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Mapping and permafrost altitudes in a periglacial environment: the Laguna del Diamante Reserve (Central Andes, Argentina)

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with 9 figures

Summary. The Laguna del Diamante Reserve, in the Province of Mendoza (Argentina), a protected area in a volcanic caldera (around 15 km in diameter), encloses the Maipo Volcano, 5,323 m (a snow and ice-capped volcano), and the Diamante Laguna at 3,300 m a.s.l., which constitutes an important water resource for the province. A geomorphological map, made on an ASTER image from aerial photographs and corroborated by fieldwork, reflects how this area, although previously glaciated, is at present an outstanding periglacial environment with a few residual glaciers. Talus slopes, debris cones, alluvial fans, debris flow deposits, landslides and rockglaciers cover the Maipo flanks and the slopes surrounding the caldera. Periglacial landforms, occurrence of ice found during fieldwork, and rockglaciers were used to make a first approach to determine permafrost altitude. The inferior limit of *quasi continuous permafrost* at south exposition, detected by ice in a shelter in different years, is presently calculated at 3,870 m a.s.l. approximately. In the same valley however, and considering the noses of cryoforms with creeping permafrost, cryogenic activity is observed at a height of approx. 3,750 m a.s.l. In other sites of the area, cryoforms reach down to even 3,600 m with signs of inactivity. Historic registers from 1951–1952 indicated a height below 3,850 m a.s.l. as lower permafrost limit. Palaeopermafrost was identified at 3,400–3,500 m a.s.l. approximately on the foot of the southern slope of the Maipo Volcano. At present, the zone, still in a paraglacial state, is characterized by intense cryodynamics and it is considered adequate to be proposed as "type region".

Zusammenfassung. Das Naturschutzgebiet Laguna del Diamante liegt in der Provinz Mendoza, Argentinien und umfasst eine vulkanische Kaldera (von ca. 15 km Durchmesser), die den mit Schnee und Eis bedecken Maipo-Vulkan mit 5323 m Höhe und die Diamante Lagune auf 3300 m Höhe einschließt. Die Lagune ist aktuell ein wichtiges Wasserreservoir für die Provinz Mendoza. Die hiermit vorgestellte geomorphologische Karte der Region wurde aus einem ASTER Bild und Luftbildern gemacht und sie wurde im Gelände geprüft. Die Karte spiegelt, trotz vergangener Vergletscherungen, periglaziale Prozesse und die heutige vorhandene periglaziale Geomorphologie wider. Gletscher bleiben heute nur als kleine Geoformen. Sedimentäre kryogene Hänge, schuttkegelförmige Ablagerungen, Muren, Ablagerungen, Bergstürze und Blockgletscher bedecken die Seiten des Maipo Vulkans und umschließen auch die Kaldera. Periglaziale Mikroformen und Blockgletscher wurden in der Arbeit benutzt, um Dauerfrostböden zu finden. Die untere Grenze des südexponierten quasi continuous permafrostes liegt bei ca. 3870 m Höhe. Der Dauerfrostboden wurde durch Eis in einer Berghütte in verschieden konsekutiven Jahren bestätigt. Im Tal scheint die untere Grenze des kriechenden Permafrostes aber etwas niedriger, bei 3750 m, zu sein. In anderen Fällen erreichen Kryoformen 3600 m Höhe, aber sie scheinen inaktiv zu sein. Historischen Daten (zwischen 1951–1952) zeigen, dass

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die untere Grenze des Permafrostes bei 3850 m lag. Paleopermafrost wurde auch in der Region identifiziert. Bei einer Höhe von 3400–3500 m, am Fuß des Maipo Vulkans sind Beispiele zu sehen. Heute wird die Region der Laguna del Diamante als paraglaziale Region bezeichnet. Sie ist eine typische Region, wo sich kryodynamische Prozesse untersuchen und zeigen lassen.

Key words: mountain landscape, periglacial environment, permafrost altitude, Diamante Caldera, Laguna del Diamante Reserve, Central Andes

1 *Introduction*

The Laguna del Diamante area, located at 34° 10′ S on the eastern flank of the Andes in the Mendoza Province (Argentina) and covering a surface of 170 km^2, is a Provincial Reserve since 1194 aimed at the conservation of wildlife in an extreme climatic environment, but it also includes the protection of the high mountain landscape among its specific purposes. Two features characterize this landscape: the Maipo Volcano (MV), 5,323 m a.s.l., on the Chile-Argentina border and the Diamante Laguna (DL) > 7 km long and 3 km wide, at 3,250 m a.s.l.; both inside the Diamante Caldera (DC), a large intramountainous depression of volcanic origin (fig. 1).

