

Hot spring evolution recorded in Pleistocene hydrothermal travertines, Salta, Puna of Argentina

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INTRODUCTION

Modern hydrothermal activity at the Puna of Argentina is largely limited to few springs with low water volume discharges. Although their thermal activity is low, some of them show large volumes of fossil travertine deposits associated to the hot spring (*Vilela, 1969, Ferreti and Alonso, 1993*) indicating high paleo water discharges able to supply enough thermal water to precipitate these significant amounts of carbonate. In this work, we present an isotopic study of one of these travertine bodies in order to understand the factors that control the capacity, of the thermal areas, to generate travertine deposits and their relationship with high humidity climate phases.

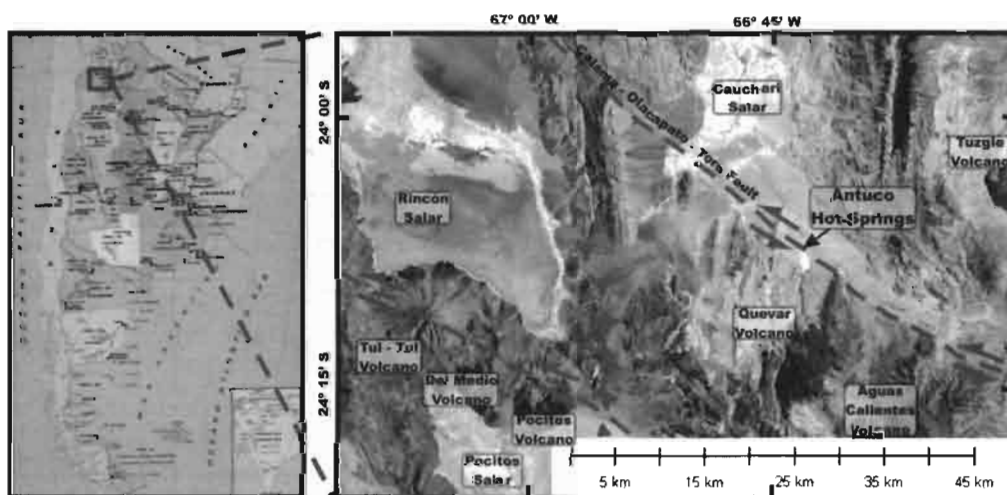


Figure 1. Landsat photograph showing location of Antuco Hot-springs and major volcanic centers and fault systems that controls occurrence of geothermal springs studied.

The studied travertine deposit is associated with a thermal complex: Antuco Hot-Springs, located at 4.200 meters of altitude on the NW-SE Calama-Olacapato-Toro fault (Andean range, Altiplano, NW Argentina) (Fig.1). The main Antuco travertine body is 12m thick and occupies about 400m². The travertine body is composed by different carbonate beds. At the base, the travertine body is characterized by large aragonite prismatic crystals (mm to dm long) precipitated in a pond/lake environment. These travertine beds are crossed by a stockwork of fossil thermal conducts rimed by pink calcite travertine. The uppermost travertine beds are made

of grey micritic calcite travertine with calcified filaments, interpreted of bacterial origin. Laterally to the travertine body, present day hot spring waters are flowing along the valley and form a thin new travertine crust.

METHODS

The present work resulted from the investigation of 55 samples collected from the Antuco travertine outcrops. Different carbonate morphologies, mineralogies and paragenetic evolution are recorded in the thermal travertine carbonates showing the evolution of the Antuco hot springs during the last 500.000yrs.

Travertine mineralogy was determined by X-ray diffraction on selected microsamples. Both the thermal waters and the carbonate crystal digests were analyzed for semiquantitative multielemental measures on an Elan-6000 Perkin-Elmer ICP-ES. Calcite and aragonite microsamples were reacted at 70°C in a Kiel device and CO₂ was analyzed for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ using a Finnigan MAT-252 mass spectrometer. Precision of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ for duplicate samples and standards was better than $\pm 0.1\%$ (2σ). Microthermometry of fluid inclusions trapped in travertine crystals were measured with a THM600 Linkam TMS 91 hot stage.

Dating using uranium-series disequilibrium method was performed with a Finnigan MAT Element I, high-resolution ICP-MS following a technique developed at Minnesota Isotope Lab (MIL) (*Edwards et al, 1987 and Shen et al 2002*).

RESULTS

Lower travertine

Primary fluid inclusions trapped in Antuco aragonite crystals shows homogenization temperatures about 87°C. This temperature is similar to the water boiling temperature at 4.200m altitude and is commonly recorded at other active hot springs from the region (El Tatio, Polloquere). This suggests that aragonite crystals formed within a free water mass at atmospheric pressure. Pond related travertine carbonates have $\delta^{13}\text{C}$ values of -5‰ to -2.1‰ and $\delta^{18}\text{O}$ values of -22.4‰ to -14.2‰ recording a trend to higher $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values (Fig.2). This trend is caused by a decrease in the temperature of carbonate precipitation with local evaporation effects of thermal waters.

