
***Figure 8. Alano section (modified after Agnini et al., 2011). (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 post-MECO (lithozone B). (D) The upper part of the sapropelic interval with indication of the prominent bioclastic layer Palladio (lithozones 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).***

laterally and no faults (even with small displacement) are visible in the section. The sediments cropping out in the Alano section 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). The Alano section is continuously exposed along the banks of the Calcino Creek for at least 500 meters (Figs. 2, 8). Above the investigated section, there are an additional fifteen meters of continuously outcropping marls followed downstream by spotted outcrops. In the lower part of the section, from ~ 17 m level to ~ 25 m level, the grey marls facies is interrupted by a distinctive ~ 8 m-thick package of laminated dark to black organic-rich clayey marls (ORG1 and ORG2), which is interpreted as the 'post-MECO interval' (Luciani et al., 2010). Among the sandy-silty layers, eight are more than 6 cm thick, and six of these are crystal tuff layers that have been named, from the bottom to the top, after famous Venetian painters: Mantegna, Giorgione, Tiziano, Tiepolo, Tintoretto and Canaletto (Figs. 7, 8). The other two layers are biocalcarenite-rudite beds that have been named Palladio and Canova after famous Venetian artists (Figs. 7, 8). Field observations and a $CaCO_3$ record permit the subdivision of the section into four lithozones: A, B, C and D (Agnini et al., 2011; Fig. 7). The Tiziano crystal tuff layer, here proposed as the GSSP of the Priabonian, occurs in the lower portion of lithozone D (which extends from 59.95 m to the top of the section; Fig. 7). Because none of the existing local lithostratigraphic units (Cita, 1975) can be properly applied to the succession cropping out at Alano, Agnini et al. (2011) provisionally introduced the informal term *Marna scagliosa di Alano* for the grey marls cropping out in the Alano section (Fig. 2).

