of Martini (1971) and Okada and Bukry (1980); several additional calcareous nannofossil biohorizons are also reported. Age estimations of calcareous plankton bioevents are after Berggren et al. (1995; BKSA95), Fornaciari et al. (2010), and this work. The chronostratigraphies used are those previously proposed by Berggren et al. (1995; BKSA95) and more recently by Gradstein et al. (2004; GTS04). On the right, the main paleoclimatic events and/or long-term trends are presented together with enhanced preservation interval of CaCO₃ (Lyle et al., 2005; Tripati et al., 2005) and the sea-level curve of Miller et al. (2005).
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Figure 2. Geographic and geological context of the Alano section. (A) Paleogeographic reconstruction of the main paleogeographic elements of the southern Alps during the Paleogene (adapted from Bosellini and Papazzoni, 2003). (B) Simplified geological scheme of the Southern Alps (adapted from Doglioni and Bosellini, 1987). (C) Simplified geological sketch of the study area. (D) Location map of the study area with indication of the Alano section. The best access to the section (dashed line) is also reported.
calcareous plankton are abundant and facies are suitable for long-distance correlations, was particularly promising. The section was intensively studied in the seventies (Bolli, 1975). Unfortunately, the transition from the Middle to the Upper Eocene is poorly outcropping, and no meaningful proposal of the GSSP of the Priabonian could be made. However, detailed geological mapping executed close to the village of Alano di Piave, some 8 km NE of Possagno (Treviso Province; Fig. 2), indicated that the transition from the Middle to Upper Eocene was present there in a deep-water, expanded succession that spectacularly outcrops with absolute continuity (Fig. 3). This section, in the following termed the Alano section, which has been orally presented at the ISPS since 2004 (the annual reports are available at the Web site http://wzar.unizarec.isps/priabonian2004.htm), is first described in this paper, wherein:

1. we provide a detailed lithologic description and report a high-resolution integrated calcareous plankton biostratigraphy and magnetostratigraphy carried out in the section;

2. we present an improved biomagnostratigraphic framework of the middle to late Eocene transition based on the results obtained from the Alano section and data collected specifically for this work on the calcareous nanofossils at Ocean Drilling Program (ODP) Site 1052, in the western North Atlantic, a reference section for the transition based on the results obtained from the Alano di Piave section. Actually, tectonic deformation in the Alano section seem to have not been deeply buried, as testified by the good preservation of microfossils and the scarce maturity of the organic matter (Spofforth et al., 2010).

3. we show that the Alano section is complete, straddling the critical interval for defining the middle Eocene–late Eocene boundary, and it is well and widely correlatable worldwide;

4. we propose a specific lithologic level in the Alano section as the GSSP of the Priabonian, discussing the rationale for the proposal in terms of historical appropriateness and global correlation; and

5. we discuss the work that still is lacking for making the geologic time scale at the transition from the middle to late Eocene more reliable.

ALANO DI PIAVE SECTION

In the following, we provide general geographic and geologic information on the Alano section, with a special emphasis in its lithostratigraphy.

Location and Outcropping Conditions

The Alano section is located in the southern part of the Belluno Province, Veneto region, in NE Italy, ~8 km NNE from the well-known deep-water Possagno section and ~50 km NE from the Priabona section, the historical stratotype of the late Eocene Priabonian Stage (Fig. 2). Its latitude is 45°54'51.10"N, and its longitude is 11°55'4.87"E (WGS84).

The study section is exposed for ~500 m along the banks of Calcino Creek, between the small villages of Colmirmano and Campo, ~1 km NE of the Alano di Piave village (Fig. 2). In correspondence to the section outcrop, Calcino Creek has deeply eroded the Quaternary deposits (Figs. 3 and 4), exposing the marly substratum in banks 2 m up to 6 m high, along which the succession outcrops with total continuity (Fig. 5).

The lithology is mainly represented by grayish hemipelagic marls with intercalated numerous millimeter-thick sandy-silty layers and 8- to ~6-cm-thick sandy-silty layers that represent useful marker beds. Six of these thicker layers are crystal tuff layers and have been named from the bottom to the top after famous Venetian painters: Mantegna, Giorgione, Tiziano, Tiepolo, Tintoretto, and Canaletto beds (Fig. 6); the other two marker beds are bioclastic rudite beds and have been named Palladio and Canova after famous Venetian artists (Fig. 6).

The general bedding strike is 130–140°N and the dip is ~20–25°. The section is unaffected by tectonic deformation in the Alano section seem to have not been deeply buried, as testified by the good preservation of microfossil and the scarce maturity of the organic matter (Spofforth et al., 2010).

The section measured for the present work is ~105 m thick (Fig. 6). Above the study interval, there are at least 15 m of continuously outcropping marls, followed downstream only by spotted outcrops.

Access to the Section

The Alano di Piave village is easily reached by regional road SR 348 and provincial road SP10 (Fig. 2D). The best way to access the section is to pass the small Colmirmano village and reach the soccer field reported in Figure 2D. From the parking lot of the soccer field to the base of the section, there is an easy walk of some 300–400 m in a plain grass field (Fig. 2D).

Regional Geologic Context

The Veneto region is part of the eastern Southern Alps (NE Italy; Fig. 2), a major structural element of the Alpine chain interpreted as a south-verging fold-and-thrust belt (Dolgioni and Bosellini, 1987) resulting from the polyphasic deformation of the southern passive continental margin of the Mesozoic Tethyan Ocean (Bermoulli, 1972). This continental margin is interpreted either as a part of a promontory of the Africa continent (Channell et al., 1979; D’Argenio et al., 1980) or an independent microcontinent (Adria; e.g., Dercourt et al., 1986). During the Middle–Late Triassic, this area was characterized by extensive shallow-water carbonate platforms (e.g., Dolomia principale; Costa et al., 1996) that were broken up during the Early Jurassic because of regional rifting that resulted in the separation between Europe and Africa. In particular, this process led to the drowning of the entire Southern Alps, where several NNE-SSW-trending “lows” and “highs” began to develop. From east to west, these are the Friuli Platform, the Belluno Basin, the Trento Platform (or Trento Plateau), and the Lombardian Basin (Bermoulli and Jenkyns, 1974; Bermoulli et al., 1979; Winterer and Bosellini, 1981; Fig. 2A). As the rifting process came to an end, widespread, rather uniform pelagic sedimentation (Rosso Ammonitico Veronese, Biancone, Scaglia Rossa; Costa et al., 1996) began throughout the Southern Alps, spanning from the Middle Jurassic to the early Eocene (Bosellini, 1989; Channell et al., 1992). This widespread pelagic sedimentation was terminated in the early Eocene, when a major paleogeographic reorganization of the Southern Alps, tied to the complex collision between Europe and the African promontory (or Adria microplate; Dolgioni and Bosellini, 1987), occurred. The former Trento Plateau was uplifted and block-faulted, and significant basic to ultrabasic volcanic activity characterized the area in between the Giarda Lake and the Brenta River since the Paleocene (e.g., Beccaluva et al., 2007). An articulated and complex paleogeography developed that resulted in rapid changes of facies, from continental to deep marine deposits. In the western part of the Veneto region, carbonate shallow-water sedimentation resumed with the formation of an articulated carbonate platform referred to as Lessini Shelf (Bosellini, 1989; Fig. 2A). This platform represents, albeit reduced in size, the renewed Trento Platform (Bosellini, 1989; Fig. 2). In the eastern part of the region, where the Jurassic Belluno Basin was set, deep-water sediments persisted up to early Eocene time. These pelagic and hemipelagic sediments attributable to the Scaglia Rossa (Dallanave et al., 2009) were capped by a turbiditic succession, locally up to 1000 m thick, referred to as the Flysch di Belluno (Stefani and Grandesso, 1991; Costa et al., 1996; Stefani et al., 2007), which represents the foredeep deposits linked to
Figure 3. Geologic map of the study area. A legend with a detailed description of lithostratigraphic units is also reported in the lower part of the figure (see text for discussion).
the erosion of the Dinaric chain; these sediments become younger southwestward (Grandesso, 1976) due to the migration of the Dinaric thrusts system (e.g., Doglioni and Bosellini, 1987). Between the Belluno Basin and the Lessini Shelf, a transition area developed, where a hemipelagic sedimentation, referable to Scaglia Rossa sensu latu persisted up to the early-middle Eocene. These deep-water deposits were later capped by slope to outer-shelf marlstones and claystones, referred to in the literature as Scaglia Cinerea (see following) and Marna di Possagno from the middle to late Eocene (Cita, 1975; Trevisani, 1997), that show a clear regressive trend eventually leading, in the advanced Priabonian, to the deposition of inner-shelf mud and sand (upper part of the Marna di Possagno) and shelf carbonates (Calcare di Santa Giustina). Both the Alano and Possagno sections are located in this transitional area.

**Local Geologic Context**

In order to frame the Alano section in its geologic context, we provide a geological map of the area (Fig. 3). The section is located in the core of a wide fold that is W-E oriented and composed of Upper Jurassic–Eocene deep-water units (e.g., Biancone, Scaglia Rossa; Figs. 3 and 4). This fold is referred to as the Alano–Segusino syncline and is located between the Tomba Mountain anticline to the south and the Grappa Mountain–Tomatico Mountain anticline to the north, and it is bounded to the west by the Schievenin line (Fig. 2C).

**Lithostratigraphic Assignment**

Despite the fact that the Paleogene of the Veneto region has been investigated for a long time, the lithostratigraphic assignment of the succession outcropping at Alano is not straightforward. The marly sediments at Alano are virtually identical to those observed in the upper part of the Carcoselle segment of the classical Possagno section (middle Eocene), where they have been referred to as Scaglia Cinerea (Agnini et al., 2006). However, Scaglia Cinerea is one of the traditional Italian lithostratigraphic units first described in the Umbria-Marche area by Bonarelli at the end of nineteenth century (Bonarelli, 1891) and later ascribed to late Eocene–Miocene age (Canavari, 1894; Selli, 1954; Coccioni et al., 1988). In addition, this term was improperly used for describing a Paleocene lithostratigraphic unit outcropping in eastern part of the Belluno Basin (Di Napoli Alliata et al., 1970). The ambiguous significance of this term creates confusion and uncertainty and should be abandoned in the Veneto region. The lithologic assignment of the Alano section still remains problematic, because at Alano, the succession shows a carbonate content higher than 20%, thus preventing a possible association with Marna di Possagno, which is defined by CaCO₃ values never exceeding 20% (Cita, 1975).

Because none of the existing formational units available can be properly applied to the succession outcropping at Alano, we have decided to provisionally and informally introduce the term “Marna Scagliosa di Alano” for referring to the entire succession of the Alano section. However, it is noteworthy that at the Possagno section, similar sediments, interposed between Scaglia Rossa and Marna di Possagno, have been previously referred to as Scaglia Cinerea. On this basis, we thus stress the need for a systematic revision of the regional Paleogene lithostratigraphy to overcome the current situation.

**Detailed Lithologic Description**

We logged the lithology of the Alano section at very high resolution with observation at the centimeter scale. A simplified columnar log of the section is reported in Figure 5, together with the CaCO₃ contents (%) determined by the EUROPA Scientific GEO 20–20 isotope mass spectrometer (Spofforth et al., 2010). The rather monotonous mudstone facies is interrupted by a distinctive ~8-m-thick package of often laminated dark to black, organic-rich clayey marls in the lower part of the section. A repetitive characteristic feature throughout the section is also the presence of sandy-silty layers, six of which are more prominent, being thicker than 6 cm.

**Crystal Tuff Layers**

In order to avoid repetitions in describing the sandy-silty layers, in the following text, we provide a general overview of the similar petrographic characters while referring to Table 1 for a detailed description of each layer. These beds are dark gray–black in color, and a millimeter- to centimeter-thick greenish plastic clay is sometimes present at the top. There is no evidence of current activity, while the bed thickness is slightly laterally variable. Quite abundant, small (4–10 mm in diameter), horizontal to subvertical, cyclindrical burrows sometimes filled with greenish clays, suggest a quick depositional mechanism. The optical analyses reveal that these layers are almost exclusively made of angular crystal-shape twinned or zoned feldspars, quartz grains, biotite flakes, vitric or microlithic volcanic rock fragments, scarce heavy minerals, and sporadic bioclasts. All data, which include mineralogical composition, grain size, lack of cementation, common vertical burrowing, and the lack of current activity, point to a common volcanic source for these type of layers, which are suspected to be tephra layers, i.e., linked to fallout deposits. Due to prevailing types of grains, they are classified as crystal tuffs (Schmid, 1981). The scattered bioclastic content is linked to common bioturbation traces or to normal water-column deposition. X-ray analyses on the clay intervals show great abundance of illite-smectite clay (IS) material (Tateo, 2009, personal commun.).

