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Albian high-resolution biostratigraphy and isotope stratigraphy: The Coppa della Nuvola pelagic succession of the Gargano Promontory (Southern Italy)

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Key words: Biostratigraphy, isotope stratigraphy, planktonic foraminifera, calcareous nannofossils, Albian, Marne a Fucoidi, Scaglia, Gargano Promontory

ABSTRACT

High-resolution $\delta^{13}C$ and $\delta^{18}O$ curves, calibrated against planktonic foraminiferal and calcareous nannofossil biostratigraphy, are provided for the upper Aptian–lower Cenomanian pelagic succession of the Gargano Promontory (Coppa della Nuvola section, southern Italy). The succession consists of two superimposed formations: the Marne a Fucoidi and the Scaglia (lower portion only). According to our integrated biostratigraphy, the entire succession spans the latest Aptian (planktonic foraminiferal *T. bejaouaensis* and calcareous nannofossil *R. angustus* Zones) and early Cenomanian stages (*R. cushmani* Zone CC9c). The Marne a Fucoidi–Scaglia transition falls in the late Albian (*R. ticinensis* Zone; CC9a+b Subzones).

The high-resolution $\delta^{13}C$ curve from the Coppa della Nuvola section can be subdivided into characteristic segments. Four negative shifts of $\delta^{13}C$ are recorded, followed by increasing values in, respectively, the early Albian (C11, C12), the early late Abian (C14, C 15), the late Albian (C16, C17), and the early Cenomanian (C22). The late Albian carbon-isotope event, corresponding to the Oceanic Anoxic Event (OAE) 1d or Breistroffer Event, is possibly missing in the Coppa della Nuvola section as a result of condensation or erosion (C19–C20?). Even if, in the section studied, carbon-rich levels are not recorded (though some stratigraphic intervals are covered by Quaternary deposits in the lower portion), it is likely that the lower Albian (*T. primula*; *P. columnata* Zones) and the upper Albian (*T. praeticinensis* Subzone–*R. subticinensis* Zone; *R. achlyostaurion* Zone) positive $\delta^{13}C$ peaks succeeding negative trends in $\delta^{13}C$ (C11–C12; C16–17) record the pattern of global carbon burial, documented in other areas of the Gargano Promontory and elsewhere and connected to the OAE1b and OAE1c. Some or all of the negative $\delta^{13}C$ shifts may record the introduction of isotopically light carbon into the ocean–atmosphere system from the dissociation of gas hydrates.

The $\delta^{18}O$ curve of the Coppa della Nuvola section shows a similar trend to that of the $\delta^{13}C$ curve. Although partly of diagenetic origin, the negative shifts in the early Albian, late Albian and early Cenomanian may be interpreted as records of warming events resulting from the introduction of methane and its oxidation product carbon dioxide into the atmosphere.

The palaeoceanographic conditions inferred by the biotic and isotopic changes suggest fluctuating meso-eutrophic conditions through the late-Aptian–early-middle Albian and increasingly stable oligotrophic situation starting from the late Albian interval. Two main possible episodes of increased eutrophy, suggested by pulses in radiolarian abundance and marked drop in foraminiferal diversity, occurred during the Albian and correlate with the above-mentioned positive carbon-isotope shifts and regional and supraregional accumulation of organic matter (OAE1b and OAE1c).

RIASSUNTO

In questo lavoro sono presentate le curve ad alta risoluzione degli isotopi stabili del carbonio e dell'ossigeno ($\delta^{13}C$, $\delta^{18}O$), calibrate con la biostratigrafia a foraminiferi planctonici e nannofossili calcarei per l'intervallo cronostratigrafico Aptiano superiore–Cenomaniano inferiore della successione pelagica di Coppa della Nuvola (Promontorio del Gargano, Italia meridionale). Dal punto di vista litostratigrafico, la successione è costituita nella porzione inferiore dalle Marne a Fucoidi e nella porzione superiore dalla Scaglia. Lo studio biostratigrafico integrato della sezione ha permesso di riferire l'intera successione all'intervallo compreso tra l'Aptiano superiore [Zona a *Ticinella bejauoaensis* (foraminferi planctonici) e Zona a *Rhagodiscus angustus* (nannofossili calcarei)] ed il Cenomaniano inferiore (Sottozona a nannofossili CC9c e Zona a foraminiferi *Rotalipora cushmani*). Il limite tra le Marne a Fucoidi e la Scaglia cade nell'Albiano superiore [Zona a *Rotalipora ticinensis* (foraminiferi planctonici); Sottozone CC9a+b (nannofossili calcarei)]. A differenza di altre successioni pelagiche del Gargano, nella sezione di Coppa della Nuvola non sono stati osservati livelli di *black shale*, anche se non è possibile escludere che questi coincidano con i tratti coperti nella parte inferiore della sezione.

La curva ad alta risoluzione del $\delta^{13}C$ può essere suddivisa in diversi segmenti caratteristici. In particolare, quattro picchi negativi, ognuno dei quali seguito da un aumento del valore, sono osservabili rispettivamente nell'Albiano inferiore (C11, C12), alla base dell'Albiano superiore (C14, C15), al termine dell'Albiano superiore (C16, C17) e nel Cenomaniano inferiore (C22). Tali picchi negativi sono separati da tre intervalli nei quali i valori del $\delta^{13}C$ si mantengono pressochè costanti. Sembra mancare, probabilmente per fenomeni d'erosione o condensazione, l'evento isotopico dell'Albiano superiore (C19-C20?) corrispondente all'evento anossico OAE1d (Evento Breistroffer). Nonostante nella sezione Coppa della Nuvola non siano stati rinvenuti livelli ricchi in carbonio organico, è comunque probabile che i picchi positivi del $\delta^{13}C$ documentati nell'Albiano inferiore (C12, Zone a *Ticinella primula* e a *Prediscosphaera columnata*) e nell'Albiano superiore (C16, Sottozona a *Ticinella praeticinensis* della Zona a *Rotalipora subticinensis* e Zona a *Rhagodiscus achlyostaurion*) corrispondano agli episodi globali di seppellimento di carbonio organico già segnalati per altre aree del Gargano e connessi con gli eventi anossici OAE1b e OAE1c. I picchi negativi nella curva del $\delta^{13}C$ possono rappresentare la documentazione dell'introduzione di grandi quantità di carbonio isotopicamente leggero nel sistema oceano-atmosfera in seguito a dissociazione di gas idrati.

La curva del $\delta^{18}O$ della sezione analizzata mostra un andamento simile alla curva del carbonio. Benchè parzialmente di origine diagenetica, i picchi negativi osservati nell'Albiano inferiore, Albiano superiore e Cenomaniano inferiore possono essere interpretati come la registrazione di eventi di riscaldamento risultanti dall'introduzione di anidride carbonica come prodotto di ossidazione di metano.

Le condizioni paleoceanografiche, deducibili dai segnali biotici e isotopici, sono caratterizzate da fluttuazioni tra mesotrofia ed eutrofia durante l'intervallo compreso tra l'Aptiano superiore e l'Albiano inferiore e medio. A partire dall'Albiano superiore vengono ad instaurarsi condizioni più stabili tendenti all'oligotrofia. Due principali episodi di aumento dell'eutrofia, documentati durante l'Albiano, sono suggeriti da picchi d'abbondanza dei radiolari accompagnati da una marcata diminuzione della diversità dei foraminiferi. Tali episodi si correlano con i sopracitati picchi positivi degli isotopi del carbonio e accumulo regionale e sopraregionale di sostanza organica (OAE1b e OAE1c).

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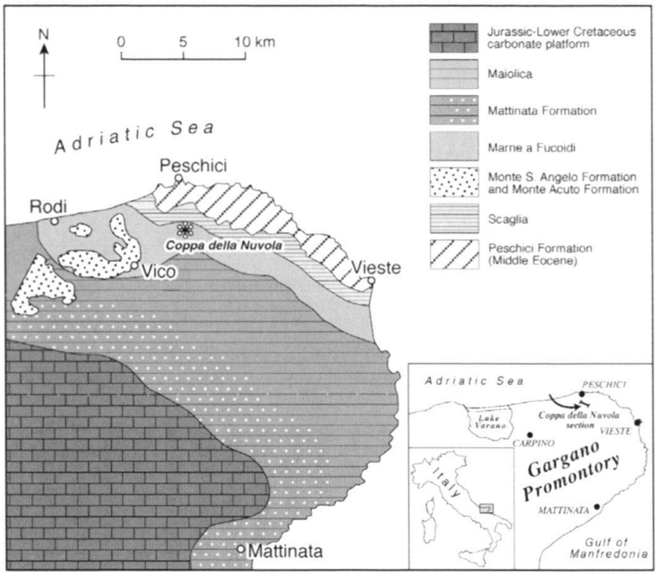


Fig. 1. Simplified geological and geographical map of the Gargano Promontory, showing the location of the section studied near the village of Peschici.

