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New evidence concerning the Plio-Pleistocene landscape evolution of southern Santa Cruz region

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Abstract

Remnants of an old aggradational landscape, Cerro Cuadrado Proglacial, are preserved on top of the high mesetas Pampa Alta and La Meseta on both sides of the upper Santa Cruz river valley, South Patagonia.

A first dissection of the mesetas, attributable to extended river erosion, predates the expansion of glacier lobes down the piedmontane area. The glacial advance is represented by the moraines of Pampa Alta Glaciation displayed on the top of Meseta Pampa Alta. Glacifluvial outlets contribute to the proglacial plain, Pampa Alta Proglacial, which is widespread to the southeast.

Strong and persistent fluvial erosion followed the retreat of the ice masses leading to the formation of several terrace levels in the main upper valley, La Australasia Terraces and San Fernando Terraces, and a step, Cordón Alto, that truncates the Meseta Pampa Alta. These foreland features and the relief covered by the basalts at Cerro Fraile in the cordillera, are probably a consequence of a diastrophic phase that affected both areas during this stage.

Late Pliocene basaltic lavas draining into the main and tributary valleys overran this landscape. The evidence indicates that during the eruption of the basalts the glaciation was active in the cordillera and that coeval fluvial and lacustrine aggradation took place in the extra-andean valleys.

During the Middle Pleistocene subsequent lava flows covered the high pampas and partially occupied the fluvial valleys again. After this last volcanic episode the glaciers reached their maximum expansion to the east.

Resumen

En la región sur de Patagonia, sobre ambas márgenes del alto valle del río Santa Cruz, cubriendo las mesetas Pampa Alta y La Meseta, se preservan rastros de un antiguo paisaje agradacional correspondiente al Proglaciar Cerro Cuadrado.

A un primer escalonamiento del terreno, producto de una extensa erosión fluvial, siguió la expansión de una serie de lóbulos glaciarios hacia sectores pedemontanos. Este avance glaciario se vincula a las morenas de la Glaciación Pampa Alta dispuestas sobre la parte más elevada de la meseta homónima. Escapes glacifluviales, vinculados a dichos depósitos morénicos, aportaron a la extensa capa de rodados proglaciarios que se extiende hacia el sureste.

Tras el retiro de las masas glaciarias, una fuerte y persistente erosión fluvial labró niveles de terrazas paralelos al alto valle del río Santa Cruz, Terrazas de La Austalasia y San Fernando, y un marcado escalón, Cordón Alto, que trunca la meseta Pampa Alta. Estos rasgos del paisaje desarrollados en el antepaís y el relieve cubierto por los basaltos del cerro Fraile en el sector cordillerano, son probablemente consecuencia de una fase diastrófica que afectó a ambos sectores simultáneamente.

Durante el Plioceno tardío coladas basálticas invadieron los valles tributarios y principal anegando parte del paisaje preexistente. Las evidencias indican que durante dichas erupciones basálticas imperaba la actividad glaciaria en el sector cordillerano, mientras que los valles extra-andinos eran afectados por agradación fluvial y lacustre.

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Erupciones volcánicas subsecuentes ocurridas durante el Pleistoceno medio derramaron lavas que cubrieron parte de las elevadas pampas y se encauzaron nuevamente en los valles fluviales preexistentes.

Con posterioridad a estos últimos episodios volcánicos los glaciares alcanzaron su máxima expansión hacia el este.

1. Introduction

The studied area comprises mainly the upper Santa Cruz river valley (USCRV) including adjacent localities of the extra-andean region in the Province of Santa Cruz, roughly within 50° and 51° Southern Latitude and 71° 30′ and 70° 30′ Western Longitude (Fig. 1). Phytogeographically it is ascribed to the Patagonian Steppe with semiarid continental climatic conditions characterized by an annual average temperature of 7.7°C, 150–200 mm of annual precipitation and westerly derived persistent winds.

Although the landscape looks similar to other Patagonian regions, the selected area is the most suitable place to study the paleolandscape evolution. Exceptionally well preserved, still clearly recognizable old geoforms, very good exposures of sediments and sedimentary rocks, together with Plio-Pleistocene volcanics, cropping out along both sides of the USCRV, are the main features that give an outstanding opportunity to interpret the stratigraphy as well as the involved geomorphological processes. On this basis a research project started two years ago to study the geomorphology and post-Miocene stratigraphy of the area, resulting in new data and original interpretations concerning the evolution of the landscape during the Pliocene–Middle Pleistocene.

