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A preliminary inventory of periglacial landforms in the Andes of La Rioja and San Juan, Argentina, at about 28°S

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Abstract

The Cerro El Potro and nearby mountain chains belong to the Andean Frontal Cordillera (28°S). Cerro El Potro is a glaciated mountain that is surrounded by huge valleys both on its Chilean and Argentinean flanks. Its southern limit is a steep rock wall towards the trough-shaped Río Blanco valley in Argentina, with a wide valley floor. The other sides of the mountain are characterized by well-developed Pleistocene cirques. The predominant landforms in this area have been shaped in a periglacial environment superimposed on an earlier glacial landscape. It is a region with abundant rock glaciers, a noteworthy rock glacier zone, but nevertheless, it is a relatively little known area in South America. In this preliminary inventory, the landforms surveyed were mainly gravitational in origin, including valley rock glaciers, talus rock glaciers, debris cones, landforms originated by solifluction processes and talus detrital sheets on mountain sides. Ancient moraine deposits have been found on the sides of the main rivers that cross the area form west to east, including the Blanco and Bermejo rivers. Present day fluvial activity is limited, and restricted to these main rivers. In this area of glacial valleys and small cirques, there are small lakes and other water bodies, grass covered patches and zones with high mountain vegetation. Present day glacial activity is restricted to the highest part of the area, above 5500 m a.s.l., mainly in the Cerro El Potro (5879 m) where a permanent ice field exists, as well as small mountain glaciers.
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1. Introduction

In the Cerro El Potro and adjoining areas, the landforms originating from the present glacial environment prevail only at altitudes higher than 5000 m. Periglacial landforms modify an early glacial landscape, which in the recent past occupied lower altitudes.

Fluvial activity is limited in the area and restricted mostly to the Blanco, Macho Muerto and Bermejo rivers. These rivers are permanent and rework the older glacial, periglacial and landslide deposits. Nevertheless, their erosional activity is not very important and mainly deepens the drainage system in the outwash plains.

Because the rainfall in the area is very limited (150 mm per year) and because of the prevailing glacial and periglacial environments, the minor order drainage pattern is poorly integrated and developed, whereas the major order drainage is well integrated and is fed mainly from ice melt. The channels of the main rivers are braided, due mostly to the high volume of bedload.

Even though the current glacial activity is limited, in the past it was an active relief modelling agent in the region. It is possible to observe erosive landforms as cirques, arêtes, horns, glacial valleys and hanging valleys. Some accumulation landforms of glacial origin are longitudinal and transversal moraines and small lakes and ponds are limited by them. The most representative periglacial landforms are detrital slopes, patterned grounds, rock glaciers, solifluction forms, talus cones and asymmetrical valleys, with south facing slopes being steeper than the north facing slopes.

The distribution and significance of rock glaciers in the Central Andes is controlled particularly by climatic and topographic factors and glacial history. In this region of predominant winter rainfall, annual precipitation ranges between 200 and 2000 mm, covering almost the entire

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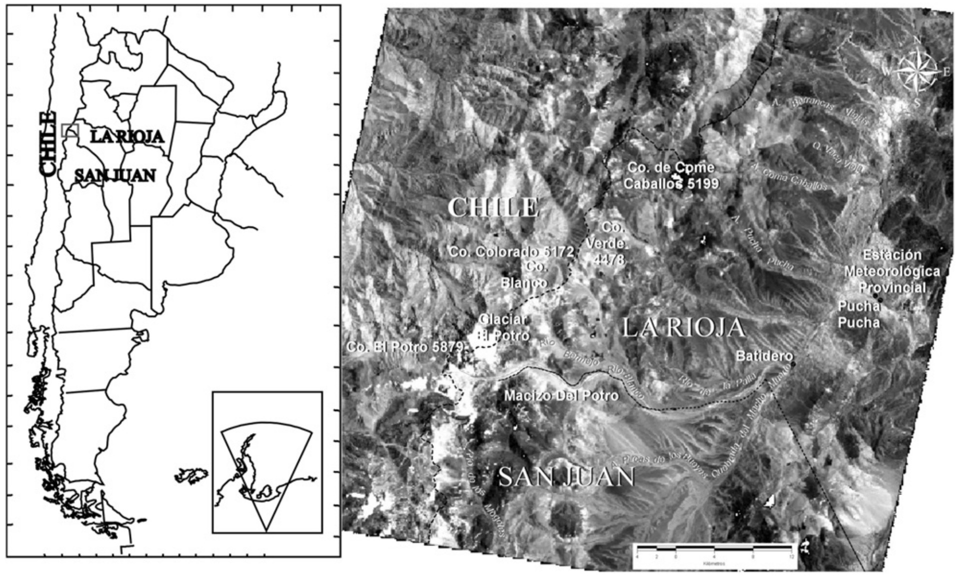

Fig. 1. Overview of the study area at approximately 28°S.

humidity range that is suitable for rock glacier development (Haeberli, 1975). At the present time, in South America periglacial environments are restricted to some portions of Andean Cordillera with low temperatures because of the mountain height. Excellent conditions for rock glacier formation prevail from the Arid North at 28°30′S to the Andes of Santiago at 33°–34°30′S (Brenning, 2005).

