Published in Paleoceanography 21, PA4211, 1-16, 2006
which should be used for any reference to this work

# Interactions between environmental change and shallow water carbonate buildup along the northern Tethyan margin and their impact on the Early Cretaceous carbon isotope record

Karl B. Föllmi,[1] Alexis Godet,[1] Stephane Bodin,[1] and Pascal Linder[1]

[1] The evolution of the Early Cretaceous, northern Tethyan carbonate platform was not only influenced by changes in sea level, detrital influx, and surface water temperature but also by changes in trophic levels. We distinguish between phases of carbonate production dominated by oligotrophic photozoan communities and by mesotrophic and eventually colder-water heterozoan communities. Superimposed on this bimodal trend in platform evolution were phases of platform demise for which we provide improved age control based on ammonite biostratigraphy. The initial phase of these episodes of platform demise corresponds in time to episodes of oceanic anoxic events and environmental change in general. On the basis of a comparison between the temporal changes in an Early Cretaceous, ammonite-calibrated $\delta^{13}$C record from southeastern France and coeval changes in the platform record, we suggest that the history of carbon fractionation along the northern Tethyan margin was not only influenced by changes in the oceanic carbon cycle such as in the rate of production and preservation of organic and carbonate carbon and in the size of the oceanic dissolved inorganic carbon reservoir, but it was also influenced by the above-mentioned changes in the ecology and geometry of the adjacent carbonate platform. Phases of photozoan carbonate production induced positive trends in the hemipelagic carbonate $\delta^{13}$C record. Phases of heterozoan carbonate production pushed the $\delta^{13}$C system toward more negative values. Platform drowning episodes implied an initial increase in $\delta^{13}$C values, followed by a longer-term decrease in $\delta^{13}$C values.

## 1. Introduction

[2] Shallow water carbonate successions of Early Cretaceous age are widespread in the western Carpathians, the Alps, southeastern France, the Pyrenees, and the Betic Cordillera [e.g., *Garcia-Hernandez*, 1979; *Pascal*, 1982; *Arnaud-Vanneau and Arnaud*, 1990; *Masse*, 1993; *Funk et al.*, 1993; *Michalík*, 1994; *Föllmi et al.*, 1994; *Bernaus et al.*, 2003]. They embody the remains of an extensive shallow water carbonate platform, which developed along the northern Tethyan margin along a distance of over 2500 km [e.g., *Golonka*, 2004]. The central European portion of the platform is presently locked up in the northern, Helvetic Alps, which extend from southeastern Germany and western Austria through Switzerland to eastern France (Figure 1). The structural architecture of the Helvetic nappe and thrust belt allows for the palinspastic reconstruction of proximal-distal transects across the former platform for distances surpassing 80 km (Figure 2), and the Early Cretaceous platform sediments preserved therein provide therefore excellent insight into the spatial and temporal evolution of this platform. Furthermore, the presence of ammonites in marker horizons within the Helvetic succession is the key to excellent time control.

[3] Of special interest is the observation that the Helvetic platform succession does not only document the influence of regional environmental change such as relative sea level fluctuations, variations in ambient sea surface water temperature, and the type and intensity of detrital influx, but also the impact of global paleoceanographic and paleoenvironmental change, such as modifications in the carbon and phosphorus cycles in association with global oceanic anoxic events [*Föllmi et al.*, 1994; *Weissert et al.*, 1998; *Wissler et al.*, 2003; *van de Schootbrugge et al.*, 2003; *Bodin et al.*, 2006a]. One important indicator of the paleoceanographic influence on the evolution of this carbonate platform system is the near coincidence in timing of the phases of platform demise with episodes of major paleoceanographic change during the Valanginian, Hauterivian, Aptian, and Albian [*Schlanger and Jenkyns*, 1976; *Arthur and Schlanger*, 1979; *Jenkyns*, 1980; *Weissert et al.*, 1979; *Weissert*, 1981; *Schlager*, 1981; *Hallock and Schlager*, 1986; *Erbacher et al.*, 2001; *Leckie et al.*, 2002; *Höfling and Scott*, 2002; *Erba et al.*, 2004].

[4] The changes in carbonate platform growth and the phases of platform demise in association with the global anoxic events had a probable, but poorly quantifiable influence on the marine carbon cycle and associated $\delta^{13}$C

---

[1] Geological Institute, University of Neuchâtel, Neuchâtel, Switzerland.

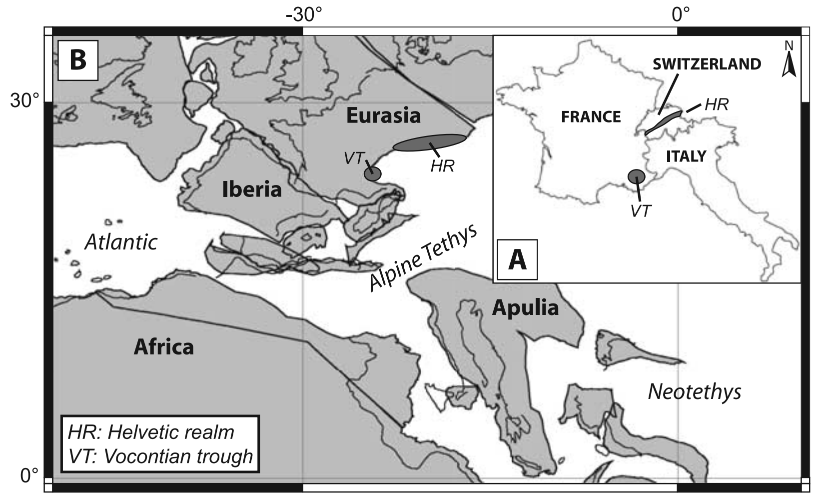

**Figure 1.** (a) Geographic location of the studied areas. (b) Paleogeographic map of the northern Tethyan margin during the late Hauterivian–early Barremian showing the position of the studied areas (modified from *Bodin et al.* [2006a]).

record, in that carbonate carbon burial may have generally been diminished in neritic domains, whereas organic carbon burial may have been increased in general [e.g., *Weissert et al.*, 1998; *Weissert and Erba*, 2004]. Triggering mechanisms for these events proposed so far include modifications in the global output rate of primordial $CO_2$ by episodes of intense volcanic activity, and eventually by the increased release of methane (see, e.g., *Jenkyns* [2003] but also compare *Heimhofer et al.* [2004]).

[5] With this contribution, we give an update on the temporal record of the northern Tethyan carbonate platform exposed in the Helvetic Alps and provide improved time control on the episodes of platform demise by ammonite biostratigraphy, thereby using new data obtained from recently published and ongoing Ph.D. theses [*Kuhn*, 1996; *van de Schootbrugge*, 2001; *Linder et al.*, 2006; *Bodin et al.*, 2006b, 2006c]. We also present a new, high-resolution compilation of $\delta^{13}C$ records for the Early Cretaceous, which has been derived from hemipelagic sections invariably belonging to the Vocontian basin (southeastern France) and its immediate surroundings (Figures 1 and 3). The here presented record is obtained from a single region, thereby precluding the potentially blurring effect related to the accumulation of records from different basins with different environmental and depositional histories. Furthermore, it is derived from a marginal epicontinental basin indented into the northern Tethyan margin, bordered to the north, west, and south by the northern Tethyan carbonate platform [e.g., *Bréhéret*, 1997]. Its proximity to this platform is, for this reason, ideal for a study of the potential interactions between the northern Tethyan platform and the adjacent basin in terms of the carbon cycle. A further important advantage of this record is its calibration by ammonite biostratigraphy, which facilitates its correlation with the record from the Early Cretaceous northern Tethyan shelf environment.

[6] We also propose a novel interpretation of the changes in the here presented $\delta^{13}C$ record, which we view not only as the consequence of ocean-wide changes in the ratio of $C_{carb}$ to $C_{org}$ burial flux rates, and changes in continental output of dissolved inorganic carbon (DIC) and oceanic DIC reservoir size, but also as the result of changes in the ecology and geometry of the adjacent shallow water carbonate platform. We thereby follow up on earlier publications, in which a close link between the Tethyan whole-rock $\delta^{13}C$ record and the evolution of the northern Tethyan carbonate platform was already suggested [*Föllmi et al.*, 1994; *Weissert et al.*, 1998; *Godet et al.*, 2006a].

## 2. Methodology

[7] The sediments of the Helvetic platform have been investigated by a combination of traditional fieldwork consisting of detailed logging and sampling of key sections, the analysis of sedimentological features and determination of biostratigraphically significant fossils (mostly ammonites), and different types of geochemical and mineralogical laboratory analyses (stable carbon and oxygen isotopes, organic matter contents, XRD, XRF, etc.). The data discussed here are extracted from a selection of publications which resulted from a long tradition of research in the Helvetic zone [e.g., *Heim*, 1910–1916; *Fichter*, 1934], and are also based on the results of more recent and still ongoing research projects at the ETH Zürich, and the Universities of Berne, Geneva, and Neuchâtel [e.g., *Mohr*, 1992; *Kuhn*, 1996; *van de Schootbrugge*, 2001].

[8] The here proposed compilation of stable carbon isotopes is based on earlier published work. All data were extracted from whole-rock samples of limestone beds within hemipelagic carbonate and carbonate-marl alternating sections [*Emmanuel and Renard*, 1993; *Moullade et al.*, 1998; *Hennig et al.*, 1999; *van de Schootbrugge et al.*, 2000; *Herrle et al.*, 2004; *Godet et al.*, 2006a]. A small series of stable carbon isotope measurements of Early Cretaceous

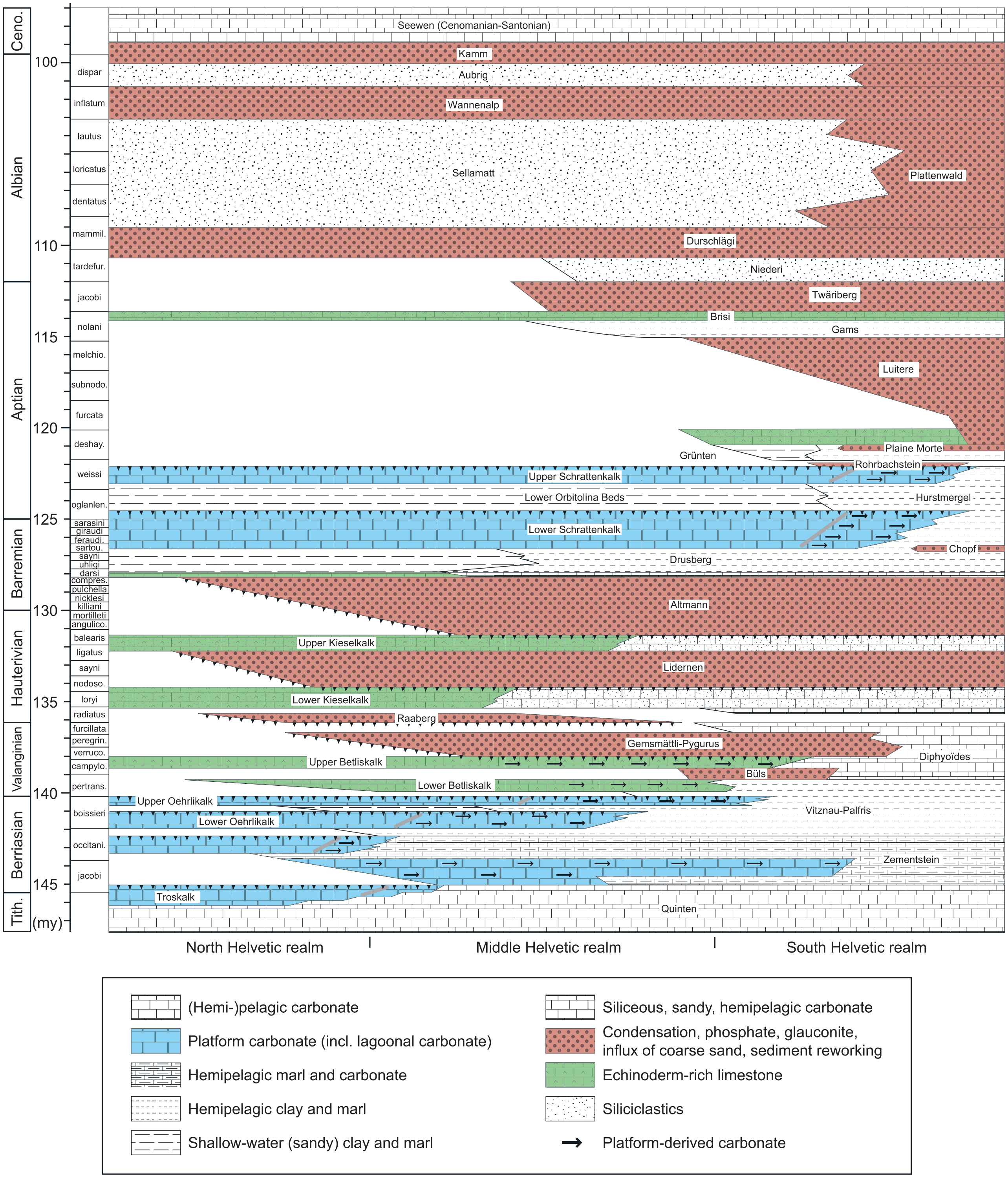

**Figure 2.** Time-space diagram showing the temporal evolution of the distal portion of the northern Tethyan carbonate platform during the Early Cretaceous, based on occurrences in the Helvetic Alps of central and eastern Switzerland (modified from *Föllmi et al.* [1994]). Timescale is after *Gradstein et al.* [2004].