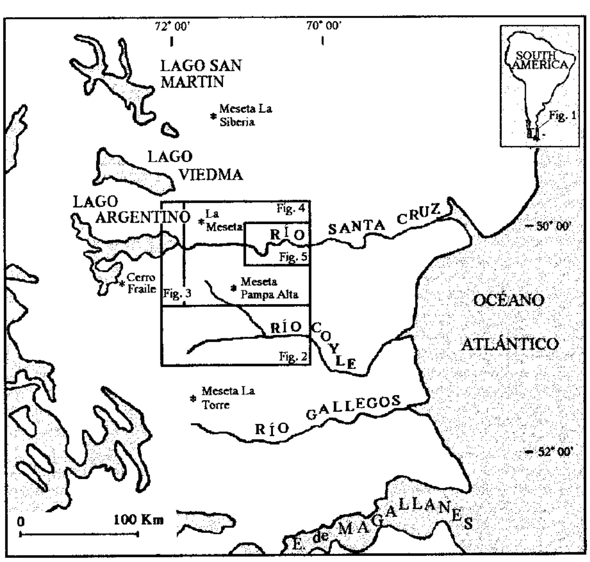

Fig. 1. Location map.

2. Previous work

In a pioneering study, Charles Darwin (Darwin, 1842) made the first interpretation of the typical southern Patagonian wide highplanes. After surveying part of the USCRV, Condor Cliff and upstream, he concluded that the wide Patagonian mesetas covered by gravel (shingle formation) and by large exotic boulders (boulder formation), derived from the cordilleran domain, were indicative of a marine environment. His assumption is based on the existence of marine shells on the valley floor. It is difficult to judge the age of elements considered by Darwin (1842) to be post-Pliocene. It is likely that he collected reworked fossils from the pre-Pliocene Monte León Formation (Bertels, 1970), that includes living species, or, as inferred by Feruglio (1950), the shells could be recent, but carried by natives from the Atlantic coast up to the USCRV. Since those initial observations several researchers discussed the possible origin of the shingle formation and its bearing on the understanding of the paleolandscape evolution of the extra-andean Patagonia. Caldenius (1932, 1940) and Feruglio (1944, 1950) critically analyze this previous work concerning the origin of the extensive gravel unit. Both authors believe that the "Rodados Patagónicos" (and other denominations mentioned therein) have a fluvial origin with or without glaciers in their valley heads. Both also agree on an Upper Pliocene age for the erosion and deposition of this unit, considering that the gravel was emplaced immediately after the accumulation of the Cerro Laciar–Cabo Buen Tiempo marine sediments. Caldenius (1940) invoked that solifluction (gelifluction) made a significant contribution to the erosion and leveling of the graveled landscape during the climatic deterioration prior to the first Patagonian glaciation. Terraces that approximately parallel the principal Patagonian rivers were considered to be formed by fluvioglacial processes during regional uplift phases of the continent and were linked also to climatic fluctuations. Some of the gravelly terraces displayed along the Atlantic coast were assigned to a marine process.

Feruglio (1950) recognized four main continental terrace levels in the Santa Cruz river valley. The uppermost level (level I, "Nivel de La Meseta–Meseta de las Vizcachas"), thoroughly covered by basaltic lavas, was considered as preglacial and the remaining three terraces (level II, III and IV) were considered as formed during defined glaciations. The level II ("Nivel de la Pampa Alta–Meseta del Monte León"), which is interrupted by a prominent step nearby Estancia Cordón Alto, may correspond to more than one glacial period. The level III ("Cerro Fortaleza–La Barrancosa–Santa Cruz") is ascribed to the penultimate glaciation in the Santa Cruz river valley as well as in the Deseado river region. The lowermost continental terrace level of Feruglio (1950; level IV, "Terraza de Los Guindos") is related to the last glaciation and includes the post-glacial levels only in the Santa Cruz river valley.

Strelin (1995) analyzed the controversy raised by the different interpretations given by Caldenius (1932) and Feruglio (1944, 1950) concerning the oldest glacial advances in the USCRV ('Per Dusén moraines', Caldenius, 1932 and "Sistema Externo", Feruglio, 1944, 1950). Figs. 2 and 3 summarize these versions, to which the interpretations proposed by Mercer et al. (1975) and by Strelin (1995) are added.

Mercer et al. (1975) and Mercer (1976) considered that the oldest Patagonian gravel unit was formed prior to the easternmost expanded glaciation and was probably deposited as outwash from earlier cordilleran glaciation. After these authors, this oldest glacifluvial, capped by basaltic flows of 2.95 My, shows up in northern USCRV and may correspond to the glacial deposits interbedded with basaltic lavas of 3.5 My

