Quaternary International 438 (2017) 50–64

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

First cosmogenic ages for glacial deposits from the Plata range (33° S): New inferences for Quaternary landscape evolution in the Central Andes

Stella M. Moreiras [a, b, *], María S. Páez [a], Carolina Lauro [a], Pilar Jeanneret [a]

[a] IANIGLA – CONICET, Av Ruiz Leal s/n, Ciudad, Mendoza 5500, Argentina
[b] Cátedra de Edafología, Facultad de Ciencias Agrarias, Universidad Nacional de Cuyo, Luján de Cuyo, Mendoza, Argentina

ARTICLE INFO

Article history:
Available online 21 November 2016

Keywords:
Glaciations
TCN
Blanco River
Central Andes
Argentina

ABSTRACT

This paper presents the first numerical cosmogenic ages of glacial deposits from the eastern slope of the Plata peak (6000) in the arid Central Andes (32° S). The moraines are distributed along three different valleys: Vallecitos, Angostura, and Las Mulas. In the first, only one moraine was identified and no blocks could be sampled for dating. The other two have evidence of two glacial advances, Angostura I and Angostura II. The advances Loma de los Morteritos I and II were recognised in the Las Mulas valley. In both cases, first and second advances are preserved at a similar altitude. Surface boulders on the top of moraines were sampled for Be^{10}. Obtained ages are all similar and Late Pleistocene in age. They fit very well with local stratigraphy and regional paleoclimate evidence. The Loma de los Morteritos moraine II located at 3000 masl dated to ~25,000 years. Ages of ~8,000 and ~12,000 years were found for the Angostura II deposit (~3300 masl). An age was obtained for the outwash deposit identified along the El Salto valley (~69,000 years) associated with a Late Pleistocene drift. Quantitative datings presented here improve knowledge about the glacial chronology of the Plata range and Quaternary stratigraphy of the Central Andes, even though they represent a maximum age for these glacial advances. New findings support the occurrence of two Late Pleistocene glacial advances, and an older one in the Blanco River valley. Adjusted ages around ~8,000 and ~25,000 years for younger stage could be evidence of the Last Glacial Maximum (LGM) period for this region.

© 2016 Elsevier Ltd and INQUA. All rights reserved.

1. Introduction

Throughout the Andes, the glacier history reveals that glaciers had a maximum extension during the Last Glacial Maximum (LGM) and the Late Glacial, with rather consistent ages of ca. 31–18 ka BP and 18–12 ka BP from Alaska to Southern Chile (Clapperton, 2000). Diachronic intervals of glacier advances have been determined for the humid tropical Andes, the Central Andes of Argentina and Chile, and the Patagonian Andes (Zech et al., 2008). However, a regional glacial chronology is not yet fully established for the Central Andes. Late glacial advances were distinguished both in the subtropical Andes (Espizúa, 1999, 2004; Zech et al., 2005; Zech et al., 2007; Zech, 2012) and Patagonia (Douglass et al., 2006; Rabassa et al., 2011), where drifts identified between ~36°–39°S have been interpreted as LGM in age, but no dates are available. Climatic archives show a complex pattern of timing and even antiphase climate responses in the arid Central Andes (Grosjean et al., 2003; Font and Chiesa, 2015). Hence the reconstruction of Late Pleistocene and Holocene environmental variability is poorly understood across this region (Harrison, 2004; May et al., 2008; Bräuning, 2009; Zech et al., 2009; Tripaldi and Zárate, 2016; Hermanns et al., 2015) and available palaeoclimate records are equally scarce (Tripaldi and Forman, 2007; Rojo et al., 2012). Although the last decade has seen an increase in palaeoclimatic studies in the southern Andes, continuing palaeoenvironmental research clearly shows the necessity to analyse past climate variability from a more regional perspective (Piovano et al., 2009). Consequently, multiproxy data are necessary for a more accurate understanding of the region's Late Pleistocene climate.

* Corresponding author. IANIGLA – CONICET. Av Ruiz Leal s/n, Ciudad, Mendoza 5500, Argentina.
E-mail addresses: moreiras@mendoza-conicet.gob.ar (S.M. Moreiras), paez.solange@gmail.com (M.S. Páez), clauro@mendoza-conicet.gob.ar (C. Lauro), pjeanneret@mendoza-conicet.gob.ar (P. Jeanneret).

http://dx.doi.org/10.1016/j.quaint.2016.08.041
1040-6182/© 2016 Elsevier Ltd and INQUA. All rights reserved.

There are serious questions on the timing of Late Pleistocene and Holocene glaciations in the arid Central Andes. Knowledge about timing is severely limited due to the scarcity of organic material for radiocarbon dating, so very few studies for establishing glacial stages time have been carried out at this latitude. Espizúa (1999) identified Late Pleistocene glacier advances in the eastern slope of the Andes along the Mendoza River valley at 32° S, as did Zech et al. (2007) on the western, wetter side of the Andes at 31° S. In the Blanco River Basin (BRB), a number of ambiguous Quaternary glacial stages have been proposed (Corte, 1957; Polanski, 1965; Wayne, 1981; Wayne and Corte, 1983). Initially, high relief moraines over 3200 masl were identified (Polanski, 1958) and associated with limited glacial advances in the eastern arid slope of the Andes. This is maybe the explanation for short extension tongues (10 km) of covered glaciers (Polanski, 1963, 1972). A glacier inventory was carried out a decade later during the Cordilleran Plan in the early 80s. Several snow patches, many ice-covered rock glaciers, and debris glaciers were identified (Corte and Espizúa, 1981; Espizúa, 1983), but curiously, moraine deposits were scarce. Contrasting previous ideas, Wayne (1981) proposed at least four main glaciations along the BRB that would have reached very low altitudes near the confluence of the Mendoza River valley (1400 masl). Assuming temporal correlations with Northern Hemisphere Glaciations and using relative dating techniques (e.g., soil development, loess thickness, block weathering degree, and preserved morphology) a tentative chronology for glacial deposits was suggested (Wayne and Corte, 1983). The Vallecitos Glaciation, evidenced by moraine deposits (Vallecitos I) and moraines related to fossil rock glaciers (Vallecitos II) located above (2600–3400 masl) were assigned to the Late Pleistocene. The authors proposed a speculative age of 17–22 ka BP for Vallecitos I and 12–16 ka BP for Vallecitos II. They also distinguished two older drifts called Río Blanco and Rio Mendoza preserved along the Blanco River valley at 2400 and 2100 masl, respectively, arbitrarily assigned to MIS 6 and 12 (Wayne and Corte, 1983). The Angostura Glaciation, supported by a chaotic deposit located downstream, was also correlated with MIS 12. However, Wayne (1988) rejected this interpretation and concluded it corresponds to a previously identified diamicton (Polanski, 1972). Furthermore, the glaciation stages would have been conditioned by the active tectonics in the region, so the oldest glaciation must have happened after the last topographic uplifting event in this part of the Andes (Wayne and Corte, 1983). Nevertheless, no numerical ages have been yet performed for glacial deposits for the last uplifting of the Plata range.

Defining Quaternary Glaciations along the Central Andes plays a key role in past climate reconstructions and understanding glacier distribution. With the advent of surface exposure dating, more detailed glacial chronologies can provide important insights into climate change forcing and glaciations in South America. The focus of this paper is the specific distribution and timing of Quaternary glaciations along the BRB. There is no recent research on local climate reconstructions in this basin, which motivates this research. Here we present the first Terrestrial Cosmogenic Nuclide (TCN) datings on glacial deposits in this basin trying to shed light on Late Quaternary paleoclimatic reconstruction of the Central Andes. This is necessary because the traditional glacial sequence in the region seems to be questionable (Moreiras, 2006; Fauqué et al., 2009a, 2009b; Hermanns et al., 2015; Moreiras et al., 2015).

2. Geographic settings of the study area

The BRB is located on the eastern slope of the Plata range at 33° S and 69°25′ W in the Central Andes (Fig. 1a). These mountains are characterised by abrupt topography, low temperatures at high elevations, intense insolation, marked diurnal temperature amplitude, and extremely dry conditions. This aridity is mainly linked to the Arid Diagonal, which inhibits tropical circulation to the south. Most humidity in this sector is linked to the westerlies coming from the Pacific Ocean and generating winter snows. This system is exacerbated during warm phases of the ENSO climatic phenomenon during which precipitation is above the mean, glacier mass

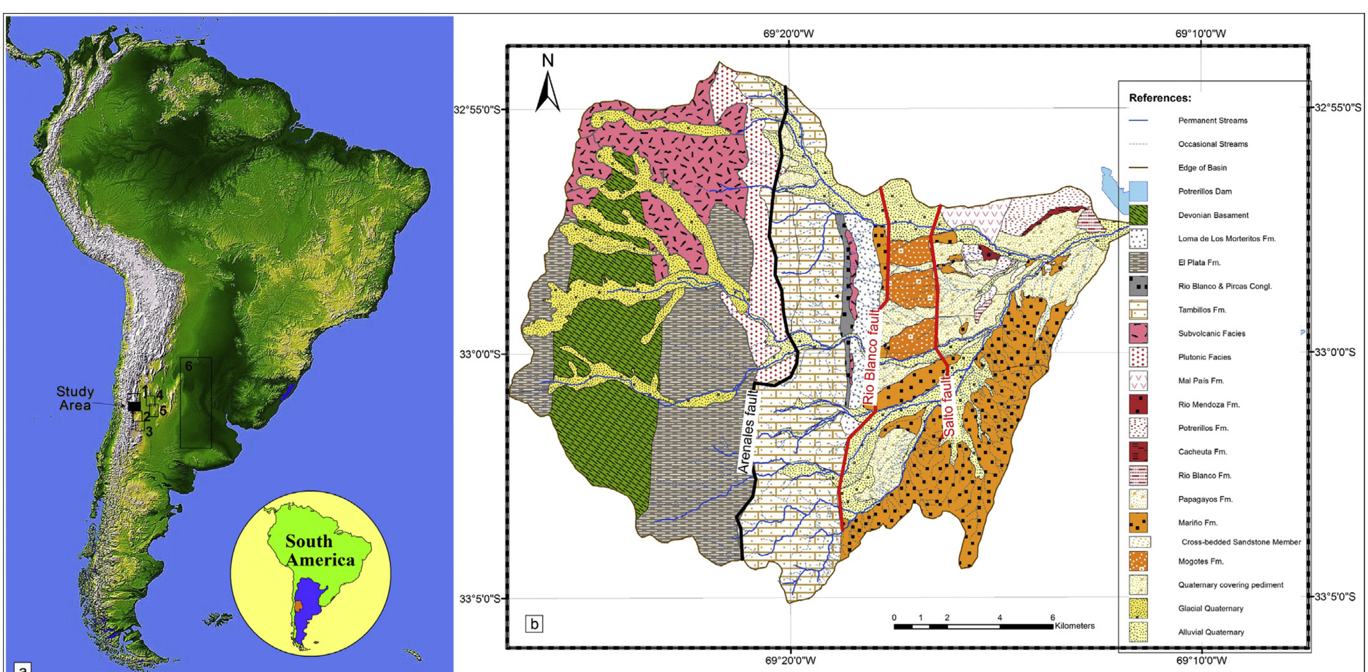

Fig. 1. a. Shuttle Radar Topography Mission (SRTM) showing location of the study area and other areas mentioned through the text: 1. Mendoza River valley (Espizúa, 1999; Hermanns et al., 2015), 2. Tunuyán River (Tripaldi and Forman, 2007; Zárate and Mehl, 2008; Zárate et al., 2009; Rojo et al., 2012), 3. Diamante River (Baker et al., 2009), 4. Médanos de Los Naranjos (Tripaldi et al., 2011; Tripaldi and Zárate, 2014), 5. Desaguadero River, San Luis province (Kemp et al., 2004; Font and Chiesa, 2015), and 6. Pampean Aeolian System (Iriondo and Kröhling, 2007; Iriondo et al., 2011); and b. Geological map showing lithological units and main Quaternary faults of the Carrera fault system.

balance is positive, and rivers increase in water volume (Masiokas et al., 2010; Moreiras et al., 2012).