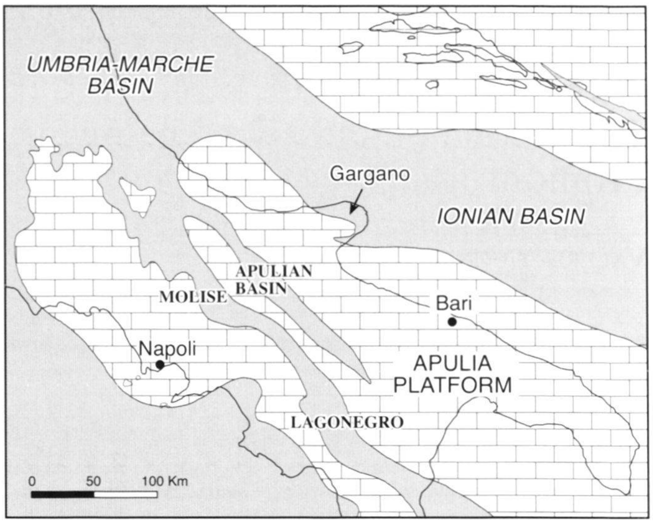


Fig. 2. Palaeogeography in southern Italy during the Jurassic–Cretaceous (after Zappaterra, 1990, modified)

1. Introduction

The aim of this study is to describe biotic changes and accompanying carbon- and oxygen-isotope signals during the late Aptian–early Cenomanian, a time interval characterized by global palaeobiological and palaeoceanographic events. During this interval, a world-wide pulse or series of pulses in oceanic crustal production, together with formation of large igneous provinces, is credited with causing increased outgassing of carbon dioxide to produce a 'greenhouse climate' (Larson 1991; Tarduno et al. 1991; Jones & Jenkyns 2001). Warm temperatures and regional increases in primary productivity produced dysoxic and anoxic conditions on the sea floor and promoted several distinct episodes of organic-carbon accumulation (Oceanic Anoxic Events, OAEs: Schlanger & Jenkyns 1976; Jenkyns 1980; Arthur et al. 1990). The major oceanographic changes of this period also influenced microfossil evolution (e. g. Erbacher & Thurow 1997; Bischoff & Mutterlose 1998; Mutterlose 1998; Leckie et al. 2002).

To investigate the palaeoceanographic changes of the mid-Cretaceous, several hemipelagic and pelagic sections have been recently analysed using a combined biostratigraphical, sedimentological and geochemical approach. However, most of the studies to date have focused on the Aptian stage, which records the well-known Selli Event (OAE1a), whereas the Albian has attracted less attention. The pelagic succession cropping out in the northeastern part of the Gargano Promontory, southern Italy offers an almost continuous sedimentary record from the Hauterivian to the Coniacian stage, and this paper describes the upper Aptian–lower Cenomanian section at Coppa della Nuvola (Fig. 1).

The main goals of this study are: to provide high-resolution $\delta^{13}C$ and $\delta^{18}O$ curves, calibrated against planktonic foraminiferal and calcareous nannofossil data, in order to investigate respectively: 1) carbon cycling; 2) palaeotemperature evolution and (3) palaeoceanographic and biological changes through correlation between geochemical and micropalaeontological data.

2. Geological and stratigraphical setting

The Gargano Promontory is a peninsula almost entirely constituted by carbonate rocks belonging to the Apulian Platform in the southwest and the Ionian Basin in the northeast (Fig. 2). Modern research on the stratigraphy of the Gargano Promontory began in the mid-1960s by AGIP geologists and the Italian Geological Survey (Pavan & Pirini 1966; Martinis & Pavan 1967; Cremonini et al. 1971). These workers proposed a general stratigraphic framework, recognizing that the western half of the promontory was part of the shallow-water Apulia Platform while the eastern half was constituted by slope and basinal sediments. A series of biostratigraphic studies focused more recently on the slope and basinal deposits of the eastern Gargano Promontory (Luperto Sinni & Masse 1987; Coccioni & Luperto Sinni 1989; Luciani 1993; Luciani & Cobianchi 1994; Luperto Sinni & Borgomano 1994; Neri & Luciani 1994; Cobianchi et al. 1997; Cobianchi et al. 1999; Luciani et al. 2001). The current lithostratigraphic terminology of the Cretaceous basin-and-slope units varies according to different authors who have undertaken modern stratigraphical researches on the Gargano Promontory. The stratigraphical framework here adopted follows Bosellini et al. (1993), Cobianchi et al. (1997) and Bosellini et al. (1999).

The classical basinal Cretaceous succession recognized in the Umbria–Marche Basin, central Italy, can be extended farther south to the Gargano Promontory, near the margin of the Apulia carbonate platform, though some lithological differences exist (Cobianchi et al. 1997; Cobianchi et al. 1999; Luciani et al. 2001). The Cretaceous pelagic succession across these areas consists of three superimposed stratigraphic units: Maiolica (Valanginian–early Aptian), Marne a Fucoidi (early Aptian–late Albian), and Scaglia (late Albian–Coniacian). Near the margin of the platform, the Mattinata Formation, rich in gravity-displaced deposits, laterally replaces the Maiolica (Bernoulli 1972; Bosellini et al. 1993; Luciani & Cobianchi 1994; Cobianchi et al. 1997; Graziano 2000).

The Apulian Platform, during the Late Jurassic–Early Cretaceous interval, was a productive carbonate platform with the rim colonized by bioconstructors and the inner area characterized by typical peritidal environments. The external margin zone passed gradually eastwards to the slope and finally to the basin (Morsilli & Bosellini 1997; Morsilli 1998). During the early Aptian, the Apulia Platform and the adjacent slope became abruptly inactive as a consequence of a drowning event (Bosellini et al. 1999; Cobianchi et al. 1997). During the latest Albian–Cenomanian interval, huge megabreccia bodies were deposited along the slope and base-of-slope belt coeval with the general emergence and karst development of the southern Apennine carbonate platforms.

Shallow-water deposits of late Aptian–Albian age are rare and crop out only locally (Bosellini et al. 1993; Bosellini et al. 2000). An inner-platform succession of Albian–Cenomanian age crops out in the southern Gargano and consits of mudstone–wackestone with peloidal packstone–grainstone intercalations containing orbitolinids of late Albian age (Merla et al. 1969; Luperto Sinni 1996). The late Aptian–Albian margin of the Apulia Platform is represented by bioconstructed limestones. Of this platform, only the upper Aptian portion is preserved (rudists, *Ellipsactiniae* and stromatoporoids), whereas the Albian part is documented only in platform-derived breccias (rudists, corals, spongae and *Nerinea*) occurring in the slope and base-of-slope deposits (Luciani & Cobianchi 1994; Bosellini et al. 2000).

3. The Coppa della Nuvola section

3a. Location and lithology

The Coppa della Nuvola section, 106 m thick, is located southwest of the town of Peschici (Figs. 1, 3). In the lower part (from the base to 78 m) the succession consists of white fine-grained marly limestones, locally silicified (5–15 cm) interbedded with bioturbated grey marlstones (5–50 cm). The chert colour varies from whitish to brown or black. This unit can be attributed to the Marne a Fucoidi. Burrows, mainly represented by *Chondrites* and *Planolites,* also occur commonly in the marls and locally at the top of calcareous strata. The typical marl–limestone couplets of the Marne a Fucoidi formation are probably controlled by orbital (Milankovitch) parameters that influenced palaeoclimate and palaeoceanography (e. g., Premoli Silva et al. 1989a, b; Coccioni & Galeotti, 1991).

The upper portion of the section, referable to the Scaglia, is characterized by white, thinly bedded (10 cm) chalky lime mudstones with reddish chert, mainly in the form of nodules. The occurrence and thickness of marls decrease transitionally from the Marne a Fucoidi to the Scaglia, whereas the colour of the cherty nodules and layers changes sharply from the black-grey to reddish. Thin (10–15 cm) resedimented deposits, containing microbenthonic foraminifera, rare orbitolinid fragments, echinoids and bivalve fragments, occur locally in the Scaglia. Unlike other pelagic successions of the Gargano Promontory, no black shales have been observed in the Coppa della Nuvola section.

3b. Samples and data collection

A total of 161 samples was taken at 50-cm intervals or less from the Coppa della Nuvola section. Samples were collected in order to carry out a detailed analysis of the calcareous nannofossil and foraminiferal content and to determine bulk carbon- and oxygen-isotope ratios. The same set of samples was used for micropalaeontological and geochemical studies in order to compare the results directly.

Standard laboratory methods for foraminiferal analysis were carried out: they consist of disaggregation of marly samples in Desogen and subsequent washing through a sieve of 38-micron screen in order to avoid the loss of very small specimens. The unevenly distributed planktonic foraminiferal assemblages and the different preservation throughout the section do not allow a quantitative analysis. 105 samples were taken from limestones and cherty limestones and analyzed in thin-section; the remaining 56 samples were analysed in washed residues.

Thin-sections were obtained also from the marlstones in order to evaluate throughout the section the radiolarian percentage abundances of the total sediment, according to the diagrams for the visual percentage estimation in sedimentary rocks given by Baccelle & Bosellini (1965).

For the calcareous-nannofossil analysis, smear-slides from samples of all the rock-types (marly limestone, marl, calcareous shale) were prepared and were analysed under a polarizing light microscope at a magnification of x1250. For each smear slide, 300 fields of view were observed in random traverses. Calcareous nannofossil totals and species were semi–quantitatively estimated.

Bulk samples for isotopic analysis were first powdered, cleaned with 10% H_2O_2 followed by acetone, and then dried at 60°C. Powders were then reacted with purified orthophosphoric acid at 90°C and analysed on-line using a VG Isocarb device and Prism Mass Spectometer at Oxford University. Normal corrections were applied and the results are reported, using the usual δ notation, in per mil deviation from the PDB standard. Calibration to PDB was performed via our laboratory Carrara marble standard. Reproducibility of replicate analyses of standards was generally better than 0.1‰ for both carbon- and oxygen-isotope ratios.