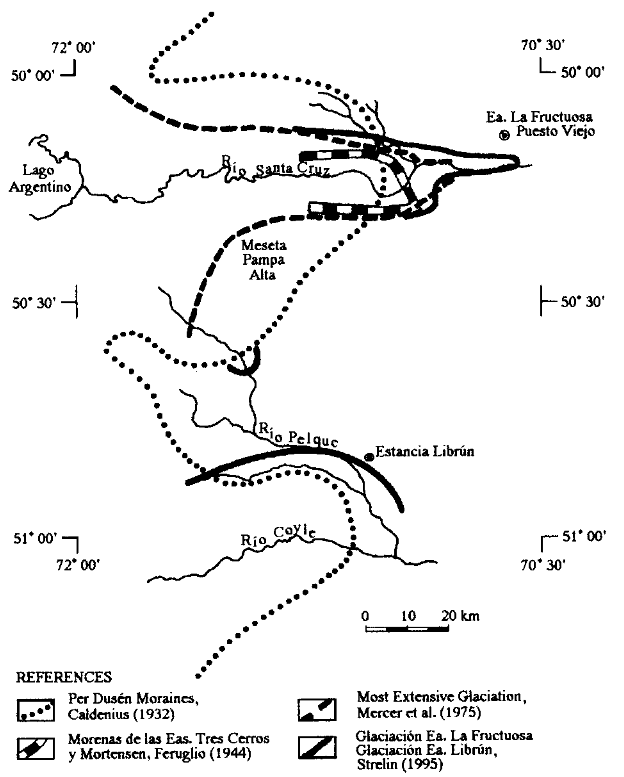

Fig. 2. Different interpretation of the locations of the most external moraine deposits during the most extended extra-andean glaciations (Strelin, 1995).

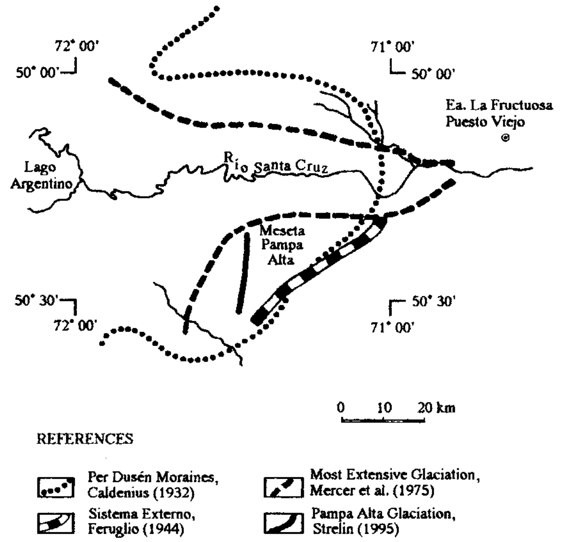

Fig. 3. Different interpretation of the locations of the most external moraine deposits during the oldest extra-andean glaciations (Strelin, 1995).

north of Lago Viedma (Meseta Chica and Meseta Desocupada).

Feruglio (1944, 1950) described moraine deposits interbedded and covering basaltic lavas (4–6 lava flows) in Cerro Fraile, just south of Brazo Rico–Lago Argentino. The upper moraine deposits, covering the higher lava flows, were referred to the last glaciation and the remaining to the "Sistema Externo" moraines. Mercer (1969) describes in Cerro Fraile a similar section, concluding that the uppermost lava flow lacks any hint of glacial activity. In addition, absolute radiometric ages (K/Ar whole rock sample) of 1.7 ± 0.5 My for the upper lava flow and of 3.2 ± 1.0 My for the lava that covers the lowermost till unit were presented. Fleck et al. (1972) and Mercer et al. (1975) obtained statistically more precise radiometric data (K/Ar whole rock sample) and paleomagnetic polarity from all but one of the eight basaltic flows in Cerro Fraile. After those results a new minimum age of 2.43 My is given to the lowermost till deposit and 1.03 My is the minimum age for the youngest till unit underlying the topmost basaltic lava. Mercer et al. (1975) correlated this youngest till unit with the easternmost glacial deposits, thus assigning to this glaciation an age older than 1.03 ± 0.05 My and younger than 1.17 ± 0.05 My, this last date obtained from a basalt underlying till that crops out between the Gallegos river and Magellan Strait. The glacial tongue of this easternmost reaching glaciation flowed through the paleo-USCRV and may have reworked and redeposited part of the oldest Patagonian gravel units. The subsequent climatic changes and the regional uplift caused the USCRV to deepen, cutting through different glacial–glacifluvial and volcanic units down to its present level.

Like Caldenius (1940) and Feruglio (1950), and bearing in mind Mercer's (1976) absolute chronology, Clapperton (1993) considered for the South Patagonian Gravels a late Miocene origin for an initial alluvial–colluvial gravel accumulation, followed by a prevailing glaciofluvial episode, that was restricted during the late Quaternary glaciations to narrow valleys, cut into the older deposits.

3. Description of the oldest geomorphic units of the USCRV (Figs. 4 and 5)

3.1. Cerro Cuadrado Proglacial (Strelin, 1995)

This geomorphic unit is equivalent to level I of Feruglio (1950) and probably corresponds to the gravel level described by Mercer et al. (1975) at Cerro La Criolla (1074 m.a.s.l.), the highest tip of Meseta Pampa Alta.

