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Late Pleistocene glacial fluctuations in Cordillera Oriental, subtropical Andes

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ABSTRACT

The behavior of subtropical glaciers during Middle to Late Pleistocene global glacial maxima and abrupt climate change events, specifically in Earth's most arid low-latitude regions, remains an outstanding problem in paleoclimatology. The present-day climate of Cordillera Oriental, in arid northwestern Argentina, is influenced by shifts in subtropical climate systems, including the South American Summer Monsoon. To understand better past glacier-subtropical climates during the global Last Glacial Maximum (LGM, 26.5–19 ka) and other time periods, we combined geomorphic features with forty-two precise ^{10}Be ages on moraine boulders and reconstructed paleo-equilibrium line altitudes (ELA) at Nevado de Chañi (24°S) in the arid subtropical Andes. We found a major glacial expansion at ~23 ± 1.6 ka, that is, during the global LGM. Additional glacial expansions are observed before the global LGM (at ~52–39 ka), and after, at 15 ± 0.5 and 12 ± 0.6 ka. The ~15 ka glacial event was found on both sides of Chañi and the ~12 ka event is only recorded on the east side. Reconstructed ELAs of the former glaciers exhibit a rise from east to west that resembles the present subtropical climate trajectory from the Atlantic side of the continent; hence, we infer that this climate pattern must have been present in the past. Based on comparison with other low-latitude paleoclimate records, such as those from lakes and caves, we infer that both temperature and precipitation influenced past glacial occurrence in this sector of the arid Andes. Our findings also imply that abrupt deglacial climate events associated with the North Atlantic, specifically curtailed meridional overturning circulation and regional cooling, may have had attendant impacts on low subtropical Southern Hemisphere latitudes, including the climate systems that affect glacial activity around Nevado de Chañi.

1. Introduction

Present-day glaciers in the Andes exist under diverse climatic conditions (Lliboutry, 1999; Sagredo and Lowell, 2012). In the driest part of the Chilean Andes, between 18°30' and 27°S, no present-day glaciers are found due primarily to extreme aridity (Ammann et al., 2001; Casassa et al., 2007). Moreover, between 25 and 27°S, there is no clear evidence of former glaciers during the late Quaternary inclusive of ranges as high as 6000 m asl (Ammann et al., 2001). This particularity makes the subtropical arid Andes a special place to study the present and former evolution of the cryosphere, and in particular the glacial evolution during the last glaciation. Several lines of evidences support the existence of cooling and phases of higher precipitation during the last 130 ka producing, among other changes, the expansion of large lakes on the Altiplano (Baker et al., 2001b; Placzek et al., 2006; 2013; Blard et al., 2011). Such climatic, including hydrologic, variations have impacted the landscape due to the enhancement of surface processes such as landslides (Trauth et al., 2000, 2003; Hermanns et al., 2006). The Late Pleistocene glacier chronology in the subtropical Andes is not precisely constrained on a regional spectrum to evaluate the influence of such

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past climate changes. Given the lack of age control along the subtropical Andes, more geochronological data are needed on glacial deposits in order to have a better understanding of such relationships, and to strengthen glacial-climate reconstructions based on geomorphologic evidence (e.g., Porter, 2001; Ammann et al., 2001; Haselton et al., 2002).

Furthermore, in tropical to subtropical South America, questions remain on past climate regime shifts during glacial-ages, including changes in the Intertropical Convergence Zone (ITCZ) and the mid-latitude Southern Hemisphere Westerlies, as well as the relative importance of far-field influences such as polar and North Atlantic conditions (Denton et al., 2010; Baker and Fritz, 2015). It is unclear how the South American Summer Monsoon (SASM) responded to these low-latitude and far-field influences, especially during the global Last Glacial Maximum (LGM) (26.5–19 ka; Clark et al., 2009) and during abrupt climate changes that are seen in both polar ice-cores and high latitude ocean records in the North and South Hemispheres (Barker et al., 2009; Pedro et al., 2011; Members, 2015). Some works pointed out the link between North Atlantic cooling and the SASM was enhanced in the Amazonas region and Central Andes during the last glacial to interglacial period (Wang et al., 2004, 2007; Quade et al., 2008; Blard et al., 2011; Kanner et al., 2012; Placzek et al., 2013; Stríkis et al., 2015). This is a mechanism by which climate drivers far outside South America (e.g., Northern Hemisphere ice sheets) can have a major impact on its glacier and geomorphic history. However, it remains unclear to what extent the SASM may have shifted southward, especially at high-altitude sites in the subtropical Andes, and affected the glaciers.

