Cretaceous Oceanic Red Beds: Stratigraphy, Composition, Origins, and Paleoceanographic and Paleoclimatic Significance

Edited by Xiumian Hu, Chengshan Wang, Robert W. Scott, Michael Wagreich, and Luba Jansa
CRETACEOUS OCEANIC RED BEDS: STRATIGRAPHY, COMPOSITION, ORIGINS, AND PALEOCEANOGRAPHIC AND PALEOCLIMATIC SIGNIFICANCE

Edited by:
Xiumian Hu, Chengshan Wang, Robert W. Scott, Michael Wagreich, and Luba Jansa

SEPM (Society for Sedimentary Geology)
Special Publication No. 91
SEPM and the authors are grateful to the following for their generous contribution to the cost of publishing

_Cretaceous Oceanic Red Beds: Stratigraphy, Composition, Origins, and Paleoceanographic and Paleoclimatic Significance_

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**Geosciences Department, The University of Tulsa**

**Ministry of Science and Technology, China, 973 Project**

**National Natural Science Foundation of China**

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4111 S. Darlington, Suite 100

Tulsa, Oklahoma 74135-6373, U.S.A.

Printed in the United States of America
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CONTENTS

Thank you to reviewers ................................................................................................................................................................................ 1
Photos from the first two workshops of the IGCP 463 in 2002 and the IGCP 463 and 494 in 2006 ................................................... 2

Introduction

Cretaceous oceanic red beds: stratigraphy, composition, origins, and paleoceanographic and paleoclimatic significance
ROBERT W. SCOTT, XIUMIAN HU, CHENGSHAN WANG, MICHAEL WAGREICH, AND LUBA JANSA ....................... 7

Overview

Overview of Cretaceous oceanic red beds (CORBs): A window on global ocean and climate change
CHENGSHAN WANG, XIUMIAN HU, YONGJIANG HUANG, ROBERT W. SCOTT, AND MICHAEL WAGREICH .......... 13
Chronostratigraphic database for Upper Cretaceous oceanic red beds (CORBs)
ROBERT W. SCOTT .................................................................................................................................................................................... 35
Cretaceous pelagic black shales and red beds of the North Atlantic: origins, paleoclimate and paleoceanographic implications
LUBA JANSA AND XIUMIAN HU ............................................................................................................................................................ 59
Cretaceous oceanic red beds (CORBs) in the Austrian Eastern Alps: passive margin vs. active-margin depositional settings
MICHAEL WAGREICH, STEFANIE NEUHUBER, HANS EGGER, INES WENDLER, ROBERT SCOTT, EWA MALATA, AND DIETHARD SANDERS ......................................................................................................... 73

CORBs in the Tethys and New Zealand

Stratigraphic constraints for climate control of Lower Cretaceous oceanic red beds in the Northern Calcareous Alps (Austria)
MICHAEL WAGREICH ............................................................................................................................................................................. 91
Cretaceous oceanic red beds in the outer Western Carpathians, Czech Republic
PETR SKUPIEN, MIROSLAV BUBÍK, LILIAN ŠVÁBENICKÁ, RADEK MIKULÁŠ, ZDENĚK VAŠÍČEK, AND DALIBOR MATYŠEK .................................................................................................................................... 99
Eastern Carpathians Cretaceous oceanic red beds: lithofacies, biostratigraphy, and paleoenvironment
MIHAELA MELINTE-DOBRINESCU, DAN C. JIPA, TITUS BRUSTUR, AND STEFAN SZOBOTKA ................................................ 111
A continuous Cretaceous–Paleocene red bed section in the Romanian Carpathians
ANA-VOICA BOJAR, MIHAELA CARMEN MELINTE-DOBRINESCU, AND HANS PETER BOJAR ........................................ 121
Cretaceous oceanic red beds from the Pindos Basin of Greece: long-term siliceous pelagic deposition punctuated by anoxia
PETER NEUMANN AND MICHAEL WAGREICH .............................................................................................................................. 137
Upper Cretaceous oceanic red beds in New Zealand
DANIEL (DAN) C.H. HIKUROA, PETER CRAMPTON, BRAD FIELD, AND POUL SCHIØLER ........................................ 145
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Photo taken in front of the Bonarelli Level in the Contessa Quarry section near Gubbino, Italy during the field excursion of the first workshop of IGCP 463, September 2002.

