ORIGIN OF THE NORTHERN PATAGONIAN MASSIF REGIONAL PALEOSURFACE

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ABSTRACT – The crystalline basement landscape of the Northern Patagonian Massif is a geomorphological unit at a regional scale. During our studies on the regional geomorphological analysis of this morphostructural unit, an extensive paleosurface named as the Gondwana Surface has been recognized. The studies were oriented to the nature of this very large granitic relief landform and its state of degradation due to the action of several geomorphological processes. The lithology and structure of the crystalline basement units is analyzed, which is related to the global geology in terms of the Gondwana magmatic arc, that extended since the lower to middle Carboniferous (334 Ma) until the Jurassic (180 Ma). The magmatic evolution of this region, together with movements associated to this episode, produced a crustal uplifting that exposed the landscape to intense erosion. Field evidence indicates that the crystalline basement rocks have been exposed to an extended and severe erosion process, in which deep weathering conditions have been the most relevant processes, generating an important alteration (saprolite/regolith) under tectonic stability circumstances. The interaction between a complex series of different climatic events over extensive time periods, the alteration processes of the rocky mass, and the erosion and transport of the regolith are responsible for its superficial morphogenesis. This particular mega-landform of the granite relief, a product of deep weathering, is interpreted as a denudated surface originally formed as a result of chemical corrosion in tropical climate which is known as etchplain. The paleosurface shows an areal exposition over more than 20,000 km^2, almost as large as one of the smaller provinces of Argentina or the size of Belgium. This granitic plain does not represent a perfect, absolute planation surface, being instead more like an undulating plain, occasionally with rounded hills, of very small local relief. In some restricted areas, the surface has been partially buried by Cretaceous sedimentary and/or volcanic units and later re-exposed as a totally or partially exhumed surface. Other large and small features belonging to granitic landscapes have been found associated. With respect to the possible ages of this paleosurface and other associated features, the determination of relative age shows that the surface is younger tan the units that it eroded and younger than the oldest beds covering it. Based on these criteria, it is herein inferred that this surface started to form sometime after the Late Permian-Triassic and/or Early Jurassic times and was completed in the Late Jurassic-Middle Cretaceous.
Keywords: Paleosurface, granitic relief, weathering, etchplain, exhumation, Northern Patagonian Massif, Patagonia.

RESUMEN – *E. Y. Aguilera & J. Rabassa - Origen de la paleosuperficie del macizo Nordpatagónico*. El paisaje del basamento del macizo Nordpatagónico constituye una unidad geomorfológica de magnitud regional. En el análisis geomorfológico regional se ha reconocido una extensa paleosuperficie denominada Superficie Gondwánica. Los estudios están orientados a la naturaleza de esta forma del relieve granítico y su estado de degradación por la interacción de diversos procesos geomórficos. Se analiza la estructura y litología integrada por rocas de basamento cuya relación con la geología global se vincula con el arco magmático gondwánico que se extendió desde el Carbónico inferior a medio (334 Ma) hasta el Jurásico (180 Ma), esta evolución magmática y los movimientos asociados a dicho episodio produjeron un levantamiento a la corteza en esta región que expuso el paisaje a una intensa erosión. Evidencias de campo indican que las rocas del basamento cristalino han sido expuestas a un prolongado e intenso proceso erosivo, donde la meteorización profunda ha sido el proceso de mayor relevancia generado importante alteración (saprolito /regolito) bajo condiciones de estabilidad tectónica. La interacción entre la sucesión de diferentes eventos climáticos en extensos periodos de tiempo, los procesos de alteración de la masa rocosa, erosión y transporte del regolito son responsables de la morfogénesis superficial. Esta particular megaforma del relieve granítico, producto de la meteorización profunda se interpreta como una superficie arrasada, denominada de corrosión química o grabada (etchplains). La superficie muestra una exposición superficial de alrededor de 20.000 km^2, esta llanura granítica no representa un aplanamiento perfecto, se trata más bien de una llanura ondulada y en ocasiones redondeada, de escaso relieve altimétrico. En restringidos sectores la superficie ha sido parcialmente sepultada por los depósitos sedimentarios cretácicos y/o volcánicos y re-expuestas posteriormente como superficie total o

parcialmente exhumada. Asociadas a esta megaforma se encuentran otras formas mayores y menores del paisaje granítico. Respecto de las edades posibles, de la paleosuperficie y los demás rasgos, mediante determinación relativa la paleosuperficie es posterior las rocas que corta y anterior a los depósitos más antiguos que la cubren. Criterio por el cual se infiere que esta superficie comenzó a formarse en tiempos del Pérmico tardío, el Triásico y/o el Jurásico temprano, culminando en tiempos del Jurásico tardío a Cretácico medio.
Palabras Clave: Paleosuperficie, relieve granítico, meteorización, superficie grabada, exhumación, Macizo Norpatagónico, Patagonia.

INTRODUCTION

The Northern Patagonian Massif is a positive element of the crust and it has been exposed to subaerial conditions for many millions of years. The typical landforms of the granitic landscape are represented by a Granitic Plain, a regional scale unit with development of domes, inselbergs, castle-koppies and nubbis, associated to some minor forms.

The development and evolution of this landscape is related to the morphostructural environment of the massif and with the morphoclimatic systems acting over it. Through million of years, erosion agents have permanently worked to reduce the crystalline masses to the level of granitic plains and their associated landforms. The rocks of the massif basement, largely composed of granitoids and volcanic rocks belonging to several epochs, have been under the intervention of the morphoclimatic systems, with a wide set of climates from temperate to tropical and from wet to semiarid, while regional tectonic events were responsible for the uplifting, deformation and dismembering of Gondwana, somewhat since 300 Myr ago, when break up started. A varied morphostructural context set the conditions for the granite landforms, where primary rock characteristics, such as texture and structure, control their weathering and transformation into altered rock or regolith. A fundamental factor in the evolution of this landscape is the tectonic structure, that is, fracture systems, faults and joints, which fragment the granitic bodies generating pathways that allow the circulation of fluids of a varied nature, which actively and selectively attack the minerals. The scale of observation of the fracturing pattern comprises those fractures of regional magnitude that articulate large relief units, faults that divide plutonic bodies with relative block displacement, joint systems inherent to the igneous rocks emplacement and microfractures.

