Supplementary material

Stalagmite carbon isotopes suggest temperature controlling a deglacial increase in soil respiration in Western Europe

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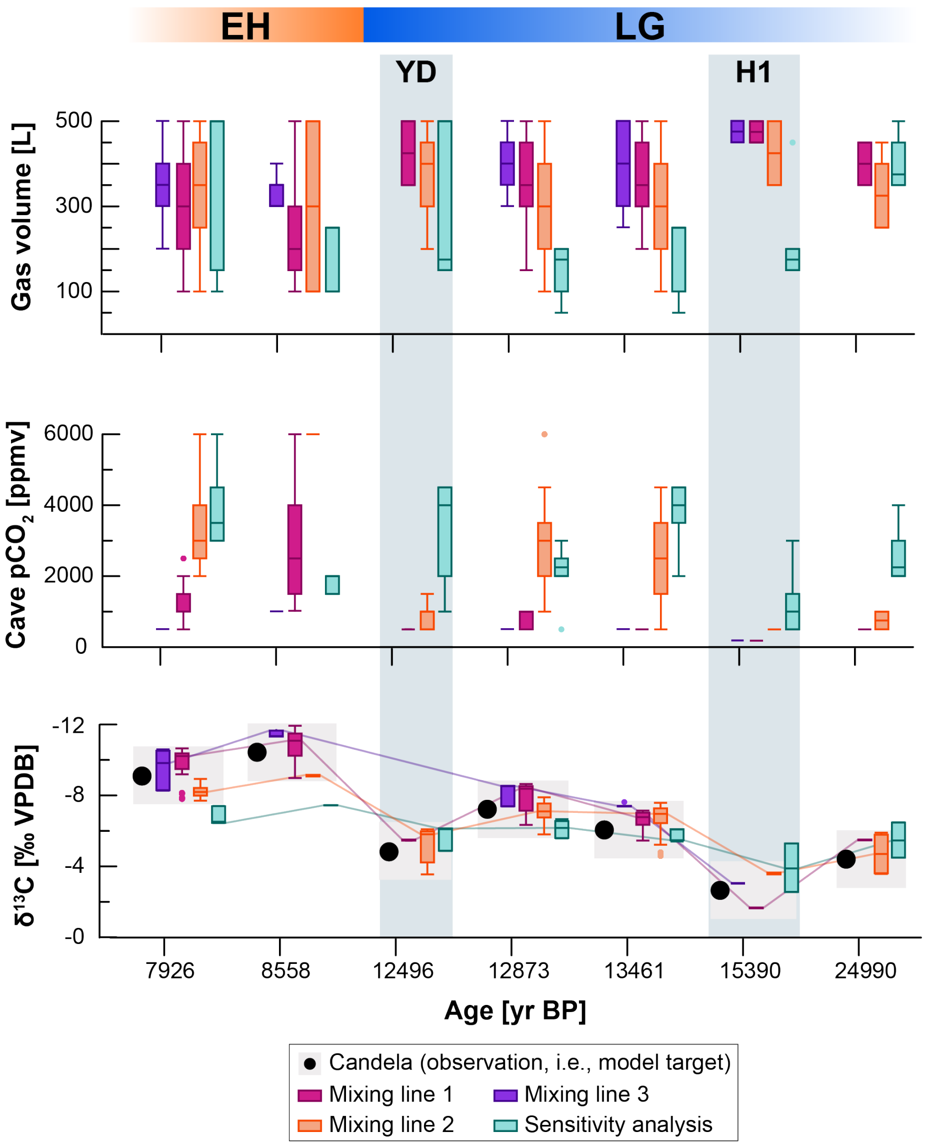
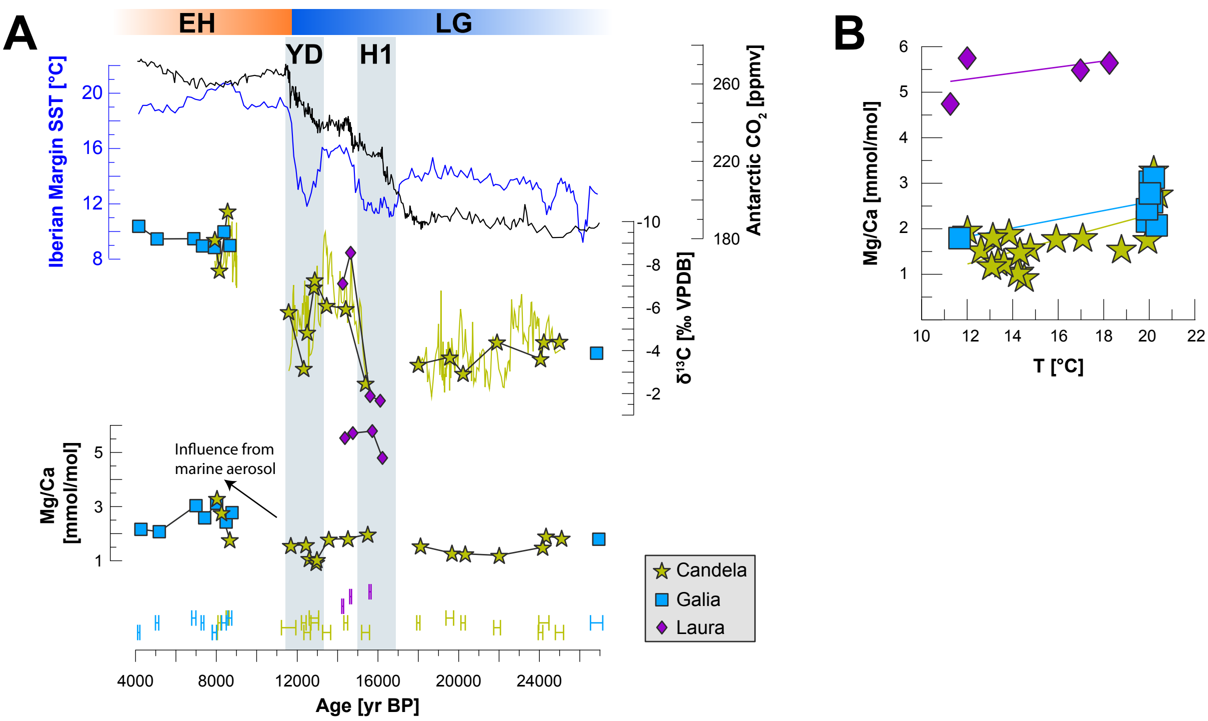