The DC was widely glaciated during the Last Glaciation; erosional forms and deposits are distributed to a great extent in the caldera and in the surrounding areas. Although it can be considered as a deglaciated area, there are some glacier remnants: on the volcano flanks and to the northeast and northwest of the Laguna, with their fronts above 3,760 m. Glacial deposits are distributed mainly to the north of the volcano; a group of arcuate frontal moraines to the northwest of the Laguna indicate a

Fig. 1. Oblique air view to the southwest of the Diamante Caldera taken at the beginning of the austral summer in December 2009. The Maipo volcano is in the left while the Diamante Laguna lies to the right. An asterisk marks the zone known as “La Herradura”.

gradual receding for the main glacier to the north of the volcano, with small remnants of glacier ice occupying three cirques with a southeast aspect.

After deglaciation, the strong reliefs in combination with the high altitudes and large amounts of nival melt waters gave rise to a well-developed periglacial landscape. Rockglaciers, of cryogenic and of glacigenic origin, and belonging to more than one phase, were formed on the Maipo slopes and on the mountain slopes of the caldera borders.

A climograph was constructed with data between the years 2000 and 2010. Five months show average daily minimum temperatures below 0 °C indicating strong periglacial conditions. Unconsolidated slope deposits have been partially removed by the river system, but torrential and gravitational processes on slopes are very active in the area, still readjusting with the prevailing periglacial conditions.

A previous work (Alonso & Trombotto Liaudat 2009) has shown the importance of a detailed cartography for the analysis of the processes in a mountain area. The aim if this paper is to analyse the periglacial record of this remote zone taking as a starting point a detailed mapping from an Aster image (Trombotto Liaudat & Alonso 2012). The DL area constitutes a Provincial Reserve of great ecological and landscape value, hence the interest of making a detailed cartography which could be used for the reserve management planning and also as a base for further investigations on the periglacial geology of the zone.

2 *Regional setting*

The Diamante Caldera-Maipo Volcano complex is located at 34° 10′ S, in the southern volcanic zone (between lat. 33° S and lat. 46° S) of the South American Andes, on the Argentina-Chile border. Stern et al. (1984) attributed to the formation of the DC (16 × 20 km) an age of ~ 450 ka, when a large evacuation of ignimbrites, that cover an approximate surface of 23,000 km^2, caused the collapse of the area. After a long period of volcanic inactivity, a second volcanic episode (the Maipo stage) led to the construction of the Maipo stratovolcano (5,323 m a. s. l.) in the eastern part of the caldera. During the last 100 ka, seven eruptive events (emissions with alternating andesitic and dacitic compositions) have been identified; three of them were dated in less than 14 ka (Sruoga et al. 2005). According to these authors, pre-caldera Mesozoic units constituted by sedimentary rocks intruded by subvolcanic materials are exposed at the north caldera limit, but most of the caldera substrate is made by volcanic rocks. At present, the MV has no signs of activity, although González Ferrán (1995) indicates a possible eruptive event in 1912 or in 1931.

The Diamante region was used by Groeber (1946, 1954) to support the existence of a Great Pleistocene Glaciation characterized by an ice field with two main ice tongues: one flowing through the Diamante River valley and the other discharging through the Atuel River valley. Two phases, the Diamante glaciation and the Atuel glaciation, were associated to the Middle Pleistocene and to the Upper Pleistocene respectively. This author attributes the moraines left by glaciers in different sites like those in Cerro Laguna and Cerro Borborán, at the end of the Pleistocene, to a third episode which, having a nearby origin, hardly reached the Arroyo Yaucha.

Corte (1953), studying the zone in the years 1951/52 from a cryological perspective, gave a detailed view of periglacial micro and mesoforms, although he did not