In the Central Andes of Mendoza (33°S), the present lower permafrost limit is found at an elevation of 3700–3800 m (Trombotto, 2000; Trombotto et al., 1997, 1999), while in the Patagonian Andes (51°S), permafrost was registered at an elevation of 980–1100 m during 1977–1978 (Roig, 1986) and at 44°S has been found above 2060 m (Trombotto, 2000). Towards the north, at about 28°S, the lower limit of Andean Permafrost is restricted to discontinuous permafrost, with abundant rock glaciers (Barsch, 1977) at an elevation of 4300–4500 m. In this study, the limit of "approximately continuous permafrost" (Garleff and Stingl, 1986) was recognized to be at about 5000 m a.s.l. Between 22° and 28° s.l., many periglacial landforms have been reported from the high mountains of northwestern Argentina with an upper level from 4000 to 5000 m, with intense gelifraction, rock glaciers (active and inactive) and old moraine deposits and cirques (Ahumada, 2002).

Additional studies are required for the distribution of permafrost at these latitudes of Central Andes of South America. For example, it is very important to know its ice content and behaviour regarding its importance to water supply in a very arid area of Argentina.

2. Climate setting

The area where the present preliminary geomorphological analysis was carried out is in the NW extreme of the province of San Juan and adjoining areas in the province of La Rioja, in Central Western Argentina, next to the boundary with Chile. It lies between 28°15′S and 28°30′S latitudes (Fig. 1).

This mountainous area has climatic features different from those in the region where it is located, which is typically arid, because of the temperature decrease concomitant with increasing altitude. This negative thermal gradient, 0.5–1 °C every 100 m, causes an increase in the relative moisture content in the air, as well as orographic rains on the windward mountain sides, but less frequent in the lee sides.

Precipitation is minimal (around 50 mm) in the lower areas, increasing to the west and southeast. Snowfall diminishes from south to north, from about 300 to 150 mm. The first snowfalls occur in May, with the most important during July and early August. The snowfalls in general are of short duration. After each storm, a layer of ice forms that protects the cap of snow and prevents evaporation.

The orientation with respect to the prevailing winds is of paramount importance, because the north facing mountain slopes receive more insolation than the south facing ones and have a specific wind regime. These features create a differential topoclimate.

Dry climates with rigorous winters, such as the one that characterizes the Andes from 28° to 30° latitude have very low temperatures in winter, short-lived summers, little precipitation and violent winds. Present day permafrost soils are characteristic of these climates. Therefore, a distinctive feature of this climate type is a morphogenetic system where the influence of frost is very important, running water has a very small role, and wind action is very important.

In this study, we used the Köppen (1936) Climate Classification System, one of the most widely used for classifying the world's climates. According to Köppen's

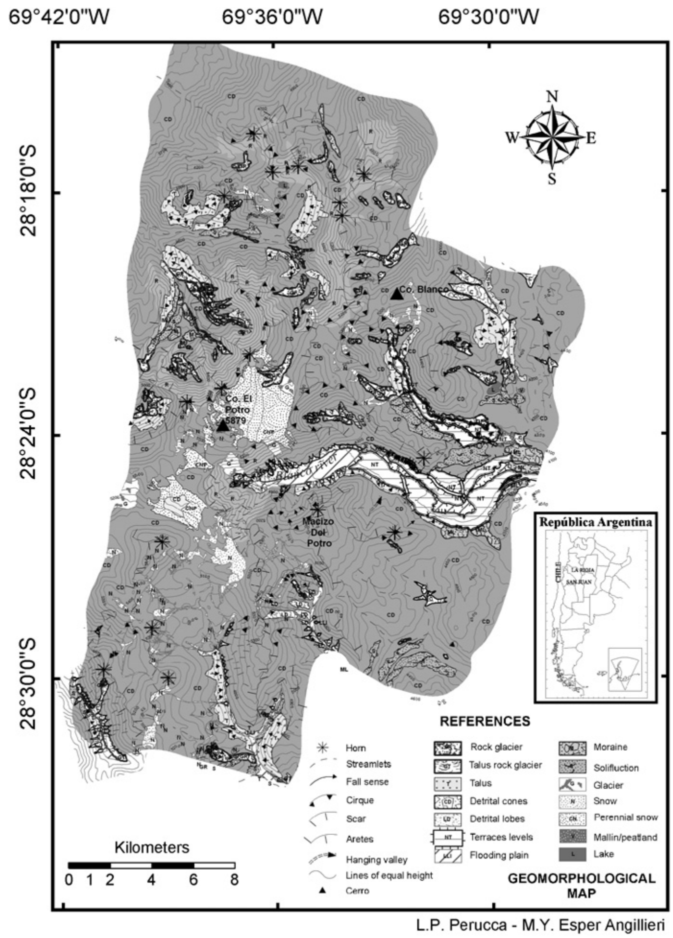

Fig. 2. Geomorphological map of the Cerro El Potro area.

