Solid Earth, 3, 225–249, 2012
www.solid-earth.net/3/225/2012/
doi:10.5194/se-3-225-2012

Solid Earth

Shallow water carbonate platforms (Late Aptian–Early Albian, Southern Apennines) in the context of supraregional to global changes: re-appraisal of palaeoecological events as reflectors of carbonate factory response

A. Raspini

Istituto di Geoscienze e Georisorse (IGG), CNR, Via Giorgio La Pira, 4, 50121, Firenze, Italy

Correspondence to: A. Raspini (raspini@igg.cnr.it)

Received: 10 October 2011 – Published in Solid Earth Discuss.: 21 October 2011
Revised: 17 July 2012 – Accepted: 18 July 2012 – Published: 20 August 2012

Abstract. This paper discusses the palaeoenvironmental significance of the "Orbitolina Level", the microbial carbonates and the *Salpingoporella dinarica*-rich deposits encased in the Aptian/Albian shallow water carbonate platform strata of Monte Tobenna and Monte Faito (Southern Italy). These facies show a peculiar field appearance due to their color and/or fossil content. In the shallow water carbonate strata, the Late Aptian "Orbitolina Level" was formed during a period of decreasing accommodation space. Microbial carbonates occur in different levels in the composite section. They reach their maximum thickness around the sequence boundaries just above the "Orbitolina Level" and close to the Aptian–Albian transition, and were not deposited during maximum flooding. *S. dinarica*-rich deposits occur in the lower part of the Monte Tobenna-Monte Faito composite section, in both restricted and more open lagoonal sediments. *S. dinarica* has its maximum abundance below the "Orbitolina Level" and disappears 11 m above this layer.

On the basis of δ^{13}C and δ^{18}O values recorded at Tobenna-Faito, the succession has been correlated to global sea-level changes and to the main volcanic and climatic events during the Aptian. Deterioration of the inner lagoon environmental conditions was related to high trophic levels triggered by volcano-tectonic activity. Microbial carbonates were deposited especially in periods of third-order sea level lowering. In such a scenario, periods of increased precipitation during the Gargasian induced the mobilization of clay during flooding of the exposed platform due to high-frequency sea-level changes, with consequent terrigenous input to the lagoon. This and the high nutrient levels made the conditions unsuitable for the principle carbonate producers, and an opportunistic biota rich in orbitolinids (*Mesorbitolina texana* and *M. parva*) populated the platform. In the more open marine domain, the increased nutrient input enhanced the production of organic matter and locally led to the formation of black shales (e.g. the Niveau Fallot in the Vocontian Basin).

It is argued that the concomitant low Mg/Ca molar ratio and high concentration of calcium in seawater could have favoured the development of the low-Mg calcite skeleton of the *S. dinarica* green algae.

During third-order sea-level rise, no or minor microbial carbonates formed in the shallowlagoonal settings and *S. dinarica* disappeared. Carbonate neritic ecosystems were not influenced by the environmental changes inferred to have been induced by the mid-Cretaceous volcanism.

The "Orbitolina Level", the microbial carbonates and the *Salpingoporella dinarica*-rich deposits in the studied Aptian/Albian shallow water carbonate strata are interpreted to be the response to environmental and oceanographic changes in shallow-water and deeper-marine ecosystems.

1 Introduction

Shallow-marine carbonate platforms are sensitive to changes of climate, oceanography and sea level since most carbonate-precipitating organisms require specific ecological conditions (Schlager et al., 1988; Philip, 2003). Different biotic communities thus may reflect variations in temperature,

Published by Copernicus Publications on behalf of the European Geosciences Union.

salinity, light, and/or nutrients induced by regional to global palaeoenvironmental changes.

This paper deals with the environmental significance of Aptian–Albian shallow marine carbonate platform facies cropping out at Monte Tobenna and Monte Faito (Southern Apennines, Italy) and showing a peculiar field appearance due to their color and/or fossil content: the "Orbitolina Level", microbial carbonates and *Salpingoporella dinarica*-rich deposits. The Aptian–Albian was a time punctuated by biotic and environmental changes (e.g. Weissert et al., 1998; Takashima et al., 2007; Hay, 2008; Huck et al., 2010; Donnadieu et al., 2011) that resulted in the drowning of many Tethyan carbonate platforms (Föllmi et al., 1994; Graziano, 1999, 2000; Pittet et al., 2002; Heldt et al., 2010; Masse and Fenerci-Masse, 2011; Skelton and Gili, 2012). Increased geodynamic activity and massive injection of carbon dioxide in the ocean–atmosphere system accelerated the water cycle and increased weathering rates, thus threatening carbonate-precipitating organisms (e.g. Larson and Erba, 1999; Jahren, 2002; Hu et al., 2005; Coffin et al., 2006; Najarro et al., 2011; Hong and Lee, 2012; Hu et al., 2012; Huang et al., 2012). High nutrient transfer from continents to oceans (Weissert and Erba, 2004; Wortmann et al., 2004) and an increase of dissolved Ca^{2+} and HCO_3^- (Kump et al., 2000) led to the blooming of mesotrophic and eutrophic biota on carbonate platforms (Bachmann and Hirsch, 2006; Burla et al., 2008), including the microbial colonization of wide-spread shallow water environments (Whalen et al., 2002; Wortmann et al., 2004). In addition, deep-sea igneous activity influenced the chemical composition of seawater, and the concomitant low Mg/Ca ratio and high concentration of Ca favoured the development of low-Mg calcite secreting organisms (e.g. Stanley, 2006).

During the Aptian–Albian, orbitolinid-dominated, often clay-rich facies occurred in shallow-marine (Arnaud-Vanneau and Arnaud, 1990; Pittet et al., 2002; Burla et al., 2008; van Buchem et al., 2002) and in deeper, sand-dominated settings (Vilas et al., 1995; Ruiz-Ortiz and Castro, 1998) in many parts of the western Tethys, the North Atlantic and the Middle East. This implies that orbitolinid-rich facies cannot be directly related to a specific palaeoenvironment on carbonate platforms. The synchronous partial decline in the abundance of oligotrophic biota indicates an important deterioration of the palaeoenvironment as the result of highly trophic seawater (e.g. Vilas et al., 1995; Graziano, 1999; Simmons et al., 2000; Embry et al., 2010; Schroeder et al., 2010), and as also testified by the simultaneous local development of microbialites (Whalen et al., 2002; Rameil et al., 2010; Schroeder et al., 2010).

In the Apenninic carbonate platform sequence the so-called "Livello ad Orbitolina" (Orbitolina Level) marks the first occurrence of *Mesorbitolina texana* and *Mesorbitolina parva*. This upper Aptian biostratigraphic marker of the middle Gargasian (Cherchi et al., 1978; De Castro, 1991) crops out over a distance of more than 300 km (De Castro, 1963; Cherchi et al., 1978; Di Lucia, 2009) and has been correlated between widely spaced (at present >100 km) carbonate platform successions in Southern Italy (D'Argenio et al., 1999). The "Orbitolina Level" is well visible in the field, being often clayey and green to grey. Its lithological and paleontological features have been accurately described (e.g. Costa, 1866; Guiscardi, 1866; De Castro, 1963; Cherchi et al., 1978), but no documentation exists on a number of fundamental questions such as the striking concentration of orbitolinids in just a few beds and their palaeoenvironmental significance.

In order to clarify the palaeoenvironment of the "Orbitolina Level", the microbial carbonates and the *Salpingoporella dinarica*-rich sediments in the lagoonal setting of the Aptian–Albian Apenninic carbonate platform, previous sedimentological, cyclostratigraphic and chemostratigraphic studies (Raspini, 1996, 1998; D'Argenio et al., 1999; Raspini, 2001; D'Argenio et al., 2004) are synthesized, integrated and upgraded on the basis of further field and laboratory work. These peculiar facies of the Tobenna-Faito composite section are described and interpreted in relation to long-term changes in accommodation space on the shelf as well as to volcanic, oceanographic and climatic events during the Aptian.

2 Geological setting

The carbonate successions in the Southern Apennines consist of well-bedded and laterally continuous beds deposited in the central Mesozoic Tethys (Fig. 1). This area was characterized by the broad Apenninic Carbonate Platform (Mostardini and Merlini, 1986) that formed part of a larger, articulated carbonate platform-basin system (e.g. Patacca and Scandone, 2007). The tectonic evolution of this area experienced a phase of continental rifting along the northern margin of the African Craton during the Triassic–Early Jurassic, and ocean-floor spreading in the Early Jurassic (Middle Liassic) to Late Cretaceous/Eocene accompanied by the formation of passive margins, and continental collision (with Eurasia) in the Late Cretaceous/Eocene to Holocene (Zappaterra, 1994; Korbar, 2009; Vezzani et al., 2010). The latter led to a pile of thrust sheets of the Apenninic carbonate platform and encasing basinal sediments (Casero et al., 1988; Mazzoli et al., 2001). Following the opening of the Tyrrhenian back-arc basin during the Miocene, the pile of thrust sheets rotated counterclockwise (Scheepers and Langereis, 1994; Gattacceca and Speranza, 2002), and was ultimately thrust onto the Apulian Carbonate Platform, the undeformed part of which represents the foreland of the Southern Apennines Fold-and-thrust Belt (Doglioni, 1994; Argnani, 2005).

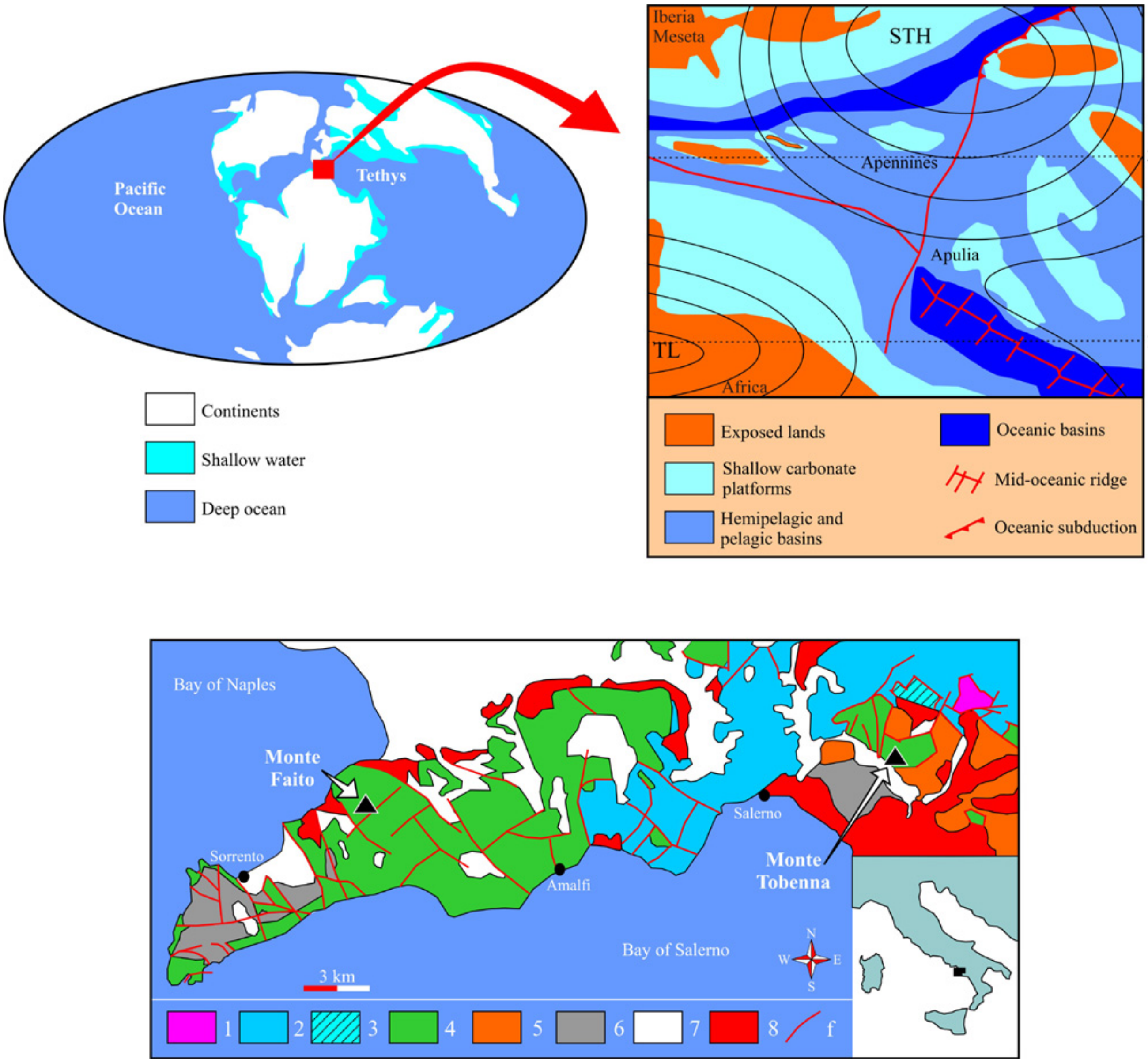

Fig. 1. Palaeogeographic reconstructions of the Aptian (world map redrawn from Smith et al., 1994; palinspastic map of the Tethyan realm redrawn and modified from Danelian et al., 2004, and Masse et al., 2004, redrawn and simplified) and location of the studied sections (from Bonardi et al., 1992). (1) Undifferentiated Lagonegro sequences. (2) Carbonate platform dolomites and limestones. Late Triassic-Jurassic. (3) Carbonatic reworked sediments and cherty limestones. Jurassic. (4) Carbonate platform limestones and dolomites. Cretaceous. (5) Calcarenites, sandstones and claystones. Cretaceous-Lower Miocene. (6) Terrigenous deposits. Late Tertiary. (7) Continental deposits. Quaternary. (8) Volcanics. Quaternary. f = fault. TL: tropical low-pressure system; STH: subtropical high-pressure system (from Wortmann et al., 1999).

3 The studied sections

The stratigraphically lower section crops out at Monte Tobenna, near the village of S. Mango Piemonte (Picentini Mountains, Campania Apennines; Fig. 1), and is part of a succession of Mesozoic-Tertiary rocks, the oldest being Triassic in age. The 32 m-thick section consists of well bedded carbonate strata in the lowermost 16 m overlain by the 115-to-175 m thick “Orbitolina Level”, an upper Aptian (middle Gargasian) litho- and biostratigraphic marker in the carbonate platform successions of the Southern Apennines, rich in *Mesorbitolina texana* and subordinately *Mesorbitolina parva* (Cherchi et al., 1978; see also De Castro, 1963, 1991). Above ∼20 m, an about 8 m-thick interval shows an alternation of clay layers and marls with abundant charophytes. The top 4 m consist of carbonate strata.

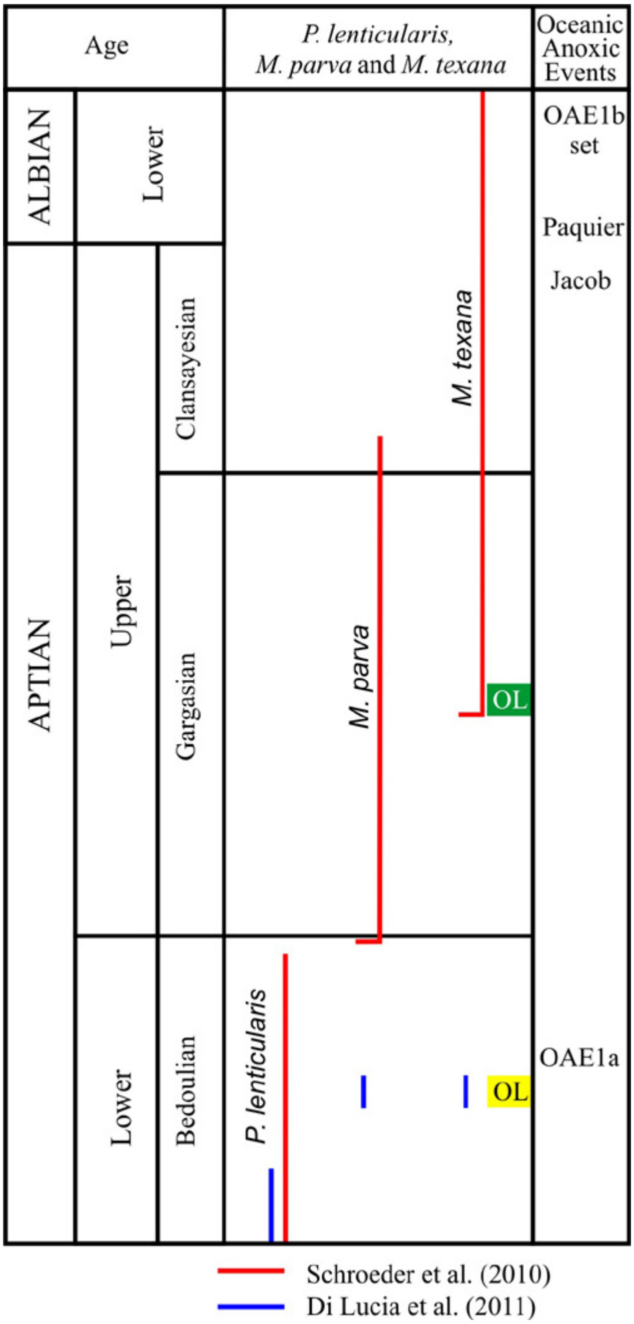

Fig. 2. General stratigraphic distribution of *Palorbitolina lenticularis*, *Mesorbitolina parva* and *Mesorbitolina texana* according to Schroeder et al. (2010; see also Cherchi and Schroeder, 2012) and Di Lucia et al. (2011). OL: Orbitolina Level. (From Schroeder et al. (2010) and Cherchi and Schroeder (2012), redrawn and modified). See text for further explanation.

