

Zeitschrift: Eclogae Geologicae Helvetiae
Herausgeber: Schweizerische Geologische Gesellschaft
Band: 89 (1996)
Heft: 2

Artikel: Middle and Late Jurassic carbon stable-isotope stratigraphy and radiolarite sedimentation of the Umbria-Marche Basin (Central Italy)
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DOI: <https://doi.org/10.5169/seals-167925>

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Middle and Late Jurassic carbon stable-isotope stratigraphy and radiolarite sedimentation of the Umbria-Marche Basin (Central Italy)

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Key words: Middle-Late Jurassic, carbon stable-isotope stratigraphy, radiolarites, carbonate platforms, paleoclimate, Umbria-Marche-Sabina Apennines

ABSTRACT

A continuous carbon isotope curve from Middle-Upper Jurassic pelagic carbonate rocks was acquired from two sections in the southern part of the Umbria-Marche Apennines in central Italy. At the Colle Bertone section (Terni) and the Terminillette section (Rieti), the Upper Toarcian to Bajocian Calcari e Marne a Posidonia Formation and the Aalenian to Kimmeridgian Calcari e Marne a Posidonia and Calcari Diasprigni formations were sampled, respectively. Biostratigraphy in both sections is based on rich assemblages of calcareous nannofossils and radiolarians, as well as some ammonites found in the upper Toarcian-Bajocian interval. Both sections revealed a relative minimum of $\delta^{13}\text{C}_{\text{PDB}}$ close to + 2‰ in the Aalenian and a maximum around 3.5‰ in early Bajocian, associated with an increase in visible chert. In basinal sections in Umbria-Marche, this interval includes the very cherty base of the Calcari Diasprigni Formation (e.g. at Valdorbina) or the chert-rich uppermost portion of the Calcari a Posidonia (e.g. at Bosso). In the Terminillette section, the Bajocian-early Bathonian interval shows a gradual decrease in $\delta^{13}\text{C}_{\text{PDB}}$ values and a low around 2.3‰. This part of the section is characterised by more than 40 m of almost chert-free limestones and correlates with a recurrence of limestone-rich facies in basinal sections at Valdorbina. A double peak with values of $\delta^{13}\text{C}_{\text{PDB}}$ around + 3‰ was observed in the Callovian and Oxfordian, constrained by well preserved radiolarian faunas. The maxima lie in the Callovian and the middle Oxfordian, and the minimum between the two peaks should be near the Callovian/Oxfordian boundary. In the Terminillette section, visible chert increases together with $\delta^{13}\text{C}_{\text{PDB}}$ values from the middle Bathonian and reaches peak values in the Callovian-Oxfordian. In basinal sections in Umbria-Marche, a sharp increase in visible chert is observed at this level within the Calcari Diasprigni. A drop of $\delta^{13}\text{C}$ values towards + 2‰ occurs in the Kimmeridgian and coincides with a decrease of visible chert in outcrop.

The observed $\delta^{13}\text{C}$ positive anomalies during the early Bajocian and the Callovian-Oxfordian may record changes in global climate towards warmer, more humid periods characterised by increased nutrient mobilisation and increased carbon burial. High biosiliceous (radiolarians, siliceous sponges) productivity and preservation appear to coincide with the $\delta^{13}\text{C}$ positive anomalies, when the production of platform carbonates was subdued and ceased in many areas, with a drastic reduction of periplatform ooze input in many Tethyan basins.

The carbon and silica cycles appear to be linked through global warming and increased continental weathering. Hydrothermal events related to extensive rifting and/or accelerated oceanic spreading may be the endogenic driving force that created a perturbation of the exogenic system (excess CO_2 into the atmosphere and greenhouse conditions) reflected by the positive $\delta^{13}\text{C}$ shifts and biosiliceous episodes.

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RESUME

Nous présentons pour la première fois une stratigraphie continue des isotopes stables du carbone du Jurassique moyen et supérieur, basée sur des mesures de carbonates de la Téthys méditerranéenne.

Le Jurassique de l'Apennin sud-oriental de l'Ombrie-Marche-Sabina est caractérisé par l'abondance de résédiments carbonatés pendant tout l'intervalle biosiliceux téthysien. Cette région était proche de la plateforme de Lazio-Abruzzi, située paléogéographiquement au sud du bassin de l'Ombrie-Marche-Sabina. Les séries du Jurassique moyen-supérieur sont caractérisées par des calcaires à silex interstratifiés avec des résédiments de plateforme sous forme de «mass flows», turbidites fines et surtout de la boue carbonatée «periplatorme». Ces séries se sont révélées particulièrement utiles à la stratigraphie intégrée à l'aide de nannofossiles, radiolaires, ammonites et isotopes stables.

Des analyses d'isotopes du carbone et de l'oxygène ont été effectuées dans la coupe de Colle Bertone (M. Lacerona, Terni), dans la formation des Calcari e Marne a Posidonia (Toarcien – Bajocien) et dans la coupe du Terminilletto (M. Terminillo, Rieti) dans les formations des Calcari e Marne a Posidonia et des Calcari Diasprigni (Aalenien – Kimméridgien). Les datations biostratigraphiques sont basées sur des riches faunes à nannofossiles et radiolaires, ainsi que quelques ammonites du Toarcien supérieur, de l'Aalenien et du Bajocien.

Les deux coupes étudiées ont montré un minimum relatif du $\delta^{13}\text{C}_{\text{PDB}}$ d'environ + 2‰ dans l'Aalénien et un maximum d'environ + 3.5‰ dans le Bajocien inférieur. Ce maximum est accompagné d'une augmentation de la silice biogène, visible sous forme de silex dans la coupe. Dans le bassin, ce maximum est biostratigraphiquement corrélé avec le début des Calcari Diasprigni à Valdorbia et avec la partie supérieure des Calcari a Posidonia, très siliceuse, à Bosso. Le Bajocien supérieur – Bathonien inférieur du Terminilletto montre une diminution graduelle des valeurs $\delta^{13}\text{C}_{\text{PDB}}$ et un minimum de + 2.3‰. Cet interval est représenté par plus de 40 m pratiquement dépourvu de silex.

Un double maximum de $\delta^{13}\text{C}_{\text{PDB}}$ autour de + 3‰ a été mesuré dans le Callovien – Oxfordien, daté par des faunes à radiolaires bien préservées. Un premier maximum se situerait dans le Callovien moyen, un minimum proche de la limite Callovo-Oxfordienne et un deuxième maximum serait daté de l'Oxfordien moyen. A Terminilletto, les silex augmentent ensemble avec les valeurs de $\delta^{13}\text{C}_{\text{PDB}}$ depuis le Bathonien moyen et sont dominants dans le Callovo-Oxfordien. Dans le bassin les faciès les plus siliceux sont également datés du Bathonien moyen-supérieur. Les valeurs de $\delta^{13}\text{C}_{\text{PDB}}$ commencent à diminuer dès le Kimméridgien ensemble avec les silex pour arriver à +2‰.

Les maxima observés de $\delta^{13}\text{C}_{\text{PDB}}$ du Bajocien inférieur et du Callovien – Oxfordien se corrélerent avec des montées eustatiques du niveau marin et enregistreraient donc des changements climatiques globaux vers des époques plus chaudes et humides. Ces époques étaient caractérisées par une mobilisation accrue de nutriments ayant pour conséquence finale un enfouissement de carbone organique accrue, ce qui se traduit par des valeurs plus positives de $\delta^{13}\text{C}_{\text{PDB}}$ enregistrées dans les sédiments. La mobilisation de nutriments aurait conduit à une eutrophisation modérée des bassins téthysiens qui a causé une haute productivité et une bonne préservation des organismes siliceux (radiolaires, éponges siliceuses). En même temps la productivité des plateformes carbonatées a sensiblement diminué, voire cessé dans beaucoup de domaines. Le Bajocien est une époque privilégiée du début des radiolarites suite à une réduction drastique de l'apport de boue «periplatorme» dans beaucoup de bassins téthysiens.

Les cycles du carbone et de la silice semblent liées par les processus climatiques du réchauffement et d'une altération continentale accrue, ce qui aurait provoqué un cyclage plus élevé à la fois du carbone et de la silice. Nous pensons que des processus endogéniques soient à l'origine des fluctuations observées: l'augmentation des taux de dérive océanique et du rifting aurait introduit un excès de CO_2 et de silice dans le système exogène provoquant ainsi un processus de régulation par des mécanismes de «feedback». Cette régulation aurait ramené le système exogène à des conditions proche des initiales.

1. Introduction

Our incentive to study the stable isotope stratigraphy of the Middle-Late Jurassic is two-fold. (1) A detailed, continuous and biostratigraphically calibrated carbon isotope record could potentially serve as a tool for global correlation (Scholle & Arthur 1980; Jenkyns et al. 1994). (2) Independent geochemical data pertaining to Jurassic paleoenvironments is needed to understand the onset and the wide distribution of radiolarites in the Tethyan realm and elsewhere.

Carbon-isotopic variation has been linked to changes in ocean structure, productivity and ultimately to the concentrations of greenhouse gases in the atmosphere (Kroopnick et al. 1977; Arthur 1982; Arthur et al. 1985; Berner et al. 1983; Berner & Lasaga 1989; Berner 1990; Lasaga et al. 1985; Shackleton & Pisias 1985; Berger & Vincent 1986; Delaney 1989; Weissert & Br  h  ret 1991; Arthur et al. 1991; Kerrick & Caldeira 1993 and many others). Positive carbon-isotope events reflect perturbations in the global carbon cycle and generally coincide with stratigraphic evidence for increased organic carbon burial (Schlanger et al. 1987; Arthur et al. 1985; Arthur et al. 1990). Since organic carbon is preferentially enriched in the lighter isotope ^{12}C , its removal from the oceanic reservoir and escape from oxidative recycling renders ocean waters relatively enriched in ^{13}C (Scholle & Arthur 1980). In recent years, the carbon isotope stratigraphy of the Lower Cretaceous for low latitudes has been refined (Weissert 1989; Weissert & Lini 1991; Lini et al. 1992; Channell et al. 1993). The Late Valanginian positive $\delta^{13}\text{C}$ event has been postulated to be due to accelerated carbon cycling triggered by elevated atmospheric CO_2 levels coupled with a warm and humid climate (Weissert & Lini 1991; Lini et al. 1992). These episodes of greenhouse climate conditions may be related to increased CO_2 emissions caused by extensive volcanic activity (see Larson 1991a, b). Enhanced continental

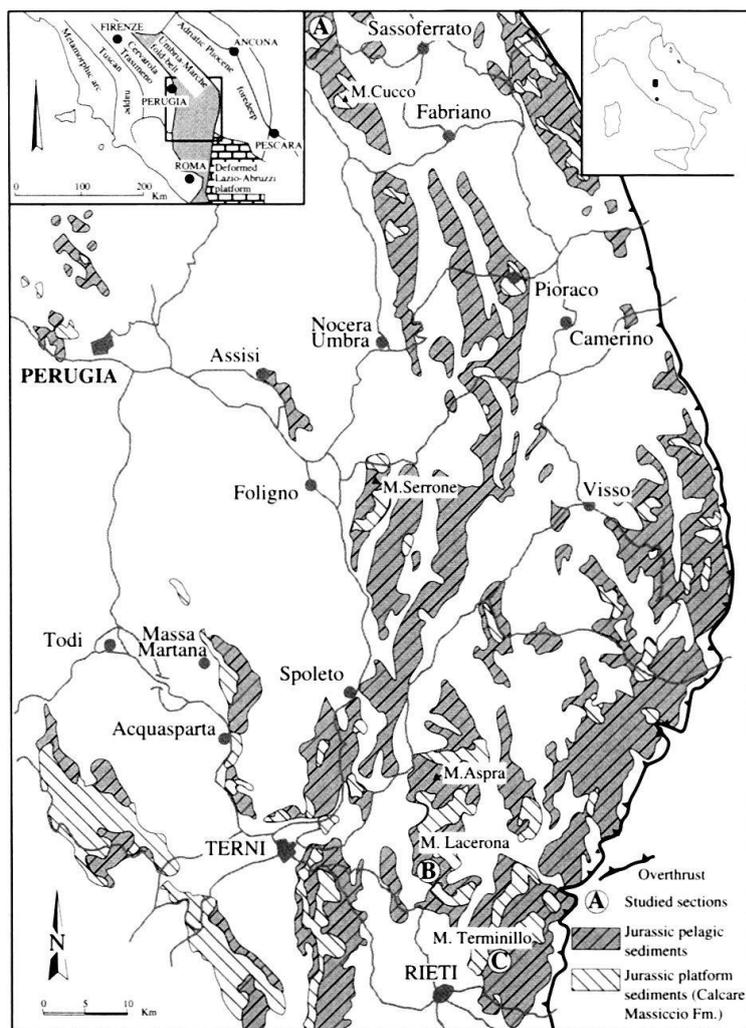


Fig. 1. Simplified geological map of the Umbria-Marche-Sabina Apennines with locations of sections A = Valdorbina; B = Colle Bertone; C = Terminilletto.

weathering and increased runoff may have led to elevated transfer rates of nutrients to the oceans, favouring primary productivity and increasing rates of biological carbon burial in marine sediments. Jenkyns (1985, 1988), Jenkyns & Clayton (1986) and Jenkyns et al. (1991) investigated black shales and carbon isotopes in pelagic sediments from the Tethyan Lower Jurassic. The positive carbon anomaly of the Early Toarcian was attributed to an "oceanic anoxic event", correlating to an Early Toarcian transgression (Hallam 1981), high productivity and the production of an extensive oxygen-minimum zone in both epicontinental and oceanic environments. No continuous carbon-isotope curve for the Middle-Late Jurassic is available. The Bajocian-Kimmeridgian interval of the Alpine-Mediterranean area is generally very siliceous in basal settings and condensed or absent on submerged structural highs. Weissert & Channell (1989) produced a $\delta^{13}\text{C}$ curve of the Upper Jurassic (Kimmeridgian-Tithonian) from Southern Alpine sections. Corbin (1994) studied the Middle Jurassic of the Digne area (Southern France). Bill et al. (1995) and Weissert & Mohr (in press) have studied the Oxfordian from the Helvetic nappes and the Swiss Jura. Jenkyns (in press) has analysed pelagic limestones, ranging from Callovian to Oxfordian in age, from the sections of Chabrières (southern France), Camposilvano and Roverè Veronese (north Italy).

In the Mesozoic basins of Western Tethys the onset of radiolarite sedimentation is diachronous, varying from Late Triassic to Late Jurassic in age (Baumgartner 1984; De Weaver 1989; Gorican 1994). Previously, increased subsidence was seen as the cause of the "drowning" of carbonate platforms and the onset of siliceous sedimentation. Radiolarites were considered as a solution-resistant sediment that accumulated wherever the seafloor dropped below the calcite compensation depth (Garrison & Fischer 1969; Bosellini & Winterer 1975; Hsü 1976; Kálin et al. 1979; Winterer & Bosellini 1981; Jenkyns & Winterer 1982). Radiolarian biostratigraphy and basin-platform correlation in the Western Tethys clearly shows that the onset of radiolarites is controlled by productivity and paleogeography (Baumgartner 1987; Baumgartner 1990; Gorican 1994). Predominantly siliceous sedimentation in the Western Tethys can occur at any time since the middle Triassic in areas connected to an open ocean (Neotethys), provided the basin was sheltered or away from carbonate input from the neighbouring platforms.

For the combined objectives of carbon isotope stratigraphy and the understanding of radiolarites we have chosen an area that is „sensitive“ to monitor the changes in carbonate versus biosiliceous sedimentation. The South-Eastern sector of the Umbria-Marche-Sabina Apennines (Fig. 1) was close to the Lazio-Abruzzi Carbonate Platform. The Middle-Upper Jurassic is characterised by thick, continuous pelagic sections with cherty limestones and abundant platform-derived resediments that occur both as coarse mass flow deposits, fine turbidites, and as periplatform ooze. Well preserved radiolarians occur throughout, allowing for an integrated biostratigraphy by mean of radiolarians, nanofossils and ammonites (Tonielli 1991; Bartolini 1995; Mattioli 1995; Bartolini et al. 1995).

