Volcanic Landscapes of Patagonia: A Geomorphological Map of the Piedra del Águila Volcanic Plateau, Province of Neuquén, Argentina

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Abstract: The map of the Piedra del Águila Volcanic Plateau or “Escorial” (Province of Neuquén, Northern Patagonia, Argentina) shows the geomorphological characteristics of one of the most important volcanic extrusions of extra-Andean Patagonia. This map has been prepared based upon the visual interpretation of vertical aerial photographs and Landsat TM images. In the study area landforms of volcanic origin as well as of aeolian, fluvial and mass movement processes have been recognized. Due to the significant role of these volcanic plateaus as site of ground water reservoirs, the map also records the grassy wetlands or “mallines”, which are present around the edge of the remnants of the former lava flows.
1. Introduction

Most of the Patagonian volcanic landscapes were formed from extensive basaltic lava flows which took place mainly between the Miocene and the Early Pleistocene. These flows later originated the basaltic plateaus due to relief inversion, which are locally named as “escoriales”, that is, “scoria surfaces”, preferably located to the east of the Andean volcanic arc, along a zone up to 300 km wide. As a whole, they cover approximately 15% of the entire Patagonian territory.

The “escoriales” have a significant regional value as water reservoirs (e.g. (Mazzoni, 1987; Hernández, 2000), mainly in the extra-Andean region of Patagonia, where annual rainfall is less than 300 mm. The densely cracked volcanic surface receives and absorbs precipitation. Water flows underground until it springs along the slopes of the plateau, allowing the formation of grass wetland ecosystems (Figure 1), locally named “mallines”, which are a natural resource of high economic, ecological and scenic value (Figure 2).

![Figure 1](image_url) Model of a hypothetical basaltic plateau illustrating infiltration and underground runoff.
The geomorphological map shows the characteristics of one of the largest, and geomorphologically complex, volcanic eruptions of the whole Patagonian region. The main landforms have been recognized along the surface, slopes and the plateau surroundings, including the aforementioned wetlands.

The study area is located in the Province of Neuquén, in NW Patagonia, Argentina, between lat. 39° 30’ and 40° 05’ S and long. 70° 00’ and 70° 35’ W (Figure 3). The surface area is more than 2,500 km$^2$. The area is characterized by a dry-temperate, windy climate, with a water deficit estimated at around 500 mm/year, which is reflected in a poor development of soils and vegetation. The dominant ecosystem is the shrubby steppe, with a plant cover index lower than 40% (León et al., 1998).

2. Methodology

The geomorphological map of the Piedra del Águila Volcanic Plateau was prepared based upon information obtained from vertical aerial photographs
(approximate scale of 1:50,000), satellite images, topographic maps and the geological literature. As a cartographic base, the Landsat TM image (231/88) from 15/01/98 was used and georeferenced to the Universal Transverse Mercator coordinate system. The cartographic work was performed using MapInfo Professional 6.5.

The different geological units, landforms and wetlands were identified by visual interpretation of the remote sensing products, particularly the stereoscopic interpretation of aerial photographs. The observed landscape elements were later digitalized on to the satellite base image as polygons, lines and points.

Figure 3 Location of the study area.
3. Geomorphology of the Piedra del Águila “Escorial”

The name of “Escorial de Piedra del Águila” is assigned as a generic term to an extensive lava plateau which, in the regional cartography, receives different names which otherwise make reference only to small sectors of the landform (“El Escorial”, “Meseta de Santo Toms”, “El Pedrero”, “Pampa Fra”, etc.). The proposed name corresponds to the closest inhabited locality to this lava plateau, located at its SE end (lat. 40° 03’ S; long. 70° 04’ W).