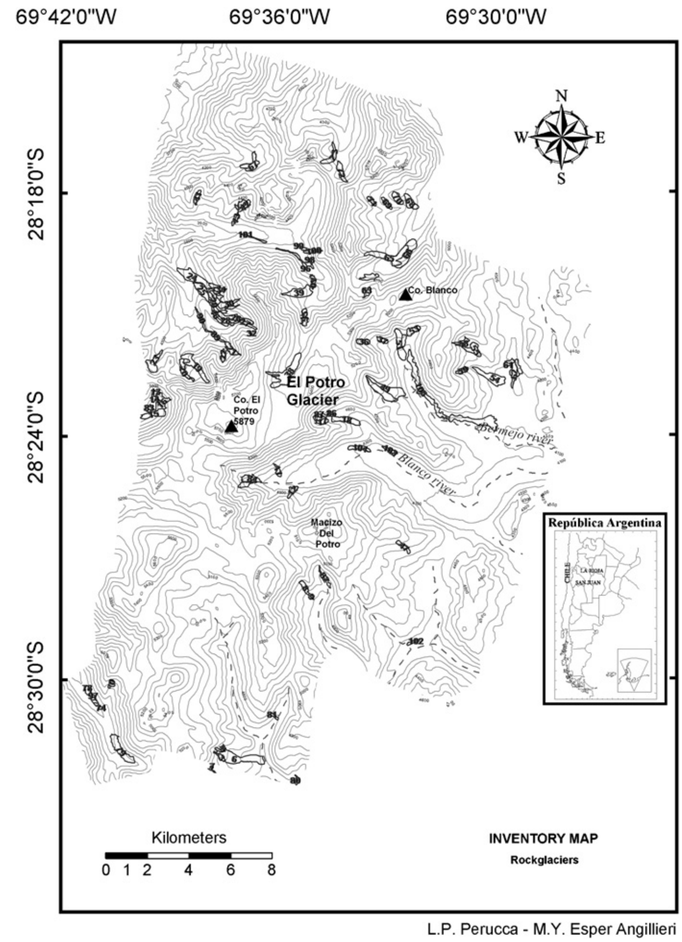

Fig. 3. Preliminary Inventory map with the location of rock glaciers in the Cerro El Potro area.

classification, from 3500 to 4000 m a.s.l., the climate is Et type, high mountain tundra, with temperatures between −18 and 10 °C. Above 4300 m a.s.l., the climate type in the area is Ef, or of perpetual ice, where the average temperature in the warmest month is lower than 0 °C. These conditions are ideal for the formation of permafrost.

The highest winter temperatures recorded in the Cordilleran region are caused by the influence of the so-called Zonda wind, which produces a Foehn effect. The yearly thermal amplitude between winter and summer is high: 70.1 °C.

Between 4000 and 6000 m a.s.l., precipitation is mainly snow and frost, the former associated with the Foehn effect. Below 4000 m, rains are scarce and very irregular; snowfalls in the Cordilleran zone, north of San Juan, are small and decrease considerably from south to north.

As expected, rains are more abundant in the Cordilleran sector and diminish to the east. Minetti et al. (1986), using annual averages from meteorological stations in surrounding areas, determined a regional average of 150 mm per year at 29°S. Most precipitations in the area take place in winter and are of snow. The frequency of days with rain or snow is very low.

3. Methods

The present study was carried out on the basis of the interpretation of photograph stereopairs of scale 1:50,000. The photographs were taken during regional flights done in autumn months in the 1960s and 1980s. The interpretation was plotted on photomosaics of orthorectified air photographs and ASTER (January 2005) and Landsat (February 1985) satellite images, at scale 1:100,000.

Icebodies, perennial snow fields, rock glaciers, fluvioglacial and glacial landforms, as well as other geomorphological features were transferred to the mosaics and images. With this information a preliminary geomorphological map was prepared (Fig. 2).

A map with an inventory of the rock glaciers was prepared on a topographic map base with altitude contours, in order to visualize the relationship between relief and the periglacial features identified. About 100 active or inactive rock glaciers were counted, and it was observed that they are located in the highest mountain sectors, above 4300 m a.s.l., mostly in the south facing slopes, which are less exposed to insolation (Fig. 3).