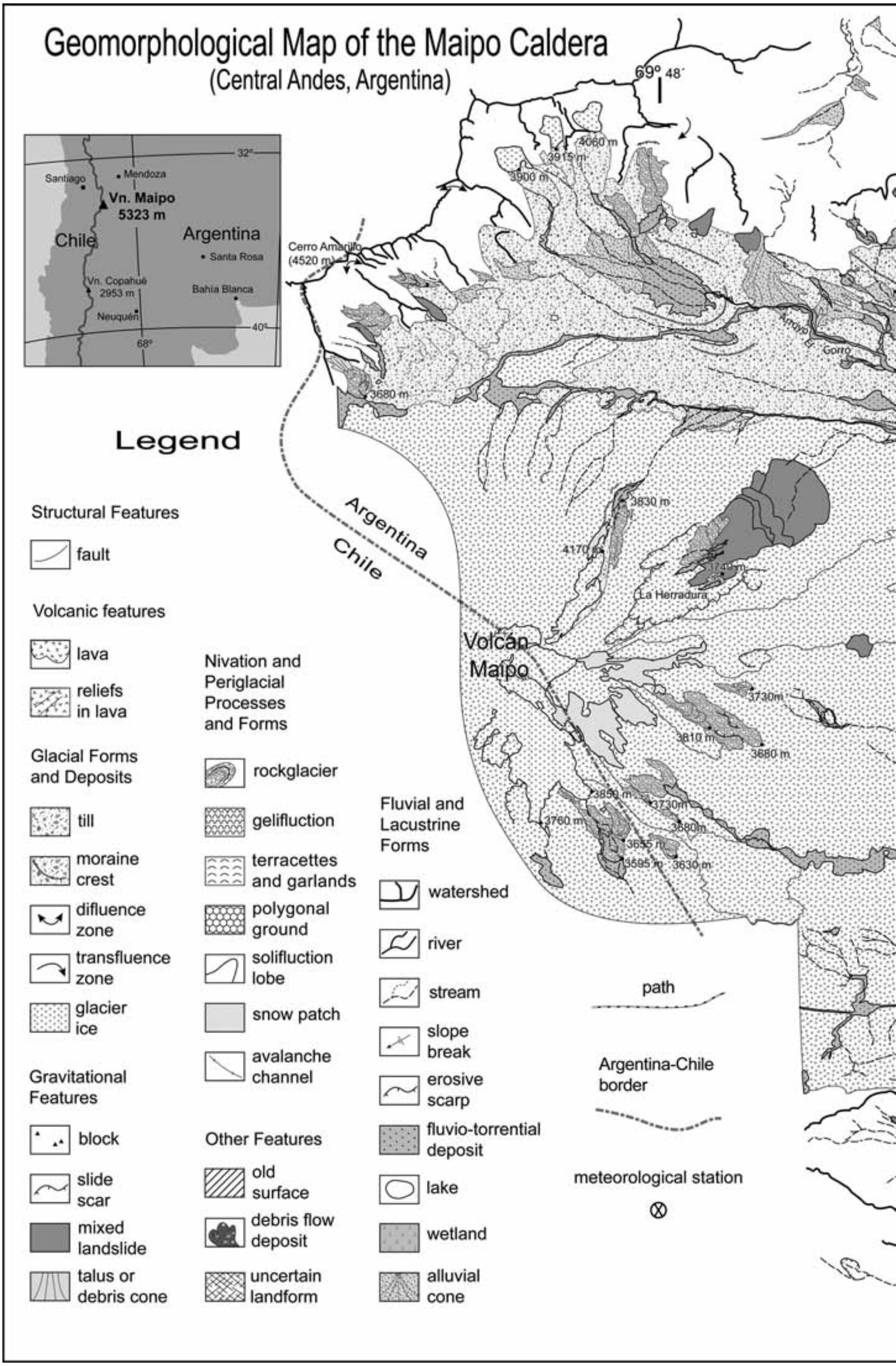
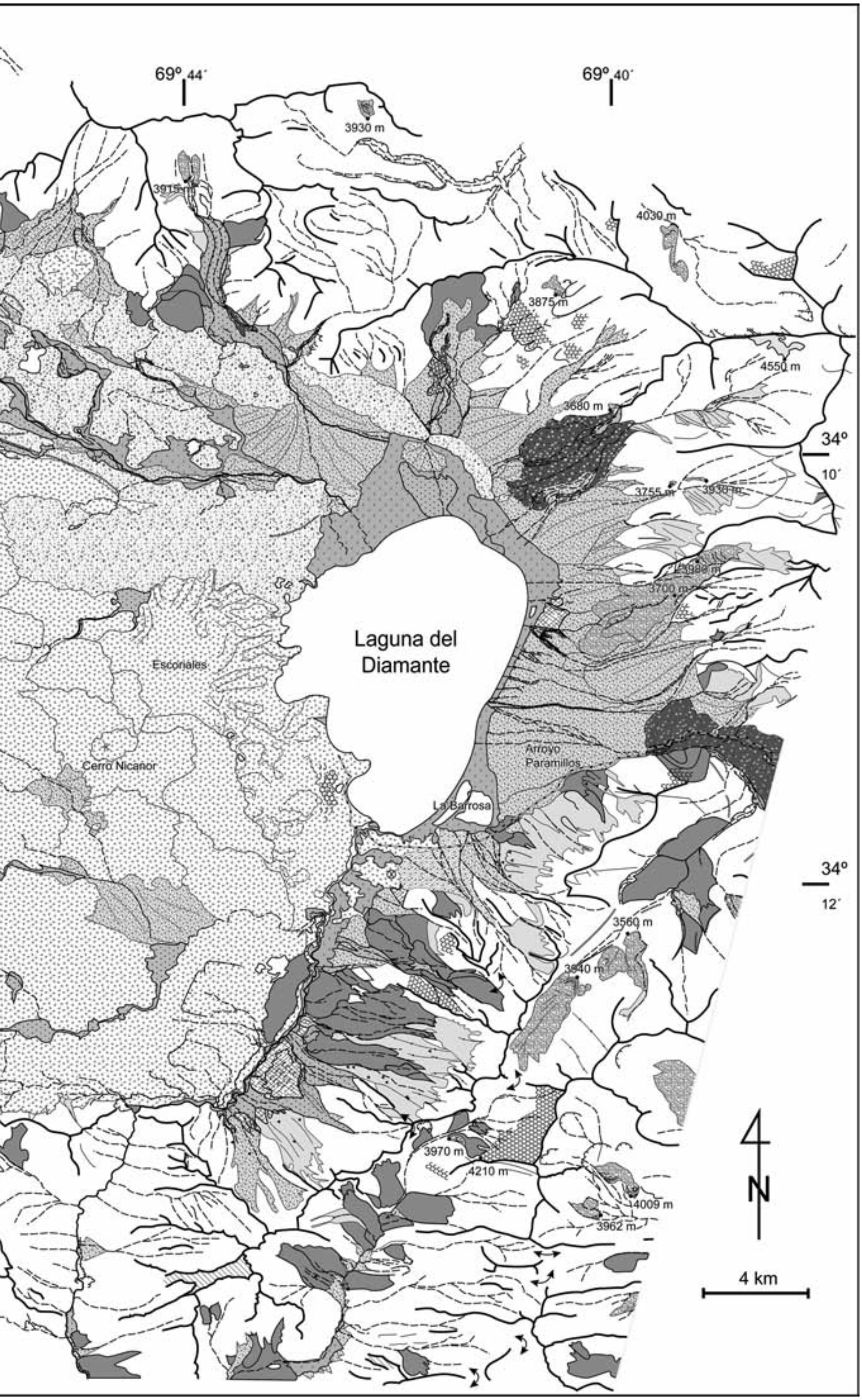


