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Paleoclimatic significance of lacustrine microbialites: A stable isotope case study of two lakes at Torres del Paine, southern Chile

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ABSTRACT

Two Patagonian lakes studied here, Lago Sarmiento and Laguna Amarga, are located within the orographic rain shadow formed to the east of the Southern Patagonian Ice Field in the Andes Range. Major thrombolite colonies are present in Lago Sarmiento, whereas widespread stromatolites occur in Laguna Amarga. Based on the characterization of the hydrologic system of these two lakes, together with an estimation of the isotopic balance and an analysis of the equilibrium conditions between the water and biologically induced carbonates, it is concluded that the microbialites of Lago Sarmiento are better suited as paleotemperature indicators than those of Laguna Amarga. Lago Sarmiento thrombolites contain unique carbonate mineral species in which carbonate precipitation occurs close to isotopic equilibrium and where the variation in water temperature controls fractionation of the stable oxygen isotope.

The results indicate that at 1215 cal yr Bp the level of the lake was at 85 m a.s.l with a temperature close to 9.3 °C, was at 82 m a.s.l. at 600 cal yr Bp with a temperature close to 8.5 °C. This coincides with the timing of the Northern Hemisphere Medieval Warming Period. At 183 cal yr Bp the level of the lake was at 80 m a.s.l with a cooler temperature close to 7.7 °C, representing a colder period coinciding with the timing of the Little Ice Age (LIA). An interesting outcome of this study is that it reinforces the idea that the $\delta^{13}C$ signal in carbonate deposits can be an effective tool in distinguishing between inorganic and biologically induced precipitation.

1. Introduction

The stable isotope record of oxygen in microbial carbonates has generated considerable debate as potential inventories of paleoclimatic and paleoenvironmental information. To evaluate the isotopic equilibrium and establish how local hydrological and mineralogical conditions can influence the use of microbialite carbonates as paleoclimatic tools, we studied the hydrological system and microbial communities of Lago Sarmiento and Laguna Amarga in the Patagonian region of southern Chile.

Microbialites are organo-sedimentary deposits that accrete as a result of benthic microbial communities trapping and binding detrital sediment and forming nuclei for mineral precipitation (Burne and Moore, 1987). Dupraz et al. (2009) proposed that in carbonate microbialites, the key components of organo-mineralization (Perry et al., 2007) are microbial metabolism, the environmental conditions that impact calcium carbonate saturation, and an organic matrix comprised of extracellular polymeric substances (EPS).

EPS are produced by the cyanobacteria that compose the microbialites, which facilitate the trapping of detrital minerals and also provide a chemically protective microenvironment in which biologically induced mineral precipitation can take place around the cells (Decho et al., 2005). The latter process results from photosynthesis that liberates O_2 and traps the CO_2, with a consequent rise in pH that induces the precipitation of carbonates (Burne and Moore, 1987). Although caused by the microbes, however, the precipitation of carbonate minerals can be considered as inorganic (Burne and Moore, 1987; Vasconcelos et al., 2005).

The stable isotopic record of $\delta^{18}O$ in microbial carbonates has received significant attention as potential inventories of paleoclimatic and environmental information (Casanova and Hillaire-Marcelo, 1992; Andrews et al., 1993, 1997; Teranes et al., 1999; Vasconcelos et al., 2005) and has also been the subject of considerable debate (see the review of Chafetz and Lawrence, 1994). The paleothermometric interpretation of isotopic variation in microbialite lakes is based on the assumption that the oxygen isotope fractionation between the water and precipitated carbonate is produced in equilibrium. However, equilibrium does not always exist (Kim and O'Neil, 1997; Teranes et al., 1999), while temperature variations and the water balance also control the oxygen isotopic fractionation of the lake water.

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In order to evaluate the isotopic equilibrium and establish how local hydrological and mineralogical conditions can influence the use of microbialite carbonates as paleoclimatic tools, we studied the hydrologic system and microbial communities of Lago Sarmiento and Laguna Amarga.

Lago Sarmiento and Laguna Amarga were selected because they have certain important common characteristics, which facilitate their comparison with respect to stable isotopes. These include the fact that both contain carbonate microbialite communities, that they experience the same regional climatic conditions, and that both lie within an isolated surface drainage basin where the underlying rocks are formed by the Cerro Toro Formation.

2. General background

Lago Sarmiento and Laguna Amarga are enclosed by five moraine systems (Fig. 2) labelled by Marden (1993) as A, B, C, D, and E. Of which A, B and C were correlated with the last global glacial cycle (Marden and Clapperton, 1995) and recently investigation proposed that these glacial lobes are younger than 21,493 cal yr BP (Solari et al., accepted for publication). Cosmogenic ^{10}Be dating of erratics from the D moraine indicates a short-lived re-advance of Patagonian ice culminating at 12–15 kyr BP, coincident with the time of the Antarctic Cold Reversal (Fogwill and Kubik, 2005; Moreno et al., 2009). The lakes are developed over an area with sandstones, siltstones and conglomerates of the Cerro Toro Formation, a deep-marine succession thrust and folded into an approximately NNW-trending system (Fig. 2).

