Paleoguía 03
Paleonturology 23 award edition
Advanced level

paleonturología

English version

ISSN: 2990-3289 (online version)

Paleoguía collection

Edited in 2024 in Teruel (Spain) by the Paleontological Network Foundation of Teruel - Dinópolis

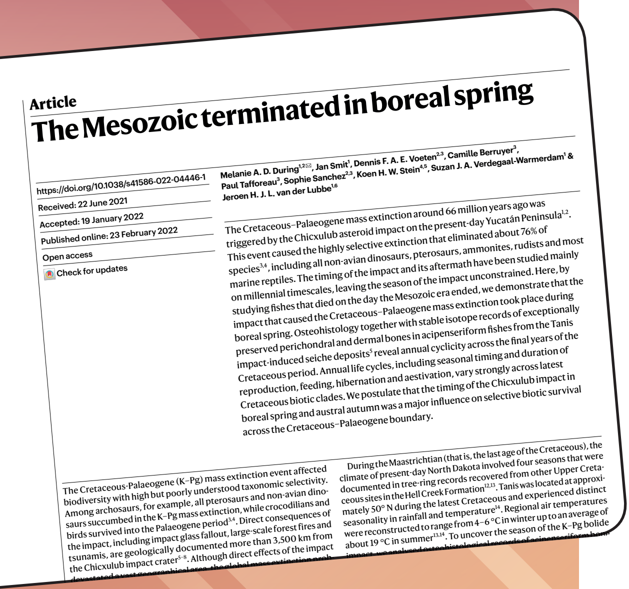
The meteorite that caused the extinction of the dinosaurs, struck in boreal spring

This **Paleoguía** (**Paleo**guide) is a dissemination version of the scientific article awarded with the ***21th International Prize for Research in Paleontology*** paleonturology 23, promoted by the Paleontological Network Foundation of Teruel - Dinópolis.

The paleonturology 23 award consists of an award economic prize plus the edition of a dissemination version (**Paleo**guía) of the winning work.

Bibliographical reference of the awarded article:

Melanie A.D. During, Jan Smit, Dennis F.A.E. Voeten, Camille Berruyer, Paul Tafforeau, Sophie Sanchez, Koen H.W. Stein, Suzan J.A. Verdegaal-Warmerdam & Jeroen H.J.L. van der Lubbe, 2022. The Mesozoic terminated in boreal spring. *Nature*, 603, 91–94.


Article

The Mesozoic terminated in boreal spring

Melanie A. D. During[1,2], Jan Smit[1], Dennis F. A. E. Voeten[2,3], Camille Berruyer[3], Paul Tafforeau[3], Sophie Sanchez[2,3], Koen H. W. Stein[4,5], Suzan J. A. Verdegaal-Warmerdam[1] & Jeroen H. J. L. van der Lubbe[1,6]

https://doi.org/10.1038/s41586-022-04446-1

Received: 22 June 2021

Accepted: 19 January 2022

Published online: 23 February 2022

Open access

Check for updates

The Cretaceous–Palaeogene mass extinction around 66 million years ago was triggered by the Chicxulub asteroid impact on the present-day Yucatán Peninsula[1,2]. This event caused the highly selective extinction that eliminated about 76% of species[3,4], including all non-avian dinosaurs, pterosaurs, ammonites, rudists and most marine reptiles. The timing of the impact and its aftermath have been studied mainly on millennial timescales, leaving the season of the impact unconstrained. Here, by studying fishes that died on the day the Mesozoic era ended, we demonstrate that the impact that caused the Cretaceous–Palaeogene mass extinction took place during boreal spring. Osteohistology together with stable isotope records of exceptionally preserved perichondral and dermal bones in acipenseriform fishes from the Tanis impact-induced seiche deposits[5] reveal annual cyclicity across the final years of the Cretaceous period. Annual life cycles, including seasonal timing and duration of reproduction, feeding, hibernation and aestivation, vary strongly across latest Cretaceous biotic clades. We postulate that the timing of the Chicxulub impact in boreal spring and austral autumn was a major influence on selective biotic survival across the Cretaceous–Palaeogene boundary.