The jointing due to the emplacement of the igneous bodies consists in parallel joint systems with curve geometry and wide curvature radium. These systems could be related to the liberation of lithostatic charges where the plutonic body, once outcropping due to the decompression effect, resolved the efforts by means of this type of fracturing (Vidal Romaní & Twidale, 1998). The fractures surging during the solidification and volume reduction of the magmatic mass volume are considered as elements of the internal structure of the intrusions. The cooling fractures separate the intrusive and extrusive rocks in disjunctive zones. The latter may have a regular parallelepiped shape or irregular, with spheroidal shapes. The planar fractures are distributed transversally to the oriented textures (transversal fractures), those of parallel texture design and with strong inclination (longitudinal ones) and those of smooth inclination and strike parallel to the lineal textures favour sheet and layer disjunctions. Diagonal fractures with oblique pattern with respect to the lineal texture are also present. The fluid circulation through these fractures is an important factor in the final modelling of the granitic landforms.

In early phases of the development of the geomorphological knowledge, the planation surfaces had been analyzed by numerous authors, being the theory of William M. Davis (Davis, 1922) the triggering element to debate their genesis. He named them as peneplains and attributed them a fluvial genesis. Walther Penck (1927) considered them to be formed by the parallel retreat of the slope, a concept that would later be the base of the landscape models by Lester C. King (King, 1950, 1967). Both authors called pediment plains or pediplains to the erosion surfaces which had been previously named as peneplains. The concept of etchplain, of more restricted circulation, was used to define a low relief surface which was considered as a peneplain category. Fennemann (1936) interpreted those topographic surfaces with accordant summits as those produced by levelling of a resistant formation and called them structural plains.

Finally, Wayland (1934) introduced the concept of etchplain (corrosion plain or etched plain) after his studies of topographic surfaces in Uganda, Africa. The process for generation of an etchplain was that of deep weathering, whereas the subsequent process of denudation of this surface was called as “etchplanation”.

Etchplains derive from pre-existing plains or flat topographic areas, in which a deeply weathered saprolite rocky surface is developed, with depths of up to several hundreds of meters. The chemical weathering processes are very important, as well as those related to dismantling of the regolith. Etchplains are associated in general to crystalline rock zones and ancient massifs in tropical climate zones, which forced a fast chemical weathering on susceptible rocks.

Twidale (1985) classified the erosion surfaces in three types: epigenetic, etched and exhumed. The epigenetic surfaces are formed by the active processes at and near the surface of the Earth. Most of the epigenetic surfaces are due to weathering by atmospheric action and later washing away of the debris due to stream action. Most of them developed a layer of weathered rock as regolith. The etched forms (Wayland, 1934; Willis, 1936) are surfaces produced as a result of the stripping mobilization of the regolith of epigenetic surfaces and of the exposition of the weathering front to the atmospheric action (Mabbutt, 1961). The morphology of the etched plains generally mimics the morphology of the related epigenetic forms. The etched surfaces are formed in two genetic phases and have two ages: The first phase corresponds to the sub-superficial preparation time and the second represents the period of dismantling of the regolith and the final exposition (Twidale, 1987, 1990). The epigenetic and etched surfaces are buried by sedimentary or volcanic deposits and later re-exposed as exhumed surfaces.

LOCATION OF THE STUDY AREA

The study region is located in the province of Río Negro, Argentina, between latitudes 40°00´- 42°00´ S and longitudes 67°30´-70°30´ W (Figure 1). It belongs to the extra-Andean Patagonian geographical region, characterized by tableland landscapes, low hills, blow-out hollows, depressions and wide, terraced fluvial valleys, mostly oriented W-E and carved by streams originating in the Patagonian Andes. The climate is cold and arid, with strong winds coming from the west. The aridity of the present climate is a consequence of the uplifting of the Patagonian Andes which act as a barrier to the wet westerlies crossing the Pacific Ocean. The vegetation is steppe-like due to a general lack of water.

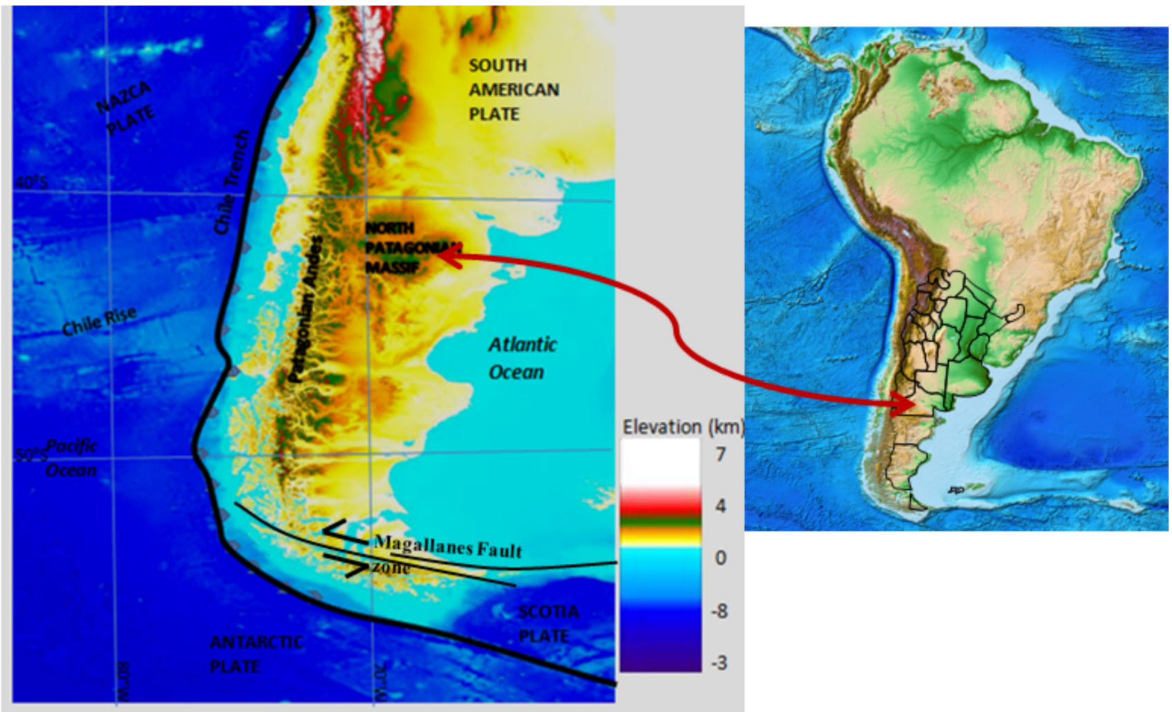


FIGURE 1. Regional location of Patagonia, Argentina, showing the Somún Cura Massif and the geotectonic setting.