Group photo taken in front of the Jinma Hotel, Beijing, China during the last workshop of the IGCP 463 and 494, September 2006.
Panoramic photo of the Vispi Quarry section near Gubbio, Italy, showing the positions of the Cretaceous Oceanic Red Beds (from ORB3 to ORB9), the Bonarelli level (OAE2), and the Urbino level (OAE1b).

Birthplace of the Cretaceous Oceanic Red Beds—the Chuangde section near Gyangze, Tibet, China.
Introduction
INTRODUCTION TO CRETACEOUS OCEANIC RED BEDS:
STRATIGRAPHY, COMPOSITION, ORIGINS, AND
PALEOCEANOGRAPHIC AND PALEOClimATIC SIGNIFICANCE

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CORB DEFINITION

Cretaceous oceanic red beds—CORBs—are reddish to pinkish to brownish sedimentary rocks, of Cretaceous age, deposited in pelagic marine environments. Generally these are limestone, marl, shale, and/or chert.

IGCP 463 AND IGCP 494

The occurrence of marine red beds has been known for at least 140 years, since Štúr (1860) and Gümbel (1861) first described them from the Púchov beds in the Carpathians and the Nierental beds in the Eastern Alps. A few biostratigraphic and sedimentological studies followed, particularly in European countries. However, detailed investigations on paleoceanographic and paleoclimatic implications related to Cretaceous marine red beds and were initiated by Prof. Chengshan Wang, Dr. Xiumian Hu, and their colleagues. During late 1990s they discovered and studied Upper Cretaceous oceanic red beds in the Chuangde section, southern Tibet, which were deposited in the Eastern Tethys Ocean. Subsequently, within the framework of the IGCP 463 and 494, attention has been paid to the global distribution, correlation, and significance of the oxidation of these deposits for paleoceanographic reconstructions, and their relationships to the distinctly different, interbedded mid-Cretaceous black shales.

This collection of papers resulted from two collaborative research projects funded in part by UNESCO/IUGS International Geosciences Project IGCP 463 and IGCP 494. The IGCP 463 “Upper Cretaceous Oceanic Red Beds: Response to Ocean/Climatic Global Change” (2002–2006) was led by Prof. Chengshan Wang (China University of Geosciences, Beijing, China), Prof. Massimo Sarti (Università Politecnica delle Marche, Italy), Dr. Robert Scott (University of Tulsa and Precision Stratigraphy Associates, USA), and Prof. Luba Jansza (Dalhousie University, Canada). The objective of IGCP 463 was to study major paleoceanographic phenomena recorded by sedimentary sequences in the world oceans. Cretaceous deposition changed several times from widespread organic-carbon-enriched shales that indicate a dysoxic to anoxic deep ocean environment, to mostly reddish clays and marls deposited in an oxic marine environment during the Late Cretaceous.

The IGCP 494 “Dysoxic to oxic change in ocean sedimentation during mid-Cretaceous: a study of the Tethyan realm” (Young Scientists Project, 2003–2005) was led by Dr. Xiumian Hu (Nanjing University, China), Dr. Krzysztof Bak (Cracow Pedagogical University, Poland), Dr. Jens Wendler (University of Bremen, Germany), and Dr. Natalyia Tur (All-Russian Geological Research Institute, Russia). The aim of the Young Scientist Project IGCP 494 was to gain knowledge about the mid-Cretaceous oceanographic conditions that caused occasional changes from dysoxic–anoxic to oxic deep-sea sedimentation, especially in the Tethys Ocean.