Corresponding terrace levels are presumed to be preserved underneath the widespread volcanics and partly below Pliocene glacial–fluvioglacial deposits accumulated closer to the Andes. The geoform was only clearly individualized at Cerro Cuadrado (*ca* 500 m.a.s.l.), a flat topped isolated hill located south of the USCRV, *ca* 200 km distant from the main cordilleran range. This relict geoform has a semicircular shape with 3 km in diameter and is *ca* 60 m higher than the surrounding highplane Pampa Alta. Discontinuous gravel, up to 0.20 m in diameter, with resistant lithics of prevailing Andean provenance, cap

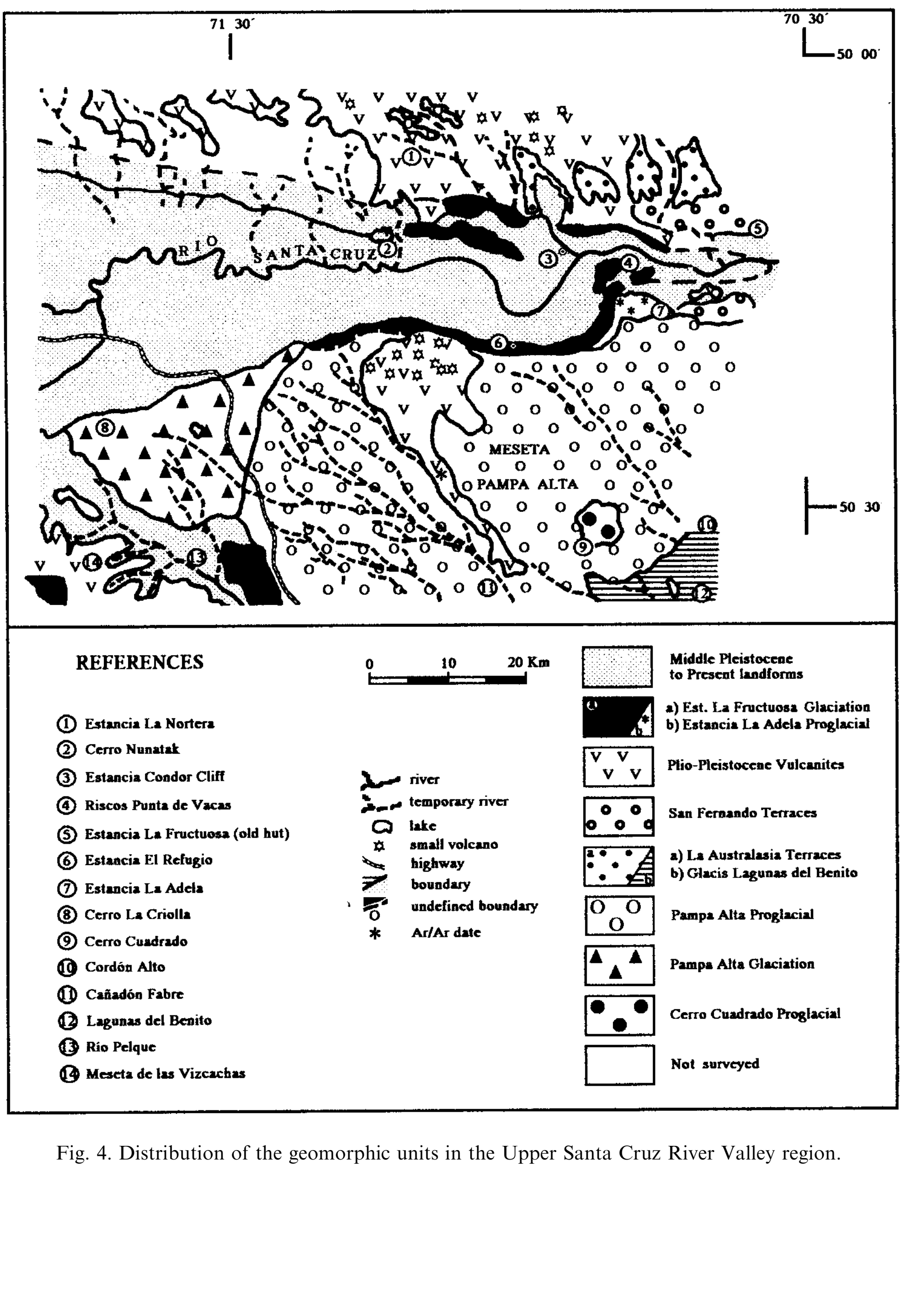

Fig. 4. Distribution of the geomorphic units in the Upper Santa Cruz River Valley region.

