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Factors controlling alpine glaciations in the Sierra Baguales Mountain Range (50º - 51º S) as inferred from morphometric analysis of glacial cirques

José Araos* **, Jacobus Le Roux* * and Mike Kaplan******

* *Departamento de Geología. Universidad de Chile. Plaza Ercilla 803, Santiago, Chile.*
*** Departamento de Geografía. Universidad Alberto Hurtado. Cienfuegos 41, Santiago, Chile.*
**** Andean Geothermal Centre of Excellence, Plaza Ercilla 803, Santiago, Chile.*
***** LDEO of Columbia University, Palisades, NY 10964.*

**Mail:josearaos@ug.uchile.cl*

Abstract. We mapped the spatial and elevation distribution of 143 cirques in southern Patagonia, between 50 º and 51º S, and analyzed their morphometry using simple and multivariate statistical methods. The cirque basins are located east of the Southern Patagonian Ice Field and around the Sierra Baguales Mountain Range, about 200 km from the Pacific coast. The geomorphologic evidence indicates that alpine glaciations have been the predominant style in the study area.

The distribution and activity on glacial cirques are influenced by both tectonic factors (Andean uplift) and climate (Westerly Winds). Morphometric characteristics indicates a persistent climate contrasts between the western (maritime, temperate) and eastern (dry and cold) sides of southern Patagonia since the Last Glacial Maximum (LGM).

Based on our analyses, we infer that glaciers located at the higher elevations were not affected by post LGM high-frequency climatic variations that would have led to only small glaciers of limited influence on cirque form evolution; on the other hand most glacial cirques analyzed shows an isometric developing trend, which could indicate that the deglaciation process in Sierra Baguales occurred quickly and continuously, and equilibrium line altitudes (ELAs) experienced a relatively rapid rise of about 400 m after the last major occupation.

Keywords: Southern Patagonian Ice Sheet, alpine glaciations, ELA, Last Glacial Maximum.

1 Introduction

Patagonian past glacier variations have shaped the landscape, generating geomorphological, sedimentological and stratigraphic evidence, that according to Rabassa et al. (2011), represent the action of continental and alpine glaciations of varying ages and extensions. Glacial chronologies developed for the last glacial cycle in outlet glaciers located at the Torres del Paine massif and surroundings of the Patagonian Ice Cap, indicate that the ice retreat after the last glacial term T1 (~ 18-10 ka, 103 cal. Years) did not happen quickly, and in addition was interrupted by a glacial readvance or stabilization at about 11.8 Ka.

The Sierra Baguales Mountain Range in the eastern foothills of the Andes (Figure 1), located 50 km northeast of the Torres del Paine massif presents active alpine glaciers and geomorphological evidence that indicates the existence of an former system of glacial cirques located in the Westerly Winds area and topographically isolated from the SPI. The accumulation zone of these glacial cirques is located above1000 m a.s.l and more than 200 km from the Pacific coast. Therefore, it represents a suitable site for the description and estimation of the factors that controlled the variations of isolated alpine glaciers located toward the interior of the continent and that possibly responded independently to climatic changes that operated since the LGM. The research will help to clarify the current knowledge gap identified by various authors (Rabassa et al., 2011), related to the duration and structure of the LGM in an area neighboring Torres del Paine (Marden, 1997; Garcia et al., 2012; Sagredo et al., 2011).

2 Method, Samples, Results

2.1 Cirques morphological types

Cirques mapping was carried out using topographic maps at a scale of 1:50,000, aerial photographs at a scale of 1:70,000, Landsat imagery and digital elevation models. Three field campaigns were carried out during 2013 and 2014 to map cirques and observe, describe and interpret the general geomorphology of the Sierra Baguales Mountain Range.

Each cirque was digitized as a closed polygon with a unique ID number, upon which a table containing morphometric information associated with each digitized polygon was generated. Calculations of planimetric and hypsometric indices (Křížek et al., 2012) were conducted using the open source software QuantumGIS 2.2 and GRASS 6.0.

Following Delmas et al. (2013), morphometric variables were defined in such a way as to make them directly comparable with previous work on glacial cirques located in middle and high latitudes. The variables considered are: Surface (S), perimeter (P), length (L), width (W), cirque depth (H), maximum elevation (Emax), mean elevation (Emed), minimum elevation (Emin), aspect (A), ratio of length to elevation range (L/H), ratio of width to elevation range (W/H), ratio of length to width (L/W), slope (M), and circularity (C).