Since 2002, a series of meetings and workshops were held in Ancona, Italy (2002), Bartin, Turkey (2003), Bremen, Germany (2003), Bucharest, Romania (2004), Neuchâtel, Switzerland (2005), and Beijing, China (2006). The projects sponsored symposia at the 32nd International Geological Congress in Florence, Italy in 2004 and at the 7th International Symposium on the Cretaceous in Neuchâtel, Switzerland in 2005. More than thirty persons from more than ten nations have participated in each meeting. The final meeting in September, 2006, in Beijing was followed by a field trip to Tibet to examine important sites and to formulate and test final hypotheses.

A major achievement during the past five years has been to provide evidence that CORBs are globally distributed, extending as far north as Greenland and as far south as New Zealand, between 60° N and 60° S Cretaceous paleolatitudes. Through
international cooperation it was possible to document occurrences of such deposits in Europe, Asia, New Zealand, and the Atlantic, Pacific, and Indian oceans.

The widespread distribution of CORBs indicates that major paleoceanographic conditions changed globally in the Cretaceous ocean, as witnessed by the development of strongly oxygenated sea-bottom conditions. This contrasts with the mid-Cretaceous, when organic-carbon-enriched black shales with several prominent organic-carbon-enriched horizons (OAEs) were deposited. These are widely interpreted to indicate dysoxic to anoxic ocean-bottom conditions. The driving force for such changes could be changes in ocean circulation, bioproductivity, changes in nutrient and/or sediment input, or paleoclimate, or any combination of the above.

Work on the projects led to the recognition that oceanic red beds were also deposited during the so-called “mid-Cretaceous greenhouse” period. This has considerable implications for our understanding of the global carbon cycle and paleoclimate, because it is generally thought that increases in atmospheric carbon dioxide will result in dysoxic or anoxic ocean-bottom conditions.

The aim of both IGCP projects was to present data on the timing of CORB occurrences, and their lithologic, sedimentologic, and geochemical characteristics. Thus, paleoceanographic processes, paleogeographic processes and “models”, stability of the paleoclimate, and regional tectonic changes during Cretaceous time would be tested. The significance of changes in the character of ocean-bottom sedimentary deposits is that they record major changes in the location of the global carbon reservoir and, more importantly, how Earth’s natural systems respond with the periods of increased atmospheric CO₂.

The results we obtained will influence future research by geoscientists and climate modelers on sedimentary environments, biostratigraphy, geochemistry, diagenesis, paleoecography, paleoclimates, sequence stratigraphy, and economic geology. The results are also relevant to geoscience educators and are of interest to the wider scientific community.

The standard measure of sediment accumulation rates is the Bubnoff, m/myr or mm/kyr, which will be used in this set of papers.

CHAPTER OVERVIEWS

The first paper summarizes many of the important results of both IGCP studies. In “Overview of Cretaceous Oceanic Red Beds (CORB): A Window on Global Ocean and Climate Change” Chengshan Wang and colleagues report that CORBs are the result of oxic conditions at or below the sediment–water interface in the deep Cretaceous oceans and are globally distributed. Lower Cretaceous oceanic red beds were geographically limited. However, in the Late Cretaceous, and especially beginning in the Early Turonian, marine red beds were widespread in the Tethys and as far south as New Zealand. Calcareous CORBs yield planktic foraminifera and nannofossils, and in argillaceous CORBs benthic agglutinated foraminifera are age diagnostic. In some sections dinoflagellates or radiolarians are also identified. CORBs constitute a special type of fine-grained pelagic–hemipelagic deposits that differ from gray beds by their red-brownish color and higher hematite content. CORBs can be classified as a variation of three end members—clayey CORBs, consisting mainly of terrigenous clay minerals, calcareous CORBs, mainly pelagic limestones, and siliceous CORBs, consisting mainly of biogenic SiO₂. Low sediment accumulation rates and great paleo–water depth were significant controlling factors of CORBs. Clay minerals mainly are mixed-layer illite–smectite and illite. CORBs are characterized by their high hematite content and low organic-matter content. The trace-element composition suggests little influence of source area and depleted marine nutrients. The rare earth cerium anomaly is consistent with oxic sediment conditions. The integrated data indicate that CORBs were deposited under highly oxic, oligotrophic, and low-productivity conditions, which suggests active ocean circulation. New ocean circulation models are needed to explain CORB occurrences.

