Journal of African Earth Sciences 120 (2016) 23–30

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Ichnological record of palaeoenvironment from the Cretaceous-Paleogene boundary interval at El Kef, Tunisia: The first study of old and new sections at the stratotype area

F.J. Rodríguez-Tovar [a, *], A. Uchman [b], A. M'Hamdi [c], S. Riahi [c], K.B. Ismail-Lattrache [c]

[a] Departamento de Estratigrafía y Paleontología, Facultad de Ciencias, Universidad de Granada, 18002 Granada, Spain
[b] Jagiellonian University, Institute of Geological Sciences, Oleandry 2a, PL-30-063 Kraków, Poland
[c] Department of Geology, Faculty of Sciences of Tunis, University Tunis El Manar, Unit of Research UR 11 ES 15, Campus Universitaire, 2092, El Manar II, Tunisia

ARTICLE INFO

Article history:
Received 16 January 2016
Received in revised form
19 April 2016
Accepted 21 April 2016
Available online 22 April 2016

Keywords:
Cretaceous-Paleogene event
Trace fossils
Oxygenation
GSSP section
El Kef (Tunisia)

ABSTRACT

Trace fossil analysis of the Cretaceous-Paleogene (K/Pg) boundary interval at El Kef (Tunisia) has provided new information on the response of the macrobenthic tracemaker community to the K/Pg boundary event. Ichnological data from the Global Stratotype Section and Point (GSSP) for the Cretaceous-Paleogene (K/Pg) boundary were completed with those from a new, well-exposed section nearby. The trace fossil assemblage consists of dominant *Trichichnus*, frequent *Chondrites*, and rare *Thalassinoides* and *Zoophycos* in the uppermost Maastrichtian, and only *Trichichnus* in the lowest Danian, the diversity being comparatively lower than in other K/Pg boundary sections worldwide. Bioturbational structures are observed continuously across the K/Pg boundary interval, without primary lamination; this discards anoxic conditions. However, the upward-decreasing diversity in the sections may be related to a transition from a moderately dysoxic or slightly dysoxic macrobenthic habitat in the sediment during the latest Maastrichtian to a strong or very strong dysoxia during early Danian. Comparison with micropaleontological data reveals a minor influence of the K/Pg boundary event on the macrobenthic tracemaker community, while the change in oxygenation of pore waters at the El Kef sections can be attributed to local or regional phenomenon, marked by increasing clay content in the Danian sediments.

1. Introduction

Ichnological research has proven very useful for characterizing and interpreting palaeoenvironmental changes associated with past bio-events, with special attention placed on the Cretaceous-Palaeogene (K/Pg) boundary (Rodríguez-Tovar and Uchman, 2004a,b, 2006, 2008; Rodríguez-Tovar et al., 2002, 2004, 2006, 2010, 2011; Rodríguez-Tovar, 2005; Sosa-Montes de Oca et al., 2013, 2016; Monaco et al., 2015). Moreover, the importance of the bioturbational redistribution of microfossils by tracemakers at the K/Pg boundary, as demonstrated, may have affected original signatures, therefore inducing possible misinterpretations (Rodríguez-Tovar et al., 2010; Kędzierski et al., 2011; Alegret et al., 2015).

It might appear that the Global Stratotype Section and Point (GSSP) for the Cretaceous-Paleogene (K/Pg) boundary at El Kef in Tunisia has no ichnological characteristics. This is not the case, however; and the aim of this paper is to fill the gap.

