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Geochemical and isotopic characterization of trace fossil infillings: New insights on tracemaker activity after the K/Pg impact event

Claudia Sosa-Montes de Oca [a, *], Francisco J. Rodríguez-Tovar [a], Francisca Martínez-Ruiz [b]

[a] Departamento de Estratigrafía y Paleontología, Universidad de Granada, Avda. Fuentenueva s/n, 18002 Granada, Spain
[b] Instituto Andaluz de Ciencias de la Tierra, IACT (CSIC-Universidad de Granada), Avda. Las Palmeras 4, 18100 Armilla, Granada, Spain

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ABSTRACT

Geochemical and isotopic analyses of the Cretaceous–Paleogene (K/Pg) boundary deposits were conducted at the Caravaca section (External Subbetic, southeast of Spain) in order to evaluate the recovery of the macrobenthic tracemaker community and the bioturbational disturbance. Samples from the infilling material of several lower Danian dark-colored trace fossils (*Chondrites*, *Planolites*, *Thalassinoides* and *Zoophycos*) located in the uppermost 8-cm of the light upper Maastrichtian strata, as well as samples from the host sedimentary rock of these trace fossils, were analyzed and compared with data from the lower Danian deposits. The values of element ratios indicative of extraterrestrial contamination (Cr/Al, Co/Al and Ni/Al) are higher in the infilling trace fossil material than in the upper Maastrichtian and lower Danian deposits, which suggests a contribution of the ejecta layer. Regarding the isotope composition, the $\delta^{13}C$ values are lower in the infilling material than in the Maastrichtian host sedimentary rocks surrounding the traces, while the $\delta^{18}O$ are higher in the infilling material. The geochemical and isotopic compositions of the infilling material evidence the unconsolidated character of the sediment, including the red boundary layer. Softground conditions confirm a relatively rapid recovery by the macrobenthic tracemaker community, starting a few millimeters above the K/Pg boundary layer. The mixture of the infilling material of the trace fossils moreover reveals a significant macrobenthic tracemaker activity affecting K–Pg boundary transition sediments that may have significantly altered original signatures.

1. Introduction

The Cretaceous–Paleogene (K/Pg) boundary, recently dated as ≈ 66.04 Ma ago (Husson, Galbrun, Gardin, & Thibault, 2014; Vandenberghe, Hilgen, & Speijer, 2012), is associated with the second most relevant mass extinction taking place during the Phanerozoic, with 40% of genus extinction (Bambach, 2006) and the disappearance of about 70% of the marine and continental species existing at this time (D'Hondt, 2005). Currently, the hypothesis of an extraterrestrial impact (Alvarez, Alvarez, Asaro, & Michel, 1980; Smit & Hertogen, 1980) causing the end-Cretaceous mass extinction is widely accepted (Molina, 2015; Schulte et al., 2010). The synchronicity of the Chicxulub impact and the mass extinction at the K/Pg boundary has also been widely demonstrated (e.g., Pälike, 2013; Renne et al., 2013 and references therein).

Over recent decades numerous literature on this topic has provided details about the impact site on the Yucatan peninsula in Mexico (Hildebrand et al., 1991); the size of the meteorite, around 10 ± 4 km in diameter (Donaldson & Hildebrand, 2001; Kyte & Wasson, 1982); its nature, of carbonaceous chondritic type CM or CO (Goderis et al., 2013; Kyte, 1998; Shukolyukov & Lugmair, 1998); and the amount and nature of debris ejected to the atmosphere that led to major environmental perturbations (Kring, 2007 and reference therein).

The impact event also resulted in geochemical anomalies worldwide, recognized both in marine and continental depositional environments. The extraterrestrial effects are particularly evident in marine distal sections, located further than 7000 km from the Chicxulub crater (Smit, 1999). In these sections, trace metals of extraterrestrial origin show higher concentrations than in proximal and intermediate sections, wherein the extraterrestrial contribution is highly diluted by target rocks (Berndt, Deutsch, Schulte, & Mezger, 2011; Martínez-Ruiz et al., 2001).