An initial issue at the beginning of IGCP 463 was whether CORB deposition was synchronous or not. Robert Scott compiled a chronostratigraphic database to test the global synchrony of Upper Cretaceous oceanic red beds—CORBs—and to measure precisely their rates of sediment accumulation, “Chronostratigraphic Database for Upper Cretaceous Oceanic Red Beds (CORBs)” Late Cretaceous bioevents in numerous reference sections were integrated by graphic correlation, and stage boundaries are defined by GSSP or key reference sections. The time scale is similar to the recent geological time scale (Ogg et al., 2004). CORB strata were deposited at different times in different places for varying durations and at different rates beginning in the Aptian and continued sporadically into the Maastrichtian. CORB deposition generally was shorter in epicontinental basins than in oceanic basins, but the average rate of sediment accumulation of 13–14 m/myr tended to be similar in epicontinental and oceanic basins. Case studies of four Upper Cretaceous sections illustrate the effects of local tectonic and climatic conditions on CORB deposition.

A second overview paper challenges some generally held ideas about Cretaceous dark-gray shales and deep marine red beds. Luba Jansa and Xiuming Hu in “Cretaceous Pelagic Black Shales and Red Beds in western Tethys: Origins, Paleoecology, and Paleoceanographic Implications” compare and contrast depositional conditions of these two contrasting types of pelagic deposits. Two types of dark-gray Cretaceous shale were deposited in the deep oceans, the thick Hatteras Formation–type black shale and thinner beds of organic-rich shale. The deep North Atlantic Hatteras shale (HBS) was deposited after the ocean floor subsided below the carbonate compensation depth (CCD) during warm, humid, wet climate when terrigenous input of organic matter and marine productivity were high. However, organic-rich shale (OAE 1a and OAE 2) accumulated during the onset of eustatic sea-level rises, when phytoplankton blooms were promoted by iron fertilization from extensive local volcanism. Anaerobic conditions developed within the organic-matter-rich sediment, so it is not necessary to invoke widespread anoxic bottom-water masses. On the other hand, pelagic clays became red-colored during early diagenesis where the sediment accumulation rate was less than 20 m/kyr (2 cm/kyr). These conditions were favored by eustatic sea-level rise and increased ventilation of the ocean basins. The authors argue that just as modern deep-sea pelagic red clays in the Pacific Ocean extend across major climatic boundaries, so Cretaceous pelagic red shales were not directly or intrinsically related to paleoclimate.

One well-studied area for CORBs is the Austrian Eastern Alps. Michael Wagreich and his colleagues summarize their comprehensive study, “Cretaceous Oceanic Red Beds (CORBs) in the Austrian Eastern Alps: Passive-Margin vs. Active-Margin Depositional Settings”. They present a north–south transect from the passive European margin with the Helvetic–Ultrahelvetic shelf and continental slope through the Alpine Tethys onto the southern, tectonically active margin of the Austro-Alpine microplate. In the Ultrahelvetic units, CORBs comprise a continuous red interval from the lower Turonian to the lower Campanian. In the Helvetic–Ultrahelvetic zones, the proportion of CORBs increases significantly with increasing water depth and increasing pelagic character. In the
Rhenodanubian Flysch hemipelagic CORBs occur in the Upper Aptian–Lower Cenomanian Lower Varicolored Marls, the Coniacian–Lower Campanian Seisengen Formation, and the uppermost Campanian Perneck Formation. CORB deposition was controlled mainly by tectonic events and sea-level changes, and occurred during times of transgressions, low clastic input, and low turbidite frequencies. In the Northern Calcareous Alps, CORBs occur from the Santonian up into the Maastrichtian within the upper parts of transgressive sequences of the Gosau Group. These authors conclude that the premises for CORB sedimentation are low clastic input, low sedimentation rates, and increasing paleo-water depth.