The second section, some 30 km west of the Monte Tobenna outcrop, crops out along the panoramic road from Vico Equense to Monte Faito (Lattari Mountains, Sorrento Peninsula; Fig. 1). The 54 m-thick section forms part of a 400 m-thick succession spanning the upper Hauterivian-Albian (Robson, 1987), and starts about 8 m above the "Orbitolina Level". Strata in the basal part are thicker than those in the central and upper part, and the sections continues up to the Aptian/Albian boundary as testified by the first occurrence of *Ovalveolina reicheli* (De Castro, 1991; Chiocchini et al., 1994; Bravi and De Castro, 1995; Husinec et al., 2000, 2009) approximately 50 m above the orbitolinid-rich biostratigraphic marker. Also *Dyctioconinae* occur at 48 m above the base of the section. This section overlaps with the Monte Tobenna section by approximately 7 m (Raspini, 1996), allowing to construct and analyse the approximately 79 m thick "Tobenna-Faito composite section".

3.1 The age of the "Orbitolina Level"

Recently, the "Orbitolina Level" of the Southern Apennines has been attributed to the lower Aptian (Bedoulian) based on the δ^{13}C record of shallow carbonate sections. Based on the ^{87}Sr/^{86}Sr ratio of a sample 1 m above the first marls with *Mesorbitolina*, an age of 122.9 Ma (122.1–123.5) has been assigned to this level (Di Lucia and Parente, 2008; Di Lucia, 2009; Di Lucia et al., 2011). According to these authors, the orbitolinid-rich marly level is time-equivalent with the base of the "Selli Level" black shales in epicontinental and ocean basins (OL with yellow bar in Fig. 2).

The "Orbitolina Level" of the Southern Apennines is rich in *M. texana* with subordinate *M. parva* (Cherchi et al., 1978). Although *M. parva* possibly appeared in the uppermost Bedoulian (Velić, 2007; Schroeder et al., 2010; Cherchi and Schroeder, 2012; Fig. 2), the f.o. (first occurrence) of *M. texana* was in the upper Aptian (Gargasian; Schroeder et al., 2010; Cherchi and Schroeder, 2012). The "Orbitolina Level" therefore is one of the tie-points for the calibration of the upper Aptian biostratigraphy of central and southern Tethyan carbonate platforms (cf. Simmons et al., 2000; Bachmann and Hirsch, 2006; Chihaoui et al., 2010; Embry et al., 2010; Heldt et al., 2010; Vincent et al., 2010; Cherchi and Schroeder, 2012).

In this paper the "Orbitolina Level" is considered a Gargasian litho- and biostratigraphic marker in the carbonate platform successions of the Southern Apennines (OL with green bar in Fig. 2), in which it marks the first occurrence of *M. texana* and *M. parva*. This age is supported by the following observations:

1. The facies evolution (from prevailingly subtidal to prevailingly supratidal settings) and the systematic decrease of superbundle thickness in the lower part of the Tobenna-Faito composite section indicate a progressive decrease of accommodation space on the platform (see Sect. 5.3 and Fig. 5). This culminates with the Sequence Boundary Zone (SBZ1) above the "Orbitolina Level", as testified by the maximum abundance of characean-rich sediments. According to D'Argenio et al. (1999), these ~8 m-thick deposits represent about 800 ka. The same result was also obtained from a study

of coeval sediments cropping out at Serra Sbregavitelli, now located more than 100 km N of the Faito section and encasing the orbitolinid-rich biostratigraphic marker (D'Argenio et al., 1999). If the "Orbitolina Level" would have marked the onset of OAE1a in the Apenninic platform, as claimed by Di Lucia and Parente (2008), Di Lucia (2009) and Di Lucia et al. (2011), it would imply that: (i) taking into account the duration of the Selli Level (e.g. Larson and Erba, 1999; Li et al., 2008; Huang et al., 2010), most of the equivalent deposits at the Tobenna-Faito formed during a sea-level lowstand and not during a sea-level rise, as reported in the literature (Schlanger and Jenkyns, 1976; Jenkyns, 1980; Haq et al., 1988; Bralower et al., 1994; Erbacher et al., 1996; Erba et al., 1999; Wissler et al., 2004; Emeis and Weissert, 2009; Jenkyns, 2010; Skelton and Gili, 2012, and many others); and (ii) at Tobenna-Faito the most negative values of the negative carbon-isotope anomaly corresponding to segment C3 of Menegatti et al. (1998) would be recorded in sediments deposited after the beginning of the Selli Event (bed-scale cycle 45 in Fig. 5), instead of marking its onset (cf. also Méhay et al., 2009; Erba et al., 2010; Huck et al., 2011). This would also be the case in the Serra Sbregavitelli section, in which the segment C3-equivalent would have been recorded in inner lagoon sediments settled more than 400 ka after the deposition of the "Orbitolina Level" (D'Argenio et al., 2004).

2. According to Ferreri et al. (1997) and D'Argenio et al. (2004), carbon isotope curves from several shallow-water carbonate sections in the Southern Apennines evidence that the positive δ^{13}C spike reflecting the Selli Event clearly underlies the "Orbitolina Level". This level is placed close to the boundary of the *G. algerianus/G. ferreolensis* zone, confirming a Gargasian age (Ogg et al., 2004) as proposed by Cherchi et al. (1978).

3. The recent astronomical tuning of the Aptian Stage (Huang et al., 2010) constrains the Selli Event between 124.55 and 123.16 Ma.

4 Methodology

The "Orbitolina Level", lithofacies B3 and B4 and the *Salpingoporella dinarica*-rich deposits in the Monte Tobenna and Monte Faito successions have been described and sampled in the field. Fifty (50) new thin sections have been examined under the microscope, together with 230 "old" thin sections available from previous studies (Raspini, 1996). The different facies are indicated on the qualitative curve showing low-frequency sea-level changes (Fig. 5). The curve has been obtained from data collected during sedimentological and cyclostratigraphical analyses of the same successions (Raspini, 1998, 2001), taking into account the hierarchical stacking pattern of higher-frequency cycles (bed-scale cycles grouped into bundles, in turn forming superbundles) coupled to the vertical evolution of textures and diagenetic features in both sections (see Sects. 5.1.2 and 5.2.1 for a synthesis of these results).

The above information has been linked to the δ^{13}C and δ^{18}O trends recorded in the composite section and in coeval sediments now located more than 100 km N from the Faito section and encasing the orbitolinid-rich biostratigraphic marker (Serra Sbregavitelli outcrop; D'Argenio et al., 1999). The trends have been obtained by applying a three- and five-point moving average to the recently published carbon and oxygen stable isotope values of D'Argenio et al. (2004), thus damping possible local noise due to environmental and/or diagenetic effects. This allows a better comparison of the isotope record of the studied sections with reference curves (cf. Weissert et al., 1998; Bralower et al., 1999; Clarke and Jenkyns, 1999; Fassel and Bralower, 1999; Jenkyns and Wilson, 1999) and the main climatic and volcanic events of the Aptian (Haq et al., 1987; Weissert and Lini, 1991; Takashima et al., 2007; Mutterlose et al., 2009).

5 Results

5.1 Facies analysis

5.1.1 Previous data and their interpretation

Previous cm-scale microstratigraphic analysis of textures, sedimentary structures and early diagenetic features allowed the identification of eight lithofacies grouped into three lithofacies associations (Raspini, 1998, 2001; see also D'Argenio et al., 1999): A – Bio-peloidal limestones; B – Mili-ostracod limestones; and C – Char-ostracod limestones. Table 1 lists the lithofacies and lithofacies associations recognized in the Tobenna-Faito composite section and their interpretation in terms of depositional environment (see also Figs. 3 and 4).

Green clay layers were found between most beds, and some include small carbonate lenses of charophyte wackestone, or intraclasts of cryptalgal bindstone or charophyte wackestone reworked from underlying beds. Generally, the lenses and intraclasts show mm-size cavities filled with calcite and/or geopetal infills. The top of some charophyte-bearing beds shows cm-thick microbreccia-layers with some mm-sized clasts in an unfossiliferous green clayey matrix (Raspini, 1998).

Scattered cavities with an irregular shape and less than 1 mm in size, with crystal silt at the base grading to sparry calcite, characterize the uppermost part of many beds, and were interpreted as evidence of exposure (Raspini, 1998, 2001; Fig. 3g). The microbrecciation affecting the top of some characean-rich beds was interpreted as the effect of wettening and drying giving rise to in situ breccias (Raspini, 1998; Fig. 3h), similar to examples described by Riding and

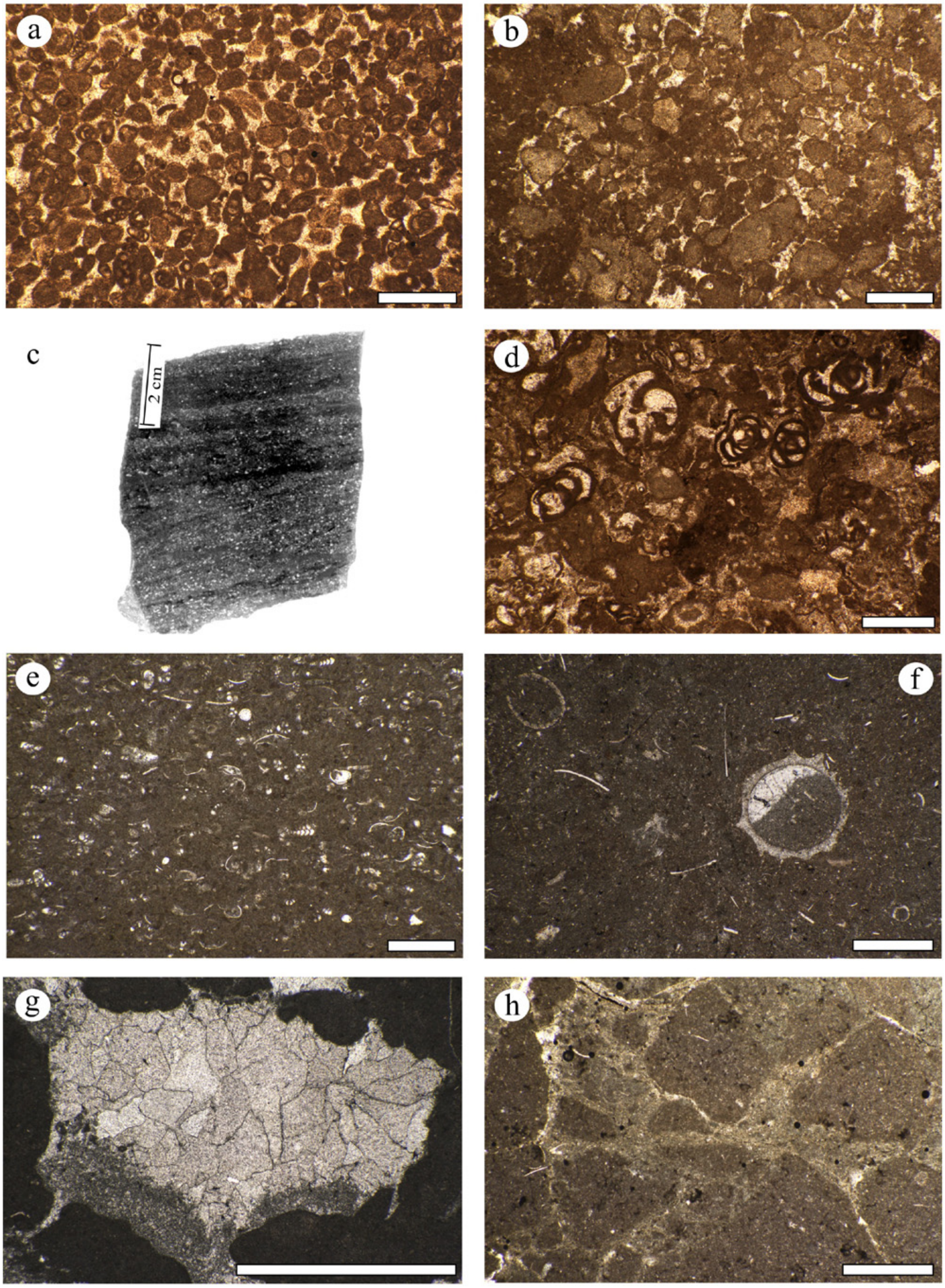

Fig. 3. Lithofacies recognized in the Monte Tobenna-Faito composite section and examples of emersion-related features affecting the sediments; **(a)** lithofacies A1: grainstone with benthic forams, peloids and intraclasts; **(b)** lithofacies A2: packstone/grainstone with intraclasts, peloids and rare bioclasts; **(c)** lithofacies A3: peloidal packstone with miliolids and small intraclasts, showing cross and parallel laminations; **(d)** lithofacies B1: wackestone with benthic forams; **(e)** lithofacies B2: wackestone with ostracods and small benthic forams; **(f)** lithofacies C1: wackestone-mudstone with charophyte and ostracods; **(g)** millimeter-size dissolution cavity showing geopetal fill represented by fine-grained peloidal packstone at the base passing upward to sparry calcite; **(h)** microbreccia affecting the C1 lithofacies. Photomicrograph scale bar is 1 mm on all pictures.

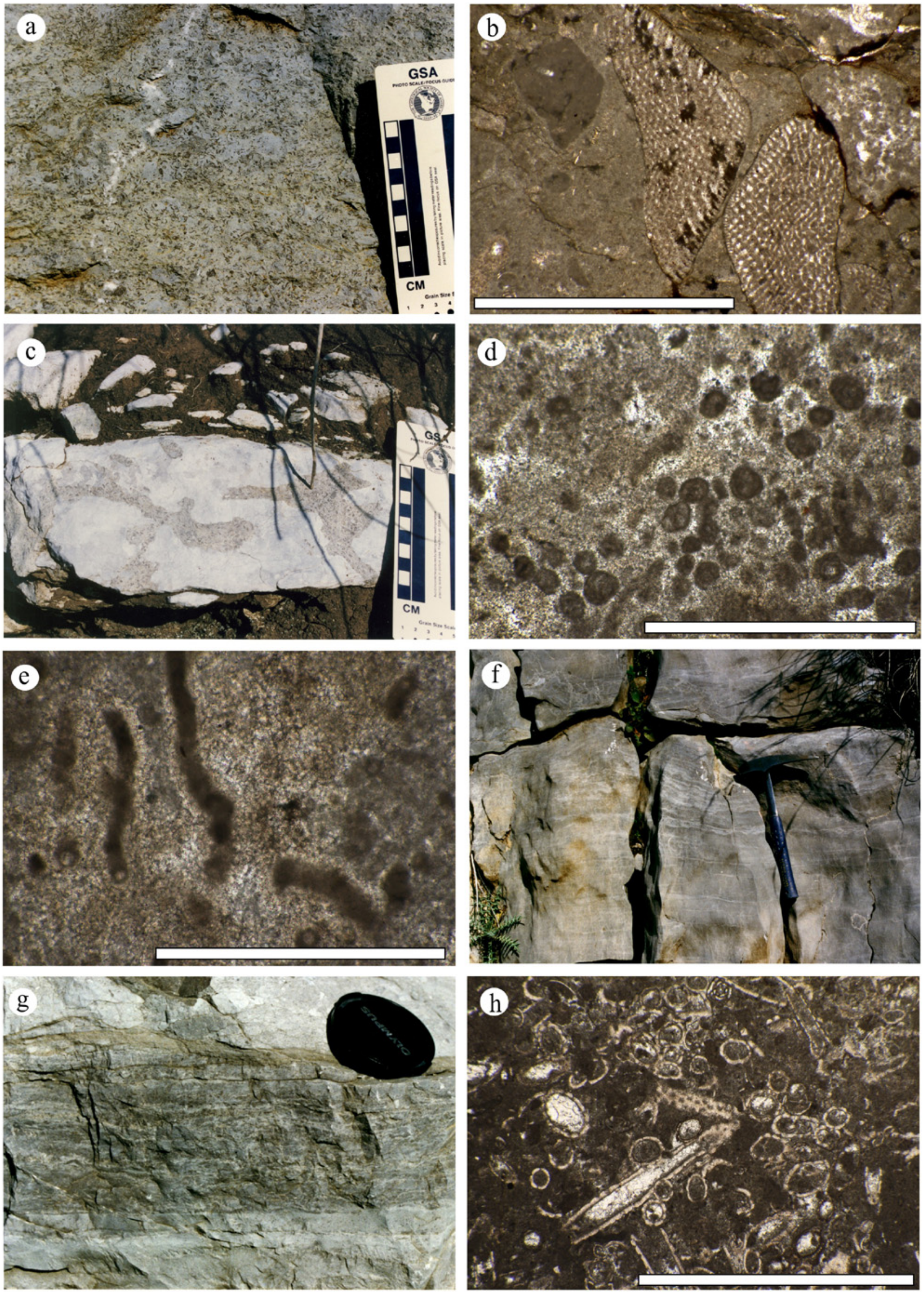

Fig. 4. Peculiar facies encased in the shallow carbonate platform strata studied: **(a)** The "Orbitolina Level" of Monte Tobenna is almost exclusively formed of discoidal foraminifera; **(b)** orbitolinids frequently show framboidal pyrite on their shells. In the top right corner, a lithoclast with clotted peloidal microspar texture can be seen; **(c)** *Thalassinoides*-like burrows filled by the orbitolinid-rich marly sediment; **(d)** and **(e)** rounded and filamentous cyanobacteria, respectively, settled in a clotted microsparitic groundmass (thrombolitic texture); **(f)** and **(g)** cryptalgal laminite with low-amplitude hemispheroidal (**f**; hammer is 33 cm long) and slightly wavy (**g**; cap diameter is 49 mm) morphology; **(h)** *Salpingoporella dinarica*-rich wackestone. Photomicrograph scale bar is 2 mm on all pictures.

