








POTENTIAL CACHOEIRA DA MULADA GEOSITE: GEOLOGICAL AND CULTURAL HERITAGE IN SERRA GAÚCHA, RS, BRAZIL

Marcelo Canals Meucci¹ ; Ingrid Müller Mohr¹ ; Vitoria Brito da Silva¹ ; Rualdo Menegat¹ ; Iasmin Raissa Beatrici¹ ; Evandro Fernandes de Lima¹ ; Rodrigo Cybis Fontana² 

1- Universidade Federal do Rio Grande do Sul. Av. Bento Gonçalves, 9500 - Agronomia, Porto Alegre - RS, 90650-001. E-mail: marcelo.cmeucci@gmail.com; vitoriab0712@gmail.com; rualdo.menegat@ufrgs.br; beatrici.iasmin@gmail.com; eflgeologo@gmail.com
2 - Universidade Nacional de Lanús. 29 de Septiembre 3901, B1832 Remedios de Escalada, Provincia de Buenos Aires, Argentina. E-mail: ingridmohr09@gmail.com; rodrigofontana.geo@gmail.com

Abstract: *Cachoeira da Mulada, located in the Reserva Bertussi in Criúva (Caxias do Sul, RS, Brazil), is a potential geosite within the volcanic Serra Geral Group (GSG). This thick package represents a vast magmatic event that preceded the opening of the South Atlantic. The site combines scenic beauty, adventure tourism, and cultural heritage, making it a significant geotourism attraction. The geological framework places the waterfall within the Paraná-Etendeka Large Igneous Province (PELIP), characterized by flood basalts and acid units of the Early Cretaceous. Two main formations occur at the waterfall: the Vale do Sol Formation (VSF) at the base and the Palmas Formation (PF) at the top, with distinctive rubbly pahoehoe basaltic flows and acidic lava structures shaping the landscape. The Bertussi family maintains the Cachoeira da Mulada, which attends to the site's cultural legacy, notably as pioneers of traditional Gaúcho music, with the "Irmãos Bertussi" duo gaining national recognition. The site also hosts one of the largest outdoor canyoneering training complexes in Rio Grande do Sul, offering varied rappel routes and training opportunities. A thematic map and digital guide were developed to enhance the visitor experience, alongside educational panels covering geological, geomorphological, botanical, and cultural aspects. Quantitative assessment using the Brilha Method yielded high scores: 290/400 for scientific potential, 310/400 for touristic potential, and 320/400 for educational potential, with a moderate degradation risk (150/400). The results highlight the site's exceptional geological features, strong geotourism appeal, and cultural importance, reinforcing its value for conservation and sustainable ecotourism.*

Keywords: *Geological heritage, Geological tourism, Serra Geral Group, Geology education, Reserva Bertussi.*

1. INTRODUCTION

The growing interest in ecotourism reinforces the idea that integrating cultural traditions into natural settings contributes to preserving biodiversity and geodiversity. The Serra Gaúcha is a promising geological and sustainable tourism hub in this context. However, geology—often confined to academic circles—remains largely inaccessible to the general public. To broaden its appeal, it is essential to adapt scientific communication into a more accessible language highlighting Earth's geological evolution and its interconnections with other scientific fields.

Geomorphologically, the Serra Gaúcha is a volcanic plateau that harbors a vast geological heritage. It forms the backbone of the identity of the "gaúchos serranos"—in contrast to the "gaúchos da campanha," whose landscapes are influenced by crystalline basement rocks and the lowlands of the Paraná Basin. The interplay between geomorphology, ecology and cultural traditions in this region drives tourism to natural attractions, such as the Geopark Caminhos dos Cânions do Sul.

Cachoeira da Mulada (Mulada Waterfall) is a significant regional attraction located within the Reserva Bertussi (Bertussi Reserve), in the Criúva district of Caxias do Sul municipality (Rio Grande do Sul, Brazil). It combines scenic beauty with opportunities for adventure sports such as canyoneering and hiking, while also offering visitors a chance to immerse themselves in the local culture. The geosite comprises volcanic successions of the Serra Geral Group (SGG), a vast volcanic event that preceded the breaking up of Gondwana supercontinent and the opening of the South Atlantic. The flow morphologies within the volcanic rock succession, combined with tectonic activity and climatic influences, have shaped the unique landscapes of the regions, particularly evident in its waterfalls and canyons.

The Bertussi family, responsible for maintaining the waterfall, has preserved a vibrant cultural legacy and boasts a long history in the region. They pioneered the rise

of traditional Gaúcho music, notably with the acclaimed accordion duo "Irmãos Bertussi."

This study aims to recognize and evaluate the potential of the Cachoeira da Mulada geosite within the geological heritage of the Serra Gaúcha. Its potential was quantified using the Brilha geosite evaluation method (Brilha, 2016). In addition, efforts were made to develop and promote geological and cultural dissemination materials designed for the general public and the academic community, ensuring accessible yet scientifically rigorous information.

2. METHODOLOGY

For the qualitative assessment of Cachoeira da Mulada, the study focused on the site's geological characterization and ecotourism infrastructure, including trails, viewpoints, and cultural and botanical aspects of the region. The research methodology included fieldwork, the creation of a columnar profile using vertical rappelling techniques, a bibliographic review, and an interview with Samantha Bertussi regarding the family's history.

The Quantitative Assessment of Geological and Geodiversity Sites, the Brilha Method (Brilha, 2016), was applied for the quantitative evaluation. This method emphasizes the appraisal of geosites in terms of their scientific, educational, touristic, and conservation attributes.

The Brilha Method assigns weighted scores to various criteria:

- **Scientific Value:** Assesses the geological characteristics of a geosite by considering its representativeness, key locality importance, associated scientific knowledge, integrity, geological diversity, rarity, and use limitations;
- **Potential Educational Use (PEU):** Evaluated based on 12 criteria: (a) vulnerability, (b) accessibility, (c) use limitations, (d) safety, (e) logistics, (f) population density, (g) association with other values, (h) scenic quality, (i) uniqueness, (j) observation conditions,

(k) didactic potential, and (l