Altitudes were obtained from topographic sheets published by the Instituto Geográfico Militar (Argentine

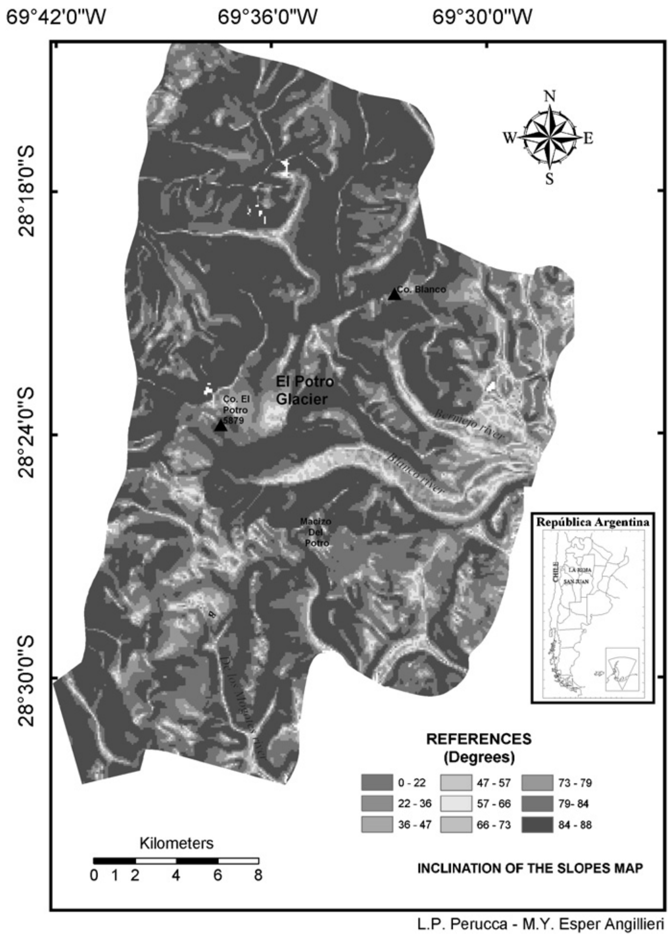

Fig. 4. Inclination of the slopes.

Military Geographic Institute) at a scale of 1:100,000 and 50 m contour interval, on which basis the map of slopes was prepared in degrees (Fig. 4).

The slope function calculates the maximum range in elevation change, based on distance between each cell and the adjoining ones. The lower the slope value, the flatter is the land. The slope function is calculated from an elevation digital model (0–90°) in degrees.

4. Geologic setting

A stratigraphic review of the geologic units exposed in the area is given below:

The oldest unit is intrusive rocks, mainly granitic or granodioritic in composition, partly coarse textured, which, elsewhere in the Frontal Cordillera, intrude Late Paleozoic marine clastics. These granitoids are Carboniferous to Early Triassic in age.

- Volcanic and pyroclastic rocks, andesitic or rhyolitic, make up extensive outcrops, especially north of the Bermejo River and its headwaters. These rocks are, in the main, Permo-Triassic.
- A sedimentary unit, with fine sandstones, reddish or purplish, interbedded with banks of conglomerates agglomerates and tuffs, mostly reddish or dark reddish grey. These deposits crop out in the lower half of the Cerro El Potro. Their age is considered to be Jurassic, because they are interbedded with fossiliferous marine Jurassic clastics in Chilean territory.
- Volcanic, subvolcanic and pyroclastic rocks, andesitic, dacitic and rhyolitic in composition, which make up extensive outcrops in the Cerro El Potro and north of the confluence of the Bermejo and Blanco rivers.

Structurally, the most outstanding feature is a series of elevated and sunken blocks, a pre-Tertiary horst-and-graben modified by Neogene and Quaternary compressional tectonism. The main structural trends in the area are NNE-SSW, but lineaments with the above-mentioned orientations and trending NE-SW also occur.

The Quaternary units in the area are sedimentary and include deposits formed by landslides, detrital slopes, rock glaciers, soil creep, moraines and alluvium. Some of these deposits are made up of blocks of hydrothermal breccias. The alluvial sediments consist mainly of angular and subangular gravels and loose sand. Deposits related to terraces, colluvial sheets, thermokarst and polygonal structures also occur in the area.

5. Main forms and processes

The use of photointerpretation permitted recognition of landforms in the region. The most important erosive landforms are horns, arêtes, cirques, and hanging valleys (with outlets in the main valleys). These formerly glacier valleys at present have rivers that cross the area from west to east, as the Blanco and Bermejo rivers, or from south to north, as Los Mogotes river.

