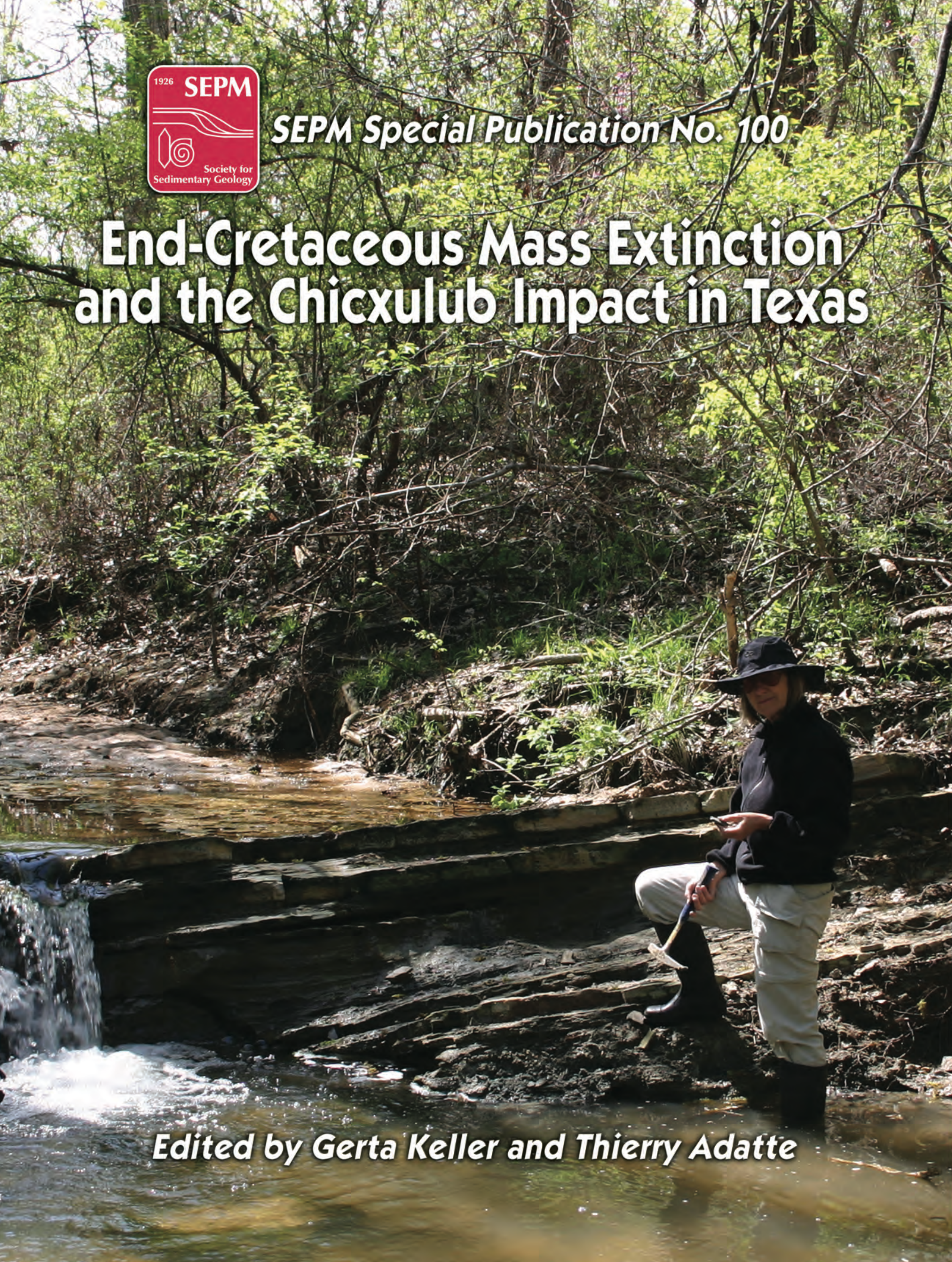
1926 SEPM
Society for Sedimentary Geology