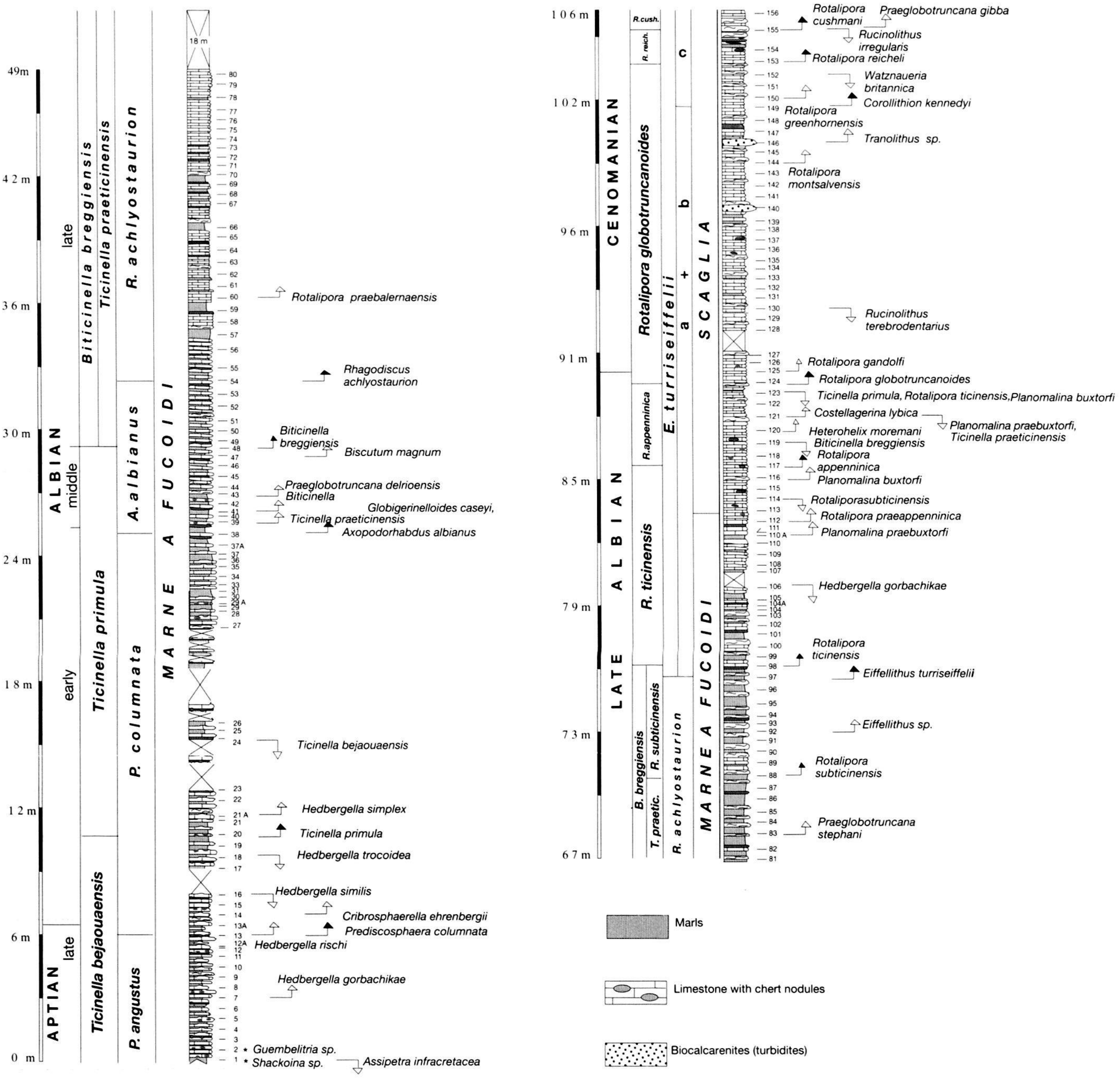


Fig. 3. Stratigraphical column of the Coppa della Nuvola section (Peschici) with the main (solid arrow) and secondary (empty arrow) planktonic foraminiferal (on the left) and calcareous nannofossil (on the right) first- and last-occurrence events. In the lower part (from the base to 82 m) the succession consists of white marly limestones and silicified limestone (5–15 cm) interbedded with bioturbated grey marlstones (5–50 cm). The chert colour varies from whitish to brown or black. This unit can be attributed to the Marne a Fucoidi. The upper portion of the section, referable to the Scaglia Formation, is characterized by white, chalky, thinly bedded lime mudstones (10 cm), with reddish chert, mainly in nodules. The frequency and thickness of marls decrease transitionally from the Marne a Fucoidi to the Scaglia, whereas the colour of the cherty nodules and layers changes sharply from the black-grey (Marne a Fucoidi) to reddish (Scaglia). Thin (10–15 cm) resedimented deposits occur locally in the Scaglia.

4. Biostratigraphy of the section

In the following sections the main microfossil events are summarized.

4a. Planktonic foraminifers

Preservation and abundance of planktonic foraminiferal assemblages from the 161 samples analysed are highly variable, both in washed residue and in thin section, with two main intervals of poor preservation (from 16 to 26 m and from 66 to 70 m from the base). In spite of this, several planktonic foraminiferal events were recognised in the Coppa della Nuvola section. In particular the main events (Fig. 3) from the base are: the first occurrences of *T. primula* (sample 20, 11 m), *Biticinella breggiensis* (sample 48, 29.2 m), *Rotalipora subticinensis* (sample 88, 71 m), *Rotalipora ticinensis* (sample 98, 76m), *Rotalipora appenninica* (sample 117, 85.70m), *Rotalipora globotruncanoides* (sample 124, 89.5m), *Rotalipora reicheli* (sample 153, 104.6m), *Rotalipora cushmani* (sample 155, 105.5m). Low-latitude planktonic foraminiferal zonation for the mid-Cretaceous is well established and reliable and the different zonal schemes proposed are rather similar (e. g. Caron 1985; Sliter 1989a, 1992; Premoli Silva & Sliter 1994; Robaszynski & Caron 1995). On the basis of the events observed in the studied section, the following biozones were identified: *Ticinella bejaouaensis* Zone, *Ticinella primula* Zone, *Biticinella breggiensis* Zone, (*Ticinella praeticinensis* Subzone, *Rotalipora subticinensis* Subzone), *Rotalipora ticinensis* Zone, *Rotalipora appenninica* Zone, *Rotalipora globotruncanoides* Zone, *Rotalipora reicheli* Zone, *Rotalipora cushmani* Zone. Beside the main events, the high-resolution analysis has enabled us to identify several secondary biostratigraphic datum levels, which are shown in Fig. 3.

4b. Calcareous nannofossils

For this study 156 samples were analysed for their constituent calcareous nannofossils. Nannofloral abundance ranges from "few" to "abundant" with minor modification due to the effects of dissolution and calcite overgrowth. In the studied section several nannofossil events were recognized, some of which have been used to define zonal or subzonal boundaries by previous authors (Thierstein 1971, 1973, 1976; Manivit et al. 1977; Sissingh 1977; Perch-Nielsen 1985; Bralower 1987; Erba 1988; Ghisletti & Erba in Premoli Silva & Sliter 1994; Bralower et al. 1995; Erba 1996; Bown et al. 1998; Erba et al. 1999; Premoli Silva et al. 1999; Bralower et al. 1999). These events are plotted in figure 3 and listed below, along with some additional events (from bottom to top): the LO (last occurrence) of *Assipetra infracretacea* at the bottom of the measured section; the FO (first occurrence) of *Prediscosphaera columnata* at 6 m from the bottom of the section; the FO of *Cribrosphaerella ehrenbergii* at 7 m; the FO of *Axopodorhabdus albianus* at 25 m; the FO of *Biscutum magnum* at 28.5 m; the FO of *Rhagodiscus achlyostaurion* at 32m; the FO of the genus *Eiffellithus* at 73 m; the FO of *Eiffellithus turriseiffelii* at 75.5 m; the LO of *Rucinolithus terebrodentarius* at 93.25 m; the LO of *Watznaueria britannica* at 103 m; the LO of *Rucinolithus irregularis* at 105.2 m.

Based on these events, five biozones have been identified, from older to younger: the *Rhagodiscus angustus* Zone (Thierstein 1973; 0–6 m); the *Prediscosphaera columnata* Zone (Hill 1976; 6–25 m); the *Axopodorhabdus albianus* Zone (Hill, 1976, emended by Erba 1988; 25–32 m); the *Rhagodiscus achlyostaurion* Zone (Erba 1988; 32–75.5 m) and the *Eiffellithus turriseiffelii* Zone (Thierstein 1971, emended by Sissingh 1977; 73 m–top of the section).

The nannofossil assemblages are diversified and moderately well preserved. Species abundant in this interval include: *Watznaueria barnesae, Cretarhabdus surirellus, Lithraphidites carniolensis, Manivitella pemmatoidea, Microstaurus chiastius, Rhagodiscus asper, Rhagodiscus splendens, Rucinolithus irregularis, Vagalapilla stradneri, Zeughrabdothus embergeri.* Nannoconids are very rare, discontinuously recorded and mainly represented by *Nannoconus truittii* and *N. elongatus.*

4c. Integrated biostratigraphy and chronostratigraphy

Figure 4 shows the main biostratigraphic events recorded in this study and correlates the calcareous nannofossil and planktonic foraminiferal biozones with mid-Cretaceous stages. The integrated biostratigraphic scheme proposed here largely confirms the standard Tethyan integrated biostratigraphy (see Hardenbol et al. 1998); the main differences with previous schemes are discussed below.

