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Constraints from monitoring on reconstruction of Gibraltar palaeoclimate in a speleothem record covering the last glacial period

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Ten years of comprehensive cave monitoring in Gibraltar provides a unique basis for interpreting proxy records in speleothems, and in this study we discuss some of the opportunities and challenges in constructing an interpretive framework for long proxy records. We present a new trace element and stable isotope record spanning 30-110 ka obtained from two neighbouring speleothems from Ragged Staff Caves, Gibraltar. The age model is defined by over 100 U-Th dates with continuous micromilling for stable isotopes, and LA-ICPMS used for acquiring the trace element proxy record. These provide highly resolved critical evidence for some of the main meteorological and environmental controls on past western Mediterranean terrestrial climate at near decadal and sub-annual resolution, respectively.

Our interpretations of the monitoring data highlight geochemical and hydrological processes critical to speleothem deposition. We conclude that δ^{13}C and δ^{18}O in speleothem calcite are controlled by within-cave conditions that vary seasonally and are themselves controlled by the temperature and water balance at the ground surface. For interpretation of trace elements, we utilize multi-annual monitoring of drip waters. The Gibraltar record shows variations in δ^{13}C and δ^{18}O on timescales from multi-decadal to multi-millennial which we compare with independently dated records of multiple proxies from marine cores, including vegetation and sea surface temperature (SST), and the Greenland ice core record.

The precision of the Gibraltar speleothem chronology allows for greater confidence in correlation with other records, and we particularly note a remarkable correspondence with δ^{18}O in Greenland in the period 40-60ka, and similarity with SST records from the Alboran Sea. We believe this reveals a dominant influence of North Atlantic climate at the gateway to the Mediterranean. However, we note that in periods which there is weaker correspondence between speleothem and ice core δ^{18}O, this may indicate changes in the dominant climate controls in the western Mediterranean.

All comparisons of proxy records show a broad similarity with the cave record over the longest timescales, i.e. δ^{13}C and δ^{18}O both display higher values in the colder, drier climates of the mid-glacial, and generally lower values in the long interstadials of the early glacial period. Superimposed on this trend are millennial-scale variations with amplitudes of the same order of magnitude seen over stadial-interstadial timescales. At times these fluctuations correspond closely to the variations seen in SST, pollen, and vegetation records while some excursions appear out of phase. We use multiproxy marine core records to explore these phase differences, as the speleothem record may partially reflect other factors independent of those recorded through SST and pollen proxies. Over centuries high frequency variations similar to those observed on multi-annual timescales in cave monitoring and modern speleothem occur, showing both the small and large scale applications of our monitoring data.