METHODOLOGY

This study was based upon the analysis of field data, maps and geological cross sections, interpretation and analysis of Landsat 7 ETM satellite imagery and terrain digital elevation models (DEM). The visual and digital analysis of satellite imagery was oriented to determine the morphological and spectral characteristics of the different geological units, focusing on alignments, fractures, contacts, geometrical relationships of structural and lithological discontinuities for the interpretation of their geological-geomorphological significance.

By means of a geographical information system (GIS), the information obtained from the spatial and temporal distribution of the identified geomorphological surfaces was criss-crossed. The digital elevation model generated from the digitalization of the topographical maps used for a base was incorporated (Instituto Geográfico Militar, Buenos Aires; scale 1:250,000). This work was completed with field reconnaissance studies for the recognition of the different units observed on the images, the combination of criteria focused to determine the origin of the different landforms, as well as for the study of the "in situ" mineral alteration (regolith/saprolite) and the resulting structures.

REGIONAL GEOLOGICAL SETTING

The study area has low relief, with ample depressions and small hills. The largest part of the surface was covered by debris and poorly developed soils. From the geological point of view, the outcrops of the crystalline basement in the Northern Patagonian Massif are formed by metamorphic rocks and granitoids of the Gondwana cycle, formed during the Late Paleozoic and Early Triassic, which are overlain by the ignimbritic and tuffaceous complexes attributed to the same cycle and whose age extended from the Late Paleozoic until the Middle Jurassic, inclusive (Llambías & Rapela, 1984).

These are two superposed magmatic cycles, the first one exclusively of a plutonic nature, of Carboniferous age, and a second one bearing intrusive facies, lavas and ignimbrites which formed an extensive ignimbritic plateau, of Late Paleozoic to Late Triassic-Early Jurassic age. This event is also associated to an Early Jurassic plutonic activity, of extensional nature (Rapela & Alonso, 1991).

The crystalline basement of the massif formed a positive area already during the Triassic and it was covered in a peripheral way by sedimentary rocks bearing fossil flora.

The Jurassic sediments developed in continental environments with pyroclastic participation and were covered by continental deposits of Early to Late Cretaceous age, in which the Maastrichtian-Danian, Eocene and Late Cenozoic marine transgressions have been recorded.

The Pacific Ocean transgression along the western side of the massif has been registered over a small area by Early Cretaceous marine sedimentary rocks.

The Northern Patagonian Massif (also called "Macizo de Somuncurá") acted as a sub-positive element which separated, to the north and to the south, two important sedimentary depocenters from the Early Cretaceous onwards: the Neuquén Group basin and the Chubut Group basin. Over the central part of the massif, only a thin and discontinuous blanket of Cretaceous rocks confirmed the continental sedimentation of both groups. Another important feature of the massif is the presence of basaltic volcanism, which started weakly during the Eocene, to continue with huge alkaline basaltic flows of Oligocene age, which finally covered most of the massif, such as the volcanic units of the Somuncurá high plains. It is identified by the development of basaltic plateau flows and alkaline and hyper-alkaline eruptive rocks, associated to a reduced number of volcanic centers, over a rigid basement, related to a tractive regime developed in the extra-Andean region, linked to a crustal thinning process that in a few million years produced huge amounts of basalt flows.

The later activity developed with important alkaline acid episodes. The Miocene basaltic volcanism is restricted to the western margin of the massif, whereas the much more modern flows took place in other positions, peripheral to the massif (Ramos, 1999).

The Tertiary deposits are interfingered with the basaltic volcanism. They do not achieve a great thickness in this region, because it behaved as a relatively stable and positive massif. The Quaternary deposits are represented by sediment accumulations produced by fluvial action and, marginally, by the Pleistocene glaciations and periglacial climates.

PALEOCLIMATE

Paleontological evidence indicates that the climate of the region during the Mesozoic was temperate to tropical and very wet, at least for most of the studied period. From the paleobotanical point of view, the presence of plants in the Middle to Late Paleozoic formations is still unknown, whereas in those corresponding to the Mesozoic the paleoflora is very important due to the existence of abundant and rich tafofloras, of Triassic and Jurassic age (Arrondo et al., 1984). Likewise, paleopalynological records reflect, with great diversity, abundant plant life which characterized then the Northern Patagonian region during the Mesozoic era (Volkheimer, 1984). With respect to the Cenozoic fossil floras, the different groups of tafofloras studied by Romero et al. (1984) are indicators of gradual changes in the environmental conditions, from a very wet, warm-temperate climate to another one, cold-temperate and dry. The microfloristic associations found, formed during the Late Eocene and the Early Oligocene indicate that some portions of the massif were located in lower topographies with humid and protected conditions, compared to others from higher elevation zones with dry climate, of undulating landscape and exposed to maritime winds with abundant seasonal precipitation (Pothe de Baldis, 1984).

Studies of mixed paleofloras during the Cenozoic of Chile and Argentina suggest that they developed in a sub-tropical climate that extended southwards until latitude 40º S, with relatively hotter temperatures and high annual precipitation with little or no seasonal variability (Hinojosa & Villagrán, 2005).

LANDSCAPE EVOLUTION

The modelling of the landforms took place on granitoids, of granitic to granodioritic composition, with coarser to mid- grain sized crystals, and lavas and ignimbrites as well. In a smaller proportion, dioritic lithologies are also present. The landforms are determined by joint networks, separating the plutonic bodies in parallelepiped-shaped blocks, affected by sub-aerial erosion, which made progress following the joints and their angles, widening the joints and progressively rounding their edges.