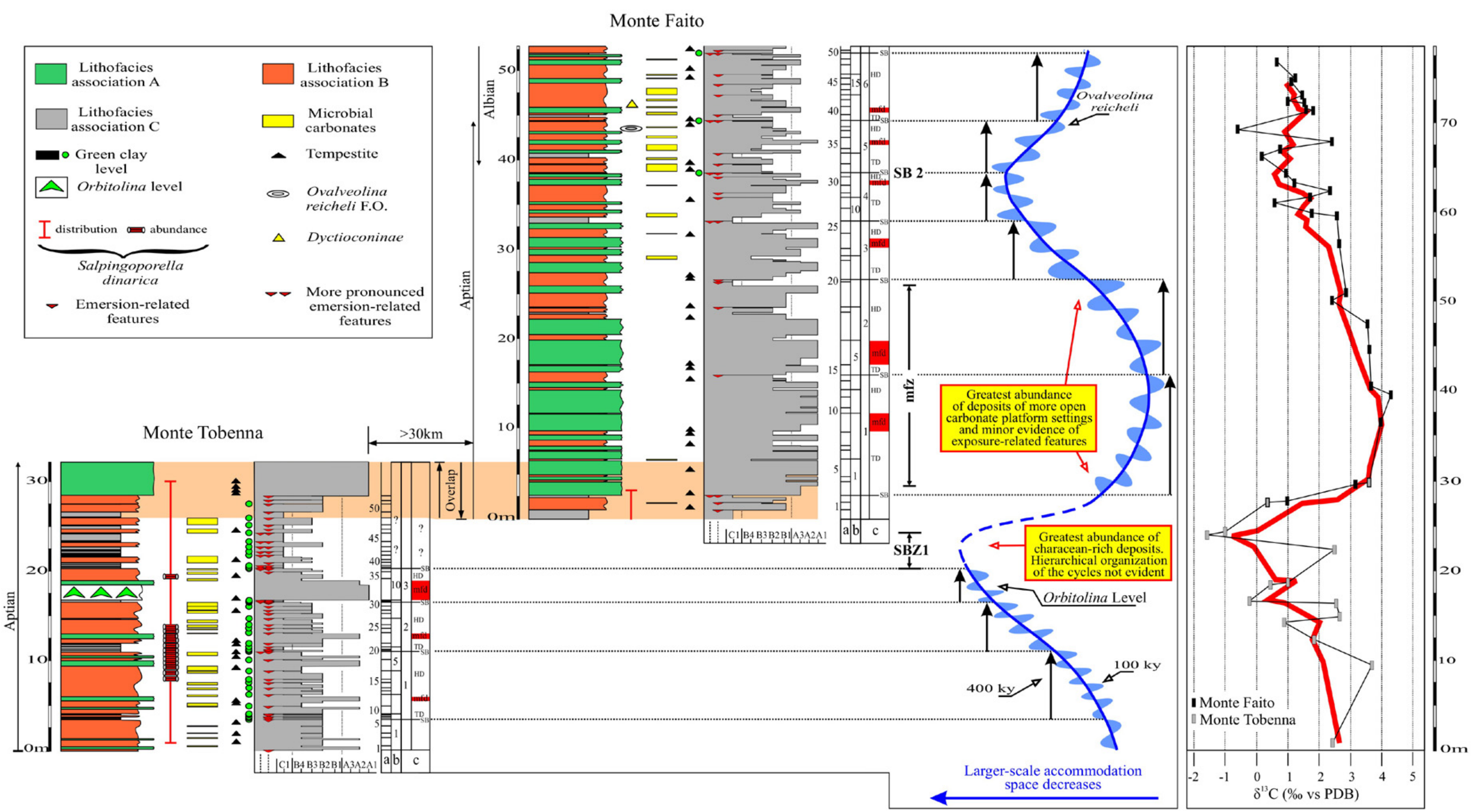

Fig. 5. Main sedimentological features and lithofacies evolution in the Monte Tobenna and Monte Faito shallow-water sections and related carbon-isotope stratigraphy. The sections are now located more than 30 km apart and show an overlap of about 7 m. For both sections A1 to C1 refer to lithofacies; the grey curves point out the evolution of the lithofacies and emersion-related features; **(a)** and **(b)** refer, respectively, to bed-scale cycles and bundles, while **(c)** indicates the superbundles and their interpretation as depositional sequences (TD: transgressive deposits; mfd: maximum flooding deposits; HD: highstand deposits; SB: sequence boundary). Larger-scale variations of accommodation space are indicated by the curve on the right, with superimposed qualitative 100 ky sea-level oscillations; vertical black arrows are adjusted to the thickness of the superbundles; SBZ: Sequence Boundary Zone; mfz: maximum flooding zone. The thick red curve represents the three-point moving average of the carbon isotope composition. Sedimentological and cyclostratigraphic data from Raspini (1998, 2001) and D'Argenio et al. (1999); isotope data from D'Argenio et al. (2004). See text for further explanation.

Table 1. Lithofacies and lithofacies associations in the Tobenna-Faito composite section (from Raspini, 1998, 2001).

A – Bio-peloidal limestones (lagoonal environments with relatively high hydrodynamic energy allowing the development of sand shoals)	
A1:	Grainstones and packstone/grainstones with bioclasts, peloids and small intraclasts (Fig. 3a).
A2:	Packstone/grainstones with intraclasts and peloids, and grainstones with small bioclasts, locally with parallel lamination (Fig. 3b).
A3:	Packstones with peloids and miliolids, rare small intraclasts and molluscan shell fragments with crossed to parallel lamination (Fig. 3c).
B – Mili-ostracode limestones (restricted lagoon)	
B1:	Wackestones with benthic forams, locally with small gastropods and/or pelecypods (Fig. 3d).
B2:	Wackestones and mudstone/wackestones with ostracods, small benthic forams and *Thaumatoporella* sp. (Fig. 3e).
B3:	Wackestones with "rounded and/or filamentous forms", *Thaumatoporella* sp. and rare ostracods, showing microsparitic patches (Fig. 4d, e).
B4:	Cryptalgal bindstones alternating with mm-thick peloidal packstone laminae, showing microsparitic patches (Fig. 4f, g).
C – Char-ostracode limestones (supratidal ponds/small lakes)	
C1:	Mudstone/wackestones and mudstones with characeans and thick-shelled ostracods (Fig. 3f).

Wright (1981) in paleosols of the Lower Carboniferous in southern Britain.

5.1.2 Peculiar facies of the Tobenna-Faito section

Further field observations and laboratory work have focused on the "Orbitolina Level", on the lithofacies B3 and B4, and on the *Salpingoporella dinarica*-rich deposits, all with a peculiar field appearance due to their colour and/or fossil content. This allowed the identification of distinctive fossil traces below the "Orbitolina Level" and the interpretation of lithofacies B3 and B4 as microbial-induced carbonates, evidencing both their diffusion and the distribution of the *S. dinarica*-rich facies along the sections.

The "Orbitolina Level"

The "Orbitolina Level" crops out about 16 m above the basis of the Tobenna-Faito composite section. Here two beds crowded with discoidal orbitolinids (high width/height ratio; Fig. 4a, b) lie above a green 25 to 45 cm thick clay level containing carbonate lenses with ostracods and charophytes. The lower bed ranges from 105–160 cm in thickness and is a floatstone with a packstone matrix. It shows a clay content that gradually diminishes upward, and has a wavy base and a typical nodular appearance due to differential compaction, cementation and stylolitization. The upper 10–15 cm thick bed is a floatstone with a grainstone matrix, and contains no or minor clay. It rests on an erosional basis where fossils are mostly arranged horizontally, and represents the type level of the codiacean alga *Boueina hochstetteri moncharmontiae* (De Castro, 1963; Barattolo and De Castro, 1991).

Bioeroded bivalve shell fragments with a micritic envelope, echinoderm fragments, *Bacinella* sp., dark muddy intraclasts and cryptalgal bindstone clasts, have been recognized in thin section, together with a large number of discoidal orbitolinids, mostly *Mesorbitolina texana* and subordinately *Mesorbitolina parva* (Cherchi et al., 1978), showing a high alteration level (e.g. Tomašových et al., 2006) and frequently framboidal pyrite on their often bioeroded shell. *Salpingoporella dinarica* (sometimes broken), *Boueina hochstetteri moncharmontiae*, *Thaumatoporella* sp., peloids and benthic foraminifers occur occasionally as well.

Orbitolina floatstone with a marly matrix penetrates downward into the carbonate strata, filling underlying cm-sized cavity-like features. Owing to the abundant vegetation cover that prevented extensive observations, these latter features have been previously interpreted as the product of paleokarst related to prolonged emersion of the platform, and subsequently covered by orbitolinid-rich clayey sediments when marine conditions returned (Raspini, 1996, 1998). Further field work has now revealed that these cavity-like features are sinuous and irregularly anastomosed "tunnels". The "tunnels" may reach 3 cm in diameter and 12 in (30.48 cm) length and are interpreted as *Thalassinoides*-like burrows (e.g. Seilacher, 2007) filled with orbitolinid-rich sediment (Fig. 4c).

The "Orbitolina Level" of the Monte Tobenna sequence thus is interpreted to represent transgressive deposits on the platform following a period of interrupted (or very low) sedimentation.

Microbial carbonates

In the field, lithofacies B3 is a yellowish brown limestone with numerous dark-orange, mm-sized patches, *Thaumatoporella* sp. and rare small ostracods (Raspini, 1998). Occasionally small benthic foraminifers (especially miliolids) occur in this 7–50 cm thick lithofacies. In thin section, mm-sized patches appear as microsparitic clots that are frequently associated with the small "subrounded grains" found in cryptalgal bindstones (Fig. 4d), and/or with "filamentous elements" showing several partitions and a final circular aperture (Fig. 4e).

Lithofacies B4, with thicknesses from 1–25 cm, is dark brown and characterized by wavy (sometimes slightly crinkled) laminae, locally forming low-amplitude hemispheroids (Fig. 4f and g). It generally occurs at the top of beds while underlying green clay levels. In thin section, irregular and frequently discontinuous mm-thick micritic, probably cryptalgal (cf. Riding, 2000), laminae generally contain rare ostracods. The laminae alternate with mm-thick packstone and/or packstone/wackestone layers with peloids, and frequently contain small "subrounded grains" with chamber-like partitions (Fig. 4d), *Thaumatoporella* sp. and rare ostracods.

Both lithofacies B3 and B4 frequently show a clotted microfabric (thrombolitic texture), consisting of irregular micritic peloidal aggregates surrounded and traversed by microspar (clast in Fig. 4b; cf. Riding, 2000), or display a microspar groundmass, and are rich in *Thaumatoporella* sp. Both the "subrounded grains" and the "filamentous elements" frequently show an orange-brown isopachous microsparitic rim and are locally concentrated in small groups. Their general morphology and internal structure resemble those of certain microbes (cf. Brock et al., 1994; Kaźmierczak and Iryu, 1999; Whalen et al., 2002; Golubic et al., 2006; Herrero and Flores, 2008) to which the thaumatoporellaceans were related recently (Cherchi and Schroeder, 2005).

Based on the above observations, lithofacies B3 and B4 are interpreted as deposits mainly produced by microbial growth and metabolism in restricted lagoonal environments. If this is the case indeed, the clotted microfabric of these deposits could represent calcification of extracellular polymeric substances widely produced by microbes (cf. Riding, 2000).

Salpingoporella dinarica-rich deposits

Salpingoporella dinarica is a calcareous alga that was isochronous in the central-southern Tethyan domain (including the Southern Caribbean Province) with its acme in the Aptian (e.g. Vlahović et al., 2003; Carras et al., 2006). At Tobenna-Faito this calcareous alga occurs in the lowermost 30 m of the composite section, in both restricted and more open lagoonal deposits. Incidentally, broken tests have been found in the char-ostracod limestones (lithofacies C1). *S. dinarica* shows its maximum abundance below the "Orbitolina Level" (at 7.5–13.7 m above the base of the section; Figs. 4h and 5). One mm-thick storm layer consisting of this green alga and peloids features the bed immediately above the biostratigraphic marker. In the composite section *S. dinarica* disappears 11 m above the "Orbitolina Level" (Fig. 5).

5.2 Cyclo-stratigraphy

5.2.1 Previous data and interpretations

Based on the vertical organization of depositional and early diagenetic features, three orders of cyclicity were recognized in the stratigraphic record of the Tobenna-Faito composite section: bed-scale cycles, bundles and superbundles (Fig. 5; Raspini, 1998, 2001). Bed-scale cycles are the smallest units whose vertical organization of lithofacies and related early diagenetic features testify a variable water depth and environmental oscillations (e.g. from more open to more restricted lagoonal deposits). Based on the vertical evolution of lithofacies, the intensity of early meteoric diagenesis, the thickness variation of bed-scale cycles and, for the Monte Tobenna section, the thickness of green clay layers, bed-scale cycles are hierarchically stacked into bundles and superbundles, as can be clearly seen in the field (Fig. 6). Bundles are groups of 2–5 bed-scale cycles, while superbundles consist of 2–4 bundles and show a transgressive/regressive facies evolution (Fig. 5).

Above the "Orbitolina Level", from 20 m and 28 m in the Monte Tobenna section, no clear hierarchical organization of cycles was recognized; here, characean-rich deposits reach their greatest abundance and green clay layers have their maximum thickness, testifying a long-lasting lowstand of the relative sea level. Locally, condensation phenomena (cf. Goldhammer et al., 1990) could have affected this part of the section. Nevertheless, some bed-scale cycles, composed of restricted lagoonal deposits, record higher frequency sea-level oscillations, which allowed subtidal conditions for short periods (Fig. 5).

Most bed-scale cycles in the composite section show evidence of early meteoric diagenesis in their uppermost part. This implies that emersion due to drops of relative sea level repeatedly interrupted sediment accumulation, and controlled the formation of the bed-scale cycles (Fig. 5). This, and the observed hierarchy of cycles (bed-scale cycles, bundles and superbundles), precludes a prevailing autocyclic control and suggests that composite eustatic sea-level fluctuations driven by the astronomical beat in the Milankovitch band were the cause of the hierarchical cycle-stacking pattern (Raspini, 1998, 2001). This would imply that the bed-scale cycles record the 20 ky precession period, while the bundles and the superbundles thus would correspond to the short ($\sim$100 ky) and the long ($\sim$400 ky) eccentricity signals (Raspini, 1998, 2001). Spectral analysis provided independent confirmation of the cyclical nature of the Cretaceous shallow-marine carbonates cropping out in the same region of the Southern Apennines (Pelosi and Raspini, 1993; Longo

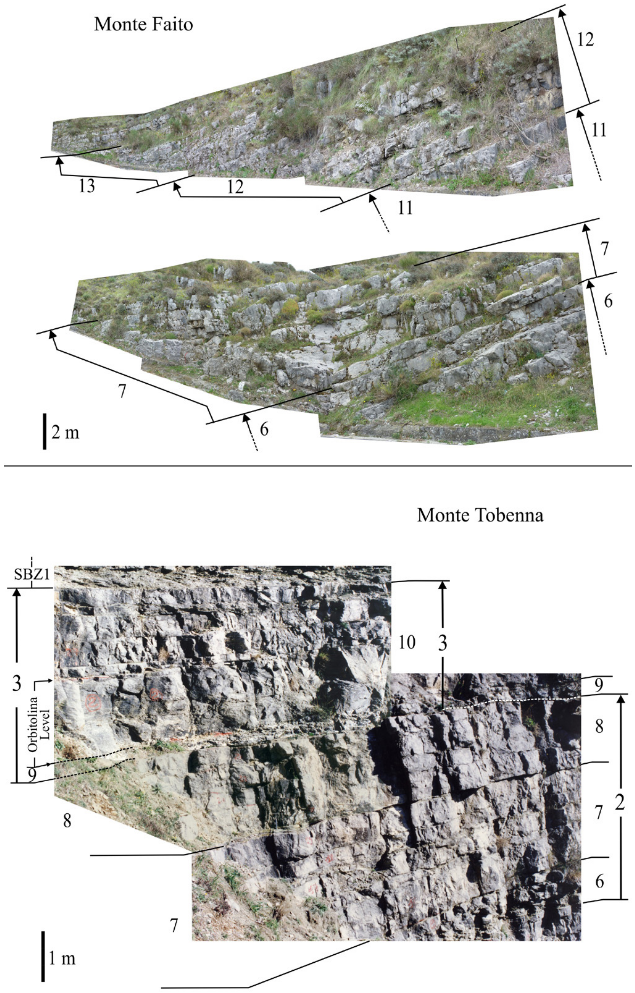

Fig. 6. The hierarchical stacking pattern of bed-scale cycles in the studied sections. Arrows point to superbundles 2 and 3 at Monte Tobenna and bundles 6–7 and 11–13 at Monte Faito. The "Orbitolina Level" and the SBZ1 of the Monte Tobenna section are also indicated (see also Fig. 5).

et al., 1994; Brescia et al., 1996; Raspini, 1996; D'Argenio et al., 1997). The ratios bed-scale cycles/bundle and bundles/superbundle, however, do not always reflect the classical 5 : 1 and 4 : 1 ratios, suggesting the occurrence of so-called missed beats that occurred when, after a relatively large fall of sea level, the next sea-level rise was insufficient to flood the platform (cf. Goldhammer et al., 1990).

5.2.2 Superbundles as small-scale depositional sequences

The cyclic and hierarchically organized shallow marine carbonate platform deposits, basically forming aggradational successions, may be analyzed in terms of depositional sequences (e.g. Kerans, 1995; Read et al., 1995). This is possible if the vertical evolution of the lithofacies and the variation in thickness of the different orders of cycles in a section are considered to be the result of the response of interior depositional settings to variations of accommodation space which determined the typical geometry of the systems tracts in corresponding seaward deposits (e.g. Montañez and Osleger, 1993; Kerans, 1995; D'Argenio et al., 1999; Sandulli and Raspini, 2004).

