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ORIGINAL ARTICLE

Short-term middle Eocene (Bartonian) paleoenvironmental changes in the sedimentary succession of Olivetta San Michele (NW Italy): the response of shallow-water biota to climate in NW Tethys

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Abstract

This study focuses on the paleontological content of the middle Eocene (Bartonian) carbonate–siliciclastic sediments of the Capo Mortola Calcarenite Formation from Olivetta San Michele (Liguria, Italy). Along the succession, there are significant paleoecological changes triggered by the variation in neritic input as a consequence of tectonic and climatic instability. Among microfossils, nummulitids prevail, followed by orthophragmines, smaller benthic, and planktonic foraminifera, whereas mollusks and ichnofossils are the most abundant macrofossils. The sudden changes in the benthic communities due to the progressive increase in fluvial input are recorded throughout the sedimentary succession. An increase in water turbidity caused stressful conditions for autotrophic taxa, reducing their size and abundance. In contrast, filter feeders became dominant, suggesting an increase in dissolved and suspended nutrients. Ichnological analysis shows environmental fluctuations controlled by the transport of neritic material offshore, thus confirming the general deepening trend of the studied succession. In the upper part of the succession, we recorded an alternation between gravity flows and marly sediments that are interpreted as short-term alternations between low and intense precipitations. The gravity flows yield taxa such as larger benthic foraminifera (LBF), smaller benthic and planktonic foraminifera, mollusks, and corals. In turn, marls display only a few LBF and abundant smaller benthic and planktonic foraminifera. In these intervals, the increase in planktonic foraminifera also suggests a deepening of the carbonate ramp coinciding with a reduction of light that did not favor the development of LBF. These changes are probably related to the climatic dynamics that occurred in the Bartonian in the western Tethys.

Keywords Paleoecology · Macrofauna · Larger benthic foraminifera · Ichnofossils · Photic zone · Carbonate ramp

Introduction

The Eocene is considered a critical epoch in terms of variation in both paleogeographic setting and climatic dynamics (e.g., Zachos et al. 2001; Torsvik and Cocks 2016). A global greenhouse climate, characterized by high temperatures in the early Eocene (Early Eocene Climatic Optimum: EECO; Zachos et al. 2001, 2008; Bijl et al. 2009; Hollis et al. 2010, 2012), was followed by a long-term cooling that was interrupted by a global warming event during the late middle Eocene (Middle Eocene Climatic Optimum: MECO; Zachos et al. 2001; Bohaty and Zachos 2003; Bohaty et al. 2009; Sluijs et al. 2013). The interplay between global and regional climate processes and the biosphere response have been largely documented for the Eocene deep-water settings (e.g., Ivany et al. 2008; Deprez et al. 2015; Boscolo Galazzo et al. 2016; Giraldo-Gómez et al. 2017; Luciani et al. 2017; Foster et al. 2020; Marchegiano and John 2022).

In contrast, shallow-water depositional settings such as carbonate platforms or mixed carbonate–siliciclastic systems, as recorded in the Mediterranean region (NW Tethys), are much less studied with respect to global climatic and

