doi: 10.3304/jmes.2020.16766

Journal of Mediterranean Earth Sciences 12 (2020), 77-86

Journal of Mediterranean Earth Sciences

Epilithic organisms in Priabonian marls with pillow lavas from the Euganean Hills (NE Italy)

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To the late, unforgettable colleague Franca Proto Decima, remembering her high value as micropalaeontologist and modest and joyous spirit.

ABSTRACT - In the Castelnuovo area of the Euganean Hills, upper Priabonian marls (referred to as Brendola Marl) are associated with products of submarine basaltic eruptions, including pillow lavas and lava flows, pertaining to the first, late Eocene magmatic phase in the district. A biostratigraphical revision of the marl by means of calcareous nannofossils allowed to ascribe the succession to the Priabonian Zone CNE19 (Agnini et al., 2014) and to the upper part of planktonic foraminiferal Zone E15, with an estimated age of 35.3-34.3 Ma (Berggren and Pearson, 2005). The benthic foraminiferal assemblage provided a palaeodepth estimation suggesting a deep neritic environment. A reconstruction of the late Priabonian events in the study area indicates various episodes of submarine eruptive activity with formation of pillows and associated hyaloclastic material, alternating with phases of colonization of the upper parts of the pillows and larger hyaloclasts by epilithic and vagile organisms such as crinoids, cirripeds, brachiopods and cidarid echinoids, followed by their post-mortem disaggregation, dispersal and eventual burial due to the uninterrupted marly sedimentation. These episodes ceased with the emplacement of a lava flow, whose flat top was colonized only by sparse cirripeds.

Keywords: Brendola Marl; biostratigraphy; palaeoecology; microbial erosion; palaeobathymetry.

Submitted: 29 May 2020-Accepted: 4 September 2020

1. INTRODUCTION

Dieni and Proto Decima (1963) described an interesting section cropping out in the Castelnuovo di Teolo area (Euganean Hills, SW of Padua, NE Italy), consisting of a marly unit containing basaltic pillow lavas dated to the late Priabonian. They first reported the peculiar fauna found in these marly sediments and the marine setting of the concomitant volcanic activity, which pertains to the first magmatic cycle in this district. Later, they described the foraminiferal content of this lithostratigraphical unit, characterized by particularly abundant Hantkeninidae (Dieni and Proto Decima, 1964 a,b). Subsequently, Bitner and Dieni (2005) and Carriol and Dieni (2005) studied in detail the assemblages of epilithic organisms living on the volcanic products, i.e., brachiopods and cirripeds.

In the present paper the integrated lithostratigraphical, palaeontological, biostratigraphical and palaeoecological data provide a reconstruction of the environmental setting and palaeobathymetry of the marly unit, and document the alternation between the emplacement of volcanic products and the settling of epilithic and motile faunas on them.

2. GEOLOGICAL AND STRATIGRAPHICAL SETTING

2.1. LITHOSTRATIGRAPHY

In the Euganean Hills the most widespread sedimentary formation consists of a complex of grey to pale yellow marl and subordinate limestone and calcareous marl of Palaeogene age, overlying the Scaglia Rossa, which has a Late Cretaceous to early Palaeocene estimated age in the Euganean area (Cucato et al., 2012, and references therein). This lithological unit has been named usually with informal terms, such as simply “marne” (e.g., De Vecchi and Sedea, 1974), or “marne euganee” (e.g., Dieni and Proto Decima, 1970; Proto Decima and Sedea, 1970; Piccoli et al., 1976), or “Marne Euganee” (Brighenti and Mesini, 2000). For this unit, Cucato et al. (2012) formally introduced the name of “Formazione di Torreglia”; they provided a detailed description of its lithological characteristics, indicating two reference sections and an estimated Lutetian-Rupelian (Middle Eocene- Early Oligocene) age (Cucato et al., 2012, and references therein); they also proposed another formation, the “Formazione di Castelnuovo”, corresponding to the Euganean marls with associated basaltic products. However, this name should not be validated, being a formational unit based exclusively on the local inclusion of additional volcanic products. Likewise, the “Formazione di Torreglia” should be considered as invalid according to the rules of international stratigraphical nomenclature (ACSN, 1961, 1970; Germani et al., 2003; Owen, 2009), since it is a junior synonym of “Marnes de Brendola”, a lithostratigraphical unit proposed in 1894 by Munier-Chalmas and Lapparent with the following short diagnosis (p. 479): “Le Priabonien des Colli Berici présente la constitution suivante: 1) Assises de Granella (…); 2) Groupe des couches à *Orbitoides* de Priabona (…); 3) Marnes de Brendola passant à l’Oligocene et charactérisées par *Spondylus Cisalpinus*, *Ostrea Brongniarti*, *Clavulina Szaboi*, *Nummulites sub-Tournoueri*”. The Brendola Marl of the Berici Mountains, a hilly group situated to the immediate NW of the Euganean area, has lithological, palaeontological and chronostratigraphical characteristics (Broglio Loriga et al., 1968) that are wholly comparable to those of the marly complex of the Euganean Hills, as already indicated by Catullo (1840, p. 227). Indeed, the deposits of the Brendola Marl are regionally isochronous, thus representing an important key unit. The Brendola Marl is also known in the literature as “Bryozoen Mergel” or “Bryozoen Schichten”; these terms were widely used in the nineteenth and twentieth centuries by Austrian authors (e.g., Reuss, 1848, 1869). Referring to the previous descriptions by Fabiani (1908, 1911), Broglio Loriga et al. (1968) suggested as type-locality for this formation the Rio delle Spesse valley, where Broglio Loriga (1969) measured and described in detail an about 40 m thick section at the base of Mt Castello; we agree in considering this section as a valuable option for the type-section of the Brendola Marl.

2.2. THE CASTELNUOVO SECTION

The studied section is located some 600 m south-east of the village of Castelnuovo, at the beginning of the street (Via Siesa), which branches off from the main road to Torreglia and leads to “Case Gastaldello” (Fig. 1). Roadwork carried out in this area has exposed a succession of the Brendola Marl and associated basaltic products for a length of 10 m and a height of 4 m. The outcrop shows the co-occurrence of marl and pillow lavas and, laterally and at the top, is delimited by compact basaltic flows, that are in turn covered by marly sediments (Fig. 2A). The area is particularly rich in submarine basaltic lava flows and volcanoclastic materials (Fig. 1B) related to the first phase of the Euganean volcanism of late Eocene age (Dieni and Proto Decima, 1963; De Vecchi and Sedea, 1974; Piccoli et al., 1976, 1981), correlative with similar eruptive episodes in the nearby Berici and Lessini mountains.