Along the Tobenna-Faito composite section, lithofacies trends within the superbundles frequently reflect transgressions and regressions. This permits the identification of maximum flooding, transgressive and highstand deposits (Fig. 5). The maximum flooding is an interval corresponding to the thickest and/or relatively more open-marine lithofacies association forming a bed-scale cycle. Below the maximum flooding, transgressive deposits are characterized by the vertical evolution of the lithofacies associations which reflects a deepening-upward trend associated to upward thickening bundles. Above the maximum flooding, highstand deposits are characterized by variations in lithofacies associations and by intensification of the emersion-related features suggesting a shallowing upward trend culminating in a sequence boundary.

5.3 Longer-term changes of accommodation space and peculiar facies

The larger-scale evolution of lithofacies associations and their diagenetic overprint define lower frequency environmental oscillations. They are coupled to a variation of superbundle thickness that reflects the changing accommodation space on the platform (Fig. 5; cf. Goldhammer et al., 1990; Matthews and Al-Husseini, 2010; Husinec and Read, 2011). In the lower 20 m of the composite section, the progressive upward thinning of superbundles 1–3, coupled with a general trend in lithofacies associations from subtidal to supratidal settings, culminating in an abundance of fresh/brackish water sediments, implies an overall decrease of accommodation space that ends, after more than 1200 ky, in Sequence Boundary Zone 1, a few metres above the "Orbitolina Level" (SBZ 1 in Fig. 5). The approximately 7 m-thick overlap of both sections shows a sudden shift towards more open lagoonal settings (Fig. 5). These deposits show minor evidence of emersion, and form the thickest superbundles in the composite section (superbundles 1 and 2 in the Monte Faito section). They mark a ∼800 ky period of maximum creation of accommodation space on the platform, and this interval is interpreted as the maximum flooding zone (mfz in Fig. 5). The predominance, from 27 m to 38 m in the Monte Faito section, of more inner lagoon sediments forming bed-scale cycles that more frequently show exposure features at their top, together with the progressive thickness decrease of superbundles 3 and 4 in the Monte Faito section, suggest a diminishing creation of accommodation space over approximately 800 ky, culminating at sequence boundary SB2. Extensive meteoric overprint and a 2 cm-thick green clay layer

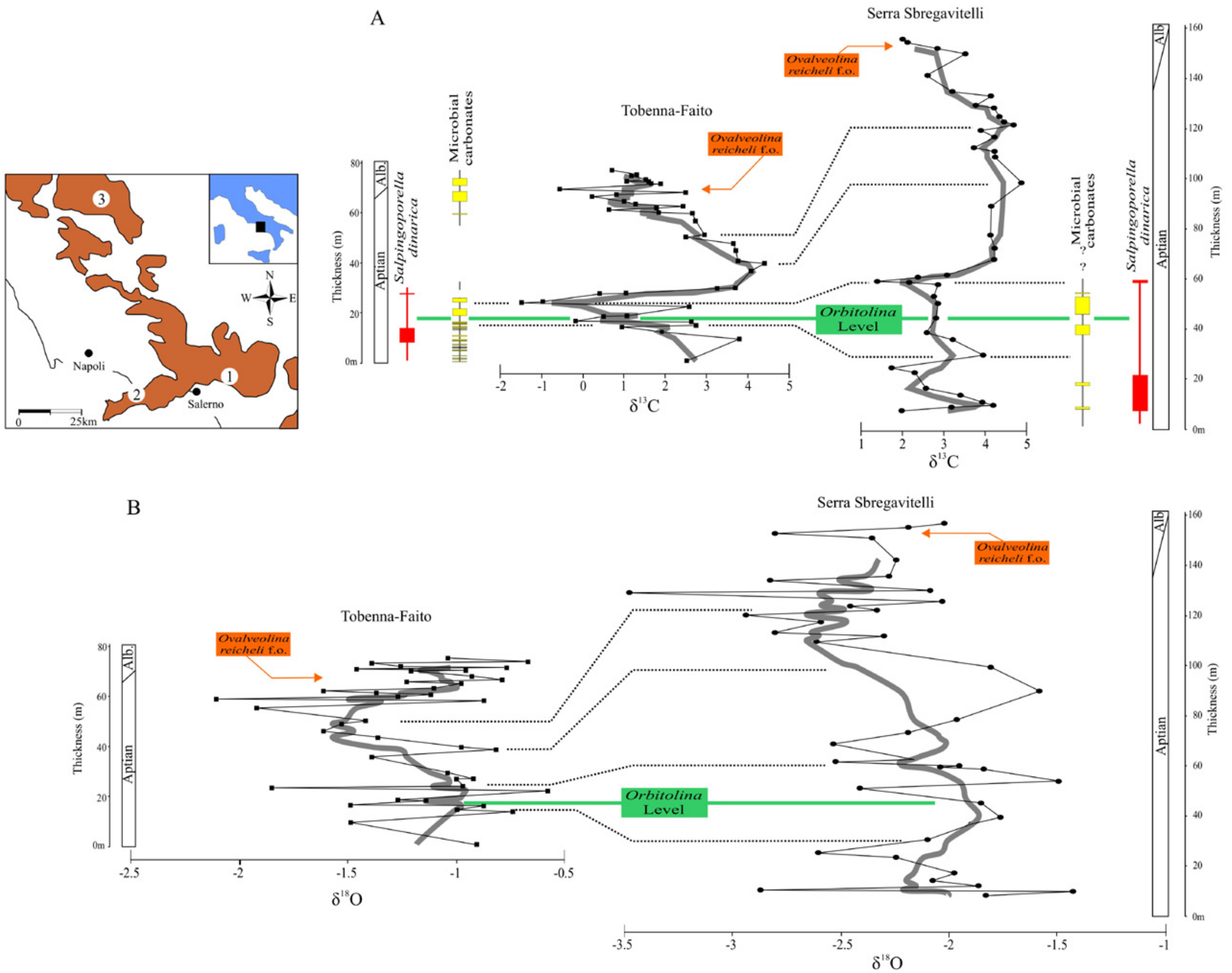

Fig. 7. Correlation of δ^{13}C **(A)** and δ^{18}O **(B)** trends of the Tobenna-Faito composite section and the Serra Sbregavitelli outcrop, using the "Orbitolina Level" as tie-point (isotope values from D'Argenio et al., 2004). The thick grey curves in **(A)** represent the three-point moving average of the C-isotope composition (see Fig. 5); the microbial carbonates (yellow rectangles), the distribution of *Salpingoporella dinarica* and its acme (red rectangles), as well as the first occurrence (f.o.) of *Ovalveolina reicheli* in both sections are also indicated. In **(B)** the thick grey curves are the five-point moving average of the O-isotope ratios. Inset in top left corner: 1, Monte Tobenna; 2, Monte Faito; 3, Serra Sbregavitelli.

characterize the top of the thinnest superbundle in the Monte Faito section, close to the Aptian–Albian transition (Fig. 5). Although the evolution of lithofacies associations does not show any clear trend up to the top of the composite section, the thickening upward of superbundles 5 and 6 reflects an increase of accommodation space in the uppermost Aptian–lowermost Albian.

The "Orbitolina Level" thus was formed during a transgressive phase of high-frequency sea-level changes superimposed on a third-order sea-level lowering, just before sequence boundary zone SBZ1 (Fig. 5). During this time, the *Salpingoporella dinarica* green alga was well represented in the lagoonal sediments and reached its maximum abundance below the "Orbitolina Level". Microbial carbonates were a common product of the shallow marine ecosystem only during times of relative lowering of sea level and sea-level lowstand. They were absent in periods of long-term relative sea-level rise, as seen in the maximum flooding zone (mfz in Fig. 5).

5.4 Chemostratigraphy

The stable carbon and oxygen isotope record of the Tobenna-Faito composite section used in this study was published by D'Argenio et al. (2004). They measured δ^{13}C and δ^{18}O values on bulk samples collected during the sedimentological

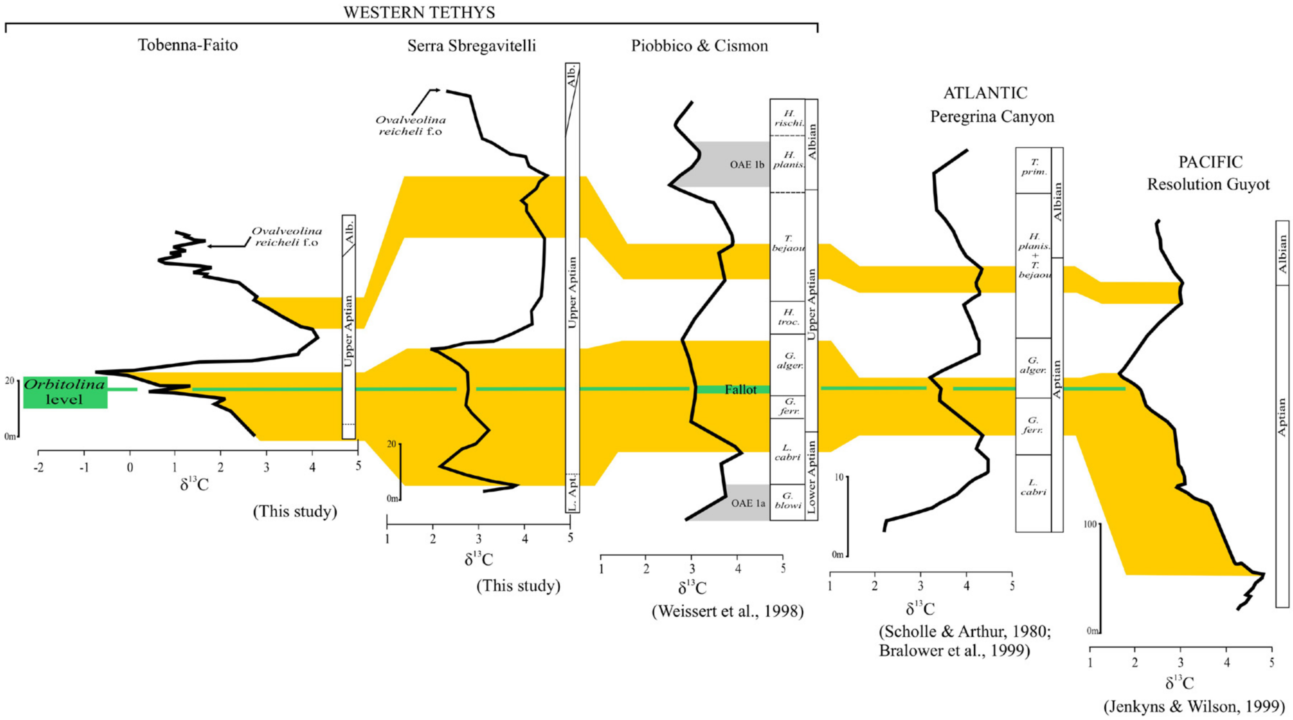

Fig. 8. Trends of δ^{13}C values of Tobenna-Faito and Serra Sbregavitelli sections plotted against reference curves of the Tethys (Piobbico and Cismon, in Weissert et al., 1998), Atlantic (Scholle and Arthur, 1980; Bralower et al., 1999) and Pacific (Jenkyns and Wilson, 1999). Note that the planktonic foraminiferal zones refer to different zonal schemes. Aptian substages on the Piobbico and Cismon isotope curve are from Takashima et al. (2007). The lower/upper Aptian boundary on the Tobenna-Faito and Serra Sbregavitelli isotope δ^{13}C curves is inferred from the Piobbico and Cismon curve.

and cyclostratigraphical studies of the Monte Tobenna and Monte Faito successions by the author between 1992 and 1995 (Raspini, 1998, 2001).

Regional-to-global significance of the isotope record

The high-amplitude fluctuations of carbon-isotope values in the lower and upper part of the Tobenna-Faito section, formed in periods of long-term sea-level lowstand, are ascribed to early meteoric diagenesis that repeatedly occurred in periods of non-deposition. On a large scale there are clear C-isotope trends over tens of metres and throughout different lithofacies associations. This indicates that the long-term trend was not greatly affected by variations of the local environment (Fig. 5). A similar δ^{13}C trend was recorded in coeval sediments in the Serra Sbregavitelli succession. It also encases the “Orbitolina Level” (D’Argenio et al., 2004), has been recently interpreted as exposed part of the Apulia Carbonate Platform (Carannante et al., 2009), and is now located more than 100 km N of the Faito section (Fig. 7a). This indicates a forcing at least on a regional scale.

The long-term δ^{18}O curves in Tobenna-Faito and Serra Sbregavitelli are well comparable (Fig. 7b), despite diagenetic effects and freshwater input that locally affected δ^{18}O values, e.g. in the upper part of both sections with repeated emersion-related features, and around the “Orbitolina Level” at Tobenna-Faito within characean-rich deposits. This lends further support to the regional correlation of Fig. 7a.

In Fig. 8, the δ^{13}C trends in the Tobenna-Faito and Serra Sbregavitelli sections are plotted against reference curves for the Tethys (Weissert et al., 1998), the Atlantic (Scholle and Arthur, 1980; Bralower et al., 1999) and the Pacific (Jenkyns and Wilson, 1999). The trend of decreasing δ^{13}C at the base of the Apenninic carbonate sections, reaching the lowest values above the upper Aptian “Orbitolina Level”, corresponds to the global trend of decreasing δ^{13}C in the *G. ferreolensis* to *G. algerianus* zone (Weissert et al., 1998; Weissert and Erba, 2004), whose overall shift is approximately −1.5 to −3 ‰ in these reference curves. The subsequent long-term positive excursion to values of 3–4 ‰, starting in the *G. algerianus* zone, is consistent with the shift toward positive δ^{13}C values at the overlap of the Monte Tobenna and Monte Faito sections (Fig. 5).

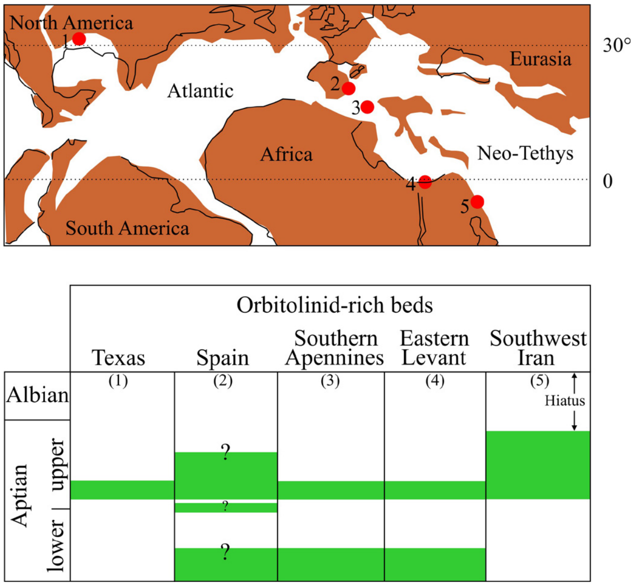

Fig. 9. Spatial and stratigraphic distribution of orbitolinid-rich beds in Texas (Stricklin et al., 1971), Spain (Ruiz-Ortiz and Castro, 1998; Castro et al., 2008), Southern Apennines (Cherchi et al., 1978), Eastern Levant Basin (Bachmann and Hirsch, 2006) and Iran (Schroeder et al., 2010). Aptian substages are from Pittet et al. (2002). Palaeogeographic map from Heldt et al. (2010).

6 Discussion

6.1 Response of the shallow carbonate platform to the Late Aptian supraregional changes: the "Orbitolina Level"

The "Orbitolina Level" of the Southern Apennines accumulated during a high-frequency sea-level change (precession-controlled bed-scale cycle; Raspini, 1998; D'Argenio et al., 1999) superimposed on a long-term (>1200 ky) sea-level lowering (Fig. 5). From 3 m upward in the Monte Tobenna section mm- to cm-thick green clay layers occur at the top of bed-scale cycles. They locally include charophyte-bearing carbonates. The clay layers become progressively thicker upwards, culminating, at 21.50 m, in a 30 cm-thick layer that is part of an interval with abundant charophyte-rich facies, testifying that a minimum creation of accommodation space on the platform was reached (SBZ 1 in Fig. 5).

In successions formed in sectors of the Apenninic platform with a (near-)supratidal setting (proximal areas, e.g. the Tobenna-Faito composite section, but see also De Castro, 1963), the 115–175 cm-thick "Orbitolina level" shows an exceptional concentration of discoidal foraminifera. Bioerosion of their shells indicates that the high fossil content of the biostratigraphic marker was possibly related to a reduced rate of sedimentation, rather than to a high population density of shell producers (cf. Kidwell, 1985, 1986; Tomašových et al., 2006), as also testified by *Thalassinoides*-like burrows filled with marly orbitolinid-rich sediment (Fig. 4c). In the succession formed in more open lagoonal sectors of the platform, away from supratidal settings (distal areas, e.g. the Serra Sbregavitelli section, see Fig. 7 for location), discoidal orbitolinids feature a 150 cm-thick calcareous bed with no (or minor) clay content are not as dense as at Tobenna-Faito. These foraminifera are micritised and associated with dasycladacean algae, miliolids and echinoderm fragments, suggesting a relationship between the abundance of orbitolinids and detrital influx. The association of discoidal orbitolinids with calcareous algae and echinoderms suggests high trophic conditions (Pittet et al., 2002). The fact that Aptian orbitolinid-rich strata can be correlated over hundreds to thousands of kilometres around the western Tethys, the eastern Levant Basin, the Middle East and even to the western Gulf of Mexico (e.g. Stricklin et al., 1971; Wilson and Jordan, 1983; Ruiz-Ortiz and Castro, 1998; Bachmann and Hirsch, 2006; Castro et al., 2008; Schroeder et al., 2010; Fig. 9), makes a link to supraregional changes plausible.