The valleys have marked asymmetric profiles, because the slopes facing north are exposed to solar action. For this reason, these slopes are gentler and more gradual than those facing south, which are steeper and have colder climates. It is in these steeper slopes where most rock glaciers are found. The sides of lower glaciated valleys have detrital cover, since gelifluction is the dominant debris transporting agent.

Exposed ice includes perennial ice masses. These landforms make up snowfields and mountain glaciers, and are restricted to areas higher than 5500 m a.s.l.

By comparison with the air photographs taken in the 1960s and 1980s with the Landsat satellite images taken in 1985 and the ASTER satellite image taken in 2005, it is observed that practically no variation exists in the area occupied by the permanent ice field in the Cerro El Potro (5879 m). Small ice glaciers have been observed here, as well as frontal and lateral moraine deposits (Figs. 5–7).

Numerous perennial snow patches, a characteristic feature of the high Andes, were observed (Fig. 8). The lower limit for this patches, at the latitude of the Cerro El Potro (28°15′S) is at 5000 m a.s.l., mostly on the south facing slopes, in contrast with the 4300 m elevation in the

Fig. 5. View to the northwest of Cerro El Potro. Perennial ice masses and Cerro El Potro glacier can be seen in the upper left hand portion (>5500 m a.s.l.).

Fig. 6. Northern slope of río Blanco valley. El Potro glacier and features of periglaciar landforms (photograph taken in December 2006).

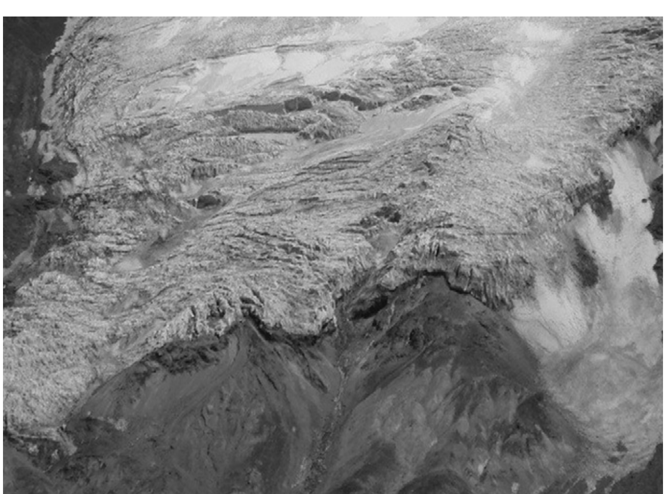

Fig. 7. El Potro glacier over 5500 m a.s.l. (photograph taken on December 2006).

Fig. 8. Cryoplanation surfaces and snow patches, >5200 m a.s.l.

Central Andes of the province of Mendoza, at 33°S (Trombotto, 2000).

Moraines surround small glaciers and ancient glacier valleys, have moderate slopes, and lack flow morphology. Nevertheless, in some sectors these landforms are considered to be of uncertain origin, because possibly they are transitional forms to rock glaciers, especially where the cover considered as morainal in origin is thick (20–25 m) and considering permafrost conditions. Old morainal deposits have been observed in the Bermejo and Blanco river valleys at 4000 m a.s.l.

Thermokarst is characterized by the formation of round-shaped depressions and holes surpassing 200 m in diameter, and with a gentler sun facing slope (Black, 1969). In the region, thermokarst is developed on rock glaciers with depressions formed by the ice melting, and filled with water or ponds.

Cryoplanantion plains are located on the summits of the high areas (Eakin, 1916) (Figs. 8 and 11). They are very important because they are a great sedimentary transport agent, second only to rock glaciers. These forms coalesce to build cryoplanation terraces, very common landforms above 5000 m a.s.l. in the region. The cryoplanation surfaces are related to the continuous permafrost of the Andes and, at 30°S, are found above 5000 m (Scholl, 1992).

Solifluction landforms are the result of vertical selection nivation and creep. The commonest forms in the area are solifluction lobes, which occur as bulges on the mountain slopes of the main present day fluvial valleys. Other landforms recognized in the area are solifluction terraces.

On detrital slopes, the rock fragments resulting from gelifluction are channelled, producing a cleft in the substratum that is used by rocks or snow avalanches. The debris thus mobilized finally is deposited and give rise to a cone with convex profile. This cone frequently coalesces with others, producing more or less continuous slope accumulations of debris. These are very frequent in the Cerro El Potro area, especially on the mountainsides,

with slopes facing north and surpassing 70°, as in the Blanco river valley (Fig. 2).

Rock glaciers are outstanding landforms in the periglacial areas of the region. Rock glaciers are bodies with ice and angular debris, lobe or spatula shaped and they move slowly downslope. Their surfaces have longitudinal ridges on the edges, but transverse in their end position. These ridges and furrows are indicators of flow. The front slope of active rock glaciers is characterized by a steep gradient, but in fossil rock glaciers (without ice) the front slope is less steep.