1 – The foraminiferal *Hedbergella planispira* Zone, generally placed between the *Ticinella bejaouaensis* and *Ticinella primula* Zones (e. g. Sliter 1989a; Robaszynski & Caron 1995), was not identified in the Coppa della Nuvola section, a circumstance already recorded for other sections of the Gargano Promontory (Cobianchi et al. 1997). Therefore, the foraminiferal *Ticinella bejaouaensis* Zone correlates with both the nannofossil *Rhagodiscus angustus* Zone and the lower portion of the *Prediscosphaera columnata* Zone.

According to the definition of Caron (1985), the *Hedbergella planispira* Zone zone represents the interval from the appearance of the zonal marker to the first occurrence of *Ticinella primula*. In many localities the upper boundary corresponds, however, to an interval characterized by a low-diversity assemblage dominated by *Hedbergella planispira* including several levels that are completely barren. Such assemblages are characteristically found in black shales (e. g. Bréhéret et al. 1986; Premoli Silva et al. 1989 a, b; Sliter 1989a, b). The absence of larger taxa (ticinellids) has been interpreted as a response to an expanded oxygen-minimum zone that destroyed the habitats of the relatively larger, less tolerant forms. The barren levels can also be the result of intense dissolution at the sediment-water interface. The depauperate interval was attributed to the *Hedbergella planispira* Zone; both the upper and lower boundaries of the *Hedbergella planispira* Zone are

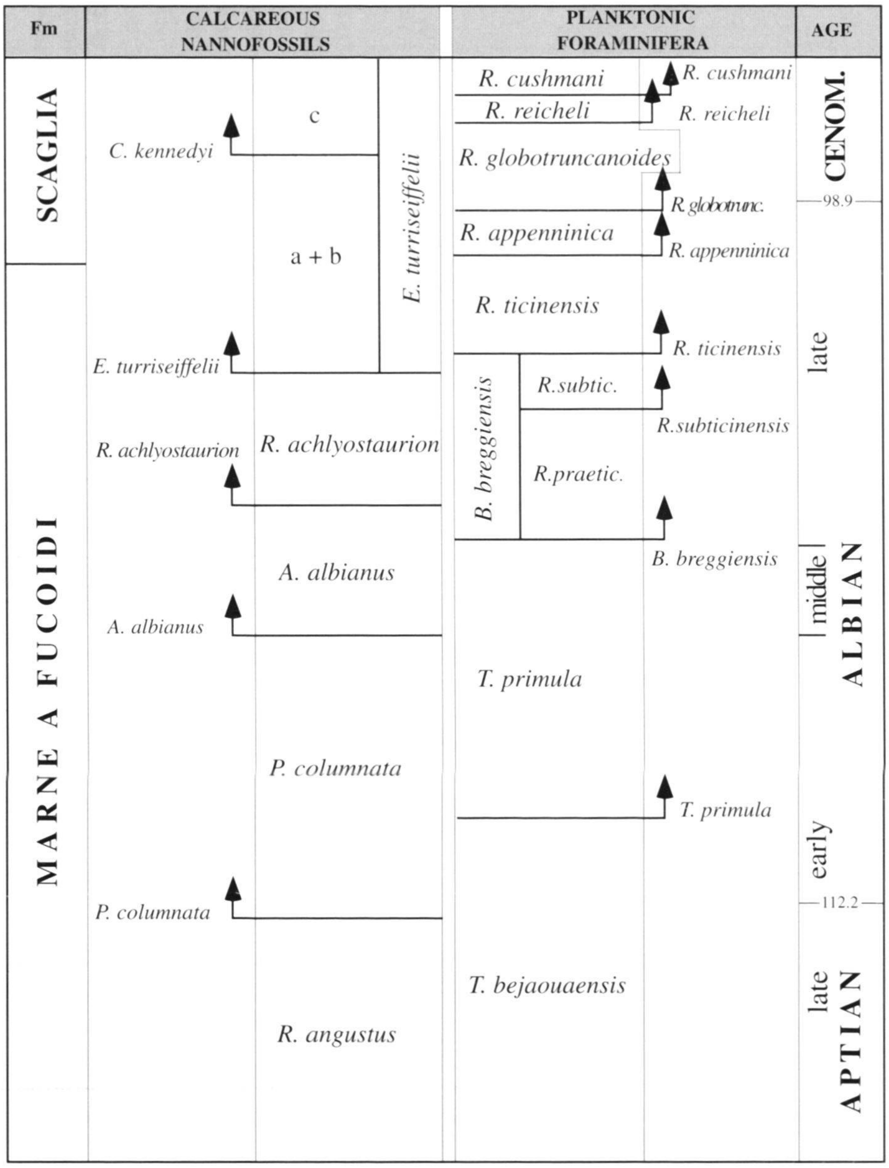


Fig. 4. Planktonic foraminiferal and calcareous nannofossil integrated biostratigraphy from the Coppa della Nuvola section (Peschici) with the events characterizing the zonal boundaries and correlation with formations and ages. The integrated biostratigraphical scheme mainly confirms the standard Tethyan integrated biostratigraphy, except for the absence of the *Hedbergella planispira* Zone. This zone, generally placed between the *T. bejaouaensis* and *T. primula* Zones, was not found in the Coppa della Nuvola section, as is also the case for the Ischitella section, cropping out south of Rodi Garganico (Cobianchi et al. 1997).

hence uncertain, as is the age and duration of the zone. It appears probable that the lack of black shale (implying probable absence of hostile conditions) in this interval of the Gargano succession, may explain the absence of the *Hedbergella planispira* zone, even though condensation or erosion cannot be excluded.

2 – In the scheme of Hardenbol et al. (1998), the FO of *Lithraphidites acutum*, which defines the boundary between the nannofossil CC9 and CC10 Zones (Manivit et al. 1977; Sissingh 1977), is placed in the foraminiferal *Rotalipora reicheli* Zone. In the Coppa della Nuvola section the FO of *L. acutum* was not detected, so the CC9c Subzone is taken to correlate with the upper part of the *Rotalipora globotruncanoides* Zone, the *R. reicheli* Zone and the lower portion of the *R. cushmani* Zone. However, the species *L. acutum* is rare and discontinuously distributed in other Tethyan sections (Ghisletti & Erba in Premoli Silva & Sliter 1994; Luciani & Cobianchi 1999). Moreover, partial dolomitization occurring in the uppermost portion of the studied section has probably influenced the nannofossil preservation.

Owing to the absence of ammonites in the Coppa della Nuvola section, the correlation between biostratigraphy and chronostratigraphy of the mid-Cretaceous is indirect and based on schemes proposed by various authors (e.g. Erba 1988; Ghisletti & Erba in Premoli Silva & Sliter 1994; Bralower et al. 1995; Robaszynski & Caron 1995; Bellanca et al. 1996; Gale et al. 1996; Erba et al. 1999; Kennedy et al. 2000). The Marne a Fucoidi/Scaglia transition lies within the nannofossil *Eiffel-*

lithus turriseiffeli Zone and within the upper part of the foraminiferal *Rotalipora ticinensis* Zone of late Albian age, as also reported for the Bottaccione section from the Umbria–Marche Basin (Premoli Silva & Sliter 1994). Therefore, the Marne or Scisti a Fucoidi (lower 78 m) of the Coppa della Nuvola section correspond to the late Aptian–late Albian, whereas the Scaglia (upper 26.25 m) is late Albian–early Cenomanian in age.

The Boundary Point for the Aptian–Albian, in agreement with the first criterion proposed at Brussels (1995), has been placed by Kennedy et al. (2000) at the first appearance of the ammonite *Leymeriella tardefurcata* at the base of the Niveau Paquier within the expanded Marnes Bleues sequence of the Vocontian Trough (Tartonne section, southeast France). So defined, the boundary falls within the nannofossil *Prediscosphaera columnata* Zone and the planktonic foraminiferal *Hedbergella planispira* Partial Range Zone. As pointed out above, in the Coppa della Nuvola section the *Hedbergella planispira* Zone was not identified; consequentely the Aptian–Albian boundary can be placed between the FO of *P. columnata* and the FO of *Cribrosphaerella ehrenbergii* (according to Bréhéret et al. 1986 and Erba 1988, 1992). The early–middle Albian boundary is identified by the FO of *A. albianus*, and the middle–late Albian boundary coincides with the FO of *B. breggiensis* (Van Hinte 1976; Sigal 1977).

In the Second International Symposium on Cretaceous stage boundaries in Brussels (1995), the base of the Cenomanian stage was proposed to coincide with the first occurrence of the planktonic foraminifera *Rotalipora globotruncanoides* in the Mont Risou section, Vocontian Trough (southeast France). The event previously considered coincident with this boundary is the appearance of the ammonite *Mantelliceras mantelli*. This event postdates slightly the FO of *R. globotruncanoides* (Hardenbol et al. 1998). Other events very close to the Albian–Cenomanian boundary are the first occurrences of the nannofossil *Calculites anfractus* and of the planktonic foraminifera *Rotalipora gandolfi* and the last occurrence of *Rotalipora ticinensis* (Gale et al. 1996). Because the new proposal is not yet definitively accepted, the Albian–Cenomanian boundary in the Coppa della Nuvola section is placed slightly above the first occurrence of *Rotalipora globotruncanoides*.