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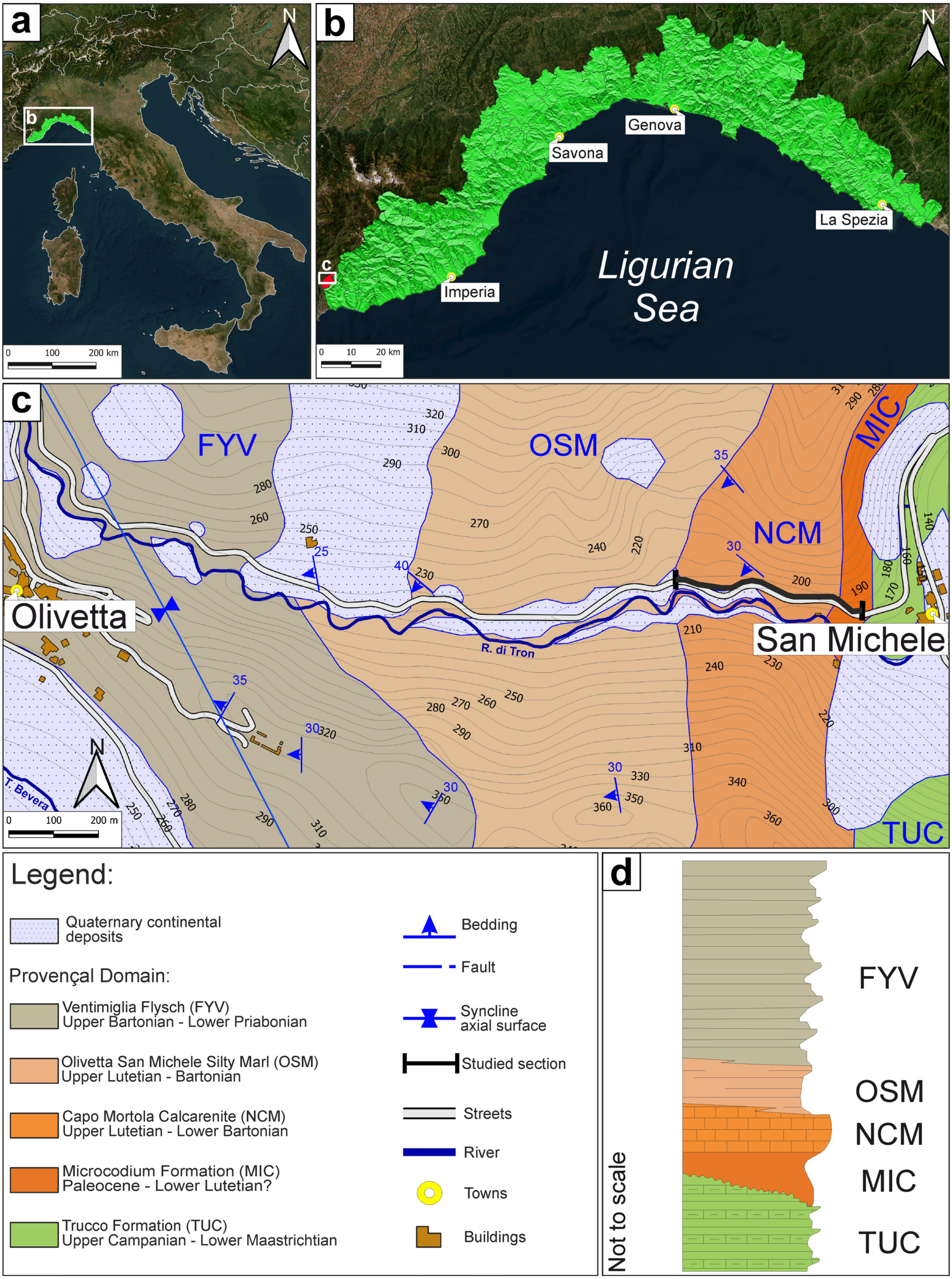
a
b
N
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Genova
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La Spezia
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Ligurian Sea
c
0 10 20 km
c
FYV
OSM
NCM
MIC
TUC
Olivetta
San Michele
R. di Tron
T. Bevera
0 100 200 m
Legend:
Quaternary continental deposits
Provençal Domain:
Ventimiglia Flysch (FYV) Upper Bartonian - Lower Priabonian
Olivetta San Michele Silty Marl (OSM) Upper Lutetian - Bartonian
Capo Mortola Calcarenite (NCM) Upper Lutetian - Lower Bartonian
Microcodium Formation (MIC) Paleocene - Lower Lutetian?
Trucco Formation (TUC) Upper Campanian - Lower Maastrichtian
Bedding
Fault
Syncline axial surface
Studied section
Streets
River
Towns
Buildings
d
Not to scale
FYV
OSM
NCM
MIC
TUC

◂**Fig. 1** **a** Map of Italy showing the Liguria region highlighted in green (modified from https://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery). **b** Location map of the Liguria region displaying the municipality of the Olivetta San Michele (modified from https://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery) **c** Detailed geological map of Olivetta San Michele area, showing the studied section, modified from Dallagiovanna et al. (2012b). **d** Simplified stratigraphic column of the study area modified from Decarlis et al. (2014)

environmental perturbations. These sedimentary successions yield an extraordinary diversity of both micro- and macrofauna that during the Eocene experienced the effects of climate change, as evidenced by high water temperatures, increased continental weathering, and shifting hydrological cycles (e.g., Martín-Martín et al. 2021; Coletti et al. 2021; Brandano and Tomassetti 2022; Bosellini et al. 2022; Briguglio et al. 2024).

The paleogeographic setting of the Ligurian Alps (Italy) and the Provençal Domain (Gèze and Nestéroff 1968; Lanteaume 1968; Lemoine et al. 1986; Ford et al. 2006; de Graciansky et al. 2010; Giammarino et al. 2010; Dallagiovanna et al. 2012a; Seno et al. 2012; Decarlis et al. 2014) provides extended sedimentary successions where it is possible to observe and study the resilience of micro- and macrofauna to Middle Eocene climatic perturbations.

