Earth-Science Reviews 179 (2018) 287–302

Contents lists available at ScienceDirect

Earth-Science Reviews

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

South Pacific evidence for the long-term climate impact of the Cretaceous/Paleogene boundary event

Kyle W.R. Taylor[a,b,*], Pi Suhr Willumsen[c], Christopher J. Hollis[d], Richard D. Pancost[a]

[a] Organic Geochemistry Unit, The Cabot Institute and School of Chemistry, University of Bristol, Cantock's Close, Bristol BS8 1TS, UK
[b] Elementar UK Limited, Isoprime House, Earl Road, Cheadle Hulme, Cheadle Sk8 6PT, UK
[c] Department of Geoscience, Aarhus University, Høegh-Guldbergs Gade 2, 8000 Aarhus C, Denmark
[d] GNS Science, P.O. Box 30-368, Lower Hutt, New Zealand

ARTICLE INFO

Keywords:
TEX_{86}
Cretaceous-Paleogene boundary
Paleoclimate
Paleoceanography
Geochemistry
Palynology
Organic geochemistry
Biostratigraphy
New Zealand
Southwest Pacific

ABSTRACT

The Cretaceous/Paleogene (K/Pg) boundary is well-represented across a range of depositional settings in New Zealand. Trends in fossil assemblages and marine lithofacies indicate that the K/Pg event was followed by a pronounced and long-term (~1 Myr) perturbation in climate and ocean conditions. These findings are supported by a TEX_{86}-derived sea surface temperature (SST) reconstruction across the K/Pg boundary at mid-Waipara River, north Canterbury. The BAYSPAR calibration indicates that SST was very stable in the uppermost Cretaceous (~20 °C), but abruptly warmed by ~4 °C in a 25 cm-thick lowermost Paleocene interval. This interval is overlain by a ~2 m thick interval in which SST abruptly cooled by ~10 °C and then progressively returned to ~20 °C. The basal Paleocene warm interval is associated with an acme in the dinoflagellate species *Trithyrodinium evittii* and the succeeding cool interval is associated with an acme in *Palaeoperidinium pyrophorum*. Biostratigraphic correlation of the shelfal mid-Waipara section to the pelagic K/Pg sections in Marlborough reveals that a significant unconformity separates these two acme events, with the T acme event occurring in the earliest Paleocene and the *P. pyrophorum* acme occurring ~1 Myr later and lasting ~200 kyr. A succession of dinoflagellate acme events within the intervening interval in the Marlborough sections implies unstable climatic and environmental conditions in the lead up to the *P. pyrophorum* acme and cooling event at ~65 Ma. This event also coincides with a peak in biogenic silica accumulation in the Marlborough sections. We suggest that disruption to biogeochemical pathways at the K/Pg boundary caused long-term climatic cooling in the southern Pacific region.

1. Introduction

The long-term consequences of the Cretaceous–Paleogene (K/Pg) boundary event on Earth's climate remain poorly understood. Numerical models simulating the effects of the K/Pg boundary impact predict a brief (years to decades) period of global cooling induced by sulphate aerosols and dust or soot blocking out the sun's radiation, the so-called 'impact winter' (Pope et al., 1994, 1997; Pierazzo et al., 2003; Schulte et al., 2010; Bardeen et al., 2017; Brugger et al., 2017), followed by a longer episode of global warmth likely caused by both CO_2 released by the impact and reduced CO_2 uptake by plants (Pierazzo et al., 1998; Kring, 2007). This pattern of short-lived cooling followed by longer-term warming is supported by microfossil evidence in Northern Hemisphere sites (Brinkhuis et al., 1998; Galeotti et al., 2004), and has been corroborated by integrated study of the TEX_{86} sea surface temperature (SST) proxy and dinoflagellate assemblages (Vellekoop et al., 2014). TEX_{86}-based temperature reconstructions from other regions (Kemp et al., 2014; Vellekoop et al., 2015, 2016; Petersen et al., 2016) provide further evidence for SST change following the K/Pg boundary. There is also some evidence that Deccan Traps volcanism affected climate through the K–Pg transition (Courtillot et al., 1988; Chenet et al., 2009; Self et al., 2014; Schoene et al., 2015; Petersen et al., 2016).