Fig. 2. Geomorphological map of the Maipo Caldera at an approximate scale 1 : 100,000.



Modified from Trombotto Liaudat & Alonso 2012.

distinguish whether they were related to the presence of a permafrost or not. He described permafrost below 3,850 m, in the surroundings of the Refugio Perón at Cerro de la Laguna, and proposed an inferior limit of 3,650 m for cyopedological processes. However, he found plants affected by cryogenic activity much lower, down to 3,250 m a.s.l.

A geomorphological map of the area was included in the work of Sruoga et al. (2005); mainly focused on the petrology and the volcanic chronology of the DC, it shows glacial and periglacial deposits and the distribution of volcanic materials corresponding to seven past eruptions. The map, later partially modified by one of the authors (Sruoga 2008), was used to illustrate the zone as one of the "Geological Sites of Interest in Argentina".

With respect to meteorological data, mean annual air temperature registered in 1951 in the Refugio Perón (3,870 m a.s.l.) was −1.7 °C with a precipitation of 600 mm a^{-1} (Corte 1953). For the period 2000–2010, a meteorological station at 3,300 m a.s.l., and close to the Laguna (34° 11′ 56.0″ S 69° 41′ 53.3″ W; location is shown in fig. 2), gave a MAAT of 1.45 °C (fig. 3).

3 *Mapping and meteorological data*

The DC area was mapped, on an ASTER image (pixel size 15 m), from aerial photographs of 1963–64 in Adobe Illustrator software (fig. 2); mapping was carried out at an approximate 1 : 100,000 scale. Google Earth images provided additional informa-

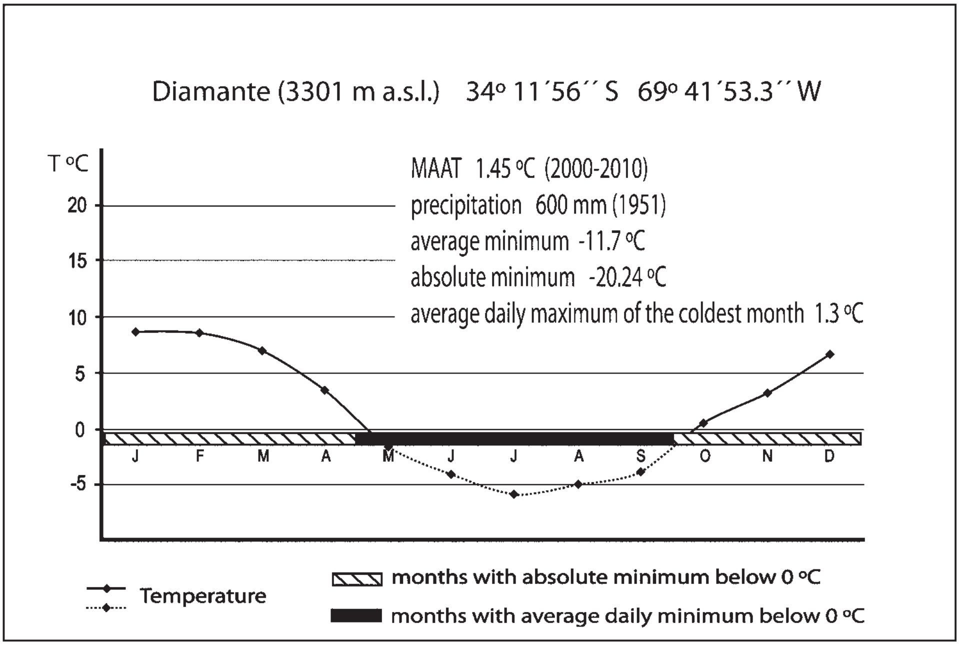


Fig. 3. Climograph of the meteorological weather station "Diamante" at approximately 3,300 m a.s.l.

tion on surficial features and other topographic features, such as paths. Field work, carried out in two campaigns, 2004 and 2011, allowed to verify forms and to add new data to the previous cartography. Because of the big size of the study area, it was divided in 20 subregions in order to identify: 1) main and big landforms, 2) important geomorphological processes, and 3) location and exposition in relation to the DL. Some diggings were carried out to corroborate sedimentary structures or other characteristics.

