Clim. Past Discuss., 8, 1209–1227, 2012
www.clim-past-discuss.net/8/1209/2012/
doi:10.5194/cpd-8-1209-2012

Climate of the Past Discussions

"OAE 3" – a low- to mid-latitude Atlantic oceanic event during the Coniacian-Santonian

M. Wagreich

Department of Geodynamics and Sedimentology, Center for Earth Sciences, University of Vienna, Austria

Received: 30 March 2012 – Accepted: 2 April 2012 – Published: 16 April 2012

Correspondence to: M. Wagreich (michael.wagreich@univie.ac.at)

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

Abstract

The Coniacian-Santonian time interval is the inferred time of oceanic anoxic event 3 (OAE 3), the last of the Cretaceous OAEs. A detailed look on the temporal and spatial distribution of organic-rich deposits attributed to OAE 3 suggests that black shale occurrences are restricted to the equatorial to mid-latitudinal Atlantic and adjacent basins, shelves and epicontinental seas like parts of the Caribbean, the Maracaibo Basin and the Western Interior Basin, and are largely absent in the Tethys, the North Atlantic, the southern South Atlantic, and the Pacific. Here, oxic bottom waters prevailed as indicated by the widespread occurrence of red deep-marine CORBs (Cretaceous Oceanic Red Beds). Widespread CORB sedimentation started during the Turonian after Oceanic Anoxic Event 2 (OAE 2) except in the Atlantic realm where organic-rich strata continue up to the Santonian. The temporal distribution of black shales attributed to OAE 3 indicates that organic-rich strata do not define a single and distinct short-time event, but are distributed over a longer time span and occur in different basins during different times. This suggests intermittent and regional anoxic conditions from the Coniacian to the Santonian. A comparison of time-correlated high-resolution δ^{13}C curves for this interval indicates several minor positive excursions of about 0.5 permil, probably as a result of massive organic carbon burial cycles in the Atlantic. Regional wind-induced upwelling and silled deep basins may have contributed to the development of anoxia during a global oxic time interval, thus highlighting the regional character of inferred OAE 3 as an Atlantic anoxic event (AAE).

1 Introduction

Oceanic anoxic events (OAEs; Schlanger and Jenkyns, 1976) have been recognized in the geological record, especially in Cretaceous marine sections, as climatically influenced major perturbations of the Earth system, especially concerning Earth's carbon cycle. These events were characterized by the widespread deposition of pelagic

CPD
8, 1209–1227, 2012

sediments rich in organic matter such as black shales, and are considered as key mechanisms for organic carbon burial and, in such, buffering Cretaceous runaway super-greenhouse (e.g. Arthur et al., 1990). OAEs constitute perturbations of the carbon cycle expressed by major carbon isotope ($\delta^{13}C$) excursions, both positive and negative (e.g. Leckie et al., 2002). Significant positive $\delta^{13}C$ excursions are mainly controlled by enhanced burial of organic carbon-rich deposits and characterize and define OAEs, especially in the absence of significant black shales (e.g. Tsikos et al., 2004). Principally, these organic-rich strata point to strongly enhanced marine productivity during short duration events, e.g. the total duration of OAE 2 including a positive $\delta^{13}C$ signal of more than 2 ‰ has an estimated duration of 300–700 kyr (Sageman et al., 2006; Voigt et al., 2008), and high productivity-events may have been even considerably shorter at the onset of OAEs (Adams et al., 2010). Subsequent extensive CO_2 draw down probably resulted in cooling of the atmosphere already during major OAEs. However, during the last three decades of intensive investigations in Cretaceous OAEs, it became clear that not all originally defined OAEs (OAE 1a, 1B, 1c, 1d, OAE 2, OAE 3, see Arthur and Schlanger, 1979; Jenkyns, 1980, 2003) record similar scenarios and more regional controls and modifications have been suggested (e.g. Leckie et al., 2002). Principle first order control by major magmatic evens (LIPs, Large Igneous Provinces) leading to extreme greenhouse gas concentrations plays a major control as trigger mechanism for such super-greenhouse events (Jones and Jenkyns, 2001; Barclay et al., 2010).

The Coniacian-Santonian (88.6–83.5 Ma; TS Creator 5.3, see http://www.tscreator.org; Ogg et al., 2004) is considered as the time during which the last Cretaceous oceanic anoxic event, OAE 3, took place (e.g. Arthur et al., 1990; Hofmann et al., 2003). Interestingly, OAE 3 was not identified in the classical paper by Schlanger and Jenkyns (1976) who only named two major oceanic anoxic events, but recognized and named lateron (Ryan and Cita, 1977; Arthur and Schlanger, 1979; Jenkyns, 1980). OAE 3 differs from other OAEs in general that it occurred during an interval of already fading greenhouse, i.e. during a major cooling trend in earth's long-term climate

CPD
8, 1209–1227, 2012

history from the mid-Cretaceous super-greenhouse to normal greenhouse conditions. Whereas a global extend was recognized by Schlanger and Jenkyns (1976) for the early Aptian OAE 1a and the Cenomanian-Turonian boundary interval OAE 2, a more restricted occurrence of Coniacian-Santonian black shales was reported by Arthur and Schlanger (1979) and Jenkyns (1980). Subsequently, also a preference of these black shales for shallow water settings and Atlantic and Caribbean regions was noted by Jenkyns (1980).

