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The potential of stalagmites from the Patagonian Andes as sub-annually-resolved paleoclimate records

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Stalagmites of the superhumid southern Andes are occasionally formed in small non-carst caves in a metamorphic and/or granitoid basement. They originate from coastal erosion in fracture zones during periods of higher sea levels. These small and relatively open caves are equilibrated with outside temperatures. Their drip rates reflect regional precipitation related to westerly wind intensities. To evaluate the reproducibility of proxies of different stalagmites we have investigated three U/Th-dated stalagmites (each one with 14-16 ages) from a single cave which grew simultaneously during the last 5 Ka.

The host rocks provide a large variety of fine-grained siliciclastic minerals which are deposited on the stalagmite. Thin sections, scanning electron microscope, electron microprobe, and cave monitoring show that up to 3 wt% of siliciclastic minerals was accumulated successively on top of the stalagmites, depending on the individual drip rates above a certain threshold level. The amount of detritus was determined by the contents of detrital elements like Y and HREE, which were measured by ICP-MS (LAM-ICP-MS) from drill-holes (1-1.5 mm diameter) and laser ablation (5-10 μm steps). The LAM-ICP-MS pattern of e.g. Y and Al show a monthly resolution with clear seasonal cycles for the last 5 Kyrs. The presumable annual cycles match well into the time span in-between single Th/U ages. The seasonality results from two times higher drip rates in southern hemisphere summer (stronger westerlies) compared to winter. The time series show annual as well as typical sun-spot-related cyclicities ($\sim$11, 90, 210 years). Since these proxies are only sensitive to precipitation (and westerly changes) we suggest that the westerly intensities are controlled indirectly by changes in the sun's activity.

Typically acid soil water with pH values of 3-5 leach several elements (U, Sr, Fe, Mg etc.) from the surrounding rocks, leading to high Mg/Ca ratios in the stalagmite during less humid periods and to lower Mg/Ca ratios during more humid phases. The amount of such calcite compatible elements was measured in drill-hole samples (40 year resolution) and by electron microprobe (20μm spot) with a time resolution of $\sim$0.3 years. The element concentrations reflect especially dilution by rain water. The highly resolved electron microprobe records indicate short scale (a few months) extreme weather periods and also typical sun cyclicities. Annual averages of the Mg/Ca ratios were calibrated by using 100 years of weather station data, indicating variations in the precipitation between 2500 and 6000 mm/yr for the last 5 ka at the climate divide of the southern Andes at 53°S.

Stable carbon and oxygen isotopes of the three different stalagmites (2-3 year time resolution) suggest a non-linear evaporation-controlled kinetic effect (especially drip rate dependent) on the isotopic fractionation, which is slightly superimposed by a temperature controlled fractionation. The isotope values of the three stalagmites show a bad correlation and only the record of the stalagmite with the highest drip rate range can be correlated with the above presented drip rate dependent chemical proxies. The other two stalagmites represent overall lower drip rates and reflect non-climatically induced fractionation. Changes in the water pathways at the cave roof probably resulted in distinct and individual residence times of the drip water.

Altogether, we conclude that our records from 53°S represent the core of the Southern hemispheric westerlies and show that the Neoglacial cold phases between 2.5 and 3.5 kyrs B.P. (sun spot minima) and from 0.6 to 0.1 Kyrs

(Little Ice Age) are characterised by relatively low precipitation. In contrast, the periods between 2.0 and 1.5 kyrs and especially the Medieval Warm Period (1.2 – 0.8 Kyrs) were extremely humid, indicating stronger westerlies. The southern Andes stalagmites have a very good potential for climate sensitive high resolution records.