**Lithozone Description**

Field observations integrated with carbonate values allow the subdivision of the section into four lithozones:

**Lithozone A (0–17 m level).** The marly facies of the basal lithozone up to 13.4 m level is the more calcareous interval in the section. Carbonate content ranges from 57% to 21%, with average values of 45%. In the interval,
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Figure 5. Lithologic column of the Alano section. The main volcanlastic/bioclastic beds are positioned in the log and named after famous Venetian artists. CaCO₃ content throughout the section is presented in the central part of the section (after Spofforth et al., 2010). The total carbonate content allows the subdivision of the section into four lithozones reported on right side.
we recognized several millimeter-thick layers and two major crystal tuff layers that have been named Mantegna and Giorgione (Figs. 5 and 6; Table 1).

**Lithozone B (17–25.5 m level).** A prominent package of dark to black, more clayey lithologies interrupts the monotonous lithology of the section. This interval is easily recognized in the field and is reminiscent of the classical Cretaceous black shales widely outcropping in the Southern Alps. The base of the interval is sharp with a marked contrast in color that is caused by an increase in organic carbon content, from the background values of ~0.1% to 3% (Spofforth et al., 2010). The stratigraphy within the package is structured: it is interrupted at 18.90 m level by a 2-m-thick interval of marls similar to those present in the underlying and overlying intervals. The carbonate content reaches the lowest values in the section (around 22%) and mimics the tripartition observed in the lithology, even if the decrease of the carbonate contents starts below the base of the interval at 13.4 m level (Figs. 5 and 6). This peculiar lithozone corresponds largely to a global major climatic perturbation, the so-called middle Eocene climatic optimum (MECO) as detailed in Spofforth et al. (2010) see also Bohaty and Zachos, [2003] and Bohaty et al. [2009] for an overview). Upward, two prominent bioclastic arenitic/ruditic layers, the first one located in lithozone B and the second one lying in lithozone C (Fig. 5), are observed in the lower-middle part of the section. The faunal associations and sedimentological characters of both strata point to re-sedimentation processes of shallow-water clasts from the nearby Lessini Shelf.

**Lithozone C (25.5–59.95 m level).** The middle-upper part of the section, starting from 25.5 m level up to the top, cannot be differentiated in the field, but the carbonate content undergoes a major change at 59.95 m level, where a decrease, used for separating the two lithozones C and D, is observed (Fig. 5). Specifically, from 25 to 59.95 m level, the total carbonate content curve shows wide oscillations ranging from 31% to 56%, with an average value of 46%. Lithozone C is characterized by the absence of thick volcaniclastic layers that are present both in lithozone A and the overlying lithozone D. The only marker bed observed in this interval is represented by the bioclastic Canova bed (Fig. 5), which can be classified as a bioclastic rudstone (Table 1).

**Lithozone D (59.95 m level to section top).** From ~60 m level up to the section top, total carbonate contents range from 29% to 51%, with an average value of 41%. In lithozone D, four prominent crystal tuff layers are present, in ascending order, they are the Tiziano Bed, the Tiepolo Bed, the Tintoretto Bed, and the Canaletto Bed (Fig. 6). The Tiziano Bed is the most prominent, being 16 cm thick (Table 1).

**Paleontological Content**

The hemipelagic marls of Alano section contain abundant calcareous nannofossils, planktic foraminifera, and common benthic foraminifera, and rare ostracods. Palinomorphs are abundant as well (Brinkhuis, 2009, personal commun.). Scattered bryozoans have been found in the upper part of lithozone D (e.g., Batopora spp.; Braga, 2009, personal

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Figure 6. Alano section. (A) View of the lower part of the Alano section (lithozone A). (B) Detail of lithozone A with indication of the crystal tuff layer Giorgione. (C) Basal portion of the sapropelic interval, the lithological expression in the study area of the middle Eocene climatic optimum (lithozone B). (D) The upper part of the sapropelic interval with indication of the prominent bioclastic layer Palladio (lithozone B and C). (E) Close-up view of the critical interval showing the prominent crystal tuff layer Tiziano (basal lithozone D). (F) Upper part of the sampled section with indication of the crystal tuff layer Canaletto (lithozone D).
commun.). The macrofossils are conspicuously absent, as expected in deep-water sediments like those cropping out in the Alano section. In our detailed field work, we found just two badly preserved bivalves in lithozone C and scattered plant debris throughout the section. Ichnofossils are commonly present throughout the section and are mainly represented by Zoophycos in the gray marls and Chondrites in the black interval during the middle Eocene climatic optimum.

DATA AND RESULTS

We first present benthic foraminiferal assemblages data and planktic/benthic (P/B) ratios that were used to infer the paleodepth of the Alano succession and thus better constrain the depositional setting throughout the section. Succesively, we illustrate the magnetostratigraphy and calcareous plankton biostratigraphy of the Alano section in an attempt to establish an accurate chronology.

Table 1. Petrographic characterization of crystal tuff and bioclastic beds

<table>
<thead>
<tr>
<th>Rock classification</th>
<th>Optical analyses</th>
<th>Field observations</th>
<th>Bed name thickness (cm)</th>
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<tbody>
<tr>
<td>Crystal tuff</td>
<td>Sand consisting of more than 80% of feldspars, quartz, biotite, volcanic lithics, and heavy minerals, with scattered planktonic foraminifera and small calcite spars</td>
<td>Uncemented sand, with biotite flakes at the base</td>
<td>Mantegna (11 cm)</td>
</tr>
<tr>
<td>Crystal tuff</td>
<td>Sand consisting of almost 70% feldspars, quartz, biotite, and heavy minerals, with scattered planktonic foraminifera and small calcite spars</td>
<td>Slightly cemented sand with horizontal burrowing</td>
<td>Giorione (4-5 cm)</td>
</tr>
<tr>
<td>Bioclastic rudstone-packstone</td>
<td>Carbonate rock with clastic texture; the grains are biosomes and clasts of nummuliths, discocyclinids, debris of bryozoans, corallineacean algae, miliolids, and echinodermata. Green particles are present both as individual grains and as infill of foraminifera tests. Sutured and concave-convex contacts between grains and mechanical fractured bioclasts</td>
<td>Normal graded bioclastic horizontal lamination arenite with sparse green grains. Quite frequent large (up to 8 cm) pelitic intraclasts at the base; common bioturbation</td>
<td>Palladio (12-16 cm)</td>
</tr>
<tr>
<td>Bioclastic rudstone</td>
<td>Carbonate rock with clastic texture; at the base, floatstone with pelitic intraclasts and scattered debris of corallineacean algae, echinodermata, bryozoa, and nummuliths, rapidly grading to a bioclastic packstone</td>
<td>Bioclastic rudite with large forams with closed-sutured contacts</td>
<td>Canova (3-6 cm)</td>
</tr>
<tr>
<td>Crystal tuff</td>
<td>Uncemented sand to silt made of transparent fragments, quartz, and biotite and green particles. Scattered heavy minerals, calcite gouges, and foraminifera tests</td>
<td>Sandy-silty bed: at the base, horizontal burrowing, sometimes crossing the entire bed. At the top a centimeter-thick green pelitic plastic interval</td>
<td>Tiziano (14-16 cm)</td>
</tr>
<tr>
<td>Crystal tuff</td>
<td>Slightly cemented sand consisting of almost 80% feldspars, quartz, biotite, and volcanic lithics</td>
<td>Very fine-grained sands, with horizontal burrowing at the base</td>
<td>Tintoretto (10-12 cm)</td>
</tr>
<tr>
<td>Crystal tuff</td>
<td>Sand consisting of almost 70% feldspars, quartz, biotite flakes, and heavy minerals, with scattered bioclastic debris</td>
<td>Coarse-grained silt, with concentration of large biotite flakes in parallel laminae; horizontal burrowing at the base</td>
<td>Tiepolo (11 cm)</td>
</tr>
<tr>
<td>Crystal tuff</td>
<td>Sand made of about 80% crystal-shape feldspars, quartz, biotite, volcanic lithics, and scattered heavy minerals</td>
<td>Medium-to-fine-grained sands with cross lamination and abundant biotite; on the top, 2-mm-thick interval of large (up to 3 mm in diameter) biotite flakes</td>
<td>Canaletto (6 cm)</td>
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Benthic Foraminifera and Paleodepth at Alano

Samples used for studying benthic and planktic foraminiferal assemblages were prepared following standard methods. Briefly, the indurate marlstones were disaggregated with hydrogen peroxide at concentrations varying from 10% to 30%. When necessary, samples were additionally treated using Neo-desogen, a surface-tension–active chemical product of the Ciba Geigy Company. Finally, to break up clumps of residue, some samples were placed in a gentle ultrasonic bath.

Paleobathymetric estimates of the section were based both on P/B ratio and presence of index taxa. The P/B ratio is expressed as 100 × P/(P + B), i.e., the percentage of planktic foraminifera in the total foraminiferal assemblages, using >63 μm size fraction. The presence of benthic foraminiferal paleobathymetric index taxa (e.g., Van Morkhoven et al., 1986) was evaluated within 23 samples throughout the entire section, scanning residues splits of both >63 and >125 μm size fractions. Bathymetric divisions follow van Morkhoven et al. (1986) and Berggren and Miller (1989): upper bathyal 200–600 m, middle bathyal 600–1000 m, and lower bathyal 1000–2000 m.

The small benthic foraminiferal assemblages at Alano are highly diverse and dominated by calcareous taxa, indicating deposition well above the calcite compensation depth. The most common calcareous taxa are bolivinoids (Bolivinoides crenulata latu sensu and Bolivina antegressa group), uniserial taxa, lenticulinitids, Osangularia pteromphalia, Globocassidulina subglobosa, Oridorosinus umbonatus, Cibicoides spp., Anomalinaeoides spissiformis, and gyroidinids (namely Gyroidinoides girardanus). Representatives of the triserial morphgroups such as Bulimina and Uvigerina consistently occur in some samples, especially from the saporpelic interval. Miliolids, which include mainly Spirococulina sp., are generally rare. The agglutinated foraminiferal assemblages are mostly represented by clavulinids, Anmodiscus, Karrerellina, Karrirella, vulvulinids, and Plectina dalmatina. Resedimented small benthic shallow-water taxa, e.g., asterigerinids, Schlossserina asterites, Sphaerovagmina globula, and Thalmannia sp., were solely observed in the marls just above bioclastic macroforaminifera-bearing layers (e.g., Canova bed).

The P/B ratio shows values >95% at the base of the section, decreasing up to ~90% at 76 m level, whereas in the remaining 30 m, it fluctuates around 85% (Fig. 7). Percentages >90% are consistent with deposition at bathyal and greater depths (e.g., Gibson, 1989; van der Zwaan et al., 1990). However, it must be noted that P/B values <90%, recorded from 81 to 105 m, are probably affected by a general up-section decrease in the planktic foraminiferal preservation state. In order to better constrain the paleodepth of the Alano section, the distributions of frequently occurring, cosmopolitan benthic taxa useful to infer paleobathymetric position are reported in Figure 7. The paleodepth ranges used here are those of Tjalsma and Lohmann (1983), van Morkhoven et al. (1986), Berggren and Miller (1989), Müller-Merz and Oberhänsli (1991), Bignot (1998), and Barbieri et al. (2003). Throughout the investigated section, many taxa occur with an upper bathyal upper depth limit or are common at bathyal depths, e.g., Bolivina antegressa group, Osangularia pteromphalia, Rectuvigerina mexicana, Cibicoides eocaenus, C. hettneri, C. micrus, Bulimina tuxpanensis, Hanzovaia ammolites, Anomalinaeoides capitatus, A. spissiformis, and A. alazanensis (e.g., Van Morkhoven et al., 1986; Holbourn and Henderson, 2002; Barbieri et al., 2003). Bolivinoides crenulata...
latu sensu, the most common and continuously present taxon at Alano, has a wide bathymetric distribution (e.g., Sztrákos, 2005; Nomura and Takata, 2005; Ortiz and Thomas, 2006; Molina et al., 2006a; Alegret et al., 2008). 