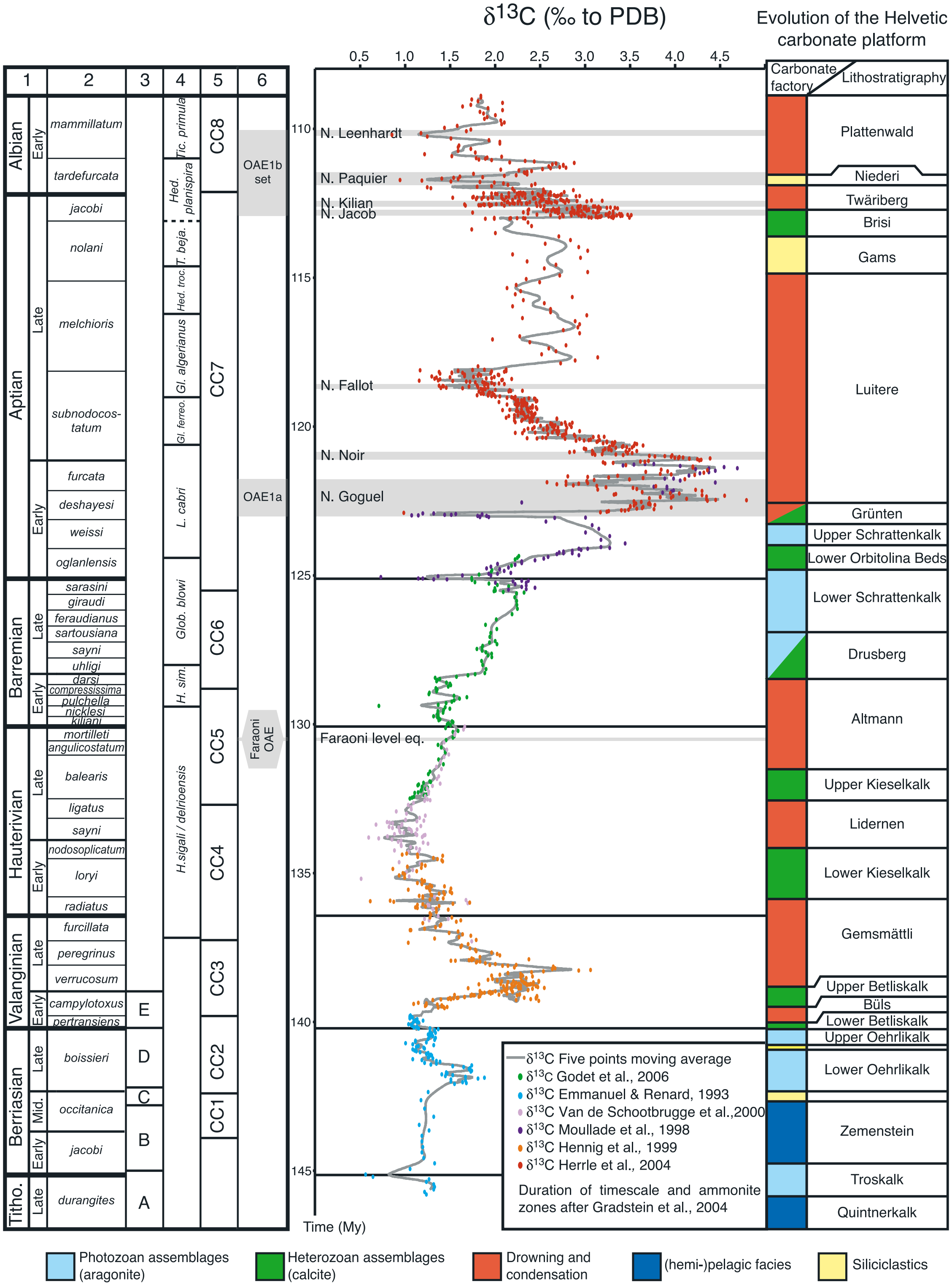

**Figure 3.** Whole-rock carbonate $\delta^{13}$C record from southeastern France. The general trends in the evolution of the northern Tethyan carbonate platform are from Figure 2. On the left side of Figure 3 the numbers on the top of columns refer to 1, stages and substages; 2, ammonite zones; 3, calpionellid zones; 4, planktonic foraminifera zones; 5, calcareous nannoplankton zones; and 6, oceanic anoxic events (all according to *Gradstein et al.* [2004]). Also shown is the timing of the occurrence of organic-rich layers resulting from oceanic anoxic events in the Vocontian basin [after *Bréhéret*, 1997; *Herrle et al.*, 2004; *Bodin et al.*, 2006a].

calcite after aragonite were performed for this study at the geochemistry laboratory, University of Orsay-Paris Sud, by using a VG SIRA 10 triple collector instrument and the methods described by *Godet et al.* [2006a]. The presence of calcite was confirmed at our laboratory (GEA laboratory, University of Neuchâtel) by using a Scintag 2000 XRD device and the methods described by *Adatte et al.* [1996a].

## 3. Evolution of the Early Cretaceous northern Tethyan Carbonate Platform Succession in the Helvetic Alps

[9] During the Early Cretaceous, the northern Tethyan carbonate platform witnessed a series of profound changes in its carbonate-producing platform ecology, which were superimposed by different episodes of platform demise. The external portion of this platform is well documented and dated by ammonite biostratigraphy in the Helvetic zone of the central European Alps [*Wyssling*, 1986; *Föllmi*, 1989b; *Mohr*, 1992; *Kuhn*, 1996; *van de Schootbrugge*, 2001; *Bodin et al.*, 2006b, 2006c], and its distal position determines it as an excellent recorder of the interactions between regional environmental and paleoceanographic change within the Tethyan basin.

[10] Temporal changes in platform paleoecology were essentially between photozoan and heterozoan carbonate-producing communities [*Lees and Buller*, 1972; *Carannante et al.*, 1988; *James*, 1997; *Mutti and Hallock*, 2003]. The preserved photozoan ecosystem includes hermatypic corals, rudists, chaetetids, stromatoporoids, and green algae, whereas the preserved heterozoan community is dominated by sessile crinoids, and includes bryozoans, bivalves, and brachiopods, in addition to variable amounts of siliceous sponge spicules.

[11] Phases of important photozoan carbonate production are discerned for the time periods between the latest Jurassic and the Berriasian-Valanginian boundary (Tros member, Oehrli Formation (Figure 2)), and the late Barremian and early Aptian (*sartousiana* to *weissi* zone: the Urgonian Schrattenkalk Formation [*Bodin et al.*, 2006b; *Linder et al.*, 2006]). These phases are associated with significant buildup and build out of the platform by aggradation and progradation (indicated in blue in Figure 2).

[12] Episodes of carbonate production and distribution by heterozoan communities are documented from the Valanginian (*pertransiens* to *verrucosum* zone: Betlis Formation (Figure 2)), the Hauterivian (*radiatus* to *nodosoplicatum* zone: lower Kieselkalk member; *ligatus* to *balearis* zone: upper Kieselkalk member (Figure 2)), and the Aptian (*deshayesi* zone: Grünten member; *nolani* zone: Brisi Beds (Figure 2)). These phases of heterozoan platform production have led to the aggradation and progradation of large volumes of carbonate (indicated in green in Figure 2). Undecompacted accumulation rates are approximately 50% higher than for those in the photozoan mode [*Föllmi et al.*, 1994].

[13] The construction of the northern Tethyan carbonate platform was interrupted by a series of episodes of platform demise, which each lasted up to several million years (indicated in red in Figure 2). These episodes are registered by hiatuses and erosion surfaces in proximal parts of the Helvetic succession, and by the presence of centimeter to several meters thick glauconite- and phosphate-rich beds in distal parts, which are either highly condensed or allochthonous. These occurrences suggest that carbonate growth was highly reduced during these episodes and that the platform was subjected to important erosion instead [*Heim*, 1910–1916, 1924, 1934; *Heim and Seitz*, 1934; *Ganz*, 1912; *Fichter*, 1934; *Schaub*, 1936, 1948; *Haldimann*, 1977; *Föllmi*, 1989a; *Föllmi and Delamette*, 1991; *Föllmi et al.*, 1994; *Kuhn*, 1996; *van de Schootbrugge*, 2001].

[14] Episodes of platform demise are observed and dated for the periods of the early Valanginian to early Hauterivian (*pertransiens* to *campylotoxus* zone: Büls Bed; *verrucosum* to *radiatus* zone: Gemsmättli-Pygurus and Raaberg Beds (Figures 2 and 4a–4b)), late early to early late Hauterivian (*nodosoplicatum* to *ligatus* zone: Lidernen Bed (Figures 2 and 4c)), latest Hauterivian to latest early Barremian (*balearis* to *darsi* zone: Altmann member (Figures 2 and 4d)), middle late Barremian (*sartousiana* zone: Chopf Bed (Figure 2), early Aptian to middle late Aptian (*deshayesi* zone to *melchioris* zone: Rohrbachstein, Plaine Morte, and Luitere Beds (Figures 2 and 4e and 4f)), and latest Aptian to earliest Albian (*jacobi* to *tardefurcata* zones: Twäriberg Bed (Figure 2)).

[15] The episode of demise associated with the Twäriberg Bed corresponds to the final phase of platform demise in the history of the central European region of the northern Tethyan carbonate platform. Shallow water carbonates younger than the Brisi Beds are not documented. Additional condensed phosphate- and glauconite-rich beds occur in sediments of Albian and early Cenomanian age, which are greatly reduced in thickness and of siliciclastic and hemipelagic facies (Garschella Formation (Figure 2) [see also *Föllmi and Ouwehand*, 1987]). These episodes are dated as *tardefurcata* to *mammillatum* zone (Durschlägi Bed), *inflatum* zone (Wannenalp Bed), and *dispar* zone to middle early Cenomanian (Kamm Bed) (Figure 2). In the distal part of the Helvetic succession, one single condensed phosphate bed occurs, which bundles these former beds and covers most of the Albian and partly also the early Cenomanian (Plattenwald Bed (Figure 2)).