CORBs in Tethys and New Zealand

Michael Wagreich in “Stratigraphic Constraints for Climate Control on Lower Cretaceous Oceanic Red Beds in the Northern Calcareous Alps (Austria)” describes two sets of CORBs in the Northern Calcareous Alps, Austria—the Anzenbach Member of the Schrambach Formation and two red intervals in the Tannheim Formation. In the Anzenbach Member, a several-meters-thick red marl to marly limestone is of Late Berrianian to Early Valanginian age. The red Hedbergella limestones at the base of the Tannheim Formation give a Late Aptian to earliest Albian age. The second red interval in the lower part of the Tannheim Formation below a prominent black shale interval (OAE 1b) is around the Aptian–Albian boundary. Whereas the Hedbergella limestones are interpreted as a condensed facies due to regional basin morphology, the other two CORB intervals coincide with cold periods in the Early Cretaceous, most probably suggesting a causal link between cool climate and CORB formation.

Petr Skupien and his colleagues in their paper “Cretaceous Oceanic Red Beds in the Outer Western Carpathians, Czech Republic” document CORBs that are mainly red shales ranging in age from the Albian to the Lower Paleocene according to microfossils including agglutinated foraminifera, dinoflagellates, and calcarious nannofossils. Both their bases and their tops are heterochronous through individual facies zones of the Outer Carpathians. Generally, the time span of the CORBs decreases from abyssal to slope facies and from inner to outer zones. The CORBs reached their maximum extent during the Turonian, and were terminated by an increased influx of terrigenous organic matter.

Mihaela Melinte-Dobrinescu and her colleagues document three CORB examples in Romania, “Eastern Carpathians Cretaceous Oceanic Red Beds: Lithofacies, Biostratigraphy, and Paleo-environment”. CORBs are composed of a variety of lithofacies, such as red shales, red radiolarians, red cherts with radiolarian, cherts, and red claystones and marlstones with microfossils. These red lithologies are interbedded with green and black radiolariites, green-gray chert, and green claystone. Albian–Coniacian CORBs of the Eastern Carpathians are rich in calcareous nannofossils, but up section the carbon content varies significantly. The paleoenvironment changed significantly from an Albian anoxic setting to an oxic, Late Cretaceous deep basin, in which CORBs were deposited.

CORBs in Romania range in age from Upper Campanian to Paleogene documented in “A Continuous Cretaceous–Paleocene Red Bed Section in the Romanian Carpathians” by Ana-Voica Bojar and her colleagues. Semiquantitative nannofossil occurrences and stable-isotope data suggest unstable ecosystems, fluctuating sea level, and/or detrital input as well as climatic changes during the Late Maastrichtian interval. Tethyan and Boreal nannofossils are intermixed and calibrated with several negative δ13C and δ18O excursions that may have stratigraphic utility.

Peter Neuman and Michael Wagreich present results of studies of the deep-water Pindos Basin, “Cretaceous Oceanic Red Beds from the Pindos Basin of Greece: Long-Term Siliceous Pelagic Deposition Punctuated by Anoxia”. Siliceous sedimentation was dominant during the Jurassic to Cretaceous. Valanginian to Coniacian red cherts and radiolarians are 25 to 100 mm thick and were deposited below the CCD at a sediment accumulation rate of 0.5–1.5 mm/kyr. The authors correlate green-black intervals within the siliceous CORBs with worldwide OAEs. Upper Cretaceous red-colored, pelagic carbonates overlie siliceous strata because the CCD deepened or the basin floor was tectonically uplifted. No major paleoceanographic change or long-term oxygen deficiency occurred in this Tethyan basin during the Early Cretaceous even though alternating warm–cool climates developed in the global greenhouse condition.