Nuttallides truempyi is present, up to 83.6 m level, and the Bulimina impendens-trinitatensis group is present up to the top of the section. These two taxa are described commonly as having an upper depth limit around 5–700 m (e.g., van Morkhoven et al., 1986; Barbieri et al., 2003; Molina et al., 2006b), which further constrains the deposition of the Alano section to at least upper-middle bathyal depths. In their bathymetric zonation of the Possagno section (7 km south of Alano), Grünig and Herb (1980) used the disappearance of Nuttallides truempyi to separate their deeper assemblage 1 (nearly 1000 m for the uppermost part) from the shallower assemblage 2 (between 1000 and 600 m). The presence of specimens of Cibicidoides grimsdalei, a cosmopolitan and easily recognizable taxon for which an upper depth limit within the lower bathyal zone has been reported (van Morkhoven et al., 1986; Bignot, 1998; Barbieri et al., 2003; Katz et al., 2003), suggests for the lower two-thirds of the measured section, deposition occurred close to the lower-middle bathyal boundary. It must be noted, however, that C. grimsdalei has been recently reported by some authors (Mancin and Pirini, 2002; Ortiz and Thomas, 2006; Živkovic and Glumac, 2007) in supposed upper-middle bathyal sediments. Summarizing the aforementioned considerations, we can hypothesize a bathymetric evolution for the Alano section from a full middle bathyal depositional depth (lower two-thirds of the section,
Paleomagnetism

Paleomagnetic samples were drilled and oriented in the field at an average sampling interval of ~0.6 m, giving a total of 159 standard ~11 cm³ specimens for analysis (Figs. 8A–8B), conducted at the Alpine Laboratory of Paleomagnetism (ALP). The intensity of the natural remanent magnetization (NRM), measured on a 2G DC-SQUID cryogenic magnetometer located in a magnetically shielded room, ranged between 0.03 and 24 mA/m (mean of 2.7 ± 8 mA/m), with a single sample reaching 89 mA/m; higher values were prevalently associated with volcanioclastic-rich intervals (Fig. 8C). All samples were thermally demagnetized from room temperature to 400–600 °C. The component structure of the NRM was monitored after each demagnetization step by means of vector end-point demagnetization diagrams (Zijderveld, 1967). Magnetic components were calculated by standard least-square analysis (Kirschvink, 1980) on linear portions of the demagnetization paths and plotted on equal-area projections. Fisher (1953) statistics were applied to calculate overall mean directions. After removal of spurious initial magnetizations, the presence of a bipolar characteristic (Ch) component trended to the origin of the demagnetization axes was observed in 65% of the samples on average between ~200 and ~400 °C. Above ~400 °C, the Ch component usually became unstable, and the origin of the demagnetization axes was rarely approached at ~550–575 °C, suggesting the presence of (titano)magnetite as main carrier of the magnetic remanence (Fig. 9A). The Ch component, characterized by a maximum angular deviation values usually below 10° (Fig. 8D), was oriented either northwest and shallow down or southeast and shallow up in geographic (in situ) coordinates, and it becomes steeper after correction for homoclinal bedding tilt (azimuth of dip/dip = 130–140°/E20–25°) (Figs. 9A–9B). These populations depart from antipodal by ~11°, which we attribute to residual demagnetization from spurious lower-temperature components. The effect of the contaminating bias on the mean direction can be minimized by inverting all directions to common polarity, which resulted in a tilted-corrected mean direction of declination (Dec.) = 351°, inclination (Inc.) = 39.5° (√N = 104, k = 12, α95 = 4°; Table 2).

We compare the mean paleomagnetic pole (paleopole) from Alano (65.4°N, 211.7°E; Table 2), calculated from the characteristic component mean direction in tilt-corrected coordinates, to the Late Cretaceous–Cenozoic (80–0 Ma) synthetic apparent polar wander (APW) path in African coordinates of Besse and Courtillot (2002). The Alano paleopole (A. obs in Fig. 9C) falls at lower latitudes with respect to the 40 Ma African paleopole (77.3°N, 191.6°E, A95 = 7.2°). This is because the characteristic component mean inclination from Alano (39.5° ± 4°) is ~13° shallow compared to the inclination expected at the site from the 40 Ma paleopole (53° ± 5°). Syn- and/or post-depositional compaction can produce an inclination flattening of the magnetic remanence in sediments (e.g., Tauxe, 2005); hence, we used the elongation/inclination (E/I) method of Tauxe and Kent (2004) to detect and correct for the shallow bias of paleomagnetic directions (see also Krijgsman and Tauxe, 2004; Kent and Tauxe, 2005).

We unflattened the Alano characteristic directions by applying flattening (f) values ranging from 1 to 0.3, and for each unflattening step, we evaluated the E/I value of the directional data set (Fig. 9D, heavy line with ticks). The E/I pair consistent with those expected from a statistical geomagnetic field model (TK03.GAD, Tauxe and Kent, 2004; Fig. 9D, dashed line) was attained at f = 0.57. The analysis was repeated 5000 times by means of bootstrap technique (examples of bootstrapped curves are plotted as light curves in Fig. 9D). In Figure 9E, we show a cumulative distribution of all inclinations derived from the bootstrapped crossing points. We obtained a corrected mean inclination and associated 95% confidence interval of Inc. = 53° (42°–69°), which is virtually identical to the inclination expected from the coeval 40 Ma African paleopole (Inc. = 53° ± 5°), and indicates a mean paleolatitude for Alano of ~34°N.

The unflattened mean characteristic direction of the Alano section (Dec. = 351.2°, Inc. = 53°) yielded a corrected paleopole (A. corr in Fig. 9C; 75.9°N, 223.5°E) that falls on the early Cenozoic portion of the African APW path and is only moderately rotated counterclockwise by 9° ± 8° with respect to the 40 Ma African paleopole. We can therefore consider this part of the Southern Alps as tectonically coherent with Africa since at least the Eocene, in substantial agreement with previous findings from the nearby Paleocene–Eocene Possagno section (Agnini et al., 2006) as well as from sites of Peruvian–Mesozoic age from elsewhere in the Southern Alps, e.g., the Dolomites (e.g., Mutti et al., 2003, and references therein).

A virtual geomagnetic pole (VGP) was calculated for each characteristic component direction in tilt-corrected coordinates. The latitude of the sample characteristic magnetization VGP relative to the mean paleomagnetic (north) pole axis was used for interpreting polarity stratigraphy (Lowrie and Alvarez, 1977; Kent et al., 1995). VGP relative latitudes approaching +90°N or ~90°N are interpreted as recording normal or reverse polarity, respectively (Fig. 8E). For polarity magnetozone identification, we adopted the nomenclature used by Kent et al. (1995). We assigned integers in ascending numerical order from the base of the section to polarity intervals as defined by successive pairs of predominantly normal and predominantly reversed magnetozones. Each ordinal number is prefixed by the acronym for the source of the magnetostatigraphy (i.e., “A” for Alano), and has a suffix for the dominant polarity (“n” is normal, “r” is reversed) of each constituent magnetozone. An overall sequence of 13 polarity magnetozones, labeled from A1r to A4r (?), has been established starting from the section base (Fig. 8F); of these magnetozones, one is poorly defined by only intermediate VGP latitudes (A1n.1r), and two are defined by only one sample (A2n.2r, A4r).

Planktic Foraminifera

For the planktic foraminifera study, 264 samples were prepared using standard methods (see benthic foraminifera and paleodepth at Alano). All samples were washed through a 38-µm-mesh sieve in order to avoid the loss of the very small specimens; the finest fraction was separated from the 63 µm residue. Foraminifera are continuously present, abundant, and diverse throughout the section, except for some levels from the sapropelic interval. The preservation varies from moderate to good, and microfossil assemblages are generally well recognizable even if recrystallization of tests commonly
Figure 8. Stratigraphic synthesis of the Alano section with (A) lithology, (B) stratigraphic position of samples for paleomagnetic analysis, (C) natural remanent magnetization (NRM) intensity, (D) mean angular deviation (MAD) of the characteristic magnetic component, and (E) virtual geomagnetic pole (VGP) latitude used for polarity interpretation (F); black is normal polarity; white reverse polarity.
Figure 9. (A) Vector end-point demagnetization diagrams of Alano samples. Closed symbols are projections onto the horizontal plane, and open symbols are projections onto the vertical plane in geographic (in situ) coordinates. Demagnetization temperatures are expressed in °C. NRM—natural remanent magnetization. (B) Equal-area projections before (in situ) and after bedding tilt correction of the characteristic component directions from Alano (Table 2). Closed symbols are projections onto the lower hemisphere, and open symbols are projections onto the upper hemisphere. The geocentric axial dipole (GAD) is indicated by the solid star. (C) The paleopole from Alano calculated from the mean characteristic component in tilt-corrected coordinates (A.obs; Table 2) falls at lower latitudes compared to the reference Late Cretaceous–Cenozoic (80–0 Ma) synthetic apparent polar wander (APW) path in African coordinates of Besse and Courtillot (2002) (solid line with A95 error circles), probably because of anomalously shallow paleomagnetic inclinations recorded in the Alano sediments. After inclination shallowing correction, obtained by using the elongation/inclination (E/I) method of Tauxe and Kent (2004), the corrected paleopole (A.corr; Table 2) is in latitudinal agreement and only moderately rotated counterclockwise by 9° ± 8° with respect to the broadly coeval 40 Ma African paleopole. The Alano sampling site is also indicated together with the poles–site colatitude great circle (dashed line). (D) Plot of elongation versus inclination for the TK03.GAD (Tauxe and Kent 2003. Geomagnetic Axial Dipole) model (dashed line) and for the Alano data (line with ticks) for different flattening (f) values from 1 to 0.3. The ticks indicate the direction of elongation, horizontal being E-W and vertical being N-S. Also shown are the results from 20 (out of a total of 5000) bootstrapped data sets. The crossing points represent the inclination/elongation pair most consistent with the TK03.GAD model. (E) Histogram of crossing points from 5000 bootstrapped data sets. The most frequent inclination (Inc_c = 53°; 95% confidence interval = 42°–69°) is in good agreement with the inclination expected at Alano from the 40 Ma synthetic pole of Besse and Courtillot (2002) (Inc_c = 53° ± 5°). The mean inclination of the raw data in tilt-corrected coordinates (Inc_c = 39.539.5° ± 4°) is also indicated. See text for discussion.
occurs. Taxonomic criteria adopted in this study are after Pearson et al. (2006). Illustrations of selected significant species, including zonal markers, are provided in Plate 1.

The biostratigraphic classification of the late Middle Eocene and late Eocene is in a state of flux. An extensive review is available in the revised tropical to subtropical Paleogene planktonic foraminiferal zonation by Berggren and Pearson (2005), to which we refer (Fig. 1), though the biozonal scheme proposed in Berggren et al. (1995) is reported as well. We have also taken into account the scheme of Toumarkine and Bolli (1970), later updated in Toumarkine and Luterbacher (1985), based on the evolution of the *Turborotalia cerroazulensis* plexus, and specifically developed for midlatitude areas, with specific reference to sections located in the Veneto region. In the scheme of Berggren and Pearson (2005), we have combined zones E10 and E11, altogether equivalent to the long zone P12 in the scheme of Berggren et al. (1995), because at Alano, the highest consistent occurrence *Gambelitrioides nuttalli* is recorded at 57.52 m level, after the HO of *Oorbuitinoides beckmanni* (Fig. 10). Indeed, rare and small specimens of *G. nuttalli* (Plate 1; Fig. 10) are present up to 75.61 m level, within zone E14.