The Cretaceous-Palaeogene (K–Pg) mass extinction event affected biodiversity with high but poorly understood taxonomic selectivity. Among archosaurs, for example, all pterosaurs and non-avian dinosaurs succumbed in the K–Pg mass extinction, while crocodilians and birds survived into the Palaeogene period[3,4]. Direct consequences of the impact, including impact glass fallout, large-scale forest fires and tsunamis, are geologically documented more than 3,500 km from the Chicxulub impact crater[5–8]. Although direct effects of the impact

During the Maastrichtian (that is, the last age of the Cretaceous), the climate of present-day North Dakota involved four seasons that were documented in tree-ring records recovered from other Upper Cretaceous sites in the Hell Creek Formation[12,13]. Tanis was located at approximately 50° N during the latest Cretaceous and experienced distinct seasonality in rainfall and temperature[14]. Regional air temperatures were reconstructed to range from 4–6 °C in winter up to an average of about 19 °C in summer[13,14]. To uncover the season of the K–Pg bolide

This publication is part of the research projects in Paleontology subsidized by: Government of Aragón through the E04_23R FOCONTUR research group; Department of Environment and Tourism of the Aragonese Government; Teruel Paleontological Unit, Ministry of Science and Innovation of the Spanish Government; Aragonese Development Institute; Dinópolis and Caja Rural of Teruel.

EDITION:

© Fundación Conjunto Paleontológico de Teruel – Dinópolis

Teruel (Spain)

AUTHORS:

Melanie A.D. During, Jan Smit, Dennis F.A.E. Voeten, Camille Berruyer, Paul Tafforeau, Sophie Sanchez, Koen H.W. Stein, Suzan J.A. Verdegaal-Warmerdam & Jeroen H.J.L. van der Lubbe.

COORDINATION:

Luis Miguel Sender and Alberto Cobos

COVER IMAGE:

Joschua Knüppe's reconstruction of the Tanis event with wave surging into the river bringing in fishes, dinosaurs and trees with impact spherules raining down.

GRAPHIC DESIGN:

JoaquinJPG

Introduction to the fifth mass extinction

The extinction event that ended the Cretaceous period had a profound impact on Earth's biodiversity. Pterosaurs and non-avian dinosaurs were amongst the unfortunate who died out, while mammals, crocodilians, birds, turtles and many sharks and fishes survived. This event was triggered by a giant asteroid impact, causing widespread devastation such as massive forest fires and enormous tsunamis. The direct effects of the impact were immense, but the global extinction likely continued over thousands of years due to rapid climate deterioration.

The Tanis event deposit in North Dakota, USA, provides a unique window into this cataclysmic event. It preserves a rich assemblage of late Cretaceous life, including fishes, shells, and plant matter, buried in sediment by the force of a massive wave triggered by the impact (cover image). The fishes were found preserved in the flow direction and with impact materials in their gills, suggesting they died in this wave and were buried alive.

Tree-ring records indicate distinct seasonal variations in temperature and rainfall in the end of the Cretaceous period in North Dakota. To uncover the season of the impact, the growth patterns in fish bones from Tanis fossil site were studied (Fig. 1). Examining the growth increments preserved in the bone from birth to death can reveal the season when the impact occurred. This research could shed light on how environmental factors influenced the survival of different species during this critical period in Earth's history

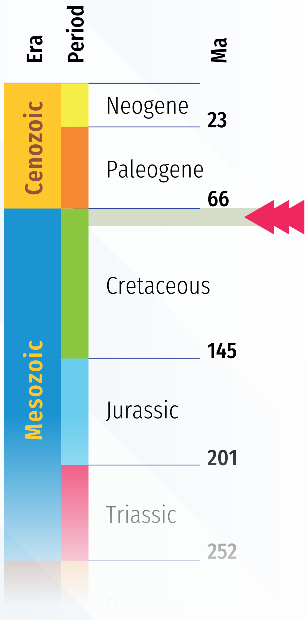


Figure 1. The Tanis deposit as a grey blanket over the river bank, with Melanie During for scale (1.72m) walking next to the deposit. Photograph courtesy by Jackson Leibach 2017.