2. Geological Setting

During the Mesozoic, the Umbria-Marche-Sabina (UMS) Basin of Central Italy (Fig.1) was part of the southern continental margin of the Western Tethyan Seaway. During the early Liassic, a large carbonate shelf in this region broke up and drowned due to the com-

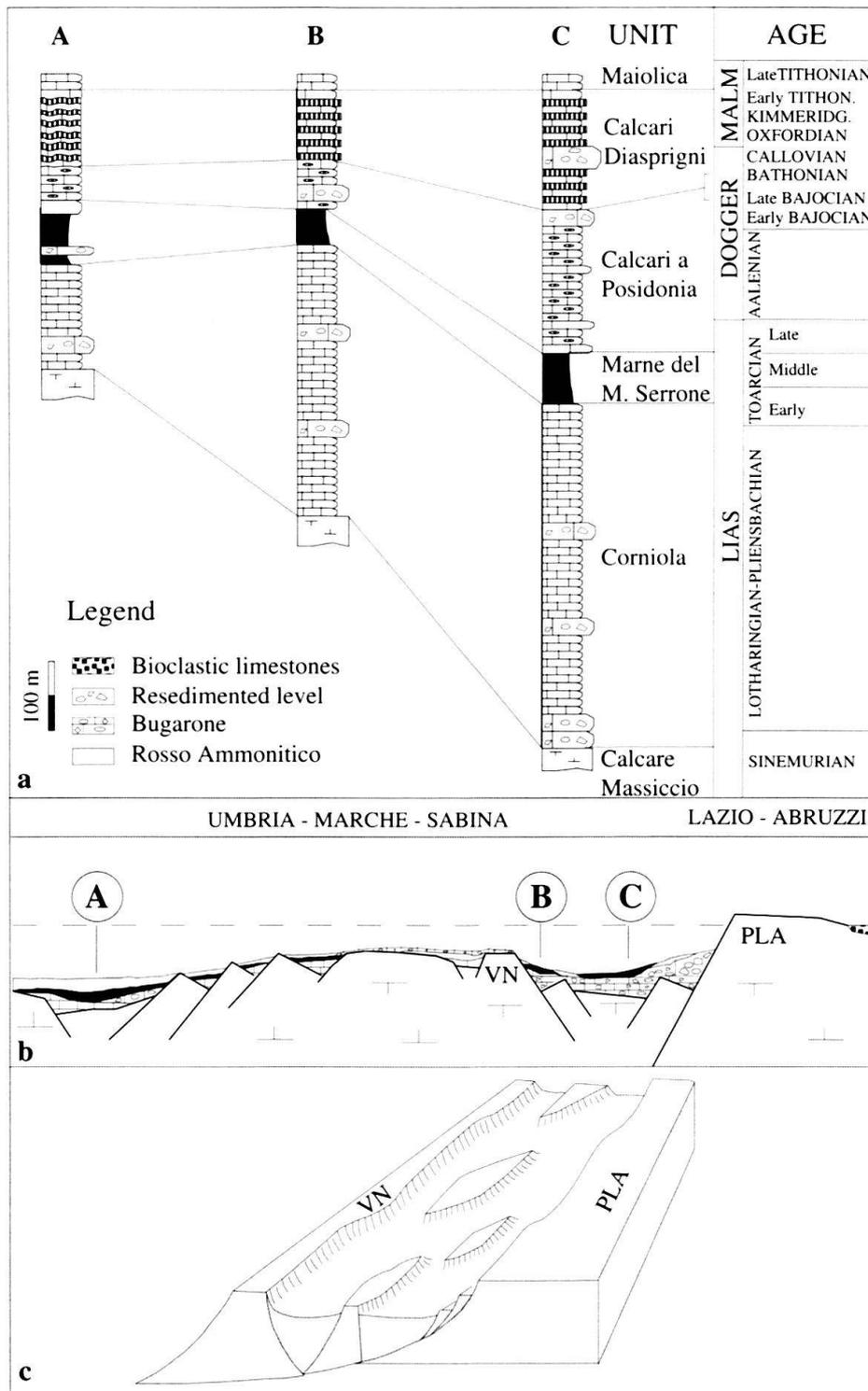


Fig. 2. (a) Simplified columnar sections and (b) paleogeographic transect of the Umbria-Marche-Sabina (UMS) Basin and the adjacent Lazio-Abruzzi (PLA) Platform. (A = Valdorbina, B = Colle Bertone, C = Terminilletto). The studied sections Colle Bertone and Terminilletto are located close to the area that represented the margin between the UMS Basin and the PLA Platform. This area was characterised by abundant carbonate resediment input from the platform, resulting in thicker and more calcareous sections than those out in the basin. (c) Schematic block model of the Lazio-Abruzzi Platform (PLA), and the proximal UMS Basin, The Valnerina Line (VN) formed a structural high during the Jurassic rifting (after Lavecchia 1985).

ination of ecological factors and intensified extensional tectonics related to continental rifting (Colacicchi et al. 1970; Colacicchi et al. 1988; Alvarez 1989; Bice & Stewart 1990; Santantonio 1993). By the late Sinemurian, shallow-water sediments were replaced by pelagic and resedimented facies. Throughout the Jurassic, shallow water carbonate sedimentation persisted to the south of the UMS basin, in the adjacent Lazio-Abruzzi (LA) carbonate shelf.

The studied sections (Colle Bertone and Monte Terminilletto) crop out in the southern part of the UMS Apennines (Fig. 1). These sections were located proximal to the adjacent Lazio-Abruzzi platform, and therefore received abundant carbonate resediments from the platform (Fig. 2). For this reason, the studied successions are more calcareous than those from the central part of the Umbria-Marche Basin, such as Valdorbia and Bosso (McBride & Folk 1979; Baumgartner 1984, 1987, 1990; Cresta et al. 1988; Monaco et al. 1994). As calcareous plankton was scarce throughout most of the Middle Jurassic, periplatform ooze (Schlager et al. 1976; Schlager & James 1978; Schlager & Chermak 1979) probably constituted the main limestone component present in the basinal sections in the Calcari e Marne a Posidonia and part of the Calcari Diasprigni formations. Sedimentation rates are high through the Early Middle Jurassic and become greatly reduced during the late Middle and Late Jurassic, probably due to a reduced input of periplatform ooze. At Colle Bertone and Terminilletto, the succession is well developed and continuous from the Corniola Formation (lower-middle Lias) to the Maiolica Formation (late Tithonian). The Calcari e Marne a Posidonia are a well-bedded limestone with local chert in nodules or ribbons and common levels of posidoniid bivalves. The Calcari Diasprigni are characterised by cherty limestones and interbedded cherts (Cresta et al. 1988).

Both sections are rich in calcareous nannofossils and radiolarians, and sporadic ammonite-bearing horizons have also been found (Bartolini et al. 1995). The nannofossil biostratigraphy is from Mattioli (1995) (Pl. 1, 2).

3. Colle Bertone Section

The Colle Bertone section (Fig. 3, Pl. 1) crops out on the south-western flank of Monte La Pelosa, along an unpaved track branching off the Polino-Colle Bertone road, shortly after the Fountain of Acquaviva. As resedimented lithologies are mainly intraformational, the Colle Bertone section was probably located in an area protected from direct platform input. Periplatform ooze, however, must have greatly diluted the autochthonous planktonic sedimentation. In the present study we only deal with the Calcari e Marne a Posidonia comprising pale brown-whitish micritic limestones, rich in posidonid remains and radiolarians. Centimetric greenish marly intercalations are also present. Bedding thickness ranges between 20 and 30 cm in the lower portion (0.00 m–43.00 m) and become thinner, from 15 cm to 30 cm, in the upper portion (43.00 m–69.00 m). In the interval from 0.00 m to 43.00 m grey chert is found discontinuously as ribbons and nodules. Most chert replaces carbonate and chert ribbons are often found within resedimented beds. In the interval from 43.00 m to 69.00 m grey-white chert is found regularly in ribbons ranging from few to ~20 cm in thickness. Chert contains abundant and locally well-preserved radiolarians and represents original radiolarian sand layers (radiolarites). Chert becomes red from 64.35 m. Both intraformational pebbly mudstones and graded and laminated calciturbidites occur. Calciturbidites are characterised by posidoniid-echi-

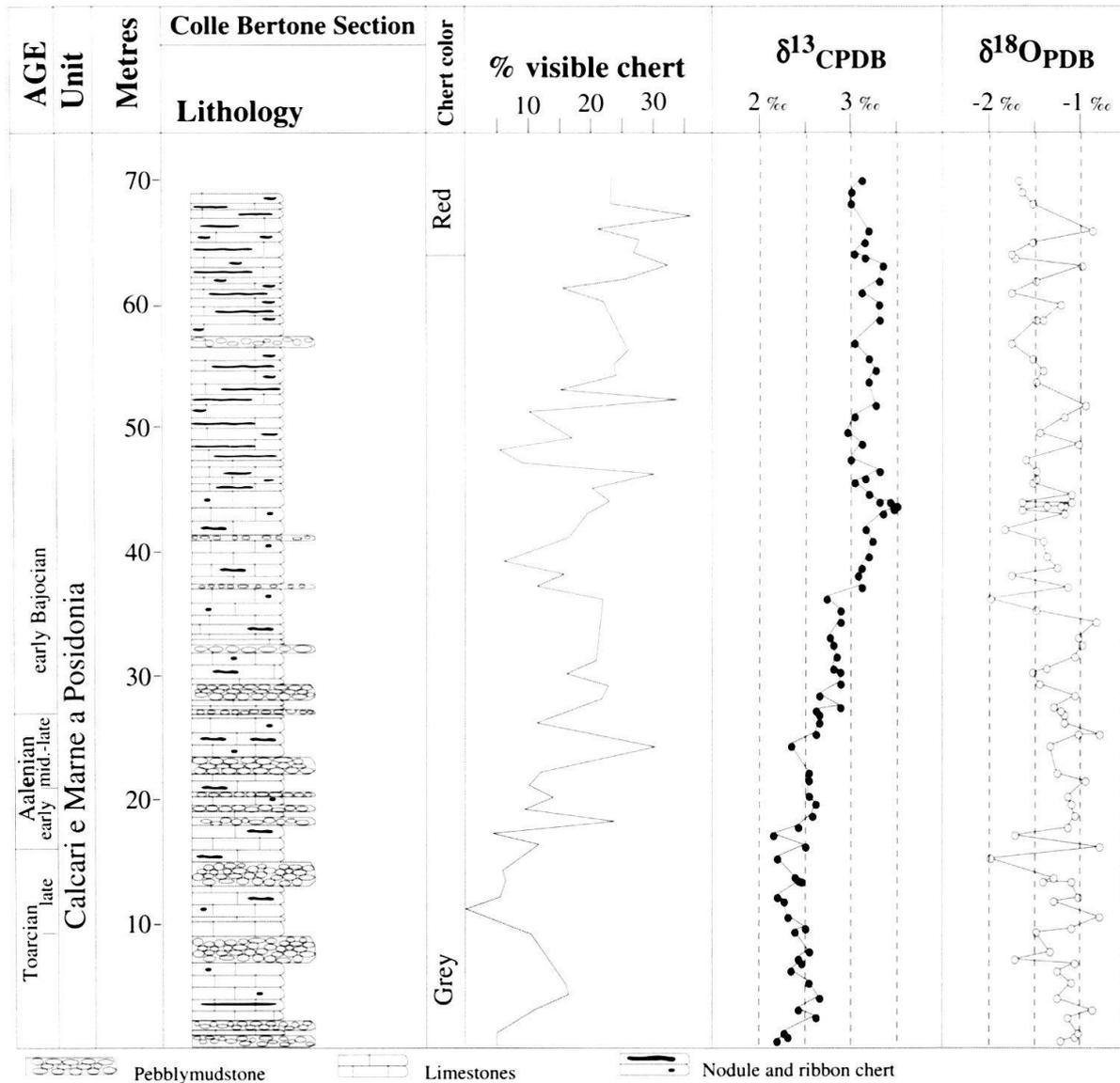


Fig. 3. Summary log of the Colle Bertone section. Lithology, visible chert percentage curve, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves of bulk carbonates are simplified. For more details on lithology, sample locations, sample numbers and biostratigraphy see Plate 1.

nodern packstones that show normal grading, parallel and low-angle cross-laminations. Pebbly mudstones are largely composed of intraplats and intraclasts of micritic limestones rich in echinoderm and posidoniid fragments. Upsection, calciturbidites and pebbly mudstones occur only sporadically.

4. Terminilietto section

The section (Fig. 4, Pl. 2) is exposed along the E-SE side of Monte Terminilietto (Terminillo Group) and its base crops out along the road that leads from Terminillo to Campofogna and to Sella di Leonessa. During the Jurassic Terminillo area was close to a nor-

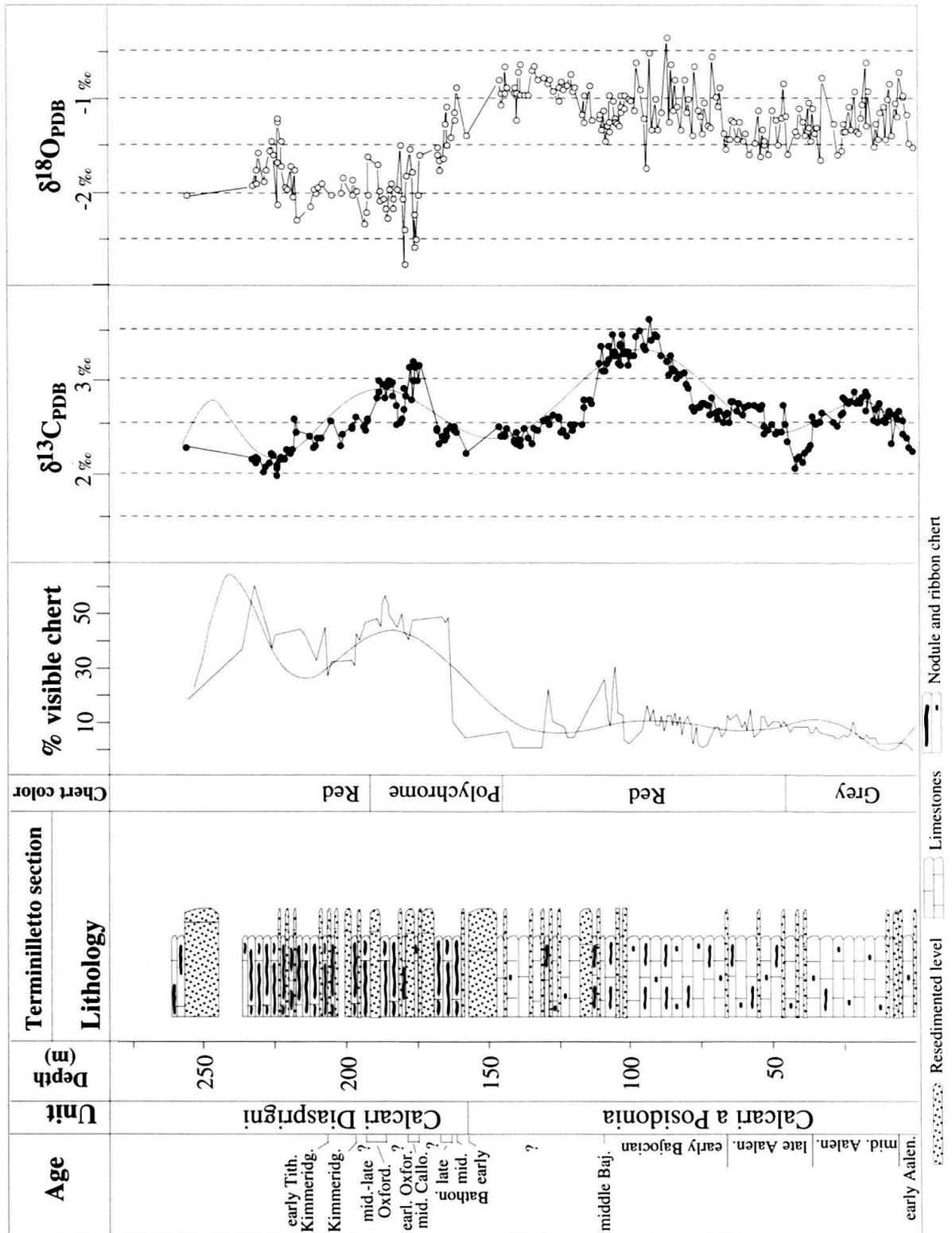


Fig. 4. Summary log of the Terminilletto section. Lithology, visible chert percentage curve, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves of bulk carbonates are simplified. For more details on lithology, sample locations, sample numbers and biostratigraphy see Plate 2. The visible chert percentage and $\delta^{13}\text{C}$ polynomial regression curves are in phase. In addition to the fluctuations, an upwards increase of visible chert % throughout the Middle Jurassic was observed. Note a sharp increase at about 163 m (middle Bathonian) and a decrease around 225 m (upper Kimmeridgian/lower Tithonian).

mal fault trending N-S, that divided the UMS basin from the Lazio-Abruzzi (LA) carbonate platform (Castellarin et al. 1978; Cantelli et al. 1982; Castellarin et al. 1984). Abundant carbonate resediments derived from the platform occur therefore in the Jurassic sections of this area. The data presented in this paper were obtained from the Calcari e Marne a Posidonia (0.00 m–160 m, upper Toarcian-Bajocian) and the Calcari Diasprigni (160 m–256 m, Bajocian/early Tithonian).

The interval from 0.00 m to 40.00 m (upper Toarcian/middle Aalenian) mainly comprises medium bedded (10 to 20 cm) pale brown micritic limestones, showing mudstones and wackestones with posidoniids. Laminated wackestones and mudstones occur in cycles of about 30 cm thickness. Platform resediments consist of 20–30 cm thick intercalations of oolitic grainstones with parallel and cross laminations and 40–90 cm thick pebbly mudstones. White chert is sporadically present (visible chert 0–5%) in small nodules (2–3 cm in diameter). The interval from 40.00 m to 110 m (middle Aalenian to lower Bajocian) is mainly comprised of mudstones and resedimented beds that decrease in abundance up section. Bed thickness varies around 5 cm. The visible chert content tends to increase to 10–15%, and occurs as nodules and thin, laterally continuous ribbons. Up section from 45 m, chert becomes red. From 100 m upwards, resedimented oolitic grainstones, partially replaced by chert, occur. From 110 m to 160 m (lower Bajocian middle Bathonian) resedimented beds are frequent. Bioclastic packstones-grainstones with dominant echinoderm fragments alternate with fine calcarenites to mudstones-wackestones bearing posidonid shells. Fining-upward cycles can be observed. Chert tends to become sporadic and disappears completely between 130 m and 160 m. From 160 m to 168 m (middle Bathonian) the lower portion of the Calcari Diasprigni is mainly constituted by thin beds (~4–10 cm) of whitish radiolarian mudstones with abundant red chert (30–40%) in irregular nodules and ribbons. Sporadic levels of detritic oolitic white chert of 16–18 cm thickness are found. The interval from 168 m to 196 m (middle Bathonian/Upper Oxfordian) mainly comprises micritic limestones and greenish, thinly stratified (2–8 cm) and laminated cherty limestones, rich in radiolarians, rhythmically alternating with varicoloured, but dominantly green, ribbon chert (40–50% visible chert). Horizons bearing radiolarian and spicule sands are also present. Resedimented beds of 3–5 m thickness constituted by ooids, crinoids and shelf-derived bioclasts are frequent. Levels of white chert replacing oolites are present. From 196 m to 256 m (Upper Oxfordian/Kimmeridgian), the sediments are mainly composed of whitish radiolarian-rich micritic limestones and fine pale brown calcarenites arranged in thin beds (8–10 cm in thickness) bearing ribbons and nodules of red chert. Up to 236 m, chert is abundant (40–50%), while up section (254.50 m) a decrease in chert content to 18–26% is evident. Resedimented beds are mainly oolitic up to 220 m, and tend to become bioclastic further on. A large shelf resedimented lens-shaped body of about 18 metres of thickness occurs at 224.8 m.