Accumulation rates for the Coppa della Nuvola section can be indirectly estimated based on the stratigraphic position of the bio-events which approximate the stage boundaries. Using the values derived from Hardenbol et al. (1998), the mean rate of sediment accumulation for the Albian interval of the succession was 6.4 m/My. This accumulation rate is faster than the value estimated for the equivalent interval in the Umbrian succession (Premoli Silva & Sliter, 1994), and probably reflects local input of lime mud from the Apulian carbonate platform.

By comparison with the Umbria–Marche Basin, the sedimentation rate in the Gargano succession appears notably slower only in the *R. appenninica* Zone. This feature could indicate a condensation or a hiatus in the Coppa della Nuvola section during the late Albian.

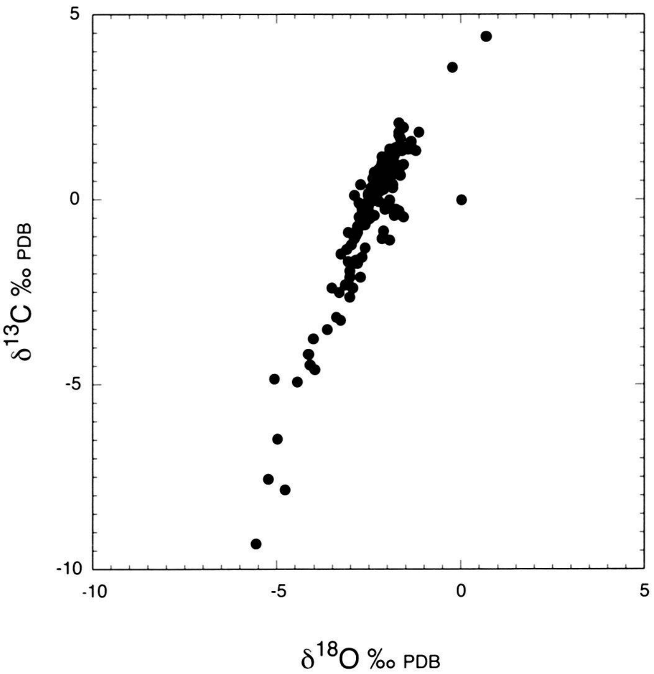


Fig. 5. Cross-plot of $\delta^{13}C$ and $\delta^{18}O$ values of bulk pelagic carbonates from the Coppa della Nuvola section. Note the wide spread of values and the apparent 'mixing line' produced by variable addition of a diagenetic cement to a primary marine carbonate. Such relationships may also have a primary origin, being produced by injection of dissociated gas hydrates ($\delta^{13}C \approx -60‰$) into the ocean–atmosphere system and consequent rapid global warming causing a fall in $\delta^{18}O$ values in skeletal and inorganic carbonate, followed by subsequent decay to equibrium values of both isotopic parameters.

5. Isotopic signature

5.a. Diagenesis versus palaeoceanography

The $\delta^{13}C$ and $\delta^{18}O$ data show a high degree of co-variance, very obviously displayed in the cross-plot (Fig. 5). Such relation-ships are usually attributed to the influence of diagenesis whereby a primary marine carbonate, with its characteristic isotopic signature, has been combined in variable proportions with cement of differing isotopic composition (e.g. Marshall 1992). However, as outlined below, this type of isotopic signature may also record primary palaeoceanographic phenomena.

Limestones displaying so-called isotopic 'mixing lines' may have lost a considerable amount of primary palaeoceanographic information. The material investigated here derives from a basin adjacent to a productive carbonate platform, which almost certainly was exporting fine-grained shallow-water aragonite and high-magnesian calcite (peri-platform ooze: Schlager & James, 1978), as well as the more obvious turbidites and breccias (Bernoulli 1972; Luciani & Cobianchi 1994; Bosellini et al., 1999). The basinal pelagic facies, typically off-white to grey marls and limestones, are notably different to

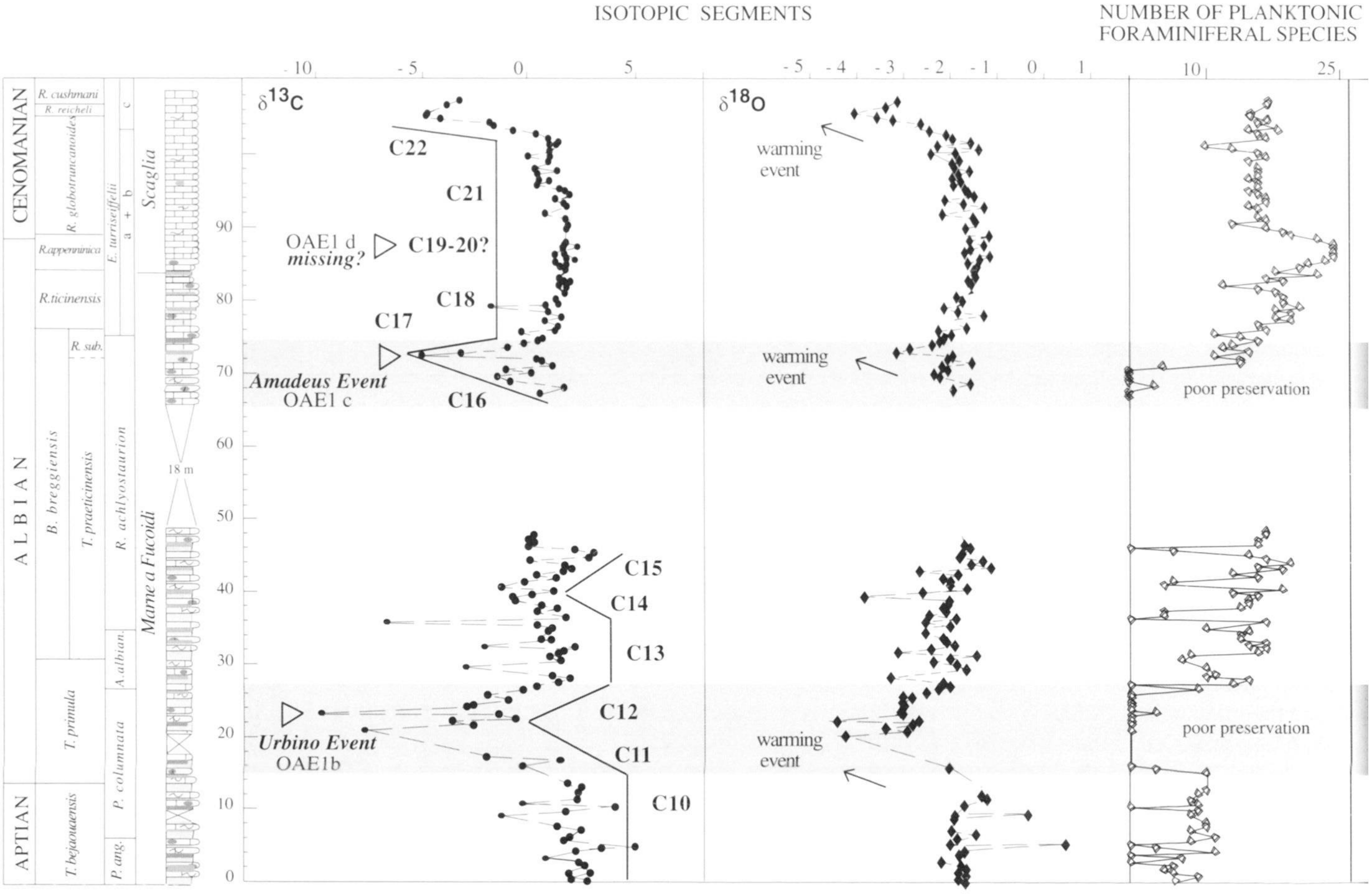
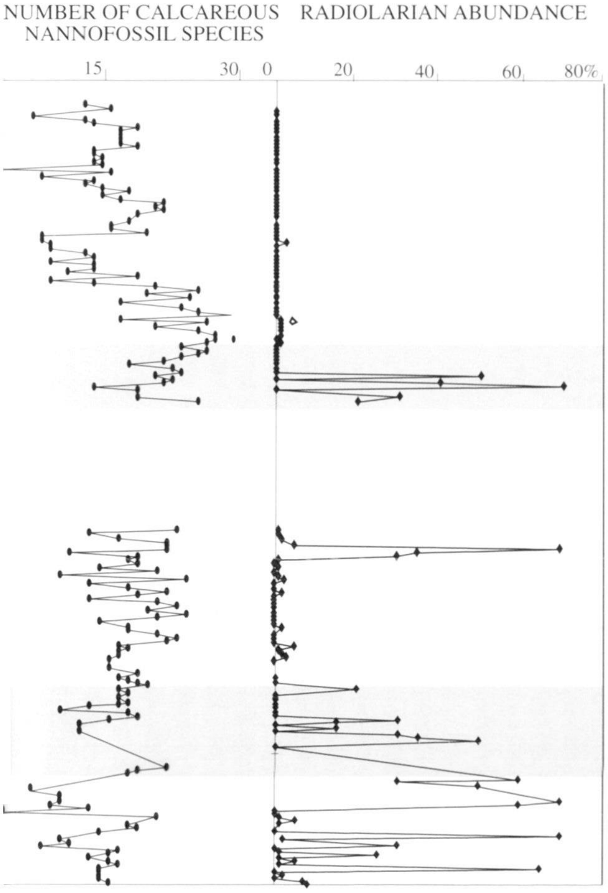