Daniel C. Hikora and his colleagues describe the southernmost CORBs known, “Upper Cretaceous Oceanic Red Beds in New Zealand.” CORBs are interbedded in siliciclastic mudstone-dominated successions interpreted as deposits of low-density turbidity currents at lower bathyal depths. The onset of deposition of these red siliciclastic, lower bathyal mudstones was contemporaneous with the Conenmanian–Turonian boundary and a rapid decline in macrofauna. CORB deposition continued into the Coniacian. Local geomorphology, low sedimentation rates, and oxic environments played a major role in New Zealand CORB sedimentation.

SHALLOW-WATER CORBS

The shelf pelagic biosedimentary system of northwestern Germany is carefully documented in “The Söhde Formation (Conenmanian, Turonian, Upper Cretaceous) NW Germany: Shallow Marine Pelagic Red Beds” by Frank Wiese. He reconstructed several sedimentary cycles of ca. 430 kyr duration in the white to red limestone succession. Red limestones were deposited on intrashelf highs above and slightly below storm-wave base. Storm- and current-induced, advective pore-water flow was associated with low accumulation rates in a nutrient-depleted intrashelf setting. He interprets this system to have been the result of excess oxygen in the sediment column. Red pigmentation was the result of precipitation of ferric iron minerals during early diagenesis, and clay minerals were identified as the most probable source of iron.

Jens Wendler and his colleagues in “Early Turonian Shallow Marine Red Beds on the Levant Carbonate Platform (Jordan), Southern Tethys” report a one-meter-thick shallow marine (shallow subtidal) red bed from Lower Turonian strata associated with the Levant carbonate platform in central Jordan. This CORB is of regional significance because deposits similar in facies and age are present farther southwest in the Sinai. The transition into red marls marks a significant change in sedimentation from marly, gypsum-rich clay representing lowstand deposits below, into a sequence including massive platform limestone beds forming a transgressive systems tract above the red bed. The red marls are related to strongly fluctuating sedimentation rates, and follow periods of high marine productivity, which occurred in the aftermath of OAE 2.

CORB ORIGINS AND PALEOECONOMIC–PALEOClimATE IMPLICATIONS

High-resolution geochemical and mineralogical data in “Origin of Cretaceous Oceanic Red Beds from the Vispi Quarry Section, Central Italy: Visible Reflectance and Inorganic Geochemistry” by Xiuxian Hu, Wenbin Cheng, and Junfeng Li document
carbonate CORBs in the Umbria–Marche Basin, Italy. The authors found no change in the sources of terrigenous detrital input in the transitional interval from the Scaglia Bianca to the Scaglia Rossa. The red limestone color is imparted by finely disseminated hematite and resulted fromoxic conditions near the sediment–water interface as indicated by high Fe$_2$O$_3$ values and a high Fe$_3+$/TFe ratio, and strongly negative Ce anomalies (0.28–0.42). They attributed the change from white to red dissolved oxygen in bottom waters as a consequence of intensified bottom circulation.

Stephanie Neuhuber and Michael Wagreich in their study, “Geochemical Characterization of Santonian Cyclic Oceanic Red Beds in the Alpine Tethys (Rehkgelgraben Section, Austria)” use mineralogical, geochemical, and stable-isotope analyses to define and interpret cyclical carbonate CORBs. Limestone-marl beds seem to record the ~20 kyr precession climatic cycle. The red-colored marls experienced oxic early diagenetic conditions based on data on iron speciation because of low sedimentation rates. The positive correlation between plagioclase and organic carbon suggest nutrient-like trace metals during volcanic periods. Geochemical and stable-isotope data indicate quite oligotrophic conditions in which organic matter and nutrients in the upper water column were recycled efficiently.