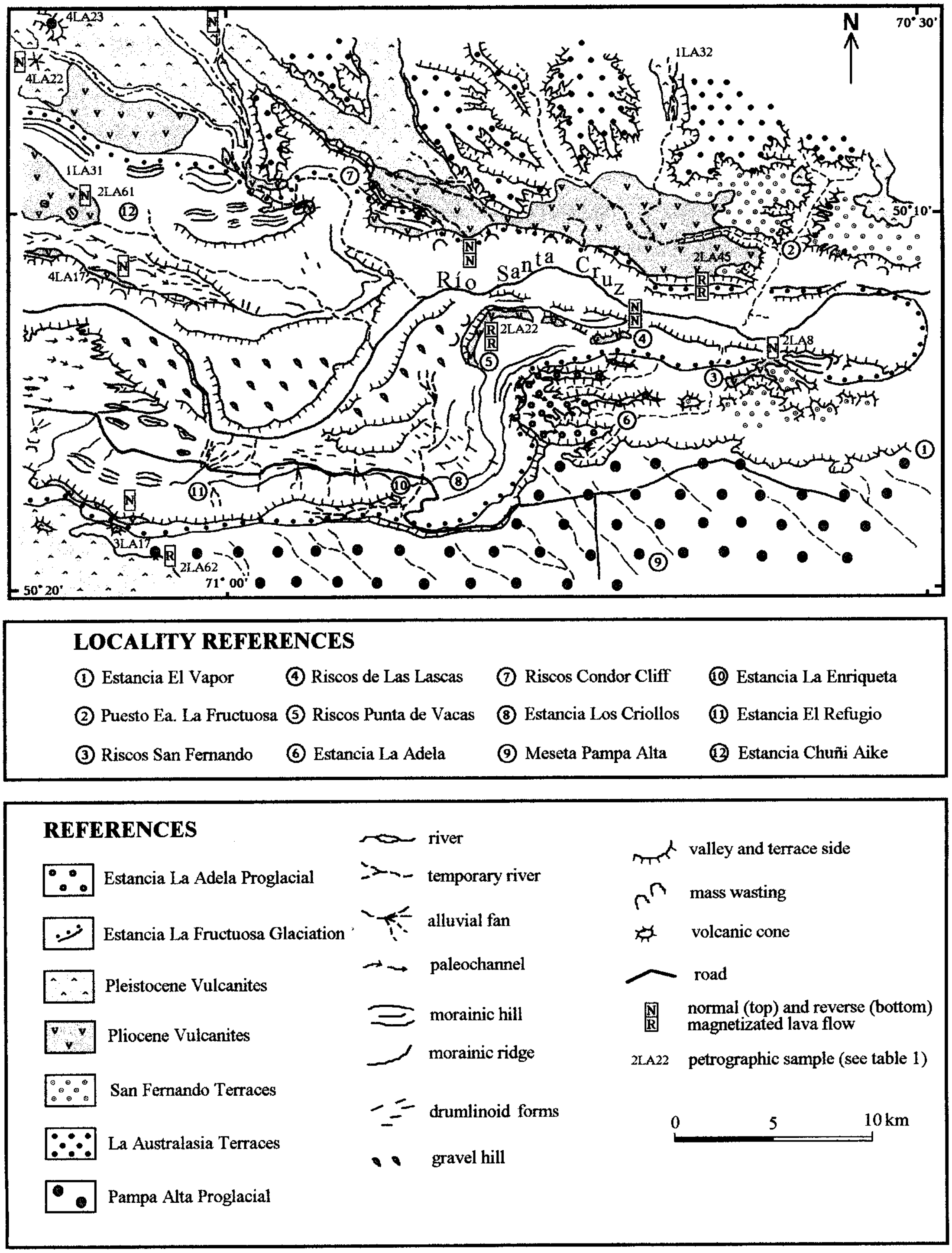

Fig. 5. Geomorphic units.

the terrace. This forms small hummocks up to 1 m high and 10 s of meters long which are separated by less gravelly lower zones. This assemblage can be explained as the eroded deposits of paleochannels resulting from relief inversion. A pit opened between these gravelly elevations exposed a meager thickness of the Cerro Cuadrado Proglacial gravels with 0.35 m of clayey soil containing scattered clasts up to 3 cm in diameter, which in turn covers a gravel layer partly cemented by carbonate with clasts up to 7 cm in diameter. The base of the gravelly bed, over 1 m thick, could not be reached.

A more complete geologic section recording silty lacustrine levels and piedmontane gravelly sediments is exposed nearby Estancia El Refugio on the higher edge of the Pampa Alta, right margin of the USCRV. This section apparently overlies an epi-pyroclastic succession, herein assigned to the Santa Cruz Formation (Furque and Camacho, 1972), and is attributable to the oldest sedimentation process that aggraded the landscape, presumably reaching the Cerro Cuadrado Proglacial level. The top of the Santa Cruz Formation is not exposed, vanishing at 480 m (a.s.l.) below scree and immature soils cover. At the height of 515 m (a.s.l.) the profile can be followed again with 40 m of partly covered grayish yellow loose silt, interstratified with thin grayish clay layers. Yellowish gray gravelly sands with pebbles up to 0.05 m in maximum diameter occur at 555 m (a.s.l.) and are succeeded at 575 m (a.s.l.) by a 10 m thick package of coarse gravel. Clasts are polymictic, mainly silica-rich acidic volcanics, quartzose sedimentites and metamorphites, though a few are basaltic. Some of the biggest blocks and gravels are faceted. The uppermost levels between 585 m and *ca* 610 m (a.s.l.) belong to moraine deposits of the Estancia La Fructuosa Glaciation (Strelin, 1995).

A referable section was observed on the same edge of the Pampa Alta *ca* 35 km valley upstream at Cuesta de la Escarchada composed of comparable thick packages of gravel that underlie moraine deposits of Pampa Alta Glaciation (Strelin, 1995).