SEPM Special Publication No. 100

End-Cretaceous Mass Extinction and the Chicxulub Impact in Texas



Edited by Gerta Keller and Thierry Adatte

The End-Cretaceous Mass Extinction and the Chicxulub Impact in Texas

Gerta Keller and Thierry Adatte, Editors

CONTENTS

Dedication to Ronnie and Jackie Mullinax of the Brazos Rose Ranch 1

Preface
GERTA KELLER AND THIERRY ADATTE 3

The Cretaceous–Tertiary Mass Extinction: Theories and Controversies
GERTA KELLER 7

Defining the Cretaceous–Tertiary Boundary: A Practical Guide and Return to First Principles
GERTA KELLER 23

Age and Origin of the Chicxulub Impact and Sandstone Complex, Brazos River, Texas: Evidence from Lithostratigraphy and Sedimentology
THIERRY ADATTE, GERTA KELLER, AND GERALD R. BAUM 43

Biostratigraphy, Age of Chicxulub Impact, and Depositional Environment of the Brazos River KTB Sequences
GERTA KELLER, SIGAL ABRAMOVICH, THIERRY ADATTE, AND ZSOLT BERNER 81

Maastrichtian Planktic Foraminiferal Biostratigraphy and Paleoenvironment of Brazos River, Falls County, Texas, U.S.A.
SIGAL ABRAMOVICH, GERTA KELLER, ZSOLT BERNER, MATAN CYMBALISTA, AND CARMI RAK 123

Calcareous Nannofossils Across the Cretaceous–Tertiary Boundary at Brazos, Texas, U.S.A.: Extinction and Survivorship, Biostratigraphy, and Paleoecology
ABDEL AZIZ TANTAWY 157

The Distribution of Benthic Foraminifera Across the Cretaceous–Paleogene Boundary in Texas (Brazos River) and Denmark (Stevns Klint)
MALCOLM B. HART, SARAH R. SEARLE, SEAN E. FEIST, ANDREW D. LEIGHTON, GREGORY D. PRICE, CHRISTOPHER W. SMART, AND RICHARD J. TWITCHETT 179

Cretaceous–Tertiary Mass Extinction in Marginal and Open Marine Environments: Texas, U.S.A., and Tunisia
GERTA KELLER 197

Platinum Group Element (PGE) Geochemistry of Brazos Sections, Texas, U.S.A.
BRIAN GERTSCH, GERTA KELLER, THIERRY ADATTE, AND ZSOLT BERNER 227

Trace-Element Geochemistry of Brazos Sections, Texas, U.S.A.
BRIAN GERTSCH, GERTA KELLER, THIERRY ADATTE, AND DAVID BARTELS 251

The Sandstone Complex in the Brazos Riverbed Section: Geochemical Constraints on Genesis and Depositional Conditions
DIRK MUNSEL, ZSOLT BERNER, AND DORIS STÜBEN 281

Geochemistry of Chicxulub Impact Spherules in the Brazos Riverbed Section, Texas, U.S.A.
PATRICK ULLRICH, ZSOLT BERNER, AND UTZ KRAMAR 297

THE CRETACEOUS–TERTIARY MASS EXTINCTION: THEORIES AND CONTROVERSIES

GERTA KELLER
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.
e-mail: gkeller@princeton.edu

ABSTRACT: The Cretaceous–Tertiary boundary (KTB) mass extinction is primarily known for the demise of the dinosaurs, the Chicxulub impact, and the frequently rancorous thirty-years-old controversy over the cause of this mass extinction. Since 1980 the impact hypothesis has steadily gained support, which culminated in 1990 with the discovery of the Chicxulub crater on Yucata´n claimed as the KTB impact site and ‘‘smoking gun’’ that virtually proved this hypothesis. In a perverse twist of fate, this discovery also began the decline of the impact hypothesis, because for the first time it could be tested directly based on the impact crater and impact ejecta in sediments throughout the Caribbean, Central America, and North America. Two decades of multidisciplinary studies amassed a database with a sum total that overwhelmingly reveals the Chicxulub impact as predating the KTB mass extinction in the impact-crater cores, in sections throughout northeastern Mexico and in Brazos River sections of Texas, U.S.A. This paper recounts the highlights of the KTB controversy, the discovery of facts inconsistent with the impact hypothesis, and the resurgence of the Deccan volcanism hypothesis as the most likely cause for the mass extinction.