Major environmental perturbations (i.e., nitric and sulfuric acid

* Corresponding author.
E-mail addresses: csosa@ugr.es, csm@iact.ugr-csic.es (C. Sosa-Montes de Oca), fjrtovar@ugr.es (F.J. Rodríguez-Tovar), fmruiz@ugr.es, fmruiz@iact.ugr-csic.es (F. Martínez-Ruiz).

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rain, widespread dust and blackout, destruction of the stratospheric ozone layer, greenhouse effect, temperature increase), followed the K/Pg event (Alegret & Thomas, 2005; Peryt, Alegret, & Molina, 2002). Diverse geochemical redox proxies, commonly used to reconstruct paleo-oxygen conditions (e.g., Calvert & Pedersen, 2007; Tribovillard, Algeo, Lyons, & Riboulleau, 2006), indicate anoxic conditions across the K/Pg boundary transition, mostly promoted by the enhanced contribution of metals to the basins (extraterrestrial contamination and terrestrial elements derived from increasing chemical alteration in emerged areas), as well as a higher input of both terrestrial and marine organic material. An abrupt spike in biomarkers such as dibenzofuran, biphenyl and cadalene evidences the increasing input of terrestrial organic material (Mizukami, Kaiho, & Oba, 2014).

The biotic response to the K/Pg impact event, including the post-event recovery, is still a matter of debate. Several contradictory hypotheses postulate the effects on planktonic vs. benthic organisms, K- vs. r-strategists, or deposit vs. suspension feeders (Labandeira et al., in press; Molina, 2015; Powell & MacGregor, 2011; Schulte et al., 2010). In the past decade, relevant information has been provided by ichnological data. The trace fossil analysis of K/Pg boundary sections reveals a minor impact of K/Pg environmental changes on the deep-sea macrobenthic tracemaker community, as well as its rapid recovery (Monaco, Rodríguez-Tovar, & Uchman, 2015; Rodríguez Tovar, Martínez-Ruiz, & Bernasconi, 2004, 2006, 2011; Rodríguez-Tovar, 2005; Rodríguez-Tovar & Uchman, 2006, 2008). As pointed out by Sosa-Montes de Oca, Martínez-Ruiz, and Rodríguez-Tovar (2013), this unusual biotic recovery could be explained by a rapid response (some few hundred years) of bottom water oxygenation that reestablished shortly after the K/Pg event. Ichnological analyses furthermore revealed the importance of the bioturbational redistribution by tracemakers, which may have affected original signatures and therefore should be considered so as to prevent possible misinterpretations (Kędzierski, Rodríguez-Tovar, & Uchman, 2011; Rodríguez-Tovar, Uchman, Molina, & Monechi, 2010).

In order to evaluate and corroborate the hypothesis of the rapid recovery of the macrobenthic tracemaker community and the bioturbational disturbance, further analyses have been performed. In particular, geochemical and isotopic analyses of the K/Pg boundary deposits at the Caravaca section (southeast of Spain) included the infilling material of trace fossils as well as the upper Maastrichtian and lower Danian host rocks.

2. Geological setting and the study section

The K/Pg boundary section at Caravaca (38°04′36.39″N, 1°52′41.45″W) is located on the NW side of road C-336, in the Barranco del Gredero, about 4 km southwest of the town of Caravaca (Murcia, Spain) (Fig. 1). It belongs to the Jorquera Formation (lower Maastrichtian-lower Eocene), around 225 m-thick, which consists of intercalated marls, marly limestones and occasional turbidites. Geologically, this outcrop belongs to the External Subbetic of the Betic Cordillera, corresponding to a comparatively distal setting mainly composed by pelagic/hemipelagic mid-Lower Jurassic-Upper Cretaceous deposits. Cretaceous–Paleogene transition sediments were deposited in a middle-bathyal environment, at a variable depth of 200–1000 m, according to previous reports (see Rodríguez-Tovar & Uchman, 2006 for review).