As in other mountain environments, local climatic conditions respond to altitude, so different climatic bands can be distinguished from topography. In lower parts of the valleys, a dry desert (BW) climate predominates with low precipitation and a permanent water deficit. On the other hand, a frozen climate (ET) is present in higher areas, while Tundra predominates between 2700 and 4100 masl with no tree growth; herbs and shrubs sometimes grow during the summer. The mean temperature is below 10 °C and above 0 °C during the warmest month (January). A few meteorological stations are present; there are records from the Vallecitos meteorological station (2470 masl) and the Las Aguaditas meteorological station. These stations have reported mean annual temperature of 5 °C and 7.6 °C and mean annual precipitation of 294 mm and 450 mm, respectively (Wayne, 1981). At the highest altitudes, a polar climate predominates with permanent ice (>4100 masl) (Fig. 2a).

The high mountain topography has peaks near 6000 m in altitude (Platita peak 6000 masl, Negro peak 5800 masl, Vallecitos peak 5750 masl, Rincón peak 5500 masl, and Pico Ibáñez peak 5500 masl). The Plata peak (6200 masl) is the highest in the Plata range system, in which elevation descends gradually towards to the north and peaks drops to 2700–3000 masl (Fig. 2b). Glaciers on the main peaks that feed the Blanco River were initially conformed by the Vallecitos and Angostura valleys. Downstream, this river merges with the El Salto valley from the north and the Las Mulas River from the south. The Blanco River runs for 25 km and then feeds into the Mendoza River where the Potrerillos reservoir was built in 2005. This fourth order stream is mainly fed by snow thaw, summer rain, and glacier melt during the summer. Its volume shows a clear season variability, which increases during the summer, but mean streamflow is very poor, only 1 m^3/sec (Secretaría de Minería de la Nación, 2015).

Marked contrast in daily temperatures favours intense cryogenic processes that generate a great amount of debris, which is mainly deposited on talus or steeper debris cones. Likewise, temperatures below 0 °C are related to the presence of frozen soils at elevations above 3200 masl. In fact, this is the lower limit of mountain permafrost (Corte and Grosso, 1993). Hillslopes are only exposed to stationary freezing/thawing processes below this altitude. Geomorphological processes are intimately forced by topography here. Between 2000 and 3500 masl, fossil periglacial geoforms associated with relict permafrost, seasonal frozen dynamic, and talus geoform predominate (Trombotto, 2002). In the semiarid periglacial level, between 3500 and 4500 masl, different types of permafrost, solifluction forms, uncovered glaciers, covered rock glaciers, and debris glaciers are the most important features. The permanent snow covert above 4500 masl includes snow patches, continuous permafrost, uncovered glaciers, ice-covered rock glaciers, and cryo-planed surfaces (Trombotto, 1991; Trombotto and Borzotta, 2009).

The limit of creeping permafrost is determined by the presence of active rock glaciers above 3700 masl. On the southern slope of the Lagunita valley, nearly continuous permafrost may reach a depth of 90 cm at an altitude of 4500 masl. It is close to perennial snow patches which may increase the permafrost limit. Dry permafrost occurs under cryogenic conditions at 4400 masl and a depth of 90 cm. Nonetheless, types and extension of glaciers greatly differ in different valleys of the study area (Brenning et al., 2005). In the Vallecitos valley, uncovered glaciers are only preserved above 4700 masl (−3.6 °C isotherm) (Buk, 2002), which are named the Vallecitos, Coloradas, Stepanek, and La Hoyada glaciers. Downslope, these glaciers are covered by debris until 3200 masl. There is also a covered glacier on the northeastern face of the Franke peak (4822 masl).

In the case of the ice-covered glacier Vallecitos, internal structures have been described: Vallecitos I and Vallecitos II moraines, Holocene moraine flows (I, II, and III), and an ice-core moraine (Wayne and Corte, 1983). These authors suggest that the debris covert of some of these deposits behaves like an active layer of permafrost with thermo-karst morphology, longitudinal bands,

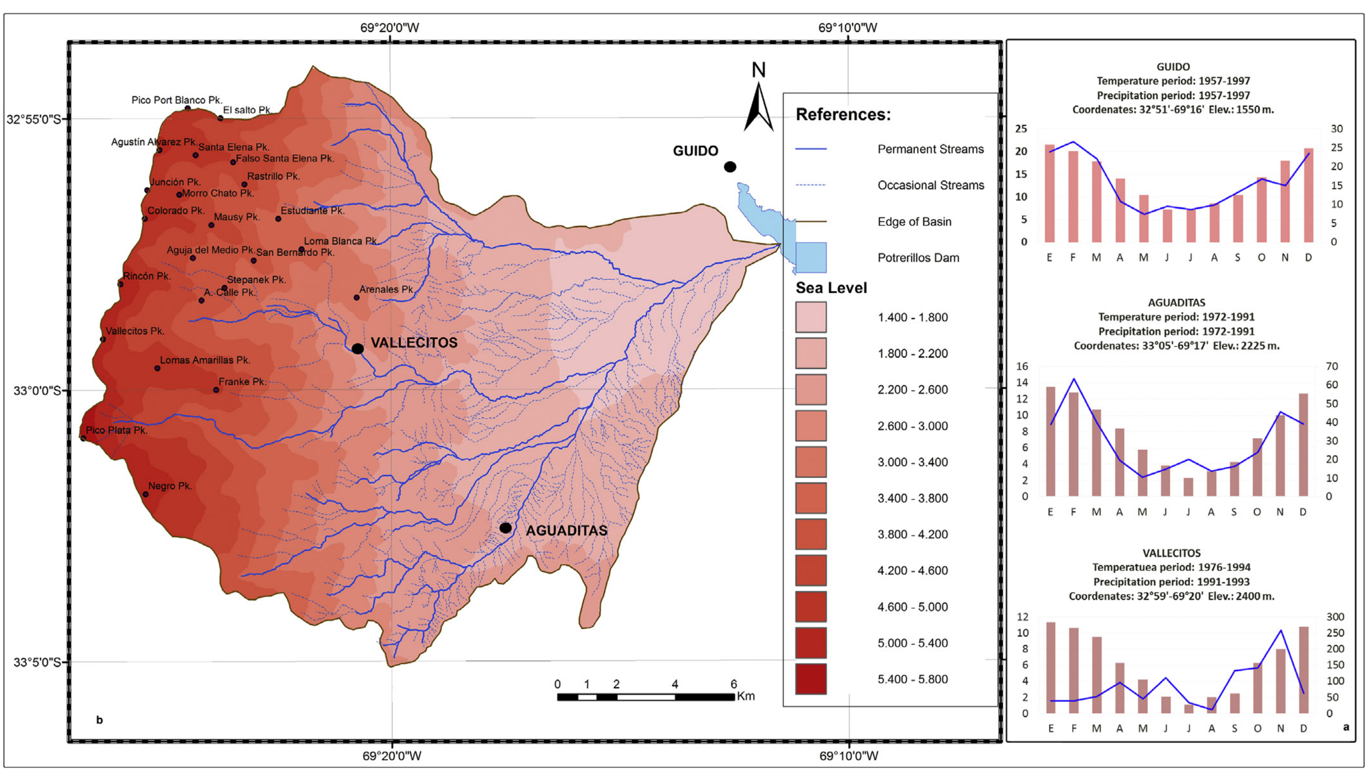

Fig. 2. a. Mean monthly precipitation measured at local meteorological stations, and b. Shutter radar DEM presenting the topography of the Blanco River basin showing the location of the local meteorological stations: Vallecitos, Aguaditas and Guido.

and transversal ridges. Additionally, different facies could be distinguished from the headwater towards downstream that revealed the thickness of debris covert, uncovered-ice, covered-ice, thermo-karst, structured debris, and a series of transversal arcs, channels, and ridges. Late facies could correspond to ice-core moraines where debris thickness reaches 5 m (Wayne and Corte, 1983). Gradual changes exist from moraine deposits to glaciogenic rock glaciers simply because moraines could have begun to move and covered the glaciers.

On the other hand, there are neither ice-covered nor uncovered glaciers in the Angostura valley. The glacial environment is confined to cryogenic rock glaciers with short tongues. The extension of these rock glaciers is rarely over 500 m and the longest one is 900 m. Nevertheless, the debris-covered Lomas de los Morteritos glacier appears in the valley to the south. This 2.7 km long glacier occupies the whole valley of the Las Mulas River until 3400 masl.

Glaciers and cryogenic forms predominate in higher mountain areas of the BRB but in the lower piedmont, very well developed alluvial fans and glacis surfaces are the most common geoforms. These deposits are intersected and eroded by frequent debris flows and floods triggered by intense summer rainstorms (Páez et al., 2013) that have generated severe damage and significant economic impacts in the region, such as the recent event in the summer of 2013. The study area could be divided into two well-defined zones according to explained above. A glacial-periglacial environment is typical above 3200 masl while below this altitude, alluvial fans and channelized debris flows are common.

3. Geological framework

The Plata range belongs to the Frontal Cordillera morphotectonic unit, whose basement comprises the metasedimentary Devonian Vallecitos Series (Heredia et al., 2012) and Upper Carboniferous to Lower Permian marine deposits of Loma de los Morteritos and El Plata formations (Caminos, 1965) (Fig 1b). A thick pile of Permo-Triassic bimodal volcanic rocks and shallow level batholiths of the Choiyoi Group unconformably overlay the previously deformed rocks. This magmatism has been associated with an extensional regime, probably related to the final stage of a subduction process (Llambías et al., 1993; Kleiman and Japas, 2009). A thick sequence of Triassic continental fluvial deposits and subordinate volcanic rocks were deposited in the Cuyo rift basin and then were overlaid by Paleogene–Lower Neogene rocks. The sequence continues with a thin succession of poorly stratified coarse conglomerates interlaid with siltstones, sandstones, and some tuff levels of the Mogotes Formation from the Late Pliocene (Caminos, 1965; Irigoyen et al., 2000).

Quaternary alluvial deposits related to the uplift of the Frontal Cordillera are broadly distributed in the lower piedmont of the study area (Polanski, 1963). Different levels of glacis have been identified by Rodríguez and Barton (1993) and Casa (2005) in this area, while relict moraines were identified in higher areas (Wayne and Corte, 1983). According to these authors, Pleistocene moraines should reach the Mendoza River Valley at this latitude. They suspect that the lower limit of Plio-Pleistocene permafrost should be below 800 masl.

The Frontal Cordillera was uplifted in various episodes during the Late Miocene to Early Pleistocene (Kozlowski et al., 1993). The study of synorogenic deposits in the Cacheuta basin (Irigoyen et al., 2002) estimates that the Plata range was uplifted during the Andean Orogeny around 12–18 Ma ago (Giambiagi et al., 2003). The Carrera fault system was the main structure responsible for its uplift. This system in the eastern margin of the Plata range is composed by north–south imbricated reverse faults with eastern vergence (Polanski, 1958). From west to east, the principal remains of this fault system are the Arenales fault that thrusts a granite intrusive over vulcanites of Choiyoi Group, the Médanos fault that displaces Neogene rocks, the Rio Blanco fault that displaces Neogene over Pliocene and Quaternary levels, and the El Salto fault (Caminos, 1965; Folguera et al., 2004; Casa et al., 2010). Neotectonic activity is associated with the Río Blanco fault, which delimits the principal mountain front. A splay of this fault affects a rock pediment and a Pleistocene alluvial fan, whereas the El Salto fault uplifts three levels of Quaternary pediment. The offsetting of Quaternary alluvial fans (Cortés et al., 1999, 2006; Borgnia, 2004; Casa, 2005, 2007, 2009; Casa et al., 2010) and the occurrence of huge rock avalanches clustered in the northern extreme of the Plata range (Moreiras, 2006; Fauqué et al., 2009a; Moreiras et al., 2015) suggests persistent Quaternary tectonic activity along the structural segment of the mountain front of the Plata range.