Pillows have generally subspherical or ellipsoidal, sometimes irregular shape (Fig. 2B). Their width varies from 10 to 80 cm, and most of them have a diameter around 20 cm. The hyaloclastic material surrounding the pillows formed during their growth as a result of the progressive breaking up of their skin. The glassy cortical part of the pillows and hyaloclasts shows an intense palagonitization, which resulted in the formation of various ochraceous products (Stroncik and Schmincke, 2002) that locally modify the original grey colour (pale yellow after weathering) of the marl. Pillows are rarely in contact, because they are completely isolated and “drowned” within the sedimentary material; moreover, the marl at the base of individual pillows shows some thermal-driven hardening and calcination. These particular features clearly indicate that the pillows were not produced during a single submarine effusive event, but are rather the result of various local volcanic episodes punctuated by eruptive inactivity, during which sedimentary material continued to be deposited.

A naked-eye examination is sufficient to ascertain that the marl surrounding the pillows contains very abundant crinoid ossicles, mainly columnals. Verrucid cirripeds, along with crinoids and bryozoans, are the dominant epilithic faunas originally growing on the basaltic pillows and larger hyaloclasts (Carriol and Dieni, 2005).

3. BIO- AND CHRONOSTRATIGRAPHY

Foraminiferal and calcareous nannofossil content of the marly beds was examined in order to obtain a more precise bio- and chronostratigraphic assignment of these sediments, already referred by Dieni and Proto Decima (1964a) to the uppermost Eocene.

3.1. CALCAREOUS NANNOFOSSILS

Some smear slides were prepared following the procedure described in Bown and Young (1998) and analysed in a light transmitted microscope at x1250 magnification. The observed calcareous nannofossils are generally well preserved and the assemblages have a high species diversity (Figs. 3, 4). *Coccolithus pelagicus, Zyghrablithus bijugatus, Lanternithus minutus, Dictyococcites* spp., and *Reticulofenestra* spp. are common taxa, whereas others represent an accessory component of the assemblages (e.g., *Discoaster* spp., *Isthmolithus* spp., *Coroannulus* spp., *Braarudosphaera* spp., *Thoracosphaera* spp., *Umbilicosphaera* spp., *Clausicoccus* spp., *Chiasmolithus* spp., *Ericsonia* spp., *Cribrocentrum* spp., *Helicosphaera* spp., *Pontosphaera* spp., *Blackites* spp.).

Semiquantitative analysis has been performed to constrain biostratigraphically the studied samples. *Cribrocentrum reticulatum, Discoaster saipanensis, Discoaster barbadiensis, Isthmolithus recurvus* and *Cribrocentrum isabellae* are present. Using the zonations of Martini (1971) and Okada and Bukry (1980), the samples belong to Zone NP19-NP20 and Subzone CP15b respectively, based on the concurrent presence

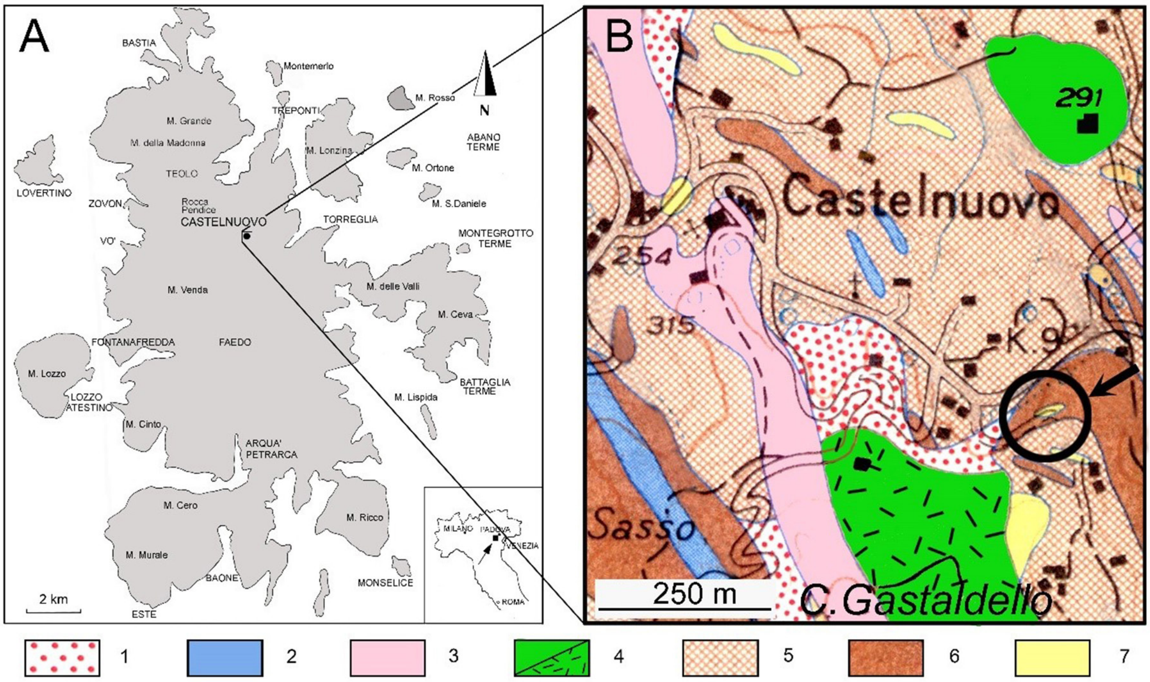

Fig. 1 - A) Schematic topographic map of the Euganean Hills. B) Geological map of the Castelnuovo area (from Sedea in Piccoli et al., 1976); circle and arrow indicate the studied section of Via Siesa (45°19'38"N–11°41'37"E). Legend: 1) Scree deposits (*Holocene*). 2) Latite: dykes (*early Oligocene*). 3) Trachyte: dykes (*early Oligocene*). 4) Rhyolite: lavas and tuffs (*early Oligocene*). 5) Basaltic hyaloclastites and breccias (*late Eocene*). 6) Basalt: lava flows, locally with pillows (*late Eocene*). 7) Brendola Marl: grey to yellowish marls (*Lutetian-Rupelian*).

