Possible magmatic CO_2 influence on Laacher See eruption date

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The Laacher See Tephra (LST) is a key Late Pleistocene chronostratigraphic unit across Europe, and an accurate date for the deposit is critical for understanding Late Glacial sedimentary sequences. Reinig et al.[1] recently used radiocarbon measurements of subfossil trees trapped within the Laacher See eruption's (LSE) pyroclastic deposits to date the eruption to 13,006 +/- 9 BP, ~130 years older than the previously accepted varve counting (12,880 ± 40 BP[2]) and $^{40}Ar/^{39}Ar$ (12,900 ± 560 BP[3]) age determinations. However, Reinig et al. did not correct for the incorporation of radiocarbon 'dead' magmatic CO_2 into the growing trees, and here we highlight the possibility that the date is in fact ~130 years too old. The implications of incorporating a high precision yet inaccurate LST age into the European chronostratigraphic framework are substantial, and include the misinterpretation of regional records, the misalignment of climate shifts, and the exclusion of the LSE from consideration as a possible driver of abrupt climate change.

Studies of trees growing adjacent to volcanoes illustrate that magmatic CO_2 (containing no radiocarbon) incorporation can lead to radiocarbon ages that are between a few decades to 200 years too old[4], providing a straightforward explanation for why the Reinig et al.[1] date is ~130 years older than previous age estimates. Reinig et al.[1] briefly explored magmatic CO_2 incorporation as the reason for an age offset in one of their carbonised wood samples, but ultimately no correction was made. Because the subfossil trees were sampled at near-vent localities, it seems likely that all the samples were affected by magmatic CO_2 to variable extents. The Laacher See volcano is currently in a quiescent phase, but magmatic gasses are still visibly being released from the subsurface. Studies indicate that the nature of magmatic CO_2 degassing varies by site, and can occur diffusely over large areas or at concentrated sources such as faults or springs[5]. This spatial variability combined with dynamic CO_2 flow rates means that small-scale studies of the modern system are insufficient to characterise ancient CO_2 flows; trees even a few hundred meters away from a concentrated CO_2 source may experience only negligible CO_2 uptake[5]. However, it is unlikely that magmatic gas flux is present now but was entirely absent in the decades preceding the large LSE, which was of a similar magnitude as the C.E. 1991 Pinatubo eruption and was fed by volatile-rich, phonolite magma.

Studies from the USA, New Zealand, and Italy demonstrate that magmatic CO_2 incorporation rates into trees are spatiotemporally variable[4,6-8] (Fig. 1). Therefore, temporally variable magmatic CO_2 fluxes[7,8] preceding the LSE may have not only made the radiocarbon dates of the wood samples appear generally older, but also affected the shape of the radiocarbon curve produced by Reinig et al.[1] (Fig. 1), consequently yielding a spurious correlation when wiggle-matched with the Swiss Late Glacial Master Radiocarbon (SWILM-^{14}C) dataset.

The varve counting (12,880 ± 40 BP[2]) and ^{40}Ar/^{39}Ar (12,900 ± 560 BP[3]) LSE dates are within 10 and 30 years (respectively) of a large sulphate spike at ~12,870 BP within the Greenland NGRIP ice core reported by Reinig et al.[1] and subsequently discussed in Abbott et al.[9] (Fig. 2). The sulphate distribution between Greenland and Antarctica suggests that this was a large, mid-to-high latitude northern hemisphere eruption, a signature consistent with the LSE. Reinig et al.[1] and Abbott et al.[9] did not consider this spike as potentially arising from the LSE because it was outside the uncertainties of the Reinig et al.[1] date. However, if the Reinig et al.[1] age determination was indeed affected by magmatic CO_2 and is ~130 years too old, this newly reported sulphur spike: i) is consistent with the ^{40}Ar/^{39}Ar date for the LSE; ii) is consistent with the varve counting age for the LSE; and iii) coincides with a smaller sulphur spike within the GISP2 ice core previously attributed to the LSE[10].

It is worth emphasizing that we currently cannot know for sure if the Reinig et al.[1] date was affected by magmatic CO_2, and, in fact, the observed increase in radiocarbon values immediately preceding the LSE is surprising. However, magmatic outgassing effects on radiocarbon data are still poorly understood, and we believe that the evidence is strong enough, and the repercussions of an incorrect age serious enough, to warrant discussion. We suggest that until the date is independently verified, the community approach the Reinig et al.[1] date in tandem with the Brauer et al. date of 12,880 ± 40 BP[2] in order to avoid possible interpretive issues.

Data availability

All datasets analysed during the current study are available from the references cited and are available from the corresponding author on reasonable request.

Code availability

No new codes were developed for use in this study.

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Contributions

The original premise for this article was developed by J.B., F.W., and A.P. All authors contributed to the text and figures. All authors contributed to the development of the concepts presented here.

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Ethics declarations

Competing interests

The authors declare no competing interests.

Figure Captions

Figure 1: An example of magmatic CO_2 effects on radiocarbon values of a tree growing near a volcanic centre. Radiocarbon measurements from a tree[7] growing on the SE flank of Mammoth Mountain, California, USA, a volcanically active area (orange circles with dashed line) compared with the northern hemisphere background radiocarbon activity in carbon dioxide[11] (from Jungfraujoch, Switzerland) (black line) and another nearby tree from a non-volcanic area ('background', Mammoth Lakes) (blue line). The grey shading highlights an interval of known magmatic carbon dioxide outgassing near Mammoth Mountain, which peaked in 1991 C.E.. Adapted from Cook et al., 2001[7].

Figure 2: NGRIP ice core sulphate plotted with both the Brauer et al.[2] and Reinig et al.[1] dates for the LSE. Cheng et al.[12] suggest that the NGRIP chronological uncertainty near the beginning of the YD is ±20-40 years.