Suppl. Fig. 1: Modelling results for cave pCO_2 and gas volume, compared to measured and modelled $\delta^{13}C_{spel}$ in stalagmite Candela. Stalagmite measurements ($\delta^{13}C_{spel}$, DCF, $\delta^{44}Ca$; black dots) are compared to best fitting model solutions (colour-coded by simulation type). Simulation results are shown as box plots, with the median and upper and lower quartiles displayed. Outliers are shown as coloured dots. Grey shading indicates intervals of the measured proxy values used to filter the simulations. The time periods (LG, EH) at the top of the figure indicate the intervals used for the modelling to define temperature and atmospheric pCO_2.

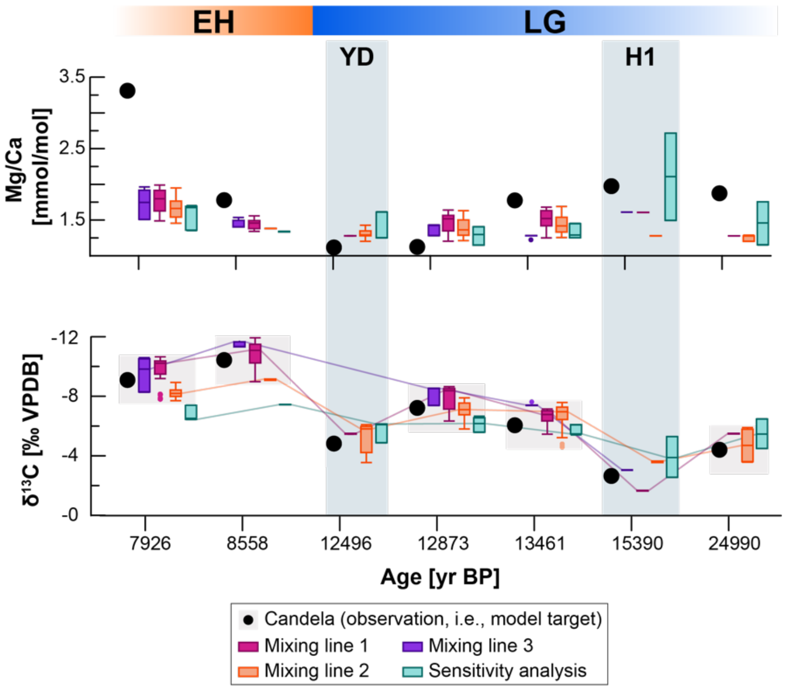
Mg/Ca measurements and modelling:

Mg/Ca ratios are also often used as qualitative proxy for prior calcite precipitation (PCP; Fairchild and McMillan, 2007). At the Pindal Cave site, where the cave currently extends to the sea cliff, Mg/Ca of dripwaters is additionally increased in the Holocene by increasing surf zone marine aerosol generation as rising sea level brings the coastline from >1 km away to within 50 m of the cave entrance. Mg/Ca was still measured on stalagmites Candela, Galia, and Laura using splits of the isotope samples, either at the University of Oviedo following previously described methods (Thermo ICAP DUO 6300, Moreno et al., 2010), or with similar standardization approaches at ETH Zürich (Agilent QQQ 8800); all ratios are reported in mmol/mol standardised to calcium.

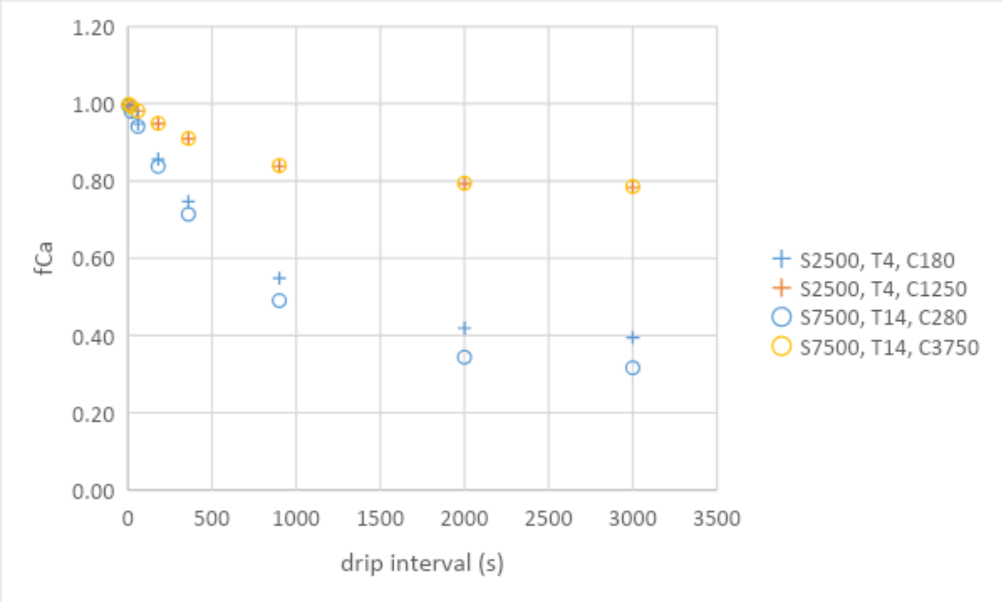
Mg/Ca ratios are similarly low during the LGM in Candela and Galia, followed by a 2- 3-fold increase at the transition to the EH (Fig. 3). In Candela, the Mg/Ca dips to its absolute minimum values at the beginning of the YD, coinciding with an increase in $\delta^{13}C$. Absolute Mg/Ca values are much higher in Laura (around 5mmol/mol, Fig. 3) and display a slight increase from the beginning of H1 towards the BA.