More recent investigations augmented this picture, reporting cyclic black shales and anoxic to dysoxic environmental conditions during the Coniacian-Santonian especially from low-latitude Atlantic ODP sites along the Ivory Coast-Ghana Transform Margin, e.g. ODP Leg 159 (Wagner, 2002; Hofmann et al., 2003; Jones et al., 2007) and the Demerara Rise, ODP Leg 207 (e.g. Friedrich and Erbacher, 2006; Beckmann et al., 2008), the Caribbean, and connected marginal and epeiric seas and seaways such as the Western Interior (Locklair et al., 2011), the Maracaibo Basin (Rey et al., 2004) and basins of northwestern Africa (El Albani et al., 1999). Overviews on the regional distribution of OAE 3 black shales (Wagner et al., 2004; Hofmann and Wagner, 2011) and the predominance of coeval oxidised deep water sediments elsewhere (CORBs – Cretaceous Oceanic Red Beds, Wagreich, 2009; Wang et al., 2011) corroborated the fact that OAE 3 is mainly restricted to the low-latitude Atlantic and adjacent basins and seaways, whereas most of the Tethys and the other ocean basins were largely characterized by oxic deep-water conditions and the deposition of mostly red to brownish or light grey deep water sediments (Wagreich, 2009).

This paper follows earlier arguments on OAE 3 distribution in time and space, looks for possibilities of a more precise definition of OAE 3, and finally poses the question if OAE 3 identifies as a distinctive widespread oceanic anoxic event at all. OAE 3 stratigraphy and the carbon isotope evolution in time are regarded as key data for identification and interpretation of anoxic event(s) during the Coniacian-Santinion and the role of climate evolution on oceanic sedimentation.

CPD
8, 1209–1227, 2012

2 Results

2.1 Spatial distribution

High organic carbon sediments of Coniacian-Santonian age, especially marine organic matter bearing black shales, appear in the southern part of North Atlantic, the South Atlantic, the Carribbean Sea, and surrounding basins and shelf areas like the Western Interior, the Maracaibo Basin (Venezuela), Columbia, Brazil, N Namibia, Angola, Gabon, Ivory Coast, northwest Africa and Marocco, Lybia, and Egypt (Wagner et al., 2004; Wagreich, 2009). Apart from these Atlantic OAE3 sites black shales of Coniacian-Santonian age have only a spurious distribution, which mainly suggests very local factors controlling organic-rich sedimentation and not a widespread or global event layer, such as exemplified by reports of organic-rich layers in Pakistan, Western Greenland, the Sverdrup Basin in Arctic Canada and southern Australia (Wagreich, 2009). The lack of black shales from the Tethys is notably, as a strong connection of the Tethys with the latitudinal Atlantic had been established during the Late Cretaceous (e.g. Trabucho Alexandre et al., 2010).

Looking for published case studies on typical Coniacian-Santonian OAE 3 strata indicates the fact that such studies are relatively rare, especially if compared to numerous work dedicated to the slightly older Cenomanian-Turonian boundary interval OAE 2. Unambiguously identified organic-rich strata of Coniacian-Santonian age were identified in the equatorial Atlantic sites as drilled by deep-sea drilling such as ODP Leg 159 (site 959), at a transect along the Ivory Coast-Ghana Transform Margin, and on the opposite margin of the Atlantic, at the Demerara Rise off Surinam by ODP Leg 207 (sites 1257–1261). Both areas are characterized by a more or less continuous succession of black shales from the Upper Cenomanian onset of OAE 2 up to the upper Santonian or lower Campanian (Wagreich, 2009). Both areas are also characterized by cyclic black shales interpreted to represent precession and eccentricity orbital cycles (Hofmann et al., 2003; März et al., 2008, 2009). Organic carbon cyclicity was caused by fluctuations in productivity and/or preservation (Hofmann et al., 2003; Beckmann et al.,

CPD
8, 1209–1227, 2012

2005b, 2008). Millenial- to centennial-scale precession cycles of oxic/dysoxic to anoxic, even euxinic conditions were recorded in the upper Coniacian to lower Santonian (e.g. März et al., 2008). Wagner et al. (2004) and Beckmann et al. (2005b) concluded that the chemical boundary conditions in the ocean have been as extreme as during global OAE 2 at the Ivory Coast-Ghana Transform Margin, but much more restricted in extent and duration. High-TOC black shales occurred in areas with restricted circulation such as sheltered subbasins, and are characterized by lower photic zone euxinia, highly unstable euxinic conditions.

Anoxia proceeded from these equatorial Atlantic sites into the Caribbean and large epeiric seas both to the north, i.e. the Western Interior Seaway (Dean and Arthur, 1998), and to the south, the Maracaibo Basin. The Western Interior Seaway record constitutes another classical OAE 3 area, with high organic carbon contents during the Coniacian-Santonian (Locklair et al., 2011). In Venezuela and Colombia, were organic-rich, cyclic strata such as laminated black shale-limestone couplets prevailed for most of the Coniacian-Santonian up to the Lower Campanian (e.g. De Romero et al., 2003; Rey et al., 2004). Here, wind driven upwelling was interpreted as the major control on black shale deposition (Macsotay et al., 2003).

