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Carbon dioxide concentration in caves and soils in an alpine setting: implications for speleothem fabrics and their palaeoclimate significance

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Carbon dioxide concentration in soils controls carbonate dissolution, soil CO_2 efflux to the atmosphere, and CO_2 transfer to the subsurface that lead, ultimately, to speleothem precipitation. Systematic studies on CO_2 concentration variability in soil and caves at regional scale are, however, few. Here, the systematic investigation of CO_2 concentration in caves and soils in a temperate, Alpine region along a 2,100 m altitudinal range transect, which corresponds to a mean annual temperature (MAT) range of 12°C is presented.

Soil pCO_2 is controlled by the elevation and MAT and exhibits strong seasonality, which follows surface air temperature with a delay of about a month. The aquifer pCO_2, by contrast, is fairly constant throughout the year, and it is primarily influenced by summer soil pCO_2.

Cave CO_2 concentration is a balance between the CO_2 influx and CO_2 efflux, where the efflux is controlled by the cave ventilation, which is responsible for low pCO_2 values recorded in most of the caves with respect to soil levels. Carbon dioxide in the innermost part of the studied caves exhibits a clear seasonal pattern. Thermal convection is the most common mechanism causing higher ventilation and low cave air pCO_2 levels during the winter season: this promotes CO_2 degassing and higher supersaturation in the drip water and, eventually, higher speleothem growth rates during winter.

The combined influence of three parameters - dripwater pCO_2, dripwater Ca content, and cave air pCO_2 - all related to the infiltration elevation and MAT directly controls calcite supersaturation in dripwater. Four different altitudinal belts are then defined, which reflect temperature-dependent saturation state of dripwaters. These belts broadly correspond to vegetation zones: the lower montane (100 to 800 m asl), the upper montane (800 to 1600 m asl), the subalpine (1600 to 2200 m asl) and the Alpine (above 2200 m asl). Each altitudinal belt is characterised by different calcite fabrics, which can shift upward/downward in elevation as a response to temperature increase/decrease through time. In the lower and upper montane zones the columnar types (compact, open, fascicular optic) are the most common fabrics, with the microcrystalline type most typical of the upper montane zone. The dendritic fabric becomes predominant in the higher upper montane and lower subalpine zones. The higher subalpine to lower alpine zones the only speleothem actually forming is moonmilk.

Eventually, the occurrence of “altitudinal” fabrics within the vertical growth axis of a stalagmite is indicative of changes in the MAT through time Therefore, fabric changes in fossil speleothems in temperate climate settings can be potentially used to reconstruct regional MAT changes in the past.