DEFINING THE CRETACEOUS–TERTIARY BOUNDARY: A PRACTICAL GUIDE AND RETURN TO FIRST PRINCIPLES

GERTA KELLER
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.
e-mail: gkeller@princeton.edu

ABSTRACT: The Cretaceous–Tertiary boundary (KTB) is one of the easiest epoch boundaries to identify, whether based on lithological changes in the field, geochemical analysis in the laboratory, or fossil content. A set of five KTB-identifying criteria, originally proposed by the ICS working group during the late 1980s–1990s, have proven globally applicable and independently verifiable: (1) mass extinction of Cretaceous planktic foraminifera, (2) evolution of the first Danian species, (3) KTB clay and red layer, (4) Ir anomaly, and (5) $\delta^{13}C$ shift. Despite this successful track record, it was recently proposed to reduce the five KTB-identifying criteria to just two, the mass extinction and impact signals, based on the assumption that the Chicxulub impact caused the mass extinction and therefore defines the KTB. Because this assumption is contradicted by stratigraphic data in many places, this has led to contentious arguments, whereas defining the Chicxulub impact as KTB in age has led to circular reasoning. This study demonstrates the contradictions, pitfalls, and erroneous assumptions that accompany the use of these reduced impact-event-based KTB criteria. Returning the definition of the KTB to its GSSP based on all five criteria, and where this is not possible based on the mass extinction, the first appearance of Danian species, and the $\delta^{13}C$ shift provide the most reliable KT boundary markers.

AGE AND ORIGIN OF THE CHICXULUB IMPACTAND SANDSTONE COMPLEX, BRAZOS RIVER, TEXAS: EVIDENCE FROM LITHOSTRATIGRAPHY AND SEDIMENTOLOGY

THIERRY ADATTE
Geological and Paleontological Institute, Anthropole, CH-1015 Lausanne, Switzerland
e-mail: thierry.adatte@unil.ch

GERTA KELLER
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.

and

GERALD R. BAUM
Lewis Energy Group, 10101 Reunion Square, Suite 1000, San Antonio, Texas 78216, U.S.A.

ABSTRACT: Multidisciplinary investigations based on the lithology, sedimentology, mineralogy, and biostratigraphy of upper Maastrichtian to lower Danian boundary (KTB) sequences along 3.5 km of the Brazos River in Falls County, Texas, reveal depositional sequences, including an impact-spherule-rich sandstone complex, characteristic of sequence stratigraphic models applied to shallow shelf areas, such as incised valleys, lag conglomerate, storm deposits, and repeated bioturbation. The top of the Corsicana Formation coincides with a channel, which we interpret as an incised valley. The erosion surface marks a major depositional sequence boundary (SB) associated with the latest Maastrichtian sea-level fall. Initial channel deposits consist of coarse shelly glauconitic sand with large lithified clasts containing impact spherules and large bored and encrusted phosphatized concretions, which we interpret to indicate that the Chicxulub impact occurred well prior to the lithification, erosion, and redeposition at the base of the channel. The primary Chicxulub ejecta layer lies about 40–65 cm below the sandstone complex in a 3-cm-thick yellow clay layer that consists of cheto smectite (altered impact glass) interbedded in claystones of the Corsicana Formation. Above the sandstone complex, claystones, and mudstones are burrowed and correspond to a condensed interval interpreted as a maximum flooding surface (MFS). Based on biostratigraphy and the $\delta^{13}C$ shift, the KT boundary is up to 1 m (50–100 ky) above the sandstone complex and coincides with increased sediment accumulation during the early Danian sea-level rise (HST). These features are inconsistent with a single catastrophic bolide impact on Yucatán and associated megatsunami deposition as commonly interpreted.

