Continental hydrothermal systems preserve a time-integrated record of the oxygen isotope composition of ancient precipitation

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A number of paleoclimate, paleoelevation, and paleohydrologic studies depend on accurate estimation of the oxygen isotope composition of ancient precipitation. This value integrates elevation changes at the site of preservation, shifts in water sources for local precipitation, as well as temperature. Disentangling these effects has important bearing on reconstruction of past terrestrial climates. Traditionally, carbonate rocks or fossil leaf waxes have been used as a record of precipitation. We present an alternative record of oxygen isotopes in precipitation: hydrothermally altered crust. The geochemical and geophysical systematics of hydrothermal alteration are well known, and we have developed an inverse model that uses a quantitative understanding of continetnial hydrothermal systems to estimate the oxygen isotope composition of the ancient precipitation that fed the system. Our results record the integrated signal over the lifetime of the hydrothermal system, thus representing precipitation over 10,000 – 100,000 year timescales. Such timescales reflect climatic signals, rather than seasonal or yearly variation, which is an advantage in reconstructing uplift and water source evolution.

As proof of concept, we have applied the model to the caldera system in the San Juan Mountains in Colorado, United States. Over a dozen calderas, many of which drove hydrothermal activity were active between about 23-10 Ma. Our results indicate a long-term shift in the oxygen isotope composition of the precipitation in this area from about -10‰ to -16‰ over this time period. Assuming a purely topographic signal, and an isotope shift with elevation of 3.0‰/km, this isotopic difference is consistent with 2 km uplift over ≈13 million years. When integrated spatially, this technique can help produce isotope contour maps present an picture of precipitation isotopes over the Western US through time, helping to distinguish between climatic shifts, topographic uplift, and atmospheric circulation. Further, the inverse technique should be widely applicable to mountain ranges worldwide that preserve records of hydrothermal activity, including the Andes and Cascades, to help reconstruct paleoelevation and climate over broad spatial and temporal scales.