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Improving paleo-rainfall estimates using a Bayesian proxy system model of calcium isotopes in stalagmites

CAMERON DE WET[1], SARAH PEDERZANI[2], GABRIEL BOWEN[2], ELIZABETH M. GRIFFITH[3], ERICA A SCARPITTI[4], JESSICA L. OSTER[4], ISABEL P MONTAÑEZ[5], YUVAL BURSTYN[5], ELIOT ATEKWANA[5], MICHAEL T HREN[6], ZHAO WANG[6] AND AIDA ZYBA[4]

[1]Middlebury College
[2]University of Utah
[3]The Ohio State University
[4]Vanderbilt University
[5]University of California, Davis
[6]University of Connecticut

Calcium stable isotopes ($\delta^{44}Ca$) in stalagmites are thought to be a direct indicator of prior calcite precipitation (PCP) with potential as a semi-quantitative proxy of past rainfall. This feature also makes $\delta^{44}Ca$ a useful tool for improving the interpretation of other PCP-sensitive proxies. Using a Rayleigh fractionation framework, $\delta^{44}Ca$ can be used to estimate the amount of Ca remaining in solution at the time of stalagmite formation (*f*), a metric for PCP. Associated fractionation factors are known to be impacted by calcite precipitation rates, but this effect has not been directly considered for PCP reconstructions from stalagmite records.

Here we present a novel $\delta^{44}Ca$ proxy system model that uses Bayesian inversion to reconstruct PCP and rainfall while considering the range of measured host rock $\delta^{44}Ca$ values and accounting for growth rate and temperature effects on calcium isotope fractionation. We apply this model to two, partially coeval stalagmite records (LSC2 and LSC3) from Lake Shasta Caverns, CA, that exhibit large fluctuations in growth rate during their formation (~35,000 to 14,000 years BP). Using a standard Rayleigh fractionation model these records yield unrealistic $f > 1$ (implying > 100% of initial dissolved Ca remaining in solution) during the intervals of fastest stalagmite growth – underlining the need for an additional correction. In contrast, the PSM-based interpretation constrains *f* to <1 in all cases by allowing fractionation factors and host rock $\delta^{44}Ca$ values to vary within expected bounds. On this basis we generate estimates of paleorainfall variability throughout the deglacial and observe a ~50% increase in paleorainfall between the Last Glacial Maximum and Heinrich Stadial 1. We also used our modeled PCP rates to obtain PCP-corrected $\delta^{13}C_{initial}$ and $\delta^{18}O_{initial}$ time series for these samples.

Our model's use of Bayesian inversion expands the number of stalagmites that $\delta^{44}Ca$ rainfall estimation can be applied to. Future work will focus on better characterizing the relationship between *f* and rainfall amounts and expanding multiproxy integration.