The biostratigraphy and KT characteristic $\delta^{13}C$ shift of the Brazos sections indicate that the KTB, the sandstone complex, and the Chicxulub impact occurred as three different stratigraphic events during the late Maastrichtian planktic foraminiferal zone CF1. These are represented by: (1) the Chicxulub impact sequence deposited about 200–300 ky prior to the KTB, (2) the sandstone complex with reworked impact spherules deposited in incised valleys during the latest sea-level fall about 100–150 ky prior to the KTB, and 3) the KTB event during the subsequent HST and following the condensed MFS.

BIOSTRATIGRAPHY, AGE OF CHICXULUB IMPACT, AND DEPOSITIONAL ENVIRONMENT OF THE BRAZOS RIVER KTB SEQUENCES

GERTA KELLER
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.
e-mail: gkeller@princeton.edu

SIGAL ABRAMOVICH
Department of Geological and Environmental Sciences, Ben-Gurion University of the Negev, Beer Sheba 84105, Israel

THIERRY ADATTE
Geological and Paleontological Institute, University of Lausanne, Anthropole, CH-1015 Lausanne, Switzerland

and

ZSOLT BERNER
Institute for Mineralogy and Geochemistry, University of Karlsruhe, 76128 Karlsruhe, Germany

ABSTRACT: Integrated biostratigraphy, sedimentology, and stable isotopes of 11 outcrops and wells along the Brazos River of Falls County, Texas, U.S.A., reveal the stratigraphic separation and sequential depositional history of the Chicxulub impact, followed by the sandstone complex and associated sea-level fall, which in turn was followed by the Cretaceous–Tertiary boundary (KTB). The KTB was identified up to 1 m above the sandstone complex based on three global standard criteria: the mass extinction in planktic foraminifera, evolution of first Danian species, and negative $\delta^{13}C$ shift. No Ir anomaly is associated with the KTB or the Chicxulub impact ejecta layers. Upper Maastrichtian sediment deposition occurred in a middle-shelf environment that shallowed to inner-shelf depth at the time of deposition of the sandstone complex. At this time, Brazos sections show distinct shallowing from inner-neritic in the north to infra-neritic and lagoonal at Cottonmouth Creek, with further shallowing to intertidal swamp or marsh conditions in the Darting Minnow Creek area to the south. The sandstone complex is the most prominent feature of the Brazos sections. At the base of this unit are reworked Chicxulub impact spherules and lithified clasts with impact spherules and mud cracks that bear witness to erosion of an older primary spherule deposit. This primary Chicxulub impact ejecta layer was discovered between 45 and 60 cm below the sandstone complex in a 3 cm thick yellow clay altered impact glass layer. The sandstone complex, the reworked impact spherules, the spherule-rich clasts, and the yellow clay layer all clearly predate the KTB.

MAASTRICHTIAN PLANKTIC FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOENVIRONMENT OF BRAZOS RIVER, FALLS COUNTY, TEXAS, U.S.A.

SIGAL ABRAMOVICH
Dept. of Geological & Environmental Sciences, Ben-Gurion University of the Negev, Beer Sheba, 84105, Israel
e-mail: sigalabr@bgu.ac.il

GERTA KELLER
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.

ZSOLT BERNER
Institute for Mineralogy & Geochemistry, University of Karlsruhe, 76128 Karlsruhe, Germany

MATAN CYMBALISTA and CARMI RAK
Dept. of Geological & Environmental Sciences, Ben-Gurion University of the Negev, Beer Sheba, 84105, Israel

ABSTRACT: Investigation of late Maastrichtian faunal and environmental changes in three subsurface wells spanning over 3 km along the Brazos River, Texas, reveals similar minimum-diversity high-stress assemblages associated with shallow shelf conditions. Upper Maastrichtian sediments recovered span planktic foraminiferal (CF) zones CF1 to CF4 in well Mullinax-1 to the north and well KT3 at Cottonmouth Creek, and zones CF1-CF2 in Mullinax-3 at Darting Minnow Creek. Biotic stress conditions are demonstrated by the minimum species richness, near exclusion of larger specialized species, dwarfing, and dominance of small generalist taxa. Faunal assemblages dominated by alternating abundances of the disaster opportunist *Guembelitria cretacea* (Cushman) (particularly in zones CF4 and CF2-CF1) and heterohelicid species [e.g., *Heterohelix globulosa* (Ehrenberg), *H. planata* (Cushman), *Paraspiroplecta navarroensis* (Loeblich)]. Other small surface and subsurface mixed-layer dwellers are rare to common (e.g., hedbergellids, globigerinellids, pseudoguembelinids).

