Reconstructing climate during the Paleocene-Eocene Thermal Maximum from traditional and dual clumped isotopes in Green River Basin soil carbonates

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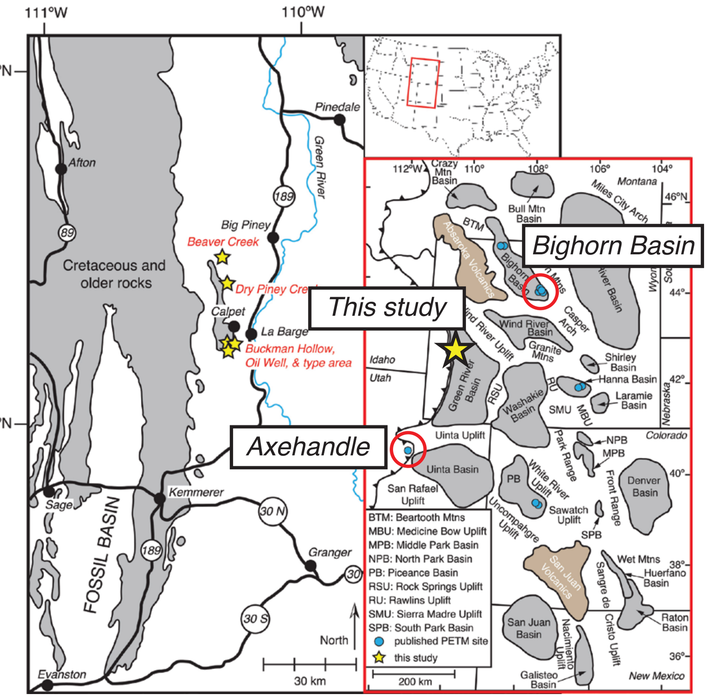
A new PETM record

Beaver Creek; Green River Basin

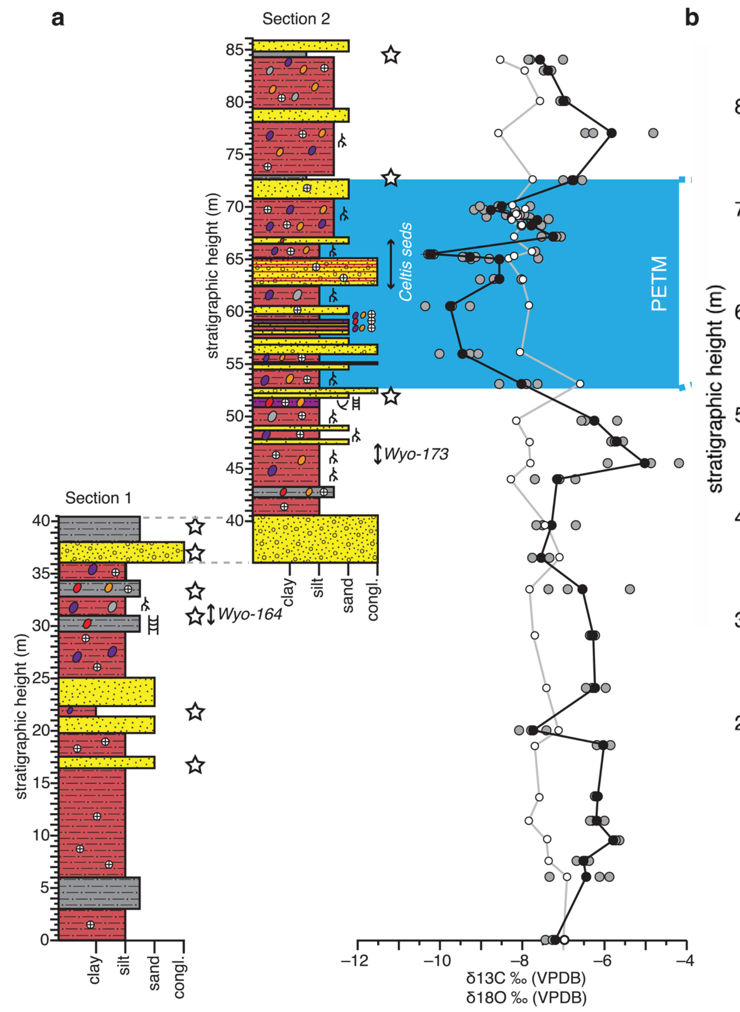
Foreman et al. (2024)

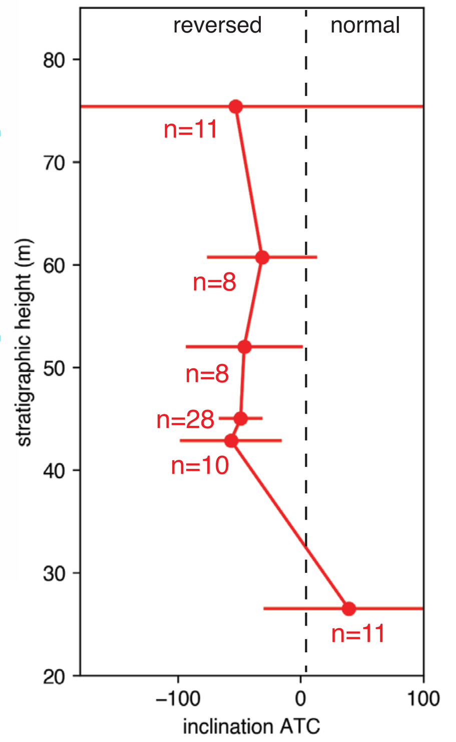


Map (left) The PETM is potentially recorded in a number of Laramide basins, but the majority of data derive from the Bighorn Basin. Here we use stable isotopes in soil carbonates to reconstruct temperature and hydroclimate from Beaver Creek. The site fills a latitudinal void between the Bighorn Basin and Axehandle Canyon

Evidence for the PETM (below)

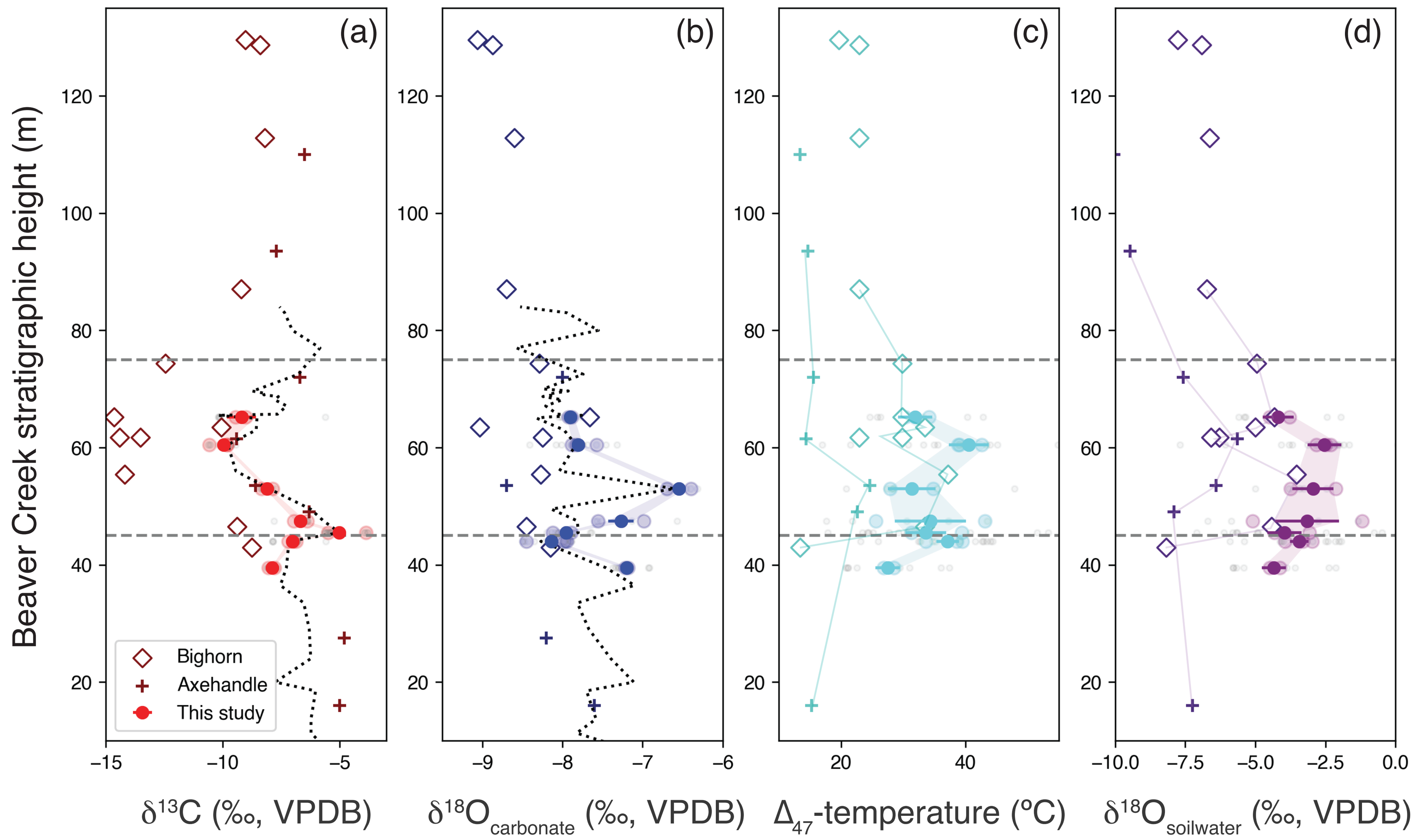
A ~4‰ carbon isotope excursion (CIE) coincides with *Celtis* endocarps, and lies above beds with late Paleocene mammal fossils. Paleomagnetic inclinations suggest reverse polarity consistent with chron 24r





Soil carbonate stable isotopes

$\delta^{13}C$, $\delta^{18}O_{carbonate}$, Δ_{47} and derived $\delta^{18}O_{soilwater}$ at Beaver Creek, Axehandle and Bighorn Basins



A subset of soil carbonate nodules was resampled for carbonate clumped isotope analyses (Nu and MAT253)

a) Carbon isotopes agree well with previous bulk isotope data (dashed line) and serve as a way to correlate the PETM acrossLaramide basin records. The magnitude of the CIE at Beaver Creek and Axehandle Canyon (Bowen and Bowen, 2008; VanDeVelde et al., 2013) is ~4‰, while it is ~6‰ at the more northerly Bighorn Basin.

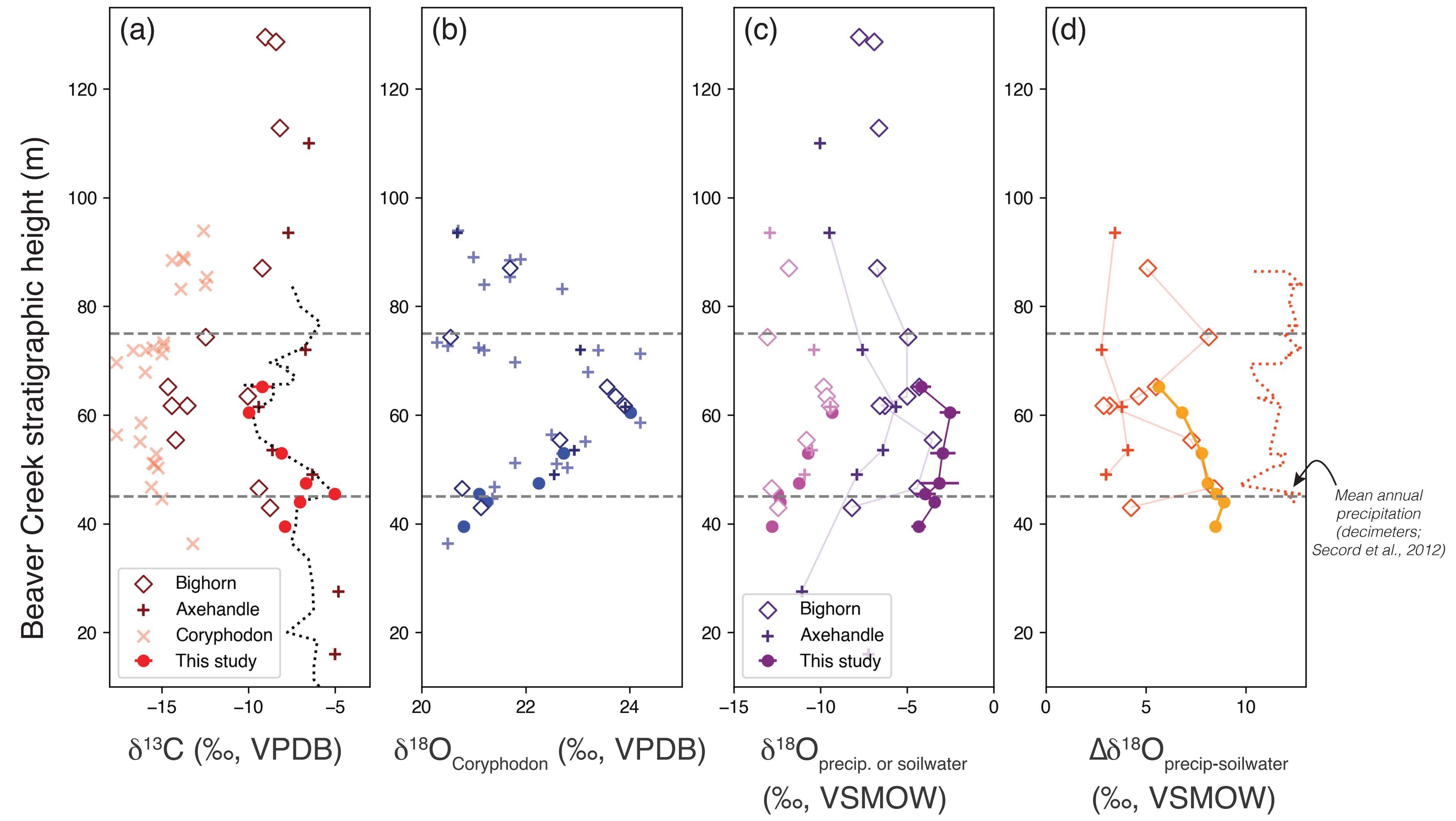
b) Carbonate oxygen isotopes at Beaver Creek show a prominent ^{18}O enrichment prior to the CIE not observed at other sites

c) Carbonate clumped isotopes suggest a warming from a pre-PETM 27°C to 33-37°C at the onset of the PETM using Anderson et al. (2021). This warming pre-dates the CIE and may reflect multiple emissions of carbon (i.e. Bowen et al. 2015). Peak warming reaches 40°C and coincides with the peak CIE. Warming of this magnitude likely reflects a combination of extreme seasonal bias, surface soil heating and/or isotopic kinetic effects associated with rapid nodule precipitation. The Bighorn Basin exhibits a larger warming from a pre-PETM 20°C to 30-37°C during the PETM (Snell et al. 2013; Havranek, 2023). Axehandle Canyon exhibits cooler pre-PETM temperatures of ~15°C and a more modest warming to 22-24°C.

d) Soilwater oxygen isotopes can be calculated from the temperature dependence of calcite-water isotopic fraction (e.g. Kim and O'Neil, 1997). Reconstructions generally trend toward more positive values during the PETM, peak near the CIE and then decline. The Bighorn Basin is somewhat of an exception with greater variability and more negative values at the CIE. Similar to temperature, the Bighorn Basin shows a larger change at the PETM onset than either Beaver Creek or Axehandle

Paleohydrology

Difference between $\delta^{18}O_{soilwater}$ and Coryphodon -based $\delta^{18}O_{precip}$ reflects evaporative enrichment



Interpreting hydrologic changes from calculated soilwater $\delta^{18}O$ alone is complicated by the fact that it cannot account for changes in the isotopic composition of meteoric water. Following Baczynski et al. (2016), we estimate the $\delta^{18}O$ of precipitation from the isotope composition of Bighorn Basin Coryphodon tooth enamel, and assume this value applies at other sites

a) Carbon isotopes of Coryphodon teeth (Secord et al., 2012) are aligned with those of soil carbonate data.

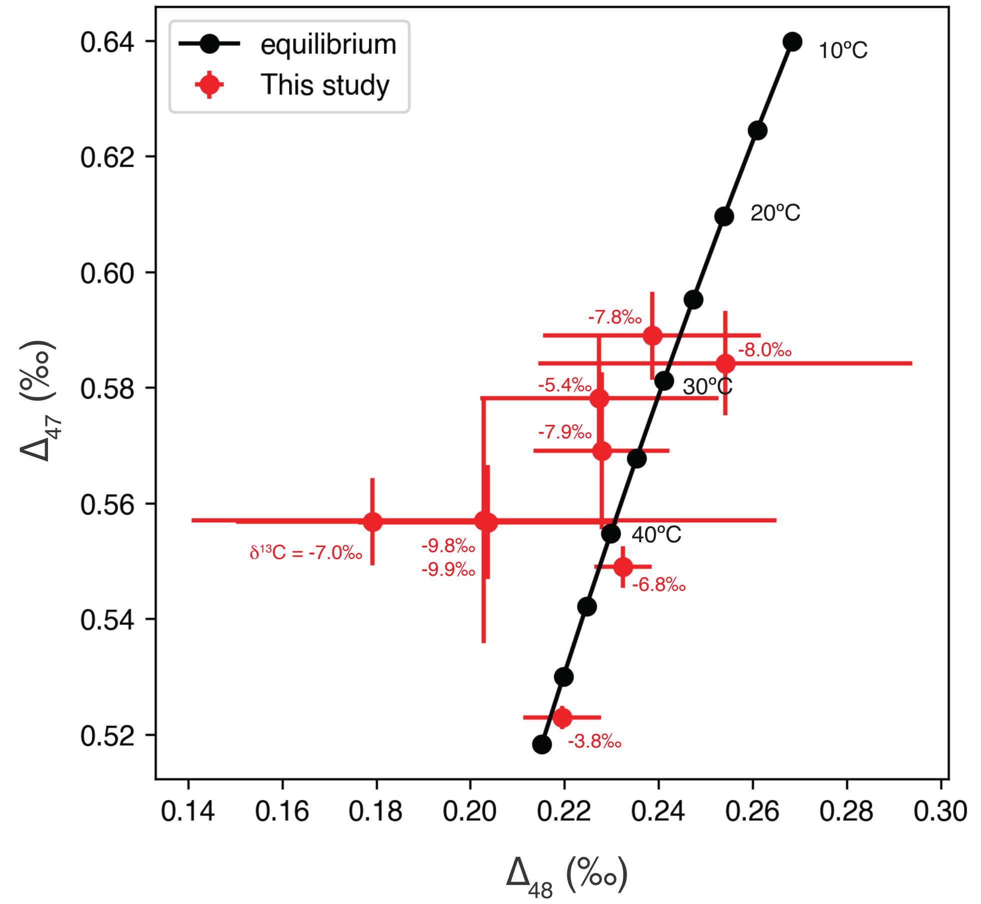
b) Coryphodon oxygen isotopes are interpolated to the depths of soil carbonate data

c) Precipitation (rain) oxygen isotopes show a similar trend to **reconstructed soil water** with a trend toward more positive values that peaks near the CIE and then declines. Soilwater consistently has a higher $\delta^{18}O$ indicative of the evaporation that accompanies soil carbonate precipitation.

d) The difference in oxygen isotopes between precipitation and soil water shows the most positive values immediately at the onset of the PETM. This signal is a subtle 0.5‰ at Beaver Creek, and a more prominent 3‰ at Bighorn Basin. The rapid shift to drier conditions at the start of the PETM is supported by a Bighorn Basin mean annual precipitation reconstruction (Secord et al., 2012) that suggests a prominent decrease in precipitation at this time. Beaver Creek suggests less evaporation through the remainder of the PETM and is apparently wetter than the pre-PETM during the CIE. The Bighorn Basin exhibits a less consistent trend, but is also apparently wetter than the pre-PETM during the CIE.

Kinetic Effects

Preliminary dual clumped isotope data suggest equilibrium precipitation



The extreme PETM warmth suggested by some soil carbonate Δ_{47} temperatures boarder on unrealistic, even if they form exclusively during the warmest times of the year.

Another contributing factor might be kinetic isotope effects associated with degassing of CO_2 if soil carbonate precipitates rapidly. Such effects are often observed in speleothems, leading to Δ_{47} temperatures that are "too warm"

Fiebig et al. (2021) provides a method for evaluating kinetic effects by leveraging the temperature dependence of both Δ_{47} and Δ_{48} simultaneously. Deviations from the equilibrium line defined by Δ_{47} and Δ_{48} are diagnositc of kinetic effects.

Preliminary data requires greater replication for robust results, but does not show evidence for kinetic effects, possibility supporting the validity of warm PETM temperatures. It may be noteworthy that nodules formed during the PETM exhibit the poorest precision.

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