Rock glaciers generally are situated at the foot of steep slopes, such as the walls of a glacial cirque or steep sides of through valleys (Martin and Whalley, 1987). In their root zone they are supplied with coarse-grained debris formed by cryoclastism. Debris moves down the slopes, thus originating different landforms. One of the most adequate classifications of rock glacier is based on their morphologic features and topographic situation, as referred by Hamilton and Whalley (1995). These authors made a re-assessment of rock glacier nomenclature by considering only gross morphology and location, either on the valley floor or the valley side.

Based on their morphology, rock glaciers are classified as:

(a) Tongue-shaped rock glaciers (Wahrhafting and Cox, 1959; White, 1971; André, 1992), valley floor rock glaciers (Outcalt and Benedict, 1965) or simply rock glaciers, when their length is greater than their width, have flow structures and a steep front (Barsch, 1996).
(b) Lobate debris glaciers, where their length is shorter than their width (Wahrhafting and Cox, 1959), known also as valley side rock glaciers (Outcalt and Benedict, 1965) or talus rock glaciers (Barsch, 1988) or protalus lobe (Richmond, 1952; Whalley and Martin, 1992). In general these glaciers are relatively small bodies, up to 1000 m long (Fig. 9).

According to their ice-content and activity, rock glaciers are classified as: (a) Active rock glaciers, which are in movement, contain from 40% to 60% of ice with steep front and well defined flow structures; (b) Inactive rock glaciers, which are at lower altitudes than active ones, without movement, but still with ice, (c) Fossil rock glaciers, with neither movement nor ice (Blagbrough, 1984; Haeberli, 1985; Barsch, 1996, Arenson et al., 2002). Brenning (2005) used aerial photos to recognize active rock glaciers existing as low as 4150 m, but are associated with inactive features up to 4500–4600 m

The most common rock glaciers recognized in the area are talus glaciers and tongue-shaped glaciers. The larger rock glaciers are near the international boundary, west of the Cerro El Potro and in Chilean territory, at about 5500 m a.s.l. They reach up to 2 km in length and 500 m in width and are typical tongue-shaped glaciers. Tongue-shaped glaciers are numerous also in the Argentine side,

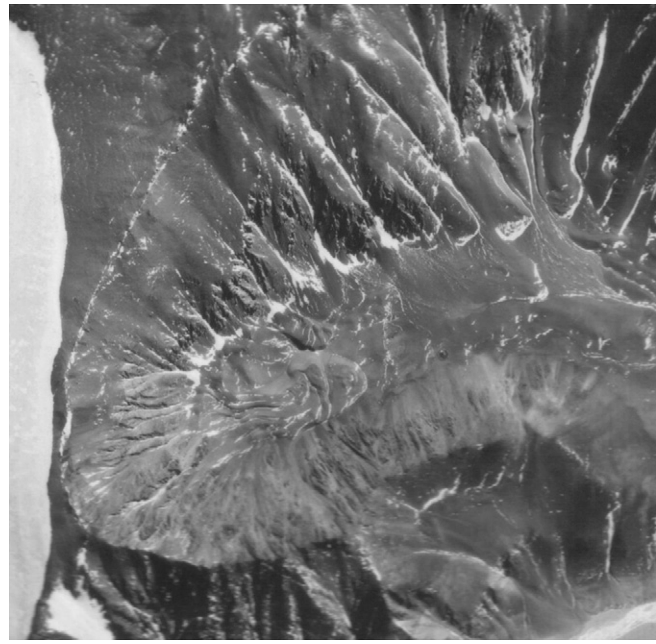

Fig. 9. Rock glacier at the head of Río Bermejo valley, about 4700 m a.s.l. Vertical aerial photograph taken in 1981.

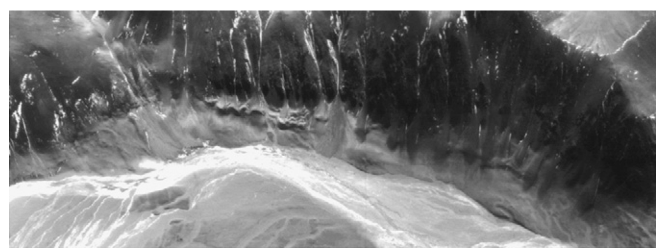

Fig. 10. Vertical aerial photograph, northern slope of Río Bermejo valley, talus rock glaciers at 4300 m a.s.l.

but they are smaller and shorter; they do not surpass 1 km in length and 300 m in width (Fig. 2).

Lobate-shaped rock glaciers have been found, most of which (>90%) are in the low part of taluses or mountain sides (talus glaciers). Lobate glaciers are very scarce in the high walls of ancient glacial cirques.

