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An ostracod-based calibration function for electrical conductivity reconstruction in lacustrine environments in Patagonia, Southern South America

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ABSTRACT

In the Patagonian region (∼37–56°S) E of the Andes, the salinity and solute composition of lakes is strongly related to their location along the marked W-E decreasing precipitation gradient that is one of the main climatic features of the area. A calibration function (n = 34) based on 12 ostracod species (Ostracoda, Crustacea) was developed by WA-PLS to quantitatively reconstruct electrical conductivity (EC) values as a salinity proxy. The selected one component model had a r^2 = 0.74 and RMSEP and maximum bias equal to 16% and 31% of the sampled range, respectively, comparable to other published ostracod-based calibration functions. This model was applied to the ostracod record of the closed lake Laguna Cháltel (49°58′S, 71°07′W), comprising seven species and dominated by two species of the genus *Limnocythere*. In order to evaluate the calibration function's robustness, the obtained EC values were compared with qualitative lake level and salinity variations inferred through a multiproxy hydrological reconstruction of the lake. Both reconstructions show good overall agreement, with reconstructed EC values in the oligo-mesohaline range (average: 11 060 ± 680 μS/cm) between 4570 and 3190 cal BP, corresponding to the ephemeral and shallow lake phases, and a marked decrease in EC concurrent with a lake level rise, reaching an average EC of 1140 ± 90 μS/cm during the deep lake phase (1720 cal BP to present). The variability in the reconstructed EC values for the ephemeral lake phase showed some inconsistency with the expected trend, which was attributed to time-averaging effects; for its part, the pace of the decrease in EC during the medium-depth phase (3190–1720 cal BP) differed from the expected, which could be due to autigenic effects (redissolution of salts) at the onset of this phase. This comparison not only lends support to the adequacy of the calibration function, but also suggests that its application in the context of a multiproxy study can greatly contribute to distinguish between autigenic and climatic-related controls of paleosalinity in closed lakes, allowing performing more accurate paleoenvironmental inferences on the basis of paleohydrological reconstructions.

1. Introduction

During the last decades, the need to contextualize major environmental processes such as acidification, eutrophication and climate change within the natural variability of the ecological and climatic systems has promoted the development of numerous approaches and techniques for paleoenvironmental reconstruction. Lake sediments, whose origin, composition and deposition are strongly influenced by climatically-controlled processes, constitute good archives of past climatic and environmental conditions, which can be analysed through the use of sedimentary components and characteristics as proxies (Smol et al., 2012). In particular, abiotic variables can be reconstructed based on the study of fossil biotic components of past ecosystems. Quantitative paleoenvironmental inferences can be achieved through the application of appropriate numerical techniques, such as the widely used multivariate calibration functions (CF), also known as transfer functions (Birks et al., 2010).

While a wealth of quantitative paleoenvironmental reconstructions has been published since the 1980s, the Southern Hemisphere and particularly South America is underrepresented in this effort with respect to its Northern counterpart. In particular, and despite its great interest for paleoclimatic reconstruction as the sole continental landmass entirely within the area of influence of the Southern Westerly Wind (SWW) belt (Kilian and Lamy, 2012), to

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date only five CF have been published for continental southern South America (Patagonia): two pollen-based CF for precipitation estimation (Tonello et al., 2009; Schäbitz et al., 2013); one chironomid-based CF for air temperature estimation (Massaferro and Larocque-Tobler, 2013); one thecamoebian-based CF for water table depth reconstruction in peat bogs (Van Bellen et al., 2014), and an ostracod-based CF for chlorine content estimation (Cusminsky et al., 2011).

Ostracods (Crustacea: Ostracoda) are aquatic organisms widely distributed throughout continental and marine environments. They secrete calcite bivalved carapaces with high preservation potential in sediments and rocks, which, coupled with their sensitivity to specific environmental conditions, render them advantageous proxies. Indeed, ostracods were among the first biological proxies to be used to draw quantitative inferences of environmental parameters (Delorme, 1971). Several continental ostracods species show marked preferences for specific water types, in terms of solute concentration (salinity) and ionic composition (e.g., De Deckker, 2002). Accordingly, most of the ostracod-based calibration functions for continental environments published to date (for a review, see Viehberg and Mesquita-Joanes, 2012) estimate salinity-related variables such as electrical conductivity (EC) or the concentration of a major ion.

To the best of our knowledge, to date only four ostracod-based CF for reconstruction of salinity-related variables have been published for the Southern Hemisphere: two for Australia (Gouramanis et al., 2010; Kemp et al., 2012) and two for South America, specifically the Bolivian Altiplano (Mourguiart and Roux, 1990) and Patagonia (Cusminsky et al., 2011). The latter, as already mentioned, was applied to the ostracod record of Lake Cardiel (49°S, 71°W) to reconstruct chlorine content concentration, but neither the calibration set nor any model parameters or performance indicators were presented, which precludes comparison with the present CF. Other than this reference, no quantitative salinity-related estimation models, based on ostracods or otherwise, have been published so far for continental Patagonia.