## 4. An Ammonite-Calibrated $\delta^{13}$C Reference Record From Southeastern France

[16] In order to compare the temporal changes in style and intensity of platform carbonate production on the northern Tethyan margin with general changes in the carbon cycle of the Tethyan ocean, we compiled a high-resolution $\delta^{13}$C whole-rock record from hemipelagic successions which were deposited in or near the Vocontian basin (Figure 3). This basin represents a regional depression within the northern Tethyan margin during the Jurassic and Cretaceous, which was bordered by the northern Tethyan carbonate platform (Figure 1) [e.g., *Bréhéret*, 1997]. The data for this compilation were obtained by our research group for the Hauterivian and Barremian intervals [*van de Schootbrugge et al.*, 2000; *Godet et al.*, 2006a], and completed by published

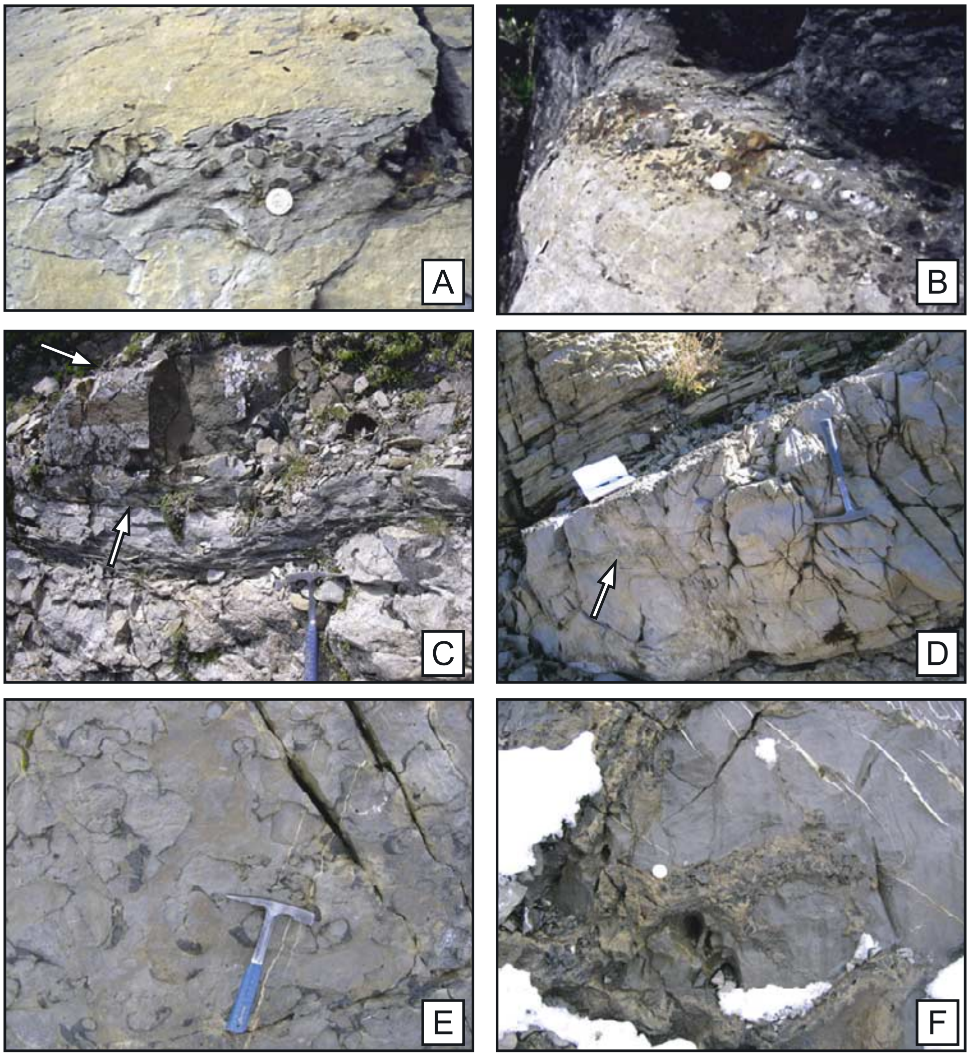

**Figure 4.** Outcrop photos of phosphate- and glauconite-rich beds that formed during the episodes of platform demise along the northern Tethyan margin. (a) Büls Bed (*pertransiens* zone, early Valanginian) [*Kuhn*, 1996]: a thin and probably reworked phosphate nodular layer in hemipelagic limestone of the Palfris and Diphyoides Formations, Büls near Walenstadt, eastern Switzerland. (b) Gemsmättli Bed (*verrucosum* to *radiatus* zone, late early Valanginian to early Hauterivian): a nodular phosphatic bed intercalated in heterozoan platform carbonates of the upper Betlis Member and lower Kieselkalk Member, north of Lake Walen, eastern Switzerland. (c) Lidernen Bed (*nodosoplicatum* to *ligatus* zone, late early to early late Hauterivian): developed here as a glauconite-rich bed (base and top indicated by arrows) following a marly interval on top of the lower Kieselkalk Member, Pilatus, central Switzerland. (d) Altmann Bed (*balearis* to *darsi* zone, late Hauterivian to late early Barremian): a thin layer rich in nodular phosphate that reaches down into the underlying top of the upper Kieselkalk Member by bioturbation (arrow), Rawil, central Switzerland. (e) Plaine Morte Bed (*deshayesi* zone, middle early Aptian): shown here in plain view is the surface of this bed, which consists of nodules of heterozoan carbonate of the Grünten Member, which are peripherically phosphatized, Rawil, central Switzerland. (f) Luitere Bed (*furcata* to *melchioris* zone, late early to middle late Aptian): a sandy and nodular phosphate-rich bed on top of the Grünten Member, which extends locally down into the top layer of the heterozoan Grünten Member through burrow-like structures, Rawil, central Switzerland.

records for the Berriasian, Valanginian, and Aptian [*Emmanuel and Renard*, 1993; *Moullade et al.*, 1998; *Hennig et al.*, 1999; *Herrle et al.*, 2004; cf. also *Wissler et al.*, 2002]. A detailed description and interpretation of the short- and long-term trends in the here compiled northern Tethyan $\delta^{13}$C records is provided in chapter 5.6. The $\delta^{18}$O records show significant offsets in the absolute values and trends between different sections and we refrain therefore from a specific discussion of these data sets (see

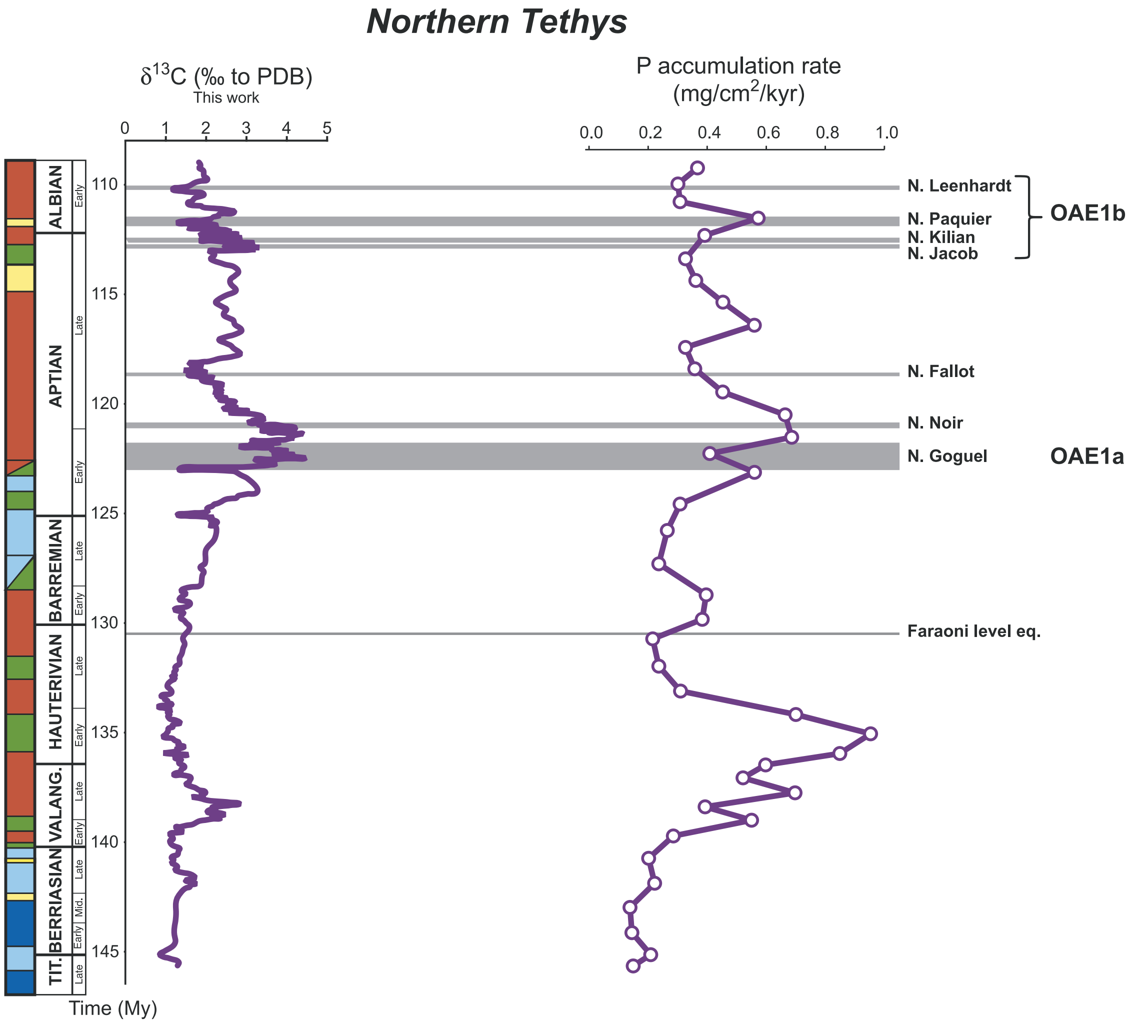

**Figure 5.** Correlation plot of the general trends in the evolution of the northern Tethyan carbonate platform (from Figure 2; see Figure 3 for the legend), the northern Tethyan $\delta^{13}$C record (from Figure 3), and the phosphorus accumulation curve (after *Föllmi* [1995], adapted to the timescale of *Gradstein et al.* [2004]). Also shown is the occurrence of organic-rich layers resulting from oceanic anoxic events in the Vocontian basin [after *Bréhéret*, 1997; *Herrle et al.*, 2004; *Bodin et al.*, 2006a].

*van de Schootbrugge et al.* [2000] for a discussion of this problem).

## 5. Discussion and Interpretations

### 5.1. Correlation Between Episodes of Platform Demise and Paleoceanographic Change

[17] We observe a fairly good correspondence in time between the phases of platform demise and general paleoceanographic change, such as is documented by the occurrence of the oceanic anoxic events (Figure 5). The oldest episode of platform demise started in the earliest Valanginian (*pertransiens* zone) and lasted until the earliest Hauterivian (*campylotoxus* to *radiatus* zone). The onset of this episode appears to predate the onset of the Valanginian "anoxic" event, which was defined to start at the onset of the Valanginian $\delta^{13}$C positive excursion dated as *campylotoxus* zone [*Erba et al.*, 2004; *Weissert and Erba*, 2004]. The phase of most intense phosphogenesis during this episode of demise took, however, place during the *verrucosum* zone [*Kuhn*, 1996], which corresponds exactly to the period of maximum $\delta^{13}$C values during the Valanginian "anoxic" event.

[18] A second episode of platform demise is dated as late early to early late Hauterivian (*nodosoplicatum* to *ligatus* zone), and this phase corresponds to a phase of important sea level change and cold-water inflow into the northern Tethyan realm [e.g., *van de Schootbrugge et al.*, 2003]. A truly anoxic event is, however, not documented from this time period.

[19] The third phase of platform demise started in the latest Hauterivian and lasted until the late early Barremian (*balearis* to *darsi* zone). Also here, the onset of the drowning phase appears to predate the Faraoni oceanic anoxic event, but a major phase of condensation, phospho-

genesis and glauconite formation appears to coincide with this anoxic event [*Bodin et al.*, 2006c].

[20] Also the onset of the fourth phase of drowning in the history of the northern Tethyan carbonate platform (*deshayesi* zone to *melchioris* zone) appears to slightly predate oceanic anoxic event 1a (OAE1a), but this event itself is nicely documented by the presence of a phosphate horizon in distal occurrences of the Helvetic platform (Plaine Morte bed (Figure 2)).

[21] The final drowning episode near the Aptian-Albian boundary coincides with OAE 1b, and younger condensed phosphatic beds (*tardefurcata* to *mammillatum* zone, *inflatum* zone, and *dispar* zone to middle early Cenomanian) all have their equivalent in oceanic anoxic events (OAE 1b upper part, OAE 1c and d) [e.g., *Leckie et al.*, 2002].

[22] With the exception of the late early to early late Hauterivian phase of platform demise, all phases of erosion, condensation, phosphogenesis and platform demise appear to have their counterpart in a paleoceanographic anoxic event, and especially the early intervals in each episode appear to coincide with periods of widespread dysaerobic conditions. The time lag between the onset of platform demise and the start of Early Cretaceous OAE's was already observed earlier [*Föllmi et al.*, 1994] and it is interpreted here as a lag in the response times of both environments to environmental change: the highly sensitive ecological systems of the northern Tethyan platform appears to have responded rapidly to environmental change, whereas it may have taken up to 1 million year for the establishment of conditions in the deeper basins which allowed for the increased accumulation of organic matter.