The K/Pg is defined at the base of the Boundary Clay in a section near El Kef, Tunisia (Molina et al., 2006). This particular location was selected for several reasons, such as the continuous sedimentation at the K/Pg boundary interval, the facies change from a grey marl to a black clay (Boundary Clay) with a thin rusty layer at its base, the completeness of exposure both above and below the GSSP and laterally, the abundance and diversity of well-preserved fossils (rich in micro- and nannofossils as well as dinoflagellates, pollen and spores), and the existence of several markers favouring correlation, such as the Ir anomaly, TOC maximum or stable isotope shift (Molina et al., 2006). Before our original proposal, the section had been profusely researched, including geochemical and isotopic studies, and micro- and macropalaeontological analyses (Molina et al., 2006 and references therein). Further detailed high-

* Corresponding author.
E-mail address: fjrtovar@ugr.es (F.J. Rodríguez-Tovar).

http://dx.doi.org/10.1016/j.jafrearsci.2016.04.017
1464-343X/

resolution planktonic foraminiferal (Gallala, 2010, 2013) and palynological (M'Hamdi, 2014, 2015) studies confirmed the completeness and continuity of the stratigraphic record across the Cretaceous-Paleogene transition.

Concerning trace fossils at the K/Pg boundary interval at El Kef, there are only scarce and general references to the presence of burrows (i.e., Molina et al., 2006). The presence of common burrows, about 2–3 cm long, in the Upper Maastrichtian sediments of the El Kef section was documented in early papers (e.g., Keller, 1988a; Smit et al., 1997; Molina et al., 2006), but no closer ichnotaxonomical assignation has since been presented. No burrows were observed through the rusty layer or in the black clay (Keller, 1988a). According to Molina et al. (2006, p. 264), the burrows registered in the uppermost Maastrichtian sediments "furnished the extremely negative $\delta^{18}O$ value of −4.94 and are also enriched in Ir, Os and Au (Perch-Nielsen et al., 1982)".

In March 2014 a field trip was conducted in the El Kef area, focusing on ichnological analysis of the K/Pg boundary at the stratotype section. However, the GSSP is difficult to work with, as pointed out several years ago by Molina et al. (2009): "the outcrop became quite deteriorated", so several auxiliary sections were designated for a better characterization and correlation of the boundary (Molina et al., 2009). At present the GSSP section (section A in this paper; Figs. 1 and 2A; GPS coordinates: N36°09.223′; E008°38.912′) is partly covered and strongly weathered. The rusty layer is not easy to recognize. Yet a few tens of metres away, a new, well exposed section (section B, Figs. 1, 2B–D; GPS coordinates: N36°09.240′; E008°38.926′) was found on the slope of a small gorge. It is continuous across the K/Pg boundary, with a well-marked rusty layer. The ichnological analysis was carried out in sections A and B, although observations in section B are clearer and more complete.

2. Geological setting

The Global Boundary Stratotype Section and Point for the base of the Danian stage is located at El Kef section, 5–6 km southwest of the city of El Kef (Northwest Tunisia). Molina et al. (2006) indicated the geographical and geological location of the El Kef section in several maps (Fig. 1; modified from Lindinger, 1988), but coordinates were not included. Several photographs of the GSSP were added, showing general overviews (fig. 3, in Molina et al., 2006) and close-up views (fig. 4 in Molina et al., 2006) of the outcrop. A detailed geological map of the GSSP area reveals lateral continuity of the K/Pg boundary interval, allowing for the study of different outcrops (i.e., see variable location in Vandenberghe et al., 2012; M'Hamdi et al., 2015; Fig. 1C). The K/Pg GSSP section belongs to the El Haria Formation (upper Maastrichtian to Paleocene).

According to Molina et al. (2006), the lithology of the boundary interval can be subdivided into five units, from bottom to top: a) the uppermost 4.5 m of the Maastrichtian consists of while-grey marls, containing burrows filled by darker Danian sediments, b) above it, 0.5 m of black clay (Boundary Clay) features at its base a 1–3 mm thick rust-coloured ferruginous layer marking the boundary event, c) then there is 0.5 m of dark grey clay, d) ca. 1 m of grey, clay-rich "shale", and finally, e) more than 10 m of white-grey clayey marls. The boundary interval sediments contain disperse ferruginous concretions, which are up to a few centimetres in diameter. Exclusively fine-grained sediments — with a high contribution of pelagic microfossils— suggest pelagic sedimentation, without turbidites, tempestites or slumping sediments, but with fluctuations in calcium carbonate content. In December 2013 and January 2014, four holes were drilled in the framework of the El Kef Coring Program titled "An International Program Designed to Explore the Mass Extinction at the Cretaceous-Paleogene Boundary in the Classic El Kef Section in Tunisia" (http://www.ktboundary.org/), with indication that the outcrop section is somewhat weathered and difficult to sample.