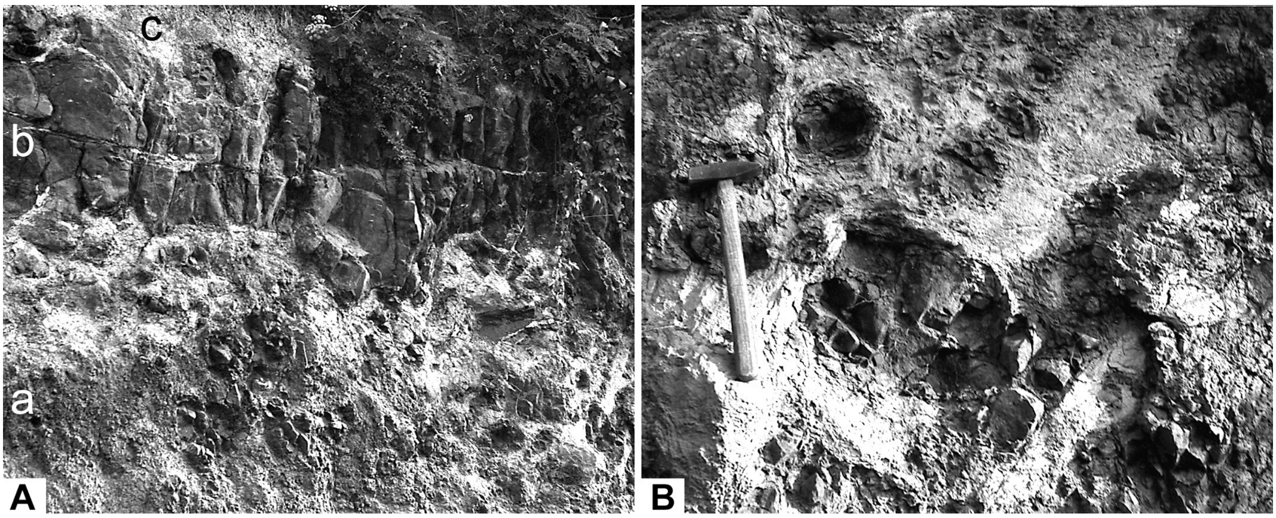

Fig. 2 - The outcrop of basaltic pillow lavas within the upper Priabonian Brendola Marl at Castelnuovo in the Euganean Hills. A: general view showing that the marl with pillows (a) is overlain by a flat-topped and load-casted basaltic flow (b), in turn capped by marl (c) devoid of volcanic products. B: detail of the exposure showing that in general the pillows are not in reciprocal contact.

of *I. recurvus* and *D. saipanensis/D. barbadiensis*. A more refined biostratigraphy was obtained applying the scheme of Agnini et al. (2014). In particular, the absence of *Cribrocentrum erbae* Fornaciari, Agnini, Catanzariti and Rio, 2010, and the presence of *I. recurvus, C. isabellae* and *C. reticulatum,* indicate that the investigated samples lie within Zone CNE19 (36.1-35.2 Ma). Based on these results the Brendola Marl can be dated to the Priabonian.

3.2. PLANKTONIC FORAMINIFERA

The biostratigraphically important planktonic foraminiferal taxa observed in the studied section (Dieni and Proto Decima, 1964 a,b) are the following:

Cribrohantkenina inflata (Howe, 1928) (Fig. 5 A,C)
Globigerinatheka index (Finlay, 1939)
Hantkenina alabamensis Cushman, 1925 (Fig. 5B)
Pseudohastigerina micra (Cole, 1927)
Subbotina gortanii (Borsetti, 1959)

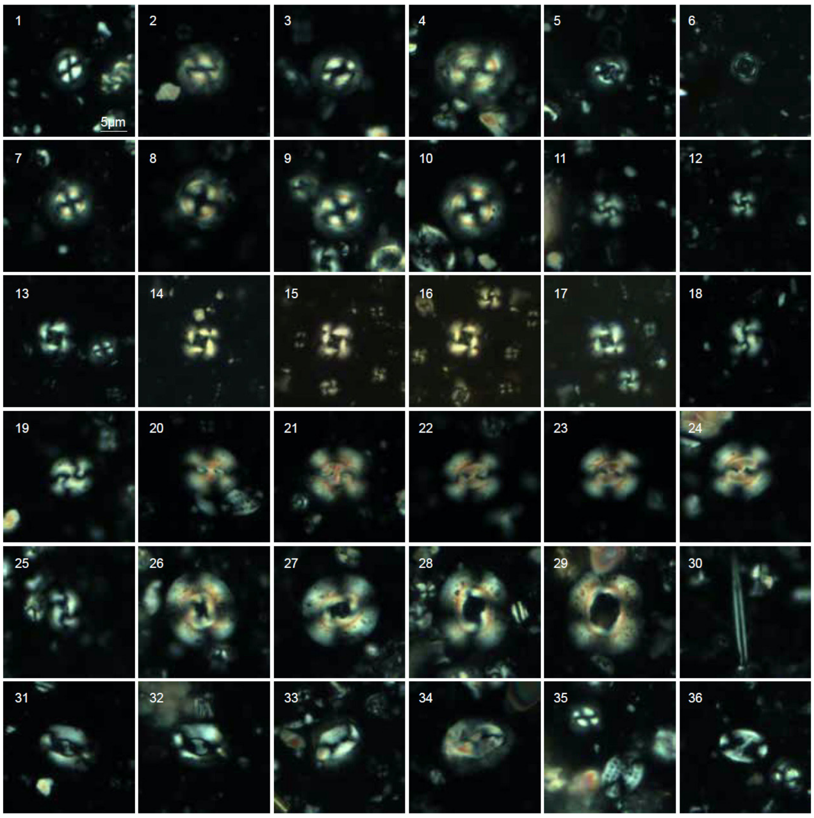

Fig. 3 - Light microscope photographs (crossed nicols) of selected calcareous nannofossils from the Brendola Marl of Castelnuovo. Bar = 5 µm. 1-4 *Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930*;* 5. *Chiasmolithus nitidus* Perch-Nielsen, 1971; 6. *Umbilicosphaera bramlettei* (Hay and Towe, 1962) Bown et al., 2007; 7-10. *Ericsonia formosa* (Kamptner, 1963) Haq, 1971; 11-12 *Cyclicargolithus floridanus* (Roth and Hay in Hay et al., 1967) Bukry, 1971; 13-17. *Cribrocentrum reticulatum* (Gartner and Smith, 1967) Perch Nielsen, 1971; 18-20. *Dictyococcites hesslandii* Haq, 1971; 21-24. *Dictyococcites bisectus* (Hay et al., 1966) Bukry and Percival, 1971 (>10 µm); 25. *Reticulofenestra daviesii* (Haq, 1968) Haq, 1971; 26-27. *Reticulofenestra hillae* Bukry and Percival, 1971; 28-29. *Reticulofenestra umbilicus* (Levin, 1965) Martini and Ritzkowski, 1968; 30. *Blackites tenuis* (Bramlette and Sullivan, 1961) Sherwood, 1974; 31-32. *Helicosphaera bramlettei* (Müller, 1970) Jafar and Martini, 1975; 33-34. *Helicosphaera compacta* Bramlette and Wilcoxon, 1967; 35. *Pontosphaera punctosa* (Bramlette and Sullivan, 1961) Perch-Nielsen, 1984; 36. *Pontosphaera exilis* (Bramlette and Sullivan, 1961) Romein, 1979.