2.2 Timing, age and duration

Coniacian-Santonian times were characterized by a relatively shallow calcite compensation depth at least in the Atlantic, and, consequently, a marked increase in deposition of carbonate-free (red) shales which are hardly biostratigraphically dateable as calcareous plankton is lacking (e.g. Jansa and Hu, 2009). Therefore, the biostratigraphic subdivision of this time interval is of rather poor resolution in the pelagic realm (see also Ogg et al., 2004) as exemplified by only 2–3 Tethyan/low latitude plankton foraminifera globotruncanid zones for the entire time interval (*Dicarinella concavata*-, *Dicarinella asymetrica*-, eventually *Dicarinella asymetrica-Globotruncanita elevata* zones, e.g. Robaszynski and Caron, 1995; Petrizzo, 2003) and 3–5 (low latitude) nannoplankton zones (CC13-17, Sissingh, 1977; Perch-Nielsen, 1985; NC15-17,

CPD
8, 1209–1227, 2012

Roth, 1978; Bralower et al., 1995; UC 9-12, Burnett, 1998). Especially the CC zones of this time interval were strongly discussed as most of the primary markers of Sissingh (1977), including *Marthasterites furcatus* (base CC13), *Reinhardtites anthophorus* (base CC15), *Lucianorhabdus cayeuxii* (base CC16) and *Calculites obscurus* (base CC17), were shown to be diachronous, ecologically controlled, and have an earlier and/or doubtful first occurrence (Burnett, 1998; Lees, 2008; Gale et al., 2007; Melinte and Lamolda, 2007). In fact, only one nannofossil event, the first occurrence of *Micula staurophora* (*Micula decussata* of some authors), is common to both (CC and UC) low-latitude nannofossil standard zonations. This results in a rather low-resolution stratigraphic subdivision of the Coniacian-Santonian in deep-water settings and in problems in correlating OAE 3 horizons from different locations and different studies (e.g. Flögel et al., 2008).

Numerical ages for the Coniacian-Santonian strongly rely on material from tuff layers and bentonites within the Western Interior where this time interval is characterized by a growing endemism and globotruncanids become rare or absent (Dean and Arthur, 1998). Therefore, biostratigraphic correlations of numerical ages into the pelagic world oceans are, at least, not straightforward and have to be dealt with caution. This may be exemplified by ongoing discussions on defining a GSSP for the base of the Santonian, and the differences in proposed nannofossil events that are connected to this boundary in the Western Interior Basin and elsewhere (see Gale et al., 2007; Melinte and Lamolda, 2007; Blair and Watkins, 2009). Using cyclostratigraphy within a macro- and microfossil framework and radiometric dates, Locklair and Sageman (2008) published a Coniacian-Santonian floating orbital timescale from the Western Interior (Niobrara Formation). According to their results, the duration of the Coniacian ranges from 3.26 to 3.50 myr, the Santonian from 2.24 to 2.53 myr, giving a total duration for the Coniacian-Santonian of 5.5. to 6 myr, which is in accordance to other recent age results (Ogg et al., 2004). Based on this timing Locklair et al. (2011) calculated durations and carbon fluxes during the OAE 3 interval. However, their curves exemplify the problem of how to define OAE 3 in time, as several peaks of organic carbon can be recognized during this

CPD
8, 1209–1227, 2012

interval in the Western Interior Basin. Their main OAE 3 level of organic carbon-rich strata lies within the middle Coniacian (Locklair et al., 2011, Figs. 4 and 5), but several other levels may be identified within their sections.

Keeping in mind the above mentioned problems in timing and correlation the published stratigraphic levels attributed to OAE 3 vary considerably. Hofmann et al. (2003) and Hofmann and Wagner (2011) refer mainly to a late Coniacian and early Santonian age. The Western Interior Seaway OAE 3 intervals named by Locklair et al. (2011) are middle Coniacian, early Santonian and at the Santonian-Campanian boundary interval. Others refer even to a late Santonian-early Campanian age, e.g. as reported from the Middle East (Jenkyns, 1980). Although OAE 3 may be dividided in several short-term events (Arthur et al., 1990) no clear OAE 3 level that applies to most of the sections and sites can be defined which is in strong contrast to the widespread OAE 2 horizon (e.g. Tsikos et al., 2003; Gebhardt et al., 2010).

2.3 Isotope data and correlations

As carbon isotope excursionen (CIEs) can be used to define OAEs (Sageman et al., 2006) a closer look on the carbon isotope record from different sites from the Boreal to the Tethyan realm may help in correlation of OAE 3 and in evaluating the global significance of these events. Detailed, continuous, high-resolution and stratigraphically constrained carbon isotope data for the Coniacian-Santonian are relatively scarce as compared to the Campanian-Maastrichtian (e.g. Voigt et al., 2010) or the Cenomanian-Turonian, including OAE 2 (e.g. Tsikos et al., 2003; Voigt et al., 2008).

A recent compilation by Wendler et al. (2009; see also Wendler et al., 2011) compared data from Tibet (Tingri, and Guru sections) with the Chalk reference curve of Jarvis et al. (2006; based on several English chalk sections) and data from Contessa, Umbria, Italy (Stoll and Schrag, 2000). All of these sites, from boreal to Tethys, do not include significant black shale intervals in the Coniacian-Santonian. To correlate with inferred OAE 3 sites (see Fig. 2) we added data from the Western Interior Basin (Locklair et al., 2011). Other carbon isotope records, e.g. from the La Luna Formation of Venezuela (de Romero et al., 2003) or the Demerara Rise (Friedrich and Erbacher, 2006) are too low-resolution during this time interval.