3. Ichnological analysis

In order to conduct the ichnological analysis, both sections A and B were trenched and cleaned. "Bed by bed" field observations and sampling were undertaken in the K/Pg boundary interval, involving around 175 cm in section A and 100 cm in section B (Fig. 3). Samples were polished along variably oriented surfaces to observe ichnofabric features. The samples were dampened to enhance visibility and then photographed. Collected samples are housed in the Department of Geology, Faculty of Sciences of Tunis, University El Manar, Unit of research UR11ES15, labelled EK-A and EK-B, for El Kef sections A and B, respectively.

Trace fossil analysis at the K/Pg boundary interval in the El Kef section revealed the presence of a scarcely diverse trace fossil assemblage, mainly composed of *Chondrites* and *Trichichnus* and with the isolated record of *Thalassinoides* and *Zoophycos* (Fig. 3).

Chondrites isp. (Fig. 4A–C) is mainly observed in cross sections as groups of oval to circular dark grey spots, 0.3–1.5 mm in diameter, but also as straight or slightly curved, occasionally branched short bars of the same diameter and filling, which are 5–15 mm long. *Chondrites* isp. is an abundant trace fossil, exclusively registered in the uppermost Maastrichtian in both sections, A and B. Black-filled *Chondrites* isp. extends up to ~10 cm below the rusty layer in section B and at least a few centimetres in section A, where the weathered rocks did not allow for closer observations.

Trichichnus isp. (Fig. 4A, B, D, E) is a straight or winding, vertical to steeply inclined, reddish or brownish ferruginous cylinder, observed mostly as spots in the cross section, 0.1–0.8 mm. It was traced for at least 15 mm. *Trichichnus* isp. is the most abundant trace fossil, registered continuously in the uppermost Maastrichtian sediments in both sections (A and B), as well as in the base of the Danian Boundary Clay, and in the black horizon directly above it.

Thalassinoides isp. (Fig. 4C) is visible in the cross section as an at least 10 mm-long horizontal cylinder, 4–5 mm in diameter, with a vertical branch that is at least 8 mm long. The trace fossil was found for certain only in the uppermost Maastrichtian sediments, up to 4.5 cm below the rusty layer in section B.

Zoophycos isp. occurs rarely in the uppermost Maastrichtian sediments, 2–3 cm below the K/Pg boundary in section B. It is seen in cross section as several subhorizontal spreite stripes, 1–2 mm-thick, surrounded by oval spots representing *Chondrites*.

4. Discussion

Most benthic foraminifera studies interpret an outer neritic-upper bathyal environment, with an estimated palaeodepth of 300–500 m for the El Kef section (see Galeotti and Coccioni, 2002), similar to sections such as those from NE Mexico (see Rodríguez-Tovar and Uchman, 2004b for a review). The trace fossil assemblage with *Trichichnus* isp., *Chondrites* isp., *Thalassinoides* isp., and *Zoophycos* isp. can be assigned to the *Zoophycos* ichnofacies, which is in accordance with the proposed palaeodepth and the pelagic sedimentation.

The trace fossil assemblage in the El Kef section is comparatively less diverse than other K/Pg boundary sections worldwide, i.e. in Stevens Klint in Denmark (Ekdale and Bromley, 1984), Millers Ferry in Alabama (Savrda, 1993), Los Ramones or El Mimbral in NE Mexico (Ekdale and Stinnesbeck, 1998), Agost and Caravaca in SE Spain (Rodríguez-Tovar and Uchman, 2004a,b, 2006), Bidart in SW France and Sopelana in N Spain (Rodríguez-Tovar et al., 2010, 2011) and Bottaccione in Italy (Monaco et al., 2015) (see table 1 in Monaco