In this study, we carried out planktic foraminiferal analysis for the >63 µm size fraction. Samples were first studied qualitatively to check for presence-absence of index species. Quantitative analysis was performed for establishing the distribution patterns of the zonal markers, including key species of middle Eocene–late Eocene transition (e.g., *morozovellids*, acarininids). The sample spacing is on average 40 cm, except in critical intervals, for instance, near the middle to late Eocene transition, where the sampling spacing is ~20 cm (roughly 8000 k.y.).

At Alano, the assemblage composition is distinctive of subtropical-temperate latitudes and shows variations in the relative abundance of different taxa throughout the section. Subbotinids and globigerinathekids are among the more frequent and common groups. The large acarininids are abundant in the lower part of the section, but they nearly decrease concomitantly with the sapropel-like interval corresponding to the middle Eocene climatic optimum (Fig. 10). Consistent with previous records from other NE Italian sections (Toumarkine and Luterbacher, 1985; Luciani and Lucchi Garavello, 1986), the middle–late Eocene genus *Hantkenina* displays an uneven distribution and, where present, constitutes a minor component of the assemblages.

Biostratigraphic classification of the Alano section, based on standard and additional biohorizons, is commented as follows:

1. (1) The basal part of the section, up to 14.40 m level, can be confidently assigned to the upper part of the combined zone E10/E11 (P12 in the zonal scheme of Berggren et al., 1995), because of the absence of *Morozovella aragonensis* and *O. beckmanni*. A noteworthy feature of this interval is the occurrence, from 13.20 m level, of rare and discontinuous specimens of *T. cerroazulensis* (Fig. 10). This is the lowest occurrence so far documented for this species, which is normally reported within E13 or higher up (e.g., Nocchi et al., 1986; Coccioni et al., 1988; Gonzalvo and Molina, 1992; Berggren et al., 1995; Berggren and Pearson, 2005). However, it should be observed that the species is rare and unevenly distributed up to 26.10 m level, becoming relatively common and continuously distributed from 46.52 m level (Fig. 10).

2. (2) The 5.1-m-thick interval from 14.40 to 19.50 m levels is assigned to zone E12 (or P13) based on the total range distribution of *Orbulinoides beckmanni*. According to Edgar et al. (2007), the origination, subsequent evolutionary development, and extinction of this short-lived species was intimately linked to environmental changes associated with the middle Eocene climatic optimum warming event. The recognition of the *O. beckmanni* lowest occurrence (LO) can however be affected by some degree of subjectivity, because the species derives from *Globigerinatheka euganea*, and transitional forms of problematic assignment with secondary apertures along the inner spire occur from 12.80 m level. Pearson et al. (2006) proposed that *O. beckmanni* has a greater number of apertures than *G. euganea*, without specifying their exact number. On the other side, Berggren and Pearson (2005) recommended a relatively broad taxonomical concept for *O. beckmanni* in order to permit a consistent identification of the base of E12 zone, but they did not provide details on the nature of the broad taxonomical concept to be applied. In this work, we have decide to assign to *O. beckmanni* forms having, beside numerous secondary apertures, a more compact, almost spherical test with less depressed sutures, almost indistinguishable, in the earlier chambers of the last whorl (Plate 1). It is interesting to note that in the Alano section, the total range distribution of *O. beckmanni* appears to be virtually confined to the middle Eocene climatic optimum interval, in agreement with Edgar et al. (2007).

However, the identification of the *O. beckmanni* HO is difficult to precisely recognize because of its scarce abundance and the moderate preservation state of planktic foraminiferal assemblages within the sapropel-like interval.

Within zone E12, we observed the first specimens ascribable to *Turborotalia cocoensis* that in the past was considered restricted to the late Eocene (e.g., Toumarkine and Bolli, 1970). At Alano, typical *T. cocoensis*, distinguishable from its ancestor *T. cerroazulensis* by an acute profile of the final chamber (Plate 1), first occurs as low as 15.60 m level, even if the specimens recorded at this level are very few. Nevertheless, the occurrence and abundance of the species are highly variable throughout the section, alternating intervals of extreme scarcity in abundance with others of relatively common and continuous presence. This feature is likely controlled by as-yet unidentified environmental factors.

(3) The 38.02-m-thick interval from 19.5 m level and 57.52 m level, where the HO of the genus *Morozovelloides* is observed, is attributed to zone E13. The top of this zone represents one of the major faunal changes in the evolutionary history of planktic foraminifera in the Cenozoic and has implications for defining the middle Eocene–late Eocene boundary (see following). Specifically, these prominent changes in planktic foraminiferal assemblages include the final extinction of large muricate planktic foraminifera (large *Acarina* and *Morozovelloides*) that...
Integrate biomagnetostratigraphy of the Alano section (NE Italy): A proposal for defining the middle-late Eocene boundary

...dominate low- and mid latitude assemblages in the early and middle Eocene. Therefore, we detailed the faunal patterns observed in this interval as sketched in Figure 10. In the Alano section, the extinction of distinctive muricate group occurred in three steps involving, respectively, the “large” (\(>250\,\mu m\)) Acarinina (i.e., A. rohri, A. pretopilensis, A. topilensis, A. bullbrooki, A. primitiva, A. collactea), the genus Morozovelloides (i.e., M. crassatus, M. coronatus), and finally the “small” (\(<200\,\mu m\)) Acarinina (i.e., A. medizzai, A. echinata).

The extinction level of large Acarinina bearing well-developed muricae occurs at 57.32 m level and is immediately followed (20 cm above, some 8000 k.y.) by the disappearance of M. crassatus and M. coronatus. It is worth pointing out, however, that muricate forms, particularly large Acarinina, display a significant decline in abundance well below the horizon of their highest occurrence, precisely within zone...
E12, in correspondence to the middle Eocene climatic optimum event. Even if these forms are not frequent close to their extinction level, their disappearance constitutes a significant, easily recognizable event.

(4) The upper 47 m of the investigated section, above the 57.52 m level, are assigned to zone E14 because *Globigerinatheka semiinvoluta* is present, although discontinuously, up to the top of the section (Fig. 10). This species first appears at 68.37 m level, i.e., 10.85 m above the HO of *Morozovelloides*. The presence of a significant gap between the LO of *G. semiinvoluta* and the HO of *Morozovelloides*, i.e., the disappearance of large muricate forms, has also been found by several other workers (e.g., Benjamini, 1980; Nocchi et al., 1986; Pearson and Chaisson, 1997; Norris et al., 1998). In particular, this datum is in agreement with data from the Cordillera Betica (Spain; Gonzalvo and Molina, 1996). However, in some areas (western North Atlantic Ocean Drilling Program [ODP] Site 1052; Wade, 2004, Umbria-Marche sections; Nocchi et al., 1986), the LO of *G. semiinvoluta* occurs just above the HO of large acarininids and *M. crassatus*.

Within zone E14, we observed the HOs of the small acarininids (<200 µm), *A. medizzai* and *A. echinata*, that overlap with the range of *Globigerinatheka semiinvoluta*, up to 80.41 m level (Fig. 10). These species represent a minor but characteristic component of the planktic foraminiferal fauna, evenly distributed up to their highest occurrence. The persistence of small acarininids into the Upper Eocene, contrary to the large forms, was noted as well in high latitudes at ODP Sites 702 and 703 (South Atlantic) by Nocchi et al. (1991), at Sites 738 and 744 (Kerguelen Plateau) by Huber (1991), and at Site 1052 (western North Atlantic) by Wade (2004). The acarininid lineage thus extends after the major biotic turnover in the latest middle Eocene. Data so far available suggest however that the extinction of this group was not a synchronous event. Further investigation is needed to verify possible regional use of this event.

**Calcareous Nannofossils**

We studied calcareous nannofossil assemblages in 303 samples that were prepared from unprocessed material as smear slides and examined under a light microscope at 1250× magnification. Samples immediately across the main useful biostratigraphic biohorizons were analyzed every 20 cm. Outside these critical intervals, samples were studied every ~60–120 cm. First, all samples were examined with qualitative methods to evaluate the abundance and state of preservation of calcareous nannofossil assemblages. We applied the following counting methods to check the presence or absence and estimate the abundance of index species: (1) counting species versus total assemblage, taking into account at least 500 nannofossils (Thierstein et al., 1977), (2) counting a prefixed number of taxonomically related forms, i.e., 50–100 sphenoliths (Rio et al., 1990); and (3) counting the number of rare but biostratigraphically useful species, that is species of genus *Chiasmolithus* and *Istmolithus*, in an area of ~9 mm² (three vertical traverses; Backman and Shackleton, 1983). The last, time-consuming counting method was used for checking the presence-absence of key index species that are particularly rare in the Alano section (*Chiasmolithus grandis, Chiasmolithus oamarauensis*, and *Istmolithus recurvus*). Taxonomic concepts used follow Perch-Nielsen (1985) and Fornaciari et al. (2010). Index species are illustrated in Plate 2 (see footnote 1).

For the purposes of this work, we have made an effort to establish in the section the standard zonations of Martini (1971; Nannoplankton Paleogene [NP] zones) and Okada and Bukry (1980; Coccolith Paleogene [CP] zones; Fig. 1). However, these zones are of problematic recognition, and therefore we will strongly rely in our correlation on a set of additional biohorizons that have been proposed in the literature over the years (e.g., Perch-Nielsen, 1985; Fornaciari et al., 2010).

Generally, the calcareous nannofossil assemblages are rich, well preserved, and diversified throughout the section. To illustrate the makeup of the calcareous nannofossil assemblages at Alano, we present Figure 11, where...
the quantitative distribution of selected taxonomic groups is reported. The assemblages are strongly dominated by placoliths, among which *Cribrocentrum* and *Dictyococcites* are prominent (together up to ~70% of the total assemblage). Discoasterids and chiasmoliths (Fig. 1), which provide important datums in the standard zonations of Martini (1971) and Okada and Bukry (1980), are exceedingly rare at Alano, as they are normally in low to middle latitude areas (Perch-Nielsen, 1985; Wei and Wise, 1989).

In Figure 12, we report the quantitative distribution patterns of index species from the Alano section that allow us to define the following types of biohorizons: lowest rare occurrence (LRO), lowest occurrence (LO), lowest common occurrence (LCO), highest common occurrence (HCO), highest rare occurrence (HRO), highest occurrence (HO), acme beginning (AB) and acme end (AE).

A biostratigraphic classification of the Alano section, based on standard and additional calcareous nannofossil biohorizons, is provided next. The positions and calibrations of used bioevents are reported in Table 3:

1. The basal part of the section up to 44.73 m level is assigned to zones NP16/CP14a (Fig. 12) because of the rare occurrence of *Chiasmolithus solitus* and the scarce/common presence of *Cribrocentrum reticulatum* and *Reticulofenestra umbilicus* (see Fig. 1).
2. The interval from 44.73 m level, where the HO of *C. solitus* was observed, to 62.85 m level.

Figure 12. Quantitative distribution patterns of selected calcareous nannofossils and resulting biostratigraphic classification of the Alano section according to the zonal scheme of Martini (1971) and Okada and Bukry (1980). Additional biohorizons shown by Fornaciari et al. (2010) as useful for correlations are evidenced. The position of the biohorizons is reported in Table 3. LRO—Lowest Rare Occurrence; LO—Lowest Occurrence; LCO—Lowest Common Occurrence; HCO—Highest Common Occurrence; HO—Highest Occurrence; AB—Acme Beginning; AE—Acme End.