The coincidence of *Guembelitria* blooms with lithological changes and oxygen and carbon stable isotope excursions may represent discrete episodes of freshwater runoff related to short-term pulses of the latest Maastrichtian (zone CF1-CF2) global climate warming. Climatewarming ended in the upper part of zone CF1 with the return to a cooler climate, lower sea level, and the formation of incised valleys in a coastal–lagoonal environment. With the subsequent early transgression, incised valleys were infilled by a sandstone complex with reworked impact spherules, as well as lithified clasts with impact spherules up to 80 cm below the KT boundary. In this environment the shallow inner-neritic setting superimposed by changes in sea level and climate is the most probable cause for the observed conditions of high biotic stress preceding the KTB in the Brazos area.

CALCAREOUS NANNOFOSSILS ACROSS THE CRETACEOUS–TERTIARY BOUNDARY AT BRAZOS, TEXAS, U.S.A.: EXTINCTION AND SURVIVORSHIP, BIOSTRATIGRAPHY, AND PALEOECOLOGY

ABDEL AZIZ TANTAWY
Department of Geology, Aswan Faculty of Science, South Valley University, Aswan 81528, Egypt
e-mail: aatantawy@yahoo.com

ABSTRACT: Brazos River sections from Falls County, Texas, U.S.A., provide an excellent opportunity for studying the Cretaceous–Tertiary (KT) transition in an expanded sedimentary record that also contains a sandstone complex with Chicxulub impact spherules at the base, which have previously been interpreted as evidence of an impact-generated tsunami at the KT boundary. This study quantifies the calcareous nannofossil assemblages to determine the environmental and ecological changes across the KT transition in a new core Mullinax-3 and three Cottonmouth Creek outcrops. Abundance and diversity of calcareous nannofossils provide evidence of the changing environmental conditions and reveal a sequence of vanishing species, survivors, and the subsequent recovery across the KT boundary. Cretaceous assemblages are dominated by high abundance of dissolution-resistant *M. decussata* reflecting periods of high-stress environmental conditions prior to the KT boundary. Most Cretaceous taxa disappeared well above the sandstone complex and at the level synchronous with the mass extinction of planktic foraminifera. In addition, a progressive decline in the calcareous nannofossils is recorded in the uppermost Maastrichtian ~25 cm above the sandstone complex and 12 cm below the KT boundary. The KT boundary is marked by an important decrease in absolute abundance of calcareous nannofossils, the blooms of the dinoflagellate cysts of *Thoracosphaera operculata* and the opportunistic survivor *Braarudosphaera bigelowii*, and the appearance of new Paleocene taxa. These micropaleontological data confirm that the Chicxulub impact predated the KT boundary, consistent with earlier observations in northeastern Mexico and the Chicxulub crater core Yaxcopoil-1. Correlation of selected nannofossil taxa from the Brazos sections with those from various onshore marine and deep-sea sections provides insights into their paleoenvironmental and paleoecological affinities.

THE DISTRIBUTION OF BENTHIC FORAMINIFERA ACROSS THE CRETACEOUS–PALEOGENE BOUNDARY IN TEXAS (BRAZOS RIVER) AND DENMARK (STEVNS KLINT)

MALCOLM B. HART
School of Geography, Earth & Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA, U.K.
e-mail: mhart@plymouth.ac.uk

SARAH R. SEARLE
Petrostrat Ltd, Tan-y-Graig, Parc Caer Seion, Conwy, LL32 8FA, U.K.

SEAN E. FEIST
Network Stratigraphic Consulting Ltd, Harvest House, Cranborne Road, Potters Bar, Hertfordshire, EN6 3JF, U.K.