5. Stratigraphic distribution of visible chert

Rock names such as “cherty limestone” or “radiolarite” only qualitatively represent sediment compositions and are inadequate for a paleoceanographic interpretation of pelagic sequences. In soft sediments, semiquantitative sediment compositions are usually obtained from smear slide studies (e.g. ODP practice). In orogenic belts, lithification and

burial diagenesis have enhanced lithologic contrasts to the extent that it is difficult to estimate long term shifts in sediment composition based on individual samples.

However, in pelagic sequences, the carbonate/silica ratio of the sediments certainly bears an important paleoceanographic signal (Jenkyns & Winterer 1982). In order to overcome bed-to-bed diagenetic variation, E.L. Winterer (oral communication) developed a semiquantitative field technique to estimate the percentage of visible chert. A metre stick is placed on the section and the number of centimetres of visible chert crossed by the stick is noted for every metre of the section. This method has been used to produce the plots of Plate 1 and Plate 2, Figure 3 and Figure 4.

This method does not account for finely dispersed silica in limestones or shales. The actual bulk silica content of metre-intervals of section is certainly higher by 10% or more than the % of visible chert. Significant amounts of clay in the section may have partially or totally hindered the formation of macroscopically visible chert. Therefore, this method is only useful to show fluctuations of chert content over several metres of section, if the overall clay content is low.

The % of visible chert is thought to be indicative of the evolution of silica/carbonate ratios of an individual section, which is controlled by productivity and sedimentation processes, as well as by dissolution and diagenesis.

6. Stable-isotope stratigraphy

All stable-isotopic analysis were carried on bulk carbonate samples. Previous work has proven the usefulness of bulk carbonate analysis in fine-grained and homogenous rocks (Scholle & Arthur 1980; Anderson & Arthur 1983; Weissert 1989). Only micritic lime-mudstones and wackestones have been sampled, the sampling points being carefully selected in the field and in the laboratory to avoid material containing stylolites and calcite veins. We sampled the sections at intervals of about one metre or less, when the lithology permitted. Bulk carbonate samples of the Aalenian-Bathonian samples are composed mainly of periplatform ooze, while the Callovian-Kimmeridgian interval yields increasing calcareous nannofossil percentage. In some levels calcareous nannofossils become the predominant constituent of limestone (Mattioli 1995). The penecontemporaneous down-slope displacement of periplatform ooze should not have affected the long term fluctuations of the carbon isotope values. Platform-derived ooze reaches mineralogical stability in the first few metres of burial (Marshall 1992). The early diagenetic products, therefore, should record average "marine" isotopic signals close to those of the original platform ooze.

The samples were prepared following the conventional procedure of McCrea (1950). We analyzed CO₂ released from a 15 hour reaction between powdered bulk samples and 100% phosphoric acid at 25 °C. A H₃PO₄-CaCO₃ fractionation factor of 1.01025 at 25 °C (Sharma & Clayton, 1965) was used. The δ¹³C and the δ¹⁸O composition of the released CO₂ gas was analysed on a Finnigan MAT 251 spectrometer. The results are reported in the usual per mil δ-notation relative to the PDB (Pee Dee Belemnite) international isotopic standard. In the isotope laboratory at the University of Lausanne, calibration to PDB is performed by Carrara marble versus NSB19 standard. Replicate analysis of selected samples showed a reproducibility of 0.05 per mil for δ¹³C and better than 0.1 per mil for δ¹⁸O.

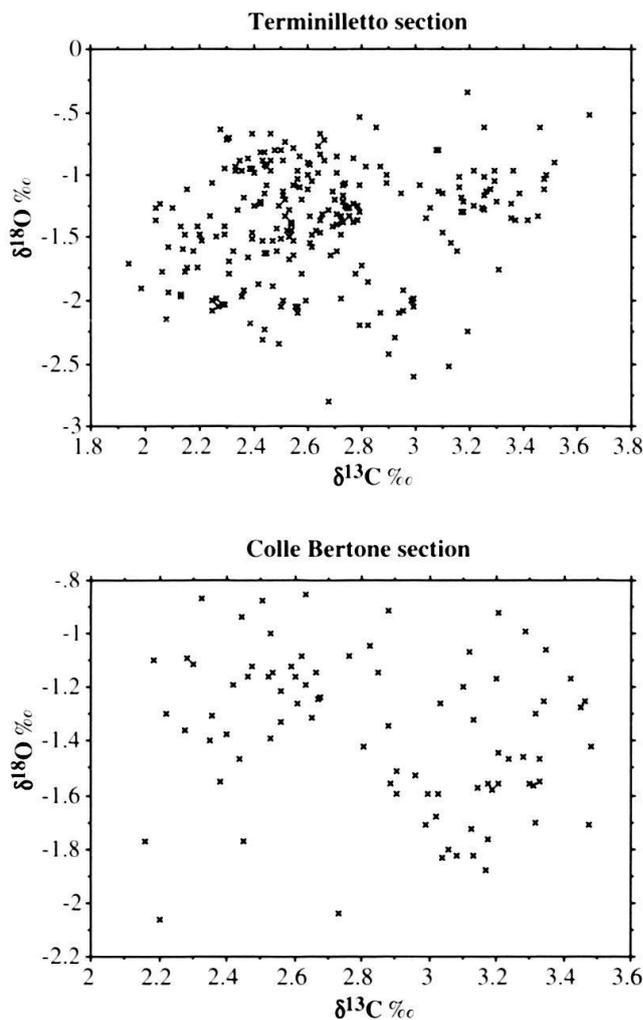


Fig. 5. $\delta^{13}\text{C}$ versus $\delta^{18}\text{O}$ scatter diagrams of the Terminilletto section and the Colle Bertone section. Data show no covariance, suggesting that the C-isotopic composition of the analysed sediments has not been altered significantly by burial diagenesis.

In both sections, the Aalenian shows a relative minimum of $\delta^{13}\text{C}_{\text{PDB}}$ close to $+2\%$ (Pl. 1, 2, Fig. 3, 4). In the early Bajocian, the values of $\delta^{13}\text{C}_{\text{PDB}}$ gradually increase towards a maximum of about 3.5% . The increase of values starts in the *Laeviuscula* ammonite zone. In the Terminilletto section, the results of the Upper-Middle and Upper Jurassic interval shows a gradual decrease of the $\delta^{13}\text{C}_{\text{PDB}}$ values in the upper part of the lower Bajocian and a minimum of 2.3% in the upper Bajocian/lower Bathonian. A small variation can be discerned in the middle Bathonian, then two distinct peaks around $+3\%$ follow in the Callovian and in the middle Oxfordian. The minimum between the two peaks should be near the Callovian/Oxfordian boundary. Small perturbations are present in the upper Oxfordian and lower Kimmeridgian and a drop towards $+2\%$ follows during the Kimmeridgian.

$\delta^{18}\text{O}_{\text{PDB}}$ values are scattered ($\pm 0.5\%$), and show no covariance with $\delta^{13}\text{C}_{\text{PDB}}$ (Fig. 5). The lack of covariance of $\delta^{13}\text{C}_{\text{PDB}}$ and $\delta^{18}\text{O}_{\text{PDB}}$ suggests that the C-isotopic composition of the analysed sediments has not been altered significantly by burial diagenesis (Jenkyns & Clayton 1986).

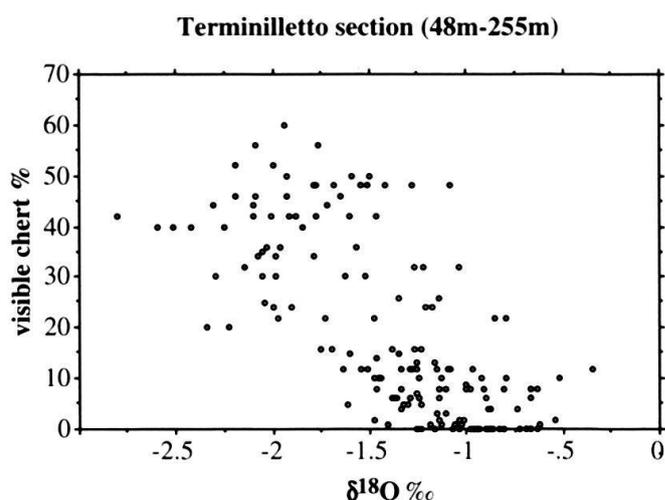


Fig. 6. $\delta^{18}\text{O}$ versus visible chert percentage scatter diagram of the Terminilletto section. Note the rough negative covariance between the values. For discussion see text.

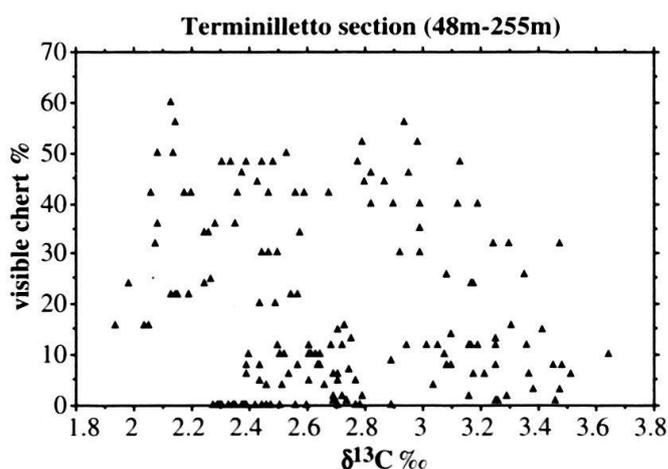
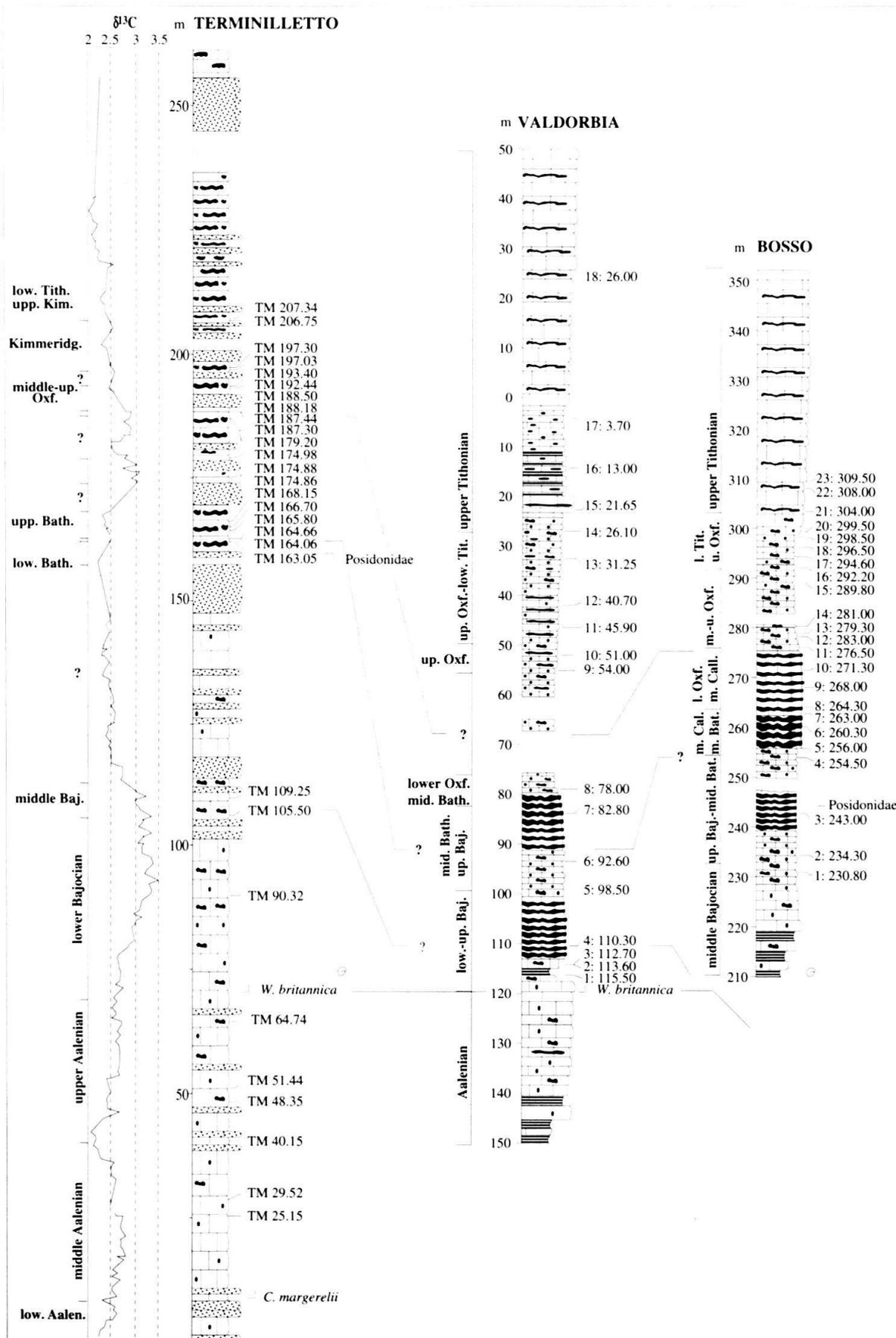


Fig. 7. $\delta^{13}\text{C}$ versus visible chert percentage scatter diagram of the Terminilletto section. The values show no covariance indicating that $\delta^{13}\text{C}$ -values are not affected by the silica diagenesis.

The $\delta^{18}\text{O}_{\text{PDB}}$ curve of the Terminilletto section presents a negative shift at 163 m (middle Bathonian) with a decrease from $\sim -1.6\text{‰}$ to $\sim -2.0\text{‰}$. This change in $\delta^{18}\text{O}$ coincides with a marked lithological change towards more cherty limestones (Calcari Diasprigni Formation) with a sharp increase of visible chert (Fig. 4). Plotted on a $\delta^{18}\text{O}$ -visible chert % graph, $\delta^{18}\text{O}$ values and percentage of visible chert show a negative covariance (Fig. 6). This means that $\delta^{18}\text{O}$ values of limestones are more negative in the presence of abundant chert.

Fig. 8. Correlation of the $\delta^{13}\text{C}$ curve of Terminilletto section with the lithological changes in the basal sections. The correlation is based on radiolarians, calcareous nannofossils and ammonites (Bartolini et al. 1995; INTERRAD Jurassic-Cretaceous Working Group 1995). The numbers to the right of the logs indicate the radiolarian samples. The lower Bajocian carbon positive shift is correlated with the very cherty base of Calcari Diasprigni in the Valdorbia section and with an increase in visible chert within the Calcari a Posidonia seen in the Terminilletto and Bosso sections. The Callovian and Oxfordian carbon positive shifts are associated with an increase in visible chert within the Calcari Diasprigni at Terminilletto and Bosso sections.



7. $\delta^{13}\text{C}$ values and visible chert percentages

If we plot $\delta^{13}\text{C}$ values against visible chert percentages for metre-intervals of the Terminilletto section no covariance is seen (Fig. 7). This suggests that $\delta^{13}\text{C}$ values are not influenced by the silica diagenesis, although positive fluctuations of $\delta^{13}\text{C}$ are accompanied by a general increase of visible chert (Fig. 8). $\delta^{13}\text{C}$ and the visible chert % curves (confidence interval from 90 to 95%, selected regression order of 9) are in phase. The early Bajocian, the Bathonian, the Callovian and the Oxfordian positive $\delta^{13}\text{C}$ shifts are all accompanied by positive fluctuations of visible chert %. The actual values of % visible chert are not comparable between shifts, because they are controlled by sedimentation processes (e. g. the rate of input of periplatform ooze and platform resediments) rather than silica productivity alone. Radiolarian biostratigraphy has allowed us to correlate fluctuations of the carbonate/silica ratio observed at Terminilletto to other sections of the UMS Basin (Fig. 8). The early Bajocian $\delta^{13}\text{C}$ peak is related to an increase of visible chert in the Calcari e Marne a Posidonia of Terminilletto section, which biostratigraphically correlates with the chert-rich uppermost portion of the Calcari e Marne a Posidonia of the Bosso section (Baumgartner 1984, 1987a, 1990), and to the very cherty base of the Calcari Diasprigni Formation of the Valdorbia section (McBride & Folk 1979; Baumgartner 1984, 1987, 1990). The Bajocian/early Bathonian interval produced low $\delta^{13}\text{C}$ values around 2.3‰. At Terminilletto this part of the sequence is characterised by more than 40 m of almost chert-free limestones. In basinal sections a recurrence of limestone-rich facies is observed at Valdorbia in the Calcari Diasprigni Formation. In the Terminilletto section visible chert increases together with $\delta^{13}\text{C}$ values from the middle Bathonian and reaches peak values in the Callovian-Oxfordian. In basinal sections a sharp increase in visible chert can be observed within the Calcari Diasprigni. At Bosso section it is roughly dated as mid-Bathonian/early Callovian and at Valdorbia it is constrained to the middle-late Bathonian by radiolarian biostratigraphy (Baumgartner 1990; INTERRAD Jurassic Working Group 1995).

8. Interpretation of oxygen-isotope record

The oxygen-isotope record of Mesozoic sediments is always suspect and is probably influenced by diagenesis as the ratio of oxygen in pore waters to oxygen in carbonate sediment is high, unlike the situation with carbon isotopes. In addition, burial diagenesis at elevated temperatures and the influence of meteoric-water can add isotopically light cement during late diagenesis. The presence of biogenic silica also seems to alter the oxygen-isotope record. Our data from the Terminilletto section (Fig. 6) clearly show a lowering of $\delta^{18}\text{O}$ -values in the presence of abundant chert. Brenneke (1977) pointed out the same phenomenon after studying the isotopic composition of Jurassic and Cretaceous limestones of DSDP site 367, where nodular chert is associated with carbonates depleted in ^{18}O . Lighter $\delta^{18}\text{O}$ values in chert-rich carbonates are reported from the Valdorbia and Fonte Avellana sections (Umbria-Marche) (Hadji 1991), where a positive shift in $\delta^{18}\text{O}$ coincides with the passage from chert-rich (Calcari Diasprigni) to chert-poor (Scisti ad Aptici and Maiolica) lithologies.