Turborotalia cerroazulensis (Cole, 1928)
Turborotalia cocoaensis (Cushman, 1928)
Turborotalia cunialensis (Toumarkine and Bolli, 1970).

Based on this assemblage and, specifically, on the absence of *Globigerinatheka semiinvoluta* (Keijzer, 1945) and the presence of *Globigerinatheka index*, the section is ascribable to Zone E15 (35.8-34.3 Ma; Berggren and Pearson, 2005; Wade et al., 2011). The presence of *Turborotalia cunialensis* suggests that the sediments can be placed in the upper part of Zone E15 with an estimated age of 35.3-34.3 Ma (Berggren and Pearson, 2005; Wade et al., 2011).

4. PALAEOECOLOGY AND PALAEOBATHYMETRY

4.1. BENTHIC ASSEMBLAGES

The reconstruction of the palaeoecological and palaeobathymetric setting is based on the analysis of benthic foraminifera assemblages and epilithic and vagile organisms that originally lived on the hard substrates of volcanic products.

4.1.1. Foraminifera

Among the most significant benthic taxa the following are noteworthy:

Alabamina wilcoxensis (Toulmin, 1941)
Anomalinoides affinis (Hantken, 1875)
Cibicidoides eocaenus (Gümbel, 1870)
Cibicidoides perlucidus (Nuttall, 1932)
Hanzawaia ammophila (Gümbel, 1868)
Osangulina plummerae (Brotzen, 1940)
Planulina cf. *mexicana* (Cushman, 1927)
Pseudoclavulina szaboi (Hantken, 1868)
Spiroloculina sp.

4.1.2. Macrofauna

The composition of the epilithic fauna growing on the volcanic products includes several groups of organisms which are listed below.

Bryozoans are common and represented, among others, by:

Batopora scrobiculata (Koschinsky, 1885)
Celleporaria sp.

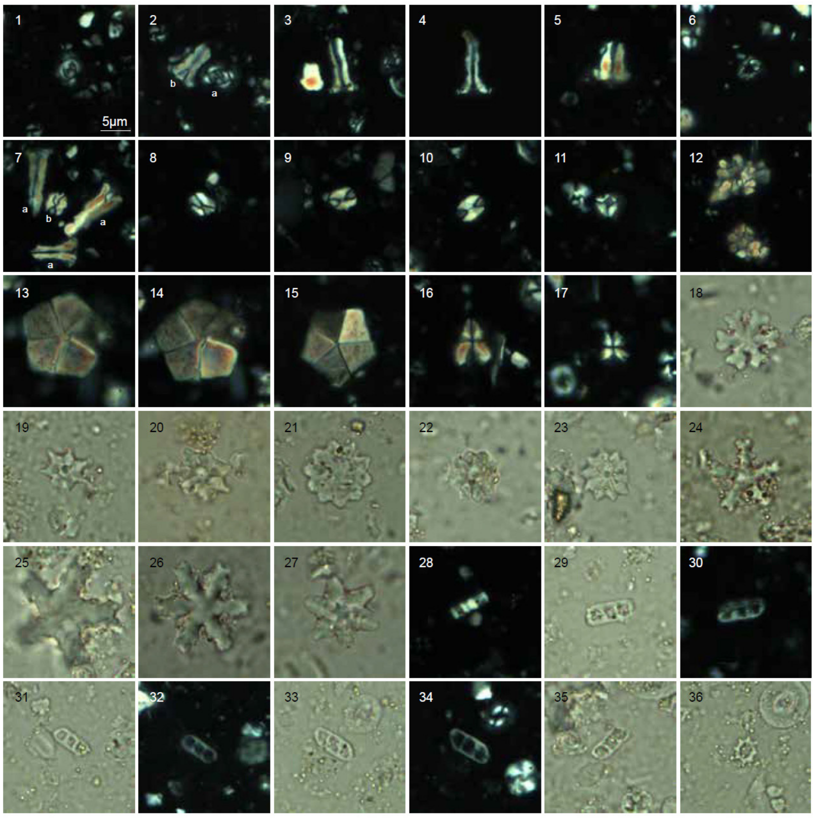

Fig. 4 - Light microscope photographs (crossed nicols and parallel light) of selected calcareous nannofossils from the Brendola Marl of Castelnuovo. Bar = 5 µm. 1-2 *Clausicoccus subdistichus* (Roth and Hay in Hay et al., 1967) Prins, 1979; 2. 2a) *Clausicoccus subdistichus* (Roth and Hay in Hay et al., 1967) Prins, 1979; 2b) *Zygrhablithus bijugatus* (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959; 3-5. *Zygrhablithus bijugatus* (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959; 6. *Zygrhablithus bijugatus* (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959, basal view; 7. 7a) *Zygrhablithus bijugatus* (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959; 7b) *Lanternithus minutus* Stradner, 1962; 8-10. *Lanternithus minutus* Stradner, 1962; 11. *Lanternithus minutus* Stradner, 1962 (lateral view); 12. *Thoracosphaera operculata* Bramlette and Martini, 1964; 13-15. *Braarudosphaera bigelowii* (Gran and Braarud, 1935) Deflandre, 1947; 16. *Sphenolithus* sp.; 17. *Sphenolithus moriformis* (Brönnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967; 18. *Discoaster deflandrei* Bramlette and Riedel, 1954; 19-20. *Discoaster saipanensis* Bramlette and Riedel, 1954; 21-23. *Discoaster barbadiensis* Tan, 1927; 24-26. *Discoaster tanii* Bramlette and Riedel, 1954; 27. *Discoaster* sp.; 28. *Isthmolithus recurvus* Deflandre in Deflandre and Fert, 1954 (lateral view); 29-35. *Isthmolithus recurvus* Deflandre in Deflandre and Fert, 1954; 36. *Corannulus germanicus* Stradner, 1962.

Conopeum hookeri (Haime, 1850)
Crassimarginatella macrostoma (Reuss, 1848)
Cribilaria radiata (Moll, 1803)
Disparella verrucosa (Philippi, 1844)
Exidmonea carinata (Roemer, 1840)
Hornera sp.
Mecynoecia proboscidea (Milne-Edwards, 1838)
Oncousoecia biloba (Reuss, 1848)
Reteporella tuberculata (Reuss, 1869)
Sparsiporina elegans (Reuss, 1848)
Stenosipora simplex (Koschinsky, 1885).

Brachiopods are present with micromorphic species, among which:
Lacazella mediterranea (Risso, 1826)
Orthothyris pectinoides (von Koenen, 1894)
"*Terebratula*" *italica* Bitner and Dieni, 2005
Terebratulina sp. cf. *T. tenuistriata* (Leymerie, 1846)
Venetocrania euganea Bitner and Dieni, 2005,
and fragments of unidentified rhynchonellids.