Longer-term climate impacts of the K/Pg event have been inferred from stable oxygen isotope records. However, poor preservation and the K/Pg extinction of planktic calcifying organisms (Zachos and Arthur, 1986; Magaritz et al., 1992) makes interpretation difficult. Ocean warming has been inferred in some studies (e.g. Douglas and Savin, 1971; Oberhänsli, 1986; Barerra and Keller, 1990; Stott and Kennett, 1990; Schmitz et al., 1992; Barrera and Keller, 1994), whereas others suggest cooling (Boersma and Shakleton, 1977; Boersma et al., 1979; Boersma and Shakleton, 1981; Keller and Lindinger, 1989) or no

* Corresponding author.
E-mail address: kyle.taylor@elementar.co.uk (K.W.R. Taylor).

https://doi.org/10.1016/j.earscirev.2018.02.012
Received 17 February 2017; Received in revised form 7 October 2017; Accepted 12 February 2018
Available online 24 February 2018
0012-8252/

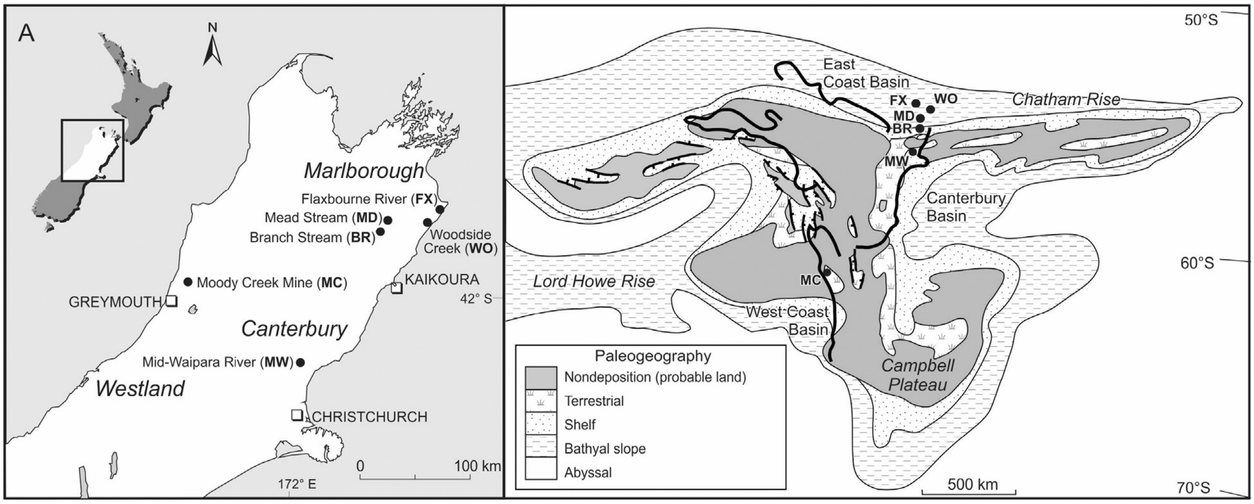

Fig. 1. Location of the mid-Waipara River section and other Cretaceous-Paleogene (K/Pg) boundary sections discussed in the text: (A) present day location and (B) earliest Paleocene paleogeographic setting (adapted from Hollis et al., 2003a).

significant change at all (Zachos and Arthur, 1986). Other studies have inferred climate fluctuations over the first 1–2 Myrs of the Paleocene from indirect evidence, such as oscillations in magnetic susceptibility, carbonate content and grain size (D'Hondt et al., 1996; Kroon et al., 2007).

For the southwest Pacific, a pattern of short-lived climate instability followed by prolonged climatic cooling over ~1 Myrs has been inferred from both marine and terrestrial K/Pg boundary records (Vajda et al., 2001; Hollis, 2003; Vajda and Raine, 2003). Prolonged cooling has been invoked to explain both a delayed recovery of calcareous plankton and the abundance of diatoms and radiolarians in the basal Paleocene pelagic sediments of northeastern South Island, New Zealand (Hollis et al., 1995, 2003a, 2003b). Compositional shifts in the marine dinoflagellate cyst assemblages have been interpreted as alternating periods of warm and cool SSTs (Willumsen and Vajda, 2010b). However, these climate fluctuations have been inferred from changes in fossil assemblages or lithology and lack corroboration from geochemical proxies for temperature. In this study, we use the TEX_{86} proxy to reconstruct SST across the K/Pg boundary in the mid-Waipara section, Canterbury Basin (Fig. 1). We combine previously reported data for the early Paleocene (Taylor et al., 2013) with new analyses from the uppermost Cretaceous. We also evaluate different GDGT paleothermometers and consider how changes in thaumarchaeotal growth environment might be reflected in this record.