PRIMARY STRUCTURES OBSERVED IN THE GRANITOIDS OF THE STUDY AREA AND THEIR INFLUENCE IN GRANITE MODELLING

Some of the inner structures of the plutonic bodies, which in our opinion are important to be considered to widen our concepts about the lithological behaviour of the granitic masses, are described. Among them, the development of late syn-magmatic dykes is produced during the plutonic crystallization in a fragile crust. This is caused by a diminution of volume, which produce contraction processes in the innermost portion of an igneous body, which cause tensional stress and inner fractures are generated.

These fractures are sealed by the magma itself forming dykes with highly welded margins, of short longitude and thicknesses smaller tan one meter (Llambías, 2001).

The grain size of these dykes is microgranular, marking a strong grain size contrast with the rest of the rock which is of medium to coarse grain size. The welded margin of the syn-magmatic dyke usually generates an unconformity which allows the formation of fractures which act as penetration ways of the exogenetic agents, where selective weathering starts to invade the granitic mass (Picure 1).

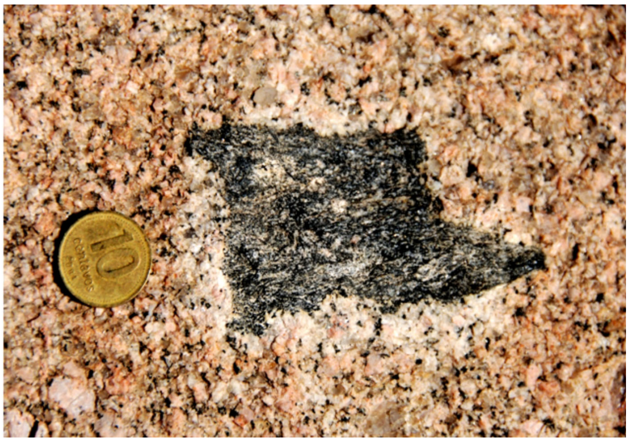
This fabric provides a relative isotropy to the inner deformation, due to which it has not a great influence in the definition of subsequent landforms, as granitic landscape forms that provide undifferentiated features typical of plains, such as rocky platforms and billiard tables.

Some granitoid rocks show a fabric which is synchronous with deformation, in which, due to magmatic flow, the minerals are oriented in a certain direction, with kinematic indicators such as parallel to sub-parallel alignments of prismatic euhedral crystals of alkaline feldspar and amphiboles, imbrications of euhedral crystals, magmatic foliation marked by the alignment of mica crystals, elongation of mafic, microgranular inclusions, and Schlieren alignments, among others. Evidence of magmatic structures formed by sub-solid flow with intra-crystalline mineral deformation, with bands of quartz, mica stretching and arching of plagioclase twinning is recorded. These preferential orientations could act as possible disjunction

PICTURE 1. The welded margin of the syn-magmatic dyke generates an unconformity which allows the formation of fractures which act as penetration ways of the exogenetic agents.

facilitators, as in the case of the granitoid rocks included in the Mamil Choique Formation. As small sub-volcanic bodies intrude the Mamil Choique Fm., clean contacts with a cataclastic margin are found, which generates an important secondary permeability.

Enclaves and xenoliths represent rock fragments of different composition which have been trapped by an igneous rock. These structures of different lithology with respect to the rest of the granitic mass enhance the possibility of generating weathering hollows by processes of selective weathering. For instance, the Cayupil and Palenqueniyeu granites, among other examples, are biotitic-hornblendic granites, with dioritic inclusions. The dioritic composition corresponds to plagioclase and hornblende and biotite. The plagioclase is less resistant to weathering than the potassium feldspar under equal environmental conditions, a reason for which the dioritic enclaves are altered before than the containing granite, leaving cavities which are deepened and enlarged. The Calvo Granite contains mafic microgranular enclaves (Picture 2).



PICTURE 2. Enclaves: structures of different lithology with respect to the rest of the granitic mass enhance the possibility of generating weathering hollows by processes of selective weathering.

Miarolas are cavities in granites which are produced due to ex-solution of magma gases at the moment of crystallization. In these cavities, the crystals of quartz, feldspar, and pneumatolithic crystals grow without being in contact among them, forming sub-euhedral crystals. The inner walls of these cavities are usually totally or partially cover by crystals. These structures have been observed in the Lipetrén and Calvo granites.

Schlieren are thin bands of iron-magnesium minerals in the granitic mass. Sometimes these bands may be followed along tens of meters. They may be formed during the flow of the granite within the magmatic chamber. These structures have been identified in the Calvo Granite.

LANDFORM IDENTIFICATION

The dominant landform is the granitic plain with a very well differentiated development and totally exposed over an area exceeding 20,000 km^2 (Figure 2). In marginal areas of the massif, this landform is fossilized by continental and volcanic deposits It is composed of a low relief surface, with development of a weathering mantle where the weathering front is exposed, revealing that weathering and regolith stripping dismantling have not been homogeneous, but the plain is interrupted by residual nuclei as blocks, boulder groups, nubbins and koppies, which are located at a topographic level above the general level of the plain and which would represent the exposition and exhumation of the unweathered rock fragments.

The regional planation processes affected, particularly in the eastern side of the massif, different rocks of the Los Menucos volcanic complex, extensive mantles of ignimbrites north of Sierra Colorada and to the south of Route 23 between that locality and the town of Los Menucos. The ignimbrites have been modelled in rounded outcrops, bounded by a large density of fractures, of dominant NE strike, which reach up to several kilometres in length. This fracture system is restricted to the flow units of the ignimbrites, and it is typical of tensional stress during the cooling of the flows. These main fractures are associated with other fractures of lower hierarchy, of a closer pattern which lie in perpendicular planes.

Topographic sections show the low relief, topographic surface developed in plutonic and volcanic rocks, over which patches of sedimentary and volcanic rocks of Late Cretaceous and Paleogene/Neogene age are overlying, which are forming younger planation surfaces, respectively (Aguilera, 2006) (Plate 1).

