

Reply to: Possible magmatic CO₂ influence on the Laacher See eruption date

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REPLYING TO J. U. L. Baldini et al. *Nature* <https://doi.org/10.1038/s41586-023-05965-1> (2023)

We agree with Baldini et al.¹ that the Laacher See tephra (LST) is a key Late Pleistocene chronostratigraphic unit across much of Europe. We also agree that the LST needs to be dated precisely to synchronize proxy archives and to better understand climate and environmental changes during the Late Glacial period. However, we disagree that our radiocarbon (¹⁴C) measurements from three subfossil trees killed and buried at different locations by the pyroclastic deposits of the Laacher See eruption (LSE)² are possibly affected by outgassing magmatic

carbon dioxide (CO₂). Although the release of CO₂ from active volcanic systems can influence ¹⁴C values³, we here provide both relict and modern radiocarbon evidence to demonstrate why our LSE date of 13,006 ± 9 calibrated years before present (BP; taken as AD 1950) is correct.

First, in the relict dataset, we found no offset between, or drop in, our high-resolution ¹⁴C measurements from individual trees (Extended Data Fig. 1 and figure 3 of ref. 2). Despite different cardinal directions, all

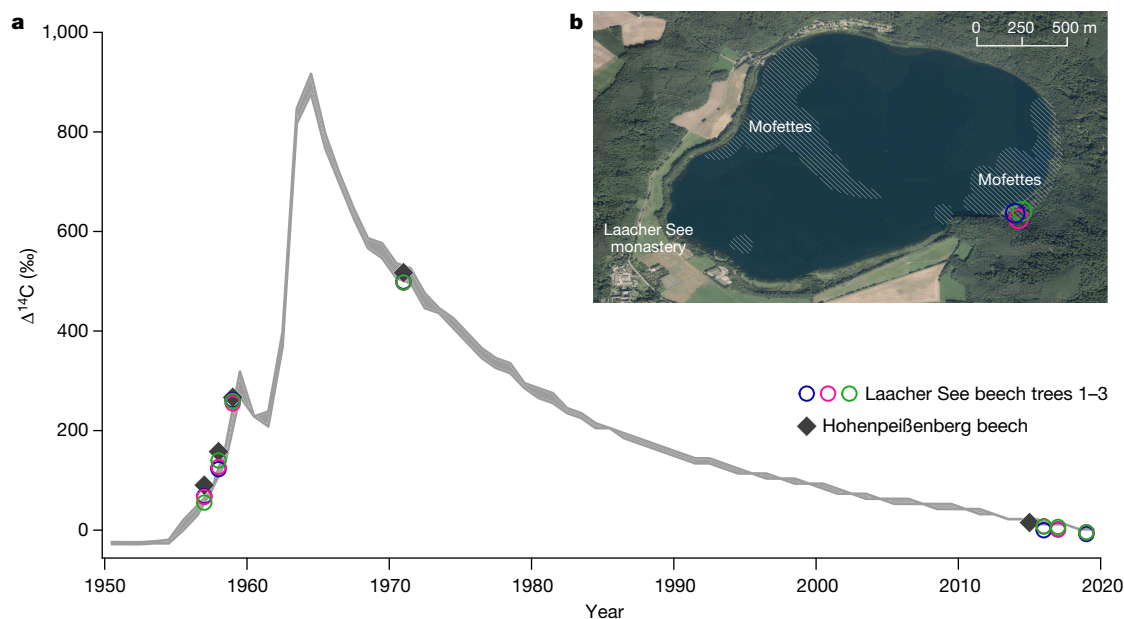


Fig. 1 | New ¹⁴C measurements from living beech trees at the eastern shore of the Laacher See. **a**, The ¹⁴C results of three trees (coloured circles) from 1957, 1958, 1959, 1971, 2016, 2017 and 2019 in the immediate vicinity of CO₂ fumaroles are in line with ¹⁴C reference measurements from Hohenpeißenberg, Bavaria, in southern Germany (black diamonds) and the IntCal20 calibration

curve¹¹ (grey shading). **b**, Map of the Laacher See and location of the three sampled trees, 1–10 m off the eastern shore of the Laacher See (digital orthophoto courtesy of the surveying and cadastral administration Rhineland-Palatinate), and the spatial distribution of the CO₂ vents, or mofettes (hashed lines; adapted from ref. 10). The map was produced using QGIS.

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existing ^{14}C measurements from different locations around the Laacher See reveal statistically similar ages^{4,5} (Extended Data Table 1). These measurements are also synchronized with independent ^{14}C dates from subfossil wood originating more than 330 km away from the Laacher See⁶. An additional interlaboratory comparison⁸ of ^{14}C data from an elk skeleton covered by LST at Miesenheim IV close to Laacher See⁷, gave a weighted mean ^{14}C date of $11,092 \pm 19$ BP, which corroborates all wood-based ^{14}C dates. These findings confirm that effects of active fumarole outgassing are, if at all, restricted to local scales⁹, because of the known mobility of large ungulates.

Second, new ^{14}C measurements of three living beech trees directly exposed to active fumaroles¹⁰ at the eastern shore of the Laacher See (Fig. 1) are in temporal agreement with twentieth-century regional and global $\Delta^{14}\text{C}$ reference data¹¹ (Fig. 1, Extended Data Fig. 2 and Extended Data Table 2). Despite the immediate proximity to active magmatic CO_2 emissions, none of the trees in this closed-canopy stand showed a bias in recent ^{14}C data between 1957 and 2019, which rejects any speculation about possible dating issues with biological material from the Laacher See region. These findings represent the closest analogue of possible outgassing effects of an active magma chamber before the LSE at $13,006 \pm 9$ calibrated years BP.

Data availability

The data used for this study are provided with this paper or are available from the references cited.

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Author contributions F.R., O.J., J.E. and U.B. wrote the Reply with input from all authors. F.K. provide material for modern radiocarbon measurements, which L.W. measured.

Competing interests The authors declare no competing interests.

Additional information

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