3.2. Pampa Alta Glaciation - Pampa Alta Proglacial (Strelin, 1995)

Landscape exponents of these two geomorphic units are present exclusively on the top of the highplanes located north and south of the USCRV. The moraines of the Pampa Alta Glaciation are partly equivalent to the Per Dusén moraines (Caldenius, 1932), to the "Sistema Externo" (Feruglio, 1950), and to the "moraines of the most extensive glaciation" (Mercer et al., 1975). The glacifluvial Pampa Alta Proglacial forms part of the level II of continental terraces (Feruglio, 1950) and is equivalent to the "outwash merging into Patagonian gravels" (Mercer et al., 1975).

The deposits of the Pampa Alta Glaciation are located in the western corner of the homonymous meseta comprising a wide drumlin field limited to the east by roughly north–south striking (Azimuth 3°–14°) terminal moraines. Their ridges have been markedly truncated by erosion on the northern edge of Meseta Pampa Alta.

The moraines rise 10–20 m above the surrounding surface showing scattered gravel and erratic blocks that reach 1 m in diameter. Till cropping out along the cuts of the new highway 40 shows angular and partly faceted cobbles, up to 0.20 m in diameter, embedded in a clayey matrix. Most clasts consist of siliceous sandstone, schist and acidic volcanics. In some sectors the till is covered by 0.30 m of a truncated brown soil.

An extended proglacial plain emerges east of the terminal moraine range and dips gently to the southeast with a 1.5% gradient. This widespread terrace is incised by a series of broad and flat bottomed valleys such as Cañadón Fabre and Cañadón Camusu Aike. From the outcrops on the laterals of these valleys and some water wells it was estimated that 8 km downstream of the terminal moraine the gravel reaches 30 m in thickness. It is possible that some of the deepest gravel belongs to an earlier aggradational event. Sandy lenses are intercalated in this gravel in the upper 10–15 m. The clasts are rounded, locally imbricated, reaching 0.20 m in maximum diameter and some are faceted. The measured direction of progradation points toward the southeast (Azimuth 120°–150°). The upper gravel levels are cemented by carbonate and are commonly covered by brown soils up to 0.80 m thick. The proglacial surface is locally topped by lava flows that were channeled into some of the ample incised valleys. The thick gravel deposits seem to hide older lava flows that are presently undergoing exhumation. On the northern margin of the USCRV, just north of Estancia La Nortera, a series of relict terraces correspond to the Pampa Alta Proglacial. The terraces reach heights between 1120 m and 1020 m (a.s.l.) with slopes of 2.5% toward the southeast (Azimuth 120°–140°). They are formed by gravel deposits including blocks up to 0.40 m in diameter, some of them faceted, with an average coarse gravel size between 0.05–0.10 m in diameter. Apart from the typically resistant clasts of Andean provenance (schist, siliceous sandstone, acidic volcanics and granite), some of the components have a basaltic composition. The overall thickness of the unit could not be determined, but it exceeds 10 m. Impure, carbonate cemented sands, tentatively attributed to the Santa Cruz Formation, crop out approximately 80 m below the gravel level. The top and the sides of these gravel levels are partially covered by basaltic flows.

3.3. La Australasia Terraces

These newly differentiated geomorphic features are shaped on the Pampa Alta Proglacial. On the northern side of the USCRV they form a set of at least six steps. The lowest and last stage agrees in height with the southeast located Glacis Lagunas del Benito (Strelin, 1995), carved at the foot of Cordón Alto, which in turn is equivalent to the level II of continental terraces of Feruglio (1950).

The last and most extended of such steps dips clearly to the south, normal to the axis of the USCRV. Though the highest looks to be distinctly erosive, this last seems to be related to a relatively thick layer of gravel suggesting aggradation. The overall

Table 1
Petrographic features of basalt samples

	Rock	Phenocrysts			Groundmass	
Sample	Texture	Type	Borders	Maximum size (mm)	Texture	Mean size (mm)
2LA22	Porphyritic	Olivine	Euhedral	3.2	Intergranular	0.04
1LA32	Porphyritic	Olivine	Euhedral	2.8	Intergranular	0.04
2LA45	Porphyritic	Olivine	Euhedral	3.0	Intergranular	0.08
2LA8	Porphyritic	Olivine and Plagioclase	Euhedral to Subhedral	1.6	Ophitic	0.12
2LA62	Porphyritic	Plagioclase	Euhedral to Subhedral	4.4	Ophitic	0.08
1LA3	Porphyritic	Plagioclase	Subhedral	3.6	Intergranular	0.08–0.04
3LA17	Hyalopilitic–Vesicular					< 0.04
4LA23	Porphyritic	Plagioclase	Euhedral	2.4	Intersertal	0.08–0.04
4LA22	Pilotaxic intersertal					0.05
1LA31	Porphyritic	Plagioclase	Euhedral	3.2	Intergranular	0.08–0.04
4LA17	Porphyritic	Plagioclase	Anhedral	2.8	Intergranular	0.08–0.04
2LA61	Porphyritic	Plagioclase	Subhedral	2.4	Intergranular	0.08–0.04
4LA26	Hyalopilitic–Vesicular					< 0.04

characteristics of the blocks and gravel are similar to that of the Pampa Alta Proglacial from which they are certainly derived. Larger blocks are up to 0.40 m in diameter. The steps descend from 600 m to 475 m (a.s.l.). At the altitude of the lowest step, a corresponding terrace located south of the USCRV, close to the Estancia La Adela, seems to be covered by much younger glacifluvial deposits of Estancia La Adela Proglacial (Strelin and Malagnino, 1996).