In the regional extent of the paleosurface it is observed that the sequence of these landforms is depicting the different stages of evolution. The fracture patterns and the primary textural characteristics of the igneous bodies generate the structural discontinuities which produce the disaggregation of the rocky masses and the later movement of the blocks. Thus, landform associations have been recognized, some of them totally lacking regolith, other landforms with smaller quantities preserved in protected depressions and some of them still surrounded by regolith.

A weathering profile corresponding to the

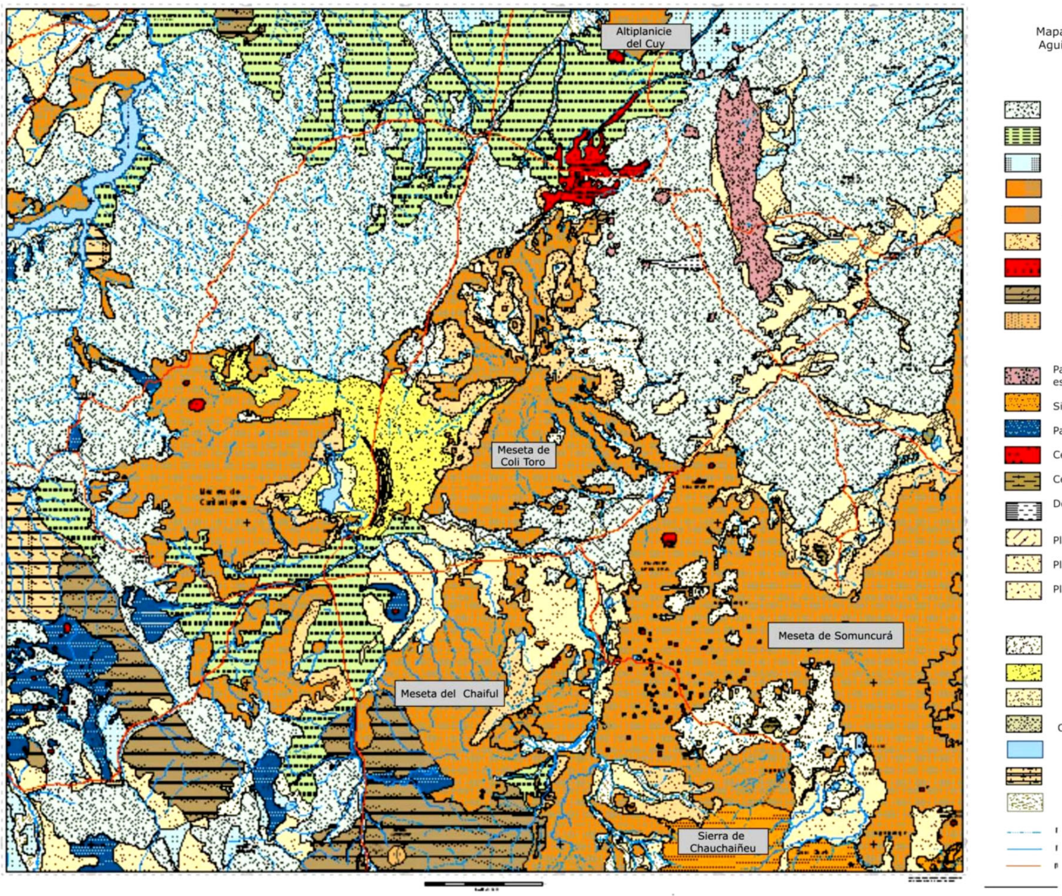


FIGURE 2. The dominant landform is the granitic plain (Gondwana surface in geomorphological map with a very well differentiated development and totally exposed over an area exceeding 20,000 km^2.

outcropping plutonic bodies in the area of La Esperanza is described. The rocks are named as the Calvo Granite (Llambías & Rapela, 1984), composed of potassium feldspar, oligoclase, quartz and biotite. The observation of the changes at the mineralogical level enable the appreciation that the potassium feldspar has offered a higher resistance to weathering than the plagioclase, since the latter has been transformed into a clayey mineral whereas the biotite has been altered to vermiculite, with the subsequent volume increase, and mobilization of opaque minerals. The abundant quartz is resistant to weathering and it persists as non altered. The medium to coarse grain size of the quartz makes it vulnerable to areolar erosion; thus the pressure exerted by the expansion over each crystalline union augments with increasing grain size (Derrau, 1970). Their hipidiomorphic grain texture, where the morphology of the crystalline faces is anhedral and in some cases, subhedral, provides a smaller cohesion than if all crystals would be anhedral.

PLATE 1. Different views of the palaeosurface developed in granitic rocks.

The upper portion of the section appears slightly disturbed in between these crystals by rare roots of xerophytic vegetation and slope landslides. The portion immediately lower to it does not show disturbance and it retains structures of the original rocks, such as "in situ" margins of the syn-magmatic dykes and unweathered rock nuclei. It is clearly observed that the minerals have not changed their composition or increased their volume (Figure 3, following the model by Ollier, 1991).

In these dykes the grain size is micrugranular, the composition is quartz-feldspar and the texture is microgranular anhedral. For these reasons, they show high resistance to weathering. The dykes occur at the surface as high benches and they keep their strike without tectonic perturbation, having been "in situ" immobilized, together with the granitic mass wholly or partially altered to regolith. According to the level of deepening of the section, bands, zones, fringes, and rounded and arenitized massifs are observed, together with other areas with fresh granite. The arenitization, in the sense of Derrau (1970, indicates a weathered and immobilized granitic material. In fact, it is a saprolite that behaves as slightly compacted sand. The unequal fracturing and fissuring of the material allows the persistency of unweathered rock nuclei and show that the base of the weathering profile is not totally flat.