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**ALANO SECTION**

<p>| NP19-20 | NP18 | NP17 | NP16 | CP14b | CP14a | C17r | C16r | C15b | C15a | C14a | C14b | C14c | C13r | C13n.1r | C12r | C12n.1r | C12n.2r | C11r | C11n.1r | C11n.2r | C10r | C10n.1r | C10n.2r |
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Figure 12.** Quantitative distribution patterns of selected calcareous nannofossils and resulting biostratigraphic classification of the Alano section according to the zonal scheme of Martini (1971) and Okada and Bukry (1980). Additional biohorizons shown by Fornaciari et al. (2010) as useful for correlations are evidenced. The position of the biohorizons is reported in Table 3. LRO—Lowest Rare Occurrence; LO—Lowest Occurrence; LCO—Lowest Common Occurrence; HCO—Highest Common Occurrence; HO—Highest Occurrence; AB—Acme Beginning; AE—Acme End.
TABLE 3. CALCAREOUS PLANKTON BIOHORIZONS AT THE ALANO SECTION AND ODP SITE 1052

<table>
<thead>
<tr>
<th>Biohorizon</th>
<th>Position Alano (m)</th>
<th>Site 1052 Depth (mcd)</th>
<th>Notation relative to chrono top Alano Site 1052</th>
<th>Age CK95 Alano (Ma)</th>
<th>Site 1052 age (Ma)</th>
<th>Multisite age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. recurvus LO (N)</td>
<td>–</td>
<td>56.89</td>
<td>–</td>
<td>1.98</td>
<td>–</td>
<td>36.787</td>
</tr>
<tr>
<td>2. A. medizzi—A. echinata HO (F)</td>
<td>80.41</td>
<td>–</td>
<td>C17n.1n</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3. recurvus spike end (N)</td>
<td>79.91</td>
<td>72.415</td>
<td>C17n.1n</td>
<td>0.78</td>
<td>37.272</td>
<td>–</td>
</tr>
<tr>
<td>4. recurvus spike beginning (N)</td>
<td>78.11</td>
<td>81.285</td>
<td>C17n.1n</td>
<td>0.853</td>
<td>37.347</td>
<td>37.589</td>
</tr>
<tr>
<td>5. C. erbae AE (N)</td>
<td>75.01</td>
<td>76.27</td>
<td>C17n.1n</td>
<td>0.972</td>
<td>37.449</td>
<td>37.417</td>
</tr>
<tr>
<td>6. G. seminvoluta LO (F)</td>
<td>68.37</td>
<td>91.67</td>
<td>C17n.2n</td>
<td>0.250</td>
<td>37.665</td>
<td>38.000</td>
</tr>
<tr>
<td>7. P. capdevilensis HO(F)</td>
<td>68.37</td>
<td>38.32</td>
<td>C17n.2n</td>
<td>0.793</td>
<td>37.665</td>
<td>38.240</td>
</tr>
<tr>
<td>8. C. grandis HO (N)</td>
<td>66.47</td>
<td>84.71</td>
<td>C17n.2n</td>
<td>0.492</td>
<td>37.724</td>
<td>37.725</td>
</tr>
<tr>
<td>9. C. erbae AB (N)</td>
<td>62.96</td>
<td>87.625</td>
<td>C17n.2n</td>
<td>0.939</td>
<td>37.833</td>
<td>37.821</td>
</tr>
<tr>
<td>10. C. oamaruensis LRO (N)</td>
<td>62.85</td>
<td>86.5</td>
<td>C17n.2n</td>
<td>0.953</td>
<td>37.837</td>
<td>37.780</td>
</tr>
<tr>
<td>11. M. crassatus—M. coronatus HO (F)</td>
<td>57.52</td>
<td>92.37</td>
<td>C17n.3n</td>
<td>0.394</td>
<td>37.996</td>
<td>38.020</td>
</tr>
<tr>
<td>12. Large acarininids HO (F)</td>
<td>57.32</td>
<td>92.77</td>
<td>C17n.3n</td>
<td>0.418</td>
<td>38.001</td>
<td>38.030</td>
</tr>
<tr>
<td>13. S. obtusus HO (N)</td>
<td>49.59</td>
<td>107.12</td>
<td>C17r</td>
<td>0.448</td>
<td>38.253</td>
<td>38.408</td>
</tr>
<tr>
<td>14. C. solitus HO (N)</td>
<td>44.73</td>
<td>106.76</td>
<td>C18n.1n</td>
<td>0.507</td>
<td>38.490</td>
<td>38.398</td>
</tr>
<tr>
<td>15. O. beckmanni HO (F)</td>
<td>19.5</td>
<td>135.69</td>
<td>C18n.2n</td>
<td>0.582</td>
<td>39.922</td>
<td>39.980</td>
</tr>
<tr>
<td>16. T. cocoaensis HO (F)</td>
<td>15.6</td>
<td>–</td>
<td>C18r</td>
<td>–</td>
<td>40.227</td>
<td>–</td>
</tr>
<tr>
<td>17. O. beckmanni HO (F)</td>
<td>14.4</td>
<td>–</td>
<td>C18r</td>
<td>–</td>
<td>40.253</td>
<td>–</td>
</tr>
<tr>
<td>18. T. cernuolusis HO (F)</td>
<td>13.2</td>
<td>–</td>
<td>C18r</td>
<td>–</td>
<td>40.366</td>
<td>–</td>
</tr>
<tr>
<td>19. D. bisectus LCO (N)</td>
<td>9.5</td>
<td>143.94</td>
<td>C18r</td>
<td>–</td>
<td>40.590</td>
<td>40.354</td>
</tr>
<tr>
<td>20. S. furcatolithoides HO (N)</td>
<td>6.3</td>
<td>144.54</td>
<td>C18r</td>
<td>–</td>
<td>40.780</td>
<td>40.384</td>
</tr>
</tbody>
</table>

Note: (F)—foraminifera; (N)—calcareous nannofossils. CK95—Cande and Kent, 1995; LO—Lowest Occurrence; LCO—Lowest Common Occurrence; HO—Highest Occurrence; AB—Acme Beginning; AE—Acme End.

*From this work and after Fornaciari et al., 2010.
†After Wade (2004).

in correspondence with the LRO of *Chiasmosolithus oamaruensis*, is assigned to zone NP17. It should be observed that the recognition of the top of this zone has been difficult at Alano because *C. oamaruensis* is exceedingly rare and exhibits a discontinuous abundance pattern, especially in the lower part of its range. However, a single specimen ascribable to *C. oamaruensis* was observed and used for recognizing the top of zone NP17. Okada and Bukry (1980) defined the top of their zone CP14b on the basis of the HO of *Chiasmolithus grandis*, which in the Alano section occurs at 66.47 m level. This event is also not easily detectable because of the scarcity of this species at Alano as in other Italian sections (Monchi and Thierstein, 1985; Fornaciari et al., 2010).

(3) In a short interval, between 78.11 and 79.91 m levels, we observed the occurrence of rare specimens of *Istmolithus recurvus*, which is termed *I. recurvus* spike. The LO of this taxon defines the bottoms of zones NP19–20/CP14b (Fig. 1). Therefore, the upper 26.38 m section is also not easily detectable because of the Alano section occurs at 66.47 m level. This easily recognizable species make these biohorizons have little practical utility for reliable biostratigraphic correlations. For these reasons, previous authors have proposed the use of alternative biohorizons (e.g., Perch-Nielsen, 1985; Lyle et al., 2002), and we have undertaken a project with the specific purpose of improving resolution and reliability of calcareous nannofossil biostratigraphy in the late middle Eocene (Bartonian) and late Eocene (Priabonian) interval (Fornaciari et al., 2010). In particular, at Alano, there are at least five biohorizons that are based on the quantitative distribution patterns of species common in Tethyan sections, which thus provide confident long-distance correlation tools. They are in ascending stratigraphic order:

(1) The HO of *Sphenolithus furcatolithoides*, at 6.30 m level; this well-defined and easily recognizable biohorizon was first proposed by Perch-Nielsen (1985) as an alternative event to the HO of *Chiasmolithus solitus* (Fig. 12). Although the HO of *S. furcatolithoides* has been observed well below the HO of *C. solitus*, it is found to maintain the same relative position with respect to other additional events (Fig. 14).

(2) The LCO of *Dictyococccites bisectus*, at 9.5 m level; this biohorizon, observed just 3.20 m above the HO of *S. furcatolithoides*, was reported by Perch-Nielsen (1985) up to the upper part of zone NP16, consistent with our findings; the species is deeply affected by taxonomic ambiguities (e.g., Wei and Wise, 1989) that in our opinion could be overcome if a biometric definition were adopted assigning only forms larger than 10 µm to *D. bisectus* (Bralower and Mutterlose, 1995). These large forms appear in Alano and in other Tethyan sections abruptly and provide a neat event (Fornaciari et al., 2010), although specimens of *D. bisectus* have been reported from ODP Site 1052 and Agost section also at lower stratigraphic levels (e.g., Mita, 2001; Larrañaga et al., 2008), and this species is widely considered to be biogeographically controlled (e.g., Perch-Nielsen, 1985; Wei and Wise, 1989). On this basis, it is thus possible to assume that the appearance at Alano is the first common and continuous occurrence of the species, possibly environmentally controlled. This interpretation is reinforced by the fact that in coincidence with the abrupt entrance of *D. bisectus*, a sharp increase in *Dictyococccites scrippsa* is also observed (Fig. 12).

(3) The HO of *Sphenolithus obtusus*, at 49.58 m level; this easily recognizable species has been reported by Perch-Nielsen (1985) as having a restricted distribution range in zones NP16–18, but it has never been formally utilized before. At Alano, the form is well distributed, showing a neat appearance and a neat extinction; by comparison with other sections, we consider that its HO is a reliable biohorizon.
(4) The AB of *Cribrocentrum erbae*, at 62.96 m level; although this new species (Fornaciari et al., 2010; Plate 2) occurs virtually throughout the entire section with rare/scare and sometimes discontinuous abundances, it shows a neat increase in abundance, up to 40%, within zone NP18. At Alano, the peculiar abundance pattern of *C. erbae* is used to identify an acme event defined as the interval characterized by percentages of *C. erbae* greater than 4%–5%. This biohorizon has also been tested at ODP Site 1052, where it maintains the same ranking and spacing, virtually coinciding with the LO of *C. oamaruensis* (Fig. 14).

(5) The AE of *Cribrocentrum erbae*, at 75.01 m level; this biohorizon marks the return of *C. erbae* to background abundances. The AE of *C. erbae* is more difficult to define because it shows a more gradual pattern, but the abundances of *C. erbae* during the acme are substantially more copious from that characterizing the rest of the section. Surprisingly, a comparison between the Alano section and ODP Site 1052 points out that the AB and AE of *C. erbae* have to be

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Figure 13. Quantitative distribution patterns of selected calcareous nannofossils and resulting biostratigraphic classification of the Alano Ocean Drilling Program (ODP) Site 1052 according to the zonal scheme of Martini (1971) and Okada and Bukry (1980). Additional biohorizons shown by Fornaciari et al. (2010) as useful for correlations are evidenced. The position of the biohorizons is reported in Table 3. LRO—Lowest Rare Occurrence; LO—Lowest Occurrence; LCO—Lowest Common Occurrence; HCO—Highest Common Occurrence; HO—Highest Occurrence; AB—Acme Beginning; AE—Acme End; rmcd—revised metres composite depth.
Correlation with ODP Site 1052

Interpreting Magnetostratigraphy by Correlation with ODP Site 1052

The calibration of calcareous plankton biohorizons to the geomagnetic polarity time scale (GPTS; Cande and Kent, 1995) at the transition from the middle to late Eocene is controversial (see Berggren et al., 1995; Table 3). For example, the HO of morozovellids and large acarininds, probably the most critical biohorizon in the interval, has been associated with the top of chron C18n in the Apennines (Nocchi et al., 1986; Premoli Silva et al., 1988), while in the oceans, it has been often associated with chron C17n (Berggren et al., 1995), with a discrepancy of some 1.0 m.y. There has been a dearth of good low- and midlatitude sections for establishing a reliable calcareous plankton magnetostratigraphy until the recovery in ODP Leg 171 of expanded and well-preserved successions in the subtropical western North Atlantic. In particular, a succession that can be considered a reference deep-sea section for the middle Eocene to late Eocene transition is that recovered at ODP Site 1052 in the Blake Nose, in which magnetostratigraphy (Ogg and Bardot, 2001), cyclostratigraphy (Pälike et al., 2001), and high-resolution planktic foraminifera biostratigraphy (Wade, 2004) have been carried out.