### 5.2. Changes in Trophic Levels and Changes in Platform Ecology and Morphology

[23] As was already outlined by *Föllmi et al.* [1994] and *Weissert et al.* [1998], we conceive changes in trophic levels as one of the important mechanisms driving the changes in style, architecture, and the efficiency of the northern Tethyan platform and linking the platform evolution with overall paleoceanographic change.

[24] During the Valanginian and Aptian, phases of platform demise start in distal portions of the platform and proceed by onlap of drowning-related sedimentary bodies onto the platform (Figure 2). During the Valanginian, for example, a first pulse of platform demise is registered by the Büls Bed in the most distal sections, and younger sediment bodies related to consequent drowning episodes expand onto the platform in the form of the Gemsmättli and the Raaberg Beds [*Kuhn*, 1996]. These highly condensed phosphate-rich beds formed during periods of progressive sea level rise as part of one or several transgressive system tracts covering major sequence boundaries. In most cases they bundle the effect of a series of successive transgressions into one single and highly condensed bed. The formation of these highly condensed and phosphate-rich beds is related to the influence of deeper-water currents, which arrived onto the platform during times of sea level rise by upwelling, and which were powerful enough to induce a sedimentary regime dominated by erosion and condensation on top of the platform [*Delamette*, 1988; *Ouwehand*, 1987; *Föllmi*, 1989a; *Föllmi and Delamette*, 1991]. These currents are thought to have consisted of cooler water, enriched in nutrients and especially phosphate, and eventually also dissolved $CO_2$. Their arrival on the platform pushed the platform into phases of carbonate production in a heterozoan mode and into the episodes of platform demise. Finally, they arrived from an essentially eastern direction, obliquely onto the platform, whereas the transfer of platform material and water from the platform into the outer shelf and basin occurred in truly proximal-distal directions, approximately perpendicular to the platform, as is indicated in the orientation of channel structures and the direction of turbidites [*Föllmi*, 1989a; *Föllmi and Delamette*, 1991].

[25] An independent confirmation of the importance of trophic levels is the overall good correlation between the record of oceanic phosphorus accumulation and the state of carbonate production on the shelf (Figure 5) [*Föllmi*, 1995; *van de Schootbrugge et al.*, 2003; *Bodin et al.*, 2006a]. A further indication of a link between platform evolution and trophic levels is the coincidence of major positive excursions in the northern Tethyan $\delta^{13}C$ record during the early Valanginian and early Aptian with periods in which the northern Tethyan carbonate platform shifted into a mixed heterozoan, demise mode (indicated by the green and red zones in Figures 2, 3, and 5). These phases of major change in the evolution of the northern Tethyan carbonate platform appear to be marked by major transformations in the ocean carbon cycle, which were highly likely induced by a nutrient-driven change in the ratio of carbonate carbon ($C_{carb}$) to organic carbon ($C_{org}$) burial (see below) [cf. also *Immenhauser et al.*, 2005].

### 5.3. Quality and Correlation of the Northern Tethyan $\delta^{13}C$ Record

[26] The here proposed compilation of the northern Tethyan $\delta^{13}C$ record shows values typical of Early Cretaceous open-marine carbonates [e.g., *Jenkyns and Wilson*, 1999; *Erba et al.*, 1999]. The stratigraphic continuity of data derived from different sections is an indication of the general quality of the $\delta^{13}C$ signal; the only exception is a jump in absolute values at the base of the late Aptian *melchioris* zone, which is likely induced by a change in diagenetic conditions between two sections [*Herrle et al.*, 2004; J. O. Herrle, personal communication, 2005]. Furthermore, the good correlation of the general trend between the here proposed $\delta^{13}C$ curve and other published curves is also an indication of its quality as a recorder of original paleoceanographic change rather than diagenetic overprint (Figure 6). The lack of correlation in a $\delta^{18}O$-$\delta^{13}C$ cross plot for all data ($R^2 = 0.0264$) appears to confirm this interpretation (Figure 7) [e.g., *Godet et al.*, 2006a].

[27] A comparison between the northern Tethyan $\delta^{13}C$ curve and the $\delta^{13}C$ records of the central Tethyan and the Pacific realms [e.g., *Weissert and Channell*, 1989; *Lini et al.*, 1992; *Adatte et al.*, 1996b; *Erbacher et al.*, 1996; *Erba et al.*, 1999; *Jenkyns and Wilson*, 1999; *Bartolini*, 2003] reveals that the long-term trend in the northern Tethyan record fits well with those in the other records, and that especially the two positive excursions during the early

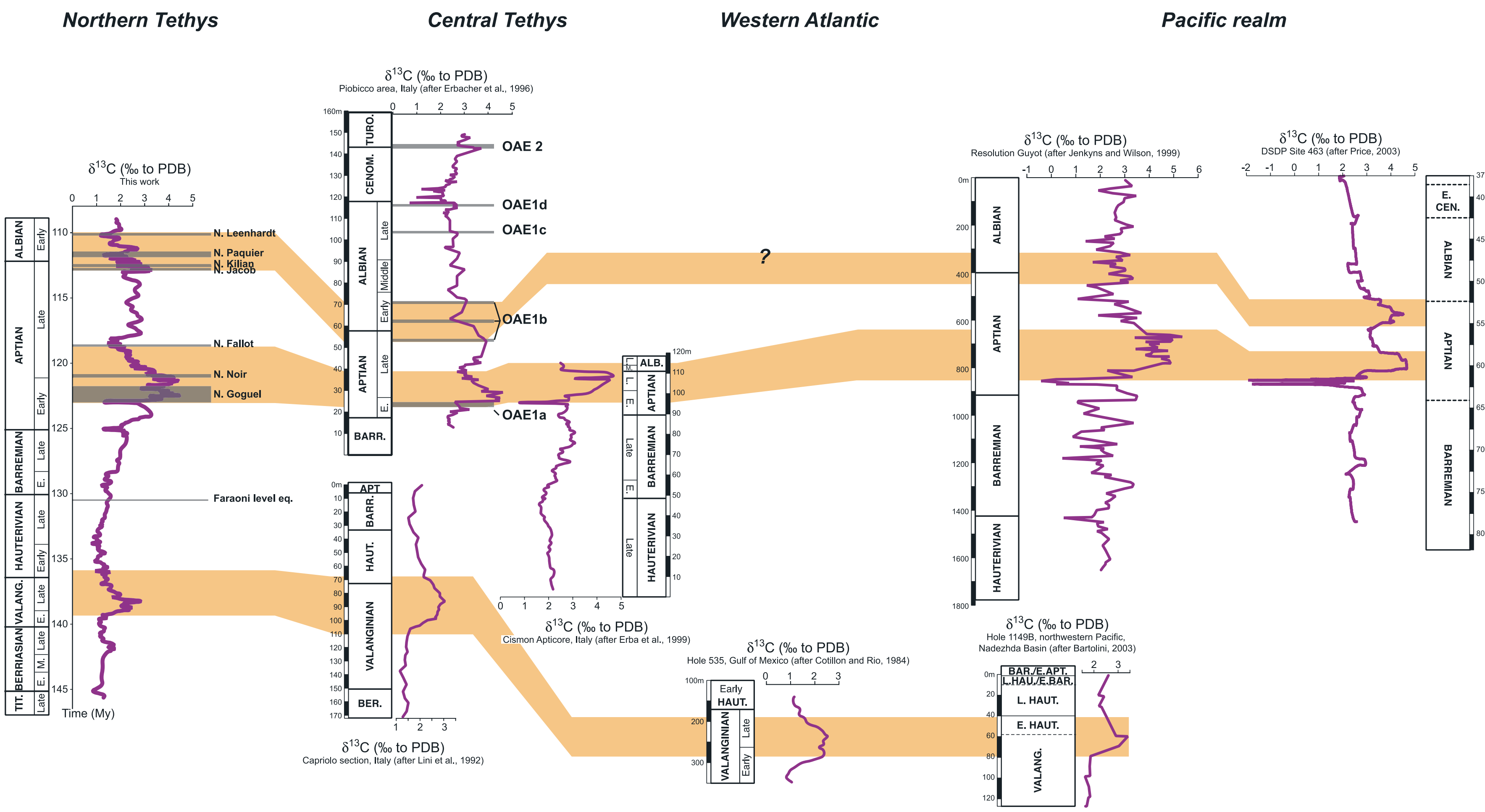
Northern Tethys
Central Tethys
Western Atlantic
Pacific realm
δ13C (‰ to PDB)
This work
Time (My)
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANG.
BERRIASIAN
TIT.
N. Leenhardt
N. Paquier
N. Kilian
N. Jacob
N. Fallot
N. Noir
N. Goguel
Faraoni level eq.
δ13C (‰ to PDB)
Piobicco area, Italy (after Erbacher et al., 1996)
TURO.
CENOM.
BARR.
OAE 2
OAE1d
OAE1c
OAE1b
OAE1a
δ13C (‰ to PDB)
Capriolo section, Italy (after Lini et al., 1992)
APT
HAUT.
VALANGINIAN
BER.
δ13C (‰ to PDB)
Cismon Apticore, Italy (after Erba et al., 1999)
ALB.
?
δ13C (‰ to PDB)
Hole 535, Gulf of Mexico (after Cotillon and Rio, 1984)
Early HAUT.
δ13C (‰ to PDB)
Resolution Guyot (after Jenkyns and Wilson, 1999)
δ13C (‰ to PDB)
DSDP Site 463 (after Price, 2003)
E. CEN.
δ13C (‰ to PDB)
Hole 1149B, northwestern Pacific, Nadezhda Basin (after Bartolini, 2003)
BAR./E.APT.
L.HAU./E.BAR.
L. HAUT.
E. HAUT.
VALANG.

Figure 6

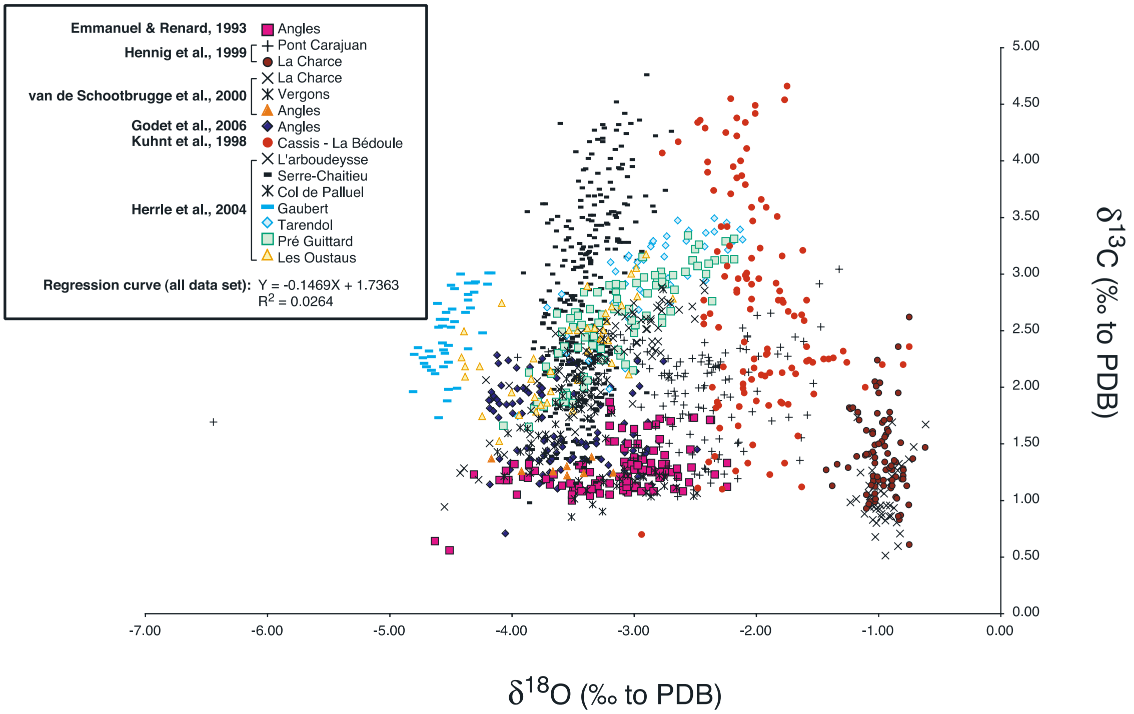

**Figure 7.** The $\delta^{13}C$-$\delta^{18}O$ cross plot of all data used in the $\delta^{13}C$ compilation of Figure 3.