Identified forms were initially represented following the guide of the Spanish Geological Survey (Martín-Serrano et al. 2004) although some symbols were slightly modified to fit the characteristics of the area. Following genetic criteria, all the features were classified in different groups: structural, volcanic, glacial, nival and periglacial, fluvial and lacustrine, and gravitational features. Uncertain landforms, as well as old erosive surfaces and debris flow deposits, with sharp frontal margins, were also depicted. Altitudes were either obtained during field work or from Google Earth for less accessible zones.

Cartography includes glaciers and perennial snow patches; glacier ice limits, partially covered by snow, are sometimes approximate.

Rockglaciers are the main periglacial feature in the area, but gelifluction forms, at medium and small scale, were also identified. For now, we have not distinguished active, inactive and degraded rockglacier forms, although all of them are present.

Fig. 4. Recent debris flow deposit to the northwest of the DL. Scale indicated by person in circle.

Among slope deposits, alluvial fans, with an important participation of surficial waters, have been distinguished from talus cones, mainly formed by gravitational processes on steeper slopes. A recent debris flow deposit, located to the northwest of the Laguna, could be represented in spite of its small size after field recognition (fig. 4).

In the fluvial network, rivers were distinguished from more seasonal streams, with changing courses, especially when flowing on alluvial fans. With respect to lavas, the map only records lava fronts, not considering eruptive events, and the reliefs in Los Escoriales area, corresponding to the eruptive event IV of Sruoga et al. (2005), located to the southwest of the Laguna. It is not ruled out that some of the mapped lava fronts might correspond with landslides fronts, similar to the ones identified in the zone known as La Herradura.

According to weather observations between the years 2000 and 2010, the absolute minimum detected in this period for the zone was of −20.24 °C (fig. 3). The average of the minimum temperatures is negative, which is important for winter processes. When the average values of monthly temperatures were also negative, it is supposed that part of the soil was frozen. This process may occur from May (fall) until spring.

At 3,300 m a.s.l., the mean annual air temperature is of 1.45 °C and the coldest month is July, when the average of daily minimum temperature is of −5.9 °C.

Precipitation data are old and from Cerro de la Laguna, on the other side of the mountains but less than 10 km from Laguna del Diamante. Precipitation data need to be updated. At the Cerro de la Laguna (3,850 m a.s.l.) the precipitation was approximately 600 mm in 1951. Although the Diamante weather station does not have old precipitation data, a new automatically weather station close to the Laguna del Diamante registered a snow bed with an equivalent in water of 487 mm in 2012 and only 161 mm in 2011. Differences might be associated to that 2011 was a dry year in some parts of the Andes but also to the difficulty to calculate the snow bed exactly with this equipment because the strong winds and the high radiation quickly remove snow in open zones and affect the accumulation and its weight. Snowfalls were detected from May to October, when the area is inaccessible.

4 *Results*

The Diamante Reserve corresponds to a monitoring zone of the IANIGLA (Instituto de Nivología y Glaciología, ascribed to the CONICET of Mendoza, Argentina) that includes Pampa de los Avestruces, a neighboring area at ca. 3,900 m a.s.l., to the east. Monitoring of this zone started in 2004, although permafrost was not detected at that time.

In the DC, bedrock, mainly constituted by volcanic rocks (andesite and dacites), is partially covered by a great variety of quaternary deposits particularly related to glacial and periglacial processes (fig. 2).

Glacial deposits occupy most the bottom of the valley to the north of the MV and connect to the valley head, in the northwest, with three cirque glaciers with a south aspect and fronts between 3,900 m and 4,060 m. In the same area (upper left corner of the map; fig. 2), glacial till at the foot of two cirques in Cerro Amarillo spread out on the plain displaying a pattern of concentric arcuate ridges and furrows. Smaller amounts of till have been identified on the Maipo slopes at the front of glacier tongues, the lowest one at 3,760 m with a south aspect. A few frontal and lateral moraines, already represented in the cartography of Sruoga et al. (2005), were ascertained in the till to the northwest of the Laguna, however we have not found signs of a terminal moraine to mark the lower position of the main glacier flowing to the southwest.

Glacier fronts presently reach an approximate altitude of 3,800 m, although on the south slope of the MV they might reach farther down, a fact that should be checked in the future. On the northern caldera divide, fronts of glaciers with a south aspect are at 3,900–4,000 m and at 3,900 m in the case of debris-covered glaciers close to the Refugio Perón in the Cerro de la Laguna, to the east of the DC, out of the scope of the map.