Growth records of end-Cretaceous fishes

The aim of this study was to determine the season when bone growth ceased in the fish fossils from the Tanis site. For this purpose, three sturgeons and three paddlefishes were examined and the annual growth layers in their bone slices were identified. Using Synchrotron micro-computed tomography, we confirmed the annual nature of these growth zones in three dimensions (Fig. 2). We also observed fluctuations in bone cell density and volume, providing further insight into seasonal patterns of bone deposition. The bone growth records were supplemented with an analysis of stable carbon isotopes from a paddlefish dentary.

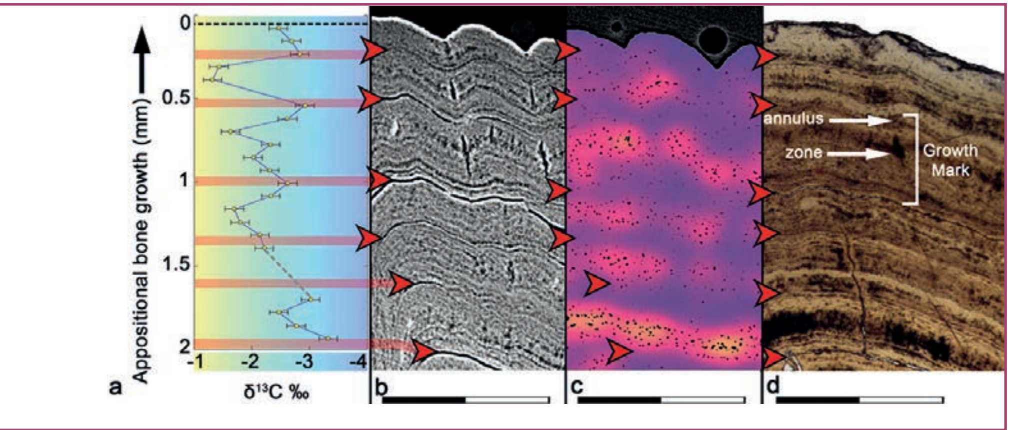


Figure 2. a. Carbon 13 ($\delta^{13}C$) isotope levels are shown to fluctuate every year during bone growth. The colors represent the range between peak values in summer (yellow) and lowest values in winter (blue). **b.** The virtual thick section displays growth zones during favorable seasons and zones where bone growth slows down (annuli)/lines of arrested growth (LAGs) during less favorable ones (red arrows). **c.** A cell density map reveals changes in bone cell densities and sizes, with higher densities and larger sizes in growth seasons (orange) and lower densities and smaller sizes outside of them (purple). **d.** The microscopic thin section displays LAGs (red arrows) and a single growth mark (bracket) between them. Scale bars indicate 1mm.

Tanis event deposit indicated, 2017 field photo. Photograph by Melanie During.

Synchrotron micro-computed tomography was also applied on a partial paddlefish skeleton (Fig. 3), showing that impact spherules (named as tektites, from rocks that were ejected into space by the asteroid impact and subsequently rained down as glassy spherules on earth) are present exclusively in its gill rakers and found no where else in the specimen. The exclusive presence of impact spherules in the gill rakers of the paddlefish indicate that they were filtering particles from the water during the asteroid impact. This suggests that the fishes were alive and actively foraging during the catastrophic event at the end of the Cretaceous period. The synchrotron scan furthermore revealed that delicate structures, including the braincase, were preserved. Further assessment of the preservation using micro-X-ray fluorescence on the bone sections suggested rapid burial and minimal alteration during fossilisation.

