

The evolution of silica precipitation at the El Tatio Geysers Field, Chile

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Introduction

Extensive silica sinter deposits are common surface expressions of concealed geothermal systems, and form due to precipitation from thermal fluids as they discharge, cool and evaporate to dryness. El Tatio is the third largest geysers field in the world after Yellowstone in the US and the Valley of Geysers in Kamchatka, Russia. However, many of its surface geothermal manifestations, sinter deposits, and depositional environments remain relatively understudied. El Tatio is located in the Chilean Altiplano at an altitude of 4200 meters above the sea level (Fig.1). Its extreme conditions of high UV radiation and diurnal temperature variation results in a unique environment analog to early Earth and Mars (Ruff and Farmer, 2016).

El Tatio geysers field includes boiling springs, silica cones, active geysers, and paleo sinter deposits over ~30 km².

Sinter deposits at El Tatio are texturally complex and are predominantly composed of non-crystalline opal-A and accessory minerals, such as halite, gypsum, and accessory phases including teruggite and canthite, among others (Rodgers et al., 2002; Nicolau et al., 2014). Distinctive sinter textures reflect the environmental conditions of its formation, such as flow rate, pH, microbial communities, water temperature and geochemistry (Jones et al., 1997).

Actual sinter accumulation rate at El Tatio has been estimated based on *in situ* silica precipitation experiments, resulting in 2.5 kg/m² per year (Nicolau et al., 2014). However, these estimations are hampered by the lack of absolute ages of stratigraphic sections, which remain largely unknown. Preliminary ¹⁴C dating by our research group indicates that El Tatio sinters may be as old as 20 ky BP, pointing to a long-lived silica precipitating geothermal system.

Our aim is to unravel the evolution of silica precipitation at El Tatio, by means of combining detailed mapping, textural observations and absolute age determinations (C-14) of silica sinter deposits. These data will provide new insights about the variation of silica deposition through time and the evolution of the geothermal system at depth.

Methodology

Detailed mapping of surface geothermal features at El Tatio were combined with textural and mineralogical characterization of silica sinter deposits. In particular, we have focused on the stratigraphical and textural description of a representative paleo sinter cone of 1.50 m in height in the northeastern portion of the

geysers field. This feature offers a unique opportunity to constrain the age of silica precipitation at El Tatio and provides an absolute estimation of silica precipitation rate.

Coupled with radiocarbon dating methods in different layers of the cone, studying this feature provides reliable information to unravel the chronology of silica precipitation.

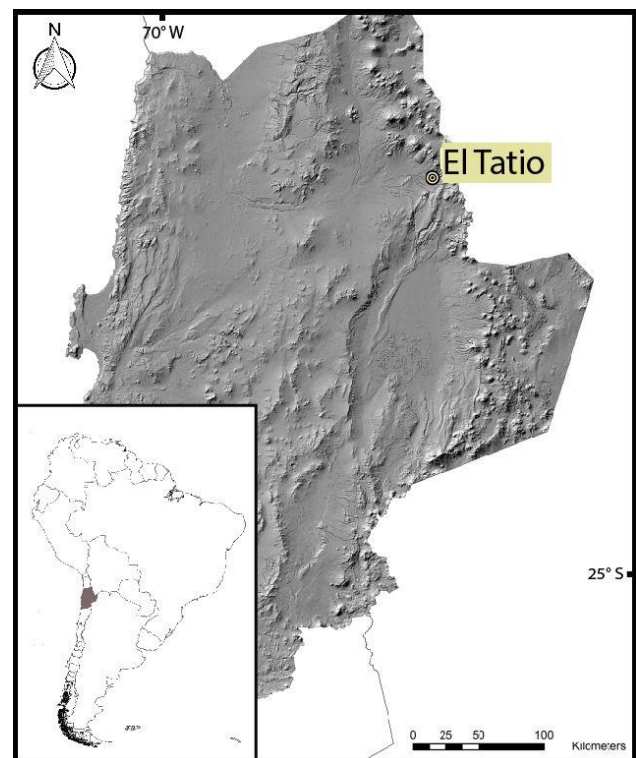


Figure 1: Location of El Tatio Geysers field. Corner inset represents the second region of Chile (Region de Antofagasta) in South America, where the study site is.