In order to obtain an improved and sound correlation between the Alano section and ODP Site 1052 reference section, we decided to conduct a high-resolution study of the calcareous nannofossils at this site, using a consistent counting methodology and taxonomy. The results of this study are presented in detail in Fornaciari et al. (2010). Here, we report (Fig. 13) the distribution patterns of the same index species that have been monitored at Alano, and in particular, the distributions of the index species not used in the standard zonations, the stratigraphic range of which is poorly known. In Figure 14, we report the correlations of calcareous plankton biohorizons between Alano and ODP Site 1052 based on data of Wade (2004) and our own data. The correlation shows that 10 biohorizons maintain the same ranking and spacing and occur in the same position with respect to the magnetic polarities. This correlation suggests a straightforward interpretation of magnetostratigraphic data from the Alano section in terms of the standard GPTS, as indicated by Figure 14 and summarized in Table 3. Specifically, Alano magnetozone A1r corresponds to magnetozone C18r, A1n.2n to C18n.2n, A1n.1n to C18n.1n, A2n.3n to C17n.3n, A2n.2n to C17n.2n, and A2n.1n to C17n.1n (Figs. 8 and 14). Based on the correlation inferred between the Alano section and ODP Site 1052 (Fig. 14), A4r is considered to be equivalent of C16r, and, as a consequence, the short magnetozone A3r at Alano is apparently missing in the geomagnetic polarity time scale of Cande and Kent (1995) time scale. In particular, the basal part of the section correlates with the upper part of chron C18r, while the single sample with a reversed polarity at the top of the section should correlate to the base of chron C16r.

Chronology and Sediment Accumulation Rates

The chronology of the middle–late Eocene GPTS is in a state of flux (see Berggren and Pearson, 2005, p. 284), and using the various available calibrations (Cande and Kent, 1995; Pälike et al., 2001; Ogg and Smith, 2004), the chronology of the Alano section varies, as do the calcareous plankton biochronology and sediment accumulation rates.
In Figure 15, we constructed an age-depth plot and derived sediment accumulation rates by means of magnetostratigraphic correlation to the geomagnetic polarity time scale of Cande and Kent (1995), taking into account the available biostratigraphic constraints. The Alano magnetostratigraphy straddles magnetochrons C18r–C16r with an average sediment accumulation rate of ~2.4 cm/k.y. (not corrected for compaction) throughout the entire section (Fig. 15).

The extrapolated age of the base of the section is 41.15 Ma, assuming for chron C18r the mean accumulation rate estimated during chron C18n, and the age of the top of the section is 36.48 Ma according to the geomagnetic polarity time scale of Cande and Kent (1995), thus extending over a 4.40 m.y. time interval. Adopting the chronology of Ogg and Smith (2004), the section would extend from 40.09 Ma to 36.40 Ma, spanning a time interval of 3.70 m.y., and if we use the time scale of Pälike et al. (2001), with the same assumptions, the bottom and the top of the section are at 40.82 and 36.26 Ma, respectively, covering a time interval of 4.56 m.y.

**Calcareous Plankton Biochronology**

Though the early Paleogene time scale is far away from being established definitively, the integrated calcareous plankton and magnetostratigraphic data reported in Figure 14 suggest that at least 10 biohorizons should be considered synchronous between the Alano section and ODP Site 1052. These datums thus provide a precise framework and a precious correlation tool that can be used to approximate the base of the Priabonian Stage.

In Table 3, we synthesize the calcareous plankton biochronology obtained in these two successions, but a more comprehensive and detailed discussion on the calcareous nannofossil biochronology can be found in Fornaciari et al. (2010). Here, we will only concentrate on biostratigraphic data concerning the chronostratigraphy of the middle and late Eocene.

In particular, high-resolution studies on planktic foraminifera and calcareous nannofossil biohorizons reported in this study improve our capability of correlation over wide areas by enhancing and strengthening the biomagnetostratigraphic scheme available to date.

**Planktic Foraminifera Biochronology**

Over the last decades, several planktic foraminifera biohorizons have been used to subdivide the middle Eocene–late Eocene transition; a brief discussion summarizes the three main bioevents next.

**The Extinction of Muricate Morozovellids and Large Acarininids.** The most important single point in the considered interval is the calibration of the extinction of morozovellids and large acarininids. The calibration of the final exit of morozovellids in Umbria-Marche sections has been associated with the top of chron C18n (Nocchi et al., 1986), while Wade (2004) associated this event with the middle part of chron C17n.3n in the NW Atlantic ocean. Our data are in perfect agreement with age estimation from Blake Nose, suggesting that the event as recorded in the Apennines might have been affected by tectonic disturbances (Jovane et al., 2007a).

**The First Appearance of Globigerinatheca semiinvoluta.** The FAD of *Globigerinatheca semiinvoluta* has been used as a primary criterion for defining the base of zone P15 of Berggren et al. (1995). The LO of *G. semiinvoluta* has been observed within chron C17n.2n (37.66 Ma) at Alano and is younger than previously indicated by Berggren et al. (1995), who placed the LO of the species close to the base of chron C17r (38.4 Ma), thus being older than the HO of *Morozovelloides* (38.1 Ma). Our data strongly suggest that the LO of *G. semiinvoluta* is likely a diachronous event, as already noted by Berggren et al. (1995) and Berggren and Pearson (2005), and thus is not suitable to be used for correlations over wide areas.

**The Final Exit of Small Acarininids.** At Alano, the extinction of small acarininids occurs within chron C17n.1n (37.27 Ma) and is older with respect to data from Wade (2004), who reported the presence of small acarininids at least up to 34.59 Ma in chron C16n. This discrepancy indicates a possible diachronity of this event and suggests caution in considering even a possible regional use for this biohorizon.

This overview clearly shows that the extinction of muricate morozovellids and large acarininids could be considered a valuable correlation tool over wide areas, except for the Umbria-Marche region, where the presence of a major fault has likely produced an incorrect age estimation for this event.

**Calcareous Nannofossil Biochronology**

Previous literature has proposed that the Bartonian-Priabonian boundary is defined at the base of calcareous nannofossil zone NP18,
where the LO of *C. oamaruensis* occurred (see Berggren et al., 1985, 1995). According to these authors, the LO of *C. oamaruensis* occurs at 37.00 Ma in chron C17n.1n, and as a consequence, the base of the Priabonian Stage correlates with chron C17n.1n, with an age of 36.9 Ma (Berggren et al., 1995).

The placement of the Bartonian-Priabonian Stage in chron C17n.1n has been commonly used without any criticisms at least in the last two decades. However, the recognition of first specimens of *C. oamaruensis*, at least in the lower part of chron C17n.2n, both in the Alano section (37.84 Ma) and at ODP Site 1052 (37.78 Ma), in turn implies, adopting the definition of Berggren et al. (1995), that the base of the Priabonian Stage now correlates with chron C17n.2n, not with chron 17n.1n. Unfortunately, the LO of *C. oamaruensis* as well as the HO of *C. grandis* have a low degree of reproducibility in many areas because of their scarce abundances. Nonetheless, the integration of these poor reference datums with the AB and AE of *C. erbae*, at 37.83 Ma and 37.49 Ma, respectively, provides alternative biostratigraphic correlation tools that also better constrain this interval.

**The Middle Eocene Climatic Optimum Interval**

Though the focus of this paragraph is on the middle to late Eocene transition, we would just note that from the biostratigraphic point of view, another interesting interval in the Alano section is that between 6.3 m level (40.60 Ma) and 22.70 m level (39.66 Ma) (Fig. 16). Several biohorizons, which include the LOs of *Sphenolithus predistentus*, *Dictyoecocites scrippae*, *D. bisectus*, and *S. obtusus* and HOs of *S. furcatolithoides* and *S. spiniger*, have been found to occur close to the middle Eocene climatic optimum event. Calibrations of these additional calcareous nanofossil biohorizons (Table 3) and of planktic foraminifera recorded in the same interval, for instance the LO and HO of *O. beckmanni*, provide a fine integrated biochronologic framework.

**CHRONOSTRATIGRAPHIC POTENTIAL OF THE ALANO SECTION: PROPOSING THE DEFINITION OF THE PRIABONIAN**

The chronology discussed herein indicates that the Alano section straddles the middle Eocene–late Eocene boundary, whatever practice is followed for its recognition (Fig. 1). The section meets all the requirements for serving as the global stratotype section and point (GSSP) of the chronostratigraphic unit (Remane et al., 1996). Hence, the Alano section is here proposed as a candidate GSSP for defining the Priabonian, the accepted stage/age corresponding to the entire Upper/late Eocene (Luterbacher et al., 2004). According to the practice recommended by ICS (Hedberg, 1976; Cowie et al., 1986; Salvador, 1994; Remane et al., 1996), the Priabonian Stage is formally defined by the GSSP of its base, which serves also as the definition of the top of the underlying Bartonian Stage and middle–late Eocene boundary. Within this practice, the chronostratigraphic units are defined solely by the GSSPs of their bases. However, recently, Hilgen et al. (2004) recommended that the practice of unit stratotype for standard chronostratigraphic units should be recovered. In the following, we detail our proposal of definition of the Priabonian Stage that is to be submitted to the ICS.

**Rationales in Choosing the GSSP**

The chronostratigraphic principles and practice recommended by the ICS have been largely influenced by Hollis Hedberg and are summarized in Hedberg (1976), Cowie et al. (1986), Salvador (1994), and Remane et al. (1996). They have received a wide consensus, but they are not, however, universally accepted (e.g., see discussions in Walsh, 2005a, 2005b, 2005c) and, when accepted, not uniformly applied. We, therefore, feel the need to make clear the rationales underlying our proposal of definition of the Priabonian Stage.

First, contrary to some recent views (see Walsh, 2004), we consider, in agreement with Hedberg (1976, p. 71), the stages (and the equivalent ages) to be “one of the smallest units in the standard chronostratigraphic hierarchy that in prospect may be recognized worldwide.” Hence, the most important single criterion that needs to be met by our proposal is its amenability to worldwide correlation. There is an almost unanimous consensus that a modern definition of global chronostratigraphic units should be defined in points of geologic time where a wealth of correlation tools is available so that the boundaries of the stage can be recognized in the different stratigraphic records. In addition, we consider that, for an elemental need of stability of the stratigraphic nomenclature, the modern definition of the global chronostratigraphic units should be historically appropriate. The historical appropriateness of redefined chronostratigraphic units has been widely discussed in the last years, and we refer to Walsh (2005a, 2005b, 2005c) for an extensive review.

In other words, in making our proposal, the rationales driving our choice of a specific point in the section will be such that: (1) the Priabonian should be recognized worldwide, (2) the historical stratotype sections of the Priabonian and Bartonian should remain largely Priabonian and Bartonian in age, and (3) the most followed practice in the recognition of the Priabonian, i.e., of the middle–late Eocene boundary, should be respected as much as possible; the latter is the most difficult task, and we are aware that it is impossible to completely fulfill this latter requirement, as well as to obtain a general consensus.

In the following, we first address the historical appropriateness issue by briefly reviewing (1) the status of the Priabonian and Bartonian Stages (and the middle–late Eocene boundary) with reference to the classical sections upon which they are based, including the historical stratotypes, and (2) the practice followed in recognizing the middle–late Eocene boundary in the different biogeographic areas and stratigraphic settings. The potential of global correlation, a major point of dispute, will be discussed after having proposed the position in the section of the GSSP that is the “golden spike.”

**The Middle–Late Eocene Boundary: An Historical Overview**

The history of the chronostratigraphic subdivision of the middle and late Eocene is extremely complex and is not reviewed here. Complete information is available in the literature to which we refer the reader (e.g., Berggren et al., 1995; Luterbacher et al., 2004). In the International Chronostratigraphic Scale by ICS, the upper part of the Middle Eocene is represented by the Bartonian Stage, while the Upper Eocene is represented by the Priabonian Stage (Luterbacher et al., 2004; Fig. 1).

As argued by Berggren et al. (1985, 1995), the problem with the placement of the Middle–Upper Eocene boundary, i.e., the base of the Priabonian, has been intimately linked with the difficulties in correlating the classical NW Europe Eocene sections, mainly located in the Paris and London Basins, with those cropping out in the Veneto region of the Mediterranean area (Munier-Chalmas and de Lapparent, 1893). Actually, for a long time, they have been considered time equivalent, and have been used for indicating the late Eocene (e.g., Berggren, 1971).