A few valley heads present the characteristic u-shaped transverse profile, but most of the valleys have their original glacial profiles modified by very active processes after ice melting. In the south zone of the map, we have identified two old surfaces not destroyed by the glacier action. Discontinuous, seasonal and perennial snow patches alternate with cryoplanation surfaces. In the left bank of the river flowing from the Laguna, a small outcrop shows an alluvial deposit of sand and gravels with parallel and cross bedding. In the same area, several surfaces, represented as uncertain landforms in the geomorphological map, seem not to be in accordance with present processes. Regarding periglacial conditions, an important volume of *refugee ice*, transparent, milky and banded, was corroborated in successive visits to the Refugio Perón (3,870 m a.s.l.), located at the foot of the Cerro de la Laguna (fig. 5). This ice was

Fig. 5. *Refugee ice* in the Refugio Perón (Cerro de la Laguna) at the end of the summer (March 2011; Pepe Hernández for scale).

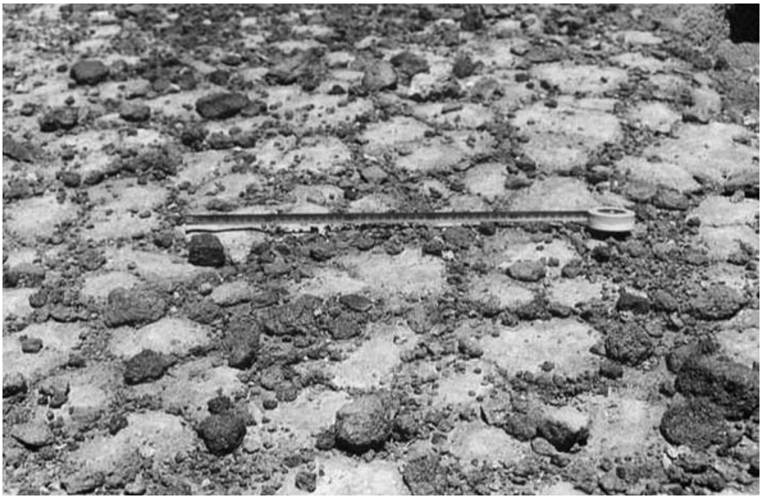


Fig. 6. Micropolygons close to the Laguna del Diamante at 3,220 m a.s.l. Scale = 50 cm.

Fig. 7. View to the east of the eastern caldera border: talus slopes, debris cones and alluvial fans partially modified by cryogenic processes.

generated after the eighties, when the shelter was already abandoned. Numerous cryogenic and glacigenic rockglaciers were identified in this study. On the Maipo slopes, rockglaciers develop from till abandoned in the glacier fronts, from talus slopes, and also at the feet of some of the lava flows. The dacitic lava flow corresponding to the eruptive event V of Sruoga et al. (2005), in spite of its strong relief, only presents small landslides modifying its borders and one rockglacier to the south, with the front at 3,730 m a.s.l. However, the lateral borders of the lava flows close to the south (event III of the same authors) have developed rockglaciers, tongue shaped and lobate forms in, at least, two recent phases and an older one represented by larger degraded forms, apparently coetaneous with the one formed in the lava flow of event V.

In the surrounding of the DL, the valley bottom presents strong winter congelation expressed by patterned ground of decimetric size: from 30 cm in size at 3,300 m a.s.l. (fig. 6), with horizontal and vertical selection, to 1 m at 3,800 m (Corte 1953). We have also found desiccation cracks with metafragmoidic fabrics, in volcanic soils, related to extrusion structures (Trombotto 2007). Pampa de los Avestruces presents contraction cracks and non-sorted patterned grounds, and other periglacial features, as solifluidal forms, not identified in the Laguna.

Besides rockglaciers, slopes display a variety of mesoforms built in various phases: debris flow deposits, complex landslides, irregularly distributed in all the area, and

Fig. 8. Cryogenic lobate rockglaciers eroded by melt waters from upper snow patches; the portion to the right shows signs of activity. Partial view of the apex of an alluvial fan in the foreground.

Fig. 9. Aeolian structures “taffoni” of mushroom forms in a periglacial environment of the Andes. Tors in the left background.

fans formed by a combination of alluvial and gravitational processes among others. Talus slopes (cryogenic sedimentary slopes) predominate in the upper zones and to the south of the Laguna; they are partially covered by alluvial fans, eroded by braided streams and sometimes modified by cryogenic activity, giving lobate rockglaciers.

To the east and to the north, numerous alluvial fans surround the Laguna (figs. 2 and 7); apices are mainly to the east or north-east and some accommodate to the relief of debris flow deposits, covering them in part. Fluvio-torrential deposits are present on slopes with different gradients; most correspond to active braided channels and affect talus slopes, rockglaciers (fig. 8), landslides, debris flow deposits and alluvial fans. Landslides, small alluvial cones and torrential deposits are slightly represented on the Maipo slopes.