This study aims to describe the paleoenvironmental development of the Bartonian deposits in the Olivetta San Michele section, with special emphasis on (1) the analysis of paleoecological parameters such as diversity and dominance, (2) the climatic influence exerted on specific taxa, and (3) the data retrieved from both the biota observed at outcrop scale and the one recorded in thin sections. With these aims, our goal is to describe in detail the sedimentary and ecological development of the early stages of the drowning of a middle Eocene ramp. The early stages of ramp drowning may vary rapidly along a sedimentary succession as the result of shifting ecological gradients; ecological niches for specific organisms may have a relatively short occurrence along the profile yet provide valuable insights on the evolutionary stages of the drowning. The integration of observations on macro-, microfacies, and trace fossils allowed us to reconstruct the paleoenvironmental succession.

Geological setting and studied section

The studied section is in the westernmost part of Liguria (Italy), which is part of the Provençal Domain (43°52.78140'–7°31.97550'; Fig. 1a, b). The Olivetta San Michele (Olivetta SM) section crops out along the eastern limb of the syncline of Piène–Olivetta SM (between the villages of San Michele and Olivetta, Imperia province, W Liguria; Fig. 1c) and represents a good exposure of the Meso–Cenozoic cover of the southern Dauphinois–Provençal Domain (European plate) involved in the Pyrenean–Provençal and Alpine orogenic events (Cretaceous–Oligocene), in the deformations related to the anticlockwise rotation of the Corsica–Sardinia Block (Miocene) and, finally, in the Pliocene to Recent extensional faulting (Gèze and Nestéroff 1968; Gèze et al. 1968; Lanteaume 1968; Lemoine et al. 1986; Ford et al. 2006; de Graciansky et al. 2010; Giammarino et al. 2010; Dallagiovanna et al. 2012a, b; Seno et al. 2012; Decarlis et al. 2014; Morelli et al. 2022).

Across the latest Cretaceous to early Paleogene, the Pyrenean–Provençal orogeny uplifted the southern Provençal Domain, which emerged and was exposed to a strong erosional event that produced a widespread unconformity at the top of the Upper Cretaceous deposits (Lanteaume 1968; Apps et al. 2004; de Graciansky et al. 2010; Giammarino et al. 2010; Dallagiovanna et al. 2012a, b; Seno et al. 2012; Marini et al. 2022; Briguglio et al. 2024). During the Eocene, the thrusting of the Ligurian Alps orogenic wedge onto this part of the European plate caused this domain to evolve into a foredeep basin, with a basin-fill succession unconformably deposited upon Upper Cretaceous deposits and characterized by shallow-water limestones grading to deep-water marls covered by siliciclastic turbidite sediment. This stratigraphic succession is known as Boussac's trilogy or Sinclair's trilogy (Boussac 1912; Lanteaume 1968; Campredon 1977; Sinclair 1997; Varrone 2004; Giammarino et al. 2009, 2010; de Graciansky et al. 2010; Dallagiovanna et al. 2012a, b; Perotti et al. 2012; Seno et al. 2012; Maino and Seno 2016; Mueller et al. 2020; Marini et al. 20222022).

In the study area (Fig. 1c, d), the stratigraphic section is composed of (a) marls and marly limestones (Trucco Formation; Campanian–lower Maastrichtian); (b) *Microcodium*-rich, burrowed marls with grayish to reddish patches and minor conglomerates (Microcodium Formation; generally referred to the upper Lutetian or lower Bartonian); (c) fine to coarse grained siliciclastic, mixed, and carbonate deposits of shallow-marine environment (Capo Mortola Calcarenite; upper Lutetian–lower Bartonian); (d) hemipelagic silty marls and marls (Olivetta San Michele Silty Marl; Bartonian–lower Priabonian); (e) siliciclastic turbidite deposits (Ventimiglia Flysch, upper Bartonian–lower Priabonian) (Lanteaume 1968; Sturani 1969; Campredon 1977; Pasquini et al. 2001; Varrone 2004; Varrone and Clari 2003; Giammarino et al. 2009, 2010; Dallagiovanna et al. 2012a, b; Seno et al. 2012; Perotti et al. 2012; Maino and Seno 2016; Brandano 2019; Mueller et al. 2020; Coletti et al. 2021; Marini et al. 2022; Briguglio et al. 2024).

The Olivetta SM section here presented, due to the continuous presence and abundance of *Nummulites perforatus* and *N. puschi*, is assigned to the shallow benthic zone (SBZ) 17 (lower Bartonian) according to the biostratigraphic scheme by Serra-Kiel et al. (1998), with updates by Papazzoni et al. (2017).

Material and methods

In this study, a total of 188 m of sedimentary succession was studied (Fig. 2a, b); it is part of a 230-m-long profile that starts from the Microcodium Formation and covers the entire Capo Mortola Calcarenite Formation. The succession here presented starts after the 13.7-m-thick vegetation cover hiding the contact between the two formations.