Valanginian and early Aptian are well reproduced (Figure 6). The evolution of the intervals between the major positive excursions is characterized by rather irregular and locally noisy trends, which are, in general, not very well correlated, neither between sections between different oceans nor within the same basin.

[28] We suggest here that whereas the large positive excursions of the early Valanginian and early Aptian are well correlated between the Tethys and the Pacific realms and appear to be a truly global phenomenon, the smaller-scale excursions of the remaining intervals in the Early Cretaceous represent most likely a response to local to regional changes in the carbon cycle.

### 5.4. Potential Mechanisms Driving the Marine $\delta^{13}C$ Record

[29] The (hemi)pelagic $\delta^{13}C$ record provides an important tracer of reorganization within the marine carbon cycle [e.g., *Kump and Arthur*, 1999; *Veizer et al.*, 1999], and temporal changes therein are traditionally interpreted as an approximation of changes in the ratio of burial fluxes of $C_{carb}$ and $C_{org}$ [e.g., *Scholle and Arthur*, 1980; *Arthur et al.*, 1988; *Weissert*, 1989; *Hoefs*, 1997; *Weissert et al.*, 1998]. Additional factors of important influence on the marine $\delta^{13}C$ record consist in the quality and flux of externally derived carbon species into the (hemi)pelagic marine realm, such as terrestrial and platform-derived $C_{org}$ and dissolved inorganic carbon (DIC), atmospheric $CO_2$, or methane derived from the dissociation of clathrates [*Cerlings et al.*, 1993; *Dickens et al.*, 1995; *Kump and Arthur*, 1999; *Immenhauser et al.*, 2003; *Weissert and Erba*, 2004; *Swart and Eberli*, 2005; *Panchuk et al.*, 2005, 2006]. Furthermore, *Bartley and Kah* [2004] recently suggested a close relationship between the size of the marine DIC reservoir and the sensitivity of the marine $\delta^{13}C$ system to changes in the carbon cycle.

[30] As we will detail out in the following, a combination of these factors influenced the northern Tethyan Early Cretaceous $\delta^{13}C$ record, whereby the precise identification of the relative importance of each factor remains a difficult task. In our interpretation, we especially pay attention to the potential effect of the export of particulate and dissolved inorganic carbon (PIC and DIC) from the northern Tethyan carbonate platform and adjacent European continent, and changes therein, on the here described $\delta^{13}C$ record. We postulate that the smaller temporal shifts in the northern Tethyan $\delta^{13}C$ record, which are not correlated on a wider scale and for which a local or regional cause is to be sought, were influenced by this phenomenon.

**Figure 6.** Correlation of the northern Tethyan $\delta^{13}C$ record with $\delta^{13}C$ records from the central Tethys, the western Atlantic, and the Pacific realms [from *Cotillon and Rio*, 1984; *Lini et al.*, 1992; *Adatte et al.*, 1996b; *Erbacher et al.*, 1996; *Erba et al.*, 1999; *Jenkyns and Wilson*, 1999; *Bartolini*, 2003; *Price*, 2003]. Note that whereas the northern Tethyan $\delta^{13}C$ record is calibrated against Early Cretaceous time [*Gradstein et al.*, 2004], the other records shown here are plotted against their lithostratigraphy. Note also that for the northern Tethyan $\delta^{13}C$ record, the central Tethyan record by *Erba et al.* [1999], and the Pacific record by *Price* [2003], a five-point moving average is shown, whereas for the remaining records, all measured data are shown.

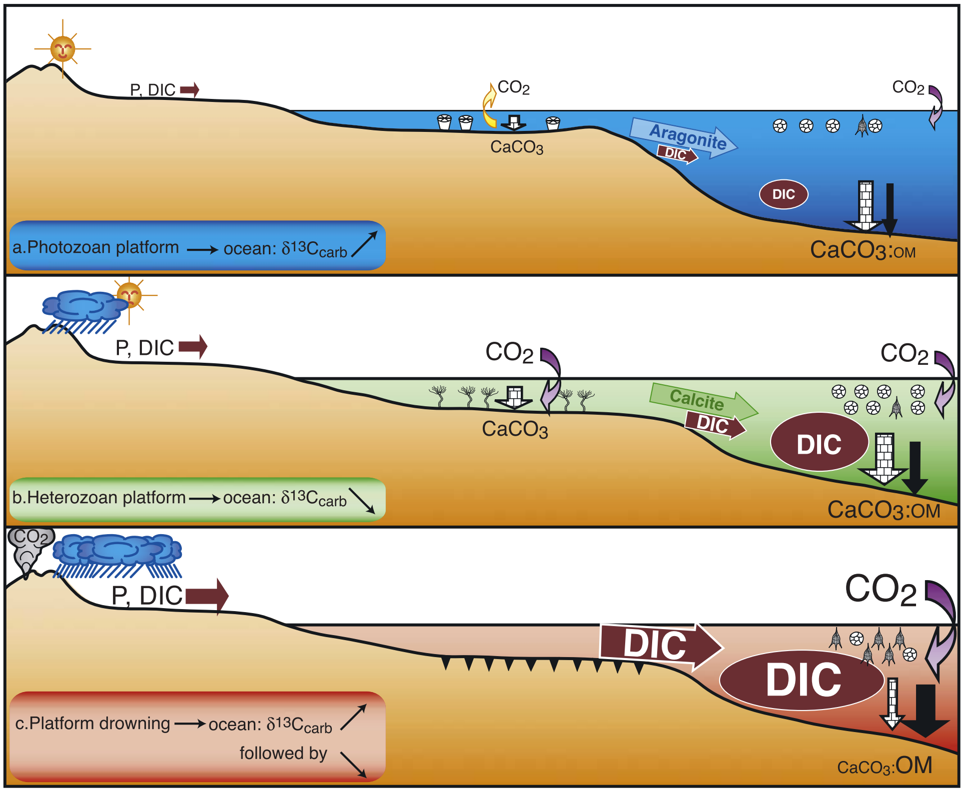

**Figure 8.** Schematic overview of the potential impact of the different stages in the evolution of the northern Tethyan platform on the oceanic carbon cycle and $\delta^{13}$C record. Differences in flux rates of dissolved inorganic carbon (DIC) into the ocean and burial rates of $C_{carb}$ and $C_{org}$ are indicated by different sizes in arrows and characters.

[31] There are several reasons for this assumption:

[32] 1. On the basis of a quantification of calcareous nannofossils in the hemipelagic carbonates of the Vocontian basin, *Reboulet et al.* [2003] were able to show that for the Valanginian sections, hemipelagic carbonate accumulation in this marginal basin was for a large part controlled by the export rate of platform-derived carbonate ooze, rather than by depositional rates of pelagic calcareous plankton (see also *Colombié and Strasser* [2003] for a similar interpretation of late Jurassic carbonate beds in Vocontian sections). The influence of shedding of shallow water carbonate mud into the adjacent basin is also indicated by the important decrease in carbonate accumulation in the Vocontian basin during periods of platform demise, such as during the *pertransiens* and *verrucosum* zone (Valanginian [e.g., *Reboulet et al.*, 2003]), and the late early to early late Aptian [e.g., *Bréhéret*, 1997].

[33] 2. As will be shown below, the timing and the negative or positive character of the shifts in the northern Tethyan $\delta^{13}$C record appear to be correlated to changes in the style and intensity in carbonate production on the northern Tethyan platform.

[34] 3. A numerical model published by *Godet et al.* [2006a] suggests that the export of platform-derived carbonate and especially aragonite may have an impact on the $\delta^{13}$C record in adjacent basins.

### 5.5. Changes in the Ecology and Geometry of the Northern Tethyan Carbonate Platform and Its Influence on the Northern Tethyan $\delta^{13}$C Record

[35] There are several mechanisms related to the predominant ecosystem and geometry of the Early Cretaceous northern Tethyan carbonate platform, which may have influenced the hemipelagic $\delta^{13}$C record described here (Figure 8). The northern Tethyan carbonate platform was constituted by photozoan and/or heterozoan ecosystems. The photozoan community included hermatypic corals, rudists, stromatoporoids, chaetitids, and green algae as its main constituents [e.g., *Bollinger*, 1988; *Mohr*, 1992; *Föllmi et al.*, 1994]. Of interest here is that these organisms precipitated their hard parts predominantly in aragonite [e.g., *Morycowa*, 1980; *Wefer and Berger*, 1991]. This is also true for the Early Cretaceous rudists, which had relatively thick aragonite shells covered by a thin calcitic layer [*Steuber*, 2002]. The participation of photosynthetic organisms in the form of green and zooxanthellic algae was important and the overall high photosynthetic rates in photozoan communities may have increased $\delta^{13}$C values in skeletal aragonite. Fractionation toward more positive $\delta^{13}$C values was likely also related to the geometry of the photozoan platform, which was confined by marginal reef buildups and oolitic shoals [*Linder et al.*, 2006; *Godet et al.*, 2006b], thereby promoting carbon recycling within the platform [e.g., *Swart and Eberli*, 2005; *Panchuk et al.*,

2005, 2006]. Furthermore, in single carbonate systems, aragonite $\delta^{13}C$ values tend generally to be higher than calcite $\delta^{13}C$ values [*Romanek et al.*, 1992]. For instance, *Swart and Eberli* [2005] reported $\delta^{13}C$ values of maximal +5‰ for aragonite on the present-day Bahamian platform. A preliminary isotopic survey of platform-derived skeletal material which consists of calcitized aragonite appears to confirm the high initial values for Early Cretaceous aragonite for samples from the Gargano platform (Italy; sample obtained from Jean-Pierre Masse: $\delta^{13}C$ value = +5‰) and the north Mexican and Texan carbonate platforms ($\delta^{13}C$ values between 2.3–4.3‰; n = 24, mean value = +3.3‰ [*Woo et al.*, 1993]).

[36] The Early Cretaceous was characterized by broad epicontinental seas and widespread carbonate platforms [e.g., *Philip*, 2003] and aragonite production rates may have been significant in photozoan shallow water communities in general. The export of this mineral into adjacent basins during, for example, storm events and probably also more generally through the process of platform build out by the formation of progradational carbonate wedges influenced the northern Tethyan $\delta^{13}C$ signal as a whole either by direct incorporation into pelagic sediments or by dissolution and transfer into the marine DIC reservoir [e.g., *Droxler et al.*, 1983; *Swart and Eberli*, 2005; *Godet et al.*, 2006a]. The potential influence of aragonite shedding on the $\delta^{13}C$ signature in carbonates of the Vocontian basin has been modeled by *Godet et al.* [2006a]. They were able to show that the presence of 20% aragonite in the total depositional rate of carbonate may increase the $\delta^{13}C$ signature by 0.2‰, in the case the initial value is at 2‰, and the initial aragonite $\delta^{13}C$ value is set at 5‰.

[37] In analogy to modern tropical carbonate platforms [*Kawahata et al.*, 1997; *Suzuki et al.*, 2001; *Suzuki and Kawahata*, 2003, 2004], the confined geometry of photozoan platforms may also have had an effect on the air-sea exchange of $CO_2$. We assume that most $CO_2$ derived from respiration of organic matter, precipitation of carbonate, and river influx was directly returned to the atmosphere, rather than transported laterally into deeper waters. This means that photozoan platforms were a likely source of $CO_2$ to the atmosphere. This also signifies that a nonnegligible part of continentally derived DIC was returned to the atmosphere as $CO_2$ or stored as platform carbonate, rather than transferred into the deep basin. All by all, the dominance of photozoan carbonate platforms may have pushed the oceanic $\delta^{13}C$ system toward more positive values both by increased aragonite exportation and by decreased output of platform-derived DIC and throughput of continentally derived DIC (Figure 8). The possibility that the Early Cretaceous photozoan platform acted as a source of $CO_2$ to the atmosphere rather than a sink signifies also that this system was less vulnerable toward changes in atmospheric $pCO_2$ [cf. *Wissler et al.*, 2003; *Weissert and Erba*, 2004].