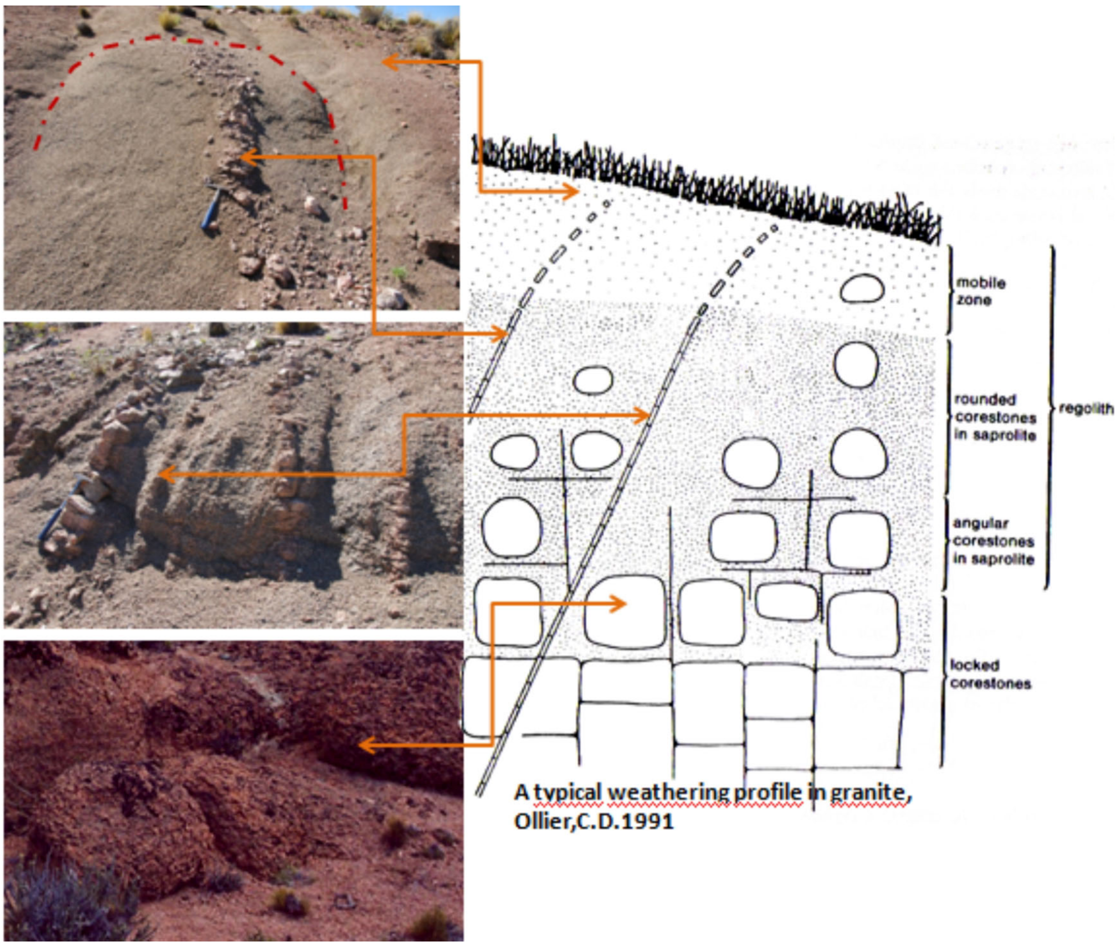


FIGURE 3. A weathering profile corresponding to the outcropping plutonic bodies in La Esperanza area.

WEATHERING RESIDUAL ELEMENTS THAT ARE PRESENT IN THE GRANITIC PLAIN

Inselbergs or other isolated positive features, such as domes, castle koppies, nubbins, and rocky crests are present in the granitic plains, accompanying medium to small sized landforms such as boulders, rounded blocks, gnammas and tafonis, among many others. Their description follows the criteria by Thomas (1978), Twidale (1982) and Vidal Romaní (1989). In these reliefs with predominant residual landforms and complex fracture patterns, regolith relicts are preserved in the negative, depressed areas.

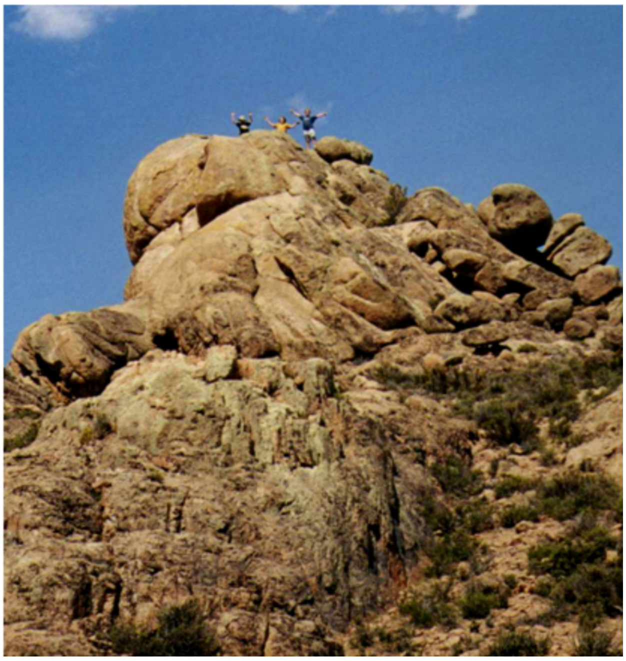
Domes are modelling landforms developed on granitoid rocks of medium to coarse grain size, with granitic to granodioritic composition and sometimes, dioritic. The granitic bodies are criss-crossed by joints of large curvature radii slightly undulated and grossly parallel to the surface of the ground, which break them in planar sheets more or less lens-shaped. This fragmentation of the granitic mass generates rounded forms, a product of the weak inclination of the joints. Their aspect is that of a spire or a bell, either symmetrical or asymmetrical (Picture 3).

Castle-koppies are formed on granitoid rocks, of medium to coarse grain size, highly jointed, with systems of orthogonal and sometimes, oblique discontinuities, which once uncovered during denudation, they adopt castle-like shapes. These joints are considered as shear planes produced by compression normal to the trajectories of magmatic fluidal lines. They are usually located closely to domes, where the different types of fracturing of both types of landforms may be observed (Picture 4).

Nubbins are features composed of low hills covered by rounded boulders or sparsely distributed blocks which adopt a domical shape. They are bounded by scaling structures and orthogonal fracture systems. Examples are observed in which the scaling structures are preserved as a domical shape covered by rounded boulders and blocks, being the latter the representation of the upper sheets fragmented by fractures perpendicular to the domical surface (Picture 5).