Silica samples from each layer of the sinter cone were observed using a FEI Quanta 200 MK2 scanning electron microscope (SEM) at CEGA, Universidad de Chile. Secondary electron (SE) images were obtained to image fresh silica sinter sample surfaces. Additionally, representative sinter samples containing organic matter were cut, cleaned, and crushed in a ring mill to ~1 mm size. Crushed sinter was treated with 10% HCl for 24 h and rinsed with Nanopure water. Samples were then digested in 48% HF, and

allowed to sit for several days, adding fresh HF as required. After that, the samples were heated in 70° water bath for two days. The remaining carbonaceous (non-soluble) material was rinsed in Nanopure water and centrifuged until all material sank to the bottom of the separation tube. The residue was eliminated, keeping the carbonaceous precipitate in the tube, and then washed five times in Nanopure water. Microscopic examination of the residue showed plant fragments, a few palynomorphs, and diatoms mixed into the mineral layer. The samples were sent to the UC-Irvine Accelerator Mass Spectrometer for ¹⁴C dating.

Textural observations

Observations of the studied sinter cone revealed a great variation in sedimentary textures. Among other textures, we identified a layer of spicular textures (Fig 2a) that are described as proximal facies, typical of high-temperature surgence (>60°C) (Walter, 1976). Observation under the optical microscope reveals the presence of bacteria filaments in the samples (Fig 2c). In addition, we recognized palisade texture, which constitutes low temperature (<60°C), laminated texture with very narrow (<1 mm wide), vertical micro-pillar structures (Campbell et al., 2011). SEM observations reveal that the main phase of silica that forms the sinters in El Tatio is opal-A. This indicates that sinters are in an early stage of diagenetic maturation (Lynne and Campbell, 2003). Silica is present as silica spheres (<10 μm in diameter), and in some cases arranged as aggregates and botryoidal crusts (Fig 2d). This is in agreement with previous mineralogical studies at El Tatio, where only minor occurrence of more mature silica phases such as opal-A/CT and opal-CT has been reported (García-Valles et al., 2008; Nicolau et al., 2014).

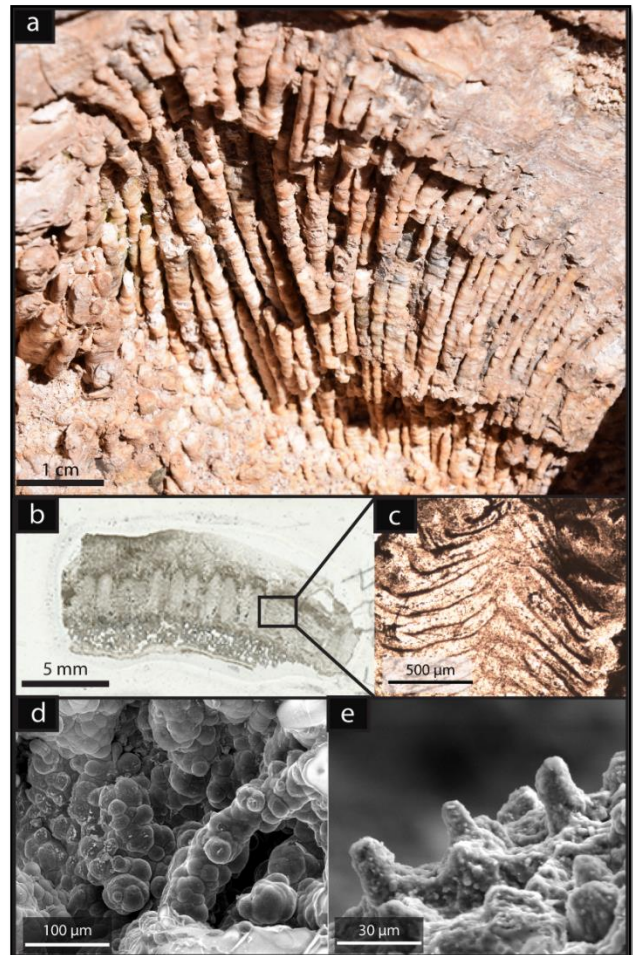


Figure 2: Spicular texture. (c: optical microscope thin section; plane polarized light; d–e: scanning electron microscope (SEM) images) a. Macroscopic view of spicular texture. b. Thin section of a scanned, showing spicules perpendicular to the lamination. c. optical thin section (zoom of the rectangle in b) showing periodic layers with light (silica) and dark (bacteria filaments) alternations. d. Botryoidal opal-A spheres. e. Detail of a spicule surface.

Conclusions

During the formation of the studied sinter cone, physical and environmental conditions varied resulting in different sinter textures. These variations represent different conditions governing silica deposition such as temperature, flow rate, and presumably, microbial activity. Opal-A has been identified as the main phase of silica forming the sinter, which indicates an early stage of diagenetic maturation of silica, despite its probably old age. Ongoing ¹⁴C dating of the sinter layers will allow constraining the age of formation of the sinter cone, and will also provide a better constrain of silica precipitation rates at El Tatio.



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