4. Material and methods

Ambiguous interpretations about glacial history in the BRB motivated us to try to better understand Quaternary glacial stages in this portion of the Central Andes. Quaternary landscapes are often well preserved in the arid Central Andes at 32° S. So an initial identification of Quaternary glacial drifts was conducted through remote sensing and field inspections. We used Landsat images, pairs of 1963 air photos and Google Earth for to identify the main Quaternary deposits and glacial geoforms. We could distinguish uncovered glaciers, ice-covered glaciers, debris rock glaciers, snowpaths, and relict moraines following Brenning's (2003) classification. These geoforms were mapped and field checked. Relict moraines were identified along the main valleys of the BRB. They were named according to hosted valley and their position along the valley (Fig. 3). Outwash deposits associated with different glacial advances were also identified in the confluence of Angostura and Vallecitos valleys and in the Las Mulas valley. During field excursions, we described each deposit, especially taking into account grain size distribution, lithological context, matrix content, roundness of blocks, structures, and presence of striations (Abele, 1984; Hewitt, 1999; Hewitt et al., 2011) (Table 1).

Table 1
Main features of moraine identified in the Blanco River Basin.

Valley	Advance/ Moraine	Max.Elev.m asl	Min. Elev. m asl	Lithology of main blocks	Max. block size m	Matrix content %	Deposit aspect
Vallecitos	Vallecitos	3250	2690	40% traquites, 35% rhyolites, 15% andesites 10% granites	6	45–60	Lobulated moraine
Angostura	Angostura I	2950	2400	40% phyllites, 40% gneiss, 13% black shales, 7% sandstones	5	45	Lateral moraine with hummocky surface
	Angostura II	3520	2910	45% squists, 35% gneiss, 9%sandstones, 7%conglomerates, 3% volcanites, 1% granite	3	40	Lateral moraine with hummocky surface
Las Mulas	Loma de los Morteritos I	2500	2400	35%Sandstones, 25%black shale, 10% phyllites, 10% gneiss 7% rhyolites, dacites and sienites 2%granites,	0.7	60	Rounded hill aspect
	Loma de los Morteritos II	2960	2800	40% gneiss, 35%sandstones, 15% pelites, 10% granites	4	45	Lobulated deposit
Blanco	Rio Blanco	2019	2019	–	0.7	50–60	Relict covered deposit

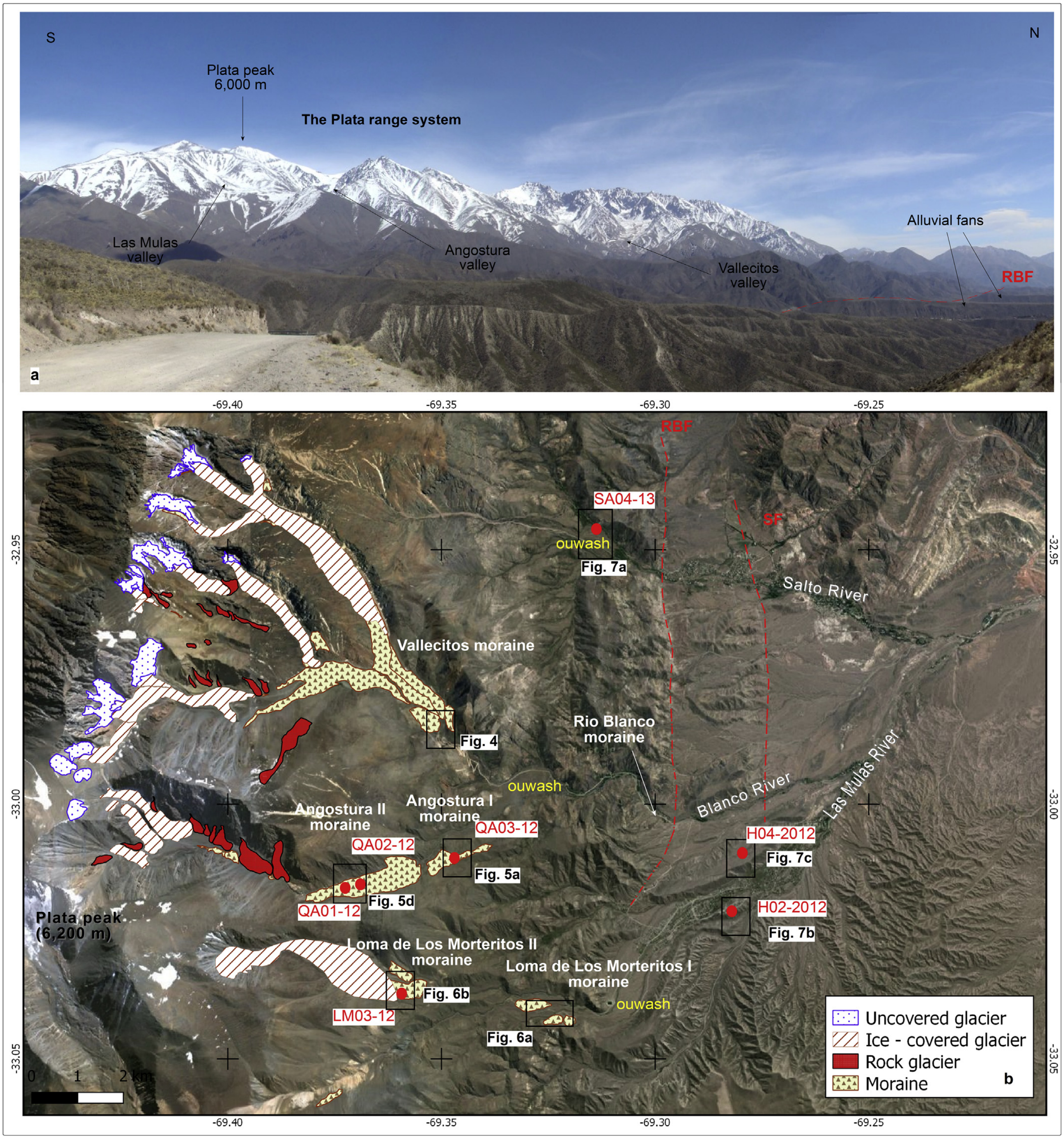

Fig. 3. a. Panoramic view of the study area from piedmont sector, and b. Distribution of uncovered glaciers, covered glaciers, debris-rock glaciers and moraine deposits with location of TCN samples. Dashed lines represent traces of the main Quaternary faults: AF- Arenales fault, RBF- Rio Blanco fault, and SF- Salto fault. The location of Figs. 4–7 is also indicated.

To establish the temporal distribution of these glacial deposits we evaluated the suitability and the possibility of applying different dating techniques. As it is widely known, dating techniques are essential for resolving uncertainties of glacial timing, but methods commonly used for Quaternary ages cannot be used to date Central Andean drifts. Their deposits generated during dry conditions lack on organic matter, which precludes radiocarbon dating. A dry climate has also limited the presence of ancient water bodies; the Optically Stimulated Luminescence (OSL) dating is not possible outside of lacustrine sequences. Furthermore, aeolian sequences often found with glacial deposits are settled far away in the eastern Andes foothill and they have been rarely dated (Tripaldi and Zárate, 2014). For these reason, the glacial chronology depends mainly on tephrochronology in this portion of the Andes (Espizúa, 1999). However, in the study area, reworked tephra interlaid in alluvial fans of piedmont area are unconnected to glacial deposits. While other methods could not be applied, TCN dating could be used to refine the chronology of glacial deposits.

TCN dating is based on cosmogenic nuclides (^{3}He, ^{10}Be, ^{14}C, ^{21}Ne, ^{26}Al, and ^{36}Cl) accumulating in the upper few decimetres of the Earth's surface, hence a proper sampling procedure is critical. The sampling procedure was carried out following the guidelines recommended by Gosse and Phillips (2001): recording the rationale for sample selection, description of block, geologic description of sample, location, orientation, sample thickness, and shielding geometry. Samples of 2–4 kg were taken from the surface of blocks using a hammer and a chisel. We sampled blocks greater than 2 m in diameter lying on the top of drifts (Table 2). Samples QA01-12 and QA02-12 were taken from boulders located at the top of the Angostura II moraine. Sample QA03-12 was taken from an exposed surface of the Angostura I moraine. Sample LM03-12 was taken from the surface of the Loma de Los Morteritos II moraine. All these samples consisted of quartz veins of metamorphic boulders. Additionally, a granodiorite was collected from an outwash deposit of the El Salto valley (SA04-13). We also sampled two blocks on ancient alluvial fan surfaces previously assigned to the Early–Middle Pleistocene (Polanski, 1965). Sample H02-12 was taken from an alluvial fan located along the Las Mulas valley and sample H04-12 was taken from alluvial fans located near Valle del Sol, very close to the previous one. The ages of these boulders are used as chronological controls because these alluvial fans surround the older drift of the Las Mulas valley (Fig. 3). They are stratigraphically related to outwash deposits where we could not find any boulders.

models where different scaling schemes for spallation were taken into account (Lal, 1991; Stone, 2000; Dunai, 2001; Desilets and Zedra, 2003; Lifton et al., 2005; Desilets et al., 2006 -Time-dependent). All samples were corrected for topographic shielding and sample thickness; no corrections were applied for transient snow cover.

Table 3
Data corresponding to ^{10}Be measurements. Nuclide concentrations and standard uncertainties established with the National Institute of Standards and Technology standard reference material 4325 by using an assigned value of (2.79 ± 0.03).10E-11 (Nishiizumi et al., 2007).

Sample	Latitude S	Longitude W	Be10/Be9 10^{-13}	$\pm 10^{-14}$	Mass g	10Be at g^{-1}	± at g^{-1}
QA01-12	33 01 03.1	69 22 25.6	3.86	1.20	24.40	321,701	10,069
QA02-12	33 01 00.4	69 22 10.8	5.30	1.73	23.51	458,090	15,063
QA03-12	33 00 55.6	69 21 58.3	6.74	2.09	24.70	547,671	17,045
LM03-12	33 02 04.7	69 21 46.5	10.44	3.40	24.67	859,666	28,133
SA04-13	32 57 05.6	69 17 16.7	7.73	2.41	13.14	1,196,535	37,534
H02-2012	33 01 28.8	69 17 24.5	3.49	1.09	25.55	276,936	8722
H04-2012	33 00 55.4	69 17 37.0	43.11	11.51	23.12	3,809,848	102,377

5. Results

5.1. Glacial geomorphology

Preserved Quaternary moraines are valuable archives for palaeoenvironmental reconstruction; however, establishing the glacial origin of these diamictons is not an easy task. Moraines attributed to glacial advances have been reinterpreted as huge rock avalanches in this region (Deckart et al., 2014; Hermanns et al., 2015; Moreiras and Sepúlveda, 2015). A detailed field examination of chaotic deposits is required to move beyond conflicting hypotheses (Corte, 1957; Polanski, 1965; Wayne, 1981; Wayne and Corte, 1983). Various moraine advances were identified along the main valleys of the BRB. Normally, recognised moraines appear as relict and eroded deposits; nonetheless we identified two glacial advances in the studied valleys, except for Vallecitos and El Salto valleys. They were called Angostura I and Angostura II in the Angostura valley; while the Loma de los Morteritos I and the Loma de los Morteritos II were identified in the Las Mulas valley. A relict moraine was identified along the Blanco River at a lower altitude (2020 m) (Fig. 3). Main features of the deposits are briefly presented in Table 1.

Table 2
Samples collected from the top surfaces of relict moraines and alluvial fan deposits in the Blanco River Basin.

Sample	Elev. masl	Block						Deposit
		Lithology	Dip	Wide m	Long m	High m	Roundness	
QA01-12	3454	Gneiss (Qz)	15NO	4	6	2	Sub-rounded	Angostura II
QA02-12	3381	Gneiss (Qz)	18 S	3.5	6	2	Sub-rounded	Angostura II
QA03-12	3231	Gneiss (Qz))	25 E	2	2.5	2	Irregular	Angostura I
LM03-12	3085	Gneiss (Qz)	15	2	1.8	1.2	Irregular	Loma de Los Morteritos II
SA04-13	1931	Granodiorite abundant Qz	10N	1.2	1	1.5	Sub-rounded	El Salto outwash
H02-2012	2031	Gneiss (Qz) with stration	15NO	1.2	1	1.2	Irregular	Las Mulas alluvial fan
H04-2012	2103	Granite	30N	0.9	1.2	2	Rounded	Las Mulas alluvial fan

Large, exposed boulders are rare in the deposits. Only seven surface boulders were sampled for this research. All boulders revealed exposure features. Samples had significant rock varnish, intense weathering, and disintegration due to arid climate conditions. In particular, sample H04-2012 has intense weathering. Table 2 summarises the main characteristics of these samples (see Fig. 3 for sampling locations).