Figure 2 shows the carbon isotope records of the above mentioned sites and possible OAE 3 levels. Minor carbon isotope excursions during the Coniacian-Santonian of ca. −0.5 permil as identified by Jarvis et al. (2006) can be correlated, i.e. the Navigation event at the Turonian-Coniacian boundary (see also Walaszczyk et al., 2010), the White Fall, Kingsdown, Horseshoe Bay, and the Santonian-Campanian boundary events. However, no clear correlation to organic-rich strata attributed to OAE 3 (grey boxes in Fig. 2) and to inferred times of OAE 3, i.e. late Coniacian-early Santonian, do exist. The general elevated carbon isotope values (ca. 0.7 permil) during this time in the Tibetian sections (Wendler et al., 2009) seem to be regional phenomenon as no corresponding carbon isotope plateaus can be matched in the other sections. Its onset was well before significant OAE 3 black shales elsewhere, as already noted by Wendler et al. (2009).

3 Discussion

OAEs have been recognized primarely by the presence and stratigraphic correlation of organic-rich strata, i.e. black shales (Schlanger and Jenkyns, 1976). Subsequently, carbon isotope data indicated major excursions (e.g. Jenkyns, 1980), pointing to significant pertubations of the carbon cycle during OAEs. Therefore, to qualify for an OAE, (1) organic-rich strata must be widespread, (2) should be correlated in time to qualify as a single event, and (3) should be accompanied by a significant carbon isotope excursion.

Based on the data presented on OAE 3, i.e. the spatial and temporal distribution and carbon isotopes, this time interval does not qualify as a global event. Inferred OAE 3 levels of organic-carbon rich intervals cannot be correlated in time and do not define a single horizon. The problems to date Coniacian-Santonian pelagic sediments, especially concerning calcareous “blue-water” plankton, contributes to the squishy definition of a Coniacian-Santonian OAE, in fact a time interval of 5.5 to 6 myr which cannot qualify as an event. In addition, no distinct short time (<1 myr) peak of organic-rich sedimentation of a suspected OAE 3 can be defined during this interval, and in the equatorial Atlantic and Venezuelan sites, the whole Coniacian-Santonian succession is characterized by black shales.

The Coniacian-Santonian comprises only small positive carbon isotope excursions (<0.5 permil). Minor carbon isotope events as identified by Jarvis et al. (2006) based on English Chalk sections and correlated to other, including Tethyan, sections (Jarvis et al., 2006; Wendler et al., 2009) characterize this interval. Inferred OAE 3 event(s) may be correlated to those minor events or fall even into times of no significant excursions at all (Fig. 2). However, these minor events are in strong contrast in relation to major global OAE intervals such as OAE 1a in the Aptian or OAE 2 in the Cenomanian-Turonian boundary interval, where major carbon isotope excursions (>2 permil) are correlatable globally and, consequently, can be used to define the durations of oceanic anoxic events. All Coniacian-Santonian carbon isotope events are smaller in magnitude than the large late Turonian Hitchwood event (Fig. 2) of Jarvis et al. (2006) which may suggest rather a late Turonian age for a suspected OAE 3.

Black shale intervals from the equatorial Atlantic and adjacent marginal seas can be correlated, as organic-rich strata are ubiquitous within the Turonian-Lower Campanian, but without any defineable and distinct through-going OAE 3 event horizon. However, to qualify as a more-than-regional anoxic event, OAE 3 horizon(s) have to be correlated also into other sites. A detailed look on the spatial distribution of organic-rich deposits attributed to OAE 3 (see also Wagner et al., 2004; Wagreich, 2009) suggests that these OAE 3 sediments are restricted essentially to the low- to mid-latitude Atlantic and adjacent seas and basins. Correlations to organic-rich deposits from sites outside the Atlantic are strongly doubtful. Therefore the inferred "OAE 3" qualifies more as an "Atlantic anoxic event" ("AAE"), a term to appreciate the restricted distribution of these black shales. Thus, the cause for organic-rich sedimentation in the Atlantic during a time of worldwide oxic deep-water sedimentation is not a consequence of

CPD
8, 1209–1227, 2012

a global climate or oceanographic event but this AAE must have been driven by a special configuration of the Atlantic Ocean and the surrounding shelf basins and continents. Wagner (2002) and Hofmann et al. (2003) suggested a strong link of these black shales to upwelling. Beckmann et al. (2005a) and Flögel et al. (2008) invoked millenial- to centennial-scale climate variability, i.e. trade winds and monsoon circulation and precipitation, and cyclic upwelling to explain cyclic black shales within the core area of AAE. Restricted ocean circulation in the equatorial Atlantic region with semi-closed deep basins and high runoff from Africa and South America fostered, via high nutrient supply and upwelling due to trade winds, high primary productivity, which resulted in anoxia over an extended period within the equatorial Atlantic and adjacent seas, a unique situation for the equatorial Atlantic (Hofmann and Wagner, 2011). Variations in weathering intensity of the continents suggest oscillations between more arid and more humid intervals. Climate modelling results (Beckmann et al., 2005a) also indicate the existence of a pronounced seasonal dry-wet cyclicity.