ANDREW D. LEIGHTON, GREGORY D. PRICE, CHRISTOPHER W. SMART, and RICHARD J. TWITCHETT
School of Geography, Earth & Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA, U.K.

ABSTRACT: The benthic foraminifera have been studied from a large number of samples collected from successions both in, and close to, the Brazos River (Falls County, Texas, U.S.A.) and from the cliffs of Stevns Klint (south of Copenhagen, Denmark). The sections from the Brazos River contain extensive and nearly continuous outcrops, recording the so-called ‘‘event’’ deposits and the Cretaceous–Paleogene boundary. Micropaleontological analysis of samples taken from the Mullinax-1 core, and some of the exposures in the Brazos River (and tributaries), have been investigated for benthic and planktic foraminifera, all of which are indicative of relatively shallow shelf conditions. The benthic foraminifera suffer a significant loss of diversity at the level of the ‘‘event’’ deposits, which appear to predate the micropaleontological Cretaceous–Paleogene boundary, but no mass extinction is recorded. The agglutinated taxa almost disappear at this level, and the faunal changes indicate that there may have been a shallowing at that time. The benthic foraminifera from Stevns Klint are very different from those recorded in Texas, being typical of assemblages in the chalk facies of northwestern Europe. At the base of the Højerup Member (previously known as the Grey Chalk) there are significant changes in the benthic assemblage, again suggestive of a shallowing event at the level of two closely spaced hardgrounds, which often merge into a single horizon. The ‘‘event’’ deposits of the Brazos River successions may, therefore, be related to events associated with the hardground horizon at Stevns Klint, and the evidence for this interpretation is presented. This, and other, correlations provide data for the construction of a sequence stratigraphy for the Cretaceous–Paleogene boundary interval.

CRETACEOUS–TERTIARY MASS EXTINCTION IN MARGINAL AND OPEN MARINE ENVIRONMENTS: TEXAS, U.S.A., AND TUNISIA

GERTA KELLER
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.
e-mail:gkeller@princeton.edu

ABSTRACT: The Cretaceous–Tertiary boundary (KTB) sequences along the Brazos River, Texas, U.S.A., have been controversial for over two decades. At issue is whether the KTB and the mass extinction should be placed at the base of a sandstone complex based on the presence of Chicxulub impact spherules or at the mass extinction. This issue goes to the very core of the KTB controversy—did the Chicxulub impact cause the KTB mass extinction? Faunal, stable isotope, platinum group elements (PGEs), and lithological analyses of six Brazos cores and outcrop sections, and comparison of these data with the Elles, Tunisia, parastratotype shed light on these issues. The KTB is well marked by the mass extinction of planktic foraminifera, the first appearance of Danian species, and the $\delta^{13}C$ negative shift, which occurs up to 1 m above the sandstone complex that contains two to three impact spherule layers at its base. There is no Ir anomaly at the KTB and mass extinction, but minor Ir enrichments are present in condensed intervals within and slightly above the sandstone complex. Clasts at the base of the sandstone complex contain impact spherules that reveal earlier deposition, lithification, erosion, and redeposition. The Chicxulub impact thus predates not only the KTB, but also the sandstone complex. A yellow clay layer consisting of altered impact glass 45–60 cm below the sandstone complex (zone CF1) may represent the original Chicxulub impact ejecta fallout.

The mass extinction pattern in the Brazos sections appears gradual or progressive compared with patterns documented from open-ocean environments. This is largely the result of high sediment accumulation rates in inner-neritic depositional settings coupled with the sea-level fall that culminated with deposition of the sandstone complex. Comparison of various extinction parameters, such as overall species richness, species abundances, life strategies, and separation into opportunists vs. specialists reveals that the shallow Brazos environment excluded the specialized larger and deeper-dwelling species (~40%) that suffered the most abrupt mass extinction at the KTB. The Brazos extinction pattern thus reflects the mass extinction in the most hardy and environmentally most tolerant assemblages, which include several KTB survivors. Similar patterns are observed in shallow-water environments of southern Tunisia, Egypt, Denmark, and Argentina. These data show that the Chicxulub impact predates the KTB and caused no species extinctions.

