Geomorphological Studies: Alegrete, State of Rio Grande do Sul

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A. INTRODUCTION

The purpose of this paper is to study environmental degradation in the rural municipality of Alegrete, state of Rio Grande do Sul.

For some time now, the issue of "sandy patches" has been a concern to technical experts. It has also had broad media coverage in interviews drawing attention to its serious impact on agriculture and cattle raising activities.

Further exploration, however, revealed that this was not the worst problem in the region. Others also affect tilled lands and are a concern for ranchers and farmers alike. In addition to the sandy patches, there are extensive ravine formations, flooding of cultivated alluvial plains, and rock outcrops.

Natural degradation is intensified by improper soil use, with substantial regional implications. It affects not only the upper basin areas, fast undergoing severe deterioration, but also the adjacent alluvial plains.

To control these natural and hazardous processes and to partially offset their effects, it is vital to determine precisely how to stop them and where intervention will be most likely to succeed on a cost-effective basis.

Some basic studies were performed in response to these needs, involving:

1 — Surveying and area determination

The several external signs of degradation were mapped. The inventory was charted on two maps on a 1:50,000 scale where damaged sites are clearly plotted:

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— The map covering the Parové Lagoon/Vila Manuel Viana area pinpoints the sand dune located between 29°35 03 and 30°00 latitude south, and 55°15 and 55°30 longitude west.

— The Inhanduí map shows crags located between latitudes 29°30' and 29°45' south; and longitudes 56°00' and 56°15' west.

Other signs of degradation such as ravines and flooded alluvial plains are also shown in the map.

2 — Rock and soil studies

This survey is presented in a summary map on a 1:130,000 scale. Based on existing geologic information, rock formations were mapped and helped locate and gain a better grasp of the extent of the damage.

Documents employed in the geomorphological survey were:

1 — Aerial photographs in a 1:60,000 scale, dated 1964;

2 — Survey maps from the Brazilian Army's Geographical Department on a 1:50,000 scale;

3 — Geological maps on a 1:50,000 scale, dated 1965. Southwest Project I — Project 01 — Alegrete — Rio Grande do Sul State. Technical/economic feasibility studies and geological maps on a 1:50,000 scale. Author: Antonio Carlos S.P. Geske. Date: 1979.

Laboratory analyses were performed at:

— The Mineralogy and Petrography Laboratory of the Institute of Geosciences, slide preparation and analysis;

— The Brazilian Geography Laboratory of the Institute of Geosciences, particle size analysis and morphoscopy.

Actual field work was performed in several steps and consisted in mapping, contouring, and sampling.

B. ANALYZING THE MAPS

Bearing in mind the goals set, field observations focused on a detailed study of two areas considered to be illustrative of the problems found:

— Manoel Viana/Parové Lagoon and

— Inhanduí

The studies resulted in the plotting of two geomorphological maps containing the special features of each area.

1 — Manoel Viana Village/Parové Lagoon Map

The chart shows a predominance of sandstone formations along the eastern portion of the county. It outlines a highly contoured terrain with flattened surfaces edged by cliff ledges. This formation is located at hilltops. The flatter sections are found at 180 — 200 meter altitudes.

Actual field work was performed in several steps and consisted in mapping, contouring, and sampling.

Cliff ledges are made up of highly cohesive rocks classified in the laboratories as: orthoquartzite, protoquartzite, arkose and arkosic sandstone.

From the hilltops down, span sloping banks *(glacis)* made up of large or segmented blocks. From the cliff ledges onward, they become colluvia shaped into crest ridges *coxilhas* (prairie slopes). As the debris moves away from the foothills its particle size becomes smaller and takes the form of sandy material interspersed with friable sandstone. In this kind of pattern, slopes of 10 to 15° gradually take on a wavy contour toward the thalwegs at softer slopes of 3° to 4° inclination, until they blend in with the mesa formations.

The larger mesas are located on the Ibicuí chute. They contain massive sandy sediments at two levels and then become the flat clayey/sandy soils of the alluvial plains. Long stretches of embankment levees and sand spits are covered by dense and low forests. On smaller river beds, several sand banks drift during major floods.

The items charted at this location provided a clear picture of the environment's vulnerability. Current or stabilized sand patches with poor vegetation cover are all located on extensive colluvial areas throughout the region. They are the sandy and silty/sandy product of soil breakdown. Their origin lies in poorly cemented, heterogeneously sized, yellowish/orange sandstone turned red/brown by weathering. This sandstone was accidentally denuded in the past and is now under continuous reworking:

— by runoff, from low sloping banks; and

— by the wind that forms small dunes (1-1.5 meters high) of shaky stability, covered only by scleromorphic stem grasses.

These loose sandy soils are under tillage where they are sufficiently packed and continuous. The ease with which roots penetrate the soil compensates for the absence of organic matter and minerals. Plants survive whenever they manage to strike a minimum environmental equilibrium. These areas were charted as stabilized sandy patches. Their plant cover protection is poor, though, and because of environmental instability including current climatic conditions, they are prone to lose whatever stability is afforded by the vegetation cover. An example is soil exposure in tilled lands. A heavy rainstorm would be enough to move great amounts of soil, and because of its sandy nature, it would spread to form sand banks at other crop sites, roads, arroyos etc., as observed in several locations.

2 — Inhanduí Map

This area is located on the western part of the municipality. In relation to the first site described, these lands lay somewhat lower topographically speaking. Maximum altitude is 202 meters at the Candelaria Range, the highest point on the Inhanduí *Coxilha*. This interfluvial section between Itapororó and Inhanduí arroyos lies SW-NE. The mean altitude along the *Coxilha* is approximately 150 meters, going down to 91 and 83 meters at thalweg level.

Geologically, this is an intertrap area with a good sampling of basalt rocks.

A contoured profile prevails, with weathered surfaces shaped into long stretches of interfluvial *coxilhas* (prairies). Slopes are not steep — around 5° to 6° -, while soils are somewhat more packed and covered by grasses. At several points the alluvial watershed of small valleys has carved out sharp, plant covered and non-active ledges. As they receded, a flat rocky bottom with very little alluvium was uncovered. One of these ledges (1.2 meters high) had a deeper sandy layer of yellowish/rusty color; a gray middle layer approximately 0.25 meters deep, and an upper layer 0.70 meters thick consisting of black clayey sand with white nodes of calcium carbonate. These carbonate concretions have been studied by Setzer (1954) and Bombin (1976).

Although the whole area is stable, it is important for its long stretches of unbroken rocky cliffs. They cover most of the Inhanduí *Coxilha* surface.

These rocks are silicate sandstone outcrops highly resistant to erosion, forming a long irregularly surfaced pavement. A few shallow circular depressions alternate with others asymmetric in shape along the rocky bed, where the dark brown or black surface soil is only 0.10 to 0.20 meters deep.

Pisolite, quartz and chalcedony nodes are scattered about the cliffs at depths under one centimeter, like the ones also charted atop the Manoel Viana map hills.

Once the morphologic features and the morphodynamic processes were determined in both areas, the data were plotted in a summary map, "Local Rock and Soil Conditions," displaying the varying lithologic features that make the environment so sensitive.

C — DEFINITION OF WEAK POINTS

1 — Sand patches

Surveys have long indicated the presence of sand patches not just around Alegrete, but also throughout extensive areas of the *Gaucho Plains.*

One such study, performed by Bombin (1976), points out that the wind is one of the three sources of sand patches in the muddy segment of the *Touro Passo* Formation: "sands resulting from erosion of the Botucatu Sandstone, brought by SE and NE winds from the Gaucho Plains dune fields. These dune fields still exist today and must have started during the dry periods of the Quaternary. At present, overgrazing and agriculture are reactivating these small deserts."

Other surveys focused specifically on the sand fields. Of prime significance was the study undertaken by technicians from

Superintendência do Desenvolvimento da Região Sul (SUDESUL), Moller et alii (1975), a "Diagnostic on the Sand Patches of Southwestern Rio Grande do Sul." In their report, the authors identified sand patches in Alegrete and Quaraí counties. They provide a general analysis of the phenomenon and findings about erosion sources. They conclude that sand encroachment is no cause for alarm and that in some cases it was receding.

Cordeiro & Soares (1977) were asked by SUPREN to make an observation field trip, subsequently reported in "Erosion on sandy soils of southwestern Rio Grande do Sul." The authors visited Sao Francisco de Assis, São Vicente do Sul, Jaguarão, Cacequi, Rosário do Sul, and Quaraí municipalities, recording fourteen kinds of erosion. They described the sources of sandy patches, and drafted technical recommendations to prevent or reclaim sandy soils.

Observations have shown that the phenomenon affects land of a geological formation assumed to be *Botucatu.* This, however, has a facies distinct to the aeolian Botucatu Formation found at other locations in the county. Perhaps what Bertoluzzi (1974) proposes for the Santa Maria region is also true here — "two genetically distinct lithologic units: one at greater depth with fluvial/lacustríne properties, comprising gutter deposits, flood plains and seasonal lakes; and a more superficial formation essentially consisting of sandstone in extensive wedge-shaped cross-stratifications, sedimented in a desert environment."

It might also be what Gamermann calls the "Rosário Formation" (1973), not mapped in this paper.

Numerous sand patches were observed on rose-colored sandstone outcrops, with rare diaclase occurrences, of varying particle sizes ranging from some granules to silt. Sand patches were not found south of Alegrete, where sandstone is thinly stratified and highly cracked, turning into quartzite in thin surface formations. A greater number of patches was found north of the Manoel Viana/Parové Lagoon chart, the pattern is more dissected and sandstone is more pervious. Sandstone impermeability is therefore a determining factor.

Silt is also abundant in surface formations, where it shows a dark brown color. Where the soils remain, they have a uniform chestnut and reddish color and little permeability.

Sand patches in several stages of development are found. The most interesting examples are those still in an early stage of formation. They are located in grazing slopes, either on the steeper and concave upper sections of the foothills, or at lower slopes along the summit convexity. The former is more frequent than the latter. They all appear on discontinuous open ranges, usually as a result of herd stomping. The process active early in sand patch formation is surface runoff due to heavy erosion caused by rain, scarce plant cover, and near absence of surface soil layers. Runoff surely damages vegetation and generates a thinning of plant cover, which in turn favor more runoff. There is a positive feedback effect resulting in the development of sand patches. It quickly moves to the next development stage, i.e. a combined action of two morphogenic processes: rainfall erosion and runoff on the one hand, and aeolian transport on the other. Typical patches show aeolian accretions in the shape of small live dunes and grooves excavated by water runoff. The relative incidence of the two processes varies from one patch to another. In certain cases, small wind-blown dunes encroach on neighboring lands; in others, sterile sand spillovers form small valleys in the trough of these patches. In this latter case, sand patches have contributed to develop a torrential type of flow in the hydrographic basin.

Field observations made in the attempt to understand the dynamics of current processes suggest: a link with paleoclimatic elements...

2. Ravines

Intensive ravine formation is observed at certain grazing fields where slopes are steeper, often entailing major changes in Pathology. Some ravines go as deep as 3 to 4 meters and have cliff-like sides. At the outlet they build up sterile sand deposit cones. Another more hazardous type of damage is experienced in farm lands, especially where whet and soybean are grown. On wheat fields where plants are already 15 centimeters tall and quite dense, there is heavy sand movement over the upper convex portion of the *coxilha*, where the slope is no more than 3° — 4°. At slopes ranging between 10° — 15° — quite common in the area's cultivated fields — ravines are formed even where the land is plowed along contour lines. Massive slope runoff concentrates on the thalwegs where it grows into a stream to carve out deep ravines. These phenomena further degrade the hydrological regimen as well as generate major impacts on agriculture. At certain sites, ablation and soil exporting prevail; at others, on the contrary, mineral sediments from upstream quickly build up. In both cases, the soil is heavily compacted, which blocks water seepage. The soil's water regimen ís so drastically altered as to make it unsuitable for cultivation. Yields decline. Runoff also carries away the fertilizers used and for the most part increases river pollution.

The location of these ravines is recorded on the Manoel Viana/Parové Lagoon map.

Some are indicated as ravines with stable plant cover. They have a flat bed lying on cohesive rock and steep banks receding several meters.

3. Crags

The Inhanduí chart draws attention to a large area centrally located on the map. It consists of rock outcrops interspersed with depressions containing patches of soil.

The rock is quartzite. There are, however, other rocky areas on hilltops or saddling *coxilha* crests that are mainly basalt. It is often hard to distinguish in the field between basalt rock and the more resistant quartzites.

Although the vast rock formations (approximately 230 km2) here are known for their barrenness, they have not been the target of as many written papers as the sand patches. It is true that these cliffs are located at a stabilized area. Their relief is basically sandstone and basalt in association in an intertrap area. The hilly terrain does not show sharp cuts. Small valleys are more open and lie on sediment beds. The area is used for grazing, primarily sheep which can more easily climb the rocky slopes to reach the grasslands.

4. Flood plains

The summary map of the municipality's problems also pinpoints also vast flood plains adjacent to major and medium-scale rivers.

The Ibirapuitã is the largest tributary of the Ibicuí river. It lies in the north-south direction and cuts through the center of the county. Rainfall is an important issue here because it affects the most densely populated area, where municipality seat is located.

The river flows generally on low rolling hills, but in the city of Alegrete its banks are sandy and over 15 meters high.

The slope is lower downstream of the Sao Diogo falls, approximately 100 kilometers away from Alegrete, decreasing at an average rate of 0.27 meters per kílometer.

The Ibirapuitã river valley lies on basalt and fine sandstone, which makes the soil impervious.

These are two elements cause both water trapping and a slow outflow, thus increasing the chances of floods.

River flows reflect an irregular rainfall pattern alternating between extreme droughts and floods.

The combination of these natural elements and soil degradation are barriers to agricultural development.

Crop fields along alluvial plains are also affected, with the following consequences:

a) changes in river flow rates bringing increasingly more violent and catastrophic floods. Mild droughts decrease outflow due to a lower feed rate from underground water. Shortages of water occur when it is most needed;
b) major build-up of sterile sand deposits carried through ravine formations during the rainy season.

The combination of both negative impacts prevent alluvial plains from being used for rice crops, which is usually the case when natural conditions are preserved.

Field observations made in the attempt to understand the dynamics of current processes suggest a link with paleoclimatic elements:

— The presence of calcium carbonate concretions found at Inhanduí indicates that in the past the climate was drier than now.

— On sandstone hills approximately ten kilometers south of Alegrete, the soil was denuded and pedogenesis seldom attacks it during the Holocene. This is both due to its imperviousness and to the strong rainfall erosion and silting. However, in the same area, several valley heads with inclinations ranging between 5° — 10° have their lower portions shaped from sloping colluvial sedimentation. These sediments are in fact a dark reworked soil. Flat-bottom ravines are also carved out of the same material.

— Throughout the cliffs charted on both the Inhanduí and Manoel Viana maps, silicon nodes reappeared and expanded as a result of drying, extending in a surface layer on rocky hilltops of *coxilhas* and *cerros.*

Grazing fields are scarce in this kind of pavement.

These aspects, as well as the xerophytic vegetation, reveal a barren heritage from the last dry period. It is easy to understand why the area is so sensitive and how difficult it will be to rehabilitate it.

The term desertification does not apply, therefore. On the contrary, current climate conditions favor expansion of the plant cover wherever there is soil and the environment is less hostile. The sand patch scars still protected by vegetation, though sparse, are examples of this.

Human interference through overgrazing and agricultural expansion has blocked natural recovery.

On the contrary, it is contributing to further environmental damage resulting in:

— vegetation destruction;
— renewed dune mobility;
— ravine formation in low slopes;
— changes in hydrological regime.

Following a determination of negative aspects, the study resulted in an Evaluation of Particular Environmental Aspects and Conclusion Table containing both diagnosis and recommendations.

CONCLUSION TABLE: DIAGNOSIS AND RECOMMENDATIONS

ENVIRONMENT	MORPHO-STRUCTURAL FEATURES	MORPHODYNAMIC PROCESSES	CURRENT PROBLEMS	RECOMMENDATIONS
Rock formations 3.00%	Low sandstone-basalt plateau; Eroded flat surfaces; Hill and coxilha tops; Highly cohesive rocks.	Rock blocks at ledge foothills; Landslides at steep slopes > 25°.	Non-productive area; Very little grazing.	Local preservation; Biological reserve; Visitors' park, e.g., Tigre Station.
Unstable sand patches 0.7%	Contoured hill and coxilha tops; Sand patch spread; Dunes; Foothills; Friable rocks & sandstone.	Rain & wind action; Ravine formation; Cattle stomping; Mass movements; Sand spits.	Risk of expansion; Sand deposits on crop and pasture lands; Sedimentation of arroyos & weirs.	Protection against ravine erosion with new plant cover; Windbreaks against SE winds; Protection against cattle; Attempts to cover soil with local grasses.
Stabilized sand patches 11.00%	Contoured hills and coxilha slopes; Friable rocks.	Surface runoff; Good seepage; Slow flow rate.	Degradation hazard with loss of plant cover; Risk of soil losses; Overgrazing; Use of tractors.	No farm machinery; Exclusion of intensive crops e.g. wheat & soya; Avoid overgrazing; Avoid slash-and-burn.
Flood plains 8.00%	Depressions and resulting high allivial volumes; Low slopes around bedrock arroyos.	Riverbed mobility: sand banks; Tendency to incisions.	Increasingly damaging floods; Water shortage at dry season; Fertilizer pollution hazard; Sedimentation hazard from weirs.	Rehabilitation of plant cover along arroyos; Training of meander banks to improve flow; Drought control reservoirs; Prevention of pollutant deposition.

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