## *Depositional Environment and Correlation Between Deep- and Shallow-water Settings*

The grey marls of the Alano section were deposited in a low energy,

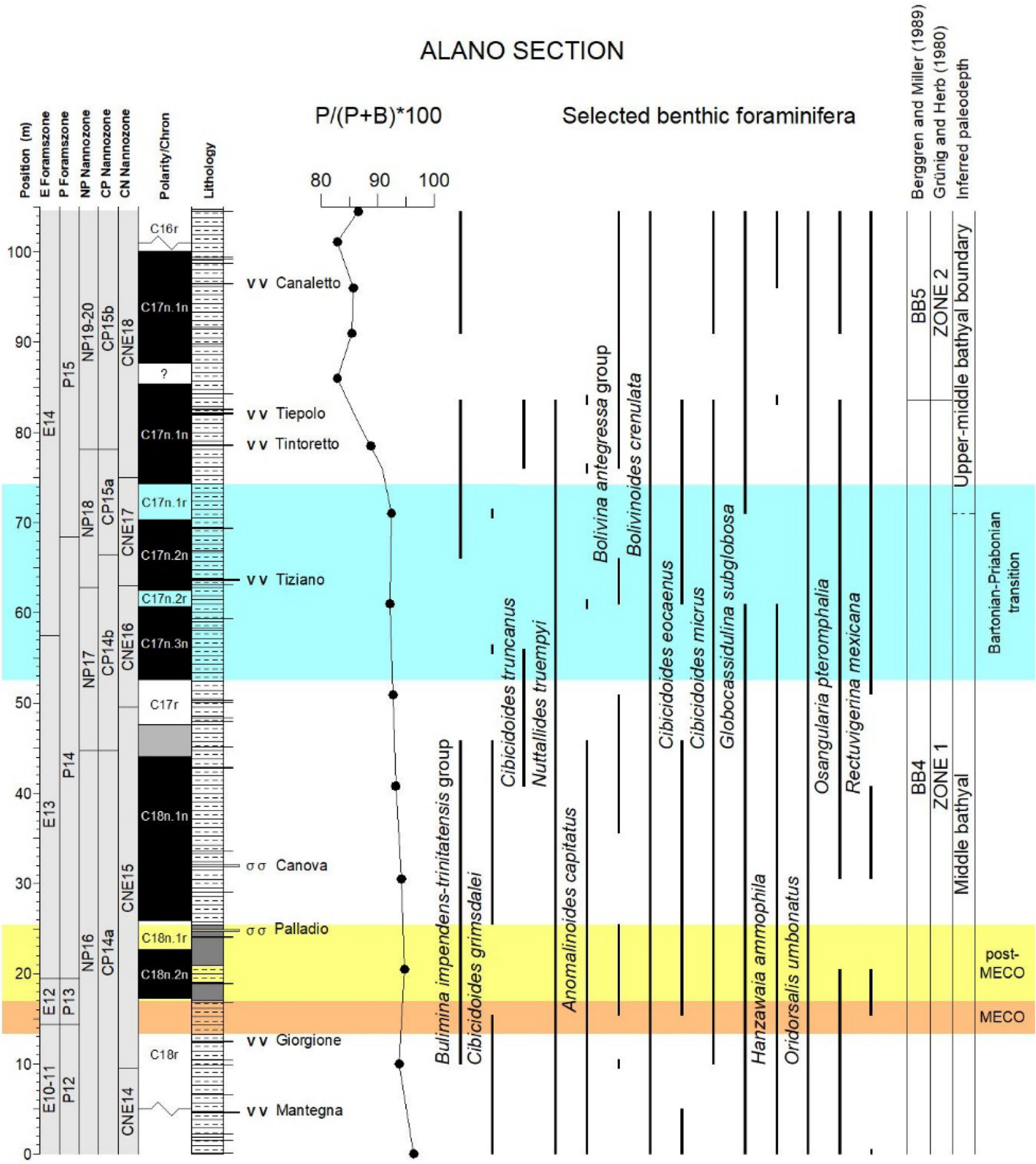


***Figure 9. (modified after Agnini et al., 2011). The P/(P + B) (%) (= planktonic to planktonic and benthic ratio) and stratigraphic distribution of selected small benthic foraminifera plotted against lithology and calcareous plankton biostratigraphy (P - Berggren et al. 1995; E - Berggren and Pearson (2005) or Wade et al. (2011); NP - Martini, 1971; CP - Okada and Bukry, 1980; CN - Agnini et al., 2014). Benthic foraminifera biozonation (Berggren and Miller, 1989), bathymetric zonation (Grünig and Herb, 1980) and inferred paleodepth of the Alano section are reported on the right side. The shaded orange band indicates the MECO, the shaded yellow band marks the post-MECO interval and the light blue shaded band identifies the Bartonian-Priabonian transition, the critical interval where the Priabonian GSSP should be defined.***

open marine slope-basin setting. Paleobathymetric estimates point to a middle bathyal depositional depth (600–1000 m) for the lower two thirds of the section, and to upper-middle bathyal depths (~ 600 m) for the remaining third of the studied section (Fig. 9; Agnini et al., 2011). This interpretation is supported by the Planktonic/Benthic foraminiferal ratio and by the changes observed in the benthic foraminiferal paleobathymetric indexes (Fig. 9; Agnini et al., 2011). Benthic foraminiferal assemblages (Boscolo-Galazzo et al., 2013) indicate well oxygenated bottom waters throughout the entire section, except for the 8 m-thick package of organic-rich sediments (17-25 m level), the 'post-MECO' interval, where hypoxic conditions prevailed, as also indicated by geochemical proxies (Spofforth et al., 2010). The abundant occurrence of bolivinids is typical of bathyal hemipelagic sediments in this area of the Tethys and has been related to the proximity