PLATINUM GROUP ELEMENT (PGE) GEOCHEMISTRY OF BRAZOS SECTIONS, TEXAS, U.S.A.

BRIAN GERTSCH and GERTA KELLER
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.
e-mail: bgertsch@princeton.edu

THIERRY ADATTE
Institut de Ge´ologie et Pale´ontologie, Universite´ de Lausanne, Anthropole, CH-1015 Lausanne, Switzerland

and

ZSOLT BERNER
Karlsruhe Institute of Technology, University, 76131 Karlsruhe, Germany

ABSTRACT: Geochemical and sedimentological analyses of platinum group element (PGE) patterns across the Cretaceous–Tertiary (KT) transition of eight sections along the Brazos River, Texas, reveal possible sources and processes responsible for PGE enrichments. Of the five global characteristics defining the Cretaceous–Tertiary boundary (KTB) (mass extinction in planktic foraminifera, first appearance of Danian species, negative δ^{13}C excursion, Ir anomaly, thin (0.5 cm) red clay layer), the Ir anomaly and the red clay layer are not present at the KTB in the Brazos sections. Instead, PGEs and especially Ir show several minor enrichments within the sandstone complex, with the largest peak at the top or just above it. Possible mechanisms of PGE enrichments include low sedimentation rates or sediment starvation that concentrates Ir and other PGEs. Absence of Ir at the KTB is likely linked to dilution effects caused by high sedimentation rates, and other still unknown processes. The source of PGEs remains elusive, but it may be linked to an increased input of extraterrestrial dust during the late Maastrichtian, or reworked PGEs from the Chicxulub impact, which predates the KTB in these sections.

TRACE-ELEMENT GEOCHEMISTRY OF BRAZOS SECTIONS, TEXAS, U.S.A.

BRIAN GERTSCH and GERTA KELLER
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.
e-mail: bgertsch@princeton.edu

THIERRY ADATTE
Geological and Paleontological Institut, University of Lausanne, Anthropole, CH-1015 Lausanne, Switzerland

and

DAVID BARTELS
Department of Geosciences, Princeton University, Princeton NJ 08544, U.S.A.

ABSTRACT: A geochemical study of major (MEs) and trace (TEs) elements across the Cretaceous–Tertiary (KT) transition was carried out on two sections of the Brazos area to investigate signals of the Chicxulub impact, as well as redox conditions and weathering processes in these shallow-water environments. Results show that ME and TE patterns are mainly affected by the type of lithology, including claystones, mudstones, a 3-cm-thick yellow clay layer, a sandstone complex with two or three spherule-rich layers, and alternating hummocky cross-bedded and laminated sandstone layers. In the yellow clay layer, TEs (Mn, Ni, Cr, Na) concentrations are comparable to the spherule-rich layers and geochemistry of spherules. Relative abundance of MEs (Al, Ca, Fe, Mg) in both spherule-rich layers and the yellow clay layer shows also a good correlation. This indicates that the yellow clay layer is likely an alteration product of a spherule-rich layer. No other evidence of the Chicxulub impact could be determined based on MEs and TEs values. In the claystone and mudstone intervals, TE concentrations are constant and slightly enriched in redox-sensitive TEs (Mo, U, V), which indicates that dysoxic conditions prevailed. Occurrence of rare large pyrite framboids (30–50 μm) below the sandstone complex confirms that redox conditions were dysoxic in the shallow-water Brazos environments. High values for Al and weathering indices show high detrital input dominated by chemical weathering. These results reveal that persistent high-stress conditions and high continental runoff prevailed through the late Maastrichtian–early Danian transition. No significant geochemical and environmental change due to the Chicxulub impact is detected. Sudden increases in trace elements (Co, Cr, Ni) possibly related to an impact are observed only in reworked intervals in the sandstone complex.