Fig. 6. Scheme showing the correlation between lithostratigraphy, biostratigraphy (foraminifera and calcareous nannofossils), stable carbon- and oxygen-isotope curves and planktonic foraminiferal and calcareous nannofossil species diversity and radiolarian abundance from the Coppa della Nuvola section. Note that the two isotopic curves display similar trends. We have produced a tentative correlation between the C10–C15 $\delta^{13}C$ isotopic segments identified by Bralower et al. (1999) from the Albian of the Santa Rosa Canyon section in Mexico and those from Peschici. The negative shift at the top of the section (C22; *R. reicheli–E. turriseiffellii* Zones) probably correlates with a similar but more poorly defined feature recorded in the Contessa section (Gubbio, Umbria–Marche Basin; Stoll & Schrag 2000). A reliable correlation exists between the Gargano Promontory, the Vocontian Basin (Southeastern France) and the Magazan Plateau (Northwest Africa, DSDP Site 545) (Herrle, 2002) in the record of a marked $\delta^{13}C$ negative trend, followed by a positive shift, in the early Albian *Prediscosphaera columnata* Zone. This chemostratigraphic event occurred just before or during during a time of widespread anoxia and regional deposition of black shales (OAE1b). Possible warming and cooling events are underlined in the oxygen-isotope curve. A possible correlation between Albian carbon-isotope fluctuations, regional deposition of organic matter (Amadeus Segment, Urbino Level) and OAEs is also indicated.

their counterparts in Marche-Umbria, which contain more clay and are vividly coloured in shades of red, green and black: such differences are compatible with the hypothesis that considerable import of off-platform calcareous fines characterized deposition in the basin. Such reactive material may well have produced early to late diagenetic cements, whose isotopic composition should nonetheless have broadly reflected global trends with respect to carbon-isotope signatures.

As far as absolute values of the carbon-isotope profile are concerned, $\delta^{13}C$ values are both more scattered and lower by some 1–2‰ than those recorded from many Tethyan sections, including those from Marche–Umbria (Scholle & Arthur 1980; Bralower et al. 1999; Jenkyns et al. 1994; Stoll & Schrag 2000; Strasser et al. 2001). Such relatively low values were also recorded for the Aptian interval of the Gargano Promontory (Luciani et al. 2001). In this case, the lower values were related to the possible input of fine-grained aragonitic and calcitic detritus of shallow-water origin derived from the Apulia Platform, where more restricted lagoonal environments were characterized by waters whose carbon–isotopic composition was influenced by oxidation of organic matter (cf. Patterson & Walter 1994). In fact, carbon-isotope values in low-latitude Cretaceous Tethyan platform carbonates are typically, but not invariably offset negatively by about -1‰ with respect to coeval pelagic facies, even though they follow global trends (Grötsch et al. 1998; Davey & Jenkyns 1999; cf. Ferreri et al. 1997). Additional support for the presence of a primary component in the isotopic signatures of the Coppa della Nuvola



succession comes from the fact that the negative carbon-isotope excursion, stratigraphically registered close to the first occurrence of *A. albianus* (OAE 1b), is also recorded from northeastern Mexico in material other than carbonate, namely marine organic matter (Bralower et al. 1999). Given that the negative carbon-isotope excursion is additionally recognized in bulk sediments from the eastern Atlantic (Mazagan Plateau) and southern France, in close stratigraphic proximity to the Paquier black shale, the $\delta^{13}C$ signal is clearly a regionally reproducible phenomenon (Herrle 2002; Jenkyns 2003).

Primary palaeotemperature signals must be encoded in the oxygen-isotope record but cementation and/or recrystallization close to or below the sea floor may have grossly compromised the primary signatures of the planktonic component. However, given that the $\delta^{18}O$ data from the Atlantic site show up to a -1‰ negative shift in concert with the abrupt change to lower carbon-isotope values, and thus conform roughly to the isotopic profiles from Coppa della Nuvola, the possible primary nature of some of the signal also needs to be explored. For example, introduction of isotopically light carbon into the ocean–atmosphere system, coincident with global temperature rise, would produce highly correlated negative $\delta^{13}C$ and $\delta^{18}O$ excursions that are totally unrelated to diagenesis.

5b. Isotopic curves

There are few high-resolution isotopic curves for the Albian and they generally describe only a portion of the stage. The detailed chemostratigraphical analysis of the Coppa della Nuvola section allowed us to reconstruct carbonate carbon- and oxygen-isotope curves for the Upper Aptian–Lower Cenomanian interval, and this represents one of the most detailed and complete isotopic carbonate records from low latitudes.

The $\delta^{13}C$ curve can be split into characteristic segments (Fig. 6) with partial reference to those documented by Bralower et al. (1999) from northeastern Mexico. The upper Aptian–lower Albian is characterized by relatively constant values of $\delta^{13}C$ (~ 1.8‰; segment C10). The $\delta^{13}C$ values then show an abrupt negative shift (C11) in the upper lower Albian (down to -3‰), followed by a return, in the middle Albian, to values of +1.8‰ (C12). Subsequently, the $\delta^{13}C$ values remain within the range of +0.5/+2‰ (C13), with a minor negative (-1‰; C14) and subsequent positive (+2‰; C15) excursion occurring in the lower upper Albian. A covered tract in the section, interrupting the isotopic record for part of the upper Albian interval, precedes a drop where values fall to -2.6‰ (C16). The following C17 segment represents a return to more positive values leading to a relatively constant tract (~ +0.8‰) spanning the uppermost Albian and the lower Cenomanian interval. Finally, the $\delta^{13}C$ curve defines a further negative spike recording the lowest values measured in this section (C21–22).

The Coppa della Nuvola $\delta^{13}C$ curve shows similar features to the $\delta^{13}C$ curve provided for Mexico (Scholle & Arthur 1980; Bralower et al. 1999), where equivalent C10–C15 segments have been recognized. Minor discrepancies in the biostratigraphical calibration can be explained by low biostratigraphical resolution for the Mexican sections due to poor general preservation of both calcareous nannofossil and planktonic-foraminiferal assemblages. Other analogies can be found with the $\delta^{13}C$ curves illustrated by Jenkyns et al. (1994) and Stoll & Schrag (2000) for sections through the Bottaccione and Contessa Gorges (Umbria–Marche Basin, Central Italy), where a negative shift (albeit more gradual with respect to the C22 Segment of the Coppa della Nuvola section) is recorded from the *Rotalipora globotruncanoides* Zone culminating in the *Rotalipora reicheli* Zone.

Pronounced positive shifts in Cretaceous carbon-isotope curves generally correlate with oceanic anoxic events (e. g. Jenkyns 1980, 1999; Scholle & Arthur 1980; Schlanger et al. 1987; Arthur et al. 1988; Menegatti et al. 1998; Larson & Erba 1999; Stoll & Schrag 2000), which record dramatic perturbations in the global carbon cycle, characterized by increases in marine productivity and burial rates of organic carbon. These processes are particularly evident in the case of OAE 1a (early Aptian Selli Event) and OAE 2 (Cenomanian–Turonian Bonarelli