[38] Early Cretaceous heterozoan ecosystems consisted predominantly of respiring organisms such as crinoids, thick shelly bivalves, brachiopods, and bryozoans, which precipitated their hard parts mainly in calcite [e.g., *Sprinkle and Kier*, 1987; *Smith et al.*, 1998; *Flügel*, 2004]. Early Cretaceous heterozoan platforms consisted of homoclinal or distally steepened ramps with good connections to the adjacent basin [e.g., *James*, 1997; *Linder et al.*, 2006]. Very few benthic photosynthetic organisms are preserved from the heterozoan assemblages and benthos-related photosynthetic processes may have been less important, at least in comparison to the photozoan carbonate platform. Because of the specific fractionation pattern of heterozoan organisms and the open-platform architecture, the overall $\delta^{13}C$ signal of precipitated calcite is less positive in comparison to that of aragonite in photozoan platforms [e.g., *Wefer and Berger*, 1991; *Swart and Eberli*, 2005]. In addition, the heterozoan mode of platform carbonate production along the Early Cretaceous northern Tethyan margin was associated with important detrital input, higher nutrient levels and eventually colder waters [*Föllmi et al.*, 1994]. This implies that phytoplankton productivity was important, thereby favoring the suspension-feeding mode exercised by an important part of the heterozoan community (crinoids, brachiopods, bryozoans). Since almost no organic matter is preserved in the heterozoan carbonate deposits, it is assumed that most of it was efficiently decomposed and reintegrated into the DIC pool, whereas $^{13}C$-enriched $C_{carb}$ was efficiently buried. This induced a decrease in the $\delta^{13}C$ signal of platform DIC and subsequently also of precipitated calcite [e.g., *Immenhauser et al.*, 2003]. To this comes that the import of terrestrially derived DIC in association with high detrital flux rates may have reinforced the trend toward a more negative $\delta^{13}C$ signal on top of the heterozoan platform.

[39] Heterozoan platforms may also have acted as a pump of atmospheric $CO_2$, which was consequently exported into adjacent basins, analogous to the present-day North Sea [*Thomas et al.*, 2004]: the open, ramp-like architecture of heterozoan platforms probably allowed for a better vertical separation of photosynthetic (by planktonic organisms) and respiration processes (by benthic, carbonate-producing organisms) in its external, deeper part. This leads to a corresponding increase of respired $CO_2$ in subsurface waters, which was ultimately exported into the adjacent basin rather than transferred back to the atmosphere (Figure 8). The absence of aragonite and the increased export of both calcite as well as platform-derived and continentally derived DIC likely influenced the marine $\delta^{13}C$ system and induced lower values in open marine carbonates. The corresponding increase in the marine DIC reservoir may also have attenuated the sensitivity of the open ocean $\delta^{13}C$ record [*Bartley and Kah*, 2004].

[40] The repeated phases of platform demise during the Early Cretaceous occurred in close relation with oceanic anoxic events (Figures 3 and 5). Such phases had an important impact on the $\delta^{13}C$ system, in that carbonate production and export were greatly diminished on shelves and also in open marine systems through the competition with siliceous organisms, whereas $C_{org}$ production and preservation were enhanced. This situation generated a general shift in the $\delta^{13}C$ record toward more positive values. The greatly reduced output of carbonates and the increased throughput of continentally derived DIC accompanied by an increase in remineralized C would automatically have led to an increase in the oceanic DIC reservoir. The environmental conditions leading to oceanic anoxia and platform drowning

also induced an increase of this reservoir by increased humidity and weathering on the continent [e.g., *Föllmi et al.*, 1994; *Föllmi*, 1995; *Weissert et al.*, 1998]. The increase in size of the oceanic DIC reservoir may have also led to a more negative $\delta^{13}$C signal by its increased recycling into the photic zone [e.g., *van de Schootbrugge et al.*, 2005] and may have also attenuated short-term shifts in the signal [*Bartley and Kah*, 2004]. Oceanic anoxic events and corresponding platform drowning episodes may therefore first have led to a rather rapid positive excursion in $\delta^{13}$C followed by a longer-term trend toward a more negative $\delta^{13}$C record, which was less sensitive toward short-term change.

### 5.6. Correlation of Changes in Carbonate Platform Ecology Along the Northern Tethyan Margin and Trends in the Northern Tethyan $\delta^{13}$C Record

[41] A direct comparison of the evolution in the northern Tethyan $\delta^{13}$C record with the changes in platform ecology along the northern Tethyan margin allows us to infer temporal correlations, which are consistent with the above described influences of platform carbonate production and morphology on basinal $\delta^{13}$C records. In the Helvetic realm, the minimum in the northern Tethyan $\delta^{13}$C record at the Jurassic-Cretaceous boundary corresponds to a halt in the growth of a photozoan platform (Tros Member) and the onset of the deposition of marly, hemipelagic sediments (Zementstein Formation). The negative excursion as such is interpreted as the result of diminished aragonite shedding and an increase in continental DIC input.

[42] The two positive excursions in the early and late *boissieri* zone correspond to two phases of platform growth in a photozoan mode (lower and upper Oehrlikalk members), which were interrupted by a phase of detrital input [*Mohr*, 1992; *Mohr and Funk*, 1995]. Here an eventual increase in aragonite shedding and a concomittant decrease in DIC output from the platform may have been influential.

[43] During the early Valanginian, the $\delta^{13}$C record is first shifted to slightly more negative values and subsequently rapidly toward heavier values. A first maximum in $\delta^{13}$C values corresponds to the early *verrucosum* zone. Thereafter, $\delta^{13}$C values show a slight regression, before they culminate again in the late *verrucosum* zone. This trend corresponds to the well-known Valanginian positive excursion, which has been established in the Apulian basin and elsewhere [*Lini et al.*, 1992; *Föllmi et al.*, 1994; *Hennig et al.*, 1999; *Erba et al.*, 2004]. A comparison with the Helvetic realm suggests that the slight negative shift at the base of the Valanginian correlates to a change from a photozoan to a heterozoan platform mode (lower Betlis member). The rapid shift toward heavier values during the early Valanginian is coeval with a first platform drowning phase (Büls Beds). The following negative shift corresponds to a return of the platform in a heterozoan mode (upper Betlis member) and the second positive shift is the result of renewed platform drowning (Gemsmättli Bed).

[44] For the remainder of the late Valanginian and the entire Hauterivian, the $\delta^{13}$C record is remarkably stable with regards to short-term changes and shows only a long-term change toward more negative values. This started in the *verrucosum* zone and lasted until the late *loryi* zone and was followed by a long-term increase toward more positive values ending at the Hauterivian-Barremian boundary [*van de Schootbrugge et al.*, 2000]. The drowning phases during the Hauterivian and near the Hauterivian-Barremian boundary are not obvious in the $\delta^{13}$C record with the possible exception that an eventual increase in organic carbon burial during the late Hauterivian (culminating in the Faraoni anoxic event) may have pushed the $\delta^{13}$C record slowly to more positive values. The relative stability of the Hauterivian-early Barremian record is probably related to the increased size of the oceanic DIC reservoir, which induced the trend toward more negative values during the late Valanginian and early Hauterivian and attenuated the sensitivity of the $\delta^{13}$C signal in general [*Godet et al.*, 2006a].

[45] The late Barremian is characterized by a positive shift in $\delta^{13}$C values, which is correlated with the progressive installation of the photozoan Urgonian platform (Drusberg Member and lower Schrattenkalk Member [*Godet et al.*, 2006a; *Bodin et al.*, 2006b]). The Barremian-Aptian boundary is marked by a well-defined negative peak in the $\delta^{13}$C record, which may, amongst others, be related to the increased output of continental detritus and DIC, leading to a corresponding increase in the oceanic DIC reservoir. The minimum of this negative excursion appears close to the onset of a widely documented interruption in photozoan platform growth along the northern Tethyan margin accompanied by an increase in detrital input (“lower Orbitolina Beds”).

[46] The Aptian shows a rather unsteady short-term evolution in $\delta^{13}$C, which starts off with an important positive shift during the *oglanlensis* zone. This shift is well correlated with a significant phase of photozoan carbonate production (upper Schrattenkalk member). This first maximum in $\delta^{13}$C values during the Aptian is followed by a decrease, which becomes accelerated near the boundary between the *weissi* and *deshayesi* zones and forms a negative spike. This decrease in $\delta^{13}$C values corresponds to a change to a heterozoan platform mode in the Helvetic zone (Grünten member [*Linder et al.*, 2006]), which is followed by the demise of the Urgonian Schrattenkalk platform (Luitere Bed). The negative spike occurs near the base of the Goguel level, an anoxic bed which corresponds to OAE 1a. It was first described by *Menegatti et al.* [1998] in the Apulian basin and has been interpreted to represent a short period of increased uptake of recycled $^{12}$C–enriched carbon and/or increased release of methane [*Menegatti et al.*, 1998; *Jenkyns*, 2003]. The early Aptian negative spike is followed by a positive excursion toward an early Aptian twofold maximum in $\delta^{13}$C values, which lasts until the top of the *furcata* zone. Subsequently, the $\delta^{13}$C record slowly returns to more negative values, and arrives at a minimum near the top of the *subnodosocostatum* zone. This trend in $\delta^{13}$C is paralleled on the Helvetic shelf by a long-lasting drowning episode, and is interpreted to have resulted from increased output of $C_{org}$ relative to $C_{carb}$ during OAE 1a, followed by an increase in the oceanic DIC reservoir, which was due to the prolonged diminution in platform carbonate production paralleled by increased input of continental DIC.

[47] The base of the minimum in the late Aptian $\delta^{13}C$ record near the boundary of the *subnodosocostatum* and *melchioris* zones corresponds to a regional anoxic event (Fallot level [*Herrle et al.*, 2004]). The subsequent excursion toward more positive $\delta^{13}C$ values is probably artificial and related to different diagenetic conditions in the set of sections measured by *Herrle et al.* [2004] (J. O. Herrle personal communication, 2005). A final phase of shallow water carbonate production in a heterozoan mode (Brisi Beds) is documented from the *nolani* zone, and appears to trace an irregular trend toward more negative values in the $\delta^{13}C$ record. In the latest Aptian and earliest Albian, an ultimate drowning phase occurred on the Helvetic platform which is documented by the Twäriberg Bed. The positive shift in $\delta^{13}C$ values in sediments of the latest Aptian (*jacobi* zone) appears to register the final demise of the platform. On the Helvetic shelf, the early Albian witnessed a phase of increased detrital input (Nideri beds), followed by a renewed phase of condensation (Plattenwald Bed), which, for its onset, correlates to OAE 1b represented in the Vocontian basin by the Paquier level [e.g., *Herrle et al.*, 2004]. The onset of OAE 1b is paralleled by an increase in $\delta^{13}C$ values of the Vocontian realm, which is followed by a renewed decrease in values.

[48] The good temporal coincidence between changes in the northern Tethyan $\delta^{13}C$ record and changes in platform ecology and morphology opens the possibility to explain almost all minor and major changes in this curve. This was hitherto not possible in using changes in Tethyan paleoceanography as the exclusive driver of carbon isotope fractionation patterns.

## 6. Conclusions

[49] The Helvetic zone preserves a distal portion of the Early Cretaceous northern Tethyan carbonate platform and its transition into the deeper outer shelf. The succession recovered in the Alps is not only the result of regional environmental conditions on the shelf, but also of global paleoceanographic conditions as is shown by the temporal correspondence between drowning episodes, OAEs, and the here presented Early Cretaceous $\delta^{13}C$ reference record of SE France. The link between paleoceanographic changes and coeval modulations in the style and architecture on the platform is provided by the upwelling of deeper and colder waters, rich in nutrients and likely in dissolved $CO_2$, onto the platform.

[50] Furthermore, virtually every change in the northern Tethyan $\delta^{13}C$ record makes sense, if correlated with the evolution of the northern Tethyan platform. This indicates that reciprocally, the northern Tethyan platform system exerted an influence on northern Tethyan ocean chemistry. We propose that this occurred by the production and storage of shallow water carbonates, and by the existing platform geometry and intensity of photosynthetic activity which both were decisive for the degree of $CO_2$ return into the atmosphere and/or ocean, and the degree of output of platform-derived DIC and throughput of continental DIC. Furthermore, the changes within the platform ecosystem between photozoan, aragonite-based carbonate production mode and heterozoan, calcite-based carbonate production mode may have also played an important role in the oceanic carbon budget, especially if corresponding carbonates became exported into the adjacent basin. The high-resolution $\delta^{13}C$ record of SE France reflects both the complexity of such changes on the adjacent northern Tethyan platform, as well as coeval changes in paleoceanographic conditions, which episodically culminated in anoxic events, thereby engaging the northern Tethyan carbonate platform in mutual feedback.