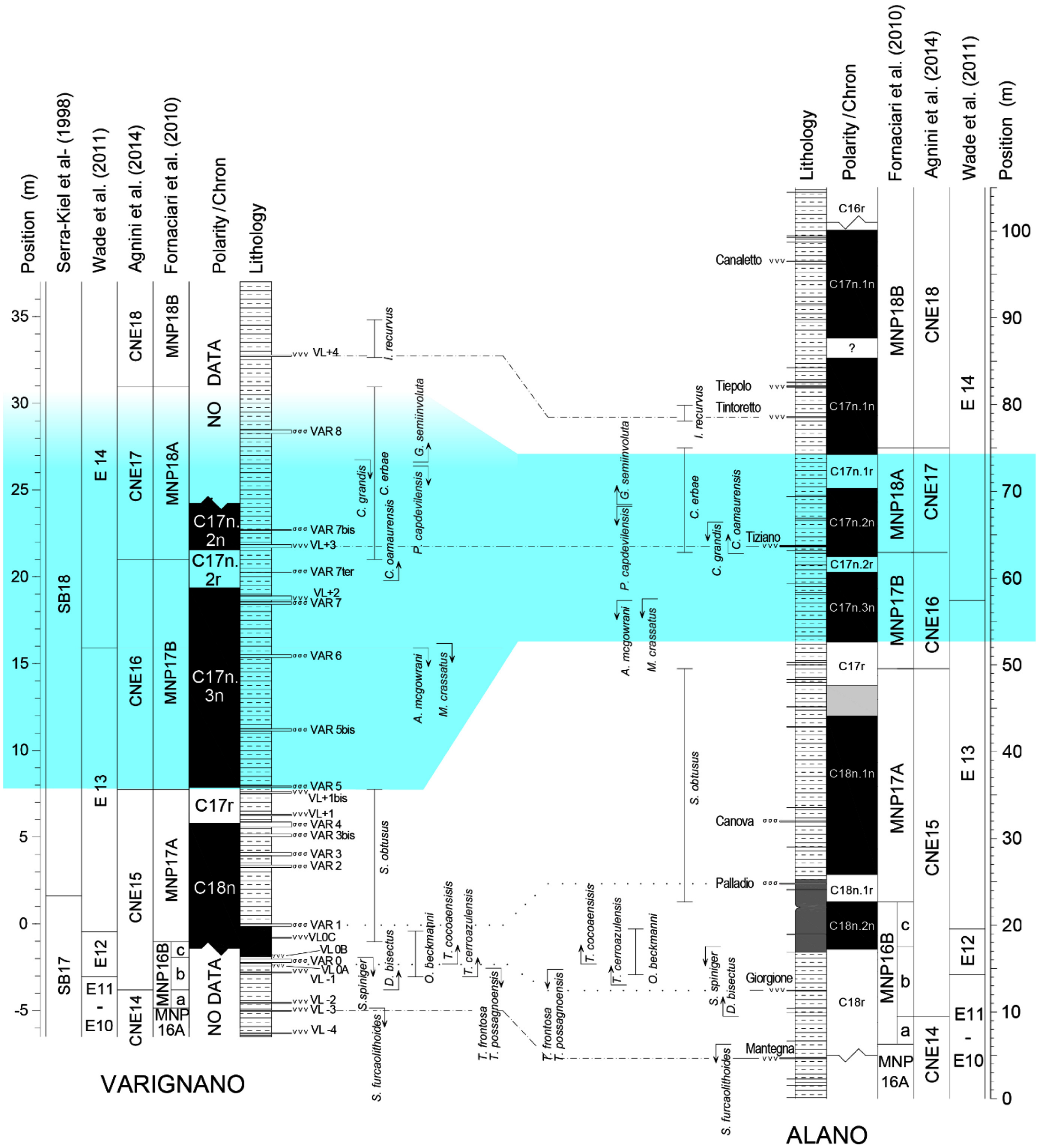


*Figure 10. (modified after Luciani et al., 2020). Correlation of main and secondary calcareous plankton events and layers with volcanoclastic material (dashed line) recorded in the Varignano (Trento) and Alano (Belluno) sections. The light blue shaded band identifies the Bartonian-Priabonian transition, the critical interval where the Priabonian GSSP should be defined. Dashed lines refer to tentative correlations.*

of land (Boscolo-Galazzo et al., 2013). As expected in deep-water sediments like those of the Alano section, macrofossils are sporadic.

At Alano, larger foraminifera occur only as re-sedimented grains in distinct beds well below the critical interval, hampering a direct correlation between calcareous plankton and larger foraminiferal zonations. However important supporting information is provided by the Varignano section (Trento Province, Italy), located ~80 km to the west of Alano, which preserves several coarse bioclastic levels rich in larger foraminifera intercalated within the bathyal marls of the Bartonian-Priabonian transition (Papazzoni et al., 2014; Luciani et al., 2020). The Varignano section contains a crystal tuff layer that is equivalent to the Tiziano bed as demonstrated by bio-magnetostratigraphical and petrographical-mineralogical data (Fig. 10; Luciani et al., 2020).