The volcanic plateau has a total surface of 840 km² and is formed of Pliocene basaltic lava flows, whose radiometric age yielded ages close to 5 Ma (Ardolino et al., 1999). It has a general slope towards the SE and, in its NW extreme, is partially covered by Pleistocene gravels (Leanza and Leanza, 1970). The basalt bedrock is composed of tuffs and tuffites of the Collón Curá Formation (Groeber, 1929), which were deposited during Early to Middle Miocene. The edge of the basaltic flows is rugged; the slopes of the plateau have strong gradients and are covered by mass movement deposits. These deposits cover approximately 250 km² and extend for hundreds of meters from the basaltic edge, up to a maximum length of 2 km. The extra-basaltic area has a total surface of 1,400 km² and is composed of Mesozoic conglomerates, sandstones and claystones, dissected by a dense, centrifugal drainage network originated along the “escorial” slopes.

The geomorphic processes have produced an interesting variety of landforms over the different lithological types. These landforms correspond both to past, inactive, mostly volcanic processes, and also to active processes. Among the latter, surficial runoff activity, mass movement processes and aeolian action are dominant. The intensity in which each of them is exposed varies according to the different sectors of the study area, in general with the predominance of erosional processes over the depositional processes.

Among the better exposed landforms of the “escorial” surface, the following have been recognized:

1. Smaller depressions, whose origin is attributed to the collapse of boulders during the lava consolidation. Most of these hollows and basins are presently occupied by water ponds or salt lakes.
2. Topographic benches (scarps and less marked thresholds), which may indicate the boundary of the different lava flows, may be a result of the pre-basaltic topography or a consequence of mass movement processes.

3. Quaternary volcanic cones superimposed upon the Cenozoic flows (Figure 4). They are dome shaped with somewhat depressed summits, in which the former craters may be recognized. They are exposed between 200 to 300 m over the level of the “meseta”, forming the highest elevations of the region. Among them, the Cerro La Fra (1301 m a.s.l.) and the Cerro Partido (1152 m a.s.l.) may be cited.

4. Ephemeral drainage lines, which are extending by headward erosion from the “escorial” slopes or the supra-basaltic depressions. The channels which have originated on top of the “escorial” are short and shallow, in most cases being almost invisible. The drainage lines that have evolved by headward erosion from the sides of the “escorial” have deeply eroded it (Figure 5).

5. Parallel channels which are oriented from W to E, following the wind dominant direction, have been interpreted as “yardangs” or “yardang depressions” (Blackwelder, 1934). Their origin is attributed to aeolian abrasion processes (McCauley et al., 1977).

6. Sand accumulations, mostly dune fields closed between topographic elevations.

7. A large irregular depression of approximately 2 km along its longer axis and around 30 m in depth, whose origin may be associated to a relief inversion process.

The NW sector of this “escorial”, which is named “Pampa Curacó”, is almost totally covered by a gravel bed less than 20 m in thickness (Leanza and Leanza, 1970), which has hidden the textural features of the aforementioned Cenozoic basaltic flows. These gravels were transported by glacial meltout waters before the relief inversion processes which eroded the extra-volcanic environment took place, thus forming the present basaltic “meseta”. Over this gravel, a dense drainage network has been developed towards the S, where a larger water supply has formed important wetlands (“mallines”).
From a geomorphological point of view, the slopes of the “escorial” are the most dynamic unit. They are abrupt and rugged and have a significant relief which indicates a long and active erosive process. Its topographic profile presents two well defined sectors: an upper, rugged, scarp-like, formed by the edge of the lava flows and another which extends in continuity up to the elevation given by the regional erosional level, carved in the pre-volcanic bedrock and partially covered by slumped volcanic blocks (Figure 5). The local relief oscillates between 200 and 250 m.

The headward erosion of the gully heads and mass movement processes are the dominant geomorphological processes in the “escorial” slopes, which have forced the dissection of the volcanic plateau and the parallel scarp retreat.

The gullies have formed at the location of the water springs located along the “escorial” slopes, generally along the contact between the flows and their substratum. The runoff coming from these outcrops is highly variable; some of them are only inferred by the existence of wet patches in the soil, whereas others appear as “water flows” with a runoff of several liters per second. In both cases, the flow is almost constant throughout the year. The high erosive action of the larger springs favours slope carving and the
slumping of the underlying basaltic margin. In this way, the heads of the gullies formed in the springs recede very rapidly, a process that is favoured by the strong gradient of the “escorial” slopes. This process models the edges of the “escorial”, producing dissection and embayments. In the geomorphological map, arrows indicate the most active gullies.