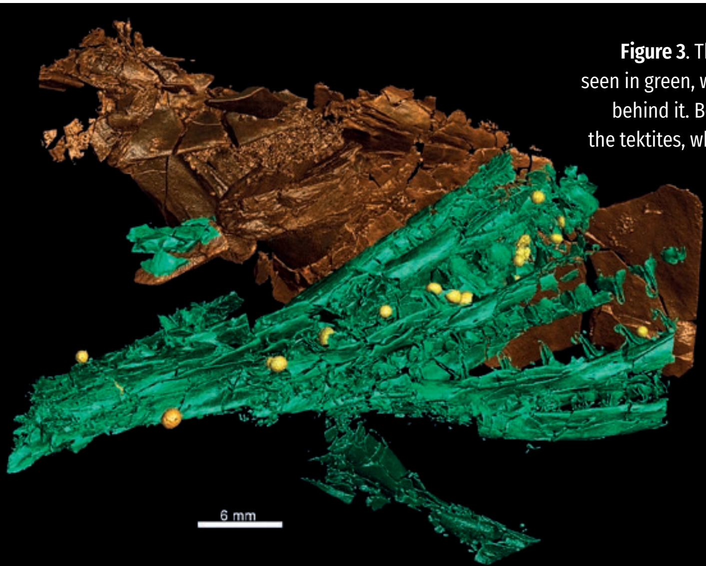


Figure 3. The paddlefish gills can be seen in green, with the gill cover (brown) behind it. Between the gill rakers are the tektites, which can be seen as small yellow hollow balls here.

Fossilized skeletons of a sturgeon and a paddlefish in the field from fieldwork 2017. Photograph by Melanie During.

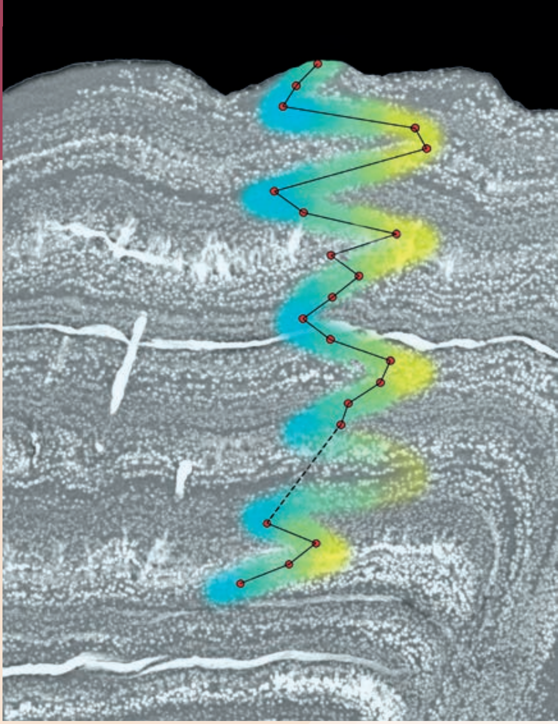


Figure 4. Detail of a virtual thin section of the paddlefish dentary overlaid with the $\delta^{13}C$ record, showing lowest values in blue (winter) and highest in yellow (summer). The peaks in growth (yellow) coincide with the highest density and largest volume in bone cells. When the fish died the bone cell distribution and $\delta^{13}C$ record both point to a spring death.

The selected bones begin to form when the paddlefish and sturgeon are embryo's and continues to grow throughout their lives. Unlike bone formation involving mineralization of cartilage, these types of bone grow exclusively through incremental bone deposition. Each annual growth mark spans a thick growth zone, a zone with narrow lines (annulus) where bone growth slows down, and ultimately a final line of arrested growth (LAG).

Bone growth analysis consistently showed that the fishes ceased growing while forming a new growth zone, shortly after the deposition of a LAG. The cyclical patterns of bone cell density and size across preceding years indicate that the last recorded growth season had not yet climaxed at the time of death (Fig. 4). These annual growth patterns (Fig. 5) are confirmed by stable carbon isotopes, revealing seasonal feeding patterns. Oxygen isotopes suggest they lived exclusively in freshwater, likely without migrations to saline habitats. These filter feeders likely fed on copepods, a tiny aquatic crustacean, with peak feeding between spring and autumn. Carbon isotope records indicate they just started eating again after winter, supporting a springtime demise.

Three fossilized sturgeon skeletons in the Tanis deposit from fieldwork 2017. Photograph by Melanie During.