The K–Pg deposits at the Caravaca section have also been profusely studied in terms of mineralogical, geochemical and isotopic composition (i.e., Arinobu, Ishiwatari, Kaiho, & Lamolda, 1999; Kaiho et al., 1999; Martínez-Ruiz, 1994; Ortega-Huertas, Martínez-Ruiz, Palomo, & Charnley, 1995, 1998; Smit, 2004; Smit & Hertogen, 1980; Sosa-Montes de Oca et al., 2013). Intensive research focuses on the exceptional record of the K–Pg boundary transition at this section; It shows a continuous succession that allows for a detailed, high-resolution biostratigraphy of the uppermost Maastrichtian to the lowermost Danian deposits based on planktonic foraminifers, as occurs with the close Agost section in Alicante (i.e., Arenillas, Arz, & Molina, 2004; Arz, Arenillas, Molina, & Sepulveda, 2000; Canudo, Keller, & Molina, 1991; Molina, Arenillas, & Arz, 1996, 2001, 2005, and references therein).

The K–Pg transition at the Caravaca section is mainly composed by light-grey marls and marly limestones. The topmost Maastrichtian (uppermost Cretaceous) consists of light-grey marls that grade into a 3 mm-thick green transitional layer (Rodríguez-Tovar & Uchman, 2006). Upper Maastrichtian deposits are capped by a 2–3-mm-thick reddish brown layer (ejecta layer) that marks the K/Pg boundary and contains impact evidence such as spherules and platinum group element (PGE) anomalies (Martínez-Ruiz, Ortega-Huertas, & Palomo, 1999, 2006; Smit, 1990; Smit & Klaver, 1981). Above the ejecta layer, a 7–10-cm-thick blackish-grey clay layer (the dark boundary clay layer) deposited in the early Danian gradually increases its carbonate content to a grey argillaceous marl similar to that of the Late Cretaceous (Fig. 1). The dark boundary clay layer shows alternating laminated and bioturbated horizons: at the bottom a 14-mm-thick laminated unit, more argillaceous and dark gray in color, is overlain by a 26-mm-thick horizon, light grey and bioturbated; above it lies a 35-mm-thick more argillaceous unit, lighter colored and with convolute laminae; while the upper part exhibits a 25-mm-thick greenish-grey non-laminated horizon (Rodríguez-Tovar & Uchman, 2006).

3. Materials and methods

For this study we selected a 11-cm-thick interval, involving Maastrichtian materials from 8.0-cm below the K/Pg boundary, and Danian rocks to 3.0-cm above the boundary. According to the sedimentation rate of 3.1 cm kyr^{-1} estimated for the Maastrichtian deposits, and of 0.8 cm kyr^{-1} calculated for the boundary clay layer (Kaiho et al., 1999), the studied transition would span a time interval of around 6330 years —from 2580 years prior to the K/Pg boundary to 3750 years afterward. Deposition of the ejecta layer at the K/Pg boundary can be considered instantaneous in the geological scale, roughly several weeks after the impact event (Artemieva & Morgan, 2009).

Geochemical and isotopic analyses were conducted on samples from the infilling material of several lower Danian dark-colored trace fossils located in the uppermost 8-cm of the light upper Maastrichtian strata (see Rodríguez-Tovar & Uchman, 2006 for detailed ichnological information), as well as on samples from the host sedimentary rocks of these trace fossils. Several specimens of dark-filled trace fossils were analyzed, belonging to *Chondrites*, *Planolites*, *Thalassinoides* and *Zoophycos*. *Thalassinoides* is commonly interpreted as having been passively filled (Bromley, 1996), as are some *Planolites* (Locklair & Savrda, 1998), while the interpretation of *Chondrites* and *Zoophycos* is not yet definitive. Thus, we analyzed samples from i) large *Chondrites* (sample CA-93 Ch) and the corresponding host rock (CA-93-HS), at 1-cm below the K/Pg boundary, and ii) small *Chondrites* (samples CA-32 Ch, CA-135 Ch, CA-192 Ch), *Planolites* (samples CA-9 Pl, CA-152 Pl), *Thalassinoides* (samples CA-135 Th1, CA-135 Th2, CA-180 Th), and *Zoophycos* (samples CA-180 Zo1, CA-180 Zo2, CA-180 Zo3), and the host sedimentary rock of each trace fossil (CA-9-HS, CA-32-HS, CA-152-HS, CA-135-HS, CA-180-HS, CA-192-HS), from 2 to 8 cm below the K/Pg boundary. Selected specimens were sampled using a Dremmel tool fitted with a fine tip diamond studded drill bit, allowing sampling even the smaller burrows.

Moreover, isotopic analyses of $\delta^{13}C$ and $\delta^{18}O$ on samples from