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Accurate dating of tropical South Pacific stalagmites using physical and chemical cycles

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Climate and environmental events recorded by speleothems are accurately dated by radiometric techniques. However, speleothems from the Tropical Pacific are difficult to date by the U-series radiometric method due to low uranium content and/or multiple sources of ^{230}Th. This is the case of stalagmites from Atiu, in the Southern Cook Islands Archipelago, which potentially record shifts of the South Pacific Convergence Zone through time and their impact on droughts and floods. Here we constrain the U-series-based chronology using synchrotron µXRF two-dimensional mapping of Sr concentrations coupled with growth laminae optical imaging constrained by in situ monitoring.

Chronology involving annual laminae counting has, to date, been focused on settings where strong temperature seasonality favours the formation of annual geochemical/physical cycles. In Atiu caves temperature is constant throughout the year (mean 23 °C), whereas precipitation exhibits a strong seasonality, with 70% of the mean Total Annual Rainfall (TAR = 1930±365 mm/yr) occurring from December to May. However, during the drier season (June through November) rainfall amounts are still substantial, which can lead to missing dry seasons in the speleothem record. Moreover, a shallow depth of the caves (5 -10 m) and limited soil cover enhance fast transmission of rain signal into the caves, possibly resulting in the formation of sub-annual growth bands. Thus, the concentration variability of Sr and Mg alone are not sufficient to identify an annual signal.

We integrated, in a multivariate analysis, high resolution (6µm) variations in trace elements analysed by LA-ICP-MS, with optically visible growth bands and two-dimensional Sr-concentration laminae as identified through synchrotron-radiation-based micro XRF mapping. Cycles of [Mg], [Sr], [Na], [Ba] and [P] concentration were counted for three independent transects in a modern stalagmite (Pu17) from Pouatea Cave. This included semi-automated counting of peak positions on individual elements, as well as on their principal components (PCA). The three independent analytical techniques produced 37 peak counting series, 20 of which were averaged and integrated into a single age model fitting into the uncertainty limits of U/Th dates. This master chronology

was used to construct an age model that integrated laminae counting errors with the U/Th uncertainty. The average uncertainty of U–Th ages included in the age model is ca. 50%, whereas the initial lamina chronology has a maximum error of 15 years (4%), thus decreasing the uncertainty by at least 45%.

Our yearly resolved chronology was then tested against the local rainfall record by using hydrologically sensitive elements Mg, Na and P. High correlation coefficients for each element corroborated the reliability of the age model, paving the way to reconstruct seasonally resolved records from trace element variations in these tropical speleothems.