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Multiproxy diagnostic criteria to identify subglacial speleothem growth: test cases from the European Alps and Western Caucasus

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Conventional models of speleothem growth require percolation through a biologically active soil layer, uptake of soil-respired CO_2, and resulting carbonic-acid dissolution of the host rock. Within this model, speleothem growth is inhibited when the mean temperature of the soil-karst-cave system falls below the freezing point of water. Hence, speleothem growth hiatuses have been interpreted at high-latitude sites to indicate permafrost conditions or glacial cover. Paradoxically, however, speleothem growth during presumably ice-covered intervals has been documented in studies of Alpine and North American caves. To explain how growth could proceed despite subzero mean annual air temperature and the absence of soil, previous work has proposed a mechanism that invokes: 1) the oxidation of sedimentary sulfides to promote sulfuric-acid dissolution of host rock; and 2) buffering of ground temperatures by a warm-based glacier above the cave site that maintains the epikarst and cave within the 0°C isotherm. In this scenario, infiltrating meteoric water is derived indirectly from basal glacial melt and seasonal moulin drainage, which act as a low-pass filter with respect to transference of the oxygen-isotope composition and associated climate signal.

Although individual components of the proposed mechanism have been observed in modern analog settings, there has been no comprehensive attempt to elucidate or constrain these processes through geochemical proxy data. Here we present preliminary data from speleothems in the Western Alps (Austria, Switzerland, France) and Western Caucasus (Abkhazia) that grew subglacially or in close proximity to the ice margin, according to U-Th dating and glacier reconstructions. Based on these results, we attempt to define multiproxy diagnostic criteria to identify intervals of subglacial conditions. First, we investigate how a switch to predominantly sulfuric-acid dissolution impacts the carbon-isotope and trace-element composition of calcite. We find that enhanced host rock contributions to the dissolved inorganic carbon pool substantially raise $\delta^{13}C$ and dead-carbon fraction, as well as increase the variance in prior calcite precipitation, as interpreted from trace-element data. We evaluate these data through proxy system modeling of a subglacial setting; however, information from these proxies is limited as they are impacted by a multitude of processes. Therefore, we test whether speleothem S/Ca and $\delta^{34}S$ are more direct proxies for sulfide oxidation. Finally, we consider paleothermometric methods to test whether cave temperatures are near zero, as the proposed mechanism requires. If successful, the identification of subglacial speleothem archives may substantially improve glacial reconstructions

by providing vital constraints on ice-sheet properties for paleomodeling, in addition to yielding proxy reconstructions of surface climate during glacial intervals, when most terrestrial archives are inactive.