Lawrence (1973) suggested that the alteration of biogenic silica to chert may be important in lowering the $^{18}\text{O}/^{16}\text{O}$ ratio of the pore waters. According to Brenneke (1977)

current theories regarding chert formation can not explain the lighter $^{18}\text{O}/^{16}\text{O}$ ratio in carbonates associated with biogenic chert. Biogenic silica ranges in oxygen isotope composition from + 2.4‰ to + 6.3‰ (Mopper & Garlick 1971; Knauth & Epstein 1975). Mesozoic and Cenozoic deep-sea cherts range in composition from + 0.5‰ to + 6.0‰ and microcrystalline quartz is depleted in ^{18}O relative to co-existing opal-CT (Knauth & Epstein 1975; Pisciotto 1981). Thus the transition from opal-CT to quartz or the direct precipitation of quartz tends to enrich pore waters in ^{18}O . Knauth & Epstein (1975) have presented data suggesting that opal-CT forms during shallow burial (less than 100 m in depth). Opal-CT replaces the calcite matrix, releasing calcium carbonate which reprecipitates in the surrounding carbonate ooze. Authigenic carbonate formed at this temperature (very shallow burial) should be relatively heavy in $\delta^{18}\text{O}$, even if the pore water was somewhat depleted in ^{18}O due to chert formation.

We speculate that the release of isotopically highly negative water during the transition from opal-CT to quartz could account for the lower $\delta^{18}\text{O}$ values of the pore water around the chert. Knauth & Epstein (1975) provided some data to support such a speculation. When they dried an opal-CT sample at 1000 °C, they found a total water loss of 1.2 wt % with a corresponding gain of 0.7‰ in $\delta^{18}\text{O}_{\text{SMOW}}$. This means that the lost water had an $\delta^{18}\text{O}$ composition of around - 60‰. In order to shift porewater composition around chert by - 2‰ (as observed by Lawrence 1973), we would need to add about 3% lighter water from opal-CT. This is only possible in the immediate vicinity of chert, since the opal-CT chert transformation possibly releases only around 3 vol. % of light water which rapidly becomes diluted by diffusion away from chert bodies.

The observed negative shift of $\delta^{18}\text{O}$ may be a primary paleoceanographic signal, recording a change in paleotemperature and/or isotopic composition of sea-water. If the temperature coefficient of $\Delta^{18}\text{O}$ ($\text{CaCO}_3 - \text{H}_2\text{O}$) is ~ 0.2‰ per 1 °C (McCrea 1950), this change in $\delta^{18}\text{O}$ may account for an increase in temperature of ~ 2 °C. Although the oxygen isotopic values of the studied sediments have a clear diagenetic overprint (see the scatter trend), general primary trends may still be preserved. Jenkyns et al. (1994) observed a consistent trend in the oxygen-isotope values of various Cretaceous British Chalk sections and of the more lithified Scaglia Rossa and Scaglia Bianca formations in the Umbria-Marche Apennines. The authors concluded that this trend may reflect real variation in palaeotemperature. In any case, further analyses of more sections of the same age and from different depositional environments are needed to find out if the observed negative shift is diagenetic or paleoenvironmental in origin.

9. Correlation of Middle-Late Jurassic carbon isotope stratigraphy

In Figure 9, we present a tentative correlation among Jurassic carbon-isotopic stratigraphies. The correlation of Middle-Upper Jurassic carbon-isotope events is an important step towards understanding their origin. The early Bajocian carbon isotope excursion observed in the UMS Basin correlates with an analogous excursion reported from the Digne area, in the Northern Tethyan margin (Corbin 1994). The Chaudon-Norante section studied by Corbin (1994) yielded an exceptional Bajocian ammonite record (Pavia 1973, 1983). Although the absolute $\delta^{13}\text{C}$ values of the Chaudon-Norante section are offset by about 1‰ with respect to the UMS Basin pelagic limestones (a fact that presumably relates to different diagenesis), an analogous positive excursion of about 1.3‰ can

be observed. The $\delta^{13}\text{C}$ values increase in the lower part of the *Laeviuscula* Zone and reach maximum values in the upper part of the *Sauzei* Zone. Corbin's $\delta^{13}\text{C}$ curve represents a composite peak, where the values decrease in the lower part of the *Humphriesianum* Zone and increase again in the middle to upper part of the same zone. This pattern was not observed in the UMS Basin sections.

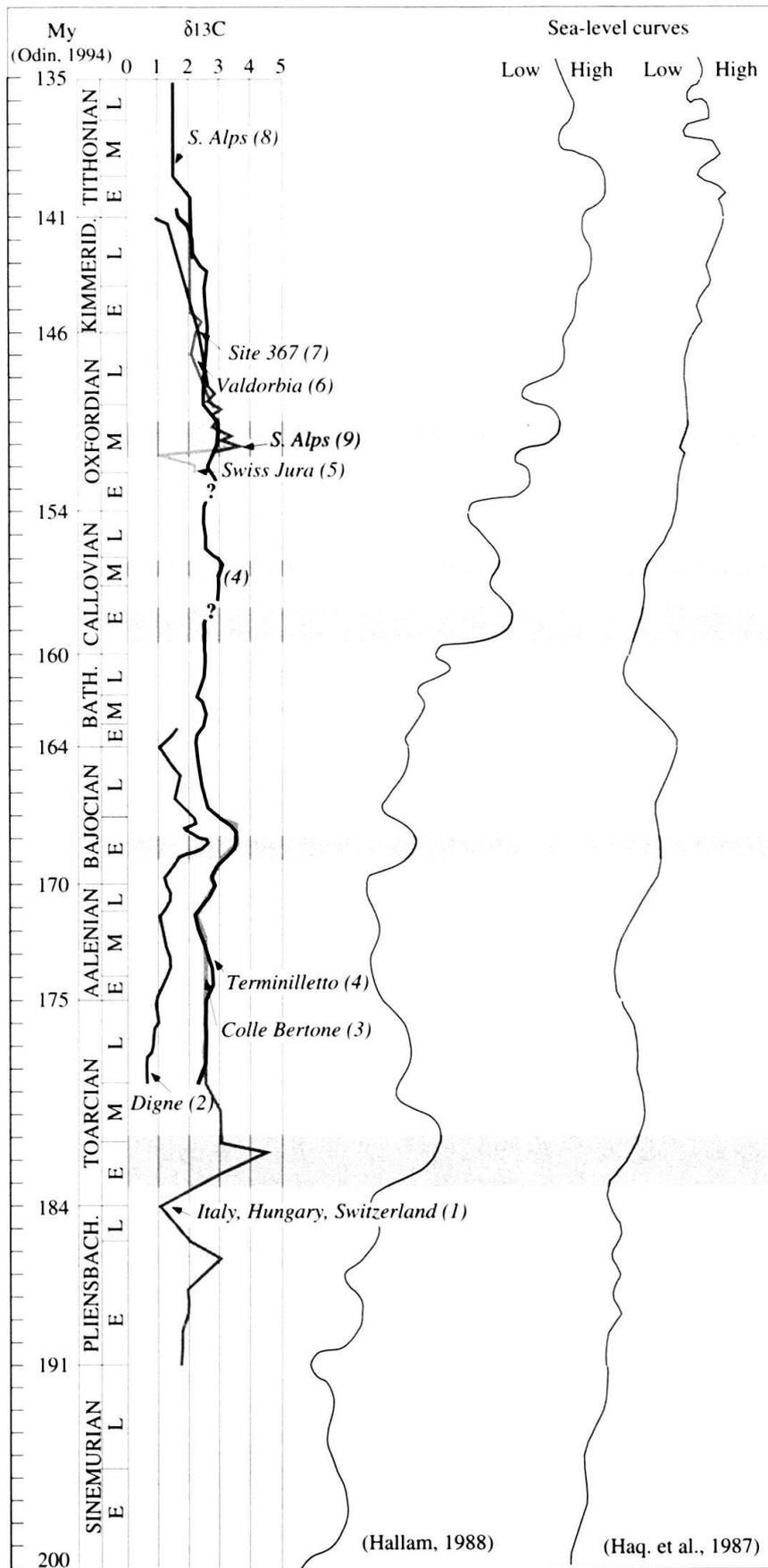
The Callovian positive excursion observed at Terminilietto section can be correlated to peaks of $\delta^{13}\text{C}_{\text{TOC}} \text{‰}$ picked out in the Peterborough and Stewartby Members of the British Oxford Clay formation (Kenig et al. 1994). The more evident $\delta^{13}\text{C}_{\text{TOC}}$ peaks are in the *Calloviense* Zone (lower Callovian) and in the *Jason* Zone (middle Callovian). Carbon-isotope stratigraphy from condensed pelagic section of Camposilvano (north Italy) revealed a positive $\delta^{13}\text{C}$ in the Lower-Middle Callovian interval (Jenkyns, in press).

Coralliferous mid-Oxfordian facies from northern Poland show $\delta^{13}\text{C}$ values in the range 2.5 to 3.5‰ (Gruszczynski et al. 1990). Hoffman et al. (1991) found positive excursions in the *Cordatum* Zone and *Transversarium* Zone from brachiopod calcite taken from Oxfordian sponge facies in central Poland. Carbon-isotope data from brachiopods from Late Jurassic carbonates in eastern Spain show $\delta^{13}\text{C}$ values that increase through the mid Oxfordian (Pisera et al. 1992). Bill et al. (1995) found a positive 2–2.3‰ excursion of $\delta^{13}\text{C}$ in the *Transversarium* Zone (middle Oxfordian) from the platform carbonate echinoderm fragments of the Liesberg Beds Member of the Swiss Jura. A $\delta^{13}\text{C}$ positive excursion in the transversarium Zone was documented by Jenkyns (in press) in the pelagic limestones from the sections of Chabrières (southern France), and Camposilvano and Roverè Veronese (northern Italy). A similar Upper Jurassic $\delta^{13}\text{C}$ trend has recently been reported by Weissert and Mohr (in press). The authors studied carbon and oxygen isotopic compositions from Northern Tethyan shallow-shelf pelagic sediments of the Schilt Formation (lower to middle Oxfordian) and of the Quinten Formation (upper Oxfordian to upper Tithonian) of the Helvetic nappes of eastern Switzerland. Their data show a change in the $\delta^{13}\text{C}$ of + 1‰ in the middle-late Oxfordian, with a minor positive shift in the late Kimmeridgian (~ 0.5‰). A $\delta^{13}\text{C}$ shift of – 1.5‰ is recognised between early and late Tithonian corresponding to a comparable decrease in carbonate carbon-isotope records established in the North Atlantic (Brennecke 1977; Létolle et al. 1978), in the Southern Alps (Weissert & Channell 1989) and in the Umbria-Marche Basin (Hadjji 1991). The positive $\delta^{13}\text{C}$ events of the early Bajocian and middle Oxfordian are recorded in both Southern and Northern Tethyan margin sediments, and the middle Oxfordian event has been found in pelagic and carbonate-platform sediments. Further analysis is required to evaluate the other events.

10. Positive $\delta^{13}\text{C}$ events and the sedimentary record

Positive shifts in carbon-isotope values in biogenic carbonate are conventionally interpreted in terms of local or regional burial patterns of organic carbon. The Early Jurassic

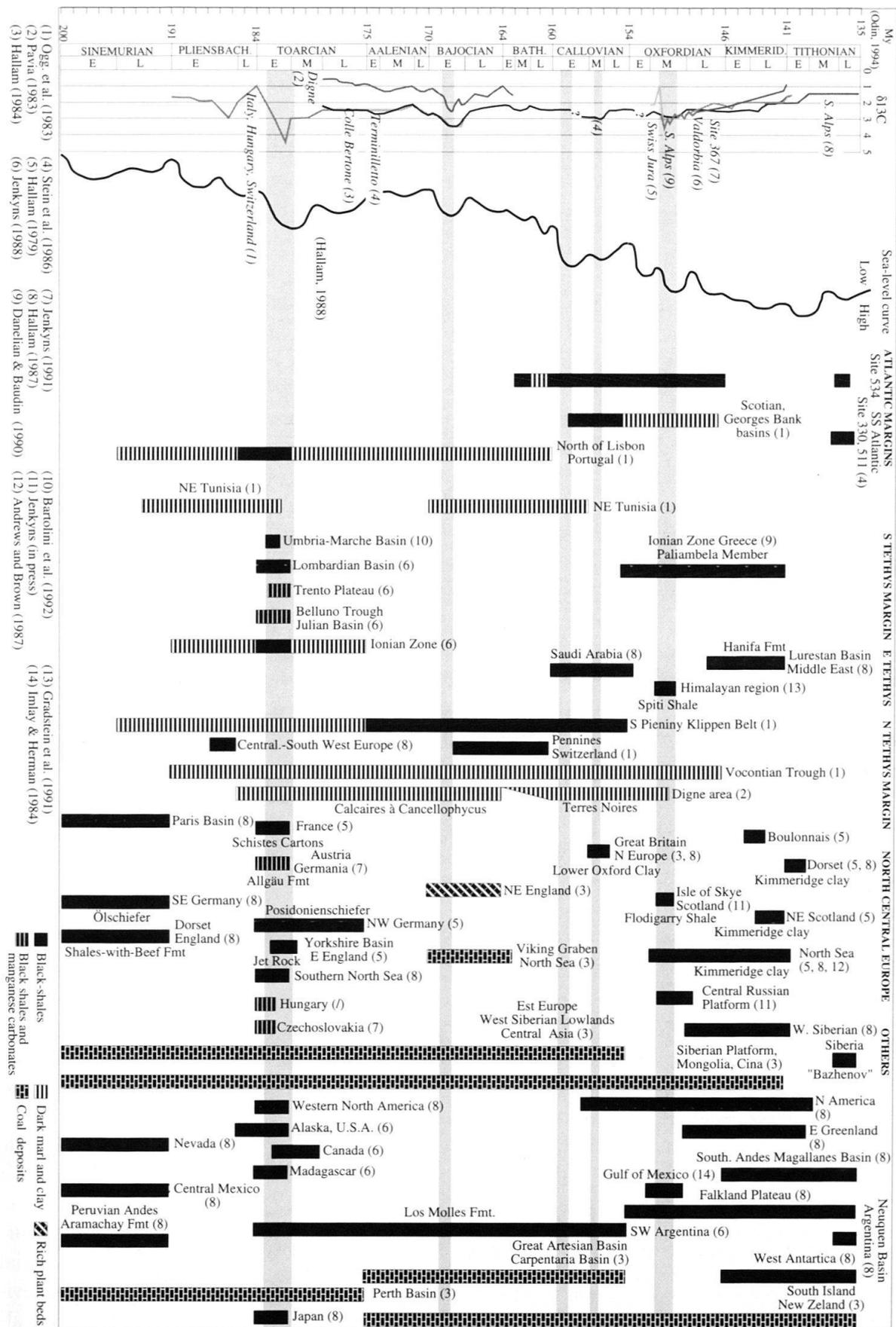
Fig. 9. Tentative correlation between the carbon isotope events described in this paper (grey shading), results published previously, and the sea-level curves of Hallam (1988) and Haq et al. (1987). Sources: (1) Jenkyns (1988, 1991); (2) Corbin (1944); (3) and (4) this paper; (5) Bill et al. (1995); (6) Haidji (1991); (7) Brennecke (1977); (8) Weissert & Channell (1989); (9) Jenkyns (in press). Timescale after Odin (1994) informal stage subdivisions after Gradstein et al. (1994).



Toarcian positive anomaly is clearly related to the deposition of widespread and short ranging black-shales (Fig. 10). For this reason, Jenkyns (1988, 1991) named the early Toarcian event as an "Oceanic Anoxic Event". On the other hand, individual Middle-Late Jurassic carbon isotope shifts cannot be easily related to individual black-shale events. Other positive carbon-isotope excursions that are not accompanied by an obvious "global" marine black-shale record are the Paleocene (Shackleton 1986), the Late Valanginian (Lini et al. 1992) and the mid-Cenomanian (Jenkyns et al. 1994). Storage of terrestrial organic carbon may have to be considered in these cases (Shackleton 1987). Examples of Bajocian black-shales are known in Southern Pieniny Klippen Belt (Ogg et al. 1983) and in Southern Argentina (Los Molles Formation ranging from Pliensbachian to lower Bajocian, Jenkyns 1988). Lower-middle Callovian black shales occur in the Lower-Oxford Clay outcropping in Central-Southern England (Hallam 1987a; Kenig et al. 1994). In the Svalbard, Callovian-Tithonian black-shales are present (Steel & Worsley 1984). In the Central Graben of the North Sea, Callovian hydrocarbons are characteristic of the Pentland Formation (Brown 1989). Ulmishek & Klemme (1990) dated up to 29% of available fossil fuel reserves as Late Jurassic in age. Near Staffin Bay, on the Isle of Skye (Scotland), the mid Oxfordian locally shows a change in facies from sandy siltstones (Digg Siltstone) to bituminous shales and mudstone (Flodigarry Shale) within the *Transversarium* Zone (Jenkyns, in press). Jenkyns (in press) suggested the correlation of the black locally bituminous clay unit in the central Russian platform, (attributed to the *Alternoides* Zone of the upper Oxfordian) with, at least part of, the *Transversarium* Zone of the middle Oxfordian. The black shales of the Nupra Formation (Central Nepal) has yielded a rich ammonite fauna of *Transversarium*-Zone age (Gradstein et al. 1991; Ogg et al. 1992). Stratigraphically wide-ranging black shales, including Oxfordian ones, are documented in Northern Alaska (Upper Kingak Formation, Oxfordian-Kimmeridgian, Embry 1989), in the North American Gulf Coast (Smackover Formation, Oxfordian; Claypool & Mancini 1989, Fails 1990); in the Svedrup basin (Ringnes Formation, Oxfordian-?, Embry 1989), in the Western Barents Sea (Hekkingen Formation, Oxfordian-Berriasian, Dalland et al. 1988), in the Haltenbanken (Norway, Spekk Formation, Oxfordian-Berriasian, Dalland et al. 1988), in the Eastern Rift of the Greenland (Hareelv and Bjernberg Formations, Oxfordian-?, Surlyk 1978), in the North Sea (Brown 1989; Vollset & Dore 1984), in Siberian Basin (Oxfordian and Volgian/Tithonian, Nesterov et al. 1990) and in the Arabian Shield (Oxfordian-Kimmeridgian, Alsharhan 1993).