**The Bartonian Stage**

Though the stage was first introduced with reference to rocks in the Paris Basin, its name was derived from the Barton Clay in the Hampshire Basin of England (Mayer-Eymar, 1857), and it is best known today from spectacular exposures, serving as a “unit stratotype” for the Bartonian, on the Isle of Wight (Fluegeman,
Integrated biomagnetostratigraphy of the Alano section (NE Italy): A proposal for defining the middle-late Eocene boundary

Figure 16. Summary of the biomagnetostratigraphic results obtained in the Alano section. The position of the middle Eocene climatic optimum (MECO) as evidenced by Spofforth et al. (2008, 2010) is indicated in the lower part of the section. The shaded light-gray band between 57.32 and 68.37 m highlights the critical interval for defining the base of the Priabonian Stage. LRO—Lowest Rare Occurrence; LO—Lowest Occurrence; LCO—Lowest Common Occurrence; HCO—Highest Common Occurrence; HO—Highest Occurrence.
2004). On the base of data reported in Aubry (1986), Berggren et al. (1995) assigned the Bartonian Stage to nanofossil zones NP16 and NP17, and consequently to a part of zone NP18. Specifically, Aubry reported the presence of *Sphenolithus furcatolithoides* as restricted to the Lower Barton Beds (Fig. 15 in Aubry, 1986), whereas *Sphenolithus obtusus* was observed just in lower part of the Middle Barton Beds. The calcareous nanofossil magnetobiochronology established in this paper (Table 3) suggests that the Lower Barton Beds should be older than the mid-late chron C18r, where *S. furcatolithoides* becomes extinct (Fig. 1) and lie within the early NP16 zone, and that the Middle Barton Beds, containing *S. obtusus*, should correlate with chron C18n and upper NP16 to lowermost NP17 zones. To our knowledge, no data are available for time constraining the Upper Barton Beds and, hence, the top of the Bartonian as defined in its type area.

**The Priabonian Stage**

The Priabonian Stage, named after the village of Priabona in the eastern Lessini Mountains (NE Italy), was proposed by Munier-Chalmas and de Lapparent (1893, p. 479) on the basis of several localities in the Lessini Shelf, in order to overcome problems in correlating the NW Europe and Mediterranean middle–late Eocene marine stratigraphic records. Hardenbol (1968) formally proposed, among the different sections indicated by Munier-Chalmas and de Lapparent (1893), to choose as the stratotype section of the Priabonian that at Priabona (Fig. 2). This proposal was accepted at the Eocene Colloquium held in Paris in 1968, where, however, five parastratotype sections were also proposed; these were the Granella and Ghenderle (or Val Bressana) sections in the Lessini Mountains, the Brendola and Mossano sections in the Berici Hills, and the Possagno section in the Veneto pre-Alps (Cita, 1969; Fig. 17).

The sections in the Lessini Mountains (Priabona, Granella, and Ghenderle) were located in the inner part of Lessini Shelf, close to emerging lands. Their content in calcareous plankton is very poor, and their precise time framing is very difficult (e.g., Verhallen and Romein, 1983). The sections in the Berici Hills (Brendola and Mossano) were as well located in the Lessini Shelf, in more distal conditions, and have scarce content in calcareous plankton (Luciani et al., 2002). Finally, the deep-water Possagno section, located at the transition from the Lessini Shelf to the Belluno Basin, is the only one, among those proposed as parastratotype of the Priabonian, that can be framed in time accurately (Bolli, 1975; Agnini et al., 2006). To follow, we will concentrate on three of these parastratotype sections, the Priabona, Mossano, and Possagno sections, adding some remarks also on the pelagic Contessa Highway section (central Italy), which has been proposed by Lutterbacher et al. (2004) as a candidate section for defining the Priabonian.

**Traditional Criteria Used in Locating the Base of the Priabonian (Upper Eocene)**

In the shallow-water sections, the master paleontologic guiding criterion used for recognizing the Priabonian has been the first appearance of *Nummulites fabiani*. This biohorizon defines the base of the shallow benthic foraminifera zone SBZ19 (Serra-Kiel et al., 1998) and has been utilized in the Priabona and Mossano section (Hottinger, 1977; Parisi et al., 1988; Bassi and Loriga Broglio, 1999; Bassi et al., 2000) as well as in all other Tethyan shallow-water successions (e.g., Strougo, 1992; Serra-Kiel et al., 1998).

In the deep-water sections, the base of the Priabonian (Upper Eocene) has been traditionally associated with the extinction of the large muricate globorotalids, which virtually coincide with the base of zone E14 (Berggren and Pearson, 2005; Fig. 1), and with the lowest appearance of *C. oamaruensis*, which defines the base zone NP18 (Martini, 1971). These two biohorizons have been observed both in the Tethyan domain (Alano, Possagno, and Contessa Highway sections; Jovane et al., 2007a; this study) and in and NW Atlantic ODP Site 1052 (Wade, 2004; this study).

It is noteworthy that the LO of *N. fabiani*, that is the base of zone SBZ 19, was considered as correlative with the base NP18 (Serra-Kiel et al., 1998), although this correlation is not warranted by sound data to our knowledge.

**Time Frame of the Base of the Priabonian at Priabona**

The time frame of the Priabona section is particularly difficult because of the shallow-water transgressive nature of the succession (Setiawan, 1986). Probably the most reliable time frame of the section was established by Brinkhuis (1994) by means of a dinoflagellate cyst biostratigraphy from previously magnetostratigraphically well-calibrated pelagic sequences from central Italy. Brinkhuis concluded that the Priabona section belongs to *Melitasphaeridium pseudorecurvatum* cone, corelate with chron C15–C16 and zones NP19–20 and P16 (Brinkhuis and Bifli, 1993; Brinkhuis, 1994). This interpretation is supported by the evidence at Priabona where *I. recurvus* has been detected virtually from the base of the section with good continuity (Verhallen and Romein, 1983), and this form becomes well established in the Mediterranean sections only in advanced chron C16n time (Coccioni et al., 1988; Fornaciari et al., 2010). Hence, we concur with Brinkhuis (1994) that the historical Priabonian stratotype starts indeed in advanced Priabonian time, if all the current practices for its recognition are considered (Fig. 1).

**Time Frame of the Base of the Priabonian at Mossano**

The Mossano section has been intensively studied because of its rich paleontologic contents (for a comprehensive review, see Bassi et al., 2000). The Bartonian-Priabonian boundary, i.e., the LO of *N. fabiani*, has been placed in coincidence with a major facies change from shallow-water carbonate facies (Calcure nummulitico Auctorum) to deeper-water terrigenous facies (Marna di Priabona). The Priabonian at Mossano is more than 100 m thick (Ungaro, 1969), although useful fairly detailed data have been collected only in the basal most part by Luciani et al. (2002), who studied the calcareous plankton across the transition between the two formations. Specifically, they observed the total lack of calcareous plankton in the upper part of Calcure nummulitico and documented poor planktic foraminifera and calcareous nanofossils assemblages in 10 samples from the basal ~11 m of the Marne di Priabona, where significant datums are the occurrences of *Globigerinatheca semiinvoluta* (in the lower 6 m of the Marne di Priabona), *I. recurvus* (in a single sample at 8 m above the base of the Marna di Priabona), and *Turborotalia cujaniaensis* (in two samples at 9 and 10 m above the base of the Marna di Priabona). The presence of the latter form, appearing in chron C15r time (Berggren et al., 1995), strongly suggests, as for the type Priabonian at Priabona, an advanced Priabonian age with reference to the conventional criteria used for its recognition (Figs. 1 and 17). The occurrence of *I. recurvus* at ~8 m from the base would reinforce this interpretation. However, detailed interpretation of the Mossano data is difficult. Specifically, it is difficult to interpret the short spacing (just 3 m) between the HO of *G. seminivoluta* and the LO of *T. cujaniaensis*, because these two biohorizons would be separated by some 0.6 m.y. on the basis of the available biochronology (Fig. 1). Three options are possible: (1) the current distribution models of the two species are not completely known, (2) the sediment accumulation rate is exceedingly (and unreasonably) low for shelf sediments, or (3) there is a hiatus within the short interval considered. Whatever the interpretation is, it can be conservatively stated that the basal sediments at Mossano are younger than the late chron C17n2n to which we have calibrated the LO of *G. seminivoluta* at Alano (Fig. 10;
Figure 17. Stratigraphic correlation between the deep-water sections of Alano, Possagno, Contessa Highway, and Massignano and the shallow-water successions of Mossano and Priabona.
Table 3). However, probably, the most important output of this discussion is that the LO of \textit{N. fabiani}, i.e., the base of zone SBZ19, is to be correlated with a time younger, probably much younger, than the late chron C17n.2n.

**Correlation among Alano, Possagno, and Contessa Highway Sections**

In Figure 17, we show the correlation of the Alano section with the classical deep-water sections of Possagno and Contessa Highway. The correlation with Possagno is straightforward, even if the available data for Possagno have been collected in low resolution. The correlation to the Contessa Highway section is more problematic, because the position of the extinction of large acarininids, one of the most distinctive biohorizons in late Eocene planktonic foraminifera, is located in chron C17n.3n in the Alano section, whereas it was interpreted to lie in chron C18n.1n in the Contessa Highway section (Jovane et al., 2007a; Fig. 17). The apparent inconsistency between these data is likely explained by the presence of a major previously undescribed fault. We agree with Jovane et al. (2007a) that this significant fault zone has removed a portion of the record, but in our interpretation, the missing interval is much more important than indicated by these authors, covering at least the entire C18n.1n, and thus suggesting that the HO of large acarininids falls in chron C17n.3n, now in accordance with data from the Alano section and ODP Site 1052.

**Current Practice in Recognizing the Base of the Priabonian (Middle–Upper Eocene Boundary)**

We can confidently state that, in the past 30 yr, the most influential authors in determining the practices in Cenozoic chronostratigraphic assignments have been William Berggren and coworkers, in particular, with their compilations of 1985 and 1995. Marine and continental stratigraphers have, sometimes uncritically, followed the proposals of Berggren and coworkers, which have become an unofficial standard in the absence of a formally defined International Chronostratigraphic Scale. Concerning the Priabonian, Berggren et al. (1985), after carefully reviewing the status of the Bartonian-Priabonian boundary in the literature, and considering both the time frame of historical sections and the correlation tools available at that time, placed the Bartonian-Priabonian boundary, i.e., the middle–late Eocene boundary, at NP17/NP18 zonal boundary, correlated with the younger part of chron C17n (Fig. 5 in Berggren et al., 1985). Berggren et al. (1995) confirmed this placement of the boundary, assigning a revised estimated age of 37.0 Ma to the LO of \textit{C. oamaruensis}, that is, the base of zone NP18 (Fig. 2 in Berggren et al., 1995). Actually, data on the calcareous plankton biot stratigraphy and biochronology available in Berggren et al. (1985, 1995) were contradictory and poorly constrained (see Tables 9 and 15 in Berggren et al., 1995), as shown by Wade (2004) and in the present work (Table 3).

Surprisingly, Berggren et al. (1985, 1995) did not attach a major importance to the extinction of large muricate globorotalids, which they calibrated to late chron C18n, and associated the base of the Priabonian with chron C17n.1n, to which they calibrated the LO of \textit{C. oamaruensis} (Fig. 2 in Berggren et al., 1995). Hence, they privileged the latter two poor biostratigraphic datums and underplayed an event that we consider to be reliable. However, the proposal of Berggren and coworkers has become widely accepted, and it can be safely stated that the most widespread practice for locating the base of the Priabonian has been to equate the Middle–Upper Eocene boundary with the base of zone NP18 lying in late chron C17n.1n (e.g., Serra-Kiel et al., 1998). As a matter of fact, even planktic foraminifera specialists (e.g., Wade, 2004; Berggren and Pearson, 2005) have placed the Middle–Upper Eocene boundary above the extinction of large muricate planktic foraminifera. Actually, in the present work (Table 3), we have shown that our LO of \textit{C. oamaruensis}, although scarcely reproducible, is much closer to extinction of large planktic spinose foraminifera than reported by Berggren et al. (1995), and this finding is of considerable importance for proposing the GSSP of the Priabonian put forward in the following section.