North of the Cerro El Potro are some complex rock glaciers in the Chilean territory, at 5000 m a.s.l., in which it is possible to observe a set of aggregate landforms made up of different (multipart) bodies or lobes (multilobe glacier). The talus glaciers occur along the valleys, mainly in the Blanco and Bermejo river valleys, on the south facing mountain slopes, where the insolation is far less than in the north facing slopes (Fig. 10).

Although it is difficult to prove the activity of a glacier solely by observations of air photography or field work, without having recent geodetic surveys, some indications exist, such as the presence of a well developed block accumulation surface around the front talus, traces of small debris slides in the front talus, and a progressively gentler front talus.

Fossil rock glaciers have been found in the area at lower altitudes (3800 m–4300 m a.s.l.), where there is no ice at present and no evidence of movement is shown. Even though they still have furrows and ridges, their relief forms have been softened by thermokarst and erosion.

It is very difficult to determine the thickness of an active rock glacier unless subsurface evidence from drilling or geophysical logs is available. The thickness is normally determined in the frontal part of the slid mass, but this is only a rough estimation. Considering the thickness assumed for active rock glaciers of the Andes of Chile between 33° and 34°S (Brenning, 2003), it is possible to estimate that, starting from their surface dimensions, for a rock glacier less than 0.01 km^2, in extension, the average thickness should be between 10 and 30 m. For an area greater than 0.1 km^2, the rock glacier thickness can reach from 10 to 50 m.

Asymmetric valleys are another characteristic feature of this area, with one valley side much steeper than the other. Generally the steeper slope is the one facing south. The higher insolation received by the valley sides facing north gives rise to a faster ice melting during longer time. This produces a greater amount of water, which triggers solifluction and rock mass movements. On the other hand, the south facing valley slopes have less volume of ice melting during summer, and therefore, permafrost contributes to keep a steeper profile.

It is also probable that the action of the prevailing winds tends to accumulate snow on the lee side of slopes. For this reason the great volume of water produced during the summer ice melt increases the slope (Fig. 11).

Small thermokarst lakes formed by permafrost melt in the area produce land subsidence and subsequent fill with water. These are found mainly in the flat sectors, and soon are filled with sediments. An example of these landforms was observed west of the Cerro El Potro (Fig. 2). In the river valley bottoms especially in the Bermejo and Blanco rivers, peatlands or ''mallines'' have been formed at the altitude named the Altoandean level or Andean tundra by Ambrosetti et al. (1986); (Fig. 12).

Fig. 11. Thermokarst lake and cryoplanation surfaces about 4300 m a.s.l.

Fig. 12. Mallín or peatland of Río Bermejo valley, about 4100 m a.s.l. (December 2006).

6. Discussion

Permafrost can be defined as any rock material or soil that has been submitted to temperatures below 0°C more or less continuously during 2 or more years. This 2-year minimum results from excluding the surface soil layer where the water content freezes in winter and melts in summer (Muller, 1947). Rock glaciers are permafrost phenomena located in cold and dry mountain regions, with unconsolidated sediments and inclined topography.

Mountain permafrost is dependent on topoclimatic conditions to a great extent. For instance, in the study area, high mountain permafrost is found mainly on the mountain sides facing south, which are less exposed to sun radiation. Nevertheless, it appears occasionally in some north facing mountain sides, probably in areas with relative low radiation.

The energetic balance and hence, the permafrost distribution, have a regulating function in the periglacial environment. In altitudes surpassing 4500 m a.s.l., the development of continuous permafrost can be expected, as indicated by climatic data (Schrott, 1994). Nevertheless, at 33–34°S, a rock glacier facing south is inactive at a height of 4000 m, probably because of a warming process over the last decades (Trombotto, 2000).

Finally, the relation between permafrost and climate is not totally clear, because it is a result of a complex interaction of environmental factors, the most important of which is climate. The climate conditions in high mountain zones depend mainly on latitude, altitude, continentality and local conditions (precipitation, winds, etc.).

It is probable that the perennial snow limit is at about 5500 m a.s.l. in the area but, due to strong winds, snow is

retransported or impeded to accumulate over extensive high surfaces. This situation is described by Scholl (1992) at 30°S in the "Paso de Agua Negra", Province of San Juan.

Ahumada (2002) recognized two periglacial levels in the ranges located between 22° and 28°S and from 65° to 68°W. A lower level, from 2500 to 4000 m a.s.l. with seasonal freezing and solifluction, and a higher level from 4000 to 5000 m with intense gelifraction, active and inactive rock glaciers, talus rock glaciers, old moraine deposits and glacial cirques. Keidel (1922) found rock glaciers in the north of Argentina at altitudes higher than 4000 m but did not observe present activity. Corte (1982) established the lower boundary for permafrost at 4000 m a.s.l. at 25°S.