The similarity of the long-term $\delta^{13}C$ trend in the Tobenna-Faito and Serra Sbregavitelli sections with the Aptian $\delta^{13}C$ reference curves (Fig. 8) invites to link the "Orbitolina Level" with processes that affected the global carbon cycle during the lower Cretaceous (cf. Weissert and Lini, 1991; Takashima et al., 2007; Heldt et al., 2010). The "Orbitolina Level" of the middle Gargasian, in all likelihood, formed at the same time as part of the "Niveau Fallot" formed in a hemipelagic setting connected to the Tethyan Ocean, and probably to the Thalmann black shale event in California and a dark horizon on the Mazagan Plateau (DSDP Site 545; cf. Friedrich et al., 2003), as well as an organic-rich horizon in the Aptian of Iran (Vincent et al., 2010), that is in a period when sea level was falling (Haq et al., 1987; Herrle and Mutterlose, 2003; Takashima et al., 2007). A fall of sea level is accompanied by erosion, seaward transport and oxidation of organic carbon-rich sediments and other organic matter, and therefore by a drop in carbon isotope values (Jenkyns et al., 1994) as is the case for the reference curves in the *G. ferreolensis* to *G. algerianus* zone (Weissert et al., 1998; Bralower et al., 1999; Jenkyns and Wilson, 1999; Fig. 8). The Niveau Fallot and the other organic-rich levels suggest an enhanced burial of organic matter due to more eutrophic conditions and/or low oxygenation at the seafloor (Friedrich et al., 2003; Föllmi, 2012).

Although orbitolinids were considered light-dependent organisms (Hottinger, 1982, 1997), several authors have proposed that discoidal orbitolinids had an adaptive trend to light reduction with depth – the shallow water forms being smaller and higher than the deeper water ones – and are typically found in marly/clayey limestones since they throve under conditions of high nutrient supply (e.g. Vilas et al., 1995; Simmons et al., 2000; Pittet et al., 2002; Burla et al., 2008; Embry et al., 2010). During the Aptian a high nutrient supply to the oceans was proposed to have been stimulated moreover by increased amounts of carbon dioxide in the atmosphere

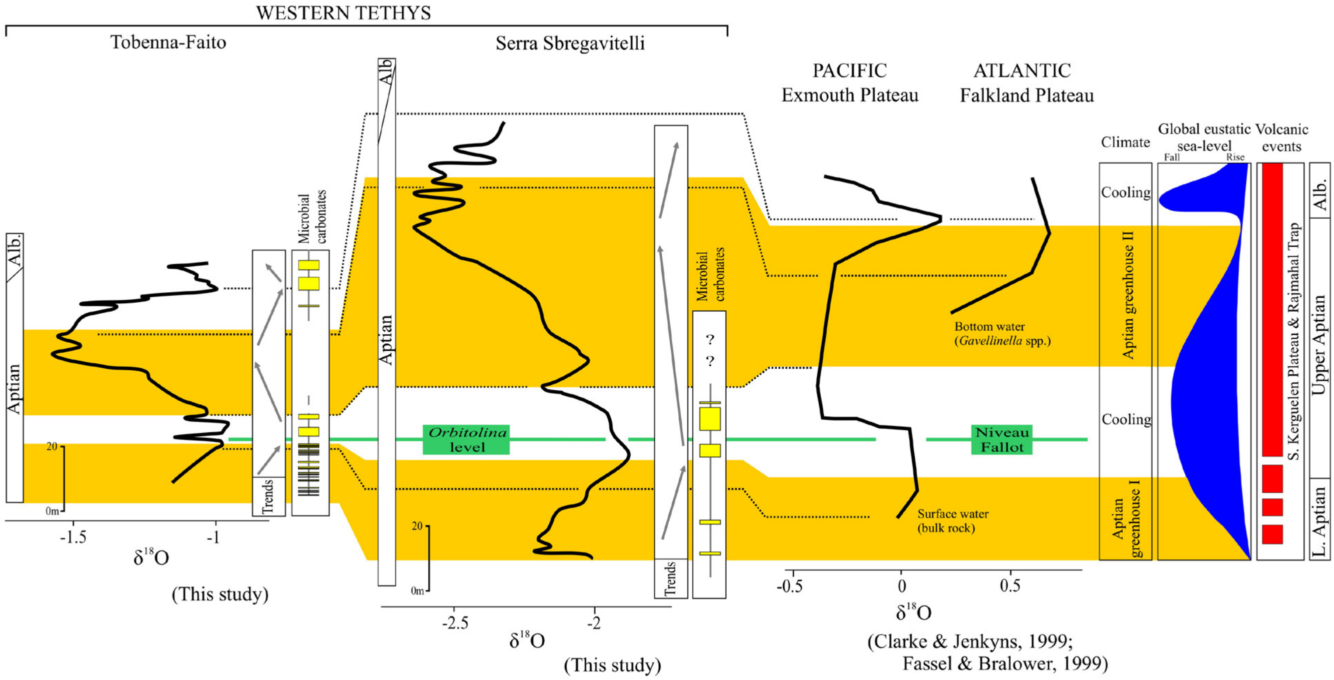

Fig. 10. Trends of δ^{18}O values of the Tobenna-Faito composite section compared to δ^{18}O curves of Clarke and Jenkyns (1999, Exmouth Plateau) and Fassel and Bralower (1999, Falkland Plateau). The distribution of microbial carbonates is as in Fig. 7. Yellow and white areas indicate, respectively, the warming (Aptian greenhouse I and II) and cooling events of Weissert and Lini (1991) as reported in Takashima et al. (2007). Global eustatic sea level is from Haq et al. (1987). Volcanic events are from Takashima et al. (2007). Aptian substages are from Mutterlose et al. (2009).

and in ocean basins as the result of increased tectonic activity and changing palaeogeography, probably accompanied by the sudden release of methane into the ocean-atmosphere system (cf. Weisset and Erba, 2004; Immenhauser et al., 2005). This would have resulted in mesotrophic to eutrophic conditions on carbonate platforms and in hemipelagic settings, creating perfect conditions for the bloom of an opportunistic biota rich in orbitolinids in shallow lagoons and the formation of black shales in deeper environments.

Recently it has been suggested that climate and consequent temperature variations during the Aptian were just a matter of a very few degrees and that $p\mathrm{CO_2}$ changes were of minor importance only (e.g. Haworth et al., 2005). In such cases, one would assume minor environmental changes on the shelves. But this is not in agreement with the deposition of the 115–175 cm-thick marly sediments with a striking concentration of discoidal orbitolinids (e.g. Pittet et al., 2002). In addition, though oxygen isotopes are sensitive to diagenesis (and thus often not reliable tools; Brandt and Veizer, 1981), and the resolution of the sampling is rather low, both the reproducibility of the main δ^{18}O trend at Tobenna-Faito on a regional scale (Fig. 7b), and the similarity with δ^{18}O reference curves (cf. Clarke and Jenkyns, 1999; Fassel and Bralower, 1999; Mutterlose et al., 2009; Fig. 10), suggest that the main trend reflects global isotope excursions, and consequently that the "Orbitolina Level" formed during a long-term global climate cooling, similarly to the Niveau Fallot in a hemipelagic setting (Takashima et al., 2007, their Fig. 5; see also Weissert and Lini, 1991; Price et al., 1998) and organic C rich intervals elsewhere (see above).

In addition to volcanic activity, another mechanism may have favoured the deterioration of the palaeoenvironment, with stress in the carbonate neritic ecosystem that fostered the settlement of the "Orbitolina Level" on the Apenninic carbonate platform and similar deposits around the Tethys.

The Early Cretaceous Tethys Ocean was situated between two distinct climate regimes: the southern part of the ocean was affected by a tropical low-pressure system, while the northern parts were dominated by a subtropical high-pressure system (TL and STH in Fig. 1; Price et al., 1995, 1998; Wortmann et al., 1999). The dry climate and the trade wind system in all probability caused extremely high evaporation rates and, as a consequence, warm and saline surface waters just north of the Apulia and Apenninic carbonate platforms (Wortmann et al., 1999, their Fig. 13). Evaporation rates may have been sufficient to trigger warm, deep water formation in shelf areas of the western Tethys Ocean (Barron and Peterson, 1989; Johnson et al., 1996; Wortmann et al., 1999; Hay, 2008), where a strong monsoonal circulation may have existed (Oglesby and Park, 1989; Price et al., 1998). The monsoonal activity may have led to variations in precipitation/evaporation ratio and wind stress and, in times of increased precipitation and runoff, to a higher nutrient supply to the sea (Herrle et al., 2003). A relative decrease in evaporation may have led to a reduction of deep water formation, with oxygen depletion at the seafloor (Wortmann et al., 1999). The high nutrient supply and the reduction of deep-water generation may have fostered the deposition of black shales in deep water settings, such as the Niveau Fallot in the Vocontian Basin (Friedrich et al., 2003). Monsoonal activity at mid-Cretaceous low latitudes has also been shown by modelling (Oglesby and Park, 1989; Price et al., 1998) and palaeoceanographic studies (Wortmann et al., 1999; see also Wang, 2009). In particular, Price et al. (1998) showed that at low latitudes "cool climate episodes" were generally moister than "warm climate episodes", probably due to intensified monsoonal activity related to the increase of the thermal contrast between land and ocean.

In such scenarios a period of intense precipitation and wind stress during the Gargasian may have induced a strong reworking of clay (including the cm-to-dm-thick deposits at Tobenna-Faito) and organic matter which were produced over the widening exposed platform during the third-order sea-level lowering (Fig. 5). During the flooding of the exposed platform linked to high-frequency sea-level changes, monsoonal activity increased the detrital influx to the lagoon and the already high nutrient level (related to volcanic activity). This was detrimental to carbonate platform development (cf. Hallock and Schlager, 1986; Hallock, 1988), as also documented for modern carbonate environments (Delgado and Lapointe, 1994). Nutrification was also associated with increased rates of bioerosion that further reduced rates of carbonate accumulation (cf. Hallock, 1988). During a transgressive phase, which allowed a high input of clay into the subtidal setting, the stressed shallow lagoonal ecosystem, following a period of interrupted (or very low) sedimentation, finally responded with the development of the "Orbitolina Level" that also filled *Thalassinoides*-like burrows in the underlying deposits (Fig. 4c).

However, high-frequency sea-level changes, monsoonal activity and volcanism also occurred before and after the deposition of the "Orbitolina Level" of the Tobenna-Faito, as well as was the production of clay over the exposed platform, which can be found intercalated all-along the studied sequence (Fig. 5). Accordingly, what can have been the crucial change that caused the supply of clay to the lagoon and the formation of this peculiar facies?

There are no data indicating tectonic control on the clastic input into the lagoon during deposition of the *M. texana* and *M. parva*-rich marker of the Southern Apennines. Also, the hypothesis that the clay constituting the "Orbitolina Level" and other layers of the Tobenna-Faito composite section was directly supplied by volcanic activity during the upper Aptian needs yet to be tested (Bravi and De Castro, 1995; Mondillo et al., 2011). In addition, the correlation of upper Aptian orbitolinid-rich strata around the Tethys and the Gulf of Mexico (Fig. 9) makes plausible a link to supraregional changes. Therefore, long-term (3rd order) sea-level changes seem to have played a major role in deposition of the "Orbitolina Level" in the above depicted scenario. Specifically, the 3rd order sea-level lowering, modulating high-frequency sea-level changes (Fig. 5) allowed part of the platform to be repeatedly exposed over increasingly longer time intervals, thus controlling the supply of clay. In the Monte Tobenna section, green clay layers indeed thicken upward in tune with long-term sea-level lowering. Therefore, during flooding of the exposed platform linked to high frequency sea-level changes, the 3rd order lowering regulated the amount of clay which could be mobilized and supplied by monsoonal activity to the lagoonal environment, whose high-trophic conditions were additionally influenced by volcanic activity (e.g. Weissert and Erba, 2004).

Before deposition of the "Orbitolina Level", monsoonal activity during flooding probably brought clay into the lagoon but the supply was largely insufficient (some clay can be found only as insoluble residue in stylolites in a few lagoonal strata) to foster the development of an orbitolinid-rich biota. This could be because, at this stage, the 3rd order sea-level lowering did not yet allow part of the platform to be sufficiently exposed to produce the proper amount of clay (and organic matter). Also, mesotrophic conditions alone, testified by the diffused microbial colonization of the shallow water environments (cf. Whalen et al., 2002; Rameil et al., 2010; Schroeder et al., 2010; see below), were insufficient for the development and blooming of *M. texana* and *M. parva*.

After deposition of the "Orbitolina Level", a prolonged emersion occurred. This led to the development of a lacustrine environment on the platform (see above; cf. also Dean and Fouch, 1983) with widespread conifers and angiosperms (Bartiromo et al., 2009, 2012). However, there is no evidence of clay supply to the lagoonal setting (except as insoluble residue in stylolites), which is characterized by muddy to laminated carbonates (e.g. in the Serra Sbregavitelli section; Raspini, 1996; see also Buonocunto et al., 1994). During flooding of the exposed platform related to high frequency sea-level changes, therefore, the lacustrine setting prevented clay mobilization or allowed insufficient supply of clay to the lagoon for the development of orbitolinids. Nevertheless, the fact that microbial carbonates reached their maximum thickness just above the "Orbitolina Level" in both the Tobenna-Faito and Serra Sbregavitelli successions (Figs. 5 and 7; see also Sect. 6.2) suggests higher trophic levels in seawater. This could have been the result of a surplus of nutrients in the lagoon due to monsoonal activity during flooding of the lacustrine environment, allowing for subtidal conditions over short periods.

The "Orbitolina Level" formed when clay mobilization by monsoonal activity during flooding of the exposed platform, coupled to high trophic levels in the sea, led to conditions which were advantageous for the blooming of *Mesorbitolina texana* and *M. parva* (cf. Birkeland, 1987; Vilas et al., 1995; Pittet et al., 2002; Embry et al., 2010).

According to Friedrich et al. (2003), the deposition of part of the Niveau Fallot in the Vocontian Basin was controlled by monsoon cycles which led to changes in the precipitation/evaporation rate on a precession time scale. The 20 ky cycle controlled the organization of the bed-scale lithofacies along the Tobenna-Faito composite section (Raspini, 1998; D'Argenio et al., 1999); thus, the marly "Orbitolina level", which represents approximately 75 % of a bed-scale cycle, may reflect the precipitation changes within a precessional cycle.

6.2 Response of the shallow carbonate platform to the Late Aptian global events: microbial carbonates

Several authors have suggested that volcanic activity increased during the Late Aptian (Bralower et al., 1997; Jones and Jenkyns, 2001; Coffin et al., 2002). The effects of such volcanic activity on a global scale, i.e. increased $p\mathrm{CO_2}$ and increased nutrient levels (Weissert and Erba, 2004; Kuroda et al., 2011; Najarro et al., 2011), may have influenced the sensitive carbonate factory of the Southern Apenninic platform, leading to the settlement of other peculiar shallow-water facies along the studied sections.

It is possible, for example, that progressive enhancement of the continental weathering, due to the acceleration of the global water cycle, caused an increase of dissolved Ca^{2+} and HCO_3^- in the ocean (Kump et al., 2000) which may potentially have facilitated the microbial colonization in shallow water environments (Kaźmierczak et al., 1996; Kaźmierczak and Iryu, 1999; Whalen et al., 2002; Rameil et al., 2010). Microbes are, in fact, important contributors in carbonate systems during times of environmental change and biotic crises (Whalen et al., 2002; Graziano, 2003; see also Huck et al., 2010) and develop well under high-trophic levels (Hallock, 1988; Miller et al., 1989; Mutti and Hallock, 2003). Along the Monte Tobenna section, deposits interpreted as microbial carbonates reach their maximum thickness above the "Orbitolina Level" (Figs. 5, 7 and 10). Similar observations also emerge from the first data of an ongoing study by the author that show the distribution of microbial carbonates along the Serra Sbregavitelli basal section (Figs. 7 and 10). At Tobenna-Faito, microbial carbonates disappear above SBZ 1, although tectono-volcanic activity was still increasing (Bralower et al., 1997; Jones and Jenkyns, 2001; Coffin et al., 2002). This may be because the $\sim$800 ky lasting third-order sea-level rise (mfz in Fig. 5) did more than offset the effects of the increasing alkalinity on the main carbonate producers (cf. Schlager, 2003; Hallock, 2005), allowing more suitable physico-chemical conditions to be re-established and the return of the platform to a healthy state. Microbial carbonates again occur in the upper part of the section, close to the Aptian–Albian boundary. They reach their maximum thickness close to the first occurrence of *Ovalveolina reicheli* (Figs. 5 and 7), around the SB 2, when long-term sea-level lowering induced more restricted marine circulation on the inner platform and unsuitable conditions for the main carbonate producers.

6.3 *Salpingoporella dinarica* acme: a possible response of the shallow-water platform to changes in seawater chemistry?

As stated above, at Tobenna-Faito *Salpingoporella dinarica* shows its maximum abundance below the "Orbitolina Level", while disappearing 11 m above it (Fig. 5). First results of the ongoing study by the author indicate that this is also the case for the Serra Sbregavitelli section (Fig. 7). Cathodeluminescence and chemical microprobe observations by Simmons et al. (1991), indicate that the skeleton of this alga was originally made of low-Mg calcite, with a dark inner layer derived from a primary organic membrane (Carras et al., 2006). Secular changes in the Mg/Ca ratio and the absolute concentration of calcium in seawater – driven by changes of deep-sea igneous activity – have strongly influenced the biomineralization of calcium carbonate-producing organisms, similarly as in the case of nonskeletal carbonates (Stanley and Hardie, 1998; Stanley, 2006). During the Aptian, seawater was characterized by a concomitant low Mg/Ca molar ratio and high concentration of Ca ("Calcite Sea"; Fig. 11a), resulting in accelerated growth of calcitic organisms. It is therefore not unreasonable to argue that seawater chemistry of the Early Cretaceous – in particular the Late Aptian (112–121 Ma, Ogg et al., 2004) – affected not only the more complex carbonate-producing organisms (e.g. corals, rudists; cf. Steuber, 2002), but could have favoured the production of the low-Mg calcite skeleton of *S. dinarica*, thus explaining, at least partly, the abundance of this calcareous alga in the shallow-water carbonates of the studied interval and of coeval deposits along the southern Tethys margin (e.g. Varol et al., 1988; De Castro, 1991; Carras et al., 2006; Tasli et al., 2006; Di Lucia, 2009; Husinec et al., 2009). This may have been the case because *S. dinarica* was not a sophisticated biomineralizer (Lowenstam and Weiner, 1989) and, therefore, seawater chemistry would have exerted a relatively strong effect on its rate of growth and calcification (Stanley, 2006). Since *S. dinarica* developed from the Berriasian to the Albian but its acme is seen in the Aptian, it may well be that this calcareous alga survived in times when the physico-chemical conditions of the seawater did not favour its mineralogy. It was, however, able to bloom when the seawater chemistry, at least, favoured the secretion of the low Mg/Ca skeleton, at increasing Ca^{2+} levels that may have more than offset the effects of ocean acidification on *S. dinarica* calcification (Hansen and Wallmann, 2003; Royer et al., 2004; Ridgwell and Zeebe, 2005; Stanley, 2006; Fig. 11b).

