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Magnific canyons sculpted in the Aparados da Serra scarps of the volcanic plateau of the Paraná Basin

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Aparados da Serra is a popular designation to the Serra Geral basaltic escarpment that faces the Atlantic Ocean, in the southeastern part of Santa Catarina and northeastern part of Rio Grande do Sul states. For those who want to visit the basaltic plateau from Gramado to Cambará do Sul towns, the canyons are an unforgettable landscape, and those who come from the flat coastal plain to the continent meet one of the most expressive and longest cliffs in Brazil. Some canyons have a particular name such as Itaimbezinho, that comes from the native Tupi-Guarani language, meaning sharp (imbé) rock (ita), and Fortaleza, that got its name from the vertical canyon front, that looks like a huge fortress wall. These are two of the biggest escarpments formed on the basaltic rocks that could be visited in the Upper Triassic volcanic sequence. In a broad sense, Aparados da Serra is one of the highest escarpment systems in the Brazilian coastal area. Taking into account the geological conditions, geomorphology and physiographic situation, this is one of the most important relicts from the Atlantic splitting that created the South American and African continents. In Torres beach it remains one of the last testimonies of the escarpment retraction and of the faulting system that uplifted the basalts, which regressed due to the erosive processes along the geologic time, shaping the present sandy coastal line.

Keywords: volcanism, Paraná Basin, Aparados da Serra, Itaimbezinho Canyon, Fortaleza Canyon, Rio Grande do Sul, Santa Catarina.

INTRODUCTION

The Itaimbezinho and Fortaleza canyons compose the most impressive landscape of the region known as Aparados da Serra, placed in the coastal board of the Serra do Mar, between Rio Grande do Sul and Santa Catarina, the southernmost states in Brazil. The region displays an outstanding set of canyons excavated on the volcanic plateau of the Serra Geral facing the coastal plain, almost a thousand meters below. Its name comes from the remarkable geomorphologic feature formed by the abrupt cut of the Campos de Cima da Serra plateau, which is constituted by the Serra Geral Formation volcanic rocks. Its geological structuralization let the appearing of huge vertical walls that extend for about 250 km, in a wonderful succession of canyons up to 900 meters high that contrast with the Atlantic coastal plain.

This region has a qualified environmental and infrastructural character that made it one of the most popular tourist addresses in southern Brazil. It bears a precious ecosystem whose preservation led to the creation of two parks: in 1959, the Aparados da Serra National Park and in 1992 the Serra Geral National Park, both managed by IBAMA – Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. These conservation unities emphasize the

preservation of their flora and fauna, natural landscape and other biotic and non-biotic associated resources. The main vegetal covering represents a transition from the Campos de Cima da Serra (an extensive field plateau) to the Floresta Pluvial Atlântica (Atlantic Rainforest).

This scenery of big canyons and spurs towards the coast is also present to the north of the considered region, with beautiful features such as the Monte Negro, the Rio Grande do Sul summit – 1,403 meters high, placed in the São José dos Ausentes municipality, or the ravishing Pedra Furada, in Urubuci, Santa Catarina state.

LOCALIZATION

The referred national parks cover a region placed between the northeastern area of Rio Grande do Sul and the southernmost part of Santa Catarina. The interstate border is marked exactly at the break of the topographic gradient (Fig. 01), comprehending a part of the Cambará do Sul and São Francisco de Paula municipalities, in Rio Grande do Sul, and Praia Grande and Jacinto Machado municipalities, in Santa Catarina.



Figure 01 – Location map showing the limits of the Aparados da Serra and Serra Geral National Parks.

The Aparados da Serra National Park comprehends an area of about 10,250 ha and bears the Itaimbezinho Canyon, the best visited by tourists in the region. It is about 5.8 km long and has very steep cliffs up to 720 meters in height, from where the Perdizes creek is thrown in a 200 meters high waterfall. This park has a proper infrastructure provided by IBAMA that includes about 8.5 of accessible and signalized treks guided by official personal. The Faxinalzinho Canyon is also into its boundaries.

The Serra Geral National Park, created in 1992, has an area of about 17,300 ha and includes the spectacular Fortaleza Canyon and many others, such as the Malacara, Churriado, Josafaz, Índios Coroados, Molha Coco, Leão, Pés de Galinha, das Bonecas and Macuco canyons that fit in an impressive landscape composed by 63 giant cliffs.

The Fortaleza Canyon can be reached from the Cambará do Sul town by the CS-08 non-paved municipal road, and the Itaimbezinho Canyon is 18 km away from Cambará do Sul by the CS-360 road and about 22 km from the Praia Grande town, Santa Catarina state, by the SC-450 and the same CS-360 non-paved roads.

Cambará do Sul is 180 km away from Porto Alegre, while Praia Grande is 21 km from the BR-101

road and about 36 km from Torres, by the Santa Catarina – Rio Grande do Sul border.

SITE DESCRIPTION

The relief shapes of the Aparados da Serra region were sculpted on acid effusive rocks of the Palmas Facies of the Serra Geral Formation, which are in the top of the lava flow sequence, in this area. The stronger resistance of these rocks to the weathering and physical degradation increases the scarp regression through block falling, whereas the same relief degradation processes on basic effusive rocks give place to a flatter and festooned topography. The inferior limit between basalts and Paraná Basin sediments is gradational, marked by a break in the slope.

The Aparados da Serra region was reported by the authors in 2004, as a virtual excursion (<http://www.cprm.gov.br/Aparados/index.htm>), comprehending its geological and tourist aspects in a twenty-one sites itinerary (Wildner *et al.*, 2004).

The Serra Geral Platforms are remaining features from the scarp regression that presently constitute interfluvial hills with elongated and irregular shapes on lowland areas, specially on the coastal plain. Some of them may be completely isolated from the Aparados region, forming relict mountains such as the Morro do Farol and Pedra da Guarita, in Torres (Fig. 02).



Figure 02 – Principal canyons of Aparados da Serra region. Bird's-eye view based on a STRM Project (Shuttle Radar Topography Mission) radar image – 2000.

The topographic relief of the Aparados da Serra terrain is controlled by a close system of tectonic lineaments that cross the region and make possible the deep carving of the drainage. The work of the water streams on the structurally generated weakness lines is one of the most important exogenous agents for the formation of the rocky walls and consequent scarp regression, with the development of abrupt escarpment with a triangular shape and narrow V valleys (Figs. 03 and 05). Usually the drainage system

and the consequent trend of excavated canyons follow three main directions (Umann, 2001) directly related to faulting and fracturing systems connected to large processes of the crust rifting:

a) a regionally important direction pattern is N30°-50°W which follows the direction of the Rio Grande, São Gabriel and Ponta Grossa arches. The Tainhas and Camisas rivers and the main opening line of the Itaimbezinho Canyon are in accordance with it;

b) a second pattern roughly parallels the coastal line, along the N10°-30°E direction. It causes deep cuts that bound the plateau with the scarps of the Campos Gerais Plateau;

c) a third structural pattern in the N60°-70°E direction generated the carving of the Fortaleza Canyon and the slashing of the Itaimbezinho Canyon.



Figure 03 – LANDSAT 7 satellite image (1999) showing the Serra Geral border and the principal canyons, with emphasis on the fracture systems. (image source INPE).

Itaimbezinho Canyon

The Itaimbezinho Canyon is placed between the Cambará do Sul and Praia Grande towns and it is considered the most famous canyon in the Aparados da Serra region. It extends for about 5,800 meters and has a maximum width of 2,000 meters; its rocky walls are up to 720 meters high. The area is covered by grassy fields and native pine trees on the Campos de

Cima da Serra Geral Plateau. To be at the edge of a canyon is really an extraordinary sensation for those who do it for the first time.

The park entry is about 18 km from Cambará do Sul by the RS-360 non-paved road and 22 km from Praia Grande (Santa Catarina state) by the RS-450 and the same CS-360 roads. The latter is a beautiful course on a non-paved road along the southern border of the Malacara Canyon, through the Serra do Faxinal.



Figure 04 – A sight of the Andorinhas Fall (right), seen from the Vértice trek.

The Aparados da Serra and Serra Geral National Parks are shared by the Rio Grande do Sul and Santa Catarina states, since the border between them is positioned at 1 meter below the edge of the canyons. The parks comprehend also a fascinating landscape composed by the slopes, rivers and woods beneath the mountains.

The Perdizes River goes down the rocky cliffs to form the Andorinhas Fall. At the bottom of the canyon the Boi River idles among the rocks forming a lot of capricious cascades that flow to the neighbor state of Santa Catarina.

There are three regular treks into the park boundaries:

Vértice Trek: to see the Andorinhas Fall (Fig. 04), where the water drops 700 meters to the bottom of the canyon and produces a fog while it falls. The trek allows a beautiful sight of the Andorinhas and Veu da Noiva falls. As impressive as the waterfall is the thrilling sensation to walk along the edge of the cliffs. The trek starts at the Visitors Center (Fig. 05) and can be done in less than 1 hour by walking 1.4 km along the edge of the canyon.



Figure 05 – Itaimbezinho aerial view, showing the main access to the IBAMA office (north), the Vértice Trek (top, contouring the canyon vertex) and the Cotovelo Trek, towards the south (photo by RenatoGrimm – www.acaserge.org.br/fotos/album04).

Cotovelo Trek: it gives an amazing sight of the Itaimbezinho Canyon walls. It is an easy walk to a belvedere where a general sight of the canyon can be seen (Fig. 06). The visit all over (6.3 km) can be done in about 3 hours.



Figure 06 – Aerial view in the Cotovelo Trek (evidence of the orthogonal fracturing) – photo by Renato Grimm – www.acaserge.org.br/fotos/album04.

Rio do Boi Trek: inside the canyon, for those who prefer more radical activities. It goes along the bed of the Boi River, surrounded by the 700 meter-

high walls. The walk takes 7 hours to be completed and returned, in an 8 km journey. It is a long trek, with many stones in the way. It crosses several times the river (whose water sometimes can reach above the

knee height), with excellent natural pools for a cold bath. This is the only way with a free access to the interior of the canyon and it starts at the base, in the town of Praia Grande.



Figure 07 – Índios Coroados (first plane) and Malacara (in the distance) canyons, seen from the SC-450 road, in the Serra do Faxinal.



Figure 08 – Aerial view of the Fortaleza canyon, with the summit at right. The ocean is at background (photo by Renato Grimm – www.acaserge.org.br/fotos/album01)

Leaving the Aparados da Serra National Park by the RS-360/SC-450 roads (Fig. 07) that cross the access to the Itaimbezinho Canyon and goes downhill from the Aparados da Serra to the town of Praia Grande, it is the border between the Rio Grande do

Sul and Santa Catarina states. It is placed at the summit of the Serra do Faxinal, 1,007 meters high, where a natural belvedere permits a spectacular sight of the transition between the top of the canyons and the coastal plain. It comprehends a region between

the Rio do Boi river valley (Itaimbezinho Canyon) and the ocean, including the town of Torres and the southernmost littoral of Santa Catarina, passing by the Serra Geral Platforms, which are the volcanic flattened remnants from the erosion that caused the regression of the Aparados da Serra slope.

Fortaleza Canyon

The Fortaleza Canyon (Fig. 08) is 23 km away from the Cambará do Sul town by the CS-08 non-paved road and its summit is 1,157 meters high; it is 7.5 km long and its cliffs have up to 800 meters as level differences.

The area has a very poor tourist infrastructure. The Mirante Trek (Fig. 09) gives access to the top of the Fortaleza Mount through a walk of about 1,700 meters from the parking lot. The sight from this summit comprehends 95% of the canyon and the littoral area of the Rio Grande do Sul/Santa Catarina border. Other treks reach the Pedra do Segredo and the Tigre Preto Fall, that has three waterfalls more than 400 meters high.



Figure 09 – At distance, the scarp that leads to the Fortaleza Mount summit (1,157meters high) by the Mirante Trek.

The Fortaleza Canyon borrows its name from the shape of its walls that cut vertically the rock and are sinuous along their extension, resembling a 5,800 meters long, 2,000 meters wide and 600 meters high fortress. Its summit is 1,157 meters high, from where it is possible to see the coastal line and the town of Torres in clear days.

Thirteen acid (rhyolites-rhyodacites) flows can be identified in the Fortaleza Canyon walls. They have neat tabular limits with individual thicknesses ranging from 15 to 55 meters – 25 meters in average (Figs. 10 and 11). The limit between flows is enhanced by the presence of vesicular horizons at the top and a centimetric tabular disjunction at the base of each flow. This gives way to the water circulation and, as a consequence, the development of a sharper alteration

profile that allows a stronger and closer vegetation to develop along the contact lines. The process results in the formation of a remarkable profile break between flows, especially on the upper horizons (Fig. 12). The canyon bottom lies on an essentially basaltic set of the Gramado Facies. This compositional difference is also reflected by the geomorphologic transition from the Campos de Cima da Serra (Campos Gerais) plateau and the Serra Geral Platforms, where basalts prevail all the way to the inferior boundary. Below this line (less than 100 meters in altitude) occur the Botucatu Formation sedimentary rocks.

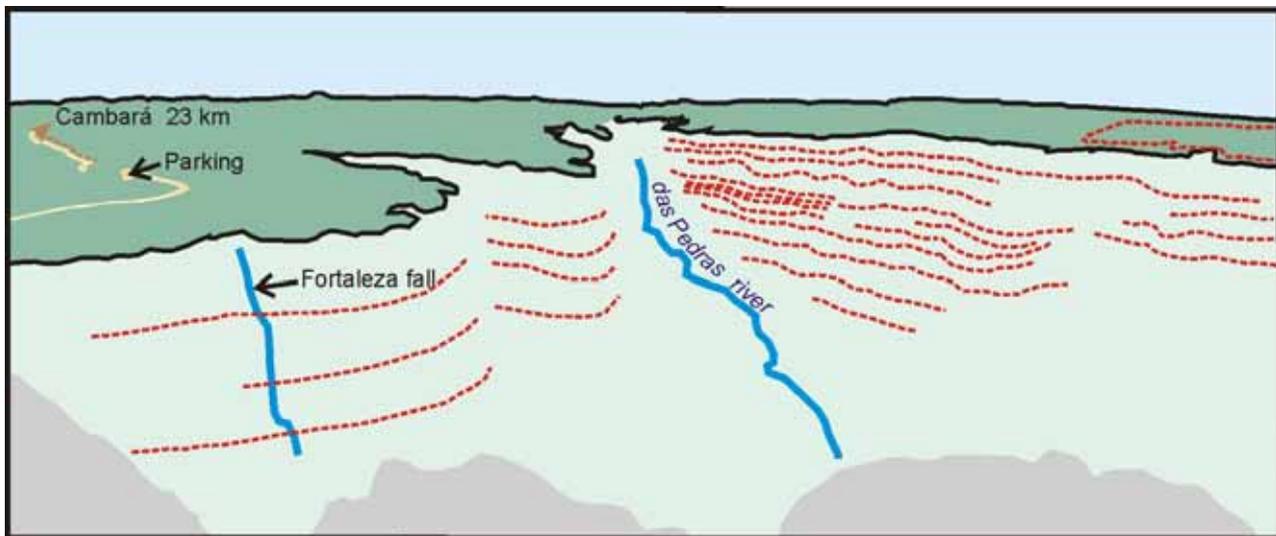
GEOLOGY OF THE CANYONS REGION

Geologic setting of the region

The Paraná-Etendeka Basin, which is the geological name of the structure the Aparados da Serra region lies on, covers the whole center-eastern portion of South America, extending to the Namibia's northwestern region, in western Africa. Both areas have similar geologic characteristics in the two continents and this is a solid indicative for the existence of a previous single and huge continent before the opening of the Atlantic Ocean and the continental displacement. This proto-continent was the Gondwana, whose rifting began around 120 Million years (My) ago.

The rifting and the separation of the Gondwana during the Lower Cretaceous period were accompanied by an impressive volcanic event whose lava flows covered the center-southern South America and the northwestern Africa portions. An extensive magmatism along the newly created margins generated the Abutment Plateau and the Walvis Ridge and Rio Grande volcanic mountain chains, among others (Gładczensko *et al.*, 1997 – Fig. 13). These are the fossil traces of the *fragments* migration of the Gondwanic Continent. This event was the responsible for the generation of the Paraná-Etendeka Province, one of the biggest basaltic volcanic plateau provinces (LIP) in the planet. It is temporally and spatially related to the fragmentation of the gondwanic western area and more specifically to the magma generation and to the Tristan da Cunha mantle plume action (Hawkesworth *et al.*, 1992; O'Connor and Duncan, 1990; Gallagher and Hawkesworth, 1994).

Tracks of this rifting may be found both in the Paraná and Etendeka basins. Here will be discussed the ones related to the final filling up episodes in these basins and their connections with the Gondwana rifting, especially concerned to the Serra Geral Volcanism, one of the world's biggest volcanic event ever occurred, which is the geologic substratum for the Aparados da Serra region.



Figures 10 and 11 – Sight of the Fortaleza Canyon where the access road to the Park and to its parking lot can be seen. On the diagram the structures in red mark the limits between the 13 acid flows that compose the canyon.

The Paraná Basin is the South American part of that huge geological entity. Its evolution comprehended four big episodes (Almeida, 1981), each one corresponding to a complete tectono-sedimentary cycle (Sloss, 1963). The first two cycles are related to the sedimentation on a subsident synform basin and the last two to the uprising and extrusion of a large amount of tholeiitic lavas due to the crust swelling occurred around 135-120 My (Million years) ago.

About 730,000 km² of the Brazilian share of the Paraná Basin are covered by the Botucatu Formation and by the flows related to the tholeiitic lavas of the Serra Geral Magmatism. They correspond to the final filling up of the basin and may reach a thickness of 1,700 meters at its depocenter, to the west of the Paraná state (Milani *et al.*, 1998).

The Serra Geral Formation (White, 1908) refers to the magmatic province related to the lava flows and effusive rocks that cover the Paraná Basin (Melfi *et al.*, 1988). It comprehends the whole center-southern part of Brazil and extends along the Paraguay, Uruguay

and Argentine borders. This unity is mainly formed by basalts and andesite basalts with a tholeiitic affiliation that constitute about 95% of the area covered by volcanic rocks in the basin. They contrast with the rhyolitic and rhyodacitic lavas that cover about 5% of the area and that outcrop on the Serra Geral countreforts of the Aparados da Serra region, what characterizes a bimodal lithological association (basalt-rhyolite).

Evolution of the canyons

The slope of the Serra Geral plateau is one of the most remarkable geomorphologic features in southern Brazil. Its origin and its magnificent canyons are geologic aspects yet unknown by the public. This beautiful landscape has always attracted the curiosity of the people who come to meet it.

For a better understanding of the way the Serra Geral slopes and canyons were built it is important to get back to 225 million years ago, to the Permian

period, when the present continents were still joined together in a super-continent named PANGEA. This

huge land mass was later on divided into two large blocks named EURASIA and GONDWANA.

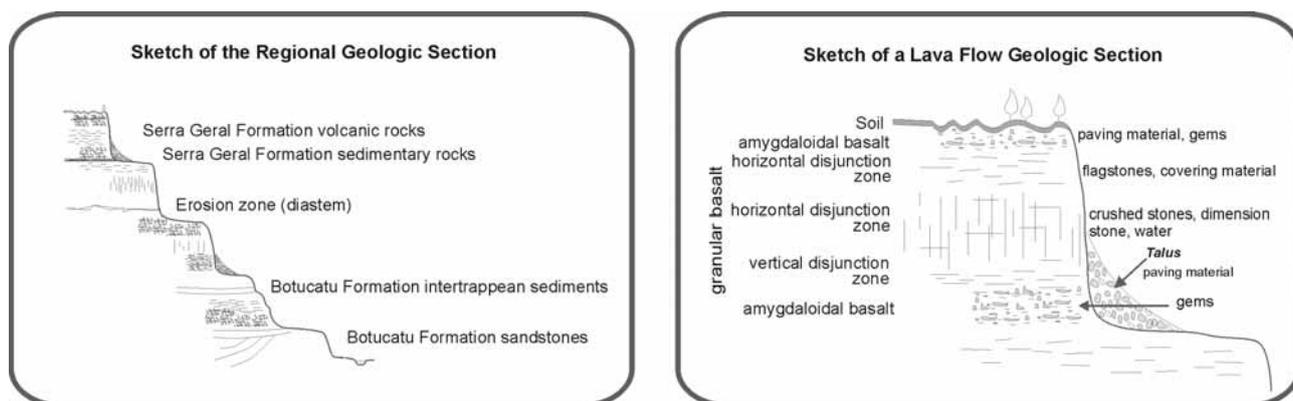


Figure 12 – Schematic representation of the flow structures in the Paraná Basin volcanism.

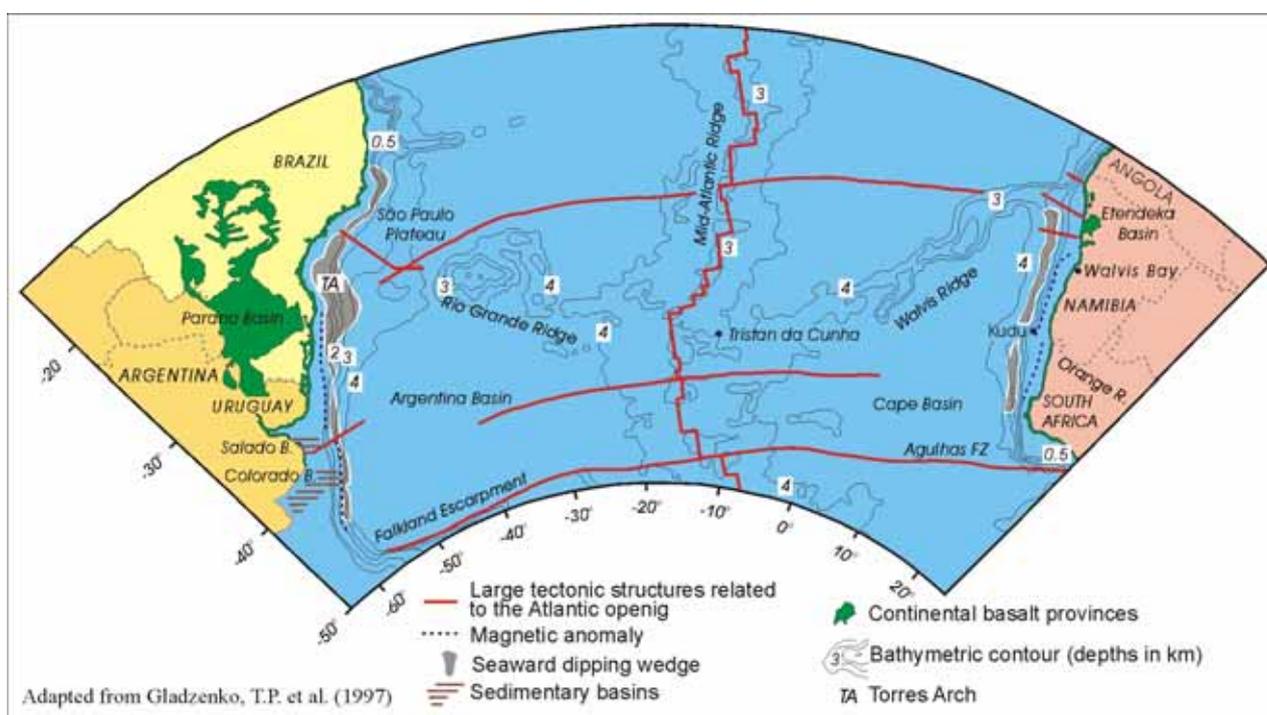


Figure 13 – The continents and the mountain chains on the Atlantic floor (Gladczensko *et al.*, 1997).

As a consequence of the Earth's crustal dynamic process managed by the Plate Tectonics rules, the Gondwana super-continent started to fragment about 135-110 million years ago. The fragmentation went along with a wide uprising in the whole eastern border of the just created South American continent and the African western border (Fig. 14). So the volcanic lava flows and the underlying rocks were topographically raised and formed the now called Serra Geral plateau and Serra do Mar mountains in the South American continent.

As the process went on, South and North Americas were gradually pulled apart from Africa and Europe, respectively, giving place to the formation of the Atlantic Ocean and to the Mid-Ocean Ridge,

which was formed by submarine volcanic flows. The morphological similarity of the Brazilian and African coasts led Alfred Wegener, in 1912, to conceive the Continental Drift Theory that proved with geologic and paleontologic evidences that Africa, South America, Australia and India were once parts of the Gondwana super-continent.

The Atlantic front in the Rio Grande do Sul and Santa Catarina coasts started to form due to the intensive tectonic movements occurred in the Cretaceous period. As the Atlantic Ocean was becoming wider and the Mid-Ocean Ridge was consolidating, intense faulting parallel to the coast broke and dropped large pieces of the just formed Serra Geral slope into the Atlantic waters. These *en*

echelon faults with their steps placed downward to the sea are the responsible for the occurrence of remnants from the original slope in different topographic altitudes of the Atlantic platform. The association between Plate Tectonics and the posterior erosive and sea level variation processes built the present coastal landscape, where the Serra Geral cliffs are away from the Atlantic beaches.

Once formed the Serra Geral slope, the compositional differences between basaltic and rhyolitic flows, their distinctive response to the weathering, the existing deep fractures and the fluvial erosive processes were slowly carving the landscape, resulting in the present morphology of the Aparados da Serra and its canyons.

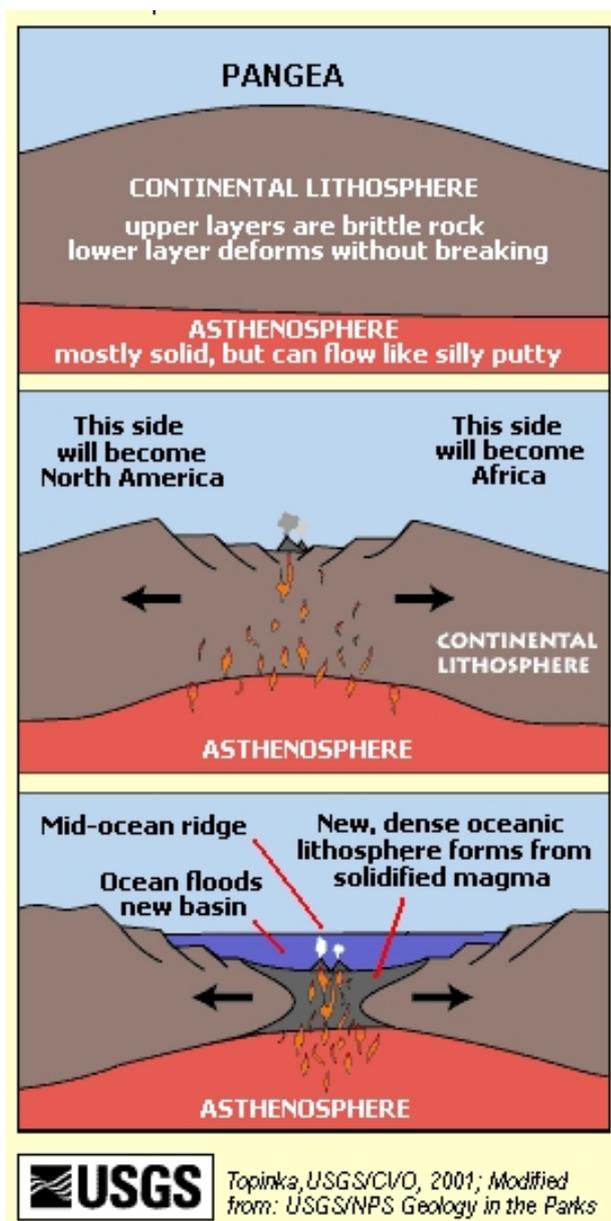


Figure 14 – Sketch showing the crustal thinning and the continental drift (adapted from Topinka, USGS/CVO, <http://vulcan.wr.usgs.gov/Glossary/> - in Geologic Time Scale/Triassic – The Break-up of the Continent Pangea).

Tectonic discontinuities are a dominant factor to the development of the canyons, whose general trend parallels the main directions of the fractures of the regional volcanic rocks. As faults and fractures are natural weak zones where the water tends to flow and form streams which, in turn, favor the vertical erosion, it is taken for granted that these features played a major role to the formation and development of the canyons.

In the Tertiary and Quaternary periods the sediments originated from the erosion of the Serra Geral slopes were deposited on the bottom of the Atlantic Ocean, forming thick sedimentary packs and fringes on the continental platform. The sea, through alternating transgressions and regressions, was progressively modeling the Rio Grande do Sul and Santa Catarina coasts to the present shape. At this time a long barrier system was formed in the littoral of these states, isolating a big volume of seawater that became a lagoonal string distributed along the Rio Grande do Sul and part of the Santa Catarina coasts. As the geologic processes are dynamic and variable along the time, the Atlantic coast is still slowly and continuously changing, but the changes can only be recorded after long geologic periods.

At the end of its formation, the Basaltic Plateau of the Rio Grande do Sul northeastern region resulted in a general cuesta inclined to the west, to the southwest and to the south, carved by several consequent streams. During the uprising of the main lava flow building, the major rivers directed to the west (Pelotas river) and to the south (left tributaries of the Jacui river) were naturally enclosed, whereas the small streams directed to the east had difficulty to migrate, festooned the Aparados region and carved short and deep canyons in particular places of the slopes.

The enclosing of streams such as the Pelotas and Antas rivers, at the continental side, reflected the successive stimuli of a hypergenesis that acted in several bounds during the Tertiary period. This compartmentalized the basaltic plateau and created the magnificent landscape of the Serra Gaúcha, the Rio Grande do Sul northeastern portion of the Serra Geral.

PROTECTING PROCEDURES

The Itaimbezinho and Fortaleza canyons are in national park areas managed by the IBAMA under a specific legislation. National parks are limited geographic areas that have exceptional natural attributes that demand a permanent preservation. They are created to preserve their special qualities such as very beautiful landscapes and rare faunal and floral specimens that are in danger or about to be extinguished. They are federal properties and are used for scientific, cultural, educational and recreational purposes.

The Aparados da Serra National Park contains the Itaimbezinho canyon. It was created in 1959 on an area protected since 1957; it was enlarged in 1972. Since 1984 it has a Management Plan that expected its expansion to incorporate new areas (the Fortaleza, Malacara and Churriado canyons, among others) that presently are in the Serra Geral National Park, created in 1992.

In the Itaimbezinho area the IBAMA keeps an administrative facility for the Aparados da Serra Park. It is equipped with information office, Visitors Center and administrative supporting services. The Park is open during a scheduled time and closes in some days of the week for preserving and administrative purposes. The admittance is paid. Particular guides are available for the treks liberated for visits. The lower part of the Park suffers a strong anthropic stress due to invasions of hunters or woodchoppers, to cattle raise or to plantations. The land ownership is partially regularized (only 58%) and there are some owners who still work on the preservation area.

(<http://www2.ibama.gov.br/unidades/parques/reuc/65.htm>).

The Fortaleza canyon, in the Serra Geral National Park area, has a worse situation. The admittance is free and there is only a sentry box with a guardian to prevent non-allowed activities such as camping, firing and unauthorized trekking. The main problems are related to hunting, forest fire and deforestation. The land ownership is not regularized yet.

(<http://www2.ibama.gov.br/unidades/parques/reuc/67.htm>).

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