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Modelling stalagmite growth rate and oxygen isotope composition

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Two numerical forward models based on monitoring data from New St Michael's Cave, Gibraltar, available between 28/04/2004 and 24/02/2008 (Mattey *et al.*, 2010) were created to investigate the growth rate and oxygen isotope (δ^{18}O) composition of stalagmite calcite, with an aim of replicating the record from stalagmite Gib04a (Mattey *et al.*, 2008). Model outputs for stalagmite growth rate variability are based on high-frequency fluctuations in cave atmosphere pCO$_2$, temperature, and dripwater [Ca^{2+}], and pseudoproxy stalagmite δ^{18}O data outputs are based on step-wise isotopic fractionation associated with seawater evaporation, moisture migration and rainout.

High-frequency fluctuations in cave atmosphere pCO$_2$ and, to a lesser extent, temperature, affect stalagmite growth rates, implying that cave atmosphere dynamics are an important control on stalagmite growth. As a result of seasonality present in dripwater [Ca^{2+}] and cave air pCO$_2$, modelled Gib04a growth rates vary seasonally. In addition, higher-frequency fluctuations in both dripwater [Ca^{2+}] and pCO$_2$ are apparent in the monitoring data and in modelled growth rates. The modelling assumed that the measured drip water [Ca^{2+}], drip discharge, and cave air pCO$_2$ patterns are representative of the entire growth period of Gib04a ($\sim$53 years). However, modelled total growth ($\sim$3 mm) considerably underestimates actual growth ($\sim$45 mm). If drip water [Ca^{2+}] is raised uniformly by 75 ppm, the required growth is achieved. On intra-annual timescales, modelling also suggests that stalagmites frequently experience temporary cessations of growth, even if dripwater is supplied continuously to the stalagmite.

The 'typical' oceanic source regions for Gibraltar precipitation between 1951 and 2004 were inferred from ensemble back trajectory analyses. Seawater δ^{18}O, sea surface temperature, and relative humidity data for these regions allow synthetic precipitation δ^{18}O and pseudoproxy stalagmite δ^{18}O time series datasets to be generated by the numerical forward model constructed. Modelled monthly meteoric precipitation δ^{18}O data are found to correlate with estimated monthly amounts of hydrologically-effective precipitation at Gibraltar (r^2 = 0.66); this correlation is comparable to that determined from Global Network for Isotopes in Precipitation (GNIP) data (r^2 = 0.63). Additionally, modelled precipitation δ^{18}O data replicate the amplitude of GNIP δ^{18}O variability. Some pseudoproxy stalagmite δ^{18}O outputs based on distinct source regions replicate the amplitude of variability in actual Gib04a δ^{18}O moderately well, although others exhibit lower amplitude. This suggests that the regions on which they are based do not contribute to precipitation in Gibraltar frequently. Additionally, adjustments of only the fraction of rainout within realistic boundaries are sufficient to produce satisfactory fits between pseudoproxy and actual Gib04a δ^{18}O data.

This research illustrates that modelling can help evaluate the parameters that ultimately affect stalagmite growth and stable isotope records, and which are otherwise difficult to constrain. Future work includes incorporating continentally-derived precipitation into the model in order to better quantify the changing contributions of different precipitation source regions through time evident in stalagmite palaeoclimate records.

References

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