



Unison, harmony or cacophony? Similarities and differences among coeval isotope records from near-neighbour speleothems.

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Reconstruction of palaeo-climate from isotope records in speleothems is based on the assumption that individual specimens have recorded climate and environment in an orderly way. Studies of modern systems have guided understanding of the relationships between climatic inputs (temperatures and water balance), speleothem outputs (isotopic and other records), and the processes through which inputs determine outputs (soil respiration, soil and unsaturated zone hydrology, rock-water interaction, carbonate solution chemistry, and cave ventilation). Such studies commonly show that (a) seasonal temperature variation in cave interiors is small or non-existent, and (b) seasonal variation of $\delta^{18}\text{O}_{\text{water}}$ in drip waters is likewise small when compared with meteoric precipitation at the same site. Isotopic differences between drip sites in the same cave are also generally small. Therefore, records from coeval speleothems deposited as close neighbours in the same cave should reflect identical cave temperatures and closely similar $\delta^{18}\text{O}_{\text{water}}$. If all specimens shared *identical* hydrologic and chemical processes then their $\delta^{18}\text{O}_{\text{calcite}}$ and $\delta^{13}\text{O}_{\text{calcite}}$ records should be very similar. On

the other hand, different isotope records would reflect differences in process conditions that affected some speleothems more than others. Given that the controls exerted by soil respiration, cave temperature, ventilation and cave air $p\text{CO}_2$ are all shared, the most likely control for differences is drip hydrology, which obviously varies from one drip site to another within a single cave. The differential effects of changing drip rate on out-gassing of CO_2 are likely to reduce the coherence of $\delta^{13}\text{C}_{\text{calcite}}$ and $\delta^{18}\text{O}_{\text{calcite}}$ records among neighbour speleothems.

We present coeval $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records from neighbour speleothems covering different time scales in three climatic settings – temperate oceanic (NW England, 3 specimens 2.5-10 ka), Mediterranean seasonally wet-dry (SE Spain, 2 specimens, 6.45-6.70 ka), and temperate continental (Slovakia, 2 Holocene stalagmites correlated by laminae). All show significant differences in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. Coherence is improved by removing the proportions of $\delta^{18}\text{O}$ variance that are correlated with $\delta^{13}\text{C}$, suggesting that $\delta^{18}\text{O}$ partly reflects kinetic control by slow hydration of CO_2 to H_2CO_3 during CO_2 out-gassing. $\delta^{13}\text{C}_{\text{calcite}}$ increases with proportion of DIC lost from drip water as out-gassed CO_2 . Its variation will be controlled by the time interval between drips and by cave air $p\text{CO}_2$. For NW England hydrologic control of $\delta^{13}\text{C}_{\text{calcite}}$ is confirmed by high correlation with Mg/Ca ratio.

We conclude that raw $\delta^{18}\text{O}_{\text{calcite}}$ should be interpreted as a mixed proxy responding to cave temperature, drip water $\delta^{18}\text{O}$, drip rate and cave air $p\text{CO}_2$. De-correlation from $\delta^{13}\text{C}$ produces $\delta^{18}\text{O}_{\text{residual}}$ whose coherent variation in two or more stalagmites reflects changes in drip water $\delta^{18}\text{O}$ and cave temperature. Drip water $\delta^{18}\text{O}$ appears to be the dominant control at all three sites.