Cirripeds are represented by extremely abundant plates (scuta, terga, carinae) of the following verrucomorphs:
Costatoverruca? *seguenzai* Carriol and Dieni, 2005
Metaverruca euganea Carriol and Dieni, 2005
Verruca veneta Carriol and Dieni, 2005,
which are associated with rare plates of balanomorphs and sparse elements of pedunculate forms, among which:
Arcoscalpellum gassinense (De Alessandri, 1906).

Crinoids are represented by very abundant ossicles of the following species:
Isselicrinus diaboli (Bayan, 1970)
Isselicrinus subbasaltiformis (Miller, 1821)
Paraconocrinus pyriformis (Münster, 1826).

4.1.3. Vagile organisms

The presence of cidarid echinoids is documented by common spines of *Cyathocidaris* sp.

4.2. MICROBIAL EROSION

A peculiar characteristic of the Brendola Marl of Castelnuovo is the intense microbial erosion affecting the

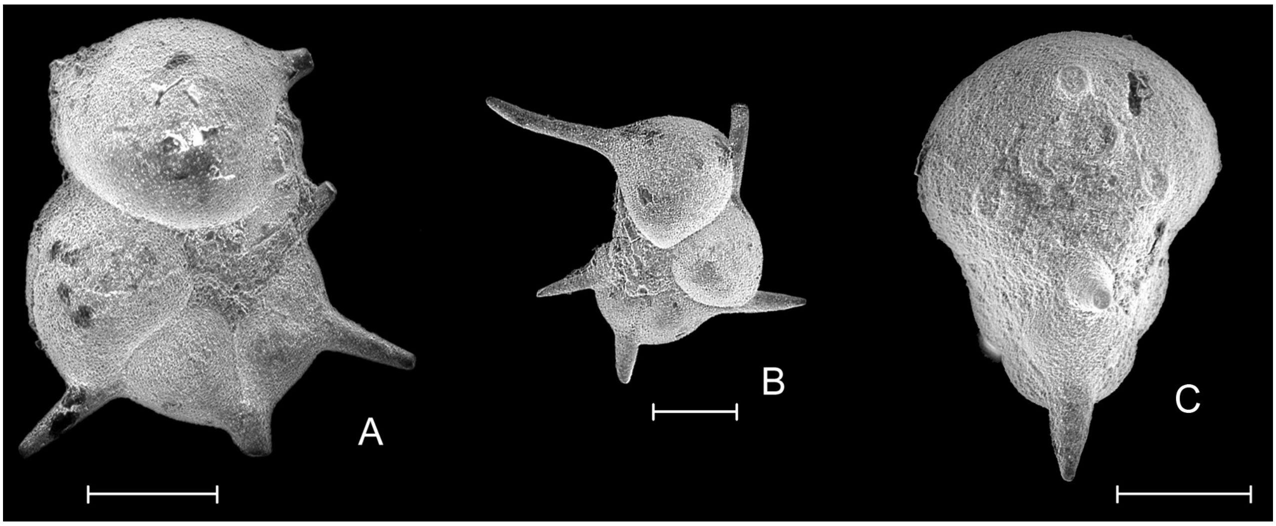

Fig. 5 - A, C - *Cribrohantkenina inflata* (Howe), lateral and apertural views; B: *Hantkenina alabamensis* Cushman, lateral view. Bar: 200 μm.

carbonate tests of the micro- and macroorganisms (Fig. 6). This feature has been commonly observed in other localities of the Venetian region where Priabonian marls crop out, such as the Berici Mountains (Brendola) and the Possagno area (Radtke, 1991).

4.3. PALAEOBATHYMETRIC ASSESSMENT BASED ON THE FORAMINIFERAL FAUNA

The benthic foraminiferal assemblage comprises various taxa with an upper limit of bathymetric distribution within the neritic environment, including *Hanzawaia ammophila*, *Planulina* cf. *mexicana, Cibicidoides eocaenus*, and *Cibicidoides perlucidus*. The latter two taxa are part of the plexus *C. eocaenus-C. perlucidus-C. tuxpamensis* (Cole), within which *C. eocaenus* represents an "ecophenotype" of shallower waters (van Morkhoven et al., 1986). Higher abundance of *C. eocaenus* compared to *C. perlucidus* in the examined samples suggests a depositional setting ascribed to the outer shelf. Accordingly, Browning et al. (1997) found relatively high percentages (>12%) of *C. eocaenus* in outer shelf setting, at a palaeobathymetry of 150-200 m. The relatively low percentage of arenaceous species in the observed assemblage agrees with this bathymetric attribution. This interpretation is also supported by the composition of the Palaeogene neritic assemblages of the southern margin of the Tethys (e.g., Kouwenhoven et al., 1997), which include a number of taxa found in the Euganean foraminiferal assemblage, e.g. *Alabamina wilcoxensis*, *Anomalinoides affinis*, *Osangularia plummerae*, and *Spiroloculina* sp.

Although the plankton/benthos ratio (P/B) varies between 80% and 90%, suggesting a deeper depositional setting, the lack or scarcity of taxa typical and/or exclusive of the bathyal environment, such as *Globocassidulina subglobosa* (Brady), buliminids and uvigerinids, support the above bathymetric attribution.

4.4. PALAEOECOLOGICAL INFERENCES

The inferred succession of events during the sedimentation of the Brendola Marl in the Castelnuovo section is illustrated in figure 7. A first episode of basaltic lava flow emplacement on the sea bottom was accompanied by the development of pillows and production of abundant hyaloclasts. Local thermal-driven calcination occurred at the base of the pillows with the consequent hardening of the marl. The prominent parts of the pillows and the larger hyaloclasts were then colonized by epilithic and vagile organisms, such as crinoids, cirripeds, brachiopods and cidarid echinoids.

After death, colonizing organisms were progressively disaggregated, and the skeletal components were dispersed within the marl around the pillows. This occurred concomitantly with the gradual reduction of the space available to epilithic and motile fauna on the top of the pillows due to continuing marl deposition. Eventually, the pillows were completely buried by marly sediment enriched in skeletal remains. The succession of volcanic episodes with pillow lavas, active biotic phases, and marl deposition was closed by the emplacement of a massive basaltic lava flow load-casted at the base and flat-topped; the lava surface was then colonized only by sparse cirripeds. The absence of other epilithic organisms may be due to the flat topography of the substrate lacking elevated mounds, and possibly to turbid waters at the sediment-water interface that hampered the settling of suspension feeders. The lava flow was subsequently buried by marl.