The rocky crests are noted by their strongly marked fracturing systems. The joint system has steep inclination, almost vertical. Generally, they are cut by oblique fracturing systems with steep inclination as well .This fracturing pattern generates rocky crests with little or none regolith remnants.

Associated to the residual forms, numerous and varied minor features are identified, such as balls, compayres, piles, pedestal rocks, channels or grooves, taffoni, polygonal breakage, cracked blocks and “A” forms (Plate 2).



PICTURE 4. Weathering residual forms, Castle-koppies near Fita Ruin locality, highly jointed, with systems of orthogonal and oblique discontinuities.

PICTURE 3. Weathering residual forms, Domes near Pilcaniyeu locality.

PICTURE 5. Weathering residual forms: Nubbins are features composed of low hills covered by rounded boulders or sparsely distributed blocks which adopt a domical shape.

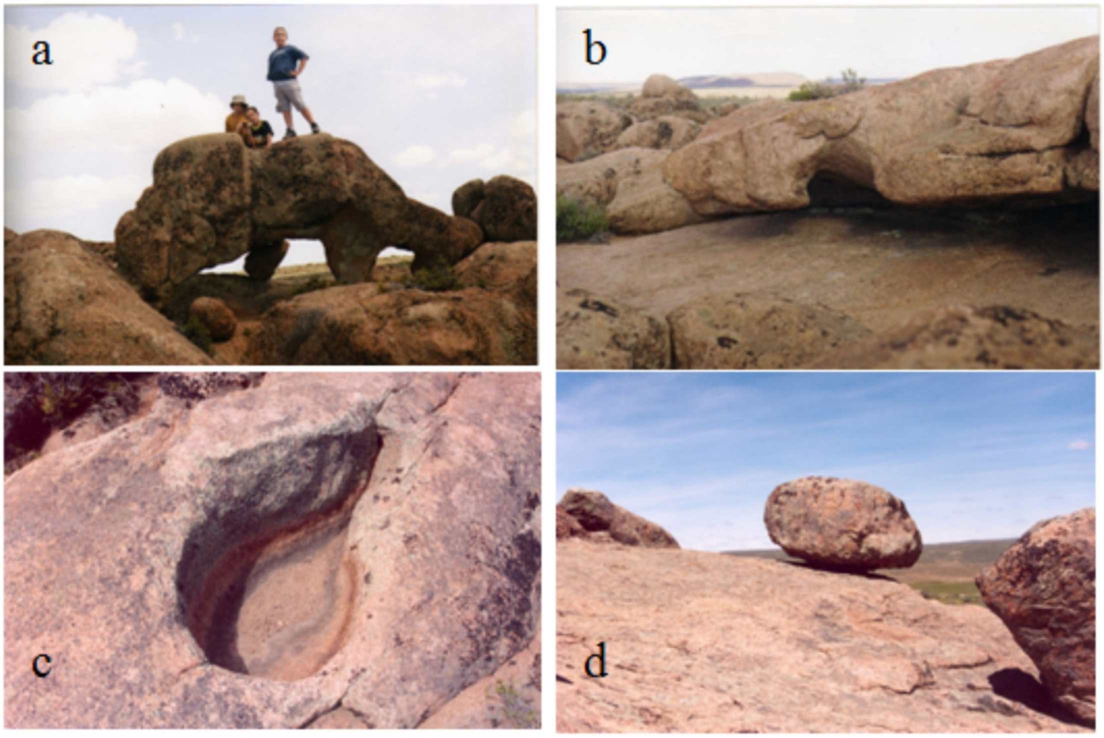


PLATE 2. Associated smaller forms: **a** and **b**: taffoni, **c**: gnama **d**: balancing rocks.

CONCLUSIONS

In the Northern Patagonian Massif, over the remnants of the ancient crystalline basement, an extensive erosion surface has developed, affecting plutonic and volcanic rocks, which are eroded alike in spite of the different lithological types involved. The processes of fluvial erosion cannot explain by themselves alone the genesis of this large planation surface, which is characterized by presenting no topographic steps due to differential lithology. The ancient flood plains or their fluvial sedimentary deposits, which would have been active in the geological past, have not been recorded either. This huge, regional planation surface is also characterized by granitic relief landforms of varied nature and size, such as an extensive granitic plain, inselbergs, domes, blocks and rounded boulders as the more frequent features and remnants of the original regolith, though most of the weathered material has been already mobilized by denudation.

This paleosurface would have basically developed in two phases. The first one would have started its formation at least during the Late Permian to Middle Jurassic lapse, partially affecting the granitoids of the Mamil Choique Fm. (Early Permian), the Los Menucos Group of Late Triassic age and the dioritoids of the Middle Jurassic. This cited period corresponds to the times of weathering process activity, the sub-superficial atmospheric action, in which the exposed material is undergoing transformation and disaggregation, a process that developed an important, residual weathering mantle which then buried the surface in its own regolith, directly depending upon the dominant climatic conditions. Paleoclimatic studies have revealed that the Paleozoic and Mesozoic climates in this region were suitable for deep weathering of the granitic masses, due to very high moisture and temperature conditions, quite different to the climate of most of the Tertiary. Both atmospheric elements are key factors in the genesis of these processes and landforms, and the planation process culminated in the Late Jurassic-Early Cretaceous.

Finally, time came in which the weathered material is remobilized and the planation surface is exposed by regolith denudation. The more plausible explanation for the mobilization of the regolith would be the crustal ascent due to the Andean uplifting, where Tertiary tectonics would have elevated the region, lowered the base level and reactivated all erosion process, under simultaneously changing climate conditions, strongly moving to drier and colder environments as those found today. The regional planation surface is a relict of ancient Mesozoic climates, which were never active again in southern South America after the Eocene.

As this surface is not completely flat, presenting instead irregularities of a varied degree, the alteration materials have not been totally denudated, but they persist in the landscape, displaying a mixture of more altered and fresher rocks, that is, exposing the original nature of the weathering front.