THE SANDSTONE COMPLEX IN THE BRAZOS RIVERBED SECTION: GEOCHEMICAL CONSTRAINTS ON GENESIS AND DEPOSITIONAL CONDITIONS

DIRK MUNSEL, ZSOLT BERNER, and DORIS STÜBEN
Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany
e-mail: zsolt-attila.berner@kit.edu

ABSTRACT: The origin and deposition of spherule-bearing, dominantly sandy beds in a sandstone complex (also called ‘‘event deposit’’) below the biostratigraphic Cretaceous–Tertiary (KT) boundary plays a key role in models linking the KT mass extinction to the Chicxulub impact. This study, which focuses on the chemostratigraphy of this complex exposed in a ca. 60-cm-thick succession along the Brazos River, Falls County, Texas, U.S.A., aims to constrain the source of the material as well as the depositional conditions and postdepositional history of this highly controversial stratigraphic unit. Major and trace elements, as well as the isotopic composition of the Ca carbonate, contrast sharply with the underlying Corsicana Formation, indicating a dramatic change in the source of material and depositional conditions. Evaluation of geochemical data by principal-component analysis permits identification of (1) siliciclastic components, (2) ejecta material, consisting of altered impact-glass spherules, and (3) Ca carbonate. The ejecta material, originally represented chiefly by glass spherules with carbonate infill, is strongly altered to clay minerals with dominantly smectitic composition and is characterized by the element association Al_2O_3, TiO_2, Fe_2O_3, P_2O_5, and SO_2 and the trace elements (TE) V, Cr, Ni, Cu, Zn, Ga, and Mo. The occurrence of two moderately high Ir peaks (0.2 and 1.1 μg/kg) suggests the presence of tiny amounts of extraterrestrial material within the sandstone complex. Based on the contrasting abundance of Ni and Cu in chondritic meteorites and middle crust, the Ni/Cu ratio was used to trace the portion of extraterrestrial material in the sequence. The distribution of this ratio reflects changes in the amount of siliciclastic components added during deposition of the sandstone complex rather than variations in the amount of meteoritic material. The disagreement between evidence suggesting a prevalence of reducing conditions during the alteration of the ejecta material (pyrite inclusions in spherules; accommodation of Mn^{2+} by secondary calcite) and sedimentologic features which indicate that the sandstone complex was deposited in a dominantly oxic, high-energy environment strongly supports the case that the ejecta material in these deposits was subjected to reworking.

GEOCHEMISTRY OF CHICXULUB IMPACT SPHERULES IN THE BRAZOS RIVERBED SECTION, TEXAS, U.S.A.

PATRICK ULLRICH, ZSOLT BERNER, and UTZ KRAMAR
Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany
e-mail: zsolt-attila.berner@kit.edu

ABSTRACT: Variations in the major-element and trace-element composition of impact spherules were investigated in the sandstone complex subjacent to the KT boundary in a section exposed along the Brazos River, Falls County, Texas, in order to identify whether any regular pattern can be discerned in the vertical distribution of the compositions of the spherules. Stable isotopes of carbon and oxygen strongly suggest that most of the carbonate in the cores of the spherules is not a secondary alteration product of glass, as currently thought, but a primary intrinsic component of spherules segregated from a melt supersaturated in carbonate. The investigation of 90 spherules (1,209 points) by l-XRF, complemented with ICP-MS analyses on individual grains, shows that the silicate glass of the shell that encased the carbonate core has been altered to Mg-rich smectite, while mafic components have been altered to a mineral which is considered to be a low-Fe chlorite. Spherules of the hummocky cross-bedded sandstone unit (referred to hereafter as HCS) can be distinguished from those of the spherulitic conglomerate bed (referred to hereafter as SCB) not only by their much smaller size, but also by their lack of a carbonate core and by the presence of a mixed-layer, more K-rich clay mineral in their composition. Spherules obtained from different layers of the SCB do not show any distinguishing characteristics with respect to bulk chemical and mineralogical compositions, per se. However, statistically significant vertical gradients can be observed in the abundance of the elements Mg, P, S, and Cr in the carbonate core of these spherules. Further high-resolution chemostratigraphic studies in other KT sections are needed in order to verify the validity and significance of such compositional gradients in the sandstone complex.