5. CONCLUSIONS

In the Castelnuovo area of the Euganean Hills, upper Priabonian marls are associated with products of submarine basaltic eruptions, including pillow lavas and lava flows, pertaining to the first volcanic phase in the district during the late Eocene. These products

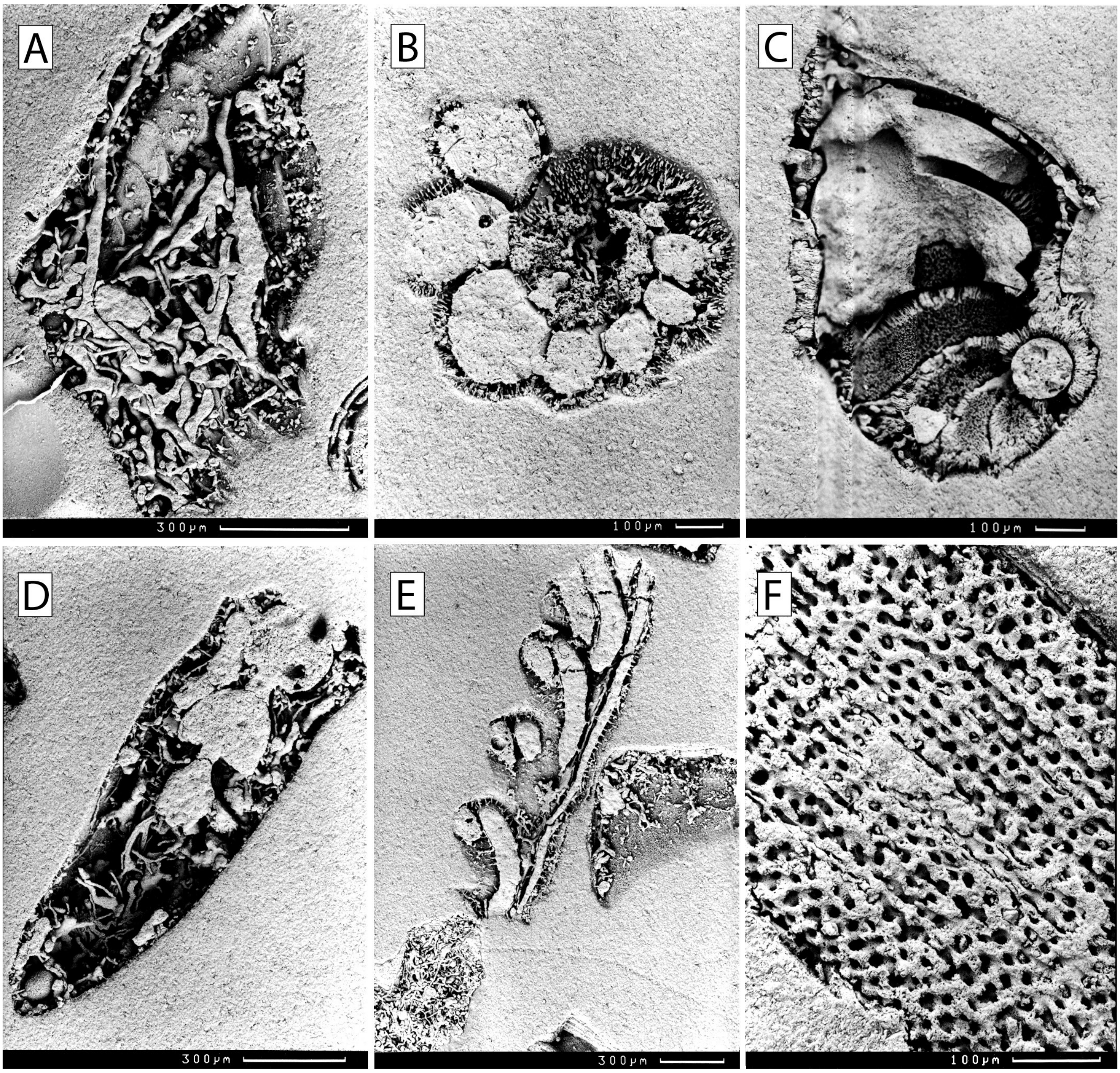

Fig. 6 - SEM images showing examples of bioerosion affecting different organisms with variable intensity. A: cirriped plate; B: cibicidid foraminifer; C: *Planularia* sp.; D: nodosarid foraminifer; E: bryozoan and cirriped plate; F. echinoid spine poorly affected by bioerosion due to the void network of the stereom. The specimens have been processed using the method of Golubic et al. (1970).

constituted the substrate on which epilithic and motile faunas could settle with several episodes of colonization alternating with eruptive events.

A review of the lithostratigraphical unit, usually known in the literature with informal terms, leads us to re-validate the name of Brendola Marl proposed by Munier-Chalmas and Lapparent (1894), of which subsequent names are clearly junior synonyms. A biostratigraphical review of the section indicates that the succession belongs to the calcareous nannofossil Zone CNE19 (Agnini et al., 2014). This chronology is confirmed by planktonic foraminiferal data indicating the *Globigerinatheka index* Highest-occurrence Zone (Zone E15; Berggren and Pearson, 2005), which points to a late Priabonian age.

The benthic foraminiferal assemblage has been analyzed in order to define the palaeobathymetry of the studied sediments, and revealed the occurrence of various taxa with an upper limit of distribution comprised within the neritic setting. This environmental attribution is also supported by the similarity with other Palaeogene neritic assemblages of the southern margin of the Tethys, with which the studied assemblage shares various taxa.

A reconstruction of the late Priabonian events that occurred in the study area during the sedimentation of the Brendola Marl leads us to identify various episodes of submarine eruptive activity characterized by formation of pillows and associated hyaloclastic material, alternating with phases of colonization: the prominent parts of the