Primary and secondary calcareous plankton bioevents across the critical interval are recorded in the same order and stratigraphic position as observed at Alano (Fig. 10). In the succession, the direct correlation between calcareous plankton and larger foraminiferal zones clearly demonstrates that the Base of Zone SB19 is positioned significantly higher that the Bartonian-Priabonian transition as found in other recent studies (Papazzoni et al., 2014; Cotton et al., 2017; Rodelli et al., 2018; Luciani et al., 2020). Instead, this interval as identified by the calcareous plankton events discussed above correlates with the middle part of Zone SB18, the base of which is marked by the Base of the distinctive genus *Pellatispira* (Papazzoni et al., 2014).

## *Calcareous Nannofossil Biostratigraphy*

Calcareous nannofossil assemblages are rich, well preserved, and diverse throughout the section (Plate I; Fornaciari et al., 2010; Agnini et al., 2011; Toffanin et al., 2011). The assemblages are dominated by placoliths, among which *Cribrocentrum, Cyclicargolithus* and *Dictyococcites* are prominent (together up to ~70 of the total assemblage). *Chiasmolithus* is very rare at Alano as is normally reported for low to middle latitude areas (Perch Nielsen, 1985; Wei and Wise, 1989); this is problematic because some biohorizons used in Martini's (1971) and Okada and Bukry's (1980) zonations, are based on *Chiasmolithus* species (Top of *C. solitus* – Base of Zone NP17 and Subzone CP14b; Base of *C. oamaruensis* – Base of Zone NP18, Top of *C. grandis* – Base of Subzone CP15a). The subdivision of NP and CP zonations is both difficult to apply and generally results in poor global correlations. Recently, a new calcareous nannofossil Paleogene biozonation has been published for low to middle latitudes (Agnini et al., 2014). This biostratigraphic scheme avoids the use of biohorizons based on *Chiasmolithus* species in favor of more reliable events (e.g., Base of common and continuous (Bc) of *Dictyococcites bisectus*, Top of *Sphenolithus obtusus*, Base of common and continuous and Top of common and continuous (Tc) *C. erbae*). With reference to this biozonation, the Alano section spans from Zone CNE14 to Zone CNE18 (Fig. 4). If the classical calcareous nannofossil zonation of Martini (1971) is followed, the Alano section covers the interval from Zone NP16 to undifferentiated Zone NP19-20 (Fig. 7). Finally, if the zonal scheme of Okada and Bukry (1980) is applied, the section extends from Subzone CP14a to Subzone CP15b (Fig.4). Agnini et al. (2011) demonstrated that the Tiziano Bed (63.57 m level) is 0.72 meters above the Base of uneven and rare (Br) *C. oamaruensis* (62.85 m level), which marks the NP17/NP18 boundary, and 2.90 meters below the Top of *C. grandis*, which defines the Subzone CP14b/ Subzone CP15a boundary. Because of the general scarcity of these taxa, these biohorizons must be used with caution for accurate correlations. The Base of common and continuous *C. erbae* (62.96 m level), as defined in Agnini et al. (2014), is recorded 0.61 meters below the base of the Tiziano bed, and represents the most reliable calcareous nannofossil biohorizon for approximating the base of the Priabonian (Fornaciari et al., 2010; Agnini et al., 2011). A more global perspective of calcareous nannofossil biohorizons across the Bartonian-Priabonian transition as well as their degree of reliability and correlatability are presented in Figure 6, where the Alano section and the reference ODP Site 1052 are compared (Agnini et al., 2011).

## *Planktonic Foraminiferal Biostratigraphy*

Planktonic foraminifera are continuously present, abundant and diverse throughout the Alano section, except for some levels of the organic rich package (from 17 m level to 25 m level), the 'post-MECO' interval (Figs. 5, 8; see Plate II for iconographic material). The preservation varies from moderate to good and foraminiferal assemblages are generally recognizable although commonly recrystallized, cemented and infilled. The assemblage composition is distinctive of subtropical-temperate latitudes and changes in the relative abundance of taxa are observed throughout the section. Subbotinids and globigerinathekids are among the more frequent and common groups.