Subtropical glacier records and their chronologies can substantially improve our knowledge of past atmospheric climate dynamics (mainly temperature and precipitation) to address the issues above. The Cordillera Oriental of Argentina is an excellent place for studying how glaciations and other morphoclimatic process manifest themselves in Earth's arid subtropical settings, and for characterizing their changes during the abrupt switch to the warmer interglacial, after the global LGM. Its location is particularly significant, being in a part of the continent where the interaction between the SASM and the South American Low Level Jet (SALLJ) dictates the climate (Garreaud et al., 2009; Vuille et al., 2012). Therefore, it is ideally situated to test the influence of the SASM on glacial activity during the Late Pleistocene.

In this work, we analyze the glacial geomorphology of the Nevado de Chañi massif (Fig. 1), located on the arid subtropical eastern slope of the Central Andes and we establish a new chronology based on high precision cosmogenic ^{10}Be surface dating. To evaluate the moisture trajectory during glaciations we reconstruct glacier paleo-equilibrium line using several newly-dated moraines. Finally, we compare and review the new glacial history with other paleoclimatic proxies and discuss local and global implications.

2. Regional settings

The Cordillera Oriental of Argentina is located on the eastern border of Puna-Altiplano, on the northeast side of the low-precipitation (less than 250 mm/yr) narrow band, the so-called Arid Diagonal. This is a major climatic boundary with a southeast-northwest trend, which crosses the Andes between 25° and 27°S (Fig. 1). Most of the annual precipitation (~75%) in Cordillera Oriental takes place during the austral summer (from December to March) and is related to the SASM (Zhou and Lau, 1998).

Specifically, during the austral spring the ITCZ migrates southward and produces the onset of the SASM in response to the thermal contrast between the continent and the adjacent ocean (Vera, 2006). The SASM reaches its mature phase between December and February. The dynamics of the ITCZ affect the SASM intensity and therefore the moisture influx and overall climate conditions to this part of the continent (Vuille et al., 2012), a circumstance that is important for this investigation. A deep continental low forms over the Chaco region (25°S) and forces the easterly winds to turn southward and transport significant amounts of moisture across the SALLJ from the Amazon region into the northwestern Argentina (Garreaud et al., 2009), including areas of our focus (Fig. 1). The winds and weather from the east-northeast create an orographic effect across the Cordillera Oriental (Bianchi and Yañez, 1992), with a much drier western side, which is reflected in the regional-scale geomorphic evolution (Strecker et al., 2007) (Fig. 1). Only the highest peak of the Cordillera Oriental of Argentina, the Nevado de Cachi (6380 m above sea level (asl)) contains glaciers. There are four small glaciers (less than 1 km^2), which are situated above 5600 m asl (Martini et al., 2013). Based on

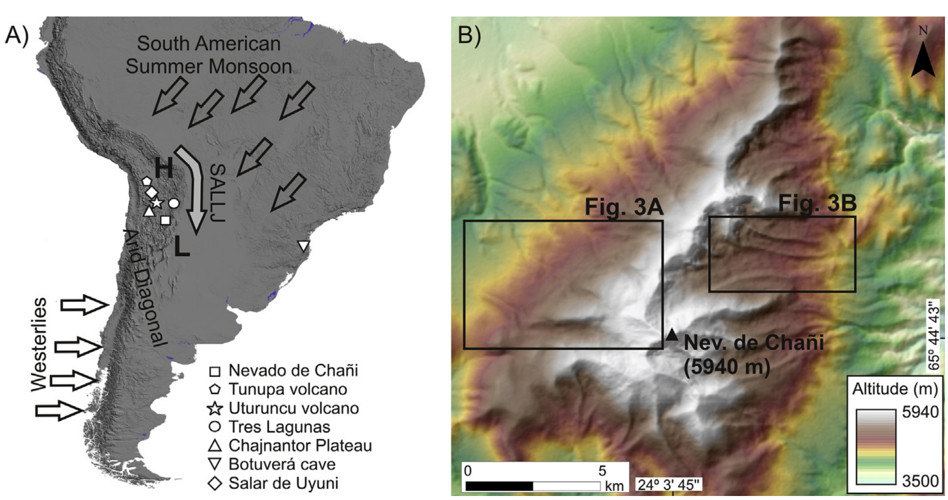

Fig. 1. (A) Mean atmospheric circulations patterns in South America. SALLJ: South American Low Level Jet; H: Bolivian High; L: Chaco Low. Arrows in low and high latitude South America denote the mean wind director at 925 hPa. Symbols indicate the locations of prior works mentioned in the text: Nevado de Chañi (this work), Tunupa volcano (Clapperton et al., 1997; Blard et al., 2009, 2013a), Uturuncu volcano (Blard et al., 2014), Tres Lagunas (Zech et al., 2009), Chajnantor Plateau (Ward et al., 2015), Botuverá cave (Wang et al., 2007), Salar de Uyuni (Placzek et al., 2006). (B) Digital Elevation Model of the Nevado de Chañi massif with the location of Fig. 3. Note the difference in slope and relief between the east and west side.