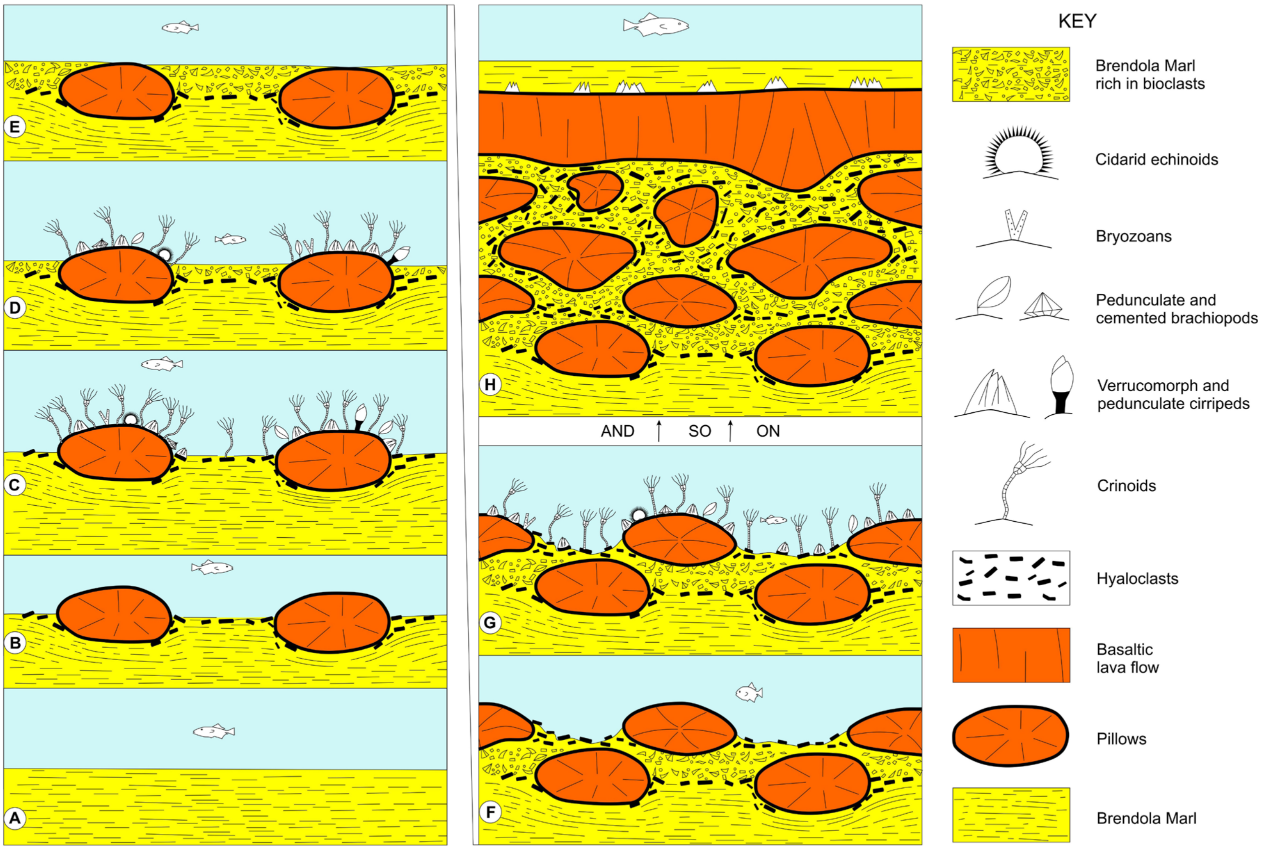

Fig. 7 - Proposed reconstruction (not to scale) of the late Priabonian events in the studied Castelnuovo area. A) Sedimentation of the Brendola Marl. B) First episode of basaltic lava flow with development of pillows and production of abundant hyaloclasts; local thermic-driven calcination and consequent hardening of the marls at the base of the pillows. C) Colonization of the prominent parts of the pillows and larger hyaloclasts by epilithic and vagile organisns (bryozoans, crinoids, cirripeds, brachiopods, cidarid echinoids). D) Disaggregation of dead colonizing organisms and their dispersal within the marl around pillows, accompanied by the gradual reduction of the space available to epilithic and motile fauna on the pillow tops due to continuing marl deposition. E) Burial of the pillows by marl rich in bioclasts. F) New submarine episode of lava flow with formation of pillows and associated hyaloclastic material. G) Colonization of the pillow tops by stationary and vagile organisms and dispersal of their elements within the marls as in the stages C to E. H) Persistence of volcanic episodes with pillow lavas, biotic activity, and marl deposition, ended by the emplacement of a massive basaltic lava flow load-casted at the base and flat-topped; colonization of the lava top only by sparse cirripeds and subsequent burial by marl.

pillows and larger hyaloclasts were colonized by epilithic and vagile organisms (mostly bryozoans, crinoids and cirripeds, associated with brachiopods and cidarid echinoids) followed by their post-mortem disaggregation, dispersal and eventual burial by continuing marl sedimentation. These repeated episodes came to an end through the emplacement of a lava flow, whose flat top was colonized only by sparse cirripeds.

ACKNOWLEDGEMENTS - I.D. and F.M. wish to thank warmly K. Vogel and the laboratory staff of the Institute of Geology and Palaeontology of the Goethe University Frankfurt a. M. for providing the casts and SEM images of the microborings. S. Galeotti (Urbino University) helped significantly in the palaeobathymetric interpretation of the foraminiferal assemblage. Johannes Pignatti and I. Raffi provided constructive insights that greatly improved the manuscript. S. Castelli and N. Michelon (Geoscience Department of Padova University) are acknowledged for their careful technical support.

REFERENCES

ACSN (American Commission on Stratigraphic Nomenclature), 1961. Code of stratigraphic nomenclature. American Association of Petroleum Geologists Bulletin 45, 645-665.

ACSN (American Commission on Stratigraphic Nomenclature), 1970. Code of stratigraphic nomenclature. 2nd ed., American Association of Petroleum Geologists Bulletin, pp. 45

Agnini C., Fornaciari E., Raffi I., Catanzariti R., Pälike H., Backman J., Rio D., 2014. Biozonation and biochronology of Paleogene calcareous nannofossils from low and middle latitudes. Newsletters on Stratigraphy 47, 131-181.

Berggren W.A., Pearson P.N., 2005. A revised tropical to subtropical Paleogene planktonic foraminiferal zonation. Journal of Foraminiferal Research 35, 279-298.

Bitner M. A., Dieni I., 2005. Late Eocene brachiopods from the Euganean Hills (NE Italy). Eclogae Geologicae Helvetiae 98, 103-111.

Bown P. R., Young J. R., 1998. Techniques. In: Bown P. R. (Ed.), Calcareous Nannofossil Biostratigraphy. Kluwer Academic, London, 16-28.

Brighenti G., Mesini E. (Eds.), 2000. Atti del 13° Geofluid "Problemi di Geoingegneria: le risorse termominerali", Piacenza, 7 ottobre 2000, pp. 85.

Broglio Loriga C., 1969. I foraminiferi bentonici delle marne a Briozoi di Brendola (Vicenza, Colli Berici). Mémoires du Bureau de Recherches Géologiques et Minières 69, 83-92.

Broglio Loriga C., Ungaro S., Braga G.P., Ascoli P., Cita M.B., 1968. Coupe de Brendola (M. Castello). In: Cita M.B. (Ed.), Colloque sur l'Éocène 1968. Guide de l'excursion en Italie, 41-45. Istituto di Paleontologia, Università di Milano.