Suppl. Fig. 2: A – Mg/Ca record from the three stalagmites, compared to $\delta^{13}C_{spel}$, as well as regional temperature (Darfeuil et al., 2016) and global atmospheric CO_2 (Bereiter et al., 2015) reconstructions. Increasing Mg/Ca with the onset of the Holocene are likely related to increasing contribution from marine aerosols at the site, a consequence of rising sea levels. B – Stalagmite Mg/Ca vs. temperature, colour-coded by stalagmite. The corresponding palaeo-temperatures are linearly interpolated from the Iberian Margin SST record by Darfeuil et al. (2016). The time periods (LG, EH) at the top of the figure indicate the intervals used for the modelling to define temperature and atmospheric pCO_2.



Suppl. Fig. 3: Modelling results for Mg/Ca, compared to measured and modelled $\delta^{13}C_{spel}$ in stalagmite Candela. Stalagmite measurements (black dots) are compared to best fitting model solutions (colour-coded by simulation type). Simulation results are shown as box plots, with the median and upper and lower quartiles displayed. Outliers are shown as coloured dots. Grey shading indicates intervals of the measured proxy values used to filter the simulations. The time periods (LG, EH) at the top of the figure indicate the intervals used for the modelling to define temperature and atmospheric pCO_2.



Suppl. Fig. 4: Influence of soil pCO_2 and cave temperature and pCO_2 on f_ca (as a measure for PCP) vs drip interval, using ISTAL (Stoll et al., 2012). We compare how drip interval influences PCP under glacial (temperature: 4°C, soil pCO_2: 2500 ppmv, cave pCO_2: 180 ppmv in winter, 1250ppmv in summer) and Holocene (temperature: 14°C, soil pCO_2: 7500 ppmv, cave pCO_2: 280 ppmv in winter, 3750ppmv in summer) conditions. The model assumes fully open dissolution conditions, a reasonable estimate at our study sites.

References:

Bereiter, B., Eggleston, S., Schmitt, J., Nehrbass-Ahles, C., Stocker, T.F., Fischer, H., Kipfstuhl, S., Chappellaz, J., 2015. Revision of the EPICA Dome C CO_2 record from 800 to 600 kyr before present. Geophys. Res. Lett 42, 542–549. doi:10.1002/2014GL061957.Received

Darfeuil, S., Ménot, G., Giraud, X., Rostek, F., Tachikawa, K., Garcia, M., Bard, É., 2016. Sea surface temperature reconstructions over the last 70 kyr off Portugal: Biomarker data and regional modeling. Paleoceanography 31, 40–65. doi:10.1002/2015PA002831

Fairchild, I.J., McMillan, E.A., 2007. Speleothems as indicators of wet and dry periods, in: International Journal of Speleology. doi:10.5038/1827-806X.36.2.2

Moreno, A., Stoll, H., Jiménez-Sánchez, M., Cacho, I., Valero-Garcés, B., Ito, E., Edwards, R.L., 2010. A speleothem record of glacial (25-11.6 kyr BP) rapid climatic changes from northern Iberian Peninsula. Glob. Planet. Change 71, 218–231. doi:10.1016/j.gloplacha.2009.10.002

Stoll, H.M., Müller, W., Prieto, M., 2012. I-STAL, a model for interpretation of Mg/Ca, Sr/Ca and Ba/Ca variations in speleothems and its forward and inverse application on seasonal to millennial scales. Geochemistry, Geophys. Geosystems 13, 1–27. doi:10.1029/2012GC004183