3.4. San Fernando Terraces

At *ca* 350 m to 250 m (a.s.l.) dissected alluvial terraces can be traced over the topmost surfaces of San Fernando and La Rampa crags. The terraces comprise an upper package, up to 20 m thick, of polymictic blocks and gravel, partly faceted, of less than 0.30 m in diameter. Basaltic lava partially overran this gravel layer in San Fernando and La Rampa crags and covered it completely in the Las Lascas, Punta de Vacas, Condor Cliff and Chuñi Aike crags. At Punta de Vacas crags, by the end of the current fluvial erosion cycle, the paleo Santa Cruz river (or a quiet water body) flowed at an elevation of 200 m (a.s.l.), some 70 m above the present river level. This paleovalley, filled by a thick stack of lavas that rest on a gravelly bed, was originally carved in sediments of the Santa Cruz Formation.

The San Fernando Terraces are included in level III of the continental terraces of Feruglio (1950).

3.5. Pliocene and Pleistocene Vulcanites

At the end of the shaping of the San Fernando Terraces the landscape was partially covered by several of the lava flows mentioned in the description of the different geomorphic units. During this time the inferred paleovalley of Punta de Vacas crags was filled by palagonitic pyroclastic breccias, overlain by 10–15 m of pillow-lavas. Aggradation of up to 100 m of at least 12 tabular lava flows completes this volcanic unit.

At Cerro Nunatak, 25 km upstream of Punta de Vacas crags, a thick succession of glacilacustrine sediments topped by gravel intercalated with a volcaniclastic layer reaches a height of *ca* 535 m (a.s.l.). The base of the section is not exposed, but it could be assigned to the Monte León Formation, that comes in this area up to 400 m (a.s.l.). At 460 m (a.s.l.), stratified silty sands with tractive structures crop out, passing upwards to an alternation of thin layers — laminae of silty sands with clayey silt. A succession of fluvioglacial sand and gravel starts at 500 m (a.s.l.) and is interrupted at 525 m (a.s.l.) by a pyroclastic–hydroclastic level of 2.5 m in thickness. The pyroclastic level is overlain by a gravel package with an irregular upper erosive contact (10–0 m of variable thickness). This section was covered by a till deposit, up to 20 m in thickness, belonging to the Cerro Fortaleza Glaciation (Strelin and Malagnino, 1996), that reaches 555 m (a.s.l.) at the top of Cerro Nunatak.

In the studied area, after detailed field observations and careful interpretation of textural features in aerial photos and satellite images, two types of lava flows, with a distinct degree of alteration, could be recognized. By using these criteria three of the oldest lavas coincide with those previously dated by Mercer et al. (1975) and Mercer (1976) as Pliocene (2.95 ± 0.07 My; 2.79 ± 0.15 My; and 2.66 ± 0.06 My), and a lava flow interpreted to be younger was isotopically dated for this study, giving an age of 0.675 ± 0.56 My ($^{40}Ar/^{39}Ar$).

The basalts can be petrographically grouped into olivine and feldspar bearing. This grouping has no relationship with the age, remaining uniform in each lava flow, and reflecting a spatial arrangement of the basalts (see Table 1 and Fig. 5). The textures are dependent on the thickness of the flow and/or the sampling place in the basaltic body. Basaltic samples of both main textural types were processed for paleomagnetic studies, resulting in normal and reverse polarities in both basalt groups (Fig. 5). All of the recognized lavas were observed to be older than, and in part covered by, moraines of the Early to Middle Pleistocene Estancia La Fructuosa, Chuñi Aike and Cerro Fortaleza glaciations (Strelin, 1995; Strelin and Malagnino, 1996).

4. Paleogeographic evolution

Our interpretation of the present Patagonian morphology seeks not only to explain the processes that led to the widespread distribution of the "Rodados Patagónicos" (s.l.), but also reasons for the degradation of the underlying landscape. There is a broad general agreement in assigning to fluvial–fluvioglacial erosion the origin of terraces oriented mainly parallel to the principal Patagonian river valleys, and with a marine origin for terraces in the Atlantic littoral. The dilemma appears when explanations are needed to understand the generation of the highest mesetas (pampas) that do not follow a predetermined fluvial axis or do not have a proximal marine influence. In this type of situation, diverse interpretations have been invoked to explain the substrate truncation: marine erosion (Darwin, 1842; Hatcher, 1897; Mercerat, 1893); fluvial–fluvioglacial erosion related or not to the accumulation of the gravel (Nordenskjöld, 1898; Keidel, 1917; Caldenius, 1940), with a significant erosion contribution by solifluction (criopedimentation) and deflation (Caldenius, 1940); or by prevalent deflation processes (Fenton, 1921).