The two studied lakes form part of a hydrologic system, the Torres del Paine Drainage Basin (TPDB), developed to the east of the Southern Patagonian Ice Field (Fig. 1). The TPDB contains 5 closed lakes in addition to Lago Sarmiento and Laguna Amarga, all of which have carbonate microbialite communities (Microbialite Lakes in Fig. 2). All these microbialite lakes are located in an isolated area disconnected from outside rivers and sources of glacial meltwater (demarcated by stippled line in Fig. 1), so that their main source of water is rainfall resulting from the predominantly westerly winds. The precipitation has a spatial distribution reaching 10,000 mm per year over the ice field itself, but decreasing to 7000 mm along its western flank (D.G.A., 1987) and less than 400 mm on its eastern side (Ibarzabal et al., 1996; Carrasco et al., 1998, 2002).

Lago Sarmiento and Laguna Amarga are located in a semi-arid steppe region. The wind speed is characterized by an annual average of 27 km/h (1987–1988) and reaches a maximum of 100 km/h during spring and summer. The average yearly precipitation (1983–1988) and evaporation (1983–1988), obtained from a meteorological station located near the administration office of the Torres del Paine National Park, is 639 mm and 839 mm, respectively. The lowest rainfall is observed at the end of winter (May) and mid-spring (September–October), whereas the highest precipitation is recorded during summer and autumn. The average air temperature (1983–1988) is 7 °C, with a seasonal maximum variation between −1 °C in winter and 13.8 °C in summer (Campos et al., 1994, 1996).

Lago Sarmiento (51°03′00″S; 72º45′01″W) receives an important contribution of water from Laguna Verde, has a maximum depth of

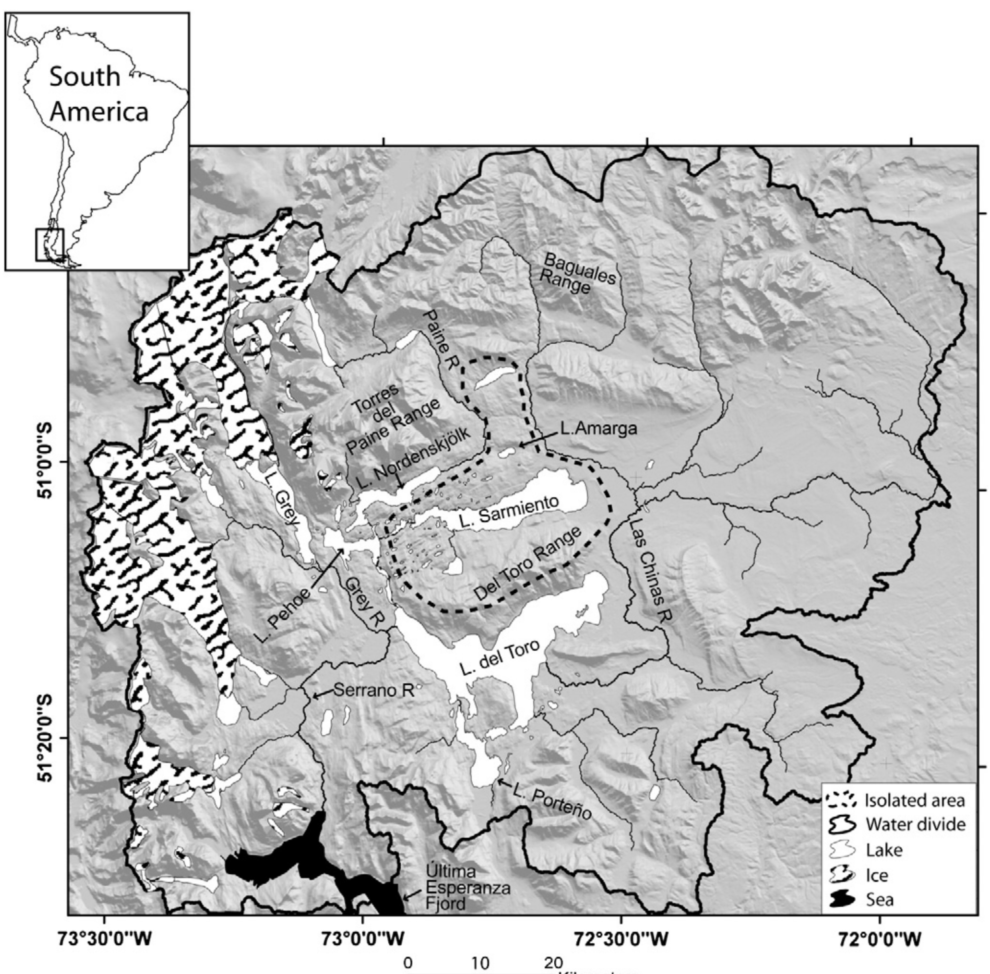

Fig. 1. Shaded Relief of Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) showing the Torres del Paine drainage basin (black line), the river (R) network and main lakes (L).