[51] **Acknowledgments.** We are grateful to Thierry Adatte, Bas van de Schootbrugge, Haydon Mort, Annie Arnaud-Vanneau, Hubert Arnaud, Thomas Steuber, Adrian Immenhauser, Helmut Weissert, Hanspeter Funk, Robert Skelton, and Jean-Pierre Masse for insightful discussions and advice. We also thank Jean-Pierre Masse and Elzbieta Morycowa for providing sample material and Nicolas Fiet for analyzing this material for its stable carbon-isotope contents. We very much appreciated the insightful and highly constructive comments from Karla Panchuk and an anonymous reviewer. We acknowledge the financial support of the Swiss National Fund for this project (projects 2100-067807/1 and 200020-105206/1).

## References

Adatte, T., W. Stinnesbeck, and G. Keller (1996a), Lithostratigraphic and mineralogic correlations of near K/T boundary sediments in northeastern Mexico: Implications for origin and nature of deposition, in *The Cretaceous-Tertiary Event and Other Catastrophes in Earth History*, edited by G. Ryder, D. Fastovsky, and S. Gartner, *Geol. Soc. Am. Spec. Pap.*, *307*, 211–226.

Adatte, T., W. Stinnesbeck, J. Remane, and H. Hubberten (1996b), Paleoceanographic changes at the Jurassic-Cretaceous boundary in the western Tethys, northeastern Mexico, *Cretaceous Res.*, *17*, 671–689.

Arnaud-Vanneau, A., and H. Arnaud (1990), Hauterivian to Lower Aptian carbonate shelf sedimentation and sequence stratigraphy in the Jura and northern subalpine chains, in *Carbonate Platforms*, edited by M. E. Tucker, *Spec. Publ. Int. Assoc. Sedimentol.*, *9*, 203–233.

Arthur, M. A., and S. O. Schlanger (1979), Cretaceous “Oceanic Anoxic Events” as causal factors in development of reef-reservoired giant oil fields, *AAPG Bull.*, *63*, 870–885.

Arthur, M. A., W. E. Dean, and L. M. Pratt (1988), Geochemical and climatic effects of increased marine organic carbon burial at the Cenomanian/Turonian boundary, *Nature*, *335*, 714–717.

Bartley, J. K., and L. C. Kah (2004), Marine carbon reservoir, $C_{org}$-$C_{carb}$ coupling, and the evolution of the Proterozoic carbon cycle, *Geology*, *32*, 129–132.

Bartolini, A. (2003), Cretaceous radiolarian biochronology and carbon isotope stratigraphy of ODP Site 1149 (northwestern Pacific, Nadezhda Basin), *Proc. Ocean Drill. Program Sci. Results*, *185*, 1–17.

Bernaus, J. M., A. Arnaud-Vanneau, and E. Caus (2003), Carbonate platform sequence stratigraphy in a rapidly subsiding area: The late Barremian–early Aptian of the Organyà basin, Spanish Pyrenees, *Sediment. Geol.*, *159*, 177–201.

Bodin, S., A. Godet, K. B. Föllmi, J. Vermeulen, H. Arnaud, A. Strasser, N. Fiet, and T. Adatte (2006a), The late Hauterivian Faraoni oceanic anoxic event in the western Tethys: Evidence from phosphorus burial rates, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, *235*, 245–264.

Bodin, S., A. Godet, J. Vermeulen, and K. B. Föllmi (2006b), New data on the age of the installation of Urgonian-type carbonates along the northern Tethyan margin: Biostratigraphy of the Chopf Member (Helvetic Alps, eastern Switzerland), *C. R. Geosci.*, *338*, 727–733.

Bodin, S., A. Godet, J. Vermeulen, P. Linder, and K. B. Föllmi (2006c), Biostratigraphy, sedimentology and sequence stratigraphy of the latest Hauterivian–early Barremian drowning episode of the northern Tethyan margin (Altmann Member, Helvetic nappes, Switzerland), *Eclogae Geol. Helv.*, in press.

Bollinger, D. (1988), Die Entwicklung des distalen osthelvetischen Schelfs im Barremian und Früh-Aptian, Ph.D. thesis, Eidg. Tech. Hochsch. Zürich, Zürich, Switzerland.

Bréhéret, J. G. (1997), L'Aptien et l'Albien de la fosse vocontienne (des bordures au bassin): Evolution de la sédimentation et enseignements sur les événements anoxiques, *Soc. Géol. Nord*, *25*, 1–164.

Carannante, G., M. Esteban, J. D. Milliman, and L. Simone (1988), Carbonate lithofacies as paleolatitude indicators: Problems and limitations, *Sediment. Geol.*, *60*, 333–346.

Cerlings, T. E., Y. Wang, and J. Quade (1993), Expansion of C4 ecosystems as an indicator of global ecological change in the late Miocene, *Nature*, *361*, 344–345.

Colombié, C., and A. Strasser (2003), Depositional sequences in the Kimmeridgian of the Voconian Basin (France) controlled by carbonate export from shallow-water platforms, *Geobios*, *36*, 675–683.

Cotillon, P., and M. Rio (1984), Cyclic sedimentation in the Cretaceous of Deep Sea Drilling Project Sites 535 and 540 (Gulf of Mexico), 534 (central Atlantic) and in the Vocontian Basin (France), *Initial Rep. Deep Sea Drill. Proj.*, *77*, 339–376.

Delamette, M. (1988), L'Evolution du domaine helvétique (entre Bauges et Morcles) de l'Aptien supérieur au Turonien: Séries condensées, phosphorites, et circulations océaniques, *Publ. Dep. Géol. Paléontol. Univ. Genève*, *5*, 1–316.

Dickens, G. R., J. R. O'Neil, D. K. Rea, and R. M. Owen (1995), Dissociation of oceanic methane hydrate as a cause of the carbon isotope excursion at the end of the Paleocene, *Paleoceanography*, *10*, 965–971.

Droxler, A. W., W. Schlager, and C. C. Whallon (1983), Quaternary aragonite cycles and oxygen isotope record in Bahamian carbonate ooze, *Geology*, *11*, 235–239.

Emmanuel, L., and M. Renard (1993), Carbonate geochemistry (Mn, $\delta^{13}$C, $\delta^{18}$O) of the late Tithonian-Berriasian pelagic limestones of the Vocontian trough (SE France), *Bull. Cent. Rech. Explor. Prod. Elf Aquitaine*, *17*, 205–221.

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

Erba, E., A. Bartolini, and R. L. Larson (2004), Valanginian Weissert oceanic anoxic event, *Geology*, *32*, 149–152.

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

Erbacher, J., B. T. Huber, R. D. Norris, and M. Markey (2001), Increased thermohaline stratification as a possible cause for an ocean anoxic event in the Cretaceous period, *Nature*, *409*, 325–327.

Fichter, H. J. (1934), Geologie der Bauen-Brisen-Kette, *Beitr. Geol. Karte Schweiz*, *69*, 1–128.

Flügel, E. (2004), *Microfacies of Carbonate Rocks*, 976 pp., Springer, New York.

Föllmi, K. B. (1989a), Evolution of the Mid-Cretaceous triad, *Lect. Notes Earth Sci.*, *23*, 1–153.

Föllmi, K. B. (1989b), Beschreibung neugefundener Ammonoidea aus der Vorarlberger Garschella-Formation (Aptian-Albian), *Jahrb. Geol. Bundesanst.*, *132*, 105–189.

Föllmi, K. B. (1995), 160 m.y. record of marine sedimentary phosphorus burial: Coupling of climate and continental weathering under greenhouse and icehouse conditions, *Geology*, *23,* 859–862.

Föllmi, K. B., and M. Delamette (1991), Comment on: Model simulation of mid-Cretaceous ocean circulation, *Science*, *251*, 94.

Föllmi, K. B., and P. J. Ouwehand (1987), Garschella-Formation und Götzis-Schichten (Aptian-Coniacian): Neue stratigraphische Daten aus dem Helvetikum der Ostschweiz und des Vorarlbergs, *Eclogae Geol. Helv.*, *80*, 141–191.

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

Funk, H. P., K. B. Föllmi, and H. Mohr (1993), Evolution of the Tithonian-Aptian carbonate platform along the northern Tethyan margin, eastern Helvetic Alps, in *Cretaceous Carbonate Platforms*, edited by T. Simo, R. W. Scott, and J. P. Masse, *AAPG Mem.*, *56*, 387–407.

Ganz, E. (1912), Stratigraphie der mittleren Kreide (Gargasien, Albien) der oberen helvetischen Decken in den nördlichen Schweizeralpen, *Denkschr. Schweiz. Naturforsch. Ges.*, *42*(1), 1–148.

Garcia-Hernandez, M. (1979), Les faciès urgoniens pendant la sédimentation barrémo-albienne dans les Sierras de Cazorla et du Segura (zone prébétique, S-E de l'Espagne), *Mem. Spec. Geobios*, *3*, 57–69.

Godet, A., S. Bodin, K. B. Föllmi, J. Vermeulen, S. Gardin, N. Fiet, T. Adatte, B. Zsolt, D. Stüben, and B. van de Schootbrugge (2006a), Evolution of the marine stable carbon-isotope record during the Early Cretaceous: A focus on the late Hauterivian and Barremian in the Tethyan realm, *Earth Planet. Sci. Lett.*, *242*, 254–271.

Godet, A., S. Bodin, K. B. Föllmi, J. Vermeulen, S. Gardin, N. Fiet, T. Adatte, Z. Berner, and D. Stuben (2006b), Clay mineral assemblages along the northern Tethyan margin during the late Hauterivian–early Aptian: Interactions between climate change and carbonate platform evolution, *Cretaceous Res.*, in press.

Golonka, J. (2004), Plate tectonic evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic, *Tectonophysics*, *381*, 235–273.

Gradstein, F. M., J. G. Ogg, and A. G. Smith (2004), *A Geologic Time Scale 2004*, 600 pp., Cambridge Univ. Press, New York.

Haldimann, P. (1977), Sedimentologische Entwicklung der Schichten an einer Zyklengrenze der helvetischen Unterkreide, *Mitt. Geol. Inst. Eidg. Tech. Hochsch. Univ. Zürich*, *219*, 1–183.

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

Heim, A. (1910–1916), Monographie der Churfirsten-Mattstock-Gruppe, *Beitr. Geol. Karte Schweiz*, *20*(1–3), 573 pp.

Heim, A. (1924), Über submarine Denudation und chemische Sedimente, *Geol. Rundsch.*, *15*, 1–47.

Heim, A. (1934), Stratigraphische Kondensation, *Eclogae Geol Helv.*, *27*, 372–383.

Heim, A., and O. Seitz (1934), Die mittlere Kreide in den helvetischen Alpen von Rheintal und Vorarlberg und das Problem der Kondensation, *Denkschr. Schweiz. Naturforsch. Ges.*, *69*(2), 185–310.

Heimhofer, U., P. A. Hochuli, J. O. Herrle, N. Andersen, and H. Weissert (2004), Absence of major vegetation and palaeoatmospheric $p\mathrm{CO}_2$ changes associated with oceanic anoxic event 1a (early Aptian, SE France), *Earth Planet. Sci. Lett.*, *223*, 303–318.

Hennig, S., H. Weissert, and L. Bulot (1999), C-isotope stratigraphy, a calibration tool between ammonite- and magnetostratigraphy: The Valanginian-Hauterivian transition, *Geol. Carpatica*, *50*, 91–96.

Herrle, J. O., P. Kößler, O. Friedrich, H. Erlenkeuser, and C. Hemleben (2004), High-resolution carbon isotope records of the Aptian to lower Albian from SE France and the Mazagan Plateau (DSDP Site 545), A stratigraphic tool for paleoceanographic and paleobiologic reconstruction, *Earth Planet. Sci. Lett.*, *218*, 149–161.

Hoefs, J. (1997), *Stable Isotope Geochemistry*, 201 pp., Springer, New York.

Höfling, R., and R. W. Scott (2002), Early and mid-Cretaceous buildups, in *Phanerozoic Reef Patterns*, edited by W. Kiessling, E. Flügel, and J. Golonka, *Spec. Publ. Soc. SEPM Sediment. Geol.*, *72*, 521–548.

Immenhauser, A., G. Della Porta, J. A. M. Kenter, and J. R. Bahamonde (2003), An alternative model for positive shifts in shallow-marine carbonate $\delta^{13}$C and $\delta^{18}$O, *Sedimentology*, *50*, 953–959.

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

James, N. P. (1997), The cool-water carbonate depositional realm, in *Cool-Water Carbonates*, edited by N. P. James, and J. A. D. Clarke, *Spec. Publ. Soc. SEPM Sediment. Geol.*, *56*, 1–20.