A more detailed survey on the stratigraphic position of major organic carbon-rich deposits shows major peaks in the Late Oxfordian, the Kimmeridgian and in the Early Tithonian (Hallam, 1987; Ulmishek & Klemme 1990; Doré 1991; Weissert & Mohr, in press), but the $\delta^{13}\text{C}$ curve presents only modest positive excursions. Some other mechanisms must have affected the mass balance of carbon reservoirs and counterbalanced the high organic-matter burial during the Late Jurassic.

Fig. 10. Carbon-isotope events (grey shading) compared to occurrences of organic-rich sediments. Facies and stratigraphic ranges are taken from the indicated literature. The lower Toarcian positive anomaly is clearly related to the deposition of widespread and short ranging black-shales (early Toarcian "Oceanic Anoxic Event", Jenkyns 1988, 1991). In contrast, Middle and Upper Jurassic carbon-isotope events are not easily related to peak occurrences of organic-rich sediments.



The Middle-Late Jurassic was a time of widespread accumulation of radiolarites in Tethys and elsewhere. Until recently, radiolarites were considered to be typically of top Middle and early Late Jurassic age (Jenkyns & Winterer 1982), but their age ranges in fact from Late Triassic to middle Cretaceous (Baumgartner 1987; De Wever 1989; Goricán 1994). The onset of radiolarites over shallow-water carbonates or deeper-water carbonate re-sediments is highly diachronous and may extend from Late Triassic to Late Jurassic in age (Jenkyns and Winterer 1982; Baumgartner 1984, 1987, 1990; De Wever 1989). Detailed biostratigraphic work in many areas (INTERRAD Jurassic-Cretaceous Working Group 1995) (Fig. 11) unravels three privileged times of onset of radiolarite sedimentation: the late early Toarcian, the early-middle Bajocian and the Callovian-Oxfordian. These periods correspond to times of positive $\delta^{13}\text{C}$ shifts.

11. Siliceous versus carbonate sedimentation

A drastic reduction of sedimentation rates on the Lazio-Abruzzi (LA) Platform that began in the middle-late Toarcian, but essentially characterised the Middle and early Late Jurassic, was documented by Colacicchi & Bigozzi (in press). Sedimentation rates dropped from 5–7 cm / 1000 y to 1.3–1.5 cm / 1000 y (Fig. 12). The authors suggested that this drop of carbonate productivity is a general phenomenon, observed also in other areas. Despite the drop in carbonate production, the LA Platform did not drown, but continued to accumulate slowly in the photic zone. This is ascribed to very low subsidence rates (Colacicchi & Bigozzi, in press).

During the Middle and early Late Jurassic, crinoid-bioclust re-sediments were deposited in the most proximal marginal areas (e.g. Sella Dei Due Corni Section, Gran Sasso). According to Föllmi et al. (1994) the dominance of crinoid-bryozoan carbonate production indicates deteriorated platform conditions due to eutrophication. In more distal marginal settings (e.g. Terminilietto section) abundant re-sedimentation of siliceous sponge spicules reflects a crisis of carbonate production and meso-eutrophic sea water conditions on the platform edge (Kitchell 1983; Hallock et al. 1988). In the internal part of the platform cyclothemetic sediments, characterised by an oligotypic community with dominant green algae, accumulated (Bigozzi 1993; Colacicchi & Bigozzi, in press).

During the late Oxfordian/early Tithonian, carbonate productivity recovered on the LA platform. Coral-chetetid patch reefs grew in the marginal areas and established a progradation tendency (Colacicchi & Bigozzi, in press). Reef growth was a widespread phenomenon during this time, both on Southern and Northern Tethyan margins (Wilson 1975; Beauvais 1980; Gygi 1986; Flügel & Flügel-Kahler 1992; Leinfelder et al. 1993), as well as in the Arabian Shield and in Central Asia (Nalivkin 1973; Wilson 1975). During the Kimmeridgian/early Tithonian, colonies of thamnastroid corals became common also on highs of Umbria-Marche Basin (Cecca et al. 1981; Pallini & Schiavinotto 1981).

The drop in platform sedimentation rate during the Middle and early Late Jurassic must correspond to a crisis of carbonate productivity and it is reflected in the basin as a reduction of periplatform ooze input. Our observations in the proximal Terminilietto section allow us to date the onset and the peak of this crisis in carbonate productivity. During the Aalenian/early Bajocian the periplatform ooze input to the basin was substantial (Fig. 12). By middle Bathonian time a sharp decrease of periplatform ooze input is evidenced by much more siliceous sediments. Of course, basinal sedimentation rates are al-

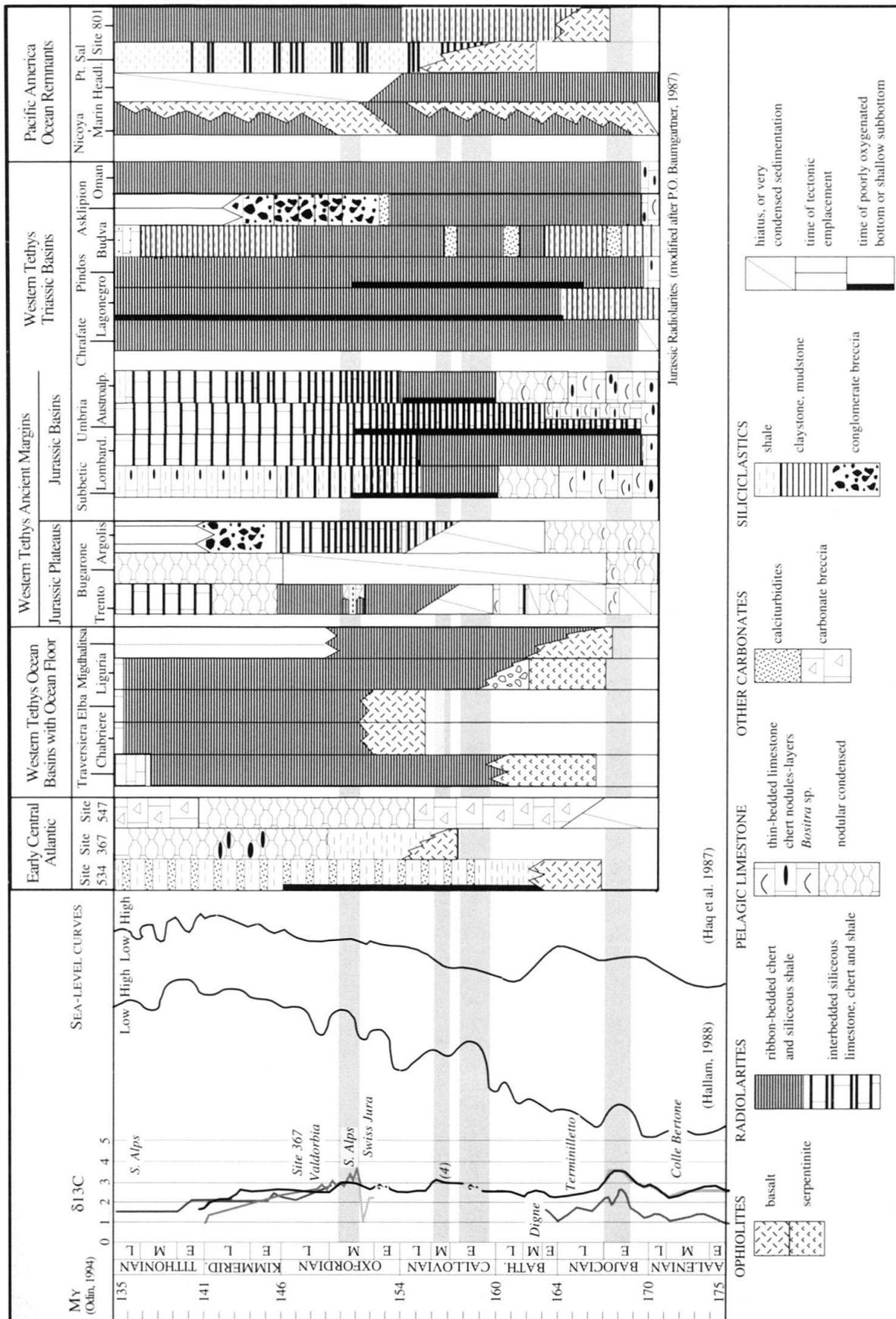


Fig. 11. Carbon-isotope events (grey shading) compared to radiolarite distribution during the Middle-Upper Jurassic. Occurrences of radiolarites and other pelagic lithologies are modified after Baumgartner (1987), and recalibrated in age by INTERRAD Jurassic-Cretaceous Working Group (1995).

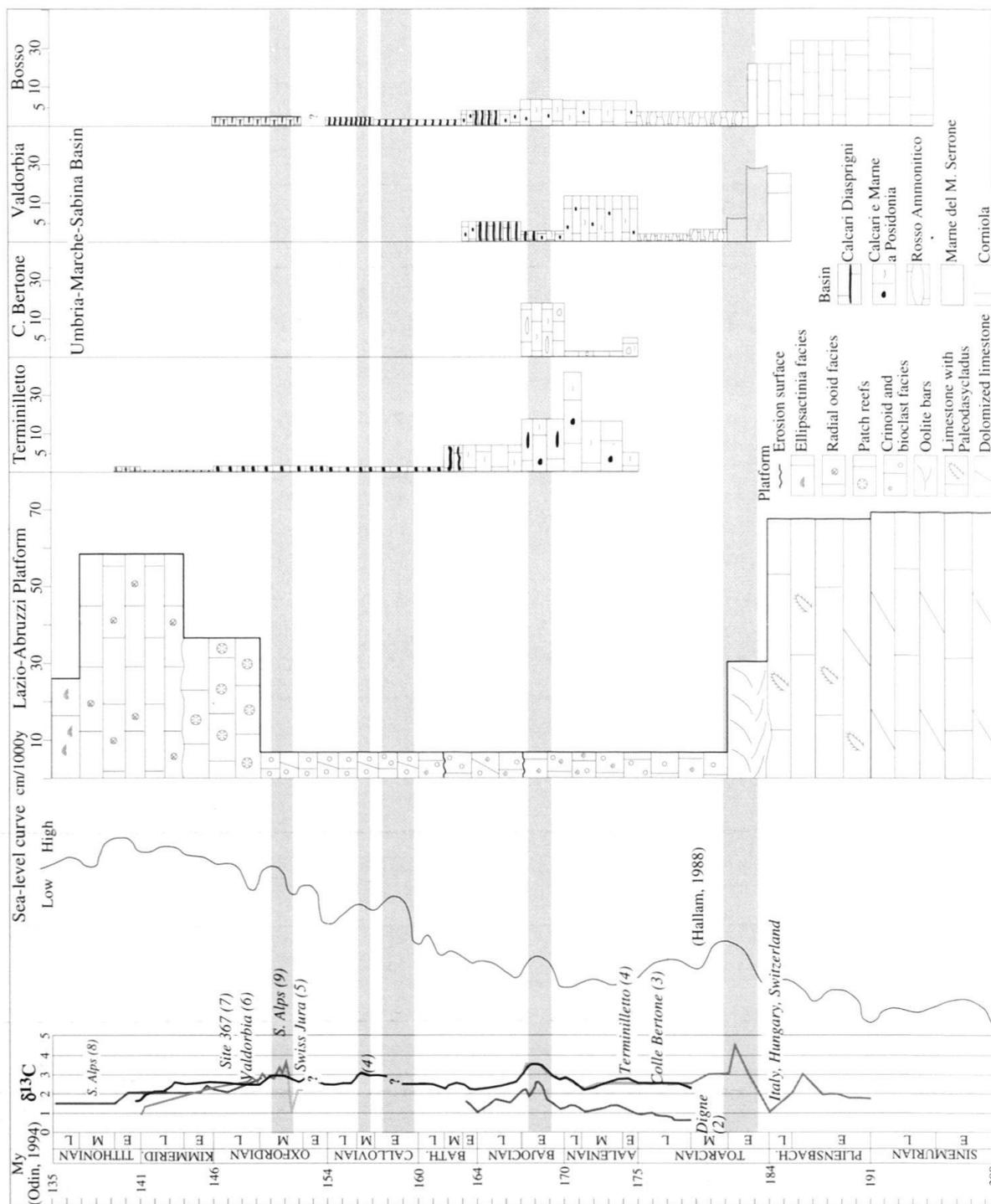


Fig. 12. Carbon-isotope events (grey shading) compared to Jurassic sedimentation rates on the Lazio-Abruzzi Platform (PLA) and some thick Umbria-Marche-Sabina basinal sections. PLA data are after Colacicchi & Bigozzi (in press), TerminiIletto and Colle Bertone data are from the present work; early Jurassic data of the Valdorbria and Bosso sections are respectively after (Monaco et al. 1993) and Cecca et al. (1990); Middle-Late Jurassic data of Valdorbria and Bosso sections are after Baumgartner (1990) and INTERRAD Jurassic-Cretaceous Working Group (1995).

so a function of the distance from the platform, paleotopography and local synsedimentary tectonics.

The onset of radiolarites took place in the deepest part of the UMS basin during the early Bajocian (e.g. Valdorbica section) or the middle-late Bathonian (e.g. Bosso, Terminetto sections), depending on the paleotopography and the paleogeographic position with respect to the platform. Since the middle-late Oxfordian basinal biosiliceous sediments became gradually diluted by carbonate, that was supplied mainly by planktonic nannofossils.

Besides nutrient availability, the presence/absence of radiolarite sedimentation was controlled by dilution by other sediments, such as clays, periplatform ooze or calcareous planktonic ooze (Baumgartner 1987). During the Paleozoic-Jurassic period, however, radiolarians were the only major producers of zooplanktonic skeletal material. Any medium-to high-fertility zone in the Jurassic ocean may have resulted in sufficient radiolarian productivity and preservation to produce radiolarites (Caulet 1974; Renz 1976; Kennett 1982; Baumgartner 1987, 1990; Takahashi 1988; De Wever et al. 1993). Even low-fertility areas may have accumulated siliceous shales at very low rates containing radiolarians as the only fossils (Murchey 1984; Baumgartner 1993; Holdsworth & Nell 1992). In marginal basins such as the Jurassic UMS-basin and most other Western Tethyan basins, carbonate and terrigenous input from the margins largely determined basinal facies evolution. Meso-eutrophic sea-water conditions caused the carbonate productivity crisis and the reduction of periplatform ooze input into the basins. At the same time, meso-eutrophic sea-water conditions favoured high radiolarian productivity. The combined effect of these two tendencies is a change to radiolarite accumulation in the basin.

Radiolarite facies attained a maximum areal extent during the early-middle Oxfordian and encroached onto many submerged platforms and pelagic paleohighs (Baumgartner 1984, 1987, 1990). Soon after, coral buildups became common on Southern Tethyan platforms. The apparent coexistence of radiolarites in basins and coral buildups on platforms is incompatible with a fertility-controlled carbonate/silica sedimentation pattern as developed above. In the Budva Basin (Gorican 1994) pure radiolarites, were deposited during the Oxfordian-Kimmeridgian, while reef buildups developed on the adjacent High Karst margin. These buildups must have prevented periplatform ooze and calciturbidites from entering the basin (bypass situation, Gorican 1994). It is interesting to note that radiolarite accumulation rates were minimal at the same time (Gorican 1994). A similar minimum can be observed in the UMS basin (Baumgartner 1990). At least the late Oxfordian-Kimmeridgian radiolarites of the Budva and other basins could represent slow accumulations in an overall low to medium fertility area, where reefs developed and silica preservation at the bottom was enhanced by silica-rich compaction waters from underlying radiolarites. On the other hand, the apparent coexistence of reefs and radiolarites may result from poor dating of the reefs. In the Swiss Jura, reef buildups (St. Ursanne Formation) rapidly prograde over organic-rich shales (Terrain à Chailles) within the *Transversarium* Zone (mid Oxfordian) (Gygi 1995; Bill et al. 1995). It is likely that the widest expansion of radiolarites coincides with the observed mid Oxfordian $\delta^{13}\text{C}$ peak and precedes the late-middle Oxfordian $\delta^{13}\text{C}$ decline.

12. Carbon burial in carbonates and the carbon isotope record

The Early-Middle Jurassic carbonate production was essentially relegated to the carbonate platforms, with only a small part to calcareous plankton. Nannofacies studies in Lower-Middle Jurassic pelagic limestones in the UMS Basin (Farinacci 1968; Kälin & Bernoulli 1984; Bombardiere 1993; Mattioli 1995) suggest that most of the calcareous portion can be ascribed to periplatform ooze and only a minor part to nannofossils. During Jurassic the isotopic composition of dissolved inorganic carbon in sea-water was probably controlled by the organic-matter burial rate, as well as by the productivity and health state of carbonate platforms (Schidlowski 1987; Weissert and Mohr, in press; Baumgartner et al. 1995). In times of global high platform carbonate productivity, the carbon cycle was dominated by carbon burial in carbonates at $\delta^{13}\text{C}$ values close to zero. This situation tended to stabilise the isotope record and the burial of moderate amounts of negative organic carbon, did not result in evident shift of the isotope curve. On the other hand, during times of crisis in carbonate-platform productivity a small increase of C_{org} burial must have resulted in a positive $\delta^{13}\text{C}$ shift. During part of Middle Jurassic, carbonate platforms suffered from eutrophication and a global carbonate productivity crisis can be postulated. Budyko et al. (1987) calculated that the ratio $C_{\text{carb}}:C_{\text{org}}$ was of 5:1 during the Early Jurassic and changed to 3:1 during the Middle Jurassic. During these times even a moderate increase of organic carbon burial rate became quantitatively important and resulted in positive shifts of the isotope curve. Hence, the scarcity of black-shale records coeval with the Middle Jurassic carbon isotope shifts may turn into a positive argument for the important control of carbonate burial on the Jurassic global isotopic composition of sea water. During the Late Jurassic, organic rich sediments accumulated in many epicontinental basins of North-Eastern Europe, while the productivity of carbonate platforms recovered both on Southern and Northern Tethyan margins. As a result, the Late Jurassic represents a time of high C_{org} burial rate in basins at middle to high latitudes and a re-established growth of carbonate platforms at low latitudes. Budyko et al. (1987) outlined the Late Jurassic as a period of efficient carbonate accumulation with a ratio of $C_{\text{carb}}:C_{\text{org}}$ of 6:1. This explains why late Jurassic $\delta^{13}\text{C}$ shifts are modest, despite a well documented black-shale deposition. According to Weissert and Mohr (in press) these $\delta^{13}\text{C}$ values could reflect a new stabilised mode of carbon cycling with both elevated C_{org} and C_{carb} burial rates during the Late Oxfordian/Early Tithonian.