This paleosurface is considered to have been formed by deep weathering with subsequent regolith mobilization, thus being classified as an etchplain (Wayland, 1934).

The importance of determining the age of these elements in ancient landscapes and analyzing the significance of their stratigraphic position enhances the hypothesis that a large portion of the Northern Patagonian Massif persisted as a positive continental element during very long periods in the Mesozoic and the Early Tertiary. Due to the action of several erosion agents, among them deep weathering, the paleosurface has survived with very little changes along very extensive periods of time. The analyzed characteristics of these ancient landscapes are not compatible with those suggested models for the evolution of the Patagonian landscape solely due to the Andean Cordillera uplifting. The chronology and geological events that they are implying enhance our understanding of the landscape in the chronological context of global tectonics and their possible correlation with other areas of the world.

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BIBLIOGRAPHIC REFERENCES

1. AGUILERA, E.Y. **Identificación y distribución de distintas superficies geomorfológicas de escaso relieve local, por medio de sensores remotos en el área del Macizo Nordpatagónico, Provincia de Río Negro**. La Plata, 2006. 285 p. Doctoral Thesis – Facultad de Ciencias Naturales y Museo de La Plata, Universidad Nacional de La Plata, Argentina.
2. ARRONDO, O.G., ARTABE, A.E., MOREL, E.M.; PETRIELLA, B. Floras fósiles Mesozoicas. In: CONGRESO GEOLÓGICO ARGENTINO, 9, 1984, S.C. de Bariloche. **Relatorio II**, 1984, n. 1, p. 367-372.
3. DAVIS, W.M. Peneplains and the geographical cycle. **Geological Society of America Bulletin**, v. 23, p. 587-598, 1922.
4. DERRAU, M. **Geomorfología**. Barcelona: Edit Ariel, 442 p., 1970.
5. FENNEMAN, N.M. Cyclic and non-cyclic aspets of erosion. **Geological Society of America Bulletin**, v. 47, p. 173-186, 1936.
6. HINOJOSA, L.F. & VILLAGRÁN, C. Did South American Mixed Paleofloras evolve under Thermal equability or in the absence of an effective Andean barrier during the Cenozoic? **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 217, n. 1/2, p. 1-23, 2005.
7. KING, L.C. **The morphology of the Earth**. Edinburgh and London: Oliver & Boyd, 2nd ed., 726 p., 1967.
8. KING, L.C. The study of the world´s plainlands: A new approach in geomorphology. **Quarterly Journal of the Geological Society of London**, v. 106, p. 101-131, 1950.
9. LLAMBÍAS, E.J. Geología de los Cuerpos Ígneos. **Serie de Correlación Geológica** 15, Instituto Superior de Correlación Geológica, San Miguel de Tucumán, INSUGEO, 232 p., 2001.
10. LLAMBÍAS, E.J. & RAPELA, C.W. Geología de los complejos eruptivos de La Esperanza, provincia de Río Negro. **Revista de la Asociación Geológica Argentina**, v. 39, n. 3-4, p. 220-243, 1984.
11. MABBUTT, J.A. A stripped landsurface in Western Australia. **Transactions of the Institute of British Geographers**, v. 29, p. 101-114, 1961.
12. OLLIER, C.D. **Ancient Landforms**. London: Belhaven, 233 p., 1991.
13. PENCK, W. **Die Morphologische Analyse**. Stuttgart, p. 176-177, 1927.
14. POTHE DE BALDIS, E.D. 1984. Microfloras fósiles Mesozoicas. In: CONGRESO GEOLÓGICO ARGENTINO, 9, 1984, S.C. de Bariloche. **Relatorio II**, 1984, n. 4, p. 393-411.
15. RAMOS, V. Las Provincias Geológicas del Territorio Argentino. Instituto de Geología y Recursos Minerales. Geología Artentina. **Anales**, v. 29, n. 3, p. 41-96, 1999.
16. RAPELA, C.W. & ALONSO, G. Composición litológica y geoquímica del batolito de la Patagonia Central. In: CONGRESO GEOLÓGICO CHILENO, 6, 1991, Viña del Mar. **Actas...** Viña del Mar, 1991, v. 1, p. 236-240.
17. ROMERO, E.J. & DIBBERN, M.C. Floras fósiles Cenozoicas. In: CONGRESO GEOLÓGICO ARGENTINO, 9, 1984, S.C. de Bariloche. **Relatorio II**, 1984, n. 2, p. 373-382.
18. THOMAS, M.F. The study of inselbergs. **Zeitschrift für Geomorphologie**. N.F., Suppl. Bd., v. 31, p. 1-41, 1978.
19. TWIDALE, C.R. **Granite Landforms**. Amsterdam: Elsevier. Pub. Com., 372 p., 1982.
20. TWIDALE, C.R. Old land surfaces and their implications for models of landscape evolution. **Revue de Géomorphology Dynamique**, v. 34, p. 131-147, 1985.
21. TWIDALE, C.R. Etch and intracutaneous forms and their implications. **Australian Journal of Earth Sciences**, v. 34, p. 367-386, 1987.
22. TWIDALE, C.R. The origin and implications of some erosional landforms. **The Journal of Geology**, v. 98, 343-364, 1990.
23. VIDAL ROMANÍ, J.R. Granite geomorphology in Galicia (NW Spain). Coruña: **Cadernos do Laboratório Xeolóxico de Laxe**, v. 13, p. 89-163, 1989.
24. VIDAL ROMANÍ, J.R. & TWIDALE, C.R. **Formas y paisajes graníticos**. Universidade da Coruña, 411 p., 1998.
25. VOLKHEIMER, W. Microfloras fósiles Mesozoicas. In: CONGRESO GEOLÓGICO ARGENTINO, 9, 1984, S.C. de Bariloche. **Relatorio II**, 1984, n. 3, p. 383-391.
26. WAYLAND, E.J. Peneplains and some erosional platforms. Geological Survey of Uganda. **Annual Report Bulletin**, p. 77-79, 1934.
27. WILLIS, B. **East African plateau and Rift Valleys - Studies in Comparative Seismology**, Washington: Carnegie Institute, Publication 470, 358 p., 1936.

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