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Astronomical calibration of paleoclimatic and planktic foraminiferal events of the Cretaceous-Paleogene transition at Zumaia, Spain

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The main trigger for the Cretaceous/Paleogene boundary (KPB) mass extinction is still subject of intense debate. The co-occurrence of the Chicxulub impact (Yucatan, Mexico) and massive Deccan Traps volcanism (India) during Chron C29r hinders disentangling their climatic and environmental effects. Unravelling the influence of Deccan volcanism on the KPB extinction and other Maastrichtian and Danian perturbations requires more accurate age calibrations and duration estimates of biotic and climatic events. Here we integrate existing astrochronologies of the Zumaia section, allowing us to produce a refined cyclostratigraphic calibration of the main planktic foraminiferal and paleoclimatic events recorded across the KPB in the well-know Zumaia section (NW, Spain).

At Zumaia, the KPB is marked by a ~8 cm-thick dark clay bed, with low values of %CaCO₃ and δ¹³C. The Chicxulub ejecta-rich airfall layer has been identified at the base of the dark clay bed, but it is partially masked within a 1–2 cm-thick diagenetic calcitic layer. At Zumaia, the KPB has been astronomically calibrated at 66 Ma (compatible with radioisotopic ages), and the duration of dark clay bed is estimated at ~10 kyr. The first appearances (FA) of the Danian planktic foraminiferal index-species *Parvularugoglobigerina longiapertura*, *Parvularugoglobigerina eugubina*, *Eoglobigerina simplicissima*, *Parasubbotina pseudobulloides*, *Subbotina triloculinoidea* and *Globanomalina compressa* have been orbitally tuned at Zumaia, to have occurred at 8, 30, 45, 70, 210, and 475 kyr after the KPB. Specimens of *Plummerita hantkeninoides* have been identified for the first time in the Maastrichtian of Zumaia, and its first occurrence is dated at ~100 kyr before the KPB. Based on δ¹³C data, we have identified the late Maastrichtian Warming Event (LMWE), the early Danian Dan-C2 and the Lower-C29N events. Additionally, a bloom of the eutrophic/opportunist genus *Chiloguembelitra*, interpreted as a period of environmental stress, has also been recognized above and separate from the KPB clay bed. Besides the KPB, the main paleoclimatic/paleoenvironmental events have been astronomically calibrated at Zumaia as follows: the LMWE between 270 and 120 kyr before the KPB, the Dan-C2 event between 205 and 305 kyr after the KPB, the Lower-C29N event between 520 and 595 kyr after the KPB, and the Chiloguembelitra bloom between 100 and 305 kyr after the KPB. According to this chronology, we conclude that the LMWE and early Danian *Chiloguembelitra* bloom seems to coincide in time with major volcanic pulses of the Deccan Traps, unlike the Dan-C2 and Lower-C29N events, which

appear to have been driven by orbital forcing. Regardless of the cause of climatic and environmental events, all these perturbations appear unrelated to the KPB mass extinction event. It supports the hypothesis that the influence of Deccan volcanism on planktic foraminiferal assemblages during the Maastrichtian and Danian was limited.