Jenkyns, H. C. (1980), Cretaceous anoxic events: From continents to oceans, *J. Geol. Soc. London*, *137*, 171–188.

Jenkyns, H. C. (2003), Evidence for rapid climate change in the Mesozoic-Palaeogene greenhouse world, *Philos. Trans. R. Soc. London, Ser. A*, *361*, 1865–1916.

Jenkyns, H. C., and P. A. Wilson (1999), Stratigraphy, paleoceanography, and evolution of Cretaceous Pacific gyots: Relics from a greenhouse Earth, *Am. J. Sci.*, *299*, 341–392.

Kawahata, H., A. Suzuki, and K. Goto (1997), Coral reef ecosystems as a source of atmospheric CO$_2$: Evidence from PCO$_2$ measurements of surface waters, *Coral Reefs*, *16*, 261–266.

Kuhn, O. (1996), Der Einfluss von Verwitterung auf die Paläozeanographie zu Beginn des Kreide-Treibhausklimas (Valanginian und Hauterivian) in der West-Tethys, Ph.D. thesis, Eidg. Tech. Hochsch. Zürich, Zürich, Switzerland.

Kuhnt, W., M. Moullade, J. P. Masse, and H. Erlenkeuser (1998), Carbon isotope stratigraphy of the lower Aptian historical stratotype at Cassis-La Bédoule (S.E. France), *Geol. Mediterr.*, *25*(3–4), 63–79.

Kump, L. R., and M. A. Arthur (1999), Interpreting carbon-isotope excursions: Carbonates and organic matter, *Chem. Geol.*, *161*, 181–198.

Leckie, R. M., T. J. Bralower, and R. Cashman (2002), Oceanic anoxic events and plankton evolution: Biotic response to tectonic forcing during the mid-Cretaceous, *Paleoceanography*, *17*(3), 1041, doi:10.1029/2001PA000623.

Lees, A., and A. T. Buller (1972), Modern temperate water and warm water shelf carbonate sediments contrasted, *Mar. Geol.*, *13*, 1767–1773.

Linder, P., J. Gigandet, J. L. Hüsser, F. Gainon, and K. B. Föllmi (2006), The early Aptian Grünten member, *Eclogae Geol. Helv.*, in press.

Lini, A., H. Weissert, and E. Erba (1992), The Valanginian carbon isotope event: A first episode of greenhouse climate conditions during the Cretaceous, *Terra Nova*, *4*, 374–384.

Masse, J.-P. (1993), Valanginian-early Aptian carbonate platforms from Provence, southeastern France, in *Cretaceous Carbonate Platforms*, edited by T. Simo, R. W. Scott, and J. P. Masse, *AAPG Mem.*, *56*, 363–374.

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

Michalík, J. (1994), Lower Cretaceous carbonate platform facies, western Carpathians, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, *111*, 263–277.

Morycowa, E. (1980), Preservation of skeletal microstructure in fossil Scleractinia, *Acta Palaeontol. Polonica*, *25*, 9–12.

Mohr, H. (1992), Der helvetische Schelf der Ostschweiz am Übergang vom späten Jura zur frühen Kreide, Ph.D. thesis, Eidg. Tech. Hochsch. Zürich, Switzerland.

Mohr, H., and H. Funk (1995), Die Entwicklung der helvetischen Karbonatplattform in der Ostschweiz (Tithonian-Berriasian): Eine sequenzstratigraphische Annäherung, *Eclogae Geol. Helv.*, *88*, 281–320.

Moullade, M., W. Kuhnt, J. A. Bergen, J.-P. Masse, and G. Tronchetti (1998), Correlation of biostratigraphic and stable isotope events in the Aptian historical stratotype of La Bedoule (southeast France), *C. R. Acad. Sci., Ser. IIa Sci. Terre Planetes*, *327*, 693–698.

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

Ouwehand, P. J. (1987), Die Garschella-Formation ("Helvetischer Gault", Aptian-Cenomanian) der Churfirsten-Alvier Region (Ostschweiz), *Mitt. Geol. Inst. Eidg. Tech. Hochsch. Univ. Zürich*, *275*, 1–296.

Panchuk, K. M., C. Holmden, and L. R. Kump (2005), Sensitivity of the epeiric sea carbon isotope record to local-scale carbon cycle processes: Tales from the Mohawkian Sea, *Palaeogeogr. Palaeoclimat. Palaeoecol.*, *228*, 320–337.

Panchuk, K. M., C. E. Holmden, and S. A. Leslie (2006), Local controls on carbon cycling in the Ordovician midcontinent region of North America, with implications for carbon isotope secular curves, *J. Sediment. Res.*, *76*, 200–211.

Pascal, A. (1982), Evolution des systèmes biosédimentaires urgoniens en Espagne du Nord, *N. Jb. geol. Paläont. Abh.*, *165/1*, 77–86.

Philip, J. (2003), Peri-Tethyan neritic carbonate areas: Distribution through time and driving factors, *Palaeogeogr., Palaeoclimat., Palaeoecol.*, *196*, 19–37.

Price, G. D. (2003), New constraints upon isotope variation during the early Cretaceous (Barremian–Cenomanian) from the Pacific Ocean, *Geol. Mag.*, *140*, 513–522.

Reboulet, S., E. Mattioli, B. Pittet, F. Baudin, D. Olivero, and O. Proux (2003), Ammonoid and nannoplankton abundance in Valanginian (early Cretaceous) limestone-marl successions from the southeast France basin: Carbonate dilution or productivity?, *Palaeogeogr., Palaeoclimat., Palaeoecol.*, *201*, 113–139.

Romanek, C. S., E. L. Grossmann, and J. W. Morse (1992), Carbon isotope fractionation in synthetic aragonite and calcite: Effects of temperature and precipitation rate, *Geochim. Cosmochim. Acta*, *56*, 419–430.

Schaub, H. P. (1936), Geologie des Rawilgebietes, *Eclogae Geol. Helv.*, *29*, 337–407.

Schaub, H. P. (1948), Über Aufarbeitung und Kondensation, *Eclogae Geol. Helv.*, *41*, 89–94.

Schlager, W. (1981), The paradox of drowned reefs and carbonate platforms, *Geol. Soc. Am. Bull.*, *92*, 197–211.

Schlanger, S. O., and H. C. Jenkyns (1976), Cretaceous oceanic anoxic events: Causes and consequences, *Geol. Mijnbouw*, *55*, 179–184.

Scholle, P. A., and M. A. Arthur (1980), Carbon isotope fluctuations in Cretaceous pelagic limestones: Potential stratigraphic and petroleum exploration tool, *Am. Assoc. Petrol. Geol. Bull.*, *64*, 67–87.

Smith, A. M., C. S. Nelson, and H. G. Spencer (1998), Skeletal carbonate mineralogy of New Zealand bryozoans, *Mar. Geol.*, *151*, 27–46.

Sprinkle, J., and P. M. Kier (1987), Phylum Echinodermata, in *Fossil Invertrebrates*, edited by R. S. Boardman, A. H. Cheetham, and A. J. Rowell, pp. 550–611, Blackwell Sci., Malden, Mass.

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

Suzuki, A., and H. Kawahata (2003), Carbon budget of coral reef systems: An overview of observations in fringing reefs, barrier reefs and atolls in the Indo-Pacific regions, *Tellus*, *55B*, 428–444.

Suzuki, A., and H. Kawahata (2004), Reef water $CO_2$ system and carbon production of coral reefs: Topographic control of system-level performance, in *Global environmental change in the ocean and on land*, edited by M. Shiyomi et al., Terrapub, pp. 229–248.

Suzuki, A., A. Kawahata, T. Ayukai, and K. Goto (2001), The oceanic $CO_2$ system and carbon budget in the Great Barrier Reef, Australia, *Geophys. Res. Lett.*, *28*, 1243–1246.

Swart, P. K., and G. Eberli (2005), The nature of the $\delta^{13}$C of periplatform sediments: Implications for stratigraphy and the global carbon cycle, *Sedim. Geol.*, *175*, 115–129.

Thomas, H., Y. Bozec, K. Elkalay, and H. J. W. de Baar (2004), Enhanced open ocean storage of $CO_2$ from shelf sea pumping, *Science*, *304*, 1005–1008.

van de Schootbrugge, B. (2001), Influence of paleo-environmental changes during the Hauterivian (early Cretaceous) on carbonate deposition along the northern margin of the Tethys: Evidence from geochemical records (C, O, and Sr-isotopes, P, Fe, Mn), Ph. D. thesis, Univ. Neuchâtel, Neuchâtel, Switzerland.

van de Schootbrugge, B., K. B. Föllmi, L. G. Bulot, and S. J. Burns (2000), Paleoceanographic changes during the early Cretaceous (Valanginian-Hauterivian): Evidence from oxygen and carbon stable isotopes, *Earth Planet. Sci. Lett.*, *181*, 15–31.

van de Schootbrugge, O. Kuhn, T. Adatte, P. Steinmann, and K. B. Föllmi (2003), Decoupling of P- and $C_{org}$-burial following Early Cretaceous (Valanginian-Hauterivian) platform drowning along the NW Tethyan margin, *Palaeogeogr., Palaeoclimat., Palaeoecol.*, *199*, 315–331.

van de Schootbrugge, B., J. M. McArthur, T. R. Bailey, Y. Rosenthal, J. D. Wright, and K. G. Miller (2005), Toarcian oceanic anoxic event: An assessment of global causes using belemnite C isotope records, *Paleoceanography*, *20*, PA3008, doi:10.1029/2004PA001102.

Veizer, J., D. Ala, K. Azmy, P. Bruckschen, D. Buhl, F. Bruhn, G. A. F. Carden, A. Diener, S. Ebneth, Y. Godderis, T. Jasper, C. Korte, F. Pawellek, O. Podlaha, and H. Strauss (1999), $^{87}$Sr/$^{86}$Sr, $\delta^{13}$C and $\delta^{18}$O evolution of Phanerozoic seawater, *Chem. Geol.*, *161*, 59–88.

Wefer, G., and W. H. Berger (1991), Isotope paleontology: Growth and composition of extant calcareous species, *Mar. Geol.*, *100*, 207–248.

Weissert, H. (1981), The environment of deposition of black shales in the early Cretaceous: An ongoing controversy, in *The Deep Sea Drilling Project: A decade of progress*, edited by J. E. Warme, R. G. Douglas, and E. L. Winterer, *Soc. Econ. Paleont. Mineral.*, *Spec. Vol. 32*, 547–560.

Weissert, H. (1989), C-Isotope stratigraphy, a monitor of paleoenvironmental change: A case study from the Early Cretaceous, *Surv. Geophys.*, *10*, 1–61.

Weissert, H., and J. E. T. Channell (1989), Tethyan carbonate carbon isotope stratigraphy across the Jurassic-Cretaceous boundary: An indicator of decelerated global carbon cycling?, *Paleoceanography*, *4*, 483–494.

Weissert, H., and E. Erba (2004), Volcanism, $CO_2$ and palaeoclimate: A late Jurassic-early Cretaceous carbon and oxygen isotope record, *Journ. Geol. Soc. London*, *161*, 695–702.

Weissert, H., J. A. McKenzie, and P. Hochuli (1979), Cyclic anoxic events in the early Cretaceous Tethys ocean, *Geology*, *7*, 147–151.

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

Wissler, L., H. Weissert, J.-P. Masse, and L. G. Bulot (2002), Chemostratigraphic correlation of Barremian and lower Aptian ammonite zones and magnetic reversals, *Intern. Journ. Earth Sci. (Geol. Rundsch.)*, *91*, 272–279.

Wissler, L. H., H. Funk, and H. Weissert (2003), Response of early Cretaceous carbonate platforms to changes in atmospheric carbon dioxide levels, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, *200*, 187–205.

Woo, K. S., T. F. Anderson, and P. A. Sandberg (1993), Diagenesis of skeletal and nonskeletal components of mid-Cretaceous limestones, *J. Sediment. Petrol.*, *63*, 18–32.

Wyssling, G. W. (1986), Der frühkretazische helvetische Schelf im Vorarlberg und Allgäu, *Jahrb. Geol. Bundesanst.*, *129*, 161–265.

---

S. Bodin, K. B. Föllmi, A. Godet, and P. Linder, Geological Institute, University of Neuchâtel, CH-2009 Neuchâtel, Switzerland. (karl.foellmi@unine.ch)