Large acarininids are abundant in the lower part of the section and include *Acarinina* with well-developed muricae and test size > 125 μm (*A. bullbrooki, A. mcgowrani, A. praetopilensis, A. primitiva, A. rohri, A. topilensis*). This group decreases at the ORG1 and ORG2 intervals (Spofforth et al., 2010) corresponding to the 'post-MECO' as defined by Luciani et al. (2010). The hantkeninids display a sporadic distribution and, where present, constitute a minor component of the assemblage. With reference to the standard zonation of Berggren et al. (1995), the Alano section extends from Zone P12 to Zone P15. In terms of the tropical to subtropical zonation of Berggren and Pearson (2005) and the subsequent revision by Wade et al. (2011), the section extends from undifferentiated Zone E10-11 to Zone E14. At Alano, the identification of the Top of *Orbulinoides beckmanni* (19.5 m level; Fig. 5), marking the E12/E13 and P13/P14 boundaries, is difficult to recognize because of the scarcity of this taxon and the moderate preservation of the foraminiferal assemblages in the 'post-MECO' interval. The E10 and E11 zones (Berggren and Pearson, 2005; Wade et al., 2011; Payros et al., 2015) have been merged because at Alano the highest consistent occurrence of *Guembelitrioides nuttalli*, which marks the Base of Zone E11, is recorded at 57.52 m level, well above the Top of *O. beckmanni*. The extinction level of large acarininids occurs at 57.32 m level and is immediately followed (57.52 m level; Fig. 5) by the disappearance of *Morozovelloides* (i.e., *Morozovelloides crassatus* and *Morozovelloides coronatus*). These biohorizons underlie the Tiziano bed by 6.25 and 6.05 meters respectively, which is equivalent to 170-173 kyr in our floating chronology (Fig. 3). To test the reliability and reproducibility of the Top of large acarininids and *Morozovelloides*, we compared the Alano section with the reference ODP Site 1052 (Fig. 6; Wade, 2004; Agnini et al., 2011). This pair of closely spaced bioevents is very solid and provides a good correlation tool to approximate the base of the Priabonian (Wade et al., 2012).