At present, the area has great nival water availability; meltwater channels, at a variety of scales, are common features throughout the study area. Snow precipitation and the melting of temporary snow patches feed some lakes, the most important one the DL, located at 3,250 m a.s.l. with a variable surface of 20–25 km^2. A river flows to the southwest connecting the Laguna with the Atuel River. Smaller lakes, some of them seasonal, are mainly distributed on glacier till, to the west of the DL; they are included in a complex drainage network with frequent flooded zones, probably related to the low permeability of the till. Wetlands (mallines), important environments for the flora and the fauna of the region, surround the DL as well as other water bodies. Strong aeolian activity in combination with mechanical weathering gave rise to different taffoni types in ignimbrites (Diamante tuff of Harrington 1989, or Diamante stage of Sruoga et al. 2005; fig. 9).

5 *Discussion*

Mapping of remote areas has profited from the increasing resolution of satellite images; zones not well covered by aerial photographs can now be studied more easily. This is the case of the DC, where ASTER and Google Earth images have facilitated geomorphological mapping and the interpretation of the surficial features and processes in the region.

Pleistocene glaciers, formed on a tertiary relief, eroded mainly head zones; only some previous surfaces are rimmed by the walls of glacier cirques. In the DC there were two main glacier focusses. One, located to the north of the Maipo Volcano, was fed by a group of cirques with a south or southeast aspect, some of them with small glacier cirques at present; during the maximum, the glacier tongue probably moved to the east in the head, turning later to the south. Another glacier must have occupied the bottom of the valley to the east of the Arroyo Paramillos, and, in this area, would have flowed from east to west. We have no evidence of the confluence of these glaciers that could have taken place in the area now occupied by the south part of the Laguna. Moraine distribution to the northwest of the Laguna indicates a gradual retreat for a large glacier tongue already melted. In recent stages, glaciers flowing from two cirques in the west (Cerro Amarillo) behaved like "debris-covered piedmont glaciers" with low gradient lobes where till surface displays subparallel arcuate crests and furrows originated by the flow of the ice below. The Cajón del Diamante, a relatively narrow cut in bedrock, controlled the movement of the ice to the south. It has not been possible to identify fronts during maximum glacier extension, although glaciers probably reached lower altitudes than those suggested by till distribution. Moraine deposits, in a lower position than those previously cited, would have been destroyed by more recent processes. Other glaciers, with a radial distribution, discharged from a small ice cap in the DV summit; till has been reworked as alluvial deposits and rockglaciers, but it not was not possible to mark old glacier limits on the Maipo slopes.

At present, glacier fronts reach an altitude of 3,800 m approximately, although on the south slope of the MV they could go farther down, a fact that should be checked in the future. On the northern caldera divide, fronts of glaciers with a south aspect are at 3,900–4,000 m and at 3,900 m in the case of debris-covered glaciers in the Cerro de la Laguna (close to the Refugio Perón), to the east of the DC.

Previous relief was modified by glacier action, while most of the original transverse glacial profiles were changed by very active processes during deglaciation. High mountain climate, strong reliefs and water availability have favored periglacial processes: a great variety of active and inactive forms were identified in the area. Different mesoforms were built in various phases, among them complex landslides and fans formed by a combination of alluvial and gravitational processes.

Distribution and the preservation degree of rockglaciers indicate two origins (glacigenic and cryogenic) and, at least, three phases: an older one represented by partially degraded forms, and two more recent phases. The structure of the *refugee ice*, corroborated in successive visits to Refugio Perón, indicates that its formation took place during numerous stages. This shelter, built in 1951 and abandoned since the ›80s, is strongly affected by cryogenic processes: frost uplifting caused the breaking of most of the main building and the breaking and displacement of the small machine hut adjacent to the refuge. The access path, made a few years earlier, in 1949, is completely out of use; Corte (1953) had already described blockages in it in 1952. These problems can be attributed to the fact that it was constructed on an active rockglacier. Considering the cryogenic processes affecting these buildings and the path, we can attribute the ice to a neo-permafrost with less than 30 years. Moreover, a profile with indicators of paleo-permafrost (segregated, Taber ice) was identified between 3,400–3,500 m approximately, which indicates a minimum depression of > 300 m for the last important cryomere (Trombotto 2007).

Cryogenic contraction cracks, as those in Pampa de los Avestruces, indicate minimum absolute temperatures of −20 °C; this is consistent with the −20.24 °C registered at a lower altitude, in the meteorological station close to the Laguna (3,300 m a.s.l.), a temperature appropriate to produce polygonation and cracking in the soil; the calculated mean annual air temperature of 1.45 °C for this station is not compatible with permafrost. Creeping permafrost, however, is present in many zones of the area and surrounding the DL at higher altitudes.