From 30° latitude to the north, the Andes are characterized by semiarid conditions with extremely high solar radiation during the entire year. Precipitations take place above 4000 m a.s.l. during the winter months, as snow or graupel. The average annual precipitation is 100–350 mm (Minetti et al., 1986). The snow cover is relatively thin and short lived.

Rock glaciers are frequent in the mountains of the Andean Cordillera (Gorbunov, 1983; Schrott, 1994, 1996; Trombotto, 2000; Brenning, 2003, 2005). Corte (1976) mentions that rock glaciers are the dominant features in the valleys and mountains of the Eastern Andes. Marangunic (1979) mapped glaciers in Chilean territory, whereas in Argentina Corte and Espizua (1981) worked at 32°S, but the inventories they made are preliminary, and with terminological uncertainties in respect of the differentiation between rock glaciers, glaciers and massive ice affected by thermokarst. Recently, Brenning (2005) and Brenning et al. (2005) carried out a quantification of the regional distribution of the rock glaciers in the Santiago Andes (Chile).

In the Agua Negra area, at 30°S, the perennial snow floor is above 5300 m a.s.l. with the south facing mountain slopes covered by a permanent snow layer. The continuous permafrost is between 4000 and 4800 m a.s.l. whilst below 4000 m permafrost forms sporadically.

At 33°S, Brenning (2003) indicated that the perennial snow floor is above 3800 m a.s.l., where the feeding zone for glaciers, snow fields and gelifraction occur. Between 3500 and 3800 m a.s.l. the discontinuous permafrost floor is located. Here the prevailing landforms are rock glaciers and taluses, ablation zones of small glaciers and inactive glaciers tongues with thermokarst. From 3000 to 3500 m a.s.l., isolated permafrost and inactive and fossil rock glaciers develop. Below 3000 m fluvial and gravitational activity predominates.

In the Cerro El Potro area, the permanent snow field and the glaciers are situated at altitudes above 5500 m. The rock glaciers are located between 4300 and 5500 m a.s.l., mostly in the south facing mountain slopes. Talus glaciers develop where the steepest slopes prevail, whilst in the cirques situated above 4300 m a.s.l. tongue shaped, probably active rock glaciers are found. Below 4000 m a.s.l., fluvial and glacifluvial processes predominate. The altitudes of these levels are in contrast with those determined south of 30° latitude, where the active landforms are above 3500 m.

On the 1:100,000 scale topographic map, with contour intervals every 100 m, the observed slopes obtained surpass 70°. Only considerably lower slope values, from 5° to 50° were obtained in the Bermejo and Blanco rivers. The slope map obtained from the topographic sheet simplified the analysis of the geomorphologic processes and permitted to distinguish the inclination categories by means of different hues (Fig. 4). For instance, with inclinations higher than 50° the predominance of gravitational processes in the mountain slopes is observed, whereas fluvial and glacifluvial processes are frequent on inclinations lower than 15°.

7. Conclusions and recommendations

The present work constitutes a first approach to the identification and knowledge pf the glacial and periglacial processes in a little known portion on the Dry Andes of the San Juan and La Rioja Frontal Cordillera. The glacial and periglacial landforms, mainly rock glaciers, are features that characterize the higher sectors of the area dealt with in the present study.

Above 5500 m altitude the permanent snow field of the Cerro El Potro and the present day glacial tongues are found. Between 4300 and 5500 m a.s.l. active and inactive rock glaciers occur. Below 4300 m a.s.l. glacifluvial, fluvial and fossil rock glacier features prevail. The results obtained in the present work, even though they constitute a substantial advance in the knowledge of the quantity, features and distribution of ice bodies and rock glaciers at 28°S, must be considered as indicative but not definitive parameters of the high mountain hydrology.

With the information already obtained, it is still not possible to establish a direct and absolute relationship among river discharges, the basin areas and the percentage of glacial and periglacial areas. Other important parameters that should be taken into consideration in future studies in the region are the precipitation regime, the average elevation and slopes of the hydrographic basins of Blanco and Bermejo rivers and the physical and lithological characteristics. Techniques of geophysical prospecting, as electric resistivity tests, seismic refraction and others, will allow the detection of the position of permafrost in the region. It will also be possible to mark the boundaries of active and inactive rock glaciers that still conserve ice and to distinguish them from fossil rock glaciers. Geophysical logging will also be useful for determining thicknesses of ice bodies.

Finally, for a real evaluation of the incidence of human activity on the glacial and periglacial landforms, as a result of mining exploration in the study area, it is recommended to plot on the maps obtained by using a GIS, the location of the civil works built in the area. In this way, it will be possible to readily visualize the incidence of these works on the different landforms and assess water supply, planning

a rational use of these water resources in this portion of Argentina.

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