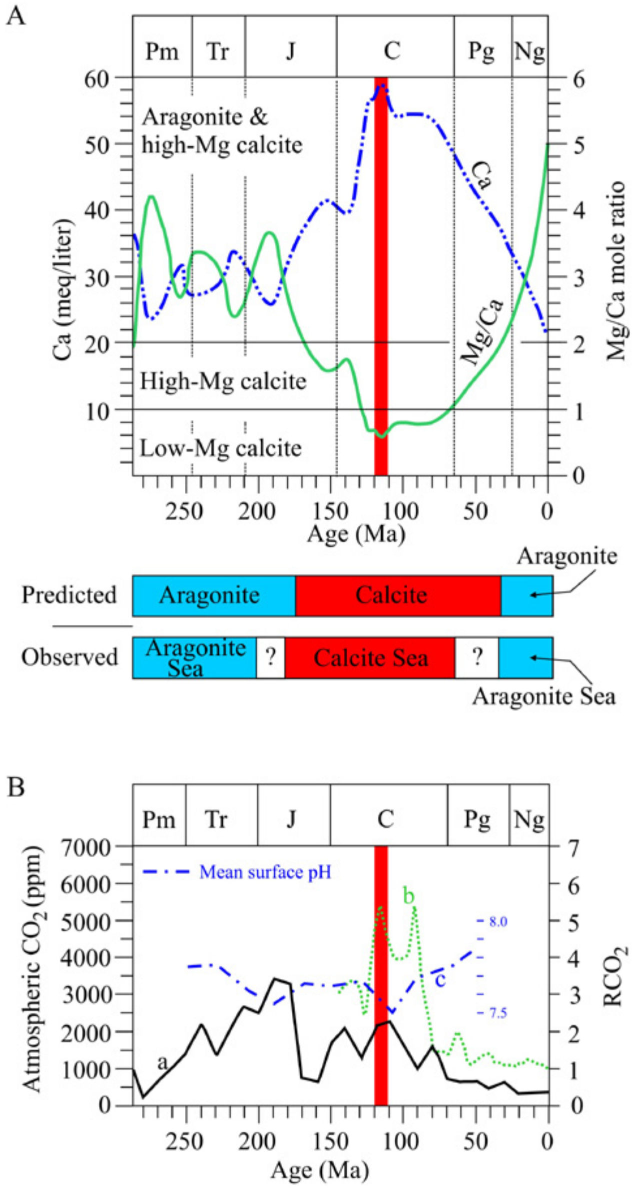

Fig. 11. Evolving physico-chemical conditions of the ocean-atmosphere system during the Mesozoic. In both diagrams, the vertical red bar roughly refers to the Aptian interval of the studied Tobenna-Faito composite section. **(A)** Ca^{2+} concentration and Mg^{2+}/Ca^{2+} mole ratio in the ocean waters with nucleation fields for low-Mg calcite, high-Mg calcite and aragonite. The temporal oscillations between calcitic and aragonitic nonskeletal carbonates are also shown (from Stanley et al., 2002; Stanley, 2006, redrawn and simplified). **(B)** Evolution of the atmospheric CO_2 concentration (**a**; from Royer et al., 2004), pCO_2 normalized to the current value (RCO_2, **b**; from Hansen and Wallmann, 2003) and trend of the mean surface pH (**c**; from Ridgwell and Zeebe, 2005).

6.4 Summary

The evolution of facies and their cyclical organization along the Tobenna-Faito composite section suggest that the clay-rich "Orbitolina Level" of the Gargasian was deposited in the lagoonal environment of the Apenninic carbonate platform after a period of interrupted (or very low) sedimentation, during a phase of third-order lowering of the sea level (Fig. 5). The correlation of the trends of $\delta^{13}C$ and $\delta^{18}O$ values in the studied sections with reference curves and the main volcanic and climatic events of the Late Aptian (Figs. 8 and 10) confirms that the orbitolinid-rich marker was formed during global climate cooling, and that it is coeval with part of the Niveau Fallot that was deposited in a hemipelagic setting connected to the Tethyan Ocean. In the "Orbitolina Level" of the Central-Southern Apennines, the discoidal foraminifera are associated to echinoderms, calcareous algae and rare bivalves, suggesting high nutrient levels. It is proposed that the supply of a proper amount of clay, induced by monsoonal activity during flooding of the exposed platform, coupled to high trophic levels related to volcanic activity, created perfect conditions for the spread of an opportunistic biota rich in orbitolinids in the lagoon during a third-order sea-level fall. Because high-frequency sea-level changes, monsoonal activity and volcanism occurred also before and after the deposition of *M. texana* and *M. parva*-rich beds, which also correlate around the Tethys and the Gulf of Mexico (Fig. 9), 3rd order sea-level changes must have played a major role in their formation. Accordingly, the Late Aptian "Orbitolina Level" is interpreted here as the response of the lagoonal ecosystem to supraregional events (monsoonal activity) superimposed on global processes (volcanic activity), whose effects were amplified by the 3rd order sea-level lowering.

During the sea-level lowering the volcanic activity remarkably influenced the stratigraphic record of Monte Tobenna-Faito, as testified by the development of microbial carbonates and the distribution of *Salpingoporella dinarica*-rich deposits along the composite section (Fig. 5). The injection of CO_2 in the ocean-atmosphere system and the consequent enhancement of continental weathering caused an increase of dissolved Ca^{2+} and HCO_3^- in the ocean, which in turn facilitated the microbial colonization of large areas of the shallow-water environments. Also, *Salpingoporella dinarica*, whose skeleton was originally made of low-Mg calcite, shows its maximum abundance (acme) below the "Orbitolina Level", disappearing above it. Probably, the concomitant low Mg/Ca molar ratio and high concentration of Ca in the Aptian seawater (Fig. 11a) fostered the production of the low-Mg calcite skeleton of *S. dinarica* that bloomed in the shallow lagoonal environment. Thus, the neritic ecosystem of the Apenninic carbonate platform was principally sensitive to changes of alkalinity and trophic levels rather than to ocean acidification during a period of long-term sea-level fall (Fig. 11b).

During the sea-level rise, despite the volcano-tectonic activity, no microbial carbonates formed in the shallow lagoon and also *S. dinarica* disappeared, probably because the physico-chemical conditions of the seawater became definitively unsuitable for secreting its skeleton. Therefore, the sedimentary record of the Tobenna-Faito is not punctuated by peculiar facies, suggesting that the marine ecosystem was not greatly influenced by palaeoenvironmental changes related to the mid-Cretaceous volcanism.

7 Conclusions

1. During the Late Aptian, third-order sea-level changes played a fundamental role in regulating carbonate sedimentation in the inner lagoonal environments of the Apenninic platform and the temporal distribution of peculiar facies during a time of increasing volcanic activity and high nutrient levels.

2. Under these environmental conditions, microbial carbonates represented a common product of the shallow marine ecosystem only during lowering of the sea level.

3. The “Orbitolina Level” formed when a proper amount of clay was supplied to the lagoon by monsoonal activity during flooding of the exposed platform related to high frequency sea-level changes just before the minimum creation of accommodation space on the shelf was reached. Input of clay and high trophic levels in the waters led to advantageous conditions for the blooming of *Mesorbitolina texana* and *M. parva*. This makes the Gargasian “Orbitolina Level” a facies “out of the standard platform sedimentary record” and, consequently, an important litho- and biostratigraphic marker of carbonate successions of the Central-Southern Apennines and elsewhere in the Tethyan domain.

4. The “Orbitolina Level” is coeval with part of the Niveau Fallot that was deposited in a hemipelagic setting connected to the Tethyan Ocean during a period of global climate cooling.

5. Considering the distribution of *Salpingoporella dinarica* along the studied sections, it emerges that the neritic ecosystem was principally sensitive to changes of alkalinity and trophic levels rather than to ocean acidification during a time of sea-level fall.

6. During sea-level rise no or minor microbial carbonates formed in the shallow lagoonal settings that did not suffer the effects of the palaeoenvironmental changes induced by the mid-Cretaceous volcanism, and therefore remained in a healthy state.

Acknowledgements. I am grateful to R. Graziano for his support and fruitful discussions on shallow water carbonates. A. Immenhauser, A. Azerêdo and K. Föllmi provided suggestions and constructive criticism on an early draft of the manuscript. I am indebted to P. L. de Boer for reviewing the final version of the paper and offering helpful comments for its improvement. I sincerely thank my wife Annalisa who repeatedly supported (and endured) my work on laptop. This research was supported by the CNR grant n. 0068163, 01/10/2009.

Special Issue: “Phanerozoic black shales and oceanic anoxic events: geochemistry, sedimentology and stratigraphy”
Edited by: J. Trabucho-Alexandre, P. L. de Boer, and D. R. Gröcke

References

Argnani, A.: Possible record of a Triassic ocean in the Southern Apennines, Boll. Soc. Geol. It., 124, 109–121, 2005.

Arnaud-Vanneau, A. and Arnaud, H.: Hauterivian to Lower Aptian carbonate shelf sedimentation and sequence stratigraphy in the Jura and northern Subalpine chains (southeastern France and Swiss Jura), in: Carbonate Platforms. Facies, Sequences and Evolution, edited by: Tucker, M. E., Wilson, J. L., Crevello, P. D., Sarg, J. R., and Read, J. F., Int. Assoc. Sedimentol., Spec. Publ., 9, 203–233, 1990.

Bachmann, M. and Hirsch. F.: Lower Cretaceous carbonate platform of the eastern Levant (Galilee and the Golan Heights): stratigraphy and second-order sea-level change, Cret. Res., 27, 487–512, 2006.

Barattolo, F. and De Castro, P.: Early Cretaceous of Mount Tobenna, in: 5th International Symposium on Fossil Algae, Field-trip guide-book, edited by: Barattolo, F., De Castro, P., and Parente, M., pp. 72–78, 1991.

Barron, E. J. and Peterson, W. H.: Model simulation of the Cretaceous ocean circulation, Science, 244, 684–686, 1989.

Bartiromo, A., Barale, G., Barone Lumaga, M. R., Bravi, S., and Barattolo, F.: The Early Cretaceous flora from Profeti, Caserta, Southern Italy, Rev. Paleob. Palynol., 158, 101–116, 2009.

Bartiromo, A., Barale, G., Barone Lumaga, M. R., Bravi, S., and Barattolo, F.: An Early Cretaceous flora from Cusano Mutri, Benevento, southern Italy, Cret. Res., 33, 116–134, 2012.

Birkeland, C.: Nutrient availability as a major determinant of differences among coastal hard-substratum communities in different regions of the tropics, in: Comparisons between Atlantic and Pacific tropical coastal marine ecosystems: community structure, ecological processes, and productivity, edited by: Birkeland, C., UNESCO Rep. Mar. Sci., 46, 45–97, 1987.

Bonardi, G., D’Argenio, B., and Perrone, V.: Carta geologica dell’Appennino meridionale, Mem. Soc. Geol. It., 41, 1341, 1992.

Bralower, T. J., Arthur, M. A., Leckie, R. M., Sliter, W. V., Allard, D., and Schlanger, S. O.: Timing and paleoceanography of oceanic dysoxia/anoxia in the Late Barremian to Early Aptian (Early Cretaceous), Palaios, 9, 335–369, 1994.

Bralower, T. J., Fullagar, P. D., Paull, C. K., Dwyer, G. S., and Leckie, R. M.: Mid-Cretaceous strontium-isotope stratigraphy of deep-sea section, Geol. Soc. Am. Bull., 109, 1421–1442, 1997.

Bralower, T. J., Cobabe, E., Clement, B., Sliter, W. V., Osburn, C., and Longoria, J.: The record of global change in mid-Cretaceous (Barremian-Albian) sections from the Sierra Madre, northeastern Mexico, J. Foraminifer. Res., 29, 418–437, 1999.

Brandt, U. and Veizer, J.: Chemical diagenesis of a multicomponent carbonate systems – 2: stable isotopes, J. Sed. Petr., 51, 987–997, 1981.

Bravi, S. and De Castro, P.: The Cretaceous fossil fishes level of Capo d'Orlando, near Castellammare di Stabia (NA): biostratigraphy and depositional environment, Mem. Sci. Geol., 47, 45–72, 1995.

Brescia, M., D'Argenio, B., Ferreri, V., Pelosi, N., Rampone, S., and Tagliaferri, R.: Neural net aided detection of astronomical periodicities in geologic records, Earth Plan. Sci. Lett., 139, 33–45, 1996.

Brock, T. D., Madigan, M. T., Martinko, J. M., and Parker, J.: Biology of Microorganisms, 7th edn. Prentice Hall, New Jersey, 1994.

Buonocunto, F. P., D'Argenio, B., Ferreri, V., and Raspini, A.: Microstratigraphy of highly organized carbonate platform deposits of Cretaceous age. The case of Serra Sbregavitelli, Matese (Central Apennines), G. Geol., 56, 179–192, 1994.

Burla, S., Heimhofer, U., Hochuli, P. A., Weissert, H., and Skelton, P.: Changes in sedimentary patterns of coastal and deep-sea successions from the North Atlantic (Portugal) linked to Early Cretaceous environmental change, Palaeogeogr. Palaeoclimatol. Palaeoecol., 257, 38–57, 2008.

Carannante, G., Pugliese, A., Ruberti, D., Simone, L., Vigliotti, M., and Vigorito, M.: Evoluzione cretacica di un settore della piattaforma apula da dati di sottosuolo e di affioramento (Appennino campano-molisano), It. J. Geosci. (Boll. Soc. Geol. It.), 128, 3–31, 2009.

Carras, N., Conrad, M. A., and Radoičič, R.: *Salpingoporella*, a common genus of Mesozoic Dasycladales (calcareous green algae), Rev. Paléobiol., 25, 457–517, 2006.

Casero, P., Roure, F., Endignoux, L., Moretti, I., Mueller, C., Sage, L., and Vially, R.: Neogene geodynamic evolution of the Southern Apennines, Mem. Soc. Geol. It., 41, 109–120, 1988.

Castro, J. M., de Gea, G.A., Ruiz-Ortiz, P. A., and Nieto, L. M.: Development of carbonate platforms on an extensional (rifted) margin: the Valanginian-Albian record of the Prebetic of Alicante (SE Spain), Cret. Res., 29, 848–860, 2008.

Cherchi, A. and Schroeder, R.: Calcimicrobial oncoid coatings from the Pliensbachian Massone Member (Calcari Grigi Formation, Trento Platform, Italy), in: Giornata di Studi Paleontologici "Prof. C. Loriga Broglio", Ferrara, 18 June 2004, edited by: Fugagnoli, A. and Bassi, D., Annali dell'Università di Ferrara, Sez. Museologia Scientifica e Naturalistica, Spec. Vol., 45–49, 2005.

Cherchi, A. and Schroeder, R.: The *Praeorbitolina/Palorbitolinoides* Association: an Aptian biostratigraphic key-interval at the southern margin of the Neo-Tethys, Cret. Res. (2012), doi:10.1016/j.cretres.2012.02.018, 2012.

Cherchi, A., De Castro, P., and Schroeder, R.: Sull'età dei livelli a Orbitolinidi della Campania e delle Murge Baresi (Italia meridionale), Boll. Soc. Nat. Napoli, 87, 363–385, 1978.

Chihaoui, A., Jaillard, E., Latil, J.-L., Zghal, I., Susperregui, A.-S., Touir, J., and Ouali, J.: Stratigraphy of the Hameima and lower Fahdene Formations in the Tadjerouine area (Northern Tunisia), J. Afr. Earth Sci., 58, 387–399, 2010.

Chiocchini, M., Farinacci, A., Mancinelli, A., Molinari, V., and Potetti, M.: Biostratigrafia a foraminiferi, dasicladali e calpionelle delle successioni carbonatiche mesozoiche dell'Appennino centrale (Italia), in: Biostratigrafia dell'Italia Centrale, edited by: Mancinelli, A., Studi Geol. Camerti, Spec. Vol. A, 9–129, 1994.

Clarke, L. J. and Jenkyns, H. C.: New oxygen isotope evidence for long-term Cretaceous climatic change in the Southern Hemisphere, Geology, 27, 699–702, 1999.

Coffin, M. F., Pringle, M. S., Duncan, R. A., Gladczenko, T. P., Storey, M., Muller, R. D., and Gahan, L. A.: Kerguelen hotspot magma output since 130 Ma, J. Petrol., 43, 1121–1139, 2002.

Coffin, M. F., Duncan, R. A., Eldholm, O., Fitton, J. G., Frey, F. A., Larse, H. C., Mahoney, J. J., Saunders, A. D., Schlich, R., and Wallace, P. J.: Large igneous provinces and scientific ocean drilling. Status quo and a look ahead, Oceanography, 19, 150–160, 2006.

Costa, O. G.: Studi sopra i terreni ad ittioliti delle provincie meridionali d'Italia. Parte III. Castellammare, Atti Rend. Acc. Sc. Fis. Mat. Napoli, ser. 173, 1–30, 1866.