Depending on the surface preservation and exposure history, the TCN technique has an effective range from the Pliocene to the Late Holocene. In this study, TCN dating was carried out on ^{10}Be in quartz grains to provide minimum estimates of moraine abandonment. Separation of quartz for ^{10}Be concentration was initially done in the Cerege Laboratory, Aix en Provence (France) following the protocol described by Von Blanckenburg et al. (1996). The $^{10}Be/^{9}Be$ ratio was obtained at the ASTER AMS laboratory in Cerege (France) and calibrated against the National Institute of Standards and Technology reference 4325 with a value of (2.79*0.03) 10^{-11} (Nishiizumi et al., 2007) (Table 3). Production rates and decay constants were updated with the CHRONUS calculator (http://hess.ess.washington.edu/math/al_be_v22/al_be_multiple_v22.php) to reflect the ^{10}Be standardization and half-life revision in Nishiizumi et al. (2007). Exposure ages were estimated by constant production rate (Lal, 1991; Stone, 2000) and by time-varying production

5.1.1. The Vallecitos valley

The Vallecitos moraine outcrops are located from 2690 to 3250 masl, just below the Vallecitos rock glacier. The thickness of this deposit is nearly 60 m, and it presents very angular and subangular boulders. Multi-lithology blocks are immersed in a finer matrix that reaches 60% in some sectors. This deposit has been intensely affected by anthropogenic action. Ski runs, an unconsolidated route for accessing ski facilities, and mountain cabins were built on this moraine. For this reason no blocks could be sampled (Fig. 4). The Vallecitos moraine has been previously referred as the Coloradas moraine (Corte, 1957; Wayne, 1981; Trombotto, 2002) due to its reddish colour, which comes from local lithologies mainly made up of vulcanites from the Permo-Triassic Choiyoi Group. This moraine deposit is related to a downstream outwash plain fed by the Vallecitos and Angostura rivers. Even though we identified a disturbed relict moraine, two Vallecitos advances were documented previously, Vallecitos I (2690 masl) and Vallecitos II (2900–3400 masl) (Wayne, 1981; Wayne and Corte, 1983). Soils have not formed over these deposits.

5.1.2. The Angostura valley

The Angostura I advance is documented by a lateral moraine, barely preserved as a ridge near the confluence of the Angostura and Vallecitos rivers. The chaotic material is tongue-like with a clear hummocky morphology on its surface. A heterolithic composition characterises this deposit with blocks up to 5 m in diameter. The blocks are from Devonian and Carboniferous outcroppings in the headwaters of the valley (Fig. 5a). The second advance, Angostura II, is documented by a lateral moraine between 2910 and 3520 masl. This lower moraine shows a very similar lithological composition to the previous one. Boulders are subangular and subrounded. Concerning weathering, the granites show an oxide concentration on the block's surface, but sedimentary rocks do not show any rock varnish (Fig. 5b). Block striation is rare.

5.1.3. The Mulas valley

A typical rounded hill moraine was identified in the middle valley of the Las Mulas River, called Loma de los Morteritos I. This moraine is also preserved downstream as a lateral moraine. It is a relict deposit over volcanic outcroppings of the Choiyoi Group at 2400 masl. In Loma de Los Morteritos I, at least 50% of blocks are angular, 30% subangular, and 20% subrounded. Blocks lithology is mainly from sedimentary rocks of the El Plata formation though a minor proportion of Permo-Triassic volcanites are present as well. This type of lithology seems to be weaker than meta-sedimentary rocks so they are found in smaller boulder sizes and more disintegrated (Fig. 6a). This precluded TCN dating on this deposit, as large blocks are normally required. The next advance was Loma de los Morteritos II, preserved as a frontal moraine on a steeper slope just below the front of the Loma de Los Morteritos rock glacier at 2960 masl. The provenance of boulders of this chaotic deposit is Carboniferous sedimentary rocks and intrusive facies of the Choiyoi Group (Fig. 6b).

5.1.4. The Blanco River valley

Downstream of the confluence of the Angostura and Vallecitos rivers, we identified a relict moraine. This deposit, the Rio Blanco moraine, is situated near the mountain range. It is eroded and covered by alluvial fans. That is the reason why there were not surface blocks available for TCN dating. The provenance of boulders' lithologies is an outcropping upstream with Carboniferous units, Choiyoi Group volcanites, and granite.

5.1.5. The El Salto valley

The glacial past of this U-shaped valley is poorly preserved by the presence of a covered glacier at 3530 masl in the headwater of the El Salto basin. Even ancient glacial deposits are not clearly distinguished along this valley, two outwash plains possibly associated with colder glacial period advances were inconclusively identified. These alluvial plain surfaces sit at altitudes 2050–2150 masl and 2380–2500 masl. The sampled boulder (SA04-13) was taken from the lower surface (Fig. 7c,d).

5.2. Terrestrial Cosmogenic Nuclide ages

TCN was used to help constrain the chronology of BRB moraines and to overcome discrepancies from earlier studies. TCN dating provided some successful numeric ages of glacial deposits in two different valleys. In the El Salto valley, a related outwash deposit was dated because moraines along this valley could not be distinguished. Furthermore, two alluvial fans in piedmont areas were also dated as they confine drifts in the Las Mulas valley.

Table 4B shows maximum mean ^{10}Be exposure ages estimated from time-varying production models (Lal, 1991; Stone, 2000; Dunai, 2001; Desilets and Zedra, 2003; Lifton et al., 2005;

Fig. 4. Picture of the Vallecitos moraine where vulcanite blocks are immersed in a finer matrix. The location of picture is indicated in Fig. 3.

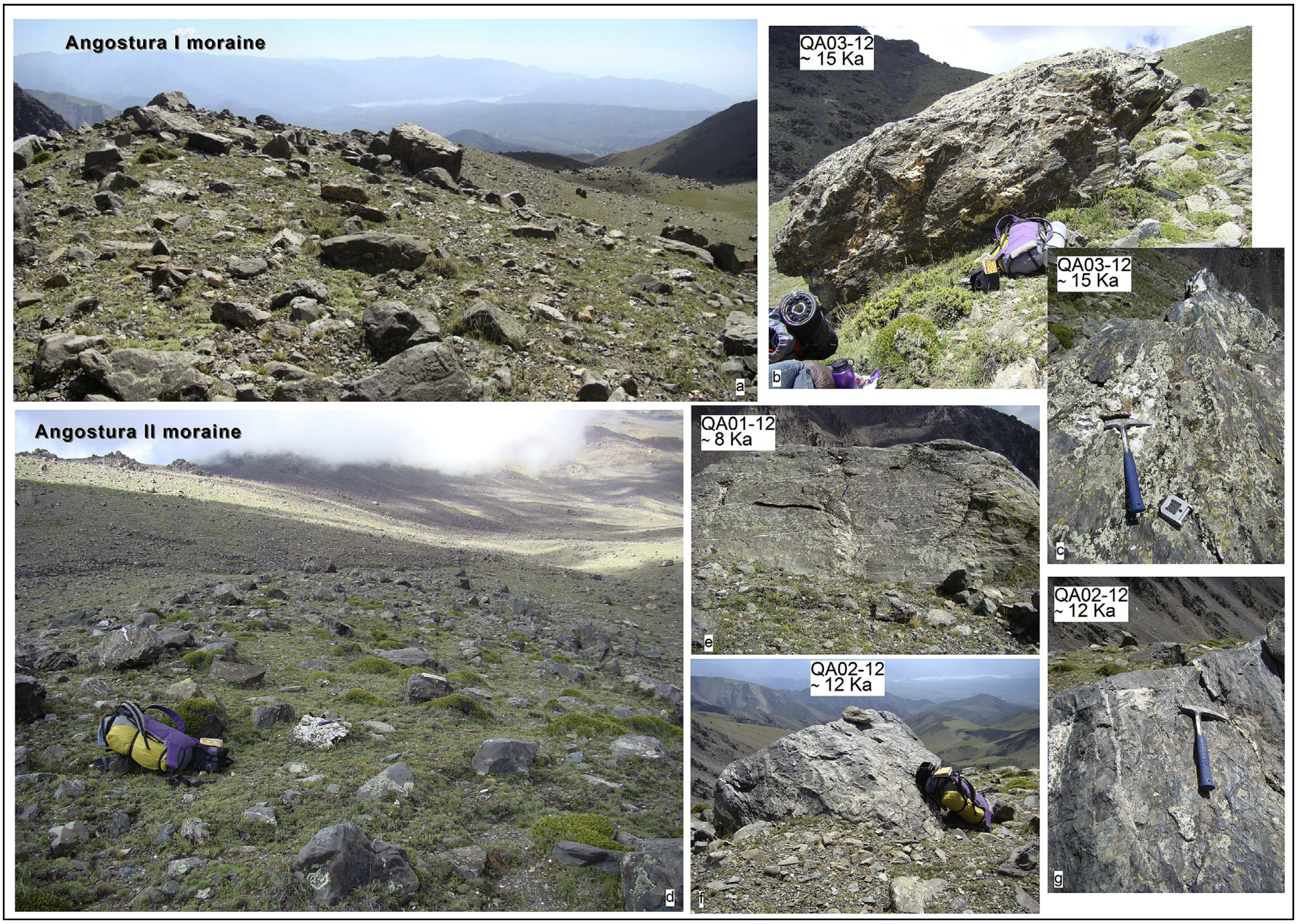

Fig. 5. Moraines identified in the Las Mulas valley: a. Angostura I moraine, b. Sampled block corresponding to QA03-12 (~11 ka BP), c. picture detail of previous block's aspect, d. Angostura II moraine, e. Sampled block corresponding to QA01-12 (~18 ka BP), f. Sampled block corresponding to QA02-12 (~25 ka BP), and g. detail of previous block's aspect. The location of pictures is indicated in Fig. 3.

Desilets et al., 2006). All samples taken from glacial deposits are Late Pleistocene in age. Samples from the Angostura II moraine, QA01-2011 and QA02-2011, were dated to 8 ± 0.7 ka, and 12 ± 1.1 ka BP, respectively. These ages agree with the age of the sample taken from older moraine Angostura I (CPQ03-12) dated 15 ± 1.4 ka BP. A Late Pleistocene age was also established for the Loma de Los Morteritos II moraine located in the upper basin of Las Mulas valley (2960 masl). In this case, a mean ^{10}Be exposure age of ~25 ± 2.3 ka BP was determined for sample LM03-12. But contradictory to these findings, an unexpectedly older age was obtained for the outwash deposited downstream in the front of the El Salto covered glacier (3200 m). In this case, sample SA04-12 was dated to ~69 ± 6 ka BP (Table 4B).

Samples taken from surfaces of piedmont alluvial fans for stratigraphic control had very different ages. Sample H04-2012, collected from the alluvial fan preserved downstream of the Loma de Los Morteritos I moraine along the Las Mulas valley, was dated to ~196 ± 18 ka BP. While, sample H2-2012, in a similar alluvial surface, was dated to only ~16 ± 1.5 ka BP. The last age is disseminated as the size of sampled boulder was smaller than the rest. Thus, obtained age is apparently too young for these alluvial deposits, which have a well-developed glacis and a significant rock varnish cover on sampling blocks. A Middle Pleistocene age seems to be more likely. These alluvial sediments could have been deposited prior to the downslope glaciations; they surround glacial drifts of Lomas de los Morteritos I in the Las Mulas valley.