4 Conclusions

Based on the data presented on spatial and temporal distribution and carbon isotopes, inferred OAE 3 levels of organic-carbon rich intervals are neither global nor contemporaneous and are characterized by only small positive carbon isotope excursions, if all. We conclude that inferred OAE 3 is not a global oceanic event but more an AAE – a regional anoxic event that is essentially restricted to the low- to mid-latitudinal part of the Atlantic and some adjacent epicontinental basins such as the Maracaoibo Basin and the Western Interior Basin. It is absent in the Pacific and the Tethys. Furthermore, OAE 3 is not a clearly defined, short-time event, but distributed over a longer time span, at least from the Coniacian to the Santonian. Most of the typical "OAE 3" sections in the equatorial Atlantic display continuous organic matter-rich successions from Cenomanian-Turonian OAE 2 to Coniacian-Santonian black shales. Carbon isotope data indicate minor excursions of about 0.5 permil, probably as a result of massive and cyclic organic carbon burial in the Atlantic during this time interval.

Acknowledgements. This paper is a contribution to IGCP 555 "Upper Cretaceous Oceanic Red Beds". Field work was supported by the Austrian Academy of Sciences and the Austrian Science Fund (FWF): P24044-N24.

References

Adams, D. D., Hurtgen, M. T., and Sageman, B. B.: Volcanic triggering of a biogeochemical cascade during Oceanic Anoxic Event 2, Nat. Geosci., 3, 201–204, doi:10.1038/NGEO743, 2010.

Arthur, M. A. and Schlanger, S. O.: Cretaceous "oceanic anoxic events" as causal factors in development of reef-reservoired giant oil fields, Am. Assoc. Petr. Geol. B., 63, 870–885, 1979.

Arthur, M. A., Jenkyns, H. C., Brumsack, H. J., and Schlanger, S. O.: Stratigraphy, geochemistry, and paleoceanography of organic carbon-rich Cretaceous sequences, in Cretaceous resources events and rhythms, edited by: Ginsburg, R. N. and Beaudoin, B., Dordrecht, Kluwer Academic Publishers, 75–120, 1990.

Barclay, R. S., McElwain, J. C., and Sageman, B. B.: Carbon sequestration activated by a volcanic CO_2 pulse during Ocean Anoxic Event 2, Nat. Geosci., 3, 205–208, doi:10.1038/NGEO757, 2010.

Beckmann, B., Flögel, S., Hofmann, P., Schulz, M., and Wagner, T.: Orbital forcing of Cretaceous river discharge in tropical Africa and ocean response, Nature, 437/438, 241–244, 2005a.

Beckmann, B., Wagner, T., and Hofmann, P.: Linking Coniacian-Santonian (OAE3) black-shale deposition to African climate variability: a reference section from the eastern tropical Atlantic at orbital time scales (ODP site 959, off Ivory Coast and Ghana), in: The Deposition of Organic-Carbon-Rich Sediments: Models, Mechanisms, and Consequences, edited by: Harris, N. B., SEPM Spec. P., 82, 125–143, 2005b.

Beckmann, B., Hofmann, P., März, C., Schouten, S., Sinninghe Damsté, J. S., and Wagner, T.: Coniacian-Santonian deep ocean anoxia/euxinia inferred from molecular and inorganic

CPD
8, 1209–1227, 2012

"OAE 3" – a low- to mid-latitude Atlantic oceanic event

M. Wagreich

markers: Results from the Demerara Rise (ODP Leg 207), Org. Geochem., 39, 1092–1096, 2008.
Blair, S. A. and Watkins, D. K.: High-resolution calcareous nannofossil biostratigraphy for the Coniacian/Santonian Stage boundary, Western Interior Basin, Cretaceous Res., 30, 367–384, 2009.
Bralower, T. J., Leckie, R. M., Sliter, W. V., and Thierstein, H. R.: An integrated Cretaceous microfossil biostratigraphy, in Geochronology, Time Scales, and Global Stratigraphic Correlation, edited by: Berggren, W. A., Kent, D. V., Aubry, M.-P., and Hardenbol, J., SEPM Spec. P., 54, 65–79, 1995.
Burnett, J. A.: Upper Cretaceous, in: Calcareous Nannofossil Biostratigraphy, edited by: Bown, P. R., Cambridge (Chapman & Hall), 132–199, 1998.
De Romero, L. M., Truskowski, I. M., Bralower, T. J., Bergen, J. A., Odreman, O., Zachos, J. Z., and Galea-Alvarez, F. A.: An integrated calcareous microfossil biostratigraphic and carbon-isotope stratigraphic framework for the La Luna Formation, Western Venezuela, Palaios, 18, 349–366, 2003.
Dean, W. E. and Arthur, M. A.: Geochemical expressions of cyclicity in Cretaceous pelagic limestone sequences: Niobrara Formation, Western Interior Seaway, in: Stratigraphy and Paleoenvironments of the Cretaceous Western Interior Seaway, USA, edited by: Dean, W. E. and Arthur, M. A., SEPM Concepts in Sedimentology and Paleontology, 6, 227–255, 1998.
El Albani, A., Kuhnt, W., Luderer, F., Herbin, J. P., and Caron, M.: Palaeoenvironmental evolution of the Late Cretaceous sequence in the Tarfaya Basin (southwest of Morocco), in: The oil and Gas Habitats of the South Atlantic, edited by: Cameron, N. R., Bate, R. H., and Clure, V. S., Geol. Soc. SP, 153, 223–240, 1999.
Flögel, S., Beckmann, B., Hofmann, P., Bornemann, A., Westerhold, T., Norris, D. R., Dullo, C., and Wagner, T.: Evolution of tropical watersheds and continental hydrology during the Late Cretaceous greenhouse; impact on marine carbon burial and possible implications for the future, Earth Planet. Sc. Lett., 274, 1–13, doi:10.1016/j.epsl.2008.06.011, 2008.
Friedrich, O. and Erbacher, J.: Benthic foraminifera assemblages from Demerara Rise (ODP Leg 207, western tropical Atlantic): Possible evidence for a progressive opening of the Equatorial Atlantic Gateway, Cretaceous Res., 27, 377–397, 2006.
Gale, A. S., Kennedy, W. J., Lees, J. A., Petrizzo, M. R., and Walaszczyk, I.: An integrated study (inoceramid bivalves, ammonites, calcareous nannofossils, planktonic foraminifera, stable carbon isotopes) of the Ten Mile Creek section, Lancaster, Dallas County, north Texas, a can-