Browning J.V., Miller K.G., Bybell L.M., 1997. Upper Eocene sequence stratigraphy and the Absecon Inlet Formation, New Jersey coastal plain. In: Miller K.G., Snyder S.W. (Eds.), Proceedings of the Ocean Drilling Program, Scientific Results 150X, 243-266.

Carriol R.-P., Dieni I., 2005. Three new Verrucidae (Crustacea: Cirripedia) from the Upper Eocene of the Euganean Hills (Northeast Italy). Geobios 38, 397-406.

Catullo T.A., 1840. Osservazioni geognostico-zoologiche sopra due scritti pubblicati nel tomo terzo delle Memorie della Società Geologica di Parigi per l'anno 1838. Nuovi Saggi della Imperiale Regia Accademia di Scienze, Lettere ed Arti in Padova 5, 217-242.

Cucato M., De Vecchi Gp., Sedea R., 2012. Stratigrafia. In: Cucato M., De Vecchi Gp., Mozzi P., Abbà T., Paiero G., Sedea R. (Eds.), Note illustrative della Carta Geologica d'Italia alla Scala 1: 50.000, Foglio 147 Padova Sud, 33-84. ISPRA, Servizio Geologico d'Italia.

De Vecchi Gp., Sedea R., 1974. Sui basalti eocenici dei Colli Euganei. Memorie degli Istituti di Geologia e Mineralogia dell'Università di Padova 31, pp. 25

Dieni I., Proto Decima F., 1963. Eruzioni sottomarine con lave a cuscini nell'Eocene superiore dei Colli Euganei. Memorie dell'Accademia Patavina di Scienze, Lettere ed Arti, Classe di Scienze Matematiche e Naturali 74, 161-170.

Dieni I., Proto Decima F., 1964a. Cribrohantkenina ed altri Hantkeninidae nell'Eocene superiore di Castelnuovo (Colli Euganei). Rivista Italiana di Paleontologia 70, 555-592.

Dieni I., Proto Decima F., 1964b. Analisi statistica multidimensionale di due gruppi di Cribrohantkenina dell'Eocene superiore di Castelnuovo (Colli Euganei). Accademia Nazionale dei Lincei, Rendiconti della Classe di Scienze Fisiche Matematiche e Naturali, s. 8, 36, 395-399.

Dieni I., Proto Decima F., 1970. Documentazione paleontologica dell'età oligocenica inferiore del vulcanesimo euganeo. Atti e Memorie dell'Accademia Patavina di Scienze, Lettere ed Arti, Classe di Scienze Matematiche e Naturali 82, 321-360.

Fabiani R., 1908. Paleontologia dei Colli Berici. Memorie della Società Italiana delle Scienze, s. 3, 15, 39-248.

Fabiani R., 1911. La Regione dei Berici. Morfologia, Idrografia e Geologia. Bollettino della Sezione Geologica del Magistrato alle Acque, Venezia, pubblicazioni 28 e 29, pp. 84.

Germani D., Angiolini L., Cita M.B., 2003. Guida italiana alla classificazione e alla terminologia stratigrafica. Commissione Italiana di Stratigrafia della Società Geologica Italiana. Quaderni APAT, s. 3, 9, pp. 144.

Golubic S., Brent G., Le Campion-Alsumard T., 1970. Scanning electron microscopy of endolithic algae and fungi using a multipurpose casting-embedding technique. Lethaia 3, 203-209.

Kouwenhoven T.J., Speijer R.P., Van Oosterhout C.W.M., Van Der Zwaan G.J., 1997. Benthic foraminiferal assemblages between two major extinction events: the Paleocene El Kef section, Tunisia. Marine Micropaleontology 29, 115-127.

Martini E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. Proceedings of the II Planktonic Conference, Tecnoscienza, Roma, 739-785.

Munier-Chalmas C.-Ph.-E., Lapparent A. de, 1894. Note sur la nomenclature des terrains sédimentaires. Bulletin de la Société Géologique de France, s. 3, 21, 438-488.

Okada H., Bukry D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973, 1975). Marine Micropaleontology 5, 321-325.

Owen D.E., 2009. How to use stratigraphic terminology in papers, illustrations, and talks. Stratigraphy 6, 106-116.

Piccoli G., Bellati R., Binotti C., Di Lallo E., Sedea R., Dal Prà A., Cataldi R., Gatto G.O., Ghezzi G., Marchetti M., Bulgarelli G., Schiesaro G., Panichi C., Tongiorgi E., Baldi P., Ferrara G.C., Massari F., Medizza F., Iliceto V., Norinelli A., De Vecchi Gp., Gregnanin A., Piccirillo E.M., Sbettega G., 1976. Il sistema idrotermale euganeo-berico e la geologia dei Colli Euganei. Memorie degli Istituti di Geologia e Mineralogia dell'Università di Padova 30, pp. 266.

Piccoli G., Sedea R., Bellati R., Di Lallo E., Medizza F., Girardi A., De Pieri R., De Vecchi Gp., Gregnanin A., Piccirillo E.M., Norinelli A., Dal Prà A., 1981. Note illustrative della carta geologica dei Colli Euganei alla scala 1: 25.000. II edizione. Memorie di Scienze Geologiche 34, 523-566.

Proto Decima F., Sedea R., 1970. Segnalazione di Oligocene marino nei Colli Euganei (Padova). Accademia Nazionale dei Lincei, Rendiconti della Classe di Scienze Fisiche Matematiche e Naturali, s. 8, 48, 156-163.

Radtke G., 1991. Die mikroendolithischen Spurenfossilien im Alt-Tertiär West-Europas und ihre palökologische Bedeutung. Courier Forschungsinstitut Senckenberg 138, 1-185.

Reuss A.E., 1848. Die fossilen Polyparien des Wiener Tertiärbeckens II. Die fossilen Anthozoen und Bryozoen der Schichtengruppe von Crosara. Naturwissenschaftliche Abhandlungen (Haidinger) 2, 1-109.

Reuss A.E., 1869. Paläontologische Studien über die älteren Tertiärschichten der Alpen. II Abtheilung. Die fossilen Anthozoen und Bryozoen der Schichtengruppe von Crosara. Denkschriften der kaiserlichen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Classe 29, 215-298.

Stroncik N.A., Schmincke H.-U., 2002. Palagonite - a review. International Journal of Earth Sciences 91, 680-697.

van Morkhoven F.P.C.M., Berggren W.A., Edwards A.S., Oertli H. J., 1986. Cenozoic cosmopolitan deep-water benthic Foraminifera. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, Mémoire 11, vii + pp. 421.

Wade B.S., Pearson P.N., Berggren W.A., Pälike H., 2011. Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geometric polarity and astronomical time scale. Earth Science Reviews, 104, 111-142.