6. Discussion

6.1. Minding the gap

The understanding of regional geodynamics during the Quaternary in the arid Central Andes requires reconstructing glacial stages, the paleoclimate, and an evaluation of climate-glacier connections. Glacial landforms are invaluable for reconstructing links between past ice bodies extension, paleoclimate, and environmental changes. A coupled system of environmental processes and the paleoclimate regimen have conditioned landform evolution in the Central Andes. The fluvial regimen and sedimentary features of the basins located in eastern Andean piedmont are directly related to Late Pleistocene glaciations. Increased snowmelt in Andean rivers during the deglaciation period ca. 17–14 ka BP favoured the generation of water bodies in the Andes piedmont (Font and Chiesa, 2015), and a similar age was established for a limnic level (17,110 ± 70 -14C BP) in the Tunuyán River (33° S), located 100 km from the study area (Mehl and Zárate, 2013). Additionally, soils and aeolian deposits of Central Argentina have been broadly associated with major glacial advances in the Andes, which indicate dry and cold conditions in the eastern piedmont (Kröhling, 1999; Zech et al., 2008; Tripaldi et al., 2011; Tripaldi and Zárate, 2014). Aeolian units from the eastern Andean piedmont, roughly synchronous with loess accumulation in several localities of the Pampas (Kemp et al., 2006; Iriondo and Kröhling, 2007; Frechen et al., 2009; Zárate et al., 2009) were deposited during the LGM and

Table 4
Results of the TCN datings (^{10}Be) using calculator CHRONUS (http://hess.ess.washington.edu/math/al_be_v22/al_be_multiple_v22.phpa.). A. Results not dependent on spallogenic production rate model. Scaling scheme for spallation: Lal (1991)/Stone (2000), and B. Exposure ages are time-varying production models. Scaling scheme for spallation according to Desilets and Zedra (2003), Desilets et al. (2006), Dunai (2001), Lifton et al. (2005), Lal (1991)/Stone (2000) – Time-dependent.

A. Exposure ages constant production rate model

Sample name	Thickness scaling factor	Shielding factor	Production rate (muons) (atoms/g/yr)	Internal uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Production rate (spallation) (atoms/g/yr)
QA01-12	0.959	1	0.516	253	8074	747	39.41
QA02-12	0.959	1	0.506	395	11,983	1116	37.84
QA03-12	0.959	1	0.486	488	15,603	1445	34.75
LM03-12	0.959	1	0.466	879	26,689	2494	31.96
SA04-13	0.959	1	0.333	2475	77,375	7286	15.43
H02-12	0.959	1	0.344	521	16,475	1528	16.54
H04-12	0.959	1	0.351	6485	227,851	21,942	17.34

B. Exposure ages are time-varying production models

Sample name	Desilets and others (2003,2006)		Dunai (2001)		Lifton and others (2005)		Time-dependent Lal (1991)/ Stone (2000)	
	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)
QA01-12	7427	908	7235	881	7279	754	8007	721
QA02-12	11,260	1382	11,006	1345	10,899	1136	11,924	1082
QA03-12	14,805	1812	14,521	1770	14,307	1484	15,376	1387
LM03-12	24,596	3028	24,011	2944	23,665	2472	25,240	2297
SA04-13	71,923	8935	69,587	8604	68,746	7234	69,123	6325
H02-12	16,711	2048	16,262	1984	16,216	1685	16,208	1464
H04-12	201,555	25,645	195,033	24,668	192,190	20,608	195,791	18,196

the Late Glacial Period. However, a scarcity of numerical ages from glacial records makes it impossible to evaluate interactions between both processes and asynchronous glacial chronologies in the Central Andes (15–40° S) (Zech et al., 2007). Hence new dates and multiple proxies are necessary for a more accurate understanding of the region's past climate.

In this study, we contributed to an understand of past glacial extent along main valleys of the BRB. Numerical dating of glacial

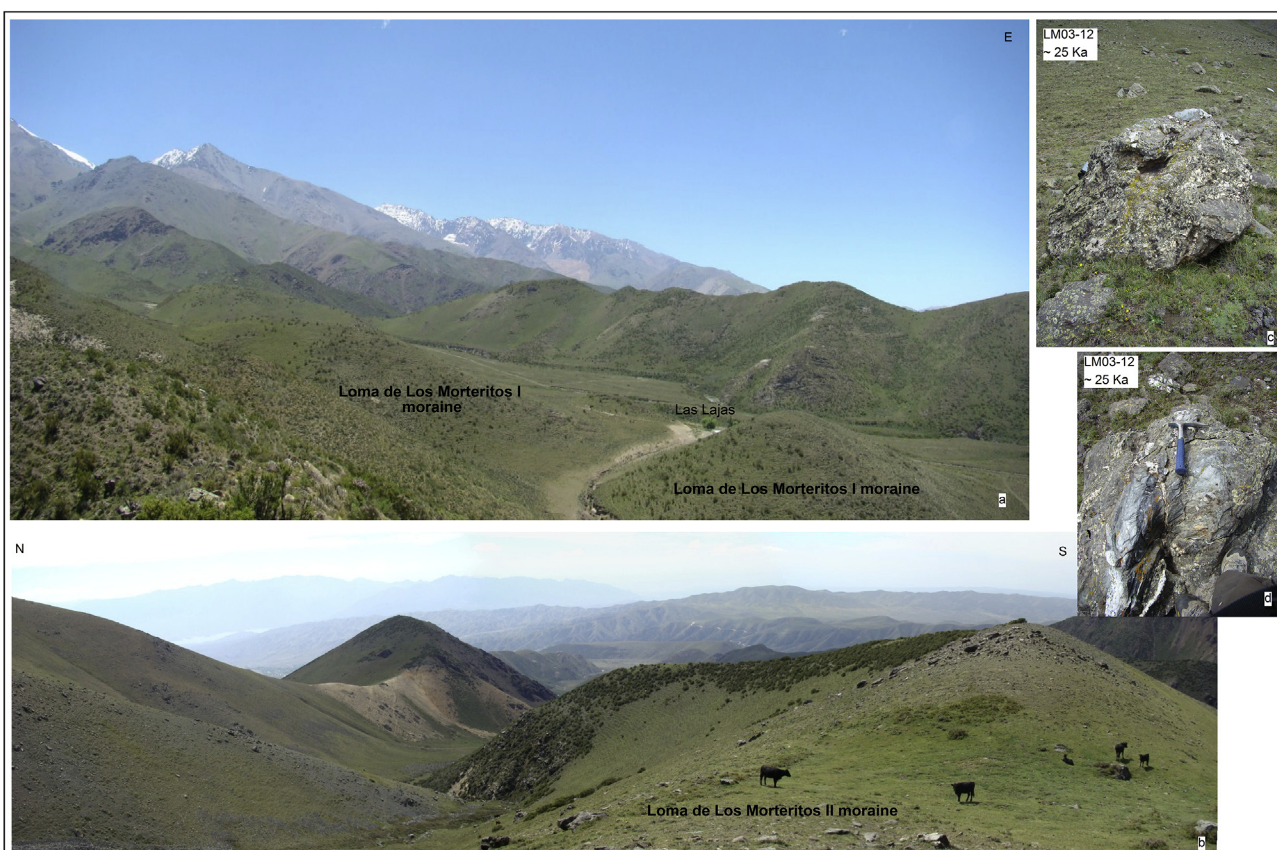

Fig. 6. Moraines deposits of the Loma de los Morteritos I (a) and II (b) identified along the Las Mulas valley, c. Sampled block corresponding to LM03-12 (~40 ka BP), and d. a detailed picture of the block. The location of pictures is indicated in Fig. 3.

Fig. 7. a. Exposed metamorphic block on alluvial fan surface along the Las Mulas valley from where sample H02-12 (~187 ka BP) was taken, the arrow indicates location of sample H04-12; b. detailed picture of Quartz vein sampled as H02-12; c. picture of the metamorphic block sampled on another alluvial fan surface (sample H04-12); d- Granodiorite boulder sampled from the outwash of the El Salto valley (sample SA04-12), the arrow indicates sampled surface; and e. detailed picture of sampled surface.

deposits in the BRB has been mainly ignored because traditional methods were unviable (e.g. tephrochronology). Likewise, the first relative chronology (Wayne, 1981; Wayne and Corte, 1983) was later rejected (Wayne, 1988) and was not verified until this study. The chronology of glacial stages previously proposed for this region should be under reconsideration (Hermanns et al., 2015; Moreiras et al., 2015). TCN dates makes it possible directly date glacial deposits. This method was successfully used in other Quaternary studies in the Central Andes (Baker et al., 2009; Pepin et al., 2013; Moreiras et al., 2015). However, TCN dating method is limited by the presence of large exposed boulders. A minimum of five samples is required to accurately characterize the cumulative cosmogenic exposure in proglacial bedrock surfaces (Beel et al., 2015). These authors suggested as few as three samples may provide accurate results, particularly from lateral locations in a glacial trough in some landscapes. Ideally, samples should be evenly distributed from the centre of the glacial trough to its lateral margin to capture the full distribution of changes in nuclide concentrations as a result of varying glacial erosion depths (Beel et al., 2015). The Laurentide continental ice-cover in New England during the LGM was documented with only nine ages of samples taken near the summits of Katahdin (n = 2), Mount Washington (n = 6), and Little Haystack Mountain (n = 1) (Bierman et al., 2015).

6.2. Timing of glacial advances

Our results show that at least three Quaternary glacial advances occurred in this portion of the Central Andes. Stratigraphic field data show that the oldest glacier advance is preserved in the lowest part of the study area, whereas evidences for two later advances appear at higher altitudes. The Rio Blanco moraine is barely preserved at 2019 masl and represents the oldest glacial advance in the study area. Even though the age of this advance has not been established in this paper, we assume it is younger than nearby alluvial fans. A great discrepancy exists for test samples taken from these alluvial fans in the piedmont area (~7 and ~187 ka BP). However, the older age matches very well with a Middle Pleistocene age, which was determined independently for these deposits (García and Casa, 2015).

The chronology of the next glacial advance could unfortunately not be determined. The absence of large blocks on the top surface of the Lomas de Los Morteritos I moraine precluded TCN dating. Thus, the age of ~11 ka for Angostura I moraine remains unconfirmed by a numeric age.

The last glacial advance, during the Late Pleistocene, was inferred from the Angostura II moraine and the Loma de Los Morteritos II moraine. The sample from the Angostura II moraine was dated to ~18 and ~25 ka BP, agreeing with outwash deposits of the El Salto valley (~25 ka BP). Nonetheless, these ages are not comparable with the ^{10}Be exposure age (~40 ka BP) obtained for the Loma de los Morteritos II. Significant, unexplained variations in ages between sites have recently been pointed out when using the CRONUS program (Borchers et al., 2016). This apparent bias could be due to problems with elevation and latitude scaling, or it could be due to problems with the characterization of the site, including incorrect assumptions about parameters such as erosion rates and atmospheric pressure. A pre-exposure is also a possible factor.

On this basis, we assumed that Angostura II, Loma de Los Morteritos II, and Vallecitos moraines are synchronic with the El Salto Drift (Table 5). Ages for this Pleistocene glacial stage seem to be in phase with the global LGM. They are in good agreement with published exposure age of this period. The last large glacial period in the Earth's climate history occurred between ~23 and 18 ka BP (Hughes and Gibbard, 2015). Mix et al. (2001) prefer a range for the LGM of 23-19 or 24–18 ka BP. Thompson et al. (2000) concluded that the LGM ended around 17.5 ka BP, based on temperature decreases at high elevations, inferred from δ^{18}O isotopes of an ice core from the Huascarán glacier in Peru. Glacier advances synchronous with the LGM were documented (~24–18 ka BP) in the humid tropical Andes (Mix et al., 2001; Ilgner et al., 2013). A glacier climate model arrived to a massive cooling with temperatures lowered 4.5–8 °C combined with a moderate precipitation increase in a factor of 2–4 was necessary to explain maximum glacier extension during MIS 2 (25–18 ka) at 22° S (Kull et al., 2003). At least two advances between ~39 and ~17.5 ka BP are documented in the Última Esperanza region (51° S), in south-western Patagonia (Sagredo et al., 2011). The Last Glacial Termination (LGT) in north-western Patagonia has been documented with abrupt warm pulses at 17,800 and 17,100 cal yrs BP, accompanied by the rapid establishment of evergreen temperate rainforests and the extensive deglaciation of the Andes (Moreno et al., 2015).

Table 5
Suggested chronological correlation of moraine deposits along the Blanco River Basin.