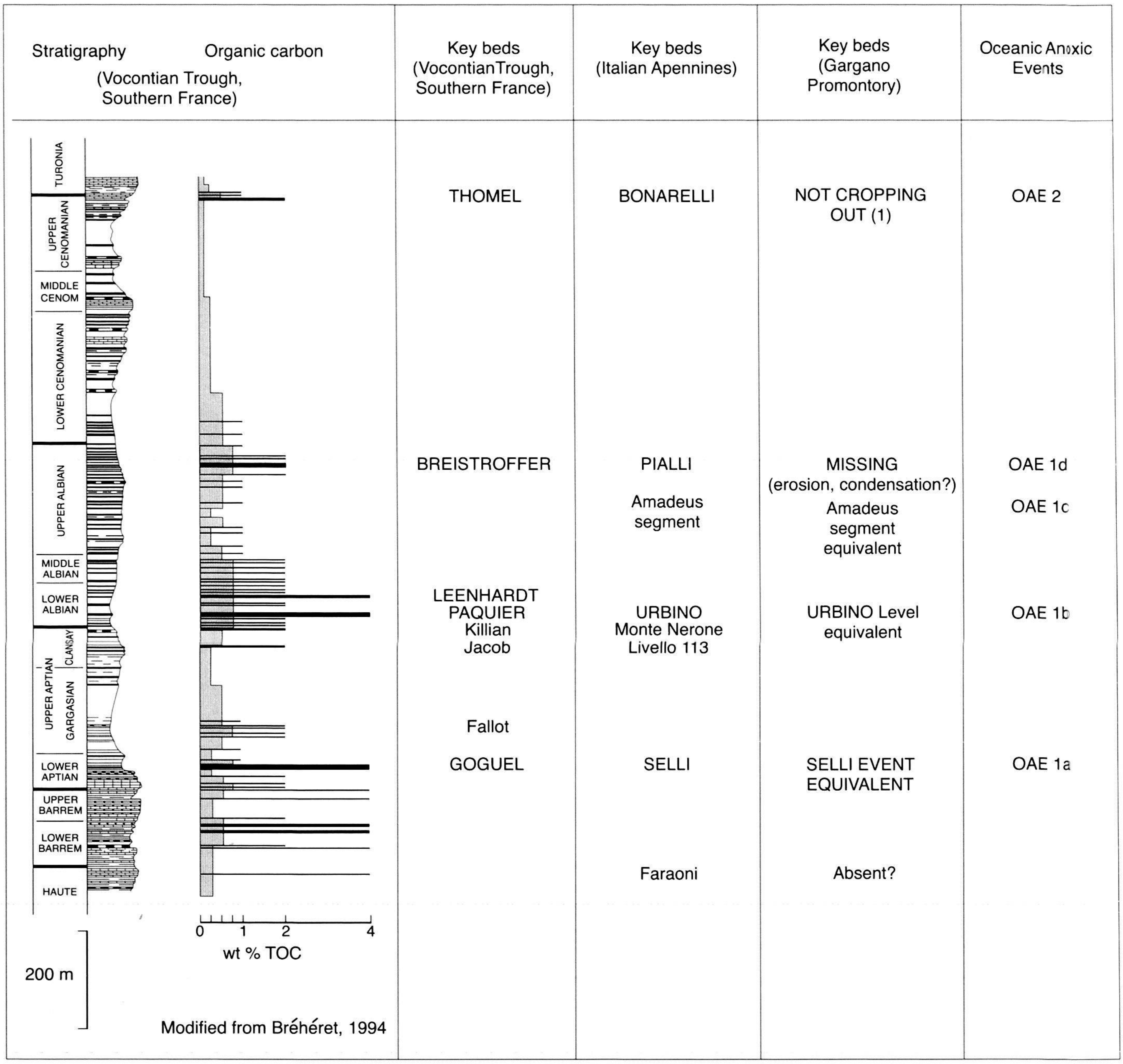


Fig. 7. Major organic-rich levels in the Vocontian Trough (southeastern France) and corresponding Oceanic Anoxic Events plotted against key beds from the Italian Apennines and Gargano Promontory. Note that the Bonarelli Level is recorded offshore from the Gargano Promontory (AGIP wells). Modified from Bréhéret (1994), with additional data from Arthur et al. (1990), Erbacher (1994), Coccioni (2001) and our observations.

Event). Complications arise in the case of the former, because of the presence of a pronounced negative carbon-isotope excursion registered immediately below the Selli Level and its equivalents (Jenkyns 1995; Menegatti et al. 1998; Jenkyns & Wilson 1999; Bralower et al. 1999; Erba et al. 1999; Erbacher et al. 1999; Luciani et al. 2001; Bellanca et al. 2002). Marked rapid negative excursions in carbon-isotope curves have been recently attributed to release of isotopically very negative ($\delta^{13}C \approx -60‰$) methane deriving from dissociation of gas hydrates within continental-margin sediments (e.g. Dickens et al. 1995; Hesselbo et al. 2000; Jahren et al. 2001; Padden et al. 2001). The release of methane gas hydrate is an abrupt event and, because the gas undergoes near-instantaneous oxidation to CO_2, it is efficiently dispersed into the ocean–atmoshere system. Rapid (10^3 yrs: Röhl et al. 2000) global warming ensues, registered by lowering of $\delta^{18}O$ values in biogenic carbonate (Jenkyns 2003).

In the Umbria–Marche Basin, as well as in the Swiss Prealps (Rotter Satel section), no major carbon-isotope shifts have been detected around the beds recording OAE1b (Stoll & Schrag 2000; Strasser et al. 2001). However, the regional negative carbon-isotope shift recorded elsewhere suggests a global phenomenon that could be attributed to release of gas hydrates (Jenkyns 2003). This record, at or just below the level of the black shale (Paquier Level and equivalents: Fig. 7), is known from carbonate materials in the Vocontian Trough (Southeast France) and the Mazagan Plateau, Atlantic Ocean (Herrle 2002), and from northeast Mexico in organic matter (Bralower et al. 1999). The $\delta^{13}C_{org}$ record of bulk organic matter and certain biomarkers of the black shale itself, however, show a substantial positive shift (~8–10‰), attributed to a fundamental change in the source of the organic matter over the interval in question (Kuypers et al. 2001). The exact nature of the negative $\delta^{13}C$ excursions associated with other Aptian–Albian anoxic events (OAE1c; Segment C16–17) as well as Segment C22 in the Cenomanian remains problematic, but dissociation of gas hydrates may also be involved in these instances.

The black shales recorded within the upper Albian *R. appenninica* Zone in several areas (Fig. 7), named as 'Breistroffer Level' and 'Pialli Level' (e. g. Northern Atlantic and western Tethys, Erbacher & Thurow 1997; Vocontian Basin, Erbacher et al. 1999; Swiss Prealps, Strasser et al. 2001; Umbria–Marche Basin, Coccioni 2001) and considered as the expression of the OAE1d, are not present in the Coppa della Nuvola section. The carbon–isotope curve does not display peaks across this interval; on the contrary there is a tract with relatively constant values (Fig. 6), as is also the case in the Roter Sattel section from the Swiss Prealps (Strasser et al. 2001). The $\delta^{13}C$ record is different in the tropical western Atlantic Ocean where a pronounced negative shift followed by a positive fluctuation marks the black-shale deposition characteristic of OAE1d (Wilson & Norris 2001). Similar isotopic signatures are also registered in the Vocontian Trough in southeastern France (Gale et al. 1996) and in the UK (Speeton, Yorkshire: Mitchell et al. 1996) but cannot be positively recognized in Marche–Umbria (cf. Stoll & Schrag 2000). The negative excursion in the early Cenomanian (Segment C22; Fig. 6) may be tentatively recognized in the $\delta^{13}C$ profile from Marche–Umbria but is not as clearly displayed in this area (Stoll & Schrag 2000).

The lack of exact correlation between the $\delta^{13}C$ curves illustrated here and those from elsewhere may relate to several factors: stratigraphical gaps in some of the sequences, diagenesis of carbonate in peri-platform ooze and/or organic-rich sediments, whether near-surface or bottom-water chemistry is recorded (planktonic vs benthonic foraminifera) and whether the signal derives from organic carbon or carbonate. With the exception of the negative excursion corresponding to OAE 1b, we are unable to ascertain to what extent the carbon-isotope record from the Coppa della Nuvola section records real changes in the isotopic composition of the dissolved inorganic-carbon reservoir and to what extent these other factors have come into play.

The Coppa della Nuvola $\delta^{18}O$ curve shows a remarkably similar trend to that of the $\delta^{13}C$ curve, although the negative excursions are less pronounced. Although clearly influenced by diagenesis, the negative shifts in the lower Albian, upper Albian and lower Cenomanian may be interpreted as a record of warming events. Wilson & Norris (2001) have recently documented, from the upper Albian *R. appenninica* Zone of the western tropical Atlantic Ocean, highly variable sea-water superficial temperatures but with minimum values 4–6°C higher than the warmest average warm season of today's tropical oceans. Moreover, the geochemical data from selected planktonic foraminifera suggest a steady thermocline temperature increase during the same stratigraphical interval. The corresponding tract in the Coppa della Nuvola $\delta^{18}O$ curve, however, records relatively constant values with a very weak positive excursion (Fig. 6). We conclude, given the diagenetic overprint, that secure palaeoceanographic information cannot be unambiguously deciphered from the $\delta^{18}O$ record of this sequence alone.

6. Calcareous plankton distribution and palaeoenvironmental changes

6a. Planktonic foraminifera

Reference to modern forms, together with stable-isotope data, enables the palaeoecological behaviour, evolution and diversification of Cretaceous planktonic foraminifera to be related to continuing stable oceanic conditions, allowing colonization of the deepest ecological niches by large, complex, keeled forms. By analogy with modern low-latitude oceans, the most diversified Cretaceous planktonic foraminiferal assemblages are expected within a stratified water-column and a deep thermocline (e. g. Hart 1980, 1999; Caron & Homewood 1983, Leckie 1987, 1989; Premoli Silva & Sliter 1999; Leckie et al. 2002). Significant changes in Cretaceous populations are interpreted as reflecting an ecological response to palaeoceanographic variations.

Although the palaeoecological behaviour of Cretaceous planktonic foraminifera is not completely understood, it is possible to place roughly the Albian–Cenomanian genera in a oligotrophic-specialized *versus* eutrophic-opportunist scale. The models generally applied (e.g. Hart 1999; Premoli Silva & Sliter 1999; Leckie et al. 2002), based on palaeoecological evidence and partly on isotopic data, link morphology and size to the depth-habitat. The larger and more complex species were specialized and the deepest-dwelling (e. g., rotaliporids), whereas the smaller and simpler forms (e. g., hedbergellids) inhabited surficial waters and were opportunists (Caron & Homewood 1983; Leckie 1987, 1989; Hart 1999; Premoli Silva & Sliter 1999). Actually, hedbergellids may have thrived in both the thermocline and in surface waters, according to the depth of highest primary productivity, as suggested by the wide range of temperature-related habitats (e. g., Douglas & Savin

1978; Corfield et al. 1990; Fassell & Bralower 1999; Norris & Wilson 1999; Wilson & Norris 2001; Price & Hart 2002; Leckie et al. 2002). The small-sized, planispiral *Globigerinelloides* mainly behaves similarly to the simplest opportunist group (hedbergellids) but appears to be slightly less tolerant to variable conditions. Globigerinelloidids are generally considered as having lived below the surface mixed layers but above keeled morphotypes (e.g., Premoli Silva and Sliter 1999; Hart 1999). As far as ticinellids and biticinellids are concerned, they displayed relatively more specialized palaeoecological behaviour, usually attributed to deeper-dwelling forms, with respect to the simpler small-sized hedbergellids (Leckie 1987, 1989; Hart 1999; Premoli Silva & Sliter 1999). Indeed, ticinellids and biticinellids temporarily disappeared during environmental crises related to deposition of black shales (e. g. Bréhéret et al. 1986, Premoli Silva et al. 1989 a, b; Sliter 1989b). On the other hand, some recently published isotopic data on Albian–Cenomanian planktonic foraminifera indicate that *Ticinella primula*, *Biticinella breggiensis* and even the keeled *Planomalina buxtorfi* grew in near-surface waters (Norris & Wilson 1998; 1999; Wilson & Norris 2001; Leckie et al. 2002). It is worth noting, however, that these data refer only to the terminal part of their range (late Albian). A possible change towards a shallower depth habitat by these forms in the late Albian following the appearance of the more specialized and deeper-dwelling rotaliporids can probably explain the apparent contrast with the palaeoecological data inferred for ticinellids and biticinellids during the late Aptian–early Albian. However, because planktonic foraminifera are sensitive to numerous environmental parameters and our knowledge of the palaeoecology of selected species is still incomplete, we cannot exclude the possibility that surface-dwelling forms exhibited rather specialized behaviour.