Primary fluid inclusions trapped in calcite crystals rimming thermal conduits record homogenization temperatures around 115°C suggesting that their formation was under a hydrostatic pressure equivalent to about 15 meters of water column. Calcite crystals from thermal conduits have lower $\delta^{13}\text{C}$ values than pond precipitates (Fig.2). Nevertheless, both display similar $\delta^{18}\text{O}$ in spite of the fact that the thermal conduits precipitated at higher temperature. This suggests that thermal waters with higher $\delta^{18}\text{O}$ were involved in the formation of the calcite filling thermal conduits.

These lower travertine precipitates yield $\delta^{13}\text{C}$ values ranging from -6 to -2‰ PDB (Fig.2). The lowermost $\delta^{13}\text{C}$ values may suggest a magmatic CO₂ source.

Upper travertine

The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of the upper micritic travertine are significantly different to the mean values for Antuco lower travertine body: $\delta^{13}\text{C}$ is $\sim 5\text{‰}$ higher and $\delta^{18}\text{O}$ is $\sim 10\text{‰}$ higher (Fig.2) and may suggest an increase of the water-rock interaction and a change of the main carbon source.

Recent hot spring precipitates

Present day thermal waters flowing from Antuco hot springs precipitate a thin calcite iron-rich crust along thermal streams. $\delta^{18}\text{O}$ values of recent calcite crusts are lower (about 7‰) than the upper travertine but they record similar carbon isotopic composition (Fig. 2).

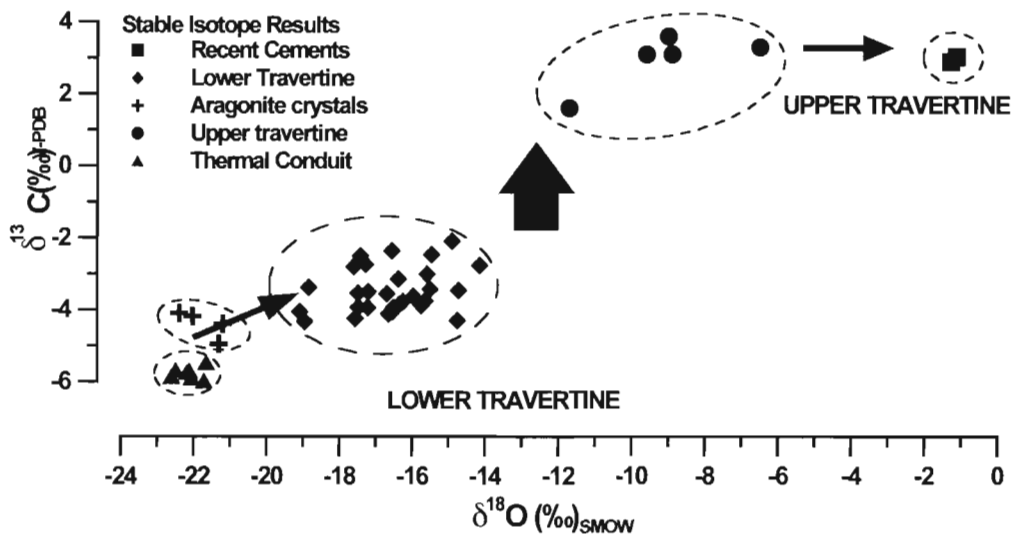


Figure 2. Carbonate $\delta^{13}\text{C}$ vs $\delta^{18}\text{O}$ values in the whole thermal system showing their evolution through Holocene.

DISCUSSION AND CONCLUSIONS

Antuco travertines were formed by precipitation from waters of meteoric origin. The trend to higher $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of the carbonates (calcite and aragonite) through time suggests a change of the thermal waters and their water/rock ratio from Late Pleistocene to Holocene.

Homogenization temperatures of carbonate precipitates from the lower travertine enable the calculation of the $\delta^{18}\text{O}$ of parental waters. These are similar to the $\delta^{18}\text{O}$ values of present-day meteoric water in the region indicating high water/rock ratio. Calcite rimming the thermal conduits crossing the lower travertine body record precipitation from evolved thermal waters with higher water-rock interaction than aragonite and calcite previously precipitated.

The higher $\delta^{18}\text{O}$ of Upper travertine carbonates and present day thermal waters can be explained by an increase of the water-rock interaction and a progressive decrease of the water/rock ratio.

Antuco hot spring travertine system was thus controlled by the water availability in the thermal system. Significant travertine deposits formed at stages of increased thermal water flow related to significant meteoric water supplies during moist periods. During drier periods, the water availability in the system decreased, and

waters display higher water-rock isotopic signatures and low capacity to form significant travertine deposits. This is the case of the Upper travertine and present day thermal waters.

The depleted $\delta^{13}\text{C}$ values of lower travertine precipitates are consistent with a magmatic CO_2 source, suggesting that the volcanic fluids were an important carbonate source in the travertine formation. The identification of magmatic carbon involved in the formation of the Antuco lower travertine is suggesting igneous activity during the Late Pleistocene (500Kyr to 260Kyr) in the zone. This magmatic activity may correspond to the late volcanic pulse identified by *Allmendinger et al. 1997* and *Petrinovic et al., 1999*, in this region of the Central Andes.

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