<table>
<tr><td>Wayne (1981)</td><td>Wayne & Corte (1983)</td><td colspan="4">This study</td></tr>
<tr><td colspan="2">Vallecitos valley</td><td>Vallecitos valley</td><td>Angostura valley</td><td>Las Mulas valley</td><td>Salto valley</td></tr>
<tr><td>Holoceno I</td><td rowspan="3"></td><td rowspan="3">Debris rock glaciers</td><td rowspan="3">Debris rock glaciers</td><td rowspan="3">Active covered Glacier</td><td rowspan="3">Active covered Glacier</td></tr>
<tr><td>Holoceno II</td></tr>
<tr><td>Holoceno III</td></tr>
<tr><td>Vallecitos II 3400 – 2900 m</td><td>12-16 ka (age proposed)</td><td rowspan="2">Vallecitos 3400 – 2600 m (disturben)</td><td rowspan="2">Angostura II 3200 – 2910 m (~8 ka) (~12 ka)</td><td rowspan="2">Loma de los Morteritos II 2960 m (~25 ka)</td><td rowspan="2"></td></tr>
<tr><td>Vallecitos I 2690 m</td><td>17-22 ka (age proposed) MIS 2</td></tr>
<tr><td colspan="2">MIS 3?</td><td colspan="4"></td></tr>
<tr><td colspan="2"></td><td></td><td>Angostura I 3200 – 2600 m (~15 ka)</td><td>Loma de los Morteritos I 2500 m</td><td>Outwash (~69 ka)</td></tr>
<tr><td colspan="2">MIS 5?</td><td colspan="4"></td></tr>
<tr><td>Rio Blanco 2010 m</td><td>MIS 6?</td><td>Rio Blanco 2020 m</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">MIS 7</td><td></td><td></td><td>Alluvial fans 2100 m (~196 ka) (~16 ka) ¿?</td><td></td></tr>
<tr><td></td><td>Angostura (2100-2600) Rio Mendoza (2010m) MIS 12?</td><td></td><td></td><td></td><td></td></tr>
</table>

Late Pleistocene ages of glacial deposits in the BRB fit very well with other Quaternary studies in the region. The Quaternary history of the Diamante River valley (34° S) includes fluvial terrace aggradations during the glacial stages of MIS 2 (Baker et al., 2009). The Qt4 terrace was TCN-dated to 19 ± 4, 22 ± 7, and 24 ± 5 ka BP. Pepin et al. (2013) gave new information for the interpretation of deep piedmont entrenchments in Las Tunas River (50 km south of the study area). These authors established that the main terrace abandonment phases took place before 0.85 Ma BP for T3 and around 20 ka BP for T1 and T2. River entrenchment agreed with major post-glaciation periods (interstadials), which are associated with greater melting and increased sediment in mountain catchments, despite local active tectonics.

Diachronic intervals of aeolian accumulation in the eastern piedmont are associated with sand supplied by fluvial systems fed by glaciated Andean valleys. The oldest aeolian record (Médanos de los Naranjos dune field) at 34° S was dated by OSL at ~24 ka BP, which correlates with the LGM (Tripaldi et al., 2011). During this cold period, aeolian accumulation also generated a dune field in San Luis province, covering sands and intercalated paleosols spanning ca. 33 to 22 ka BP (Ivy-Ochs et al., 2004; Kemp et al., 2006). Similar ages were found for a sand sheet deposited at ca 33 ka BP in the Andean piedmont (Tripaldi and Forman, 2007), which agree with our younger glacial stage in the BRB. The Pampean Aeolian System, covering more than 600,000 km^2 in the central Argentine plains, evolved during the LGM (Iriondo and Kröhling, 2007). One of the most representative loess units covering the south-western Entre Ríos, Santa Fe, and Eastern Córdoba provinces, was OSL dated to the LGM. Field dunes of the Pampean Sand Sea (south-eastern Córdoba, southern Santa Fe and north-western Buenos Aires provinces) were also generated during the LGM (Iriondo et al., 2011).

The ^{10}Be exposure ages were estimated by time depend models (Lal, 1991; Stone, 2000) and by time-varying production models (Dunai, 2001; Desilets and Zedra, 2003; Lifton et al., 2005; Desilets et al., 2006). The application of new models for scaling in situ cosmogenic nuclide production rates would vary ages (e.g. LSD, Lifton et al., 2014). This likely results on older ages push them outside of the global LGM. Yet the LSD model is enhanced at low latitudes (higher energy portions of the atmospheric flux) due to geomagnetic shielding effects, but did more middle altitudes. Chronology will also show a discrepancy with an updated of geomagnetic and solar modulation (Lifton, 2016; Marrero et al., 2016). By convention, all scaling models are referenced to conditions at sea level and high geomagnetic latitude (SLHL). Corrections due to sporadic snow cover were not considered in our age estimation. But there are more error in production rate estimation, than omitting this factor as could be check in previous datings (Moreiras et al., 2015).

The ^{10}Be exposure ages obtained in this study are quite variable and few, representing a maximum age for glacial advances. They are confined to the Late Pleistocene and are consistent with stratigraphic studies, matching regional Quaternary chronologies, and generally fit ages of alluvial fan deposits located downslope in the piedmont. Our results partially agree with the Pleistocene age previously attributed to the Vallecitos moraine (Buk, 2002) and ages suggested in previous studies by relative dating methods (Wayne and Corte, 1983; Wayne, 1988). So even though the chronology of glacial drifts in the BRB did not perform as expected, this effort has provided preliminary numerical dates of glacial deposits that shed light on BRB's glacial history and improve our knowledge of Quaternary stratigraphy in the Central Andes. Further dates are needed to better address glacial stages in the study area.

6.3. Climate and tectonic interplay

The landscape is often a result of interplay between external and internal geodynamic processes. However, landscape evolution forces are not straightforward. These processes may act on different timescales and may be responsible for uplift at local or regional scales. Particularly, this segment of the Central Andes is a suitable setting to evaluate features caused by major climatic changes induced by local or regional factors such as tectonic forcing.

The Quaternary glaciations were clearly conditioned by the steep topography of the Andes. Glaciers occupied the highest elevations (over 2000 masl) of the uplifted Plata range. The orientation of longitudinal valleys limited glacier accumulation. This explains the notable differences between glacier extension between catchment areas and their sedimentation patterns. The highest northern location and the colder southern orientation of the Vallecitos valley favoured snow accumulation, and hence the generation and retention of glaciers. Distribution of glaciers was reduced and confined to the main valleys in the lower southern mountains and eastern-facing valleys. This reflects, in part, that the glacial sediments filling in the valleys reached thicker moraines to the south. Particularly, any moraines found in the northern El Salto valley, where there were two outwash plains, could be explained by a rapid loss of internal glacial ice on warmer slopes.

Undoubtedly, these mountain glaciers played a key role in denuding the landscape and transferring sediments to rivers. Glacial and outwash deposition dominated in high glaciated mountain areas, while non-glacial debris was prevalent in valley mouths and the lower piedmont. However, this sediment flux seems to be more related to tectonic activity than climate change, because younger glacial deposits are located on hanging walls of regionally active faults of the Carrera Fault system, while older alluvial deposits cover Neogene rocks.

The oldest glaciation (the Rio Blanco drift) was not affected by neotectonic activity, however, Middle Pleistocene alluvial deposits fan (~7 and ~187 ka BP) are offset by active faults in the piedmont. This agrees with the hypothesis that younger glaciation remaining at higher positions is not affected by neotectonic activity. Therefore, as was previously noted by Wayne (1988), glaciers should be established later in a non-tectonic period. In this sense, rock avalanches linked to a shaking earthquake triggered in the northern extreme of Plata range have been recently dated to the Late Pleistocene (~45 ka BP) (Moreiras et al., 2015).

Concerning climate–tectonic interplay, the retreat of Pleistocene glaciers could be related to local uplift. This could create significant incisions along the main valleys during the post-glacial times. The overdeepened glacial valleys of the BRB are very narrow along the steeper part of the mountain. They migrate laterally downslope to outwash plains and extensive alluvial fans in piedmont, which is dominated by braided streams. Hence the paradigm mountain glaciations respond to climate change in tectonically uplifted orogen was shifting to consider glaciers are driving agents of mountain uplift, essentially by denudational unloading, and limiting topography (Owen et al., 2009). On the other hand, climate could have forced neotectonic activity, as minor reactivations of regional faults may result from terrain accommodation due to an isostatic rebound effect. However, climate–tectonic interplay forcing mountain relief is uncertain on short time scales (Tomkin and Roe, 2007).

Climate and tectonics seem to be out of phase in the study area. The colder stage in the LGM is not temporally correlated with neotectonic activity in the Carrera fault system. Chronological data of the deformed units, seismic triggered rock avalanches and out setting alluvial fans are older than glacial advances identified in the Plata range. Therefore, a warmer stage is associated with tectonically active periods alternating to a calm cold stage leading a tectonic gap.

7. Final remarks

This research provides new data on the glacial chronology of the Plata range in the BRB. New findings support the following conclusions:

1. At least three Pleistocene glacial advances were documented for the Blanco River valley.
2. A younger glacial advance (17–25 ka BP) seems to be in phase with the LGM
3. Alluvial fans affected by neotectonics are older than the BRB glacial deposits
4. The timing of neotectonic activity should be previous to glacial advances, as the moraine deposits are not affected.
5. The coupled climate–tectonic system is out of phase in the study area.

Acknowledgements

We are indebted to S. Carretier, L'Institut de recherche pour le développement (IRD) for TCN datings and Paula Rodriguez, Argentinean Research Institute of Snow and Glaciology, carried out the grain size analyses of the moraines. We thank the editor of this volume Daniela Kröhling and anonymous reviewers for comments that improved this manuscript. Field and laboratory work was supported by the National University of Cuyo and CONICET (PIP 2012-683). Other funds came from CONICET (PIP 2005-31696), lead by Moreiras. We express our sincere thanks to Leandro Mastrantonio and Camilo Arco for helping with summer fieldwork.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2016.08.041.