The scars of mass movement processes are intensively exposed along the slopes, being increased by the activity of the water outcrops. Two
dominant processes have been recognized: debris fall and slumping. By means of the first of these processes, the slopes appear to be covered by boulders, which come down the slopes either by rolling or saltation, from the cracked basaltic edge. This process does not generate particular landforms which may be represented on the map. The slumps are defined as an interrupted, recurrent movement of land masses or rocks along a relatively short distance and that typically includes a backward rotation of the involved landmass (Hutchinson (1968); Varnes (1978)). As a result, the slumped surface frequently shows a slope in an opposite direction to the landform that originated it. The movement is generally produced as small, though numerous, independent units. Its extended time development originates a stepped, lobate morphology, which is characteristic of these volcanic environments (Figure 5). Normally, the process starts with the development of cracks (Figure 6). Both phases of this process are exposed in the “Escorial de Piedra del Aguila” and have been mapped, indicating the presence of larger slumped blocks.

In the extra-basaltic environment, the dominant morphology is the result of fluvial dissection generated by the water channels formed along the “escorial” slopes, which have developed as a dense, centripetal drainage network, with dominance of first and second order streams (following Horton’s method; in Strahler (1982)). Although the models used for the study of surficial runoff basins define low order streams of ephemeral or transitory regime, the stream segments in this study present a permanent regime, although with limited runoff in their upper reaches, because they originate in springs with continuous flow all year around. Downslope, water rapidly infiltrates or evaporates, due to the prevailing climatic regional conditions. However, the available water frequently allows the development of wet-meadows (“mallines”), which show various physiographic and morphometric characteristics according to their position in the landscape. Most of the wetlands are located near the margin of the basaltic edge, have a small surface area and strong slopes, with limited soil development. Those located in sectors farther away from the “escorial” have gentler slopes, larger size, a good water supply and dense grasslands. These latter wetlands are frequently used as settlement areas by the rural population (Figure 2).
Figure 6 A crack located along the western edge of the “Escorial de Piedra de Águila”, which is affecting both the basaltic flows and their substratum. Its total length reaches 7 km. Geographical coordinates: lat. 39° 52’ S; long. 70° 22’ W.

4. Conclusions

Basaltic plateaus are a typical feature of the Patagonian landscape. In the extra-cordilleran, “meseta”-like environments, these plateaus usually break the homogeneity of the landscape and provide a valuable scenic resource, as well as bringing other benefits to the rural population, such as wind protection, water supply and biological resources, associated with their peculiar hydrological behavior.

These volcanic plateaus cover extensive surfaces. In the province of Neuquén (Argentina), 161 “escoriales” with an extension equal or larger than 1 km² have been identified (Mazzoni, 2006), with a total surface of 15,700 km², a surface similar to Northern Ireland, the Bahamas Islands or the Malvinas-Falklands archipelago. Among them, the “Escorial de Piedra del Águila” is one of the largest and one of those that have a larger variety of landforms, due either to the lithological diversity and to the varied, acting geomorphic processes. Their identification has allowed the identification of more active sectors of this landscape.
The surface is the more stable area, due to its sub-horizontal, low gradient profile and to the high secondary permeability of the basaltic rock, which inhibits the development of drainage lines of high erosive power. The aeolian action is highly significant, but the absence of human settlements minimizes its negative effects.

The slopes provide protection to the aeolian activity, thanks to their rugged topography and irregular design. However, they are geomorphologically the most unstable, due to their strong gradient and water supply from springs, which contribute to the development of mass movement processes and fluvial erosion. In this respect, Romero (1975) noted that the landforms created by these mechanisms present unstable conditions and that they are easily susceptible to perturbation: “The reactivation of the slumps, with sliding of large rock masses, may take place due to any changes in the present equilibrium conditions”.

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