13. $\delta^{13}\text{C}$ values versus sea-level variations and hydrothermal events

The observed $\delta^{13}\text{C}$ fluctuations can be correlated with global sea-level curves (Haq et al. 1987; Hallam 1988; Fig. 9). The link between high relative sea-level and positive carbon isotope anomalies has been noted in a large number of studies (Tappan 1968; Berger 1977; Fisher & Arthur 1977; Arthur 1982; Broecker 1982; Woodruff & Savin 1985; Jenkyns 1985, 1988; Myers & Wignall 1987; Magaritz & Holser 1990; Weissert & Lini 1991; Hallam 1992; Föllmi et al. 1994; Weissert & Mohr in press; Jenkyns in press). The Jurassic long-term sea level changes were probably induced, in large part, by the variations of spreading rates and mid-ocean ridge volumes.

Jones et al. (1994) produced a detailed curve of strontium isotopic variations in Jurassic and Cretaceous sea water. In their view, the Jurassic $^{87}\text{Sr}/^{86}\text{Sr}$ curve should be more

“sensitive” to the hydrothermal events than weathering, and the downward excursions of $^{87}\text{Sr}/^{86}\text{Sr}$ can be best interpreted in terms of increased hydrothermal activity. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratio decreases from the early Bajocian, correlative with the early Bajocian positive carbon isotope shift. Evident minima of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio have been identified in the early Callovian and early Oxfordian and seem to precede the positive carbon-isotope shifts observed in this study.

Hydrothermal activity due to extensive seafloor spreading and/or rifting phases certainly had their impact on Jurassic climate. The history of atmospheric CO_2 levels and of the global carbon cycle must be mirrored in the marine carbonate carbon isotope curve (-Scholle & Arthur 1980): positive $\delta^{13}\text{C}$ excursions may be regarded as response signals to fluctuations of global climate linked to atmospheric carbon dioxide concentrations (Arthur et al. 1985; Weissert 1989; Hollander & McKenzie 1991; Weissert & Lini 1991; Weissert & Mohr, in press).

During the Bajocian, Callovian and Oxfordian, hydrothermal events may have provoked high atmospheric CO_2 levels and an accelerated carbon cycling (Fig. 13): warmer-humid climate (greenhouse effect) led to an intensified global water cycling with increased continental weathering and runoff and higher input of nutrients (Weissert 1989). Consequently, the biosphere responded to these high energy climates with a hyper-productivity (“biological pumping”, Volk & Hoffert 1985) that tended to remove the excessive CO_2 from atmosphere and bury it in the sedimentary reservoir (Weissert & Lini 1991; Weissert & Mohr in press).

14. Conclusions

The presently available data suggest that rifting and/or oceanic spreading, relative sea-level changes, positive carbon-isotope shifts, carbonate-platform crises and radiolarite onset, may be directly or indirectly linked. Biosiliceous sediments, chiefly radiolarites, are common in oceanic areas throughout the Late Paleozoic and the Mesozoic (Maliva et al. 1989). They become more episodic during the Cretaceous-Tertiary as a result of more efficient calcareous plankton production and probably fundamental differences in silica cycling (Siever 1957; Wollast 1974; Wollast & MacKenzie 1983; Maliva et al. 1989; De Master et al. 1991; Takahashi 1991). Radiolarites and siliceous shales certainly constitute the bulk of pre-Cretaceous oceanic sediments in the Circumpacific and Tethyan realms. Silica accumulation rates, however, may vary by an order of magnitude, as revealed by refined radiolarian biostratigraphy (Baumgartner 1984; Baumgartner 1987; INTERRAD Jurassic-Cretaceous Working Group 1995). Local, regional and global episodes of high silica burial can be determined and related to local, regional or global paleoceanographic and/or paleoclimatic situations. During the Jurassic, episodes of expanding biosiliceous sedimentation are clearly related to times of elevated $\delta^{13}\text{C}$ -values measured in coeval carbonates.

Hydrothermal events related to extensive rifting and/or accelerated oceanic spreading must be the endogenic driving force that created a perturbation of the exogenic system reflected by the positive $\delta^{13}\text{C}$ shifts and biosiliceous episodes (Fig. 13). Global episodes of high silica burial necessitate high silica input into the ocean system by continental weathering and/or hydrothermal input. The silica and the carbon cycles were linked during the Middle-Late Jurassic. Times of increased hydrothermal input of CO_2 lead to high-

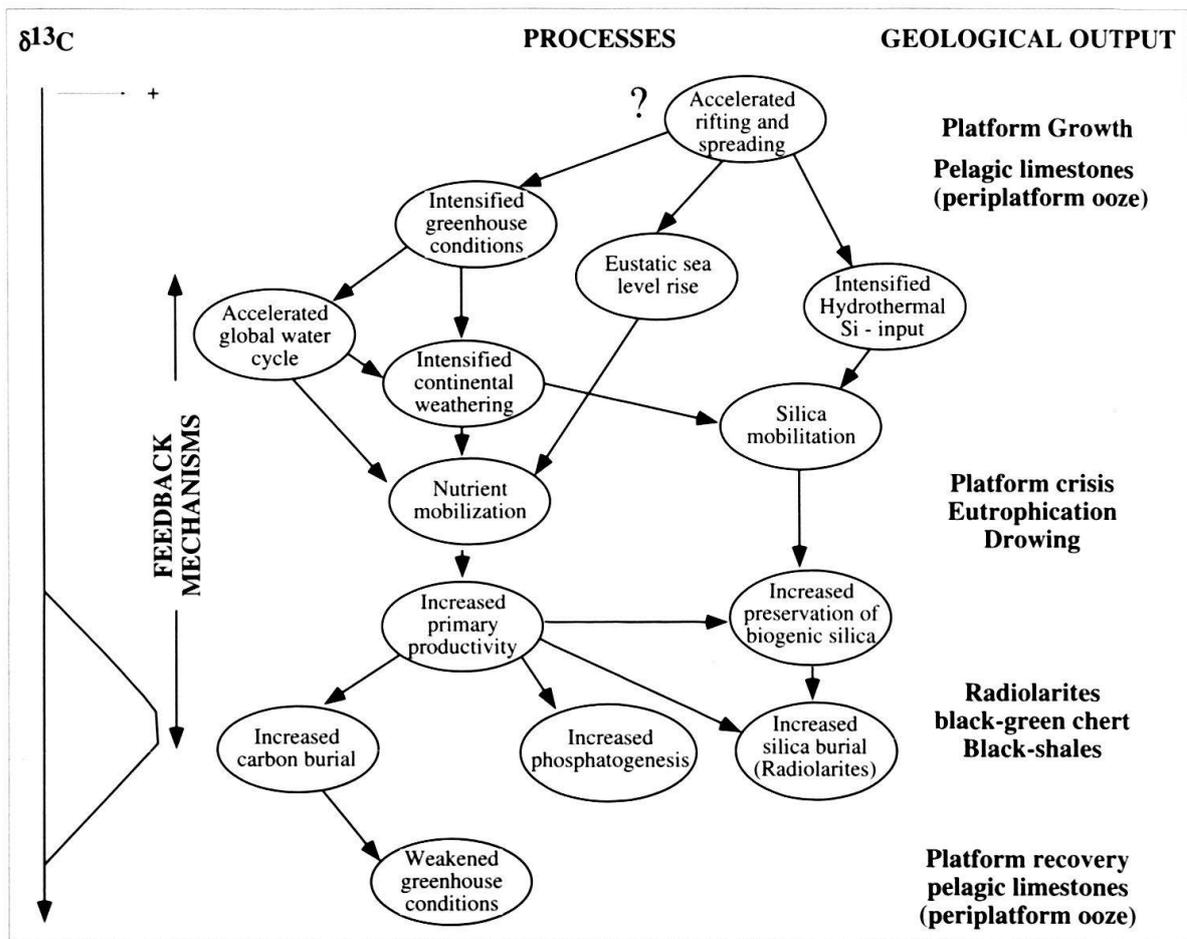


Fig. 13. Flow chart illustrating the links between carbon and silica cycles during the Middle-Late Jurassic, accelerated rifting and/or spreading supposedly was the endogenic force that triggered an exogenic regulation process through feedback mechanisms. It resulted in increased carbon and silica burial that re-established conditions like those prior to the endogenic perturbation. The time axis is from top to bottom without scale. Further explanations in the text (carbon cycle modified after Föllmi et al. 1994).

er atmospheric CO₂ concentrations (greenhouse climate). Intensified continental weathering, which occurred during times of warm-humid climate, caused highest nutrient mobilisation, resulting in increased primary bioproductivity. The increased primary bioproductivity may have resulted both in high organic carbon burial (recorded in coeval carbonates by elevated $\delta^{13}\text{C}$ -values) and in high biosiliceous productivity and preservation. The preservation after deposition of biosiliceous sediments was also enhanced by the high input of silica into the ocean system by continental weathering and hydrothermal activity (Ellis & Baumgartner 1995). The increased nutrient and silica input resulted, therefore, in high organic carbon and high silica burial. In a steady-state ocean an increase in overall silica input must result in an increase of overall silica burial. The areas and the rates of silica burial will, however, be controlled by local, regional and global factors, such as basin configuration and paleocirculation patterns. We stress that high silica burial is the combined result of biological silica fixation, silica input to the water column and preservation on the seafloor and during diagenesis. Increased productivity tends to in-

crease silica preservation on the seafloor, if the recycling within the ocean is kept constant. Alternatively, increased overall silica input may have enhanced silica preservation on the seafloor by reducing the oceanic recycling without necessary changes in productivity.

Efficient burial of organic carbon and silica may occur in similar overall paleoceanographic conditions. Sluggish deep-water circulation and density stratification may have favoured both bottom-water anoxia and saturation in dissolved silica, leading to low C and Si recycling (Siever 1957, 1962; Lewin 1961; Kennet 1982; Koutsoukos & Hart 1990).

In marginal seas surrounded by carbonate platforms, like the Mesozoic Mediterranean Tethys, radiolarite sedimentation competed with the input of periplatform ooze and turbidites (Baumgartner 1987, 1990). Highly siliceous sedimentation took place whenever the production of platform carbonate was subdued or ceased, either by platform drowning or emergence, or by eutrophication. Evidences for platform eutrophication are the dominance of crinoid-bryozoan over coral-oid facies on platform and in resediments, and the abundant sponge spicules in all marginal siliceous sediments. Eutrophication acts both for plankton and benthos in favour of silica secreting organisms and against photosynthetic carbonate secreting communities (Morris 1980; Kennett 1982; Kitchell 1983; Hallock et al. 1988).

Both the Bajocian and the Callovian-Oxfordian are times of peak expansion of siliceous sedimentation in Tethys and elsewhere that can be reasonably explained by a scenario of general eutrophication in a greenhouse climate with concomitant $\delta^{13}\text{C}$ -shifts. Jurassic radiolarites are therefore a "paleoclimatic phenomena" deposited in suitable areas sheltered from terrestrial or periplatform input, possibly related to intensified greenhouse episodes.

Acknowledgements

The research for this publication was largely financed by the Swiss National Science Foundation (Projects granted to P.O. Baumgartner No. 20-36040.92, 20-36047.92 and 2000-042281.94. Projects granted to H. Hunziker No. 20-40756.94). This study has also been supported by grants from MURST 40% and 60% to R. Colacicchi. We acknowledge the fellowship (FNRS/CNR No. 83I-043698) granted to A. Bartolini. We are very grateful for the careful reviews of this manuscript done by Helmi Weissert, Hugh Jenkyns, James Channell and an anonymous reviewer. Interesting discussions with Jim O'Neil and Roberto Colacicchi have enriched this manuscript. We thank Elena Morettini and Maritsa Economo for helpful reading of the manuscript. We also thank Emanuela Mattioli, Raffaella Bucefalo, Anna Bigozzi, Simonetta Cirilli for stimulating discussion and for help in sampling during our enjoyable field trips. We thank Zac Sharp for sharing his laboratory expertise with us.

REFERENCES

- ALSHARHAN, A.S. 1993: The Jurassic of the Arabian Gulf basin: Their facies, depositional setting and hydrocarbon habitat. *Annu. Convention Canad. Soc. Petroleum Geol. Abstr.* 3.
- ALVAREZ, W. 1989: Evolution of the Monte Nerone Seamount in the Umbria-Marche Apennines. *Boll. Soc. geol. Ital.* 108, 23–29.
- ANDERSON, T.F. & ARTHUR, M.A. 1983: Stable isotopes of oxygen and carbon and their application to sedimentologic and paleoenvironmental problems. In: *Stable Isotopes in Sedimentary Geology* (Ed. by ARTHUR, M.A., ANDERSON, T.F., KAPLAN, I. R., VEIZER, J. & LAND, L.S.). SEPM Short Course 10, 3–151.
- ANDREWS, I.J. & BROWN, S. 1987: Stratigraphic evolution of the Jurassic, Moray Firth. In: *Petroleum Geology of North West Europe* (Ed. by BROOKS, J. & FLEET, A.J.). Graham and Trotman, London, 785–795.
- ARTHUR, M.A. 1982: The carbon cycle-controls on atmospheric CO₂ and climate in the geologic past. In: *Climate in Earth History*. Natl. Acad. Press Washington, 55–67.
- ARTHUR, M.A., BRUMSACK, H.C., JENKYN, H.C. & SCHLANGER, S.O. 1990: Stratigraphy, geochemistry, and paleoceanography of organic carbon-rich Cretaceous sequences. In: *Cretaceous resources, events and rhythms* (Ed. by GINSBURG, R.N. & BEAUDOIN, B.). Kluwer Acad. Publishers, 75–119.
- ARTHUR, M.A., DEAN, W.E. & SCHLANGER, S.O. 1985: Variations in the global carbon cycle during the Cretaceous related to climate, volcanism, and changes in atmospheric CO₂. In: *The carbon cycle and atmospheric CO₂: natural variations Archean to Present* (Ed. by SUNDQUIST, E.T. & BROECKER, W.S.). *Monogr. Amer. Geophys. Union Geophys.* 32, 504–529.
- ARTHUR, M.A., KUMP, L.R., DEAN, W.E. & LARSON, R.L. 1991: Superplume, supergreenhouse? *Eos, Trans. amer. geophys. Union Suppl.* 72 (17), 301.
- BARTOLINI, A. 1995: Stratigrafia isotopica ed evoluzione dei radiolari e dei foraminiferi nel Giurassico dell'Appennino Umbro-marchigiano-sabino: una nuova chiave di lettura per l'interpretazione delle Radiolariti. Perugia University, PhD. Thesis (Unpublished), 1–258.
- BARTOLINI, A., NOCCHI, M., BALDANZA, A. & PARISI, G. 1992: Benthic life during the Early Toarcian Anoxic Event in the Southwestern Tethyan Umbria-Marche basin, central Italy. In: *Studies in Benthic Foraminifera* (Ed. by TAKAYANAGI, Y. & SAITO, T.). *Proc. Fourth. Int. Symp. Benthic Foraminifera, Sendai, Japan 1990*, 323–338.
- BARTOLINI, A., BAUMGARTNER, P.O. & MATTIOLI, E. 1995: Middle and Late Jurassic radiolarian biostratigraphy of the Colle Bertone and Terminiletto sections (Umbria-Marche-Sabina Apennines, Central Italy): an integrated stratigraphy approach. In: *Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: Occurrence, Systematics, Biochronology* (Ed. by BAUMGARTNER et al.). *Mém. de Géol. Lausanne* 23, 817–831.
- BAUMGARTNER, P.O. 1984: A Middle Jurassic – Early Cretaceous low latitude radiolarian zonation based on unitary associations and age of Tethyan radiolarites. *Eclogae geol. Helv.* 77, 729–841.
- 1987: Age and genesis of Tethyan Jurassic radiolarites. *Eclogae geol. Helv.* 80, 831–879.
- 1990: Genesis of Jurassic Tethyan radiolarites – The example of Monte Nerone (Umbria-Marche Apennines). *Atti II Conv. Int. F. E. A. Pergola*, 19–32.
- 1993: Early Cretaceous Radiolarian of the Northeast Indian Ocean (Leg 123: Sites 765, 766 and DSDP Site 261), The Antarctic – Tethys Connection. *Marine Micropaleont.* 21, 329–352.
- BAUMGARTNER, P.O., BARTOLINI, A. & HUNZIKER, J. 1995: Jurassic silica and carbon burial history and the fate of Tethyan carbonate platforms. In: *E.U.G. 8 Terra Abstracts, Abstracts Supplement N°1, Terra Nova* 7, 223.
- BEAUVAIS, L. 1980: Evolution des récifs au cours du Jurassique. *Bull. Soc. géol. France* 7, 595–598.
- BERGER, W.H. 1977: Carbon dioxide excursions and the deep sea record: aspects of the problem. In: *The Fate Fossil Fuel CO₂ in the Oceans* (Ed. by ANDERSON, N.R. & MALAHOFF, A.), 505–542.
- BERGER, W.H. & VINCENT, E. 1986: Deep sea carbonates: Reading the carbone-isotope signal. *Geol. Rdsch.* 75, 249–269.
- BERNER, R.A. 1990: Atmospheric carbon dioxide levels over Phanerozoic time. *Science* 249, 1382–1386.
- 1994: Geocarb II: A revised model of atmospheric CO₂ over Phanerozoic time. *Amer. J. Sci.* 294, 56–91.
- BERNER, R.A. & LASAGA, A.C. 1989: Modeling the Geochemical Carbon Cycle. *Sci. American*, 54–61.
- BERNER, R.A., LASAGA, A.C. & GARRELS, R.M. 1983: The carbonate-silicate geochemical cycle and its effect on atmospheric carbon dioxide over the past 100 million years. *Amer. J. Sci.* 283, 641–683.
- BICE, D.M. & STEWART, K.G. 1990: The formation and drowning of isolated carbonate seamounts: tectonic and ecological controls in the northern Apennines. *Spec. Publ. int. Assoc. Sedimentol.* 9, 145–168.