References

Abele, G., 1984. Derrumbes de montaña y morrenas en los Andes chilenos. Revista de Geografía Norte Grande 11, 17–30.
Baker, S., Gosse, J.C., Mc Donald, E., 2009. Quaternary history of the piedmont reach of the rio Diamante, Argentina. Journal of South American Earth Sciences 28 (1), 54–73.
Beel, C.R., Goehring, B.M., Lifton, N.A., 2015. How many and from where? Assessing the sensitivity of exposure durations calculated from paired bedrock 14C/10Be measurements in glacial troughs. Quaternary Geochronology 29, 1–5.
Bierman, P.R., Davis, P.T., Corbett, L.B., Lifton, N.A., Finkel, R.C., 2015. Cold-based Laurentide ice covered New England's highest summits during the last glacial maximum. Geology 43 (12), 1059–1062.
Borchers, B., Marrero, S., Balco, G., Caffee, M., Goehring, B., Lifton, N., Nishiizumi, K., Phillips, F., Schaefer, J., Stone, J., 2016. Geological calibration of spallation production rates in the CRONUSEarth project. Quaternary Geochronology 31, 188–198.
Borgnia, M., 2004. Neotectónica del piedemonte oriental del cordón del Plata al norte del río Blanco, provincia de Mendoza. Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Ciencias Geológicas (Degree thesis), p. 143. inedit.
Brenning, A., 2003. La Importancia de los Glaciares de Escombros en los Sistemas Geomorfológico e Hidrológico de la Cordillera de Santiago: Fundamentos y Primeros Resultados. Revista de Geografía Norte Grande 30, 7–22.
Brenning, A., Trombotto, D., Schroeder, H., 2005. Zur Verbreitung von Blockgletschern in den semiariden Anden (Chile/Argentinien, 32-35°S): Bedeutung, regionale Trends und der Einfluss des Reliefs. Berliner Geographische Arbeiten 100, 19–28.
Buk, E., 2002. Hidrología de ambientes periglaciales. Cuenca Morenas Coloradas –Vallecitos, Cordón del Plata, Cordillera Frontal, Mendoza. In: Trombotto, D., Villalba, R. (Eds.), IANIGLA, 1973-2003: 30 años de Investigación Básica y Aplicada en Ciencias Ambientales. Editorial ZETA, Mendoza, pp. 60–65.
Bräuning, A., 2009. Climate variability of the tropical Andes since the late Pleistocene. Advances on Geoscience 22, 13–25. www.adv-geosci.net/22/13/2009/.
Caminos, R., 1965. Geología de la vertiente oriental del Cordón del Plata, Cordillera Frontal de Mendoza. Asociación Geológica Argentina. Revista 20 (3), 351–392.
Casa, A.L., 2005. Geología y neotectónica del piedemonte oriental del cordón del Plata en los alrededores de El Santo. Universidad de Buenos Aires (Degree thesis), p. 174. inedit.
Casa, A.L., 2007. AR-86, Sistema de fallas de La Carrera (sector central). En: PMA-GCA, Proyecto Multinacional Andino: Geociencia para las Comunidades Andinas, 2009. Atlas de deformaciones cuaternarias de los Andes. Servicio Nacional de Geología y Minería, Publicación Geológica Multinacional, no. 7, p. 320, 1 CD-ROM.
Casa, A.L., 2009. Sistema de Fallas de La Carrera (AR-86; AR-114; AR-115; AR-116; AR-156). En: Proyecto Multinacional Andino: Geociencia para las Comunidades Andinas. Atlas de deformaciones cuaternarias de los Andes. Servicio Nacional de Geología y Minería, Publicación Geológica Multinacional, 7(5), pp. 118–123.
Casa, A.L., Cortés, J.M., Borgnia, M., 2010. Evidencias de deformación pleistocena en el sistema de fallas de La Carrera (32º 40′ – 33º 15′ LS), Cordillera Frontal, Mendoza. Revista de la Asociación Geológica Argentina 67 (1), 91–104.
Clapperton, C.M., 2000. Interhemispheric synchroneity of marine oxygen isotope stage 2 glacier fluctuations along the American cordilleras transect. Journal of Quaternary Science 15, 435–468.
Corte, A.E., 1957. Sobre la geología glaciar Pleistocénica deMendoza. Anales del Departamento de Investigaciones Científicas. Universidad Nacional de Cuyo 2 (2), 1–27. Mendoza.
Corte, A.E., Grosso, E., 1993. Geocriología en. In: Ramos, V.A. (Ed.), Geología y recursos naturales de Mendoza. XII Congreso Geologico Argentino y II Congreso de Exploración d Hidrocarburos, Relatorio (16), pp. 205–216.
Corte, A.E., Espizúa, L., 1981. Inventario de glaciares de la cuenca del Río Mendoza. Edit. IANIGLA, p. 64. Mendoza.
Cortés, J.M., Vinciguerra, P., Yamín, M., Pasini, M.M., 1999. Tectónica Cuaternaria de la Región Andina del Nuevo Cuyo (28º - 38º LS). In: Caminos, R. (Ed.), Geología Argentina. Subsecretaría de Minería de la Nación, Servicio Geológico Minero Argentino, Anales 29(24), pp. 760–778.
Cortés, J.M., Casas, A., Pasini, M., Yamín, M., Terrizzano, C., 2006. Fajas oblicuas de deformación geotectónica en Precordillera y Cordillera Frontal (31°30′- 33°30′ LS): controles paleotectónicos. Revista de la Asociación Geológica Argentina 61 (4), 639–646.
Deckart, K., Pinochet, K., Sepúlveda, S., Pinto, L., Moreiras, S.M., 2014. New insights on the Mesón Alto deposit, Yeso Valley, central Chile: a composite deposit of glacial and landslide processes? Andean Geology 41 (1), 248–258. http://dx.doi.org/10.5027/andgeoV41n1-a10.
Desilets, D., Zedra, M., 2003. Spatial and temporal distribution of secondary cosmic-ray nucleon intensities and applications to in situ cosmogenic dating. Earth and Planetary Science Letters 206 (1–2), 21–42.
Desilets, D., Zreda, M., Prabu, T., 2006. Extended scaling factors for in situ cosmogenic nuclides: new measurements at low latitude. Earth and Planetary Science Letters 246 (3–4), 265–276.
Douglass, D.C., Singer, B.S., Kaplan, M.R., Mickelson, D.M., Caffee, M.W., 2006. Cosmogenic nuclide surface exposure dating of boulders on last-glacial and late-glacial moraines, Lago Buenos Aires, Argentina: interpretive strategies and paleoclimate implications. Quaternary Geochronology 1 (1), 43–58. http://dx.doi.org/10.1016/j.quageo.2006.06.001.
Dunai, T.J., 2001. Document Influence of secular variation of the geomagnetic field on production rates of in situ produced cosmogenic nuclides. Earth and Planetary Science Letters 193 (1–2), 197–212.
Espizúa, L., 1983. In: Edward, B., Schluchter, C., Rabassa, Jorge (Eds.), Tills and Related Deposits; Genesis, Petrology, Application, Stratigraphy. Evenson. A. A. Balkema, Rotterdam, Netherlands, pp. 381–395.
Espizúa, L., 1999. Chronology of late Pleistocene glacier advances in the rio Mendoza valley, Argentina. Global Planetary Change 22, 193–200.
Espizúa, L., 2004. Pleistocene glaciations in the Mendoza Andes, Argentina. In: Ehlers, J., Gibbard, P. (Eds.), Quaternary Glaciations – Extent and Chronology. Elseviers III, Cambridge, pp. 69–73.
Fauqué, L., Hermanns, R., Hewitt, K., Rosas, M., Wilson, C., Baumann, V., Lagorio, S., Di Tommaso, I., 2009a. Mega-landslide in the southern wall of the Aconcagua and its relationship with deposits assigned to Pleistocene glaciations. Revista Asociación Geológica Argentina 65 (4), 691–712.
Fauqué, L.E., Hermanns, R.L., Wilson, C.G.J., 2009b. Mass removal in the Andean region. Revista Asociación Geológica Argentina 65 (4), 687–694.
Folguera, A., Etcheverría, M., Pazos, P., Giambiagi, L., Fauqué, L., Cortés, J., Rodríguez, F., Irigoyen, V., Fusari, C., 2004. Hoja Geológica 3369-15, Potrerillos, provincia de Mendoza. Servicio Geológico Minero Argentino, Boletín Nº 301, 252, 1 mapa, Buenos Aires.
Font, E.A., Chiesa, J.A., 2015. Palaeoenvironmental reconstruction based on charophytes and sedimentology: can the mid-Holocene Optimum be recognised in western Argentina? Aquatic Botany 120 A, 31–38. http://dx.doi.org/10.1016/j.aquabot.2014.08.006, 0304–3770/©.2014.Elsevier B.V.
Frechen, M., Seifert, B., Sanabria, J.A., Argüello, G.L., 2009. Chronology of late Pleistocene Pampa loess from the Cordoba area in Argentina. Journal of Quaternary Science 24, 761–772.
García, V.H., Casa, A.L., 2015. Quaternary tectonics and seismic potential of the Andean retrowedge at 33–34 S. In: Sepúlveda, S.A., Giambiagi, L.B., Moreiras, S.M., Pinto, L., Tunik, M., Hoke, G.D., Farías, M. (Eds.), Geodynamic