Three distinct major steps unrelated to a principal fluvial valley axis are identified as individual geomorphic units in the USCRV area: the Cerro Cuadrado Proglacial, the Pampa Alta Proglacial and the Glacis Lagunas del Benito. Regionally comparable elevated highplanes (Pampas) can be traced to the north into the Meseta La Siberia, east of Lago San Martín, and to the south they can be followed up to the Meseta de La Torre, east of Seno Última Esperanza, Chile.

The deposits cropping out at Cuesta de La Escarchada and Estancia El Refugio include silty lacustrine (glacilacustrine ?) layers. These layers are covered by partially faceted gravels and sands which represent the first arrival of glacifluvial deposits from the cordilleran piedmontane area into the extra-Andean domain. Both sedimentary sequences probably correlate with the glacifluvial(?) gravels recorded on top of Cerro Cuadrado (Cerro Cuadrado Proglacial). The aggradation is probably closely related to a slow and progressive cordilleran uplift and englaciation that might have taken place in the Early Miocene during the Pehuénchica phase (Ramos and Ramos, 1979). Regarding the age of these deposits it can be added that to the north of the USCRV the oldest Patagonian gravels are capped by the Late Miocene Strobel Basalt (Ramos, 1982).

The Pampa Alta Proglacial and Glacis Lagunas del Benito levels involve fluvial erosion cycles that are a consequence of a generalized continental uplift during the "Quéchuica" phase (Ramos and Ramos, 1979). These erosive surfaces were partially aggraded during proximal piedmontane glacial–glacifluvial accumulations (Pampa Alta Glaciation and Pampa Alta Proglacial). The analysis of the contribution of gelifluction to the dispersal of the Patagonian gravel are beyond the scope of this study, but considering the recorded altitude and gradients for the terrace levels it is believed that periglacial processes would be more significant towards the cordilleran domain.

Beyond the surveyed area, the Pampa Alta Proglacial continues to the north of the USCRV in the wide meseta, between Estancia El Cordero and Bajada de los Orientales, where it maintains its dominant southeastward regional dip. Precisely the northern side of the USCRV displays the various steps of the southward dipping Australasia Terraces, of which the deepest and largest stage coincides in level with the southern Glacis Lagunas del Benito (Strelin, 1995).

The paleovalley entrenchment continued until it reached the deep erosional level detected in the Punta de Vacas crags zone. The terraces of this last erosion cycle (San Fernando Terraces), clearly dipping down the Santa Cruz river valley, are covered by proglacial gravel, in some cases more than 20 m thick. The erosion here was clearly caused by the paleo-Santa Cruz river. Feruglio (1950) considered these terraces (level III) to have been generated before the Last Glaciation.

Important volcanic activity (associated with Ándica Principal phase; Ramos and Ramos, 1979) erupted during and towards the end of this strong landscape degradation cycle affecting the cordilleran and extra-andean regions. As a result, thick basalt packages accumulated, and in the Andean Cerro Fraile locality, the basalts were interbedded with glacial and fluvioglacial deposits. The age range for these basalts is established between 2.43 and 1.03 My (Fleck et al., 1972; Mercer et al., 1975). These radiometric ages correlate statistically with the Late Pliocene ages offered by Mercer (1976) and with the Early to Middle Pleistocene age herein presented for the extra-Andean domain. There, both textural types of basalt cover the glacifluvial gravels of the San Fernando Terraces. This contact can be discontinuously followed up to Cerro Nunatak, where a maaric pyroclastic deposit is interbedded within alluvial deposits. Based on one of the ages given by Mercer et al. (1975) to nearby basalts (2.95 ± 0.07 My) that cover the glacifluvial and the underlying glacilacustrine deposits of Cerro Nunatak, both sequences could be assigned to the Late Gilbert to Early Gauss magnetic epoch glaciations, and correlate well with the glacifluvial and glacial sediments that rest underneath the lower basalt of Cerro Fraile in the Cordilleran domain.

The easternmost expanded glaciation of the USCRV (Estancia La Fructuosa Glaciation; Strelin, 1995) took place at the final stages of this eruptive epoch. In the volcanic field topping the Meseta Pampa Alta, south of the USCRV, one basalt flow that postdated the Pampa Alta Glaciation provides an isotopic age of 0.675 ± 0.56 Ma. Based on a similar stratigraphic position, this basalt is correlated with that discovered underneath the moraines of the Estancia La Fructuosa Glaciation (Strelin, 1995). Though the data need more refinement, a preliminary conclusion is that the Pampa Alta Glaciation predates the youngest recorded Early to Middle Pleistocene volcanism in the USCRV-Pampa Alta region and that the initiation of the Estancia La Fructuosa Glaciation postdates this age.

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