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Cave monitoring of the stable isotope signals transmitted to speleothems in Gibraltar

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An eight-year cave monitoring effort in Gibraltar had the ultimate aim of reconstructing δ18O in past precipitation from well-dated speleothems. We measured stable isotopes in cave waters from nine sites in New St Michael's (NSM) and Ragged Staff (RS) caves, comparing them with monthly GNIP values for Gibraltar rain. Additionally we conducted artificial tracer tests that tracked two dyes from surface to drip sites in NSM.

Seepage waters have a very narrow compositional range and little difference between sites when compared with the fluctuations of δ18O and δ2H in monthly rainfall (δ18O range 12.5 ‰. δ18O varies seasonally by only tenths per mille whereas inter-annual ranges are up to 1 ‰The compressed seasonal variations indicate temporal mixing of rains that entered the sub-surface at different times. Comparison of exceptional variations in rainfall with subsequent seepage samples reveals a component of seepage that has been stored for at least one year. The artificial tracers indicated marked spatial mixing as water flowed from the surface to the caves. Tracers from single points on the surface above MSN formed overlapping plumes of dyed water that could be detected across 200 m horizontally. The tracer results confirm the temporal mixing and indicate residence times that are less than the three month monitoring period but exceed the initial breakthrough times of days to weeks after injection. Combined storage time indicated by stable isotopes, tracer results imply that the full residence time distribution for water in the unsaturated zone ranges from a few days to over one year. This temporally and spatially dispersive behaviour arises from the geometric properties of the fracture network that the cave seepages have passed through, so will have been broadly invariant in the past. The water isotope signal that Gibraltar speleothems capture is averaged over a period of around one year and very short events will not be recorded.

The stable isotope data also show the influence of other processes than simple mixing. Seepage waters have lower values than the amount-weighted averages for rainfall, suggesting a bias towards isotopically lighter rains. Plots of δ2H versus δ18O show no consistent signs of modification by evaporation, despite Gibraltar's hot dry summers, so the isotopically heavier rains are completely lost to evapo-transpiration. A less easily explained feature is that the deuterium excess of seepage is higher than that of average rainfall, although lying within its overall range. This may be caused by addition of condensation water to the shallow epikarst.

In the cooler climates of the Last Glacial evaporation would have been less than today and the isotopic composition of seepage may have been closer to the annual average of rainfall. Samples from speleothems often span several years even in highly-resolved records, with the implication that in cool climates the calcite δ18O will reflect the average for rainfall over this time interval. In climates resembling the present it may be displaced slightly towards lighter values.