**Proposal of the GSSP of the Priabonian**

In synthesis, the previous discussion shows that these are the paleontologic criteria that have been widely used for recognizing the base of the Priabonian in the marine stratigraphic records:

1. The LO of \textit{Nummulites fabiani}, i.e., the base of zone SBZ19, applied in shallow-water facies (e.g., Serra-Kiel et al., 1998);
2. The LO of large muricate planktic foraminifera, correlating with the base of zone E14 (e.g., Mancin and Pirini, 2002); and
3. The base of zone NP18, i.e., the LO of \textit{C. oamaruensis} (i.e., Berggren et al., 1985, 1995).

In the deep-water Alano section, the LO of \textit{N. fabiani} is not recorded, while events defining the other two criteria are clearly detected and occur in the lower chron C17n, in a 6–7 m interval, corresponding to ~0.16 m.y. (Fig. 18). This is the critical interval to consider for driving the “golden spike,” if we wish to guarantee both correlatability and historical appropriateness.

The most widespread practice in proposing GSSPs has been and still is to locate the “golden spike” exactly in the lithologic level where a specific, arguably widely correlatable, biostratigraphic or magnetostratigraphic event occurs. Within this practice, there would be three viable options at Alano for defining the base of the Priabonian (see Figs. 16 and 18):

1. The HO of large muricate globorotalids foraminifera at 57.32 m level, which is here considered a reliable and widely traceable event (see previous discussion); this choice would be probably the best preferred by planktic foraminifera specialists;
2. The base of zone NP18, at 62.85 m level, which we have shown to be defined by a poor biohorizon (LO of \textit{C. oamaruensis}), but which appears to be a commonly followed practice in the last years and would be probably the best preferred by calcareous nannoplankton specialists; or
3. The polarity reversal at the base of chron C17n, which would allow a correlation with continental records, and would be probably the best preferred choice by magnetostratigraphic specialists.

However, we disagree this practice and concur with Berggren et al. (1985, p. 1409) that: “...proper stratigraphic procedure requires that paleontologic criteria, although definitive for regional correlation (i.e., recognition) beyond the stratotype region, should not be part of the definition itself... (Hedberg, 1976).”

Therefore, in order to preserve harmony within the stratigraphic community, we prefer to propose as the GSSP a lithologic level easily recognized in the field around which significant changes occur that allow its approximated correlation in the different stratigraphic records worldwide. Such an approach, beyond having the advantage of making the GSSP easily recognizable in the field, serves also to make it clear that chronostratigraphy is not biot stratigraphy and/or magnetostratigraphy, and that long distance and different facies (marine and continental) correlations are essentially geochronologic in nature (Van Couvering and Berggren, 1977). It is to say, time, and not a particular biostratigraphic or magnetostratigraphic feature, is used for recognizing with approximation a chronostratigraphic boundary. Therefore, what is crucially important is to know the exact age of the lithologic point that defines a boundary. Ideally, as it has been done for the late Neogene, a GSSP should be defined in orbitally tuned sections, i.e., framed in an astrochronology with an accuracy that is not attainable with other tools. Such a chronology is not yet available in the Alano section, even if the cyclicity apparently
approximating the middle–late Eocene boundary, that is the base of the Tiziano bed, are plotted against magnetostratigraphy and lithology.

Figure 18. Close-up of the critical interval for defining the base of the Priabonian. Biomagnetostratigraphic events considered as useful for polarity time scale of Cande and Kent [1995]; GTS04; Pälike et al., 2001) and are reported on the right side. LO—Lowest Occurrence; Age estimations for the Tiziano bed as well as for biomagnetostratigraphic events are calculated using different time scales (geomagnetic middle Eocene; late Eocene; and late Eocene calcareous nannofossil taxon, remains present in geochemical and lithologic properties is presently under study.

Within this strictly Hedbergian conceptual frame, we propose to the ICS that the base of the Priabonian should be defined at the base of the Tiziano bed at 63.57 m level in the Alano section. In Figure 18, we report the chronology of the Tiziano bed with reference to the geomagnetic polarity times scale available models, none of which is probably definitive. The proposed definition allows the recognition of the Priabonian worldwide with a good approximation. The definition we propose is historically appropriate and reasonably respectful of the most recent stratigraphic practices; in fact:

1. The Priabonian, as defined in its stratotype at Priabona and recognized in the classical Veneto region, is comprehended in the proposed definition;

2. Classical middle Eocene taxa like the large muricate planktic foraminifera remain in the middle Eocene;

3. Istopomolthus recurvus, an unquestionable late Eocene calcareous nannofossil taxon, remains in the late Eocene; and

4. Nummulites fabiani, an unquestionable Late Eocene large foraminiferal taxon, remains in the late Eocene.

A major drawback of the proposed definition is represented by the fact that we do not know with accuracy the chronology of the large foraminifera evolution at the transition from the middle to the late Eocene, and there is a chance that large benthic foraminifera traditionally considered middle Eocene could result in the late Eocene moving within the proposed definition. However, looking at the stratigraphic information available in the critical interval for defining the Priabonian, we do not see alternative to the proposed definition.

Global Correlation

The GSSP is the only place where we actually know (by definition) that time and rocks coincide within our classification (Holland, 1984, p.149). Elsewhere from the type section, a chronostratigraphic boundary can only be approximated by using and cross-checking the different available correlation tools. In the following, we discuss the correlatability potentials of the proposed GSSP of the Priabonian at Alano.

Magnetostratigraphy

The chron C17r–chron C17n boundary is located 10.95 m below the proposed GSSP and serves as good approximation of the base of the Priabonian in continental and marine settings. Within the current age models of the geomagnetic polarity time scale, the approximation range from 309 to 250 ka depends on the model considered (Fig. 18).

Marine Biostratigraphy

It is beyond our scope to review all the marine fossil groups that may provide tools for recognizing the base of the Priabonian in the different depositional settings and biogeographic regions. In Figure 18 (and Table 4), we compare the age of the Tiziano bed, that is the base of the Priabonian, with the biochronology of calcareous plankton, the most powerful correlation tool available in marine sediments. The extinction of the large muricate planktic foraminifera would approximate the base of the Priabonian within 200 k.y. The well-consolidated practice of recognizing the Priabonian by the means of its original definition, i.e., the LO of C. oamaruensis, should be used with caution. Instead,
we are confident that the acme beginning of *C. erbae*, at 61 cm below the base of the Tiziano bed, recorded in many sections in Italy and in the Atlantic Ocean (see Formaciari et al., 2010), represents an easy to recognize event and accurate approximation (within less than 20 k.y.; Fig. 18; Table 4) of the base of the Priabonian.

**Required Future Work**

The proposed definition of the GSSP of the Priabonian will serve to overcome the present unacceptable state of uncertainty and contradictions in recognizing the middle Eocene–late Eocene boundary. However, further work is needed to better constrain in time the absolute age of the proposed GSSP. In particular, we are working on the radioisotopic dating of the Tiziano bed and the orbital tuning of the Alano section in order to assess a better age of the GSSP.

Other work that is needed is a better tie between the large benthic foraminifera biostratigraphy and the geomagnetic polarity time scale in order to provide a better correlation potential between shallow- and deep-water successions.

**Toward a Unit Stratotype of the Priabonian**

Within the current rules of the ICS, the top of the Priabonian, equivalent to the base of the Rupelian and to the Eocene-Oligocene boundary, is defined by the GSSP approved at Massignano, in the Marche region (Northern Apennines, Italy). If our proposal at Alano will be accepted, the Priabonian Stage may be formally and unequivocally defined according to the approved rules of the ICS. However, we concur with Hilgen et al. (2004) that a stage is a kind of stratigraphic unit that is best represented by succession of strata rather than by two single points in the stratigraphic record. It is proposed here that if the orbital tuning at Alano is successful, the unit stratotype of the Priabonian could be represented by the composite section constituted by the Alano and Massignano sections. As shown in Figure 17, these two sections together seem to represent the entire interval of time that we have proposed as representing the Priabonian.

**CONCLUSIONS**

The major output of this paper is the proposal to the ICS of designating the base of a prominent crystal tuff layer (Tiziano bed) in the Alano section, NE Italy, as the GSSP of the Priabonian Stage, the standard chronostratigraphic unit of the Upper Eocene. The section, described for the first time in this paper, is continuously and spectacularly outcropping, well accessible, unaffected by structural deformation, rich in well-preserved planktonic foraminifera and calcareous nannofossils, and contains six prominent crystal tuff layers, some of which seem amenable to isotopic dating.

A second output of our study is a much improved chronostratigraphic framework for the middle–late Eocene transition, which has been controversial in the literature. The high-resolution and solid biomagnetostatigraphic framework established at Alano has been compared with the data already available (Wade, 2004) or was acquired specifically for this work in the deep-sea ODP Site 1052, straddling the middle–late Eocene. We have shown that the extinction of large muricate planktic foraminifera, a major step in the evolution of this group during the Cenozoic (e.g., Berggren, 1969), occurred in mid–chron C17n.3n and was probably a synchronous event over wide areas. Concomitant with this event, major changes are observed in the calcareous nannofossil assemblages, the most important of which is the acme beginning of the distinctive *Cribrocentrum erbae*. We have revised the biostratigraphic reliability and biochronology of calcareous plankton, pointing out that the LO of *C. oamaruensis* and the HO of *C. grandis* must be used with extreme caution for accurate corollations, the LO of *I. recurvus* is much older than in previous age estimates (e.g., Berggren et al., 1995), and the biochronology of the LO of *T. cerroazulensis* group likely needs to be significantly changed with respect to calibration reported in Berggren et al. (1995).

We have discussed the correlation potential of the proposed Priabonian GSSP at Alano. The extinction of muricate planktic foraminifera and the acme beginning of *C. erbae* are thought to be useful tools for approximating the base of the Priabonian in the marine stratigraphic records over large areas and depositional settings. The base of chron C17n is useful for correlation with continental records. Most probably, the first appearance of Nummulites fabiani would remain a useful criterion for recognizing the Priabonian in shallow-water marine settings, even if an improved correlation between the large foraminifera biostratigraphy to the geomagnetic polarity time scale is in order.

If the proposed GSSP will be accepted, the Priabonian, the top of which is defined at Massignano (Premoli Silva and Jenkins, 1993), would have a duration of ~4.1 m.y., compared to the estimated duration of 3.5 m.y. of Berggren et al. (1995) and 3.3 m.y. of Ogg and Smith (2004).

Work is continuing on the Alano section in an attempt to establish an orbital tuning of the proposed GSSP and isotopic dating of the Tiziano bed, both of which would allow a much better time frame for the base of the Priabonian and improve the time scale of the late Eocene. However, the data available and presented in this paper are considered adequate for formalizing the GSSP of the Priabonian at the base of the Tiziano bed in Alano section, thus contributing to the task of ratifying GSSPs and stabilizing the International Chronostratigraphic Scale expected within the next International Geologic Congress in 2012.

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Plate I. 1–23: planktonic foraminiferal scanning electron micrograph (SEM) images of selected zonal markers from the middle–late Eocene Alano section (northern Italy). “Large acarininids”: 1, 2—Acarinina topilensis. Sample COL 345 b (1. ventral view; 2. spiral view). 3, 4—Acarinina rohri (3. sample COL 40a, spiral view; 4. sample COL 60b, spiral view). “Small acarininids”: 5, 6—Acarinina medicuiz. Sample COL 2799c (5. ventral view; 6. spiral view). 7, 8—Acarinina echinata. Sample COL 4045c (7. ventral view; 8. ventral view). 9—Moreozovelloides coronatus. Sample COL 2496a, ventral view. 10—Moreozovelloides crassatus. Sample COL 732c, ventral view. 11–15—Turborotalia cocoaensis (11, 12, 13—sample COL 520a [horizon of lowest occurrence of the species], profile; 14. sample COL 600 a, ventral view; 15—sample COL 1285b, profile). 16, 17—Globigerinatheka semiinvoluta, sample COL 4605c. 18, 19—Sample COL 440a, Orbulinoides beckmanni. 20–23—Gaasbeekellidae nuttalli (20. sample COL 240a, spiral side; 21. sample COL 3701c, spiral side; 22. sample COL 492c, ventral side; 23—sample COL 3281c, lateral side). Scale bar = 100 µm.