CPD
8, 1209–1227, 2012
“OAE 3” – a low- to mid-latitude Atlantic oceanic event
M. Wagreich

didate Global boundary Stratotype, Section and Point for the base of the Santonian Stage, Acta Geol. Pol., 57, 113–160, 2007.

Gebhardt, H., Friedrich, O., Schenk, B., Fox, L., Hart, M., and Wagreich, M.: Paleoceanographic changes at the northern Tethyan margin during the Cenomanian-Turonian Oceanic Anoxic Event (OAE-2), Mar. Micropaleontol., 235, 27–37, doi:10.1016/j.sedgeo.2010.06.025, 2010.

Hofmann, P. and Wagner, T.: ITCZ controls on Late Cretaceous black shale sedimentation in the tropical Atlantic Ocean, Paleoceanography, 26, PA4223, doi:10.1029/2011PA002154, 2001.

Hofmann, P., Wagner, T., and Beckmann, B.: Millenial- to centennial-scale record of African climate variability and organic carbon accumulation in the Coniacian-Santonian eastern tropical Atlantic (Ocean Drilling Program Site 959, off Ivory Coast and Ghana), Geology, 31, 135–138, 2003.

Jansa, L. and Hu, X.: An Overview of the Cretaceous pelagic black shales and red beds: origin, paleoclimate and paleoceanographic implications, in: Cretaceous Oceanic Red Beds: Stratigraphy, Composition, Origins, and Paleoceanographic and Paleoclimatic Significance, edited by: Hu, X., Wang, C., Scott, R. W., Wagreich, M., and Jansa, L., SEPM Spec. P., 91, 59–72, 2009.

Jarvis, I., Gale, A., Jenkyns, H. C., and Pearce, M. A.: Secular variation in Late Cretaceous carbon isotopes: a new δ^{13}C carbonate reference curve for the Cenomanian-Campanian (99.6–70.6 Ma), Geol. Mag., 143, 561–608, 2006.

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

Jenkyns, H. C.: Evidence for rapid climate change in the Mesozoic-Palaeogene greenhouse world, Philos. Tr. R. Soc. S.-A, 361, 1885–1916, 2003.

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

Jones, E. J. W., Bigg, G. R., Handoh, I. C., and Spathopoulos, F.: Distribution of deep-sea black shales of Cretaceous age in the eastern Equatorial Atlantic from seismic profiling, Palaeogeogr. Palaeocl., 248, 233–246, 2007.

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

Lees, J. A.: The calcareous nannofossil record across the Late Cretaceous Turonian/Coniacian boundary, including new data from Germany, Poland, the Czech Republic and England, Cretaceous Res., 29, 40–64, 2008.
Locklair, R. E. and Sageman, B. B.: Cyclostratigraphy of the Upper Cretaceous Niobrara Formation, Western Interior, U.S.A.: A Coniacian-Santonian orbital timescale, Earth Planet. Sc. Lett., 269, 539–552, 2008.
Locklair, R., Sageman, B. B., and Lerman, A.: Marine carbon burial flux and the carbon isotope record of Late Cretaceous (Coniacian-Santonian) Oceanic Anoxic Event III, Sediment. Geol., 235, 38–49, 2011.
Macsotay, O., Erlich, R. N., and Peraza, T.: Sedimentary structures of the La Luna, Navay and Querecual Formations, Upper Cretaceous of Venezuela, Palaios, 18, 334–348, 2003.
März, C., Poulton, S. W., Beckmann, B., Küster, K., Wagner, T., and Kasten, S.: Redox sensitivity of P cycling during marine black shale formation – dynamics of sulfidic and anoxic, non-sulfidic bottom waters, Geochim. Cosmochim. Ac., 72, 3703–3717, 2008.
März, C., Beckmann, B., Franke, C., Vogt, C., Wagner, T., and Kasten, S.: Geochemical environment of the Coniacian-Santonian western tropical Atlantic at Demerara Rise, Palaeogeogr. Palaeocl., 273, 286–301, 2009.
Melinte, M. C. and Lamolda, M. A.: Calcareous nannofossil biostratigraphy of the Coniacian/Santonian boundary interval in Romania and comparison with other European regions, Cretaceous Res., 28, 119–127, 2007.
Ogg, J. G., Agterberg, F. P., and Gradstein, F. M.: The Cretaceous Period, in: A Geologic Time Scale 2004, edited by: Gradstein, M., Agterberg, F. P., and Smith, A. G., Cambridge University Press, Cambridge, 344–383, 2004.
Perch-Nielsen, K.: Mesozoic calcareous nannofossils, in: Plankton Stratigraphy, edited by: Bolli, H. M., Saunders, J. B., and Perch-Nielsen, K., Cambridge, Cambridge University Press, 329–426, 1985.
Petrizzo, M. R.: Late Cretaceous planktonic foraminiferal bioevents in the Tethys and in the Southern ocean record: an overview, J. Foramin. Res., 23, 330–337, 2003.
Pratt, L. M., Arthur, M. A., Dean, W. E., and Scholle, P. A.: Paleoceanographic cycles and events during the Late Cretaceous in the Western Interior Seaway of North America, in: Evolution of the Western Interior Basin, edited by: Caldwell, W. G. E. and Kauffman, E. G., Geological Association of Canada, Special Paper, 39, 333–354, 1993.