- BIGOZZI, A. 1993: Sedimentologia e Stratigrafia sequenziale di un sistema piattaforma-bacino nel Trias superiore-Giurassico superiore in Appennino centrale. Perugia University, PhD. Thesis.
- BILL, M., BAUMGARTNER, P.O., HUNZIKER, J.C. & SHARP, Z.D. 1995: Carbon isotope stratigraphy of the Liesberg Beds Member (Oxfordian, Swiss Jura) using echinoids and crinoids. *Eclogae geol. Helv.* 88, 135–155.
- BOMBARDIERE, L. 1993: Analisi sedimentologica ed ultrastrutturale del fango carbonatico della Corniola dei massicci perugini (Umbria occidentale) e di alcune sezioni dell'area umbro-marchigiana. *Paleopelagos* 3, 113–127.
- BOSELLINI, A. & WINTERER, E.L. 1975: Pelagic limestone and radiolarite of Tethyan Mesozoic: A genetic model. *Geology* 3 (5), 279–282.
- BRENNECKE, J.C. 1978: A comparison of the stable oxygen and carbon isotope composition of the Early Cretaceous and late Jurassic carbonates from DSDP Sites 105 and 367. In: *Init. Rep. Deep Sea Drill Proj. 41* (Ed. by LANCELOT, V. & SEIBOLD, E.), 937–955.
- BROECKER, W.S. 1982: Ocean chemistry during glacial time. *Geochim. cosmochim. Acta* 46, 1689–1705.
- BROWN, S. 1989: Jurassic. In: *Introduction to the Petroleum Geology of the North Sea* (Ed. by GLENNIE, K.W.), 103–131.
- BUDYKO, M.I., RONOV, A.B. & YANSHIN, A.L. 1987: *History of the earth's atmosphere*. Springer-Verlag, Heidelberg, 1–139.
- CANTELLI, C., CASTELLARIN, A., COLACICCHI, R. & PRATURLON, A. 1982: La scarpata tettonica Mesozoica lungo il settore nord della "linea Ancona-Anzio". *Mem. Soc. geol. ital.* 24, 149–153.
- CASTELLARIN, A., COLACICCHI, R. & PRATURLON, A. 1978: Fasi distensive, trascorrenze e sovrascorrimenti lungo la linea "Ancona Anzio" dal Lias medio al Pliocene. *Geologica rom.* 17, 161–189.
- CASTELLARIN, A., COLACICCHI, R., PRATURLON, A. & CANTELLI, C. 1984: The Jurassic/lower Pliocene history of the Ancona-Anzio line (Central Italy). *Mem. Soc. geol. ital.* 24, 325–336.
- CAULET, J.P. 1974: Les Radiolaires des boues superficielles de la Méditerranée. *Bull. Mus. Natl. Hist. Nat. Sci. de la Terre* 39 (249), 217–288.
- CECCA, F., CRESTA, S., GIOVAGNOLI, M.C., MANNI, R., MARIOTTI, N., NICOSIA, U. & SANTANTONIO, M. 1981: Tithonian "Ammonitico Rosso" near Bolognola (Marche-Central Apennines): a shallow water nodular limestone. In: *Rosso Ammonitico Symp. Proc.* (Ed. by FARINACCI, A. & ELMI, S.), 91–112.
- CHANNELL, J.E.T., ERBA, E. & LINI, A. 1993: Magnetostratigraphic calibration of the Late Valanginian carbon isotope event in pelagic limestones from Northern Italy and Switzerland. *Earth and planet. Sci. Lett.* 118, 145–166.
- CLAYPOOL, G.E. & MANCINI, E.A. 1989: Geochemical relationships of petroleum source rocks of Jurassic Smackover Formation, Southwestern Alabama. *Amer. Assoc. Petroleum Geol.* 73, 904–924.
- COLACICCHI, R. & BIGOZZI, A. in press: Eventi, Cicli e Rapporti fra Piattaforma e Bacini nel Giurassico dell'Italia Centrale. *Boll. Soc. geol. ital.*
- COLACICCHI, R., PASSERI, L. & PIALLI, G.P. 1970: Nuovi dati sul Giurese Umbro-marchigiano ed ipotesi per un suo inquadramento regionale. *Mem. Soc. geol. ital.* 9, 838–874.
- COLACICCHI, R., NOCCHI, M., PARISI, G., MONACO, P., BALDANZA, A., CRESTA, S. & PALLINI, G. 1988: Palaeoenvironmental analysis from Lias to Malm (Corniola to Maiolica formations) in the Umbria-Marche basin Central Italy (Preliminary Report). 2nd Int. Symp. on Jurass. Stratigr., Lisboa 2, 717–728.
- CORBIN, J.C. 1994: Evolution géochimique du Jurassique du Sud-Est de la France: influence des variations du niveau marin et de la tectonique. Paris VI University, PhD. Thesis, 1–175.
- CRESTA, S., CECCA, F., SANTANTONIO, M., PALLINI, G., BRÖNNIMANN, P., BALDANZA, A., COLACICCHI, R., MONACO, P., NOCCHI, M., PARISI, G. & VENTURI, F. 1988: Stratigraphic correlations in the Jurassic of the Umbria – Marche Apennines (Central Italy). 2nd Int. Symp. on Jurass. Stratigr., Lisboa 2, 729–744.
- DALLAND, A., WORSLEY, D. & OFSTAD, K. 1988: A lithostratigraphic scheme for the Mesozoic and Cenozoic succession offshore mid- and northern Norway. *Bull. Norwegian Petrol. Directorate* 4.
- DANELIAN, T. & BAUDIN, F. 1990: Découverte d'un horizon carbonaté, riche en matière organique, au sommet des radiolarites d'Épire (zone ionienne, Grèce): le Membre de Paliambela. *C.R. Acad. Sci. (Paris) II* 311, 421–428.
- DE MASTER, D.J., NELSON, T.M., HARDEN, S.L. & NITTRouer, C.A. 1991: The cycling and accumulation of biogenic silica and organic carbon in Antarctic deep-sea and continental margin environments. *Marine Chem.* 35, 489–502.
- DE WEVER, P. 1989: Radiolarians, radiolarites, and Mesozoic paleogeography of the Circum-Mediterranean Alpine belts. In: *Siliceous deposits of the Tethys and Pacific regions* (Ed. by HEIN, J.R. & OBRADOVIC, J.) Springer-Verlag New York, 31–49.

- DE WEVER, P., AZÉMA, J. & FOURCADE, E. 1993: Radiolaires et radiolarites: production primaire, diagenèse et paléogéographie. *Bull. Cent. Rech. Explor.-Prod. Elf-Aquitaine* 18 (1), 1–379.
- DELANEY, M.L. 1989: Extinctions and carbon cycling. *Nature* 337, 18–19.
- DORÉ, A.G. 1991: The structural foundation and evolution of Mesozoic seaways between Europe and the Arctic. *Paleogeogr. Paleoclimatol. Paleoecol.* 87, 441–492.
- ELLIS, G. & BAUMGARTNER, P.O. 1995: "Austral" shallow-water radiolarites. Implications for the global cycling of silicon and carbon in the Mid.-Cretaceous. In: *E.U.G. 8 Terra Abstracts, Abstracts Supplement N°1, Terra Nova* 7, 225.
- EMBRY, A.F. 1989: Correlation of Upper Paleozoic and Mesozoic sequences between Svalbard, Canadian Arctic Archipelago and Northern Alaska. In: *Correlation in Hydrocarbon Exploration* (Ed. by COLLINSON, J.D.), 89–98.
- FAILS, T.G. 1990: The northern Gulf Coast basin: a classic petroleum province. In: *Classic Petroleum Provinces* (Ed. by BROOKS, J.), 50, 221–248.
- FARINACCI, A. 1968: La tessitura della micrite nel calcare "Corniola" del Lias medio. *Lincei, Rend. Sci. fis. mat. e nat.* XLIV, 284–289.
- FISCHER, A.G. & ARTHUR, M.A. 1977: Secular variations in the pelagic realm. *Spec. Publ. Soc. Econ. Paleontol. Mineral.* 25, 19–50.
- FLÜGEL, E. & FLÜGEL-KAHLER, E. 1992: Phanerozoic reef evolution: Basic questions and database. *Facies* 26, 167–278.
- FÖLLMI, K.B., WEISSERT, H., BISPING, M. & FUNK, H. 1994: Phosphogenesis, carbon-isotope stratigraphy, and carbonate-platform evolution along the Lower Cretaceous Northern Tethyan margin. *Geol. Soc. Amer. Bull.* 106, 729–746.
- GARRISON, R.E. & FISCHER, A.G. 1969: Deep-water limestones and radiolarites of the Alpine Jurassic. In: *Depositional Environments in Carbonates Rocks*. *Spec. Publ. Soc. Econ. Paleontol. Mineral.* 14, 20–56.
- GORICAN, S. 1994: Jurassic and Cretaceous radiolarian biostratigraphy and sedimentary evolution of the Budva Zone (Dinarides, Montenegro). *Mém. de Géol. (Lausanne)* 18, 7–176.
- GRADSTEIN, F.M., GIBLING, M.R., SARTI, M., VON RAD, U., THUROW, J.W., OGG, J.G., JANSÁ, L.F., KAMININSKI, M.A. & WESTERMANN, G.E.G. 1991: mesozoic Tethyan strata of Thakkhola, Nepal: evidence for the drift and breakup of Gondwanaland. *Paleogeogr. Paleoclimatol. Paleoecol.* 88, 193–218.
- GRADSTEIN, F.M., AGTERBERG, F.P., OGG, J.G., HARDENBOL, J., VAN VEEN, P., THIERRY, J. & HUANG, Z. 1994: A Mesozoic time scale. *J. geophys. Res.* 99 (B12), 24,051–24,074.
- GYGI, R.A. 1986: Eustatic sealevel changes of the Oxfordian (Late Jurassic) and their effect documented in sediments and fossil assemblages of an epicontinental sea. *Eclogae geol. Helv.* 79, 455–491.
- 1995: Datierung von Seichtwassersedimenten des Späten Jura in der Nordwestschweiz mit Ammoniten. *Eclogae geol. Helv.* 88, 1–58.
- GRUSZCZYNSKI, M., HOFFMAN, A., MALKOWSKI, K., TATUR, A. & HALAS, S. 1990: Some geochemical aspects of life and burial environments of late Jurassic scleractinian corals from northern Poland. *N. Jb. Geol. Paläont. Mh.* 1990, 673–686.
- HADJI, S. 1991: Stratigraphie isotopique des carbonates pelagiques (Jurassic supérieur/Crétacé inférieur) du Bassin d'Ombrie-Marches (Italie). *Université Paris VI, PhD. Thesis*, 1–118.
- HALLAM, A. 1981: A revised sea-level curve for the early Jurassic. *J. geol. Soc. (London)* 138, 735–743.
- 1984: Continental humid and arid zones during the Jurassic and Cretaceous, *Palaeogeogr. Palaeoclimatol. Palaeocol.* 47, 195–223.
- 1987: Mesozoic marine organic-rich shales. In: *Marine petroleum source rocks* (Ed. by BROOKS, J. & FLEET, A.J.). *Spec. Publ. geol. Soc. London* 26, 251–261.
- 1988: A re-evaluation of Jurassic eustasy in the light of new data and the revised Exxon curve. In: *Sea-Level Change: An integrated Approach* (Ed. by WILGUS, C.K.). 42, 261–273.
- 1992: *Phanerozoic Sea-Level Changes. Perspectives in Paleobiology and Earth History Series*. Columbia University Press, New York.
- HALLAM, A. & BRADSHAW, M.J. 1979: Bituminous shales and oolitic ironstones as indicators of transgression and regression. *J. geol. Soc. (London)* 136, 157–164.
- HALLOCK, P. 1988: The role of nutrient availability in bioerosion: Consequences to carbonate buildups. *Palaeogeogr. Palaeoclimatol. Palaeocol.* 63, 275–291.
- HALLOCK, P., HINE, A.C., VARGO, G.A., ELROD, J.A. & JAAP, W.C. 1988: Platforms of the Nicaraguan Rise: examples of the sensitivity of carbonate sedimentation to excess trophic resources. *Geology* 16, 1104–1107.

- HAO, B.U., HARDENBOL, J. & VAIL, P.R. 1987: Chronology of fluctuating sea level since the Triassic. *Science* 235, 1156–1166.
- HOFFMAN, A., GRUSZCZYNSKI, M., MALKOWSKI, K., HALAS, S., MATYJA, B.A. & WIERBOWSKI, A. 1991: Carbon and oxygen isotope curves for the Oxfordian of central Poland. *Acta geol. pol.* 43, 157–164.
- HOLDSWORTH, B.K. & NELL, P.A.R. 1992: Mesozoic Radiolaria Faunas from the Antarctic Peninsula: age, tectonic and palaeoceanographic significance. *J. geol. Soc. (London)* 149, 1003–1020.
- HOLLANDER, J. & MCKENZIE, J.A. 1991: CO₂ control on carbon–isotope fractionation during aqueous photosynthesis: A paleo-pCO₂ barometer. *Geology* 19, 929–932.
- HSÜ, K.J. 1976: Paleoceanography of the Mesozoic Alpine Tethys. *Spec. Pap. geol. Soc. Amer.* 170, 44.
- INTERRAD Jurassic-Cretaceous Working Group. 1995: Middle Jurassic to Lower Cretaceous radiolaria of Tethys: Occurrences, Systematics, Biochronology. (Ed. by BAUMGARTNER, P.O., O'DOHERTY, L., GORICAN, S., UROUHART, E., PILLEVUIT, A. & DEWEVER, P.). *Mém. Géol. (Lausanne)* 23.
- IMLAY, R.W. & HERMAN, G. 1984: Upper Jurassic ammonites from the subsurface of Texas, Louisiana, and Mississippi. In: *The Jurassic of the Gulf Rim* (Ed. by VENTRESS, W.P.S., BEBOUT, D.G., PERKINS, B.F. & MOORE, C.H.). *Proc. 3rd Ann. Research Conf., Gulf Coast Section, Soc. econ. Paleont. Miner. Foundation*, 149–170.
- JENKYN, H.C. 1985: The Early Toarcian and Cenomanian-Turonian anoxic events in Europe: comparisons and contrasts. *Geol. Rdsch.* 74, 505–518.
- 1988: The Early Toarcian (Jurassic) anoxic event: stratigraphic, sedimentary, and geochemical evidence. *Amer. J. Sci.* 288, 101–151.
- in press: Relative sea-level change and carbon isotopes: data from the Upper Jurassic (Oxfordian) of central and Southern Europe. *Terra Nova*.
- JENKYN, H.C. & CLAYTON, C.J. 1986: Black shales and carbon isotopes in pelagic sediments from the Tethyan Lower Jurassic. *Sedimentology* 33, 87–106.
- JENKYN, H.C. & WINTERER, E. 1982: Palaeoceanography of Mesozoic ribbon radiolarites. *Earth and planet. Sci. Lett.* 60, 351–375.
- JENKYN, H.C., GÉCZY, B. & MARSHALL, J.D. 1991: Jurassic Manganese Carbonates of Central Europe and the Early Toarcian Anoxic Event. *J. Geol.* 99, 137–149.
- JENKYN, H.C., GALE, A.S. & CORFIELD, R.M. 1994: Carbon- and oxygen-isotope stratigraphy of the English Chalk and Italian Scaglia and its palaeoclimatic significance. *Geol. Mag.* 131, 1–34.
- JONES, C.E., JENKYN, H.C., COE, A.L. & HESSELBO, S.P. 1994: Strontium isotopic variations in Jurassic and Cretaceous seawater. *Geochim. cosmochim. Acta* 58 (14), 3061–3074.
- KÄLIN, O. & BERNOULLI, D. 1984: *Schizosphaerella punctulata* DEFLANDRE & DANGERED in Jurassic deeper water carbonate sediments, Mazagan continental margin (hole 547B) and Mesozoic Tethys. In: *Init. Rep. Deep Sea Drill. Proj.* (Ed. by HINZ, K., WINTERER, E.L. et al.) 79, 411–423.
- KÄLIN, O., PATACCA, E. & RENZ, O. 1979: Jurassic pelagic deposits from southern Tuscany; aspects of sedimentation and new biostratigraphic data. *Eclogae geol. Helv.* 72, 715–762.
- KENIG, F., HAYES, J.M., POPP, B.N. & SUMMONS, R.E. 1994: Isotopic biogeochemistry of the Oxford Clay Formation (Jurassic), UK. *J. geol. Soc. (London)* 151, 139.
- KENNETT, J. 1982: *Marine Geology*. Prentice-Hall INC. Englewood Cliffs, 2–813.
- KERRICK, D.M. & CALDEIRA, K. 1993: Paleoatmospheric consequences of CO₂ released during early Cenozoic regional metamorphism in the Tethyan orogen. *Chem. Geol.* 108, 201–230.
- KITCHELL, J.A. 1983: Biotic interactions and siliceous marine phytoplankton, an ecological and evolutionary perspective. In: *Biotic interactions in recent and fossil benthic communities* (Ed. by TEVESZ, M.J.S. & MCCALL, P.L.). *Topics in Geobiology* 3, 285–329.
- KNAUTH, L.P. & EPSTEIN, S. 1975: Hydrogen and oxygen isotope ratios in silica from the JOIDES Deep Sea Drilling Project. *Earth and planet. Sci. Lett.* 25, 1–10.
- KOUTSOUKOS, E.A.M. & HART, M.B. 1990: Radiolarians and Diatoms from the mid-Cretaceous Successions of the Sergipe Basin, Northeastern Brazil: palaeoceanographic assessment. *J. Micropaleont.* 9, 45–64.
- KROOPNICK, P.M., MARGOLIS, P.M. & WONG, C.S. 1977: δ¹³C variations in marine carbonate sediments as indicators of the CO₂ balance between the atmosphere and oceans. In: *The Fate of Fossil Fuel CO₂ in the Oceans* (Ed. by ANDERSON, N.R. & MALAHOFF, A.), 295–321.
- LARSON, R.L. 1991a: Latest pulse of Earth: Evidence for a mid-Cretaceous superplume. *Geology* 19, 547–550.
- LARSON, R.L. 1991b: Geological consequences of superplumes. *Geology* 19, 963–966.