Ines Wendler and her colleagues in “Productivity fluctuations and orbital cyclicity during onset of Early to Middle Turonian marine red-bed formation (Austrian Eastern Alps)” studied a Turonian section in the Ultrahelvetic units of Upper Austria using benthic foraminifera and cyclic stratigraphy. Initially a high amount of organic material is indicated by the high abundance of the foraminifera Tappanina laciniosa and Praebulimina elata, which occur in the transitional interval just below the color change from gray to red beds. The Middle Turonian red beds show a cyclic sedimentary architecture of four marlstone–limestone couplets with increasing bedding thickness and a gray limestone bed in the top. Based on carbon isotope stratigraphy, these cycles can be related to the 400 kyr eccentricity cycle, and the four marlstone–limestone couplets per cycle are assigned to the 100 kyr eccentricity cycle. Their data show that by the time of the Early–Middle Turonian transition, ocean bottom-water oxygen concentrations had increased sufficiently to facilitate deposition of marine red beds in settings where accumulation rates were below 4 mm/kyr.

Yongjian Huang and his colleagues present a detailed examination of Fe partitioning in Cretaceous oceanic red beds in “Characterization of Iron Partitioning in Cretaceous Oceanic Red Beds of the Chuangde Section, South Tibet”. Tibet provides evidence for hematite enrichment during deposition to early diagenesis in an oxic depositional environment. They conclude that a feedback between oceanic redox and productivity might be responsible for the prolonged formation of Cretaceous oceanic red beds. This feedback mechanism could have been fostered by increased ventilation of the ocean due to global cooling and a deep connection between the North and South Atlantic Ocean during Late Santonian–Early Campanian times.

Analysis of Coniacian–Santonian black shale and pelagic red beds provides an explanation for the limited occurrence of OAE 3 in “Coniacian–Santonian Oceanic Red Beds and their Link to Oceanic Anoxic Event 3” by Michael Wagreich. A pronounced shift in $^{13}$C does not characterize beds of OAE 3, unlike those of OAE 1a and OAE 2. Strata of OAE 3 are found mainly in the equatorial Atlantic Ocean, thus representing a more regional Atlantic event. This event ceased after the final opening of the equatorial Atlantic seaway when deep-water circulation was established during the latest Santonian and early Campanian and CORB sedimentation became ubiquitous.

William Hay in “Cretaceous Oceans and Ocean Modeling” takes on the enormous task of characterizing Cretaceous atmospheric and oceanic circulation. He then speculates on a variety of geophysical and biological consequences. He argues that because the poles were ice-free during most of the Cretaceous and no high mountains diverted zonal wind flow, the overall climate was more equable than today. Thus, Cretaceous oceans could not develop subtropical and polar frontal systems that depend on steady, mid-latitude westerly winds. Without frontal systems, mesoscale eddies were generated by the variable mid- to high-latitude winds, which then acted to pump oceanic gyres upward and downward. The deep Tethyan ocean circulation would have been similar to modern overflow from Greenland–Iceland–Norwegian seas and the Mediterranean Sea into the Atlantic. Hay suggests that each basin would have had its own ventilation system and the development of oxic or anoxic conditions would have depended on local water sources.

We attempted to compile a collection of papers of high scientific quality and significance, and towards this goal, each paper was reviewed by at least two reviewers. We thank these referees who undertook the onerous task of refereeing all the papers, which greatly benefited this volume. We are grateful to Donald F. McNell and Dr. Gary J. Nichols, co-editors of SEPM Special Publications, and to Robert Clarke, SEPM Publications Coordinator, for their aid and support in presenting the results of this international cooperative project. We acknowledge the financial support of Chinese MOST 973 (2006CB701400), the NSFC project (40332020), MOE “111” project, and of the IGCP 463/494, the two projects of International Geosciences Program of UNESCO & IUGS.

ACKNOWLEDGMENTS

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DOI: 10.1007/s00018-000-0001-8

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