Danelian, T., Tsikos, H., Gardin, S., Baudin, F., Bellier, J.-P., and Emmanuel, L.: Global and regional palaeoceanographic changes as recorded in the mid-Cretaceous (Aptian–Albian) sequence of the Ionian zone (NW Greece), J. Geol. Soc., Lond., 161, 703–709, 2004.

D'Argenio, B., Amodio, S., Ferreri, F., and Pelosi, N.: Hierarchy of high frequency orbital cycles in Cretaceous carbonate platform strata, Sediment. Geol., 113, 169–193, 1997.

D'Argenio, B., Ferreri, V., Raspini, A., Amodio, S., and Buonocunto, F.P.: Cyclostratigraphy of a carbonate platform as a tool for high precision correlation, Tectonophysics, 315, 357–384, 1999.

D'Argenio, B., Ferreri, V., Weissert, H., Amodio, S., Buonocunto, F. P., and Wissler, L.: A multidisciplinary approach to global correlation and geochronology. the Cretaceous shallow-water carbonates of Southern Apennines, Italy, in: Cyclostratigraphy; approaches and cases histories, edited by: D'Argenio, B., Fischer, A. G., Premoli Silva, I., Weissert, H., and Ferreri, V., SEPM Spec. Publ., 81, 103–122, 2004.

Dean, W. E. and Fouch, T. D.: Lacustrine environment, in: Carbonate depositional environments edited by: Scholle, P. A., Bebout, D. G., and Moore, C. H., Am. Assoc. Pet. Geol., Mem., 33, 97–130, 1983.

De Castro, P.: Nuove osservazioni sul livello ad Orbitoline in Campania, Boll. Soc. Nat. Napoli, 71, 103–135, 1963.

De Castro, P.: Mesozoic, in: 5th International Symposium on Fossil Algae, Field-trip guide-book, edited by: Barattolo, F., De Castro, P., and Parente, M., 21–38, 1991.

Delgado, O. and Lapointe, B. E.: Nutrient-limited productivity of calcareous versus fleshy macroalgae in a eutrophic, carbonate-rich tropical marine environment, Coral Reefs, 15, 151–159, 1994.

Di Lucia, M.: Il record dei cambiamenti globali nelle piattaforme carbonati che del Cretacico medio dell'Appennino meridionale, Doctorate Thesis, University of Naples, available at: http://www.fedoa.unina.it/3342/1/Matteo_Di_Lucia_-_PhD_thesis.pdf. 125 p., 2009.

Di Lucia, M. and Parente, M.: Carbon-isotope stratigraphy of upper Barremian-lower Albian shallow-water carbonates of southern Apennines (Italy): high-resolution correlation with deep-water reference sections, Soc. Geol. It., Rendiconti Online, 2, 65–70, 2008.

Di Lucia, M., Mutti, M., and Parente, M.: Bio-chemostratigraphy of the Barremian-Aptian shallow-water carbonates of the southern Apennines (Italy): pinpointing the OAE1a in a Tethyan carbonate platform, Solid Earth Discuss., 3, 789–838, doi:10.5194/sed-3-789-2011, 2011.

Doglioni, C.: Foredeeps versus subduction zones, Geology, 22, 271–274, 1994.

Donnadieu, Y., Dromart, G., Goddéris, Y., Pucéat, E., Brigaud, B., Dera, G., Dumas, C., and Olivier, N.: A mechanism for brief glacial episodes in the Mesozoic greenhouse, Paleoceanography, 26, PA3212, doi:10.1029/2010PA002100, 2011.

Embry, J. C., Vennin, E., van Buchem, F. S. P., Schroeder, R., Pierre, C., and Aurell, M.: Sequence stratigraphy and carbon isotope stratigraphy of an Aptian mixed carbonate-siliciclastic platform to basin transition (Galve sub-basin, NE Spain), in: Mesozoic and Cenozoic Carbonate Systems of the Mediterranean and the Middle East: Stratigraphic and Diagenetic Reference Models, edited by: van Buchem, F. S. P., Gerdes, K. D., and Esteban, M., Geol. Soc., London, Engineering Geology Spec. Publ., 329, 113–143, 2010.

Emeis, K.-C. and Weissert, H.: Tethyan-Mediterranean organic carbon-rich sediments from Mesozoic black shales to sapropels, Sedimentology, 56, 247–266, 2009.

Erba, E., Channell, J. E. T., Claps, M., Jones, C., Larson, R., Opdyke, B., Premoli Silva, I., Riva, A., Salvini, G., and Torricelli, S.: Integrated stratigraphy of the Cismon Apticore (Southern Alps, Italy): a "reference section" for the Barremian-Aptian interval at low latitudes, J. Foraminifer. Res., 29, 371–391, 1999.

Erba, E., Bottini, C., Weissert, H., and Keller, C. E.: Calcareous nannoplankton response to surface-water acidification around Oceanic Anoxic Event 1a, Science, 329, 428–432, 2010.

Erbacher, J., Thurow, J., and Littke, R.: Evolution patterns of radiolaria and organic matter variations: A new approach to identify sea-level changes in mid-Cretaceous pelagic environments, Geology, 24, 499–502, 1996.

Fassel, M. L. and Bralower, T. J.: Warm, equable mid-Cretaceous: Stable isotope evidence, Geol Soc. Am. Spec. Pap., 332, 121–142, 1999.

Ferreri, V., Weissert, H., D'Argenio, B., and Buonocunto, F. P.: Carbon isotope stratigraphy: a tool for basin to carbonate platform correlation, Terra Nova, 9, 57–61, 1997.

Föllmi, K. B.: Early Cretaceous life, climate and anoxia, Cret. Res., 35, 230–257, 2012.

Föllmi, K. B., Weissert, H., Bisping, M., and Funk, H.: Phosphogenesis, carbon isotope stratigraphy, and carbonate-platform evolution along the Lower Cretaceous northern Tethyan margin, Geol. Soc. Am. Bull., 106, 729–746, 1994.

Friedrich, O., Reichelt, K., Herrle, J. O., Lehmann, J., Pross, J., and Hemleben, C.: Formation of the Late Aptian Niveau Fallot black shales in the Vocontian Basin (SE France): evidence from foraminifera, palynomorphs, and stable isotopes, Mar. Micropal., 49, 65–85, 2003.

Gattacceca, J. and Speranza, F.: Paleomagnetism of Jurassic to Miocene sediments from the Apenninic carbonate platform (southern Apennines, Italy): evidence for a 60° counterclockwise Miocene rotation, Earth Plan. Sci. Lett., 201, 19–34, 2002.

Goldhammer, R. K., Dunn, P. A., and Hardie, L. A.: Depositional cycles, composite sea-level changes, cycle stacking pattern and the hierarchy of stratigraphic forcing. Examples from Alpine Triassic platform carbonates, Geol. Soc. Am. Bull., 102, 535–562, 1990.

Golubic, S., Radoicic, R., and Seong-Joo, L.: *Decastronema kotori* gen. nov., comb. Nov.: a mat-forming cyanobacterium on Cretaceous carbonate platforms and its modern counterparts, Carnets de Géologie/Notebooks on Geology – Article 2006/02 (CG2006_A02), 2006.

Graziano, R.: The Early Cretaceous drowning unconformities of the Apulia carbonate platform (Gargano Promontory, southern Italy): local fingerprints of global palaeoceanographic events, Terra Nova, 11, 245–250, 1999.

Graziano, R.: The Aptian-Albian of the Apulia Carbonate Platform (Gargano Promontory, southern Italy): evidence of palaeoceanographic and tectonic controls on the stratigraphic architecture of the platform margin, Cret. Res., 21, 106–127, 2000.

Graziano, R.: The Early Cretaceous drownings of Tethyan carbonate platforms: controlling mechanisms and paleoceanography. Insights from the Apulia record, in: Temperate-type (Foramol facies) carbonate platforms versus tropical-type (Chlorozoan facies) carbonate platforms: tridimensional arrangement of lithofacies, benthic associations and evolution of the related depositional systems, edited by: Simone, L., Ruberti, D., and Graziano, R., COFIN 2000 Workshop, Pozzuoli (Naples), 25–27 February 2003, 55–62, 2003.

Guiscardi, G.: Sull'età degli scisti calcarei di Castellammare, Rend. R. Acc. Sc. Fis. Mat. Napoli, ser.1, 5, 122–123, 1866.

Hallock, P.: The role of nutrient availability in bioerosion: consequences to carbonate buildups, Palaeogeogr. Palaeoclimatol. Palaeoecol., 63, 275–291, 1988.

Hallock, P.: Global change and modern coral reefs: New opportunities to understand shallow-water carbonate depositional processes, Sediment. Geol., 175, 19–33, 2005.

Hallock, P. and Schlager, W.: Nutrient excess and the demise of coral reefs and carbonate platforms, Palaios, 1, 389–398, 1986.

Hansen, K. W. and Wallmann, K.: Cretaceous and Cenozoic evolution of seawater composition, atmospheric O_2 and CO_2: a model perspective, Am. J. Sci., 303, 94–148, 2003.

Haq, B. U., Hardenbol, J., and Vail, P. R.: Chronology of fluctuating sea level since Triassic (250 million years ago to present), Science, 235, 1156–1167, 1987.

Haq, B. U., Hardenbol, J., and Vail, P. R.: Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change, in: Sea-level changes – An integrated approach, edited by: Wilgus, C. K., Hastings, B. S., Kendall, C. G. St. C., Posamentier, H. W., Ross, C. A., and van Wagoner, J. C., SEPM Spec. Publ., 42, 71–108, 1988.

Haworth, M., Hesselbo, S. P., McElwain, J. C., Robinson, S. A., and Brunt, J. W.: Mid-Cretaceous $p CO_2$ based on stomata of the extinct conifer *Pseusofreneloplis* (Cheirolepidiaceae), Geology, 33, 749–752, 2005.

Hay, W. W.: Evolving ideas about the Cretaceous climate and ocean circulation, Cret. Res, 29, 725–753, 2008.

Heldt, M., Lehmann, J., Bachmann, M., Negra, H., and Kuss, J.: Increased terrigenous influx but no drowning: palaeoenvironmental evolution of the Tunisian carbonate platform margin during the Late Aptian, Sedimentology, 57, 695–719, 2010.

Herrero, A. and Flores, E.: The cyanobacteria: molecular biology, genomics and evolution, Caister Adademic Press, Norfolk, UK, 484 pp., 2008.

Herrle, J. O. and Mutterlose, J.: Calcareous nannofossils from the Aptian-Lower Albian of southeast France: palaeoecological and biostratigraphic implications, Cret. Res., 24, 1–22, 2003.

Herrle, J. O., Pross, J., Friedrich, O., and Hemleben, C.: Short-term environmental changes in the Cretaceous Tethyan Ocean: micropalaeontological evidence from the Early Albian Oceanic Anoxic Event 1b, Terra Nova, 15, 14–19, 2003.

Hong, S. K., and Lee, Y. I.: Evaluation of atmospheric carbon dioxide concentrations during the Cretaceous,Earth Plan. Sci. Lett., 327, 23–28, 2012.

Hottinger, L.: Larger foraminifera, giant cells with a historical background, Naturwissenschaften, 69, 361–371, 1982.

Hottinger, L.: Shallow benthic foraminiferal assemblages as signal for depth of their deposition and their limitations, Bull. Soc. Fr., 168, 491–505, 1997.

Hu, X., Jansa, L., and Sarti, M.: Mid-Cretaceous oceanic red beds in the Umbria–Marche Basin, central Italy: Constraints on paleoceanography and paleoclimate, Palaeogeog. Palaeoclimat. Palaeoecol., 233, 163–186, 2005.

Hu, X., Zhao, K., Yilmaz, I. O., and Li, Y.: Stratigraphic transition and palaeoenvironmental changes from the Aptian oceanic anoxic event 1a (OAE1a) to the oceanic red bed 1 (ORB1) in the Yenicesihlar section, central Turkey, Cret. Res. (2012), doi:10.1016/j.cretres.2012.01.007, 2012.

Huang, C., Hinnov, L., Fischer, A. G., Grippo, A., and Herbert, T.: Astronomical tuning of the Aptian Stage from Italian reference sections, Geology, 38, 899–902, 2010.

Huang, Y., Yang, G., Wang, C., and Wu, H.: The stabilisation of the long-term Cretaceous greenhouse climate: Contribution from the semi-periodical burial of phosphorus in the ocean, Cret. Res. (2012), doi:10.1016/j.cretres.2012.04.005, 2012.

Huck, S., Rameil, N., Korbar, T., Heimhofer, U., Wieczorek, T. D., and Immenhauser, A.: Latitudinally different responses of Tethyan shoal-water carbonate systems to the Early Aptian oceanic anoxic event (OAE 1a), Sedimentology, 57, 1585–1614, 2010.

Huck, S., Heimhofer, U., Rameil, N., Bodin, S., and Immenhauser, A.: Strontium and carbon-isotope chronostratigraphy of Barremian–Aptian shoal-water carbonates: Northern Tethyan platform drowning predates OAE 1a, Earth Plan. Sci. Lett., 304, 547–558, 2011.

Husinec, A. and Read, J. F.: Microbial laminite versus rooted and burrowed caps on peritidal cycles: salinity control on parasequence development, Early Cretaceous isolated carbonate platform, Croatia. Geol. Soc. Am. Bull., 123, 1896–1907, 2011.

Husinec, A., Velić, I., Fucek, L., Vlahović, I., Maticec, D., Ostrić, N., and Korbar, T.: Mid Cretaceous orbitolinid (Foraminiferida) record from the islands of Cres and Losinj (Croatia) and its regional stratigraphic correlation, Cret. Res., 21, 155–171, 2000.

Husinec, A., Velić, I., and Sokač, B.: Diversity patterns in Mid-Cretaceous benthic foraminifers and dasycladalean algae of the southern part of the Mesozoic Adriatic Platform, Croatia, in: Geologic Problem Solving with Microfossils: A Volume in Honor of Garry D. Jones, edited by: Demchuk, T. D. and Gary, A. C., SEPM, Spec. Publ., 93, 153–170, 2009.

Immenhauser, A., Hillgärtner, H., and van Bentum, E.: Microbial-foraminiferal episodes in the Early Aptian of the southern Tethyan margin: ecological significance and possible relation to oceanic anoxic event 1a, Sedimentology, 52, 77–99, 2005.

Jahren, A. H.: The biogeochemical consequences of the mid-Cretaceous superplume, J. Geodyn., 34, 177–191, 2002.

Jenkyns, H. C.: Cretaceous anoxic events: from continents to oceans, J. Geol. Soc., Lond., 137, 171–188, 1980.

Jenkyns, H. C.: Geochemistry of oceanic anoxic events, Geochem. Geophys. Geosys., 11, Q03004, doi:10.1029/2009GC002788, 2010.

Jenkyns, H. C. and Wilson, P. A.: Stratigraphy, paleoceanography and evolution of Cretaceous Pacific guyots: relics from a greenhouse earth, Am. J. Sci., 299, 341–392, 1999.

Jenkyns, H. C., Gale, A. S., and Corfield, R. M.: Carbon- and oxygen-isotope stratigraphy of the English Chalk and Italian Scaglia and its paleoclimatic significance, Geol. Mag., 131, 1–34, 1994.

Johnson, C. C., Barron, E. J., Kaufmann, E. G., Arthur, M. A., Fawcett, P. J., and Yasuda, M. K.: Middle Cretaceous reef collapse linked to ocean heat transport, Geology, 24, 376–380, 1996.

Jones, C. E. and Jenkyns, H. C.: Seawater strontium isotopes, oceanic anoxic events, and seafloor hydrothermal activity in the Jurassic and Cretaceous, Am. J. Sci., 301, 112–149, 2001.

Kaźmierczak, J. and Iryu, Y.: Cyanobacterial origin of microcrystalline cements from Pleistocene rhodoliths and coralline algal crusts of Okierabu-jima, Japan, Acta Palaeontol. Polonica, 44, 117–130, 1999.

Kaźmierczak, J., Coleman, M. L., Gruszczynski, M., and Kempe, S.: Cyanobacterial key to the genesis of micrite and peloidal limestones in ancient seas, Acta Palaeontol. Polonica, 41, 319–338, 1996.

Kerans, C.: Use of one- and two-dimensional cycle analysis in establishing high-frequency sequence frameworks, in: Milankovitch sea level changes, cycles and reservoirs on carbonate platforms in Greenhouse and Ice-house worlds, edited by: Read, J. F., Kerans, C., and Weber, L. J., SEPM Short Course, 35, part 2, 1–20, 1995.

Kidwell, S. M.: Palaeobiological and sedimentological implications of fossil concentrations, Nature, 318, 457–460, 1985.

Kidwell, S. M.: Models for fossil concentrations: paleobiologic implications, Paleobiology, 12, 6–24, 1986.

Korbar, T.: Orogenic evolution of the External Dinarides in the NE Adriatic region: a model constrained by tectonostratigraphy of Upper Cretaceous to Paleogene carbonates, Earth Sci. Rev., 9, 296–312, 2009.

Kump, L. R., Brantley, L., and Arthur, M. A.: Chemical weathering, atmospheric CO_2, and climate, Annu. Rev. Earth Plan. Sci., 28, 611–667, 2000.

Kuroda, J., Tanimizu, M., Hori, R. S., Suzuki, K., Ogawa, N. O., Tejada, M. L. G., Coffin, M. F., Coccioni, R., Erba, E., and Ohkouchi, N.: Lead isotopic record of Barremian–Aptian marine sediments: Implications for large igneous provinces and the Aptian climatic crisis, Earth Plan. Sci. Lett., 307, 126–134, 2011.

Larson, R. L. and Erba, E.: Onset of the mid-Cretaceous greenhouse in the Barremian-Aptian: igneous events and the biological, sedimentary, and geochemical responses, Paleoceanography, 14, 663–678, 1999.