Two morphological types of cirques are distinguished, they differ mainly in their area and shape parameters. Group 1, is located in higher areas of the SPI margin and mainly in the Sierra Baguales Mountain Range, while Group 2, are homogeneously distributed in the study area. Cirques concentrated toward the interior of the continent, 200 km from Pacific coast, particularly in the higher and eastern sections of the Sierra Baguales, whose cirque floor is placed at an average elevation of 1,273 m, usually show current glacial activity, and may be associated with the Group 1. On the other hand, cirques located near the SPI, and in the transition zone, whose floors are at an average elevation of 1,169 m, usually contain either perennial snow or a lack of snow/ice activity, possibly due to their lower elevation, and can be related to Group 2. Thus location and mean elevation, and particularly the cirque floor height of cirques can be considered as controlling factors in the occurrence of glacial activity.

2.2 Composite map

A composite map methodology (Le Roux and Rust, 1989) was used to assist in the cirque characterization. This methodology was originally designed for paleogeographic reconstructions and uranium exploration and is based on the combination of different maps (characteristics of cirques in this case) in to a single composite map. The input data are standardized, so that all data types have the same range of values. The main advantage of this method is that the assignment of numerical results is completely objective (Sepulveda et al., 2013).

The higher composite values, spatially concentrated in the highest sections of the eastern SPI and particularly along the high elevations of the eastern side of Sierra Baguales, are related to cirques that show current glacier or perennial snow activity, where the predominant aspects range from east to south and the evidence indicates that alpine glaciation is the predominant glaciation style. On the other hand, lower values, located at lower elevations, in an intermediate zone between the eastern margin of the SPI and specific sectors of the Sierra Baguales, are associated with cirques occupied by alpine and valley glaciers with aspects ranging from NW to NE; these show no evidence of present day glacier or perennial snow activity and they have been subject to glaciofluvial erosion. Moreover, these cirques with low values were probably influenced or covered (in part) by valley glaciers during the LGM (and prior glaciations) and, because of their low elevation, became quickly deglaciated.

2.3 Past ELA estimation

The local ELA elevation trend for former alpine glaciers of the Sierra Baguales was estimated considering the cirque distribution. Since cirques develop cumulatively over many glacial cycles (Benn and Lehmkuhl, 2000), the elevations of cirque floors were used as a proxy to estimate the elevation of former glacier snowlines for Pleistocene glaciers reflecting average climatic conditions over longer timescales (Nesje, 2007). The criteria set by Porter (1989) and Mitchell and Montgomery (2006), who suggested that cirque floors occupy a level midway between the regional LGM and modern ELA were also considered.

The LGM ELA for outlet glaciers of the SPI was depressed around 750 to 890 m (Carlson et al., 2010) in relation to the actual ELA, which is located around 970 m, considering an ELA average elevation (based on Casassa et al., 2014, and references therein) for 7 outlet glaciers located between 50º22’ and 51º16`S and an aspect ratio that varies from N to SE. On the other hand, based on the analysis of cirques and cirque floor distributions besides geomorphological evidence of cirques near outlet glaciers of the SPI, a rise in the ELA of around 400 m was estimated.

3 Discussion and Comments

The geomorphology and glacial cirque features of Sierra Baguales Mountain Range indicate that this region has been evolving relatively independent from the SPI, with dominant alpine style glaciation(s?). We infer that the overall morphology of the Sierra Baguales has been relatively more sensitive to the effects of the Westerlies Winds and other factors influencing geomorphic development, than the general region of the SPI to west. This sector may have also experienced much greater glacial erosion than what has been suggested for the area covered by the former South Patagonian Ice Sheet.

Geomorphological evidence and morphometric reconstructions allow us to estimate an ELA rise of about 400 meters since the last major occupation. Considering the smaller ELA change, it can be assumed that the deglaciation process of alpine glaciers in Sierra Baguales was probably quicker and more continuous (i.e., no evidence of regrowth), compared to the outlet glaciers of the SPI.