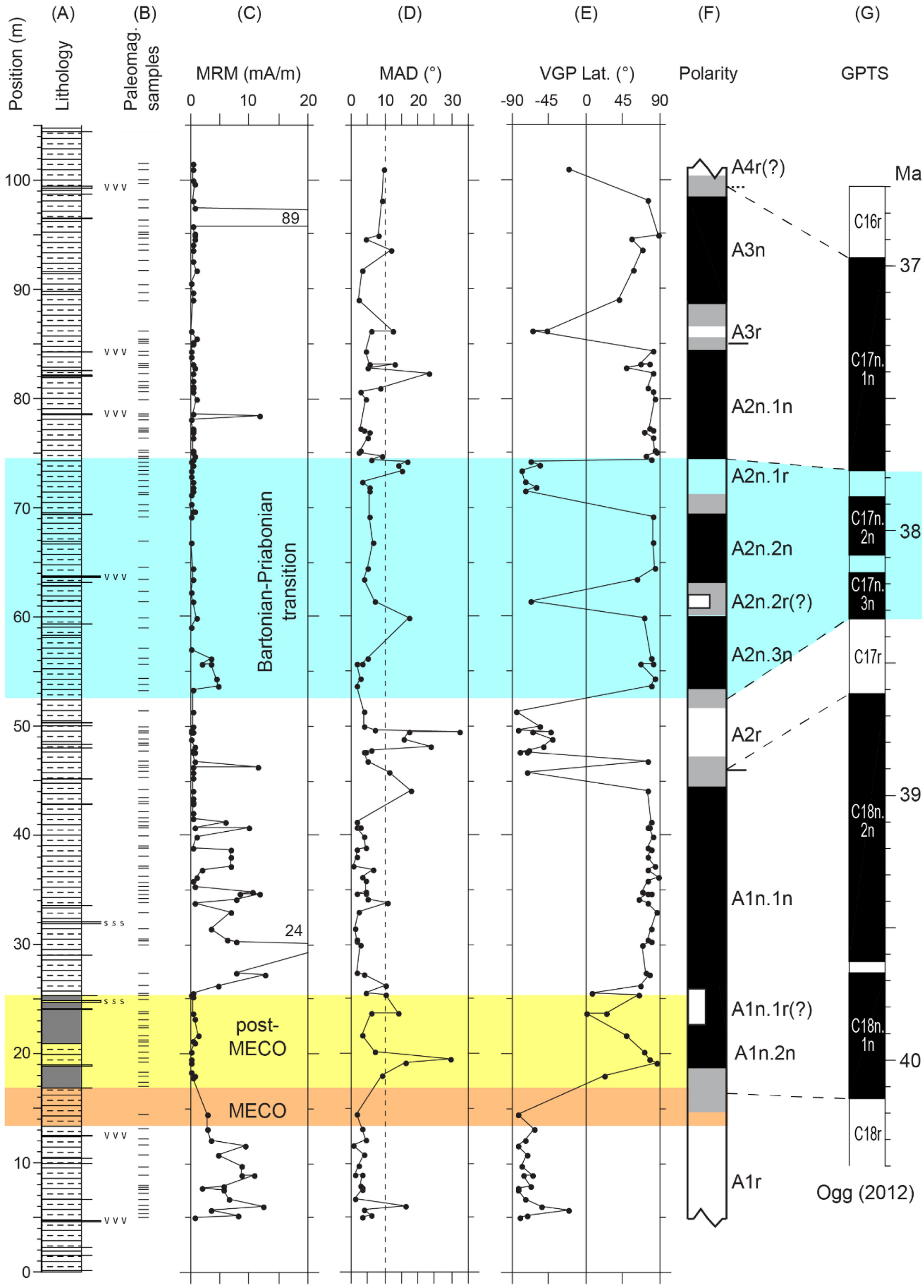


***Figure 11. (modified after Agnini et al., 2011). Stratigraphic synthesis of the Alano section with (A) lithology, (B) stratigraphic position of samples for paleomagnetic analysis, (C) natural remanent magnetization (NRM) intensity, (D) mean angular deviation (MAD) of the characteristic magnetic component, and (E) virtual geomagnetic pole (VGP) latitude used for polarity interpretation (F); black is normal polarity; white reverse polarity; (G) GPTS (Ogg, 2012; GST12). The shaded orange band indicates the MECO, the shaded yellow band marks the post-MECO interval and the light blue shaded band identifies the Bartonian-Priabonian transition, the critical interval where the Priabonian GSSP should be defined.***

## Magnetostratigraphy

The Alano section has a good magnetostratigraphic record, which permits a straightforward correlation to the geomagnetic polarity time scale of Ogg (2012; GTS12 Fig. 11). An overall sequence of 13 polarity magnetozones has been established starting from the base up to the top of the section (Agnini et al., 2011). The basal part of the section correlates with the upper part of Chron C18r, while the single sample with reverse polarity at the top of the section correlates with the Base of Chron C16r (Fig. 11). Though the base of the Priabonian has often been approximated by the Base of Subchron C17n.1n (see discussion in Vandenberghe et al., 2012), the polarity reversal with the higher correlation potential in the proximity of the Tiziano bed is the Base of Chron C17n (or Subchron C17n.3n) at 52.62 m level. It is worth noting that the polarity reversal closest to the Tiziano bed is the Base of Subchron C17n.2n (62.48 m level). The latter is defined by a single reversed datapoint. However, assuming the median points of related uncertainty intervals as base and top of this Subchron, its cyclochronological duration is consistent with the adopted timescales (Galeotti et al., 2019).