Li, Y.-X., Bralower, T. J., Montañez, I. P., Osleger, D. A., Arthur, M. A., Bice, D. M., Herbert, T. D., Erba, E., and Premoli Silva, I.: Toward an orbital chronology for the early Aptian Oceanic Anoxic Event (OAE1a, $\sim$120 Ma), Earth Plan. Sci. Lett., 271, 88–100, 2008.

Longo, G., D'Argenio, B., Ferreri, V., and Iorio, M.: Fourier evidence for high frequency astronomical cycles recorded in Early Cretaceous carbonate platform strata, Monte Maggiore southern Apennines, Italy, in: Orbital Forcing and Cyclic Sequences, edited by: De Boer, P. L. and Smith, D. G., Int. Assoc. Sedimentol., Spec. Publ., 19, 77–85, 1994.

Lowenstam, H. A. and Weiner, S.: On Biomimeralization, New York, Oxford University Press, 324 pp., 1989.

Masse, J.-P. and Fenerci-Masse, M.: Drowning discontinuities and stratigraphic correlation in platform carbonates. The late Barremian-early Aptian record of southeast France, Cret. Res., 32, 659–684, 2011.

Masse, J.-P., Fenerci-Masse, M., Korbar, T., and Velić, I.: Lower Aptian Rudist Faunas (Bivalvia, Hippuritoidea) from Croatia, Geol. Croat., 57, 117–137, 2004.

Matthews, R. K. and Al-Husseini, M. I.: Orbital forcing glacio-eustasy: A sequence-stratigraphic time scale, GeoArabia, 15, 155–167, 2010.

Mazzoli, S., Barkham, S., Cello, G., Gambini, R., Mattioni, L., Shiner, P., and Tondi, E.: Recontruction of continental margin architecture deformed by the contraction of the Lagonegro Basin, southern Apennines, Italy, J. Geol. Soc. Lond., 158, 309–319, 2001.

Méhay, S., Keller, C. E., Bernasconi, S. M., Weissert, H., Erba, E., Bottini, C., and Hochuli, P. A.: A volcanic CO_2 pulse triggered the Cretaceous Oceanic Anoxic Event 1a and a biocalcification crisis, Geology, 37, 819–822, 2009.

Menegatti, A., Weissert, H., Brown, R. S., Tyson, R. V., Farrimond, P., Strasser, A., and Caron, M.: High-resolution $\delta^{13}C$ stratigraphy through the early Aptian "Livello Selli" of the Alpine Tethys, Paleoceanography, 13, 530–545, 1998.

Miller, A. G., Espie, G. S., and Canvin, D. T.: Physiological aspects of $CO_2$and HCO_3^- transport by cyanobacteria: a review, Can. J. Bot., 68, 1291–1302, 1989.

Mondillo, N., Balassone, G., Boni, M., and Rollinson, G.: Karst bauxites in the Campania Apennines (southern Italy): a new approach, Period. Mineral., 80, 407–432, 2011.

Montañez, I. P. and Osleger, D. A.: Parasequence stacking patterns, third-order accommodation events, and sequence stratigraphy of Middle to Upper Cambrian platform carbonates, Bonanza King Formation, southern Great Basin, in: Carbonate Sequence Stratigraphy, edited by: Loucks, R. G. and Sarg, J. F., Am. Assoc. Pet. Geol., Mem., 57, 305–326, 1993.

Mostardini, F. and Merlini, S.: Appennino centro-meridionale. Sezioni geologiche e proposta di modello strutturale, Mem. Soc. Geol. It., 35, 177–202, 1986.

Mutterlose, J., Bornemann, A., and Herrle, J.: The Aptian-Albian cold snap: evidence for "mid" Cretaceous icehouse interludes, N. Jb. Geol. Paläont. Abh., 252, 217–225, 2009.

Mutti, M. and Hallock, P.: Carbonate systems along nutrient and temperature gradients: some sedimentological and geochemical constraints, Int. J. Earth Sci. (Geol Rundsch), 92, 465–475, 2003.

Najarro, M., Rosales, I., Moreno-Bedmar, J. A., de Gea, G. A., Barrón, E., Company, M., and Delanoy, G.: High-resolution chemo- and biostratigraphic records of the Early Aptian Oceanic Anoxic Event in Cantabria (N Spain): Palaeoceanographic and palaeoclimatic implications, Palaeogeog. Palaeoclimat. Palaeoecol., 299, 137–158, 2011.

Ogg, J. G., Agterberg, F. P., and Gradstein, F. M.: The Cretaceous period, in: A geologic time scale 2004, edited by: Gradstein, F., Ogg, J., and Smith, A., Cambridge University Press, 344–383, 2004.

Oglesby, R. and Park, J.: The effect of precessional insolation changes on the Cretaceous climate and cyclic sedimentation, J. Geophys. Res., 94, 14793–14816, 1989.

Patacca, E. and Scandone, P.: Geology of the Southern Apennines, in: Crop-04, edited by: Mazzotti, A., Patacca, E., and Scandone P., Boll. Soc. Geol. It., Spec. Issue 7, 75–119, 2007.

Pelosi, N. and Raspini, A.: Analisi spettrale della ciclicità di alta frequenza in successioni carbonatiche neritiche di limitato spessore. Il caso del Cretacico dei Monti di Sarno (Campania), G. Geol., 55, 37–49, 1993.

Philip, J.: Peri-Tethyan neritic carbonate areas: distribution through time and driving factors, Palaeogeogr. Palaeoclimatol. Palaeoecol., 196, 19–37, 2003.

Pittet, B., van Buchem, F. S. P., Hillgärtner, H., Razin, P., Grötsch, J., and Droste, H.: Ecological succession, palaeoenvironmental change, and depositional sequences of Barremian-Aptian shallow-water carbonates in northern Oman, Sedimentology, 49, 555–581, 2002.

Price, G. D., Sellwood, B. W., and Valdes, P. J.: Sedimentological evaluation of general circulation model simulations for the "greenhouse" Earth: Cretaceous and Jurassic case studies, Sediment. Geol., 100, 159–180, 1995.

Price, G. D., Valdes, P. J., and Sellwood, B. W.: A comparison of GCM simulated Cretaceous "greenhouse" and "icehouse" climates: implications for the sedimentary record, Palaeogeog. Palaeoclimat. Palaeoecol., 142, 123–138, 1998.

Rameil, N., Immenhauser, A., Warrlich, G., Hillgärtner, H., and Droste, H.: Morphological patterns of Aptian *Lithocodium–Bacinella* geobodies: relation to environment and scale, Sedimentology, 57, 883–911, 2010.

Raspini, A.: Sedimentologia e ciclostratigrafia del Cretacico inferiore in facies di piattaforma carbonatica dell'Appennino centro-meridionale, Doctorate Dissertation, Univ. Bologna, 1996.

Raspini, A.: Microfacies analysis of shallow water carbonates and evidence of hierarchically organized cycles. Aptian of Monte Tobenna, Southern Apennines, Italy, Cret. Res., 19, 197–223, 1998.

Raspini, A.: Stacking pattern of cyclic carbonate platform strata. Lower Cretaceous of southern Apennines, Italy, J. Geol. Soc. Lond., 158, 353–366, 2001.

Read, J. F., Kerans, C., and Weber, L. J.: Milankovitch sea level changes, cycles and reservoirs on carbonate platforms in Greenhouse and Ice-house worlds, SEPM Short Course, 35, 81 pp., 1995.

Ridgwell, A. and Zeebe, R. E.: The role of the global carbonate cycle in the regulation and evolution of the Earth system, Earth Plan. Sci. Lett., 234, 299–315, 2005.

Riding, R.: Microbial carbonates: the geological record of calcified bacterial-algal mats and biofilms, Sedimentology, 47 (Suppl. 1), 179–214, 2000.

Riding, R. and Wright, V. P.: Paleosols and tidal flat/lagoon sequences on a Carboniferous carbonate shelf: sedimentary associations of triple disconformities, J. Sed. Petr., 51, 1323–1339, 1981.

Robson, J.: Depositional models for some Cretaceous carbonates from the Sorrento Peninsula, Mem. Soc. Geol. Ital., 40, 251–257, 1987.

Royer, D. L., Berner, R. A., Montañez, I. P., Tabor, N. J., and Beerling, D. J.: CO_2 as a primary driver of Phanerozoic climate, GSA Today, 14, 4–10, 2004.

Ruiz-Ortiz, P. A. and Castro, J. M.: Carbonate depositional sequences in shallow to hemipelagic platform deposits; Aptian, Prebetic of Alicante (SE Spain), Bull. Soc. Géol. Fr., 169, 21–33, 1998.

Sandulli, R. and Raspini, A.: Regional to global correlation of Lower Cretaceous (Hauterivian-Barremian) carbonate platforms of the southern Apennines and Dinarides, Sediment. Geol., 165, 117–153, 2004.

Scheepers, P. J. J. and Langereis, C. G.: Paleomagnetic evidence for counter-clockwise rotations in the southern Apennines fold-and-thrust belt buring the Late Pliocene and Middle Pleistocene, Tectonophysics, 239, 43–59, 1994.

Schlager, W.: Benthic carbonate factories of the Phanerozoic, Int. J. Earth Sci., 92, 1–26, 2003.

Schlager, W., Philip, J., and Bosellini, A.: Cretaceous carbonate platforms, in: Cretaceous Resources Events and Rhythms, edited by: Beaudoin, B. and Ginsburg, R., Nato Adv Res Workshop, 87–112, 1988.

Schlanger, S. O. and Jenkyns, H .C.: Oceanic anoxic events: causes and consequences, Geol Mijnb, 55, 179–211, 1976.

Scholle, P. A. and Arthur, M. A.: Carbon-isotope fluctuations in Cretaceous pelagic limestones: potential stratigraphic and petroleum exploration tool, Am. Assoc. Pet. Geol. Bull., 64, 67–87, 1980.

Schroeder, R., van Buchem, F. S. P., Cherchi, A., Baghbani, D., Vincent, B., Immenhauser, A., and Granier, B.: Revised orbitolinid biostratigraphic zonation for the Barremian-Aptian of the eastern Arabian Plate and implications for regional stratigraphic correlations, GeoArabia, Spec. Publ., 4, 49–96, 2010.

Seilacher, A.: Trace Fossil Analysis. Springer-Verlag Berlin Heidelberg, 2007.

Simmons, M. D., Emery, D., and Pickard, N. A. H.: *Hensonella dinarica* (Radoičič), an originally calcitic Early Cretaceous Dasycladacean alga, Palaeontology, 34, 955–961, 1991.

Simmons, M. D., Whittaker, J. E., and Jones, R. W.: Orbitolinids from Cretaceous sediments of the Middle East – a revision of the F. R. S. Henson and Associates Collection, in: Proceedings of the Fifth International Workshop on Agglutinated Foraminifera, edited by: Hart, M. B., Kaminski, M. A. and Smart, C. W., Grzybowski Foundation Spec. Publ., 7, 411–437, 2000.

Skelton, P. W. and Gili, E.: Rudists and carbonate platforms in the Aptian: a case study on biotic interactions with ocean chemistry and climate, Sedimentology, 59, 81–117, 2012.

Smith, A. G., Smith, D. G., and Funnell, B. M.: Atlas of Mesozoic and Cenozoic Coastlines, Cambridge University Press, London, 1994.

Stanley, S. M.: Influence of seawater chemistry on biomineralization throughout phanerozoic time: Paleontological and experimental evidence, Palaeogeog. Palaeoclimat. Palaeoecol., 232, 214–236, 2006.

Stanley, S. M. and Hardie, L. A.: Secular oscillations in the carbonate mineralogy of reef-building and sediment-producing organisms driven by tectonically forced shifts in seawater chemistry, Palaeogeog., Palaeoclimatol., Palaeoecol., 144, 3–19, 1998.

Stanley, S. M., Ries, J. B., and Hardie, L. A.: Low-magnesium calcite produced by coralline algae in seawater of Late Cretaceous composition, PNAS, 99, 15323–15326, 2002.

Steuber, T.: Plate tectonic control on the evolution of Cretaceous platform-carbonate production, Geology, 30, 259–262, 2002.

Stricklin Jr., F. L., Smith, C. I., and Lozo, F. E.: Stratigraphy of Lower Cretaceous Trinity deposits of central Texas, Bur. Econ. Geol., Rep. Investigations, Austin, 71, 63 pp., 1971.

Takashima, R., Sano, S.-I., Iba, Y., and Nishi, H.: The first Pacific record of the Late Aptian warming event, J. Geol. Soc., London, 164, 333–339, 2007.

Tasli, K., Ozer, E., and Koc, H.: Benthic foraminiferal assemblages of the Cretaceous platform carbonate succession in the Yavca area (Bolkar Mountains, S Turkey): biostratigraphy and paleoenvironments, Geobios, 39, 521–633, 2006.

Tomašových, A., Fürsich, F. T., and Olszewski, T. D.: Modeling shelliness and alteration in shell beds: variation in hardpart input and burial rates leads to opposing predictions, Paleobiology, 32, 278–298, 2006.

van Buchem, F. S. P., Pittet, B., Hillgärtner, H., Grötsch, J., Al Mansouri, A. I., Billing, I. M., Droste, H. H. J., Oterdoom, W. H., and van Steenwinkel, M.: High-resolution sequence stratigraphic architecture of Barremian/Aptian carbonate systems in northern Oman and the United Arab Emirates (Kharaib and Shu'aiba Formations), GeoArabia, 7, 461–501, 2002.

Varol, B., Altiner, D., and Okan, Y.: Dasycladacean algae from the Mesozoic carbonate facies of the Sariz-Tufanbeyli autochthon (Kayseri, SE Turkey), Mineral Res. Expl. Bull., 108, 49–56, 1988.

Velić, I.: Stratigraphy and palaeobiogeography of Mesozoic benthic foraminifera of the Karst Dinarides (SE Europa), Geol. Croat., 60, 1–113, 2007.

Vezzani, L., Festa, A., and Ghisetti, F. C.: Geology and tectonic evolution of the Central-Southern Apennines, Italy, Geol. Soc. Am., Spec. Pap., 469, 1–58, 2010.

Vilas, L., Masse, J. P., and Arias, C.: Orbitolina episodes in carbonate platform evolution: the early Aptian model from SE Spain, Palaeogeogr. Palaeoclimatol. Palaeoecol., 119, 35–45, 1995.

Vincent, B., van Buchem, F. S. P., Bulot, L. G., Immenhauser, A., Caron, M., Baghbani, D., and Huc, A. Y.: Carbon-isotope stratigraphy, biostratigraphy and organic matter distribution in the Aptian–Lower Albian successions of southwest Iran (Dariyan and Kazhdumi formations), GeoArabia, Spec. Pub., 4, 139–197, 2010.

Vlahović, I., Tišljar, J., Velić, I., Matičec, D., Skelton, P. W., Korbar, T., and Fuček, L.: Main events recorded in the sedimentary succession of the Adriatic Carbonate Platform from the Oxfordian to the Upper Santonian in Istria (Croatia), in: Evolution of Depositional Environments from the Palaeozoic to the Quaternary in the Karst Dinarides and the Pannonian Basin, Field Trip Guidebook, edited by: Vlahović, I. and Tišljar, J., 22nd Int. Assoc. Sedimentol., 19–56, 2003.

Wang, P. X.: Global monsoon in a geological perspective, Chin. Sci. Bull., 54, 1113–1136, 2009.

Weissert, H. and Erba, E.: Volcanism, CO_2 and palaeoclimate: a Late Jurassic–Early Cretaceous carbon and oxygen isotope record, J. Geol. Soc. Lond., 161, 695–702, 2004.

Weissert, H. and Lini, A.: Ice age interludes during the time of Cretaceous Greenhouse Climate?, in: Controversies in Modern Geology, edited by: Muller, D. W., McKenzie, J. A., and Weissert, H., Academic Press, 173–191, 1991.

Weissert, H., Lini, A., Föllmi, K. B., and Kuhn, O.: Correlation of Early Cretaceous carbon isotope stratigraphy and platform drowning events: a possible link?, Palaeogeogr., Palaeoclimatol., Palaeoecol., 137, 189–203, 1998.

Whalen, M. T., Day, J., Eberli, G. P., and Homewood, P. W.: Microbial carbonates as indicators of environmental change and biotic crises in carbonate systems: examples from the Late Devonian, Alberta basin, Canada, Palaeogeogr. Palaeoclimatol. Palaeoecol., 181, 127–151, 2002.

Wilson, J. L. and Jordan, C.: Middle Shelf Environment, in: Carbonate Depositional Environments, edited by: Scholle, P. A., Bebout, D. G., and Moore, C. H., Am. Assoc. Pet. Geol., Mem., 33, 297–344, 1983.

Wissler, L., Weissert, H., Buonocunto, F. P., Ferreri, V., and D'Argenio, B.: Calibration of the Early Cretaceous Time Scale: a combined chemostratigraphic and cyclostratigraphic approach to the Barremian–Aptian interval, Campania Apennines and Southern Alps (Italy), in: Cyclostratigraphy; approaches and cases histories, edited by: D'Argenio, B., Fischer, A. G., Premoli Silva, I., Weissert, H., and Ferreri, V., SEPM Spec. Publ., 81, 123–133, 2004.

Wortmann, U. G., Hesse, R., and Zacher, W.: Major-element analysis of cyclic black shales: Paleoceanographic implications for the Early Cretaceous deep western Tethys, Paleoceanography, 14, 525–541, 1999.

Wortmann, U. G., Herrle, J. O., and Weissert, H.: Altered carbon cycling and coupled changes in Early Cretaceous weathering patterns: Evidence from integrated carbon isotope and sandstone records of the western Tethys, Earth Plan. Sci. Lett., 220, 69–82, 2004.

Zappaterra, E.: Source-rock distribution model of the Periadriatic Region, AAPG Bull., 78, 333–354, 1994.