The fluvial network, strongly incised in some areas, does not have the transport capacity to evacuate all the materials supplied by slope activity. Thus, the evolution of fans, formed by streams and debris flows in tributary valleys, and of landslides is mainly controlled by processes at the valley heads.

6 *Conclusions*

The geomorphological map of the Laguna del Diamante Reserve represents geoforms and cryoforms outlining glacial, periglacial, nival, gravitational, fluvial and lacustrine processes, as well as other geological features. Some sites, however, will still have to be corroborated in the field, as the area is very large and distances must be covered by foot.

The DC area, with some glaciers at high altitudes, presents highly active dynamics, which must have been even greater immediately after deglaciation; the zone is still in a paraglacial phase far from having reached the equilibrium with the present periglacial conditions. Some locations with cryogenic processes and forms, as rockglaciers, require a special attention, as until now they had been only briefly described. Both the Diamante area and the Pampa de los Avestruces had been, and still are, strongly affected by cryogenic processes: cryoweathering and creeping of permafrost or of the active layer. Relict outcrops affected by crioclastesis (tors) are frequent, as well as traces of aeolian erosion in cold environments; prone to natural or to anthropogenic changes, they might be easily altered. Temporal variations in the altitude of the lower limit of the quasi continuum permafrost refer to climatic changes that should be considered in the region in order to interpret the evolution of the quaternary relief.

Landslides, debris flow deposits and rock falls are clearly related to the cold conditions of the area. Deglaciation triggered landscape instability: catastrophic events, representing high energy environments, have been ascertained in the field (e.g. the recent debris flow deposit to the northwest of the Laguna). Cryogenic data, although not referring to any particular measurement, allow to infer the limit for a mean annual temperature of 0 °C at an approximate altitude between 3,600 and 3,700 m. Although complex, the zone presents adequate conditions to be considered a "type region" where different Andean landforms are represented.

Ice, either of glacial or periglacial origin, is a critical component in the DC systems. Further revision of the glacial and periglacial history of the area will lead us to a better understanding of the relief and landscape evolution of the region in the recent past and at present. For their importance for the ecosystem, these phenomena should receive a special attention in the planning of this natural protected area. Management institutions will be in a better position to take the adequate strategies, science-based, in order to maintain a balance between regional development and environmental preservation.

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References

Alonso, V. & Trombotto Liaudat, D. (2009): Periglacial geomorphology of El Miro area, Cantabrian Mountains, NW Spain. – Z. Geomorph. N. F. **53:** 335–357.

Corte, A. (1953): Contribución a la morfología periglacial de la alta cordillera con especial mención del aspecto criopedológico. – Anales del Departamento de Investigaciones Científicas, Tomo **1**(2): 1–54.

González-Ferrán, O. (1995): Volcanes de Chile. – Instituto Geográfico Militar, Santiago de Chile, 640 pp.

Groeber, P. (1946): Observaciones geológicas a lo largo del meridiano 70. 2. Hojas Sosneao y Maipú. – Asociación Geológica Argentina, Serie C, Reimpresiones **1:** 37–73, 1980.

Groeber, P. (1954): Bosquejo Paleogeográfico de los glaciares del Diamante y Atuel. – Rev. de la Asociación Geológica Argentina IX, 2: 89–108.

Harrington, R. (1989): The Diamante Caldera and Maipú Caldera complex in the Southern Andes of Argentina and Chile (34°10›south). – Revista de la Asociación Geológica Argentina **19**(1–4): 189–193.

Martín-Serrano, A., Salazar, A., Nozal, F. & Suárez, A. (2004): Mapa Geomorfológico de España a escala 1:50.000. Guía para su elaboración. Instituto Geológico y Minero de España, Madrid: 128 pp.

Sruoga, P., Llambías, E. J., Fauqué, L., Schonwandt, D. & Repol, D. G. (2005): Volcanological and geochemical evolution of the Diamante Caldera-Maipo volcano complex in the southern Andes of Argentina (34° 10′ S). – J. of South American Earth Sciences **19:** 399–414.

Sruoga, P. (2008): In Tomo I Norte. Sitios de Interés Geológico de la República Argentina. – SEGEMAR, Anales Nr. **46**, Buenos Aires: 215–227.

Stern, C. R., Amini, H., Charrier, R., Godoy, E., Hervé, F. & Varela, J. (1984): Petrochemistry and age of rhyolitic pyroclastic flows which occur along the drainage valleys of the río Maipo and río Cachapoal (Chile) and the río Papagayos (Argentina). – Revista Geológica de Chile **23:** 39–52.

Trombotto, D. (2007): Active layer studies in the Central Andes of Mendoza, Argentina. – 10th International Symposium on Antarctic and Earth Sciences (ISAES), Santa Barbara, USA.

Trombotto Liaudat, D. & Alonso, V. (2012): Permafrost and related forms in the Diamante Caldera (Central Andes, Argentina). – Extended Abstracts of the Tenth International Conference on Permafrost, Salekhard, Russia, Vol. **4/2:** 594–595.

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