The mid-Waipara River section (Fig. 1) contains the most complete known K/Pg transition in a neritic setting in the South Pacific region (Hollis and Strong, 2003). It provides an important link between bathyal marine and terrestrial sections in New Zealand (Hollis, 2003) and is one of only two neritic K/Pg boundary record in the Southern Hemisphere, the other being on Seymour Island, Antarctic Peninsula (Elliot et al., 1994; Bowman et al., 2012, 2014, 2015; Kemp et al., 2014; Petersen et al., 2016; Witts et al., 2016). The mid-Waipara section contains abundant and diverse palynomorphs, including dinoflagellates (Wilson, 1987a; Willumsen, 2004, 2006, 2012; Ferrow et al., 2011) and terrestrial palynomorphs (Vajda et al., 2001; Vajda and Raine, 2003; Ferrow et al., 2011), which provide qualitative indications of climatic and environmental variability. Importantly, the dinoflagellate succession can be correlated to two bathyal K/Pg boundary sections in eastern Marlborough, Branch and Mead Streams (Fig. 1), utilising a new Paleocene dinoflagellate zonation (Crouch et al., 2014) and a well-defined succession of early Paleocene acme events (Willumsen, 2004, 2006, 2011; Willumsen and Vajda, 2010b). Collectively, these data allow us to reconstruct climatic and oceanic changes through the K/Pg boundary transition in the mid-latitude southwest Pacific.

2. Materials and methods

2.1. Location and samples

The Waipara River trends northwest-southeast through a Mesozoic-Cenozoic sedimentary succession in northern Canterbury (Fig. 1).

The section examined is referred to as the mid-Waipara River section because it is located along the middle course of the river. The K/Pg boundary is located within Column 1 in the composite section described by Morgans et al. (2005). It lies at the base of a 4-m thick, non-calcareous, glauconitic sandstone, which forms the uppermost unit of the Conway Formation (Fig. 2). The underlying Conway Formation is moderately calcareous and more mud-rich. Overlying the Conway Formation is the lower Paleocene Loburn Formation, a ~60 m-thick unit of non-calcareous to slightly calcareous sandy mudstone. These sediments were deposited in a neritic mid-shelf setting during a widespread marine transgression (Field et al., 1989).

Geochemical studies (Brooks et al., 1986; Hollis and Strong, 2003; Ferrow et al., 2011) place the boundary within an irregular 2-cm thick, 'rusty' Fe-stained interval that includes a relatively small Ir anomaly (0.49 ng/g, ~50 × crustal average) as well as enrichment in Fe, Ni, Zn and Cr (Fig. 2). As discussed by Hollis and Strong (2003), an irregular distribution of these elements is probably due to intense bioturbation in these sediments (see Supplementary material S1 for cross-plotted trace metal concentrations).

Willumsen (2006) and Ferrow et al. (2011) also noted downward displacement and mixing of dinoflagellate cyst assemblages. A prominent dark, irregular band in the middle of this zone is chosen as the stratigraphic position of the K/Pg boundary (zero datum) but elemental anomalies suggest boundary components have been mixed by bioturbation into sediments 5 cm above and below this datum (Fig. 2A–D). The boundary also coincides with a marked decrease in $CaCO_3$ concentration (Fig. 2A) from ~30 wt% in the Cretaceous to < 5 wt% over the lower 5 m of Paleocene strata (Hollis and Strong, 2003). In contrast to the sudden decrease recorded in the bathyal Marlborough sections (Hollis et al., 2003a, 2003b), $CaCO_3$ concentration begins to decrease c. 0.3 m below the boundary, also likely due to bioturbation. A second "rusty" zone ~20–22 cm above the K/Pg boundary is also associated with Fe and Cr enrichments that extend to at least 1.2 m above the boundary (Fig. 2). The combined enrichment of these elements over an extended interval may indicate dysoxic conditions (Calvert and Pedersen, 1993).

Our TEX_{86} study is based on 26 samples that extend from 1.15 m below to 20 m above the K/Pg boundary, including a suite of 15 closely