Processes in the Andes of Central Chile and Argentina. Geological Society of London, Special Publications 399, pp. 311–327.
Giambiagi, L.B., Ramos, V.A., Godoy, E., Alvarez, P.P., Orts, S., 2003. Cenozoic deformation and tectonic style of the Andes, between 33° and 34° South Latitude. Tectonics 22 (4), 1041. http://dx.doi.org/10.1029/2001TC001354.
Gosse, J.C., Phillips, F.M., 2001. Terrestrial in situ cosmogenic nuclides: theory and application. Quaternary Science Reviews 20, 1475–1560.
Grosjean, M., Cartajena, I., Geyh, M., Nunez, L., 2003. From proxy data to paleoclimate interpretation: the mid-Holocene paradox of the Atacama Desert, northern Chile. Palaeogeography Palaeoclimatology Palaeoecology 194, 247–258.
Harrison, S., 2004. The Pleistocene glaciations of Chile. In: Ehlers, J., Gibbard, P. (Eds.), Quaternary Glaciations – Extent and Chronology, vol. III. Elseviers, Amsterdam, pp. 89–103.
Heredia, N., Farias, P., García-Sansegundo, J., Giambiagi, L., 2012. The Basement of the Andean Frontal Cordillera in the Cordón del Plata (Mendoza, Argentina). Geodynamic Evolution Andean Geology 39 (2), 242–257. http://dx.doi.org/10.5027/andgeoV39n2-a03, 05/2012.
Hermanns, R., Fauqué, F., Wilson, C., 2015. 36Cl terrestrial cosmogenic nuclide dating suggests late Pleistocene to early Holocene mass movements on the south face of Aconcagua mountain and in the Las Cuevas – Horcones valleys, Central Andes, Argentina. In: Geological Society of London. Special Publication 399 Geodynamic Processes in the Andes of Central Chile and Argentina. http://dx.doi.org/10.1144/SP399.19.
Hewitt, K., 1999. Quaternary moraines vs. catastrophic rock avalanches in the Karakoram Himalaya, Northern Pakistan. Quaternary Research 51, 220–237.
Hewitt, K., Gosse, J., Clague, J.J., 2011. Rock avalanches and the pace of late Quaternary development of river valleys in the Karakoram Himalaya. Geological Society American Bulletin 123, 1836–1850.
Hughes, P.D., Gibbard, P.L., 2015. The Quaternary System and its formal subdivision. Quaternary International 383, 174–185.
Ilgner, J., Zech, R., Baechtiger, C., Kubik, P.W., Veit, H., 2013. Systematic Uncertainties of Glacial Chronologies Based on Surface Exposure Dating. American Geophysical Union. Fall Meeting 2008, abstract #GC21A-0722.
Irigoyen, M.V., Buchan, K.L., Brown, R.L., 2000. Magnetostratigraphy of Neogene Andean foreland-basin strata, lat 33°S, Mendoza Province, Argentina. Geological Society of America Bulletin 112 (6), 803–816.
Irigoyen, M.V., Buchan, K.L., Villeneuve, M.E., Brown, R.L., 2002. Cronología y significado tectónico de los estratos sinorogénicos neógenos aflorantes en la región de Cacheuta-Tupungato, Provincia de Mendoza. Revista Asociación Geológica Argentina 57 (1), 3–18.
Iriondo, M., Kröhling, D., 2007. Non-classical types of loess. Sedimentary Geology 202, 352–368.
Iriondo, M., Kröhling, D., Brunetto, E., 2011. Chapter 1: aridization, dune dissipation and pedogenesis in the Quaternary of Eastern Pampean Sand Sea. In: Murphy, J.A. (Ed.), Sand Dunes: Conservation, Shapes/Types and Desertification. Nova Science Publishers, Inc, NY, USA, p. 42.
Ivy-Ochs, S., Poschinger, Kemp, R.A., Toms, P.S., King, M., Kröhling, D.M., 2004. The pedosedimentary evolution and chronology of Tortugas, a Late Quaternary type-site of the northern Pampa, Argentina. Quaternary International 114 (1), 101–112.
Kemp, R.A., Toms, P.S., King, M., Kröhling, D.M., 2004. The pedosedimentary evolution and chronology of Tortugas, a Late Quaternary type-site of the northern Pampa, Argentina. Quaternary International 114 (1), 101–112.
Kemp, R.A., Zárate, M., Toms, P., Sanabria, J., Argüello, G.L., 2006. Late Quaternary palaeosoils, stratigraphy and landscape evolution in the northern Pampa, Argentina. Quaternary Research 66, 119–132.
Kleiman, L.E., Japas, M.S., 2009. The Choiyoi volcanic province at 34°S-36°S (San Rafael, Mendoza, Argentina): implications for the Late Palaeozoic evolution of the southwestern margin of Gondwana. Tectonophysics 473, 283–299.
Kozlowski, E., Manceda, R., Ramos, V., 1993. Estructura. Geología y recursos naturales de Mendoza. In: Ramos, V. (Ed.), Relatorio XII Congreso Geológico Argentino y II Cong. de Exploracion de Hidrocarburos, pp. 235–256.
Kröhling, D.M., 1999. Upper Quaternary geology of the lower Carcarana Basin, North Pampa, Argentina. Quaternary International 57–8, 135–148.
Kull, C., Hänni, F., Grosjean, M., Veit, H., 2003. Evidence of an LGM cooling in NW-Argentina (22ºS) derived from a glacier climate model. Quaternary International 108, 3–11.
Lal, D., 1991. Cosmic ray labeling of erosion surfaces: in situ nuclide production rates and erosion models. Earth and Planetary Science Letters 104, 424–439.
Lifton, N.A., 2016. Implications of two Holocene time-dependent geomagnetic models for cosmogenic nuclide production rate scaling. Earth and Planetary Science Letters 433, 257–268.
Lifton, N.A., Bieber, J.W., Clem, J.M., Duldigc, M.L., Evenson, P., Humble, J.E., Pyle, R., 2005. Addressing solar modulation and long-term uncertainties in scaling secondary cosmic rays for in situ cosmogenic nuclide applications. Earth and Planetary Science Letters 239 (1–2), 140–161.
Lifton, N., Sato, T., Dunai, T.J., 2014. Scaling in situ cosmogenic nuclide production rates using analytical approximations to atmospheric cosmic-ray fluxes. Earth and Planetary Science Letters 386, 149–160.
Llambías, E.J., Kleiman, L.E., Salvarredi, J.A., 1993. El magmatismo Gondwánico. In: En Ramos, V.A. (Ed.), Geología y Recursos Naturales de Mendoza. 12º Congreso Geológico Argentino y 2º Congreso de Exploración de Hidrocarburos, Relatorio, pp. 53–64. Mendoza.
Marrero, S.M., Phillips, F.M., Borchers, B., Lifton, N., Aumer, R., Balco, G., 2016. Cosmogenic nuclide systematics and the CRONUScalc program. Quaternary Geochronology 31, 160–187.
Masiokas, M.H., Villalba, R., Luckman, B.H., Mauget, S., 2010. Intra- to multidecadal variations of snowpack and streamflow records in the Andes of Chile and Argentina between 30° and 37°S. Journal of Hydrometeorology 11 (3), 822–831. http://dx.doi.org/10.1175/2010JHM1191.1.
May, J.-H., Zech, R., Schellenberger, A., Kull, C., Veit, H., 2008. Quaternary environmental and climate changes in the Central Andes. In: Marquillas, Salfity (Ed.), Cenozoic Geology of the Central Andes of Argentina, pp. 247–263.
Mehl, A., Zárate, M., 2013. Paleosoils and limnic levels in the late Pleistocene and Holocene alluvial successions of the Andean Piedmont of Mendoza (33∘–34∘LS), Argentina. Latin American Journal Sedimentology Basin Analisis 20, 3–20.
Mix, A.C., Bard, E., Schneider, R., 2001. Environmental processes of the ice age: land, oceans, glaciers (EPILOG). Quaternary Science Reviews 20, 627–657.
Moreiras, S.M., 2006. Chronology of a Pleistocene rock avalanche probable linked to neotectonic, Cordon del Plata (Central Andes), Mendoza - Argentina. Quaternary International 148, 138–148.
Moreiras, S.M., Hermanns, R.L., Fauqué, L., 2015. Cosmogenic dating of rock avalanches constraining Quaternary stratigraphy and regional neotectonics in the Argentine Central Andes (32º S). Quaternary Science Reviews 112 (15), 45–58.
Moreiras, S.M., Lisboa, S., Mastrantonio, L., 2012. The role of snow melting upon landslides in the central Argentinean Andes. Earth Surface and Processes Landforms 37 (10), 1106–1119. http://dx.doi.org/10.1002/esp.3239. Special issue on Historical Range of Variability. Guest editors: Ellen Wohl and Sara Rathburn.
Moreiras, S.M., Sepúlveda, S.A., 2015. Megalandslides in the Andes of Central Chile and Argentina (32°-34°s) and potential hazards. Geodynamic processes in the Andes of Central Chile and Argentina. Geological Society of London 399, 329–344. http://dx.doi.org/10.1144/SP399.18. First published online May 13, 2014.
Moreno, P.I., Denton, G.H., Moreno, H., Lowell, T.V., Putnam, A.E., Kaplan, M.R., 2015. Radiocarbon chronology of the last glacial maximum and its termination in northwestern Patagonia. Quaternary Science Reviews 233–249.
Nishiizumi, K., Imamura, M., Caffee, M.W., Southon, J.R., Finkel, R.C., McAninch, J., 2007. Absolute calibration of 10Be AMS standards. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms 258 (2), 403–413. http://dx.doi.org/10.1016/j.nimb.2007.01.297.
Owen, L.A., Thackray, G., Yi, C., 2009. Mountain glaciation and landscape evolution. Geomorphology 103, 155–157.
Páez, M.S., Moreiras, S.M., Brenning, A., Giambiagi, L.B., 2013. Flujos de detritos-aluviones históricos en la cuenca del Río Blanco (32°55′-33°10′ Y 69°10′-69°25′), Mendoza. Revista de la Asociación Geológica Argentina 70 (4), 488–498.
Pepin, E., Carretier, S., Herail, G., Regard, V., Charrier, R., Farías, M., García, V., Giambiagi, L., 2013. 2013. Pleistocene landscape entrenchment: a geomorphological mountain to foreland field case, the LasTunas system, Argentina. Basin Research 25, 1–25. http://dx.doi.org/10.1111/bre.12019.
Piovano, E., Ariztegui, D., Córdoba, F., Cioccale, M., Sylvestre, F., 2009. Hydrological variability in South America below the tropic of Capricorn (Pampas and Patagonia, Argentina) during the last 13.0 ka. In: Vimeux, F., Sylvestre, F., Khodri, M. (Eds.), Past Climate Variability in South America and Surrounding Regions. Developments in Paleoenvironmental Research 14. Springer Science Business Media B.V, France, pp. 323–351.
Polanski, J., 1958. El bloque varíscico de la Cordillera Frontal de Mendoza. Asociación Geológica Argentina. Revista 12 (3), 165–196.
Polanski, J., 1963. Estratigrafía, neotectónica y geomorfología del Pleistoceno pedemontano entre los ríos Diamante y Mendoza; Asociación Geológica Argentina. Revista 17 (3–4), 127–349.
Polanski, J., 1965. The máximum glaciation in the Argentine Cordillera. Geological Society of America 84, 453–472. Special Paper.
Polanski, J., 1972. Descripción geológica de la Hoja 24a-b Cerro Tupungato, provincia de Mendoza. Dirección nacional de Geología y Minería. Boletín 128, 1–110.
Rabassa, J., Coronato, A., Martinez, O., 2011. Late Cenozoic glaciations in Patagonia and Tierra del Fuego: an updated review. Biological Journal of the Linnean Society 103 (2), 316–335.
Rodríguez, E., Barton, M., 1993. El Cuaternario de la llanura. In: Ramos, V. (Ed.), ,Geología y Recursos Naturales de Mendoza. Relatorio del XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos. Mendoza, pp. 173–194.
Rojo, L.D., Mehl, A.E., Paez, M.M., Zárate, M.A., 2012. Mid- to Late Holocene pollen and alluvial record of the arid Andean piedmont between 33° and 34° S, Mendoza, Argentina: inferences about floodplain evolution. Journal of Arid Environments 77, 110–122.
Sagredo, E.A., Moreno, P.I., Villa-Martínez, R., Kaplan, M.R., Kubik, P.W., Stern, C.R., 2011. Fuctuations of the Última Esperanza ice lobe (52°S), Chilean Patagonia, during the last glacial maximum and termination. Geomorphology 125, 92–108.
Secretaría de Minería de la Nación web site, 2015.
Stone, J.O., 2000. Air pressure and cosmogenic isotope production. Journal of Geophysical Research B 105, 23753–23759.
Thompson, L.G., Mosley-Thompson, E., Handerson, K.A., 2000. Ice-core palaeoclimate records in tropical South America since the Last Glacial Maximum. Journal of Quaternary Science 15 (4), 377–394.

Tomkin, J.H., Roe, G.H., 2007. Climate and tectonic controls on glaciated critical-taper orogens. Earth and Planetary Science Letters 262 (3–4), 385–397.

Tripaldi, A., Forman, S.L., 2007. Geomorphology and chronology of Late Quaternary dune fields of western Argentina. Palaeogeography, Palaeoclimatology. Palaeoecology 251, 300–320.

Tripaldi and Zárate, 2016. A review of Late Quaternary inland dune systems of South America east of the Andes. Quaternary International 410, 96–110.

Tripaldi, A., Zárate, M., Brook, G.A., Guo-Qiang, L., 2011. 2011. Late Quaternary paleoenvironments and paleoclimatic conditions in the distal Andean piedmont, southern Mendoza, Argentina. Quaternary Research 76, 253–263.

Trombotto, D., 1991. Untersuchungen zum periglazialen Formenschatz und zu periglazialen Sedimenten in der "Lagunita del Plata", Mendoza, Argentinien. Heidelberger Geographische Arbeiten 90, 171.

Trombotto, D., 2002. Present cryogenic environment and palaeopermafrost in Southern South America. In: Trombotto, D., Villalba, R. (Eds.), IANIGLA, 1973-2003: 30 años de Investigación Básica y Aplicada en Ciencias Ambientales. Editorial ZETA, Mendoza, pp. 65–70.

Trombotto, D., Borzotta, E., 2009. Indicators of present global warming through changes in active layer-thickness, estimation of thermal diffusivity and geomorphological observations in the Morenas Coloradas rockglacier, Central Andes of Mendoza, Argentina. Cold Regions Science and Technology 55, 321–330.

Von Blanckenburg, F., Belshaw, N., O' Nions, R., 1996. Separation of 9Be and cosmogenic 10Be from environmental and SIMS isotope dilution analysis. Chemical Geology 129(1 (2)), 93–99.

Wayne, W.J., 1981. La evolución de glaciares de escombros y morenas en la Cuenca del Río Blanco, Mendoza. In: Proceedings of VIII Congreso Geológico Argentino, San Luis. Actas IV, pp. 153–166.

Wayne, W.J., 1988. The diamictons of Rio Blanco basin, Cordon del Plata, Mendoza. In: Quaternary of South America and Antarctic Peninsula, V. 6. Ed. Jorge Rabassa (rotterdam/brookfield: a.a.balkema, 1990), pp. 9–31.

Wayne, W.J., Corte, A.E., 1983. Multiple glaciations of the Cordon del Plata, Mendoza, Argentina. Palaeogeography Palaeoclimatology Palaeoecology 42 (1–2), 185–209.

Zárate, M., Kemp, R., Toms, P., 2009. Late Quaternary landscape reconstruction and geochronology in the northern Pampas of Buenos Aires province, Argentina. Journal of South American Earth Sciences 27, 88–99.

Zárate, M., Mehl, A., 2008. Estratigrafía y geocronología de los depósitos del Pleistoceno Tardío/Holoceno de la cuenca del Arroyo La Estacada, Departamentos de Tunuyán Y Tupungato (Valle de Uco), Mendoza. Revista de la Asociación Geológica Argentina 63 (3), 407–416.

Zech, J., 2012. Glacier and climate reconstruction in the Las Leñas Valley (35°S), Central Argentina. Special Issue XVIII INQUA Congress, 21st–27th July, 2011, Bern, Switzerland. Quaternary International 279–280, 555.

Zech, R., Kull, C., Veit, H., 2005. Late Quaternary glacial history in the Encierro Valley, northern Chile (29°S), deduced from 10Be surface exposure dating. Palaeogeography Palaeoclimatology Palaeoecology 234 (2), 277–286. http://dx.doi.org/10.1016/j.palaeo.2005.10.011, 05/2006.

Zech, R., Kull, Ch., Kubik, W., Veit, H., 2007. Climate of the Past Exposure dating of Late Glacial and pre-LGM moraines in the Cordon de Dona Rosa, Northern/Central Chile (~31° S). Climate of the Past EGU Journal 3, 1–14.

Zech, R., May, J.-H., Kull, C., Ilgner, J., Kubik, P.W., Veit, H., 2008. Timing of the Late Quaternary glaciation in the Andes from 15 to 40◦ S. Journal of Quaternary Science 23, 635–674.

Zech, R., Smith, J.A., Kaplan, M.R., 2009. Chronologies of the Last Glacial Maximum and its termination in the Andes (~10–55°S) based on surface exposure dating. In: Vimeux, F., Sylvestre, F., Khodri, M. (Eds.), Past Climate Variability in South America and Surrounding Regions. From the Last Glacial Maximum to the Holocene. Springer, pp. 61–87.