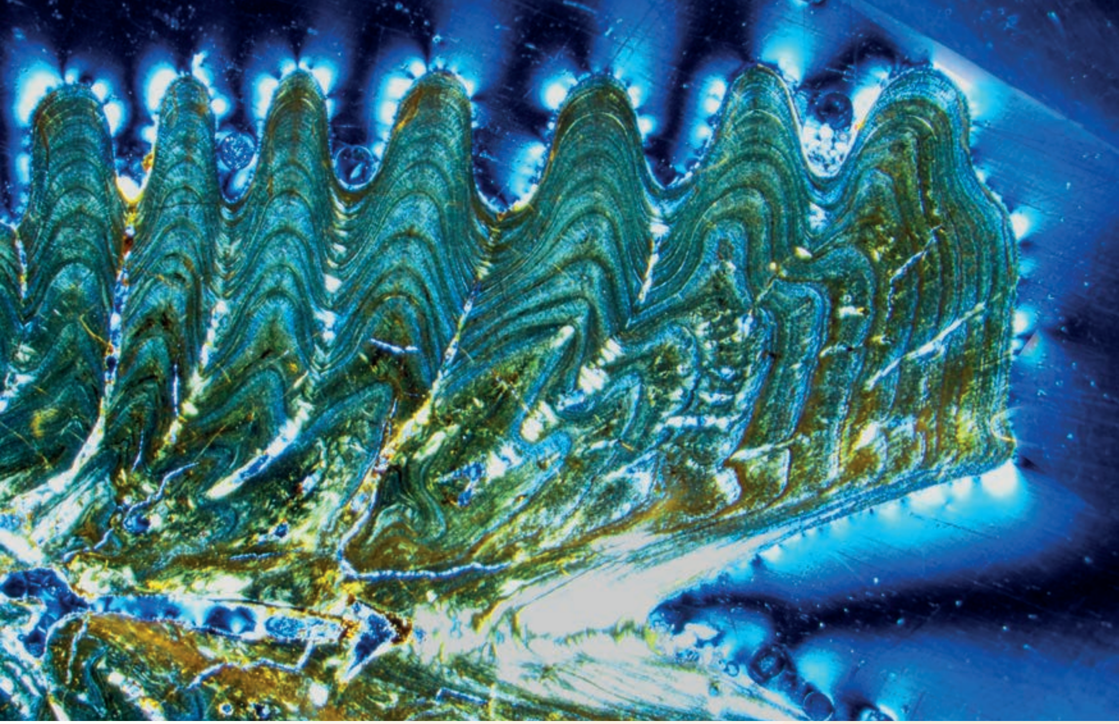


Figure 5. A sturgeon pectoral fin spine bone slice under crossed polarized light, showing the yearly growth increments.

Implications of a spring-time extinction

The immediate effects of the impact such as wildfires and heat radiation devastated environments, which were followed by acid rain and an impact winter. Northern Hemisphere organisms, especially those reproducing in spring, suffered the most, while Southern Hemisphere ecosystems recovered faster. Underground sheltering and dormancy likely aided survival. Ecological collapse affected species dependent on primary producers, but some birds and mammals persisted by exploiting alternative resources.

Conclusions

The asteroid that ended the Mesozoic era struck in spring on the Northern Hemisphere corresponding to autumn on the Southern Hemisphere. The seasonal implications of the impact will aid in further studies investigating the selectivity of the End-Cretaceous extinction and the differences in extinction and recovery between the two hemispheres. A better understanding of this mass extinction will help us better identify extinction risks and understand ecological deterioration caused by the forthcoming mass extinction.

Tanis fossil site, 2017 field photo.
Photograph by Melanie During.

Melanie During excavating paddlefish. Image from fieldwork 2017. Photograph courtesy by Jackson Leibach.

FUNDACIÓN CONJUNTO PALEONTOLÓGICO DE TERUEL-DINÓPOLIS

CAJA RURAL DE TERUEL

DINÓPOLIS TERUEL

GOBIERNO DE ARAGON

Spanish version