## *Stable isotopes (bulk $\delta^{13}C$ and $\delta^{18}O$) and the Middle Eocene Climatic Optimum*

Carbon and oxygen stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) analyses were performed on bulk rock from the entire section with an average sample spacing of ~ 20 cm (Fig. 12; Spofforth et al., 2010). The $\delta^{13}C$ and $\delta^{18}O$ profiles show a gradual decrease of ~ 0.5 ‰ up section. No sig-

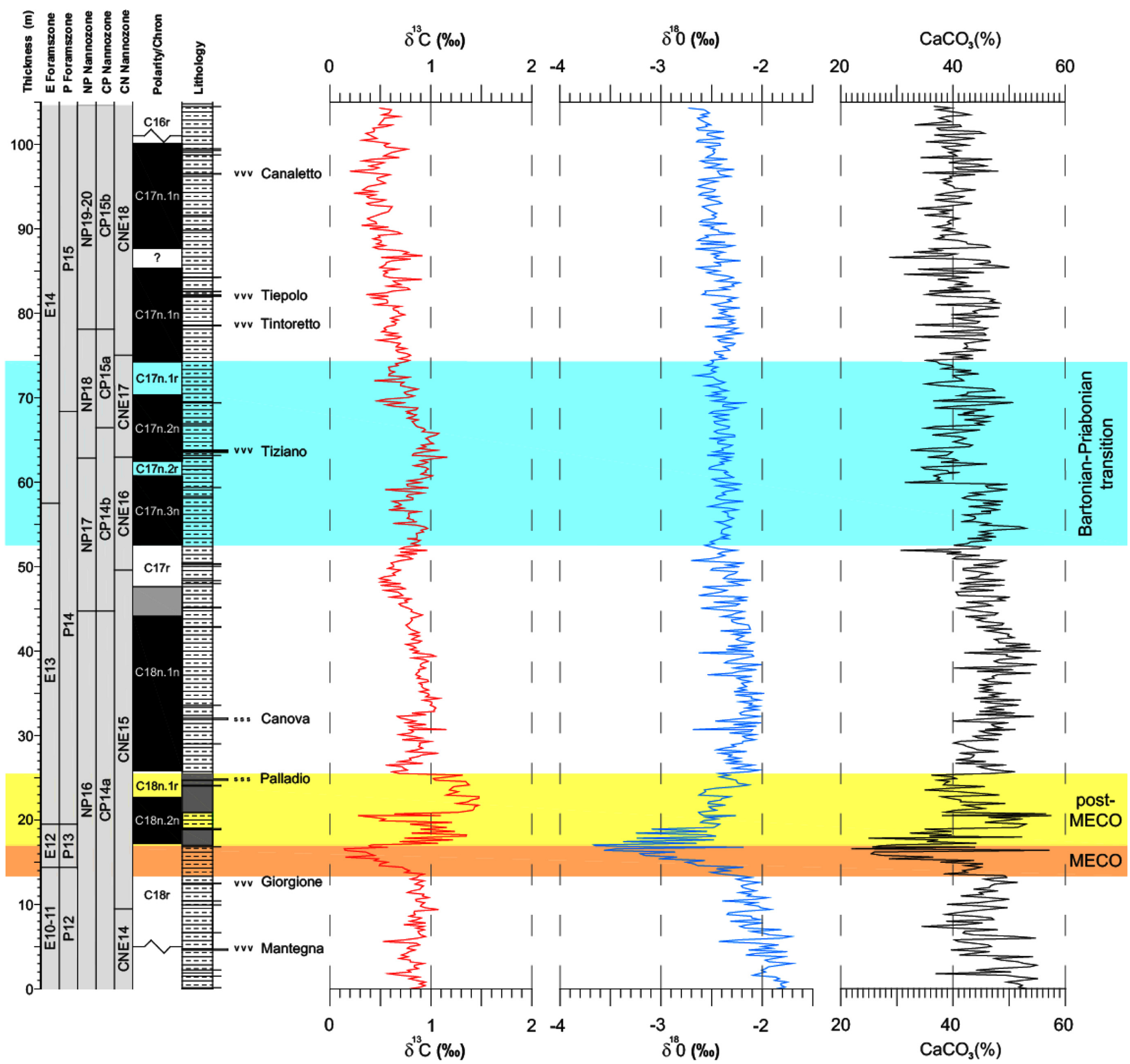


*Figure 12. (modified after Spofforth et al., 2010). Bulk carbonate stable isotopes $\delta^{13}C$, $\delta^{18}O$, and percentage $CaCO_3$ over the entire Alano section. The shaded orange band indicates the MECO, the shaded yellow band marks the post-MECO interval and the light blue shaded band identifies the Bartonian-Priabonian transition, the critical interval where the Priabonian GSSP should be defined.*