Macrofacies analysis was made with observation directly in the field (Fig. 3) at one-meter intervals: each observation point includes abundance data (0: absent; 1: common; 2: abundant) for all visible macrofossils and the lithology by using the classification scheme by Grabau (1904) and Flügel (2012). For this classification, only the size of the components of carbonate rocks (regardless of their origin) is considered for limestones, defining three classes: calcisiltite, calcarenite, and calcirudite. If fossil content is present, they are named biocalcisiltite, biocalcarenite, and biocalcirudite. Throughout the entire section, five main types of macrofossils were observed: larger benthic foraminifera (almost exclusively nummulitids), gastropods, oysters, other bivalves, and corals (Figs. 2a, b, 3; see Supplementary Table S1 for the entire dataset).

For microfacies investigation, a total of 57 rock samples (from OL-15 to OL-77) were collected (Fig. 2a, b). Two rock thin sections per sample were prepared and analyzed using a custom-made Optech GZ808 optical stereomicroscope; photos were taken with a Delta Pix by Invenio (model 6EIII) digital camera. Textures were classified following Dunham (1962), and biogenic components were identified at the most accurate taxonomic level possible (genera).

The following parameters have been estimated on all thin sections (Supplementary Table S1) and parametrized to finite numbers: (1) matrix percentage (following Folk 1959) (0: 0%; 1: 1–10%; 2: 11–50%; 3: > 50%); (2) grains roundness and grain sorting (0: poor; 1: well; 2: very well); (3) grain size (0: fine; 1: medium; 2: coarse); (4) presence of quartz, glauconite, and organic matter (0: absent; 1: common; 2: abundant); (5) taxonomic diversity including nummulitids (separating *Nummulites* and *Assilina*), orthophragmines, smaller benthic foraminifera, planktonic foraminifera, mollusks, corals, echinoderms, and worm tubes (0: absent; 1: common; 2: abundant); and (6) special features such as diagenesis, bioturbation, deformation, and transport evidence (0: absent; 1: common; 2: abundant).

This dataset was used to build a cluster analysis using Ward's algorithm (Ward 1963) to statistically discriminate the different macro- and microfacies. Pearson's correlation coefficient, calculated for both macrofacies (0.7014) and microfacies (0.7305), indicates significant clustering within the studied data. Clusters were then used to differentiate the evolution of the sedimentary environment along the stratigraphic sections (Fig. 4). All statistical data treatment was processed by PAST software v.4.1 (Hammer et al. 2001).

Following the multidisciplinary workflow of Crippa et al. (2018), we integrated sedimentology and body fossil paleontology with ichnological analysis. For the vertical exposures of the Olivetta SM section, the application of the ichnofabric approach was used, placing particular emphasis on those textural aspects that arise from biological reworking, i.e., ichnofabrics (Ekdale and Bromley 1983; Taylor et al. 2003). The ichnofabric analysis method is comparable to facies analysis (McIlroy 2008). Each of the stratigraphic intervals studied for ichnofabrics (sample) was approximately 50 cm to 100 cm thick. Each sample was attributed to an ichnofabric class based on (1) degree of bioturbation, quantified as percent of bioturbated area (Knaust 2021); (2) components of the ichnofabric, including either distinct trace fossils or biodeformational structures with indistinct outlines (Taylor et al. 2003; Wetzel and Uchman 1998); (3) diversity, i.e., the number of ichnotaxa present; and (4) distribution of bioturbation at the sample scale (Supplementary Table S1). Following standard ichnological practice (Bromley 1996; Taylor et al. 2003; Gingras et al. 2011, 2015; Knaust 2017), relative abundance, burrow size, tiering, trace fossil frequency, and primary sedimentology have also been observed.

Results

Macrofacies analysis (outcrop observation)

The Capo Mortola Calcarenite Formation is mainly characterized by two lithotypes: limestone (calcisiltite–biocalcisiltite, calcarenite–biocalcarenite, and calcirudite–biocalcirudite) and marl, as observed in the outcrop (Fig. 2a, b; Table 1 and Supplementary Table S1). Throughout the first half of the succession (42–195.75 m), a general gradation in grain size from calcisiltite to calcirudite is recorded. The upper part (195.75–215.5 m) is made of a marly succession with intercalated calcisiltite and calcarenite beds.

The macrofacies cluster analysis separates two major clusters: macrofacies A (MA) and macrofacies B (MB) (Figs. 2a, b, 4a; Table 1 and Supplementary Table S1).

Macrofacies A is characterized by intervals without visible nummulitids, and it is subdivided into three subfacies: (1) MA1 represents intervals where fossils are not recorded (barren); (2) MA2 is marked by a slight increase in abundance of corals, gastropods, and bivalves; (3) MA3 is characterized by higher diversity where gastropods, corals, bivalves, and oysters are common.