- LASAGA, A.C., BERNER, R.A. & GARRELS, R.M. 1985: An improved geochemical model of atmospheric CO₂ fluctuations over the past 100 million years. In: *The Carbon Cycle and Atmospheric CO₂: Natural Variations Archean to Present* (Ed. by SUNDQVIST, E.T. & BROECKER, W.S.). Amer. Geophys. Union Geophys. Monogr. 32, 397–411.
- LAVECCHIA, G. 1985: Il sovrascorrimento dei Monti Sibillini: analisi cinematica e strutturale. *Boll. Soc. geol. ital.* 101, 161–194.
- LAWRENCE, J.R. 1973: Interstitial water studies, Leg 15 – Stable oxygen and carbon isotope variations in water, carbonates, and silicates from Venezuela basin (Site 149) and the Aves Rise (Site 148). In: *Init. Rep. of Deep Sea Drill Proj.* (Ed. by HEEZEN, B.C., MACGREGOR, I.D. et al.) 23, 939–942.
- LEINFELDER, R.R., NOSE, M., SCHMID, D.U. & WERNER, W. 1993: Microbial crusts of the Late Jurassic: composition, paleoecological significance and importance in reef construction. *Facies* 29, 195–230.
- LÉTOLE, R., RENARD, M., BOURBON, M. & FILLY, A. 1978: O-18 and C-13 isotopes in DSDP Leg 44 carbonates: a comparison with the alpine series. In: *Init. Rep. of Deep Sea Drill Proj. 44* (Ed. by BENSON, W.E. & SHERIDAN, R. E.), 567–573.
- LEWIN, J.C. 1961: The dissolution of silica from diatom walls. *Geochim. cosmochim. Acta* 21 (3–4), 182–198.
- LINI, A., WEISSERT, H. & ERBA, E. 1992: The Valanginian carbon isotope event: a first episode of greenhouse climate conditions during the Cretaceous. In: *Global Change Spec.* (Ed. by WEZEL, F.C.). *Terra Nova* 4, 374–384.
- MAGARITZ, M. & HOLSER, W.T. 1990: Carbon isotope shifts in Pennsylvania Seas. *Amer. J. Sci.* 290, 977–994.
- MALIVA, R.G., KNOLL, A.H. & SIEVER, R. 1989: Secular Change in chert distribution: A reflection of Evolving Biological Participation in the silica cycle. *Palios* 4, 519–532.
- MARSHALL, J.D. 1992: Climatic and oceanographic isotopic signals from the carbonate rock record and their preservation. *Geol. Mag.*, 129, 143–160.
- MARSHALL, J.D. & ASHTON, M. 1980: Isotopic and trace element evidence for submarine lithification of hardgrounds in the Jurassic of eastern England. *Sedimentology* 27, 271–289.
- MATTIOLI, E. 1995: Bacino Umbro Marchigiano: Produttività primaria, Preservazione ed effetti della Diagenesi. Perugia University, PhD. Thesis.
- MCBRIDE, E.F. & FOLK, R.L. 1979: Features and origin of Italian Jurassic radiolarites deposited on a continental crust. *J. sediment. Petrol.* 49, 837–868.
- MCCREA, J.M. 1950: On the Isotopic Chemistry of Carbonates and a Paleotemperature scale. *J. Chem. Phys.* 18, 849–857.
- MONACO, P., NOCCHI, M., ORTEGA-HUERTAS, M., PALOMO, I., MARTINEZ, F. & CHIAVINI, G. 1994: Depositional trends in the Valdorbia Section (Central Italy) during the Early Jurassic, as revealed by micropaleontology, sedimentology and geochemistry. *Eclogae geol. Helv.* 87, 157–223.
- MOPPER, K. & GARLICK, G.D. 1971: Oxygen isotope fractionation between biogenic silica and ocean water. *Geochim. cosmochim. Acta* 35, 1185–1187.
- MORRIS, K.A. 1980: Comparison of major sequences of organic-rich mud deposition in the British Jurassic. *J. geol. Soc. (London)* 137, 157–170.
- MURCHEY, B. 1984: Biostratigraphy and lithostratigraphy of cherts in the Franciscan Complex, Marin Headlands, California. In: *Franciscan Geology of Northern California. The Pacific Section* (Ed. by BLAKE, M.) Soc. econ. Paleont. Mineral. 43, 51–70.
- MYERS, K.J. & WIGNALL, P.B. 1987: Understanding Jurassic organic rich mudrocks- new concepts using gamma-ray spectrometry and paleoecology: examples from the Kimmeridge Clay of Dorset and the Jet Rock of Yorkshire. In: *Marine clastic sedimentology* (Ed. by LEGGETT, J.K. & ZUFFA, G.G.), 172–189.
- NALIVKIN, D.V. 1973: *Geology of the U.S.S.R.* University of Toronto Press, 855.
- NESTEROV, I.I., SALVAMANOV, F.K., KONTOROVICH, A.E., KULAKHMETOV, N.K., SURKOV, V.S., TROFIMUK, A.A. & SHPILMAN, V.I. 1990: West Siberian oil and gas superprovince. In: *Classic Petroleum Provinces* (Ed. by BROOKS, J.) 50, 491–502.
- ODIN, G.S. 1994: Geological Time scale. *C.R. Acad. Sci. Paris* 318 série II, 59–71.
- OGG, J.G., ROBERTSON, A.H.F. & JANSÁ, L.F. 1983: Jurassic sedimentation history of Site 534 (Western North Atlantic) and of the Atlantic-Tethys Seaway. In: *Init. Rep. Deep Sea Drill Proj.* (Ed. by SHERIDAN, R.E., GRADSTEIN, F.M. et al.) 76, 829–884.
- OGG, J.G., GRADSTEIN, F.M., DUMOULIN, J.A., SARTI, M. & BOWN, P. 1992: Sedimentary history of the Tethyan margins of eastern Gondwana during the Mesozoic. In: *Synthesis of Results from scientific Drilling in the Indian Ocean* (Ed. by DUNCAN, R.A., REA, D.K., KIDD, R.B., VON RAD, U. & WEISSEL, J.K.). *Monogr. Amer. Geophys. Union* 70, 203–224.

- PALLINI, G. & SCHIAVINOTTO, F. 1981: The Upper Jurassic coral assemblages in the Umbro-Marchean facies (Central Italy): a survey of their findings and paleoecological meaning. In: Rosso Ammonitico Symp. Proc. (Ed. by FARINACCI, A. & ELMI, S.), Ed. Tecnoscienza Roma, 505–513.
- PAVIA, G. 1973: Ammoniti del Baiociano superiore di Digne (Francia SE, Dip. Basses-Alpes). *Boll. Soc. paleont. ital.* 10 (2), 75–142.
- 1983: Ammoniti e biostratigrafia del Baiociano inferiore di Digne (Francia SE, Dip. Alpes-Haute-Provence). *Mus. Reg. Sci. Nat. Monogr.* 254.
- PISCIOOTTO, K.A. 1981: Diagenetic trends in the siliceous facies of the Monterey Shale in the Santa Maria region, California. *Sedimentology* 28, 547–571.
- PISERA, A., SATIR, M., GRUSZCZYNSKI, M., HOFFMAN, A. & MALKOWSKI, K. 1992: Variation in $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in Late Jurassic carbonates, submediterranean province, Europe. *Ann. Soc. Geol. Pol.* 62, 141–147.
- RENZ, G.W. 1976: The distribution and ecology of Radiolaria in the Central Pacific plankton and surface sediments. *Bull. of the Scripps Instn. Oceanogr. Univ. California, San Diego* 22, 1–267.
- SANTANTONIO, M. 1993: Facies associations and evolution of pelagic carbonate platform/basin system: examples from The Italian Jurassic. *Sedimentology* 40, 1039–1067.
- SCHLAGER, W. & CHERMAK, A. 1979: Sediments facies of platform-basin transition, Tongue of the Ocean, Bahamas. *Spec. Publ. Soc. econ. Paleont. Mineral.* 27, 193–208.
- SCHLAGER, W. & JAMES, N.P. 1978: Low-magnesian calcite limestone forming at the deep sea floor, Tongue of the Ocean, Bahamas. *Sedimentology* 25, 675–702.
- SCHLAGER, W., HOOKER, L. & JAMES, N.P. 1976: Episodic erosion and deposition in the Tongue of the Ocean (Bahamas). *Geol. Soc. Amer. Bull.* 87, 1115–1118.
- SCHLANGER, S.O., ARTHUR, M.A., JENKYN, H.C. & SCHOLLE, P.A. 1987: The Cenomanian-Turonian Oceanic Anoxic Event, I. Stratigraphy and distribution of organic carbon-rich beds and the marine $\delta^{13}\text{C}$ excursion. In: *Marine petroleum source rocks* (Ed. by BROOKS, J. & FLEET, A.J.). *Spec. Publ. geol. Soc. London* 26, 371–399.
- SCHIDLowski, M. 1987: Application of stable isotopes to early biochemical evolution on earth. *Am. Rev. Earth. Planet. Sci.* 15, 47–72.
- SCHOLLE, P.A. & ARTHUR, M.A. 1980: Carbon Isotope Fluctuations in Cretaceous Pelagic Limestones: Potential Stratigraphic and Petroleum Exploration Tool. *Bull. amer. Assoc. Petroleum Geol.* 64, 67–87.
- SHACKLETON, N.J. 1986: Paleogene stable isotope events. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 57, 91–102.
- 1987: The carbon isotope record of the Cenozoic: history of organic carbon burial and of oxygen in the ocean and atmosphere. In: *Marine Petroleum Source Rocks* (Ed. by BROOKS, J. & FLEET, A.J.). *Spec. Publ. geol. Soc. London* 26, 423–434.
- SHACKLETON, N.J. & PISIAS, N.G. 1985: Atmospheric carbon dioxide, orbital forcing, and climate. In: *The Carbon Cycle and Atmospheric CO₂: Natural Variations Archean to Present* (Ed. by SUNDQUIST, E.T. & BROECKER, W.S.). *Monogr. Amer. Geophys. Union Geophys.* 32, 303–317.
- SHARMA T. & CLAYTON, R.M. 1965: Measurement of $^{18}\text{O}/^{16}\text{O}$ ratios of total oxygen of carbonates. *Geochim. cosmochim. Acta* 29, 1347–1353.
- SIEVER, R. 1957: The silica budget in the sedimentary cycle. *Amer. Mineralogist* 42, 821–841.
- 1962: Silica solubility, 0 degrees – 200 degrees C., and the diagenesis of siliceous sediments. *J. Geol.* 70 (2), 127–150.
- STEEL, R. & WORSLEY, D. 1984: Svalbard's post-Caledonian strata: An Atlas of sedimentational patterns and paleogeographic evolution. In: *Petroleum Geology of the North European Margin* (Ed. by SPENCER, A.M.). Graham & Trotman London, 109–136.
- SURLYK, F. 1978: Jurassic basin evolution of East Greenland. *Nature* 274, 130–133.
- TAKAHASHI, K. 1988: Seasonal and Interannual Variability of Radiolarian Productivity and Association with Phytoplankton in the Northeastern Pacific, 1982–1986. In: *First Int. Conf. on Radiolaria (EURAD V)* (Ed. by SCHMIDT-EFFING, R. & BRAUN, A.). *Abstr.*, 36.
- 1991: Mineral flux and biogeochemical cycles of marine planktonic Protozoa-session summary. In: *Protozoa and their role in marine Processes, NATO ASI Conf. Ser., Ser. IV Marine Sci.* (Ed. by REID, P.C., TURLEY, C.M. & BURKILL, P.H.). G25, 347–359.
- TAPPAN, H. 1968: Primary production, isotopes, extinctions and the atmosphere. *Paleogeogr. Paleoclimatol. Paleoecol.* 4, 187–210.
- TONIELLI, R. 1991: Associazioni a radiolari dei “Calcarei e Marne a Posidonia” del Monte Terminilietto (RI). *Paleopelagos* 1, 18–37.

- ULMISHEK, G.F.A. & KLEMME, H.D. 1990: Depositional controls, distribution and effectiveness of worlds petroleum source rocks. U.S. geol. Surv. Bull. 1931, 59.
- VOLK, T. & HOFFERT, M.I. 1985: Ocean Carbon Pumps: Analysis of relative strengths and efficiens in ocean-driven atmospheric CO₂ changes. In: *The Carbon Cycle and Atmospheric CO₂: Natural Variations Archean to Present* (Ed. by SUNDQUIST, E.T. & BROECKER, W.S.). Monogr. Amer. Geophys. Union Geophys. 32, 99–110.
- VOLLSET, J. & DORE, A.G. 1984: A revised Triassic and Jurassic lithostratigraphic nomenclature for the Norwegian North Sea. Bull. Norwegian Petrol. Directorate 3, 53.
- WEISSERT, H. 1989: C-isotope stratigraphy, a monitor of paleoenvironmental change: a case study from the Early Cretaceous. Surv. Geophysics 10, 1–61.
- WEISSERT, H. & BRÉHÉRET, J.G. 1991: A carbonate carbon-isotope record from Aptian–Albian sediments of the Vocontian trough (SE France). Bull. Soc. géol. France 6, 1133–1140.
- WEISSERT, H. & CHANNELL, J.E.T. 1989: Tethyan carbonate carbon isotope stratigraphy across the Jurassic–Cretaceous boundary: an indicator of decelerated Global Carbon Cycling? *Paleoceanography* 4, 483–494.
- WEISSERT, H. & MOHR, H. in press: Late Jurassic climate and its impact on carbon cycling. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*
- WEISSERT, H. & LINI, A. 1991: Ice Age interludes during the time of Cretaceous greenhouse climate? In: *Controversies in modern Geology* (Ed. by MÜLLER, D.W., MCKENZIE, J.A. & WEISSERT, H.). Academic Press New York, 173–191.
- WILSON, J.L. 1975: *Carbonate facies in Geological history*. Springer-Verlag, Berlin, 471.
- WINTERER, E.L. & BOSELLINI, A. 1981: Subsidence and sedimentation on Jurassic passive continental margin, Southern Alps, Italy. Bull. amer. Assoc. Petroleum Geol. 65, 394–421.
- WOLLAST, R. 1974: The silica problem. In: *The Sea* (Ed. by GOLDBERG, E.D.). Wiley-Interscience New York 5, 359–392.
- WOLLAST, R. & MACKENZIE, F.T. 1983: The global cycle of silica. In: *Silicon geochemistry and biochemistry* (Ed. by ASTOR, S.R.). Academic Press New York, 39–76.
- WOODRUFF, F. & SAVIN, S.M. 1985: $\delta^{13}\text{C}$ of Miocene Pacific benthic foraminifera: correlations with sea level and productivity. *Geology* 13, 119–122.

Manuscript received June 12, 1995

Revision accepted March 19, 1996

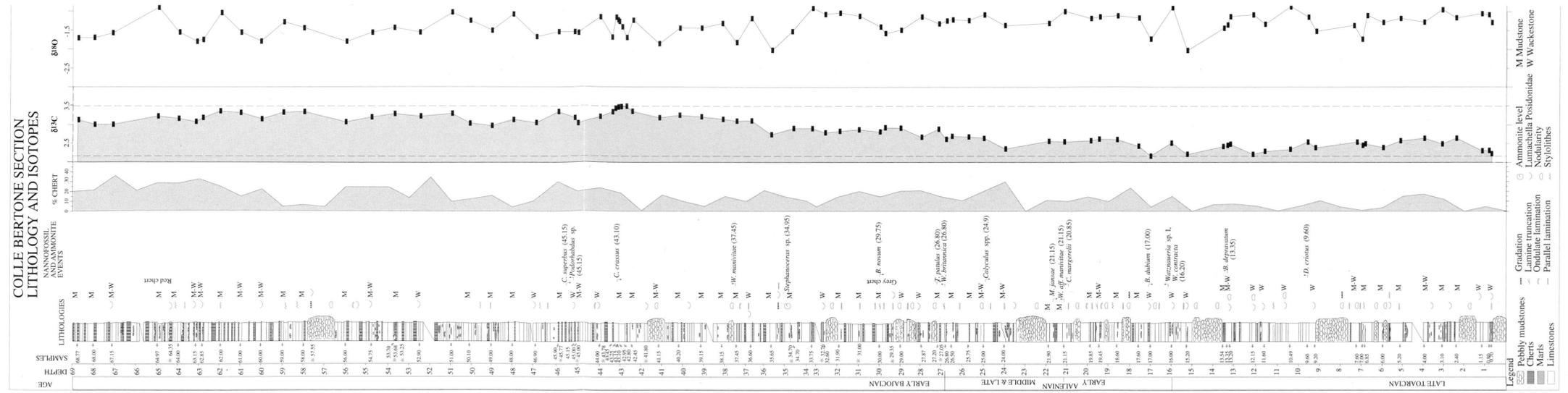


Plate 1. Detailed log of the Colle Bertone section including age, lithology, sample levels, biostratigraphic data, visible chert percentages and stable-isotope stratigraphy.