The planktonic foraminiferal assemblages from the Coppa della Nuvola section are typical of temperate low latitude. The lowest species diversity is found in the upper Aptian–lower Albian interval, though there is not the drastic drop recorded in many other areas corresponding to the *H. planispira* Zone, which is absent in the Coppa della Nuvola section (Fig. 6). The upper Aptian–lower Albian foraminiferal assemblages, dominated by small hedbergellids and globigerinelloidids, were in general characterized by poor preservation, fluctuations in abundance and number of species, which is usually low. These traits indicate a general weak stratification of the water column with oscillating eutrophic conditions, as also suggested by the abundance of radiolarians that are known to proliferate within eutrophic conditions (e. g. Hallock 1987). In the lower part of the *T. praeticinensis* Zone, species richness increases (Fig. 6) and radiolarians abundance drops. A new interval of reduced number of species, planktonic foraminiferal preservation and peaks in radiolarian abundance occurred in the early late Albian (Fig. 6).

In particular, the two cited intervals of scarce abundance and poor preservation of planktonic foraminifera (*Ticinella primula* Zone, *T. praeticinensis* Subzone, Fig. 6) are associated with high abundance of radiolarians and may be related to increased eutrophic conditions. Within these intervals, the scarcity of foraminifera could be primary, in part accentuated by the high concentrations of CO_2 related to the eutrophy (caused by oxidation of organic matter in the water column and on the sea floor) which limits carbonate preservation. Pronounced dissolution has been recorded from related strata of the Umbria–Marche basin (Premoli Silva et al. 1989a; Tornaghi et al. 1989, Erba 1992). In the Coppa della Nuvola section, these intervals correlate with the main excursions of the carbon- and oxygen-isotope curves (C11-C12, C16-C17) and with the 'Urbino'and 'Amadeus' events. Both these events, as far as the record of the Gargano area is concerned, appear to be related to episodes of increased productivity.

The appearance and progressive diversification of the specialized deeper-dwelling rotaliporids from the late Albian reveals an increase of deeper ecological niches, in turn suggesting a stratified water column and more stable oceanic conditions. It is worth pointing out, however, that rotaliporids are rare to very rare throughout the upper Albian–lower Cenomanian interval of the Coppa della Nuvola section and exhibit small size; this evidence implies that highly oligotrophic conditions were never reached.

6b. Calcareous nannofossils

The diversity curve (number of species) for calcareous nannofossils fluctuates widely throughout the Albian interval, but it displays a gradual positive trend in the late Albian, where species diversity is quite high, followed by a negative trend from the latest Albian to the early Cenomanian (Fig. 6).

Most of the literature on palaeoecology of calcareous nannofossils deals with the significance of individual taxa, whereas few papers discuss the evolutionary rates of this group. Roth (1983, 1987, 1989) studied the evolution of calcareous nannoplankton during the Mesozoic and observed a relationship between taxonomic evolution and palaeoceanography, particularly the fertility and circulation of surface waters. He pointed out that nannofossils diversify during periods of high organic-carbon accumulation (oceanic anoxic events) and postulated that low nutrient conditions led to increased competition and speciation. Leckie et al. (2002) specify that the calcareous nannofossils were most strongly affected by the late early Aptian Selli and latest Cenomanian Bonarelli Event and, to a minor extent, by the Albian events. Cobianchi & Picotti (2001) argued that diversification of nannofossils coincided with periods of increased fertility of the surface waters, whereas their evolutionary rates dropped to zero or to negative values during oligotrophic or, alternatively, very high eutrophic conditions. In fact, in highly eutrophic conditions, nannoplankton probably became less competitive with respect to siliceous plankton.

As suggested by the distribution of foraminifera and radiolarians in the Coppa della Nuvola section, a gradual change from meso-eutrophic to oligotrophic conditions is recorded in the Albian time interval. This change of the trophic status of surface water probably caused the decrease in calcareous-nannofossil diversity recorded in the Late Albian–Early Cenomanian interval. Moreover, the two intervals of scarce abundance of planktonic foraminifera, associated with high abundance of radiolarians and with the principal negative $\delta^{13}C$ excursions, show a decrease in nannofossil diversity which, however, never drops to zero. Within these two intervals, the nannofossil assemblages record a slight increase of the fertility indices *Biscutum constans* and *Zygodiscus spp.* and dominance of *Watznaueria barnesae*. The high abundance of the last species, known as a diagenetic index, is probably related to the previously discussed high concentrations of CO_2, which can produce pronounced dissolution of carbonate. But, as argued by Negri et al. (2003), *Watznaueria barnesae* was probably also a tolerant, generalized taxon, increasing in abundance during periods of instability in the water masses and high availability of trophic resources in the photic zone.

7. Summary and conclusions

The high-resolution integrated micropaleontological and geochemical analyses of the upper Aptian–lower Cenomanian Coppa della Nuvola section (Gargano Promontory) have provided an opportunity to investigate the record of mid-Cretaceous palaeoceanographic changes. The carbonate carbon- and oxygen-isotope curves represent one of the most detailed records for low latitudes (Fig. 6). The main results of this study are summarized as follows.

1. The Coppa della Nuvola curve displays four negative shifts of $\delta^{13}C$, respectively in the lower Albian (*T. primula; P. columnata* Zones), lower upper Albian (basal *T. praeticinensis* Subzone; *R. achlyostaurion* Zone: weakly developed), upper Albian (upper *T. praeticinensis* Subzone, *R. subticinensis* Zone; *R. achlyostaurion* Zone) followed by marked increases of the values, and in the lower Cenomanian (*R. reicheli* Zone; CC9c Subzone). These excursions are separated by intervals of relatively constant $\delta^{13}C$ values. The Coppa della Nuvola $\delta^{18}O$ curve shows a similar trend, albeit with less pronounced excursions.
2. The carbon-isotope curve may be partly correlated with data from Mexico (Bralower et al. 1999) and from the Marche–Umbria Basin (Stoll & Schrag 2000). A reliable correlation exists between the lower Albian successions of the Gargano Promontory, the Vocontian Basin (Southeastern France) and the Mazagan Plateau (Northwest Africa, DSDP Site 545: Herrle 2002) in the record of a marked $\delta^{13}C$ negative trend, followed by a positive shift, in the *Prediscosphaera columnata* Zone.
3. The $\delta^{18}O$ curve records negative shifts in the lower Albian (*T. primula; P. columnata* Zones), Upper Albian (upper *T. praeticinensis* Subzone, *R. subticinensis* Zone; *R. achlyostaurion* Zone) and Lower Cenomanian (*R. reicheli* Zone; CC9c Subzone) respectively, which may be interpreted as records, albeit modified by diagenesis, of warming events. The warming event recorded in the *P. columnata* Zone of the early Albian has been recorded also off northwest Africa and from southern France (Herrle 2002). These $\delta^{18}O$ signals are interpreted as essentially primary, recording rapid temperature rise consequent upon gas-hydrate release which also resulted in introduction of isotopically light carbon into the global isotopic reservoir.
4. The synchronous negative shifts in $\delta^{13}C$ and $\delta^{18}O$ may record dissociation of gas hydrates somewhere in the world ocean and the near-instantaneous oxidation of the released methane to another greenhouse gas, carbon dioxide and consequent rapid global warming (Menegatti et al. 1998; Jenkyns 2003). The regional record of the negative isotopic event that precedes or overlaps in time with the regional (Tethys–Atlantic) deposition of black shales characteristic of OAE1b (early Albian Paquier Event) renders this the best-documented example of this phenomenon in the late Aptian–early Cenomanian interval. However, the similar isotopic signatures of the intervals in the upper Albian and lower Cenomanian may record phenomena that were similar in kind.
5. The palaeoceanographic conditions inferred by the biotic and isotopic changes are fluctuating meso-eutrophy through the late Aptian–early middle Albian of the Gargano area. These conditions were related to a weak thermocline, sometimes distrupted by more vigorous vertical mixing. The consequent nutrient recycling caused an increase in surface-water fertility, as suggested by the radiolarian abundance peaks and drop in foraminiferal diversity (Fig. 6). Two main episodes of increased eutrophy occurred in the early Albian and in the early late Albian that correlate with the deposition of black shales in the same stratigraphic interval in nearby areas of the Gargano Promontory and elsewhere. These black shales, although absent in the Coppa della Nuvola section, record the effects of OAE 1b and OAE 1c. More stable oligotrophic conditions, beginning in the late Albian, are documented by biotic signals that record a general marked decrease in abundance of radiolarians and the development of the specialized foraminifera (rotaliporids). However, the planktonic community is characterized by rare and small-sized rotaliporids, suggesting that highly oligotrophic conditions were never attained. The described change in nutrient availability during the Albian probably caused the recorded decrease of calcareous nannofossil diversity.

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