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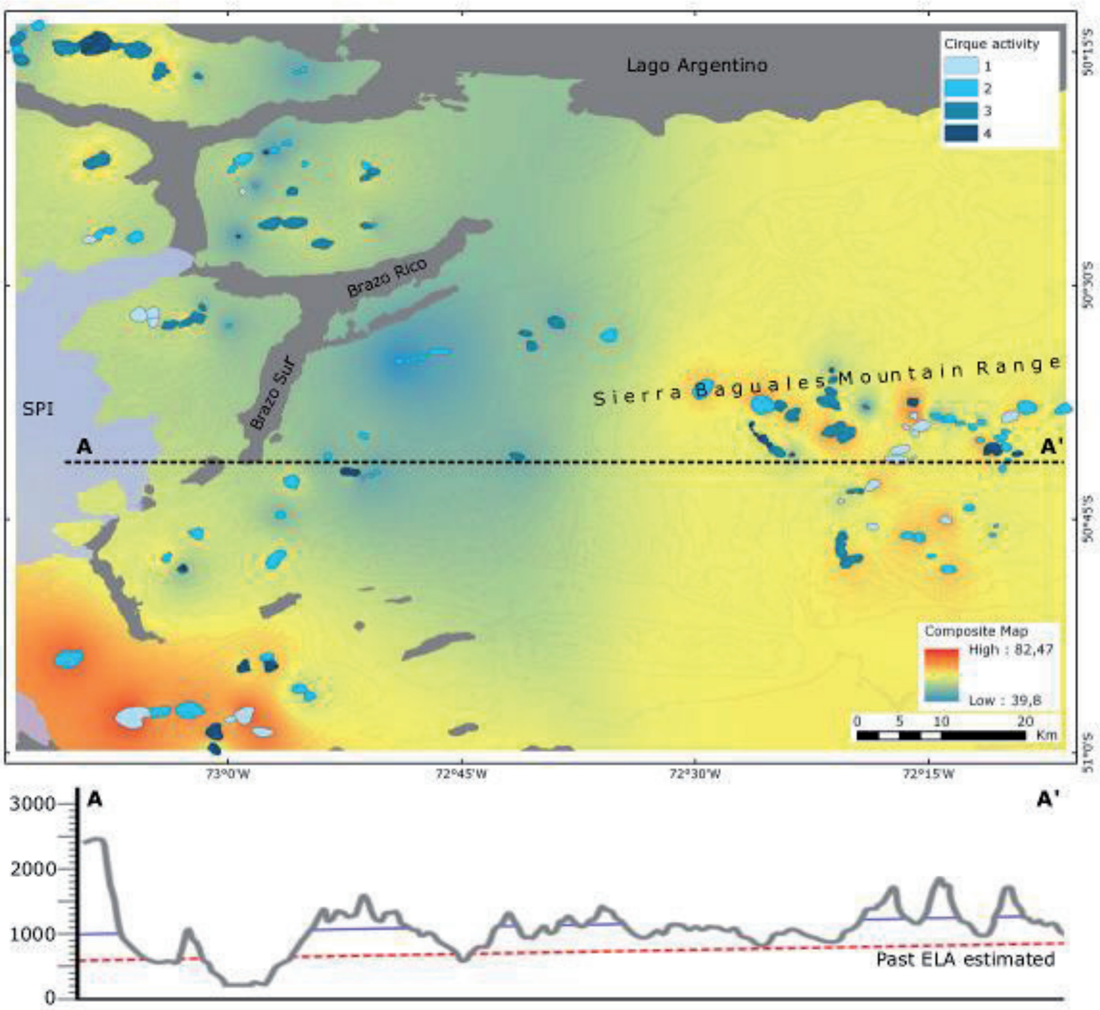

Figure 1. Composite map of study area. Cirques were categorized using 10 parameters extracted from the morphometric analysis. Cirque activity corresponds to 1. current glacier activity, 2. perennial snow activity, 3. no glacier or snow activity, 4. not categorized. The Current ELA position (blue line) is based on Aniya et al. (1996), Carrasco et al. (2008) and Casassa et al., (2014) and a paleo-ELA estimation (dotted red line), both represented in a topographic profile, is based on geomorphological and morphometric analysis as well as criteria set by Porter (1989) and Mitchell and Montgomery (2006).