Fluctuations in the salinity and lake level of closed lakes in arid and semi-arid regions have been long recognized as sensitive indicators of change in the precipitation to evaporation ratio (P/E) (e.g., Gasse et al., 1997). During dry periods evaporation exceeds water input, causing lake level to fall and ion concentration to increase; this process is affected by hydrological and morphometric features of the lakes and their watersheds, as well as lake water geochemistry (Fritz et al., 1991). In this context, ostracods from these environments can be valuable (paleo)hydrological indicators.

Patagonian lakes have been shown to vary in their major ion concentration and composition in a manner that can be related with their location within the marked West-East precipitation gradient that constitutes one of the most characteristic features of Patagonian climate east of the Andes. While the lakes located in the wetter part of the gradient present bicarbonate-dominated waters of low EC, those receiving a much lower precipitation input have high EC and present sodium-dominated waters enriched in all major anions, indicative of evaporative conditions (Baigún and Marinone, 1995; Díaz et al., 2007; Ramón Mercau et al., 2012). These distinct water types, in turn, are inhabited by different ostracod species; their marked hydrochemical preferences make it possible to use these taxa as semi-quantitative paleohydrological indicators (i.e., for the qualitative estimation of host water salinity range and major ion composition) (Ramón Mercau et al., 2012). This approach was successfully applied to the ostracod record of the volcanic crater lake Laguna Cháltel (49°58′S, 71°07′W, southern Patagonia) in the context of a multi-proxy study to reconstruct the hydrological changes that took place in it during the last 4600 years (Ohlendorf et al., 2014).

In the present contribution, we built on the hydrochemical preferences previously inferred for Patagonian ostracods (Ramón Mercau et al., 2012), incorporating new data on ostracod assemblage composition and EC of samples from Southern and Central Patagonian lakes in order to generate a calibration function for quantitative reconstruction of EC as a proxy for salinity. The calibration function obtained was applied to the Laguna Cháltel ostracod record to reconstruct past EC values of the lake. The results obtained were compared with the reconstructed lake level variations and salinity shifts inferred from several independent proxies by Ohlendorf et al. (2014), in order to assess the reliability of the ostracod-based reconstruction.

2. Study area

2.1. Regional setting and climate

The Patagonian region is located in the southernmost part of South America, between 37°S and 56°S approximately (Fig. 1a). It can be divided into two distinct subregions: the Andean Patagonia to the west, comprising the Andean Cordillera, and the Patagonian Steppe to the east, characterized by extensive tablelands (Coronato et al., 2008). The mountain range acts as a barrier to the flux of the SWW, or westerlies, which carry moist air from the Pacific Ocean; this causes abundant orographic precipitation over the windward (west) side of the Cordillera and a major rainshadow effect on its leeward (east) side. As a result, in the Argentinean Patagonia there is a dramatic West-East mean annual precipitation gradient that decreases from ca. 1400 mm in the Andean range to less than 200 mm in the steppe (Paruelo et al., 1998; Garreaud et al., 2013). During Austral summer, the westerlies are centred between 45°S–55°S and present higher intensity, while in Austral winter the wind belt migrates northward and weakens at lower levels. The seasonality of precipitations in the Eastern side of Patagonia, with a clearly defined rainy season during Austral winter, is highly correlated to this seasonal shift of the westerlies (Garreaud et al., 2013). With regards to temperature, Patagonia can be considered a temperate to cool-temperate region, with mean annual temperature ranging from 12 °C in the northeast to 3 °C in the southwest. Mean thermal amplitude exhibits a similar NE-SW decrease, varying between 16 °C and 5 °C (Paruelo et al., 1998).

2.2. Laguna Cháltel

The analysed sedimentary sequence was obtained from the crater lake Laguna Cháltel, located on a volcanic plateau at 788 m.a.s.l. in the province of Santa Cruz, Argentina (Fig. 1b). Its remote steppe location suggests low mean annual precipitations, although as Ohlendorf et al. (2014) note, its high elevation could account for locally moister conditions, as implied by local oral reports of abundant snow during winter in the plateau. The 41 m-deep lake is almost circular in shape, with the western side of the basin presenting a more pronounced slope than the eastern side (Fig. 1c). It presents three small inflows of unknown temporal stability, and no outlets. Water chemistry on the Austral summer of 2004 (2004-03-09) was characterized by dominance of carbonate and sodium; EC presented little variability throughout the water column, with a mean value of 788 μS/cm (Ohlendorf et al., 2014). On the Austral autumn of 2013 (2013-04-05), the lake presented a similar hydrochemistry, with an EC of 815 μS/cm and Na-Mg-HCO_3 ionic composition (Christoph Mayr, pers. comm.).