Rey, O., Simo, J. A., and Lorente, M. A.: A record of long- and short-term environmental and climatic change during OAE3: La Luna Formation, Late Cretaceous (Santonian-early Campanian), Venezuela, Sediment. Geol., 170, 85–105, 2004.

Robaszynski, F. and Caron, M.: Foraminifères planctoniques du Crétacé: commentaire de la zonation Europe-Méditerranée, B. Soc. Geol. Fr., 6, 681–692, 1995.

Roth, P. H.: Cretaceous nannoplankton biostratigraphy and oceanography of the northwestern Atlantic Ocean, Initial Rep. Deep Sea, 44, 731–759, 1978.

Ryan, W. B. F. and Cita, M. B.: Ignorance concerning episodes of ocean-wide stagnation, Mar. Geol., 23, 197–215, 1977.

Sageman, B. B., Meyers, S. R., and Arthur, M. A.: Orbital time scale and new C-isotope record for Cenomanian-Turonian boundary stratotype, Geology, 34, 125–128, 2006.

Schettino, A. and Scotese, C.: Global kinematic constraints to the tectonic history of the Mediterranean region and surrounding areas during the Jurassic and Cretaceous, J. Virtual Explorer, 8, 149–168, 2002.

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

Sissingh, W.: Biostratigraphy of Cretaceous nannoplankton, Geol. Mijnbouw, 57, 433–440, 1977.

Stoll, H. M. and Schrag, D. P.: High-resolution stable isotope records from the Upper Cretaceous rocks of Italy and Spain: Glacial episodes in a greenhouse planet?, Geol. Soc. Am. Bull., 112, 308–319, 2000.

Trabucho Alexandre, J., Tuenter, E., Henstra, G. A., van der Zwan, K. J., van de Wal, R. S. W., Dijkstra, H. A., and de Boer, P. L.: The mid-Cretaceous North Atlantic nutrient trap: Black shales and OAEs, Paleoceanography, 25, PA4201, doi:10.1029/2010PA001925, 2010.

Tsikos, H., Jenkyns, H. C., Walsworth-Bell, B., Petrizzo, M. R., Forster, A., Kolonic, S., Erba, E., Premoli-Silva, E., Baas, M., Wagner, T., and Sinninghe-Damsté, J. S.: Carbon-Isotope stratigraphy recorded by the Cenomanian-Turonian Ocenanic Anoxic Event: correlation and implications based on three key localities, J. Geol. Soc. London, 161, 711–719, 2004.

Voigt, S., Erbacher, J., Mutterlose, J., Weiss, J., Westerhold, T., Wiese, F., Wilmsen, M., and Wonik, T.: The Cenomanian – Turonian of the Wunstorf section – (North Germany): global stratigraphic reference section and new orbital time scale for Oceanic Anoxic Event 2, Newsl. Stratigr., 43, 65–89, 2008.

CPD
8, 1209–1227, 2012

Voigt, S., Friedrich, O., Norris, R. D., and Schönfeld, J.: Campanian – Maastrichtian carbon isotope stratigraphy: shelf-ocean correlation between the European shelf sea and the tropical Pacific Ocean, Newsl. Stratigr., 44, 57–72, 2010.

Wagner, T.: Late Cretaceous to early Quaternary organic sedimentation in the eastern equatorial Atlantic, Palaeogeogr. Palaeocl., 179, 113–147, 2002.

Wagner, T., Sinninghe Damste, J. S., Hofmann, P., and Beckmann, B.: Euxinia and primary production in Late Cretaceus equatorial Atlantic surface waters fostered orbitally driven formation of marine black shales, Paloceanography, 19, PA3009, doi:10.1029/2003PA000898, 2004.

Wagreich, M.: Coniacian-Santonian oceanic red beds and their link to Oceanic Anoxic Event 3, in: Cretaceous Oceanic Red Beds: Stratigraphy, Composition, Origins, and Paleoceanographic and Paleoclimatic Significance, edited by: Hu, X., Wang, C., Scott, R. W., Wagreich, M., and Jansa, L., SEPM Spec. P., 91, 235–242, 2009.

Walaszczyk, I., Wood, C. J., Lees, J. A., Peryt, D., Voigt, S., and Wiese, F.: The Salzgitter-Salder Quarry (Lower Saxony, Germany) and Słupia Nadbrzeżna river cliff section (central Poland): a proposed candidate composite Global Boundary Stratotype Section and Point for the base of the Coniacian Stage (Upper Cretaceous), Acta Geol. Pol., 60, 445–477, 2010.

Wang, C. S., Hu, X. M., Huang, Y. J., Scott, R. W., and Wagreich, M.: Overview of Cretaceous Oceanic Red Beds (CORBs): a window on global oceanic and climate change, in: Cretaceous Oceanic Red Beds: Stratigraphy, Composition, Origins, and Paleoceanographic and Paleoclimatic Significance, edited by: Hu, X., Wang, C., Scott, R. W., Wagreich, M., and Jansa, L., SEPM Spec. P., 91, 13–33, 2009.

Wang, C. S., Hu, X., Huang, Y., Wagreich, M., Scott, R., and Hay, W.: Cretaceous oceanic red beds as possible consequence of oceanic anoxic events, Sediment. Geol., 235, 27–37, 2011.

Wendler, I., Wendler, J., Gräfe, K.-U., Lehmann, J., and Willems, H.: Turonian to Santonian carbon isotope data from the Tethys Himalaya, southern Tibet, Cretaceous Res., 30, 961–979, 2009.

Wendler, I., Willems, H., Gräfe, K.-U., Ding, L., and Luo, H.: Upper Cretaceous interhemispheric correlation between the Southern Tethys and the Boreal: chemo- and biostratigraphy and paleoclimatic reconstructions from a new section in the Tethys Himalaya, S-Tibet, Newsl. Stratigr., 44, 137–171, 2011.

CPD
8, 1209–1227, 2012

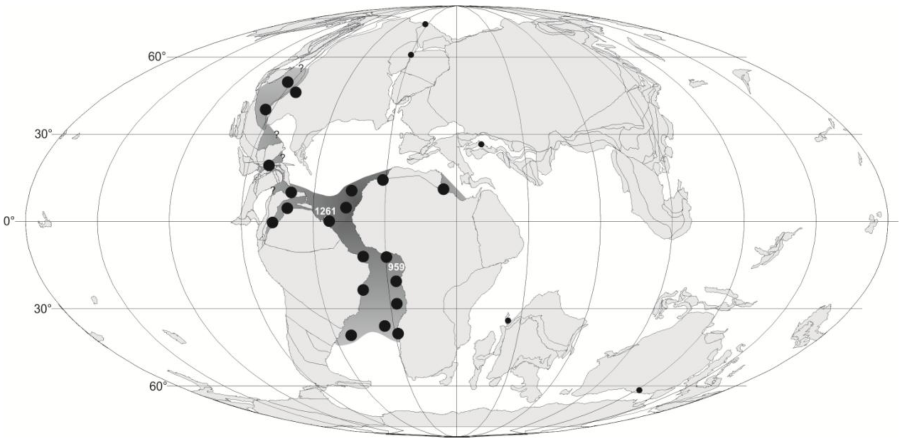

Fig. 1. Plate reconstruction for 86 Ma (around Coniacian-Santonian boundary; modified from Schettino and Scotese, 2004) with area of significant OAE 3 black shale sedimentation marked (large black circles) in the low latitudinal Atlantic and marginal basins and seaways (based on compilations of Wagner et al., 2004, 2011; and Wagreich, 2009), and other locations with reported local black shales (small black circles). ODP sites 959 (off Ivory Coast) and 1261 (Demerara Rise) with continuous black shales from OAE 2 to Santonian/Lower Campanian are indicated.

CPD
8, 1209–1227, 2012

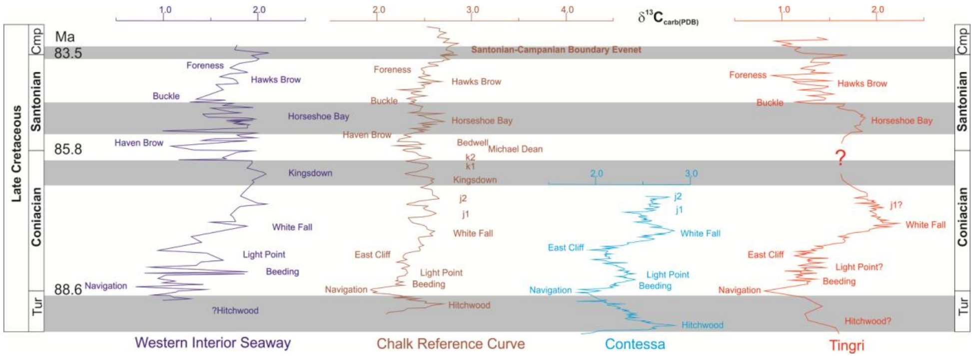

Fig. 2. Carbon isotope curves and correlations of carbon isotope events from inferred OAE 3 sites of the Western Interior (Pratt et al., 1993, stratigraphy according to Locklair et al., 2011), the English chalk reference curve (Jarvis et al., 2006, based on several sections), and two Tethyan sections, the Contessa/Vispi quarry section in Italy (Stoll and Schrag, 2000) and the Tingri section in Tibet (Wendler et al., 2009). Carbon isotope curves are time-calibrated on a chronostratigraphic scale by using the Turonian-Coniacian boundary and the correlated negative carbon isotope event (Navigation event of Jarvis et al., 2006; see also Walaszczyk et al., 2010), the Coniacian-Santonian boundary, and the Santonian-Campanian boundary and its positive carbon isotope event (Santonian/Campanian Boundary Event of Jarvis et al., 2006; see also Gale et al., 2008 and Wendler et al., 2009) as tie points, and numerical ages from Ogg et al. (2004), Locklair and Sageman (2008) and TimeScaleCreator 5.3 (http://www.tscreator.org).

CPD
8, 1209–1227, 2012

“OAE 3” – a low- to mid-latitude Atlantic oceanic event

M. Wagreich

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◄ | ►
◄ | ►
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion