

# Temperature variations across the Paleocene-Eocene boundary recorded in $\Delta_{47}$ of soil carbonates: the Esplugafreda terrestrial record, Spain

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Additions of <sup>13</sup>C-depleted carbon to the atmosphere-ocean system at 55.9 Myr ago led to global warming of 5–8 °C, profound floral/faunal turnovers and alteration of the global hydrological cycle at the Paleocene-Eocene (P–E) boundary. Environmental changes over the late Paleocene and Paleocene-Eocene Thermal Maximum (PETM) are well-preserved in continental deposits, formed in the subtropical zone (paleolatitude ~35 °N) in the Tremp-Graus Basin, northern Spain. The Esplugafreda section is made up of ~250 m of red mudstones with abundant paleosols containing numerous soil nodules and gypsum indicating a semi-arid/arid paleoenvironment. The P–E boundary is identified by a 6‰ negative carbon isotope excursion (CIE), spanning ~15–20 m of yellow cumulate paleosols formed during the PETM. The post-PETM interval comprises 20 m of red paleosols rich in gypsum, characterized by normal soil nodule  $\delta^{13}\text{C}$  values.

Here, we present clumped isotope ( $\Delta_{47}$ ) thermometry data of soil carbonates (SC) from paleosols of the upper Paleocene Esplugafreda Formation and PETM yellow soils to reconstruct paleotemperatures for this terrestrial subtropical site across the P–E boundary. The  $\Delta_{47}$  measurements were done using a Kiel IV carbonate device coupled to a Thermo Scientific 253 Plus IRMS at the Institute for Nuclear Research, Debrecen, Hungary. Stable carbon, oxygen isotope and  $\Delta_{47}$  compositions were calculated from 8–16 replicate analyses of 100–150 µg of carbonate. The temperature-dependent mass 47 anomaly is reported on the I-CDES90°C scale. Temperatures were calculated using the Anderson et al. (2021) calibration.

SCs of the Esplugafreda formation yield  $\delta^{13}\text{C}_{\text{carb}}$  values between –8.55 and –5.85 ‰, while those from PETM yellow soils are significantly more negative (–13.84 to –10.12 ‰). A much smaller, ~1.2 ‰ difference can be observed in  $\delta^{18}\text{O}_{\text{carb}}$  between these carbonates ( $\delta^{18}\text{O}_{\text{carb}}$ : –5.46 to –4.13 versus –6.35 to –4.47 ‰). The  $\Delta_{47}$ -based paleotemperatures ( $T_{47\text{carb}}$ ) indicate mean SC formation of  $33.8 \pm 9.5$  °C during the late Paleocene, which are close to modern summer temperatures of subtropical regions. By contrast, a much higher mean temperature was recorded by SCs of the PETM yellow soils ( $39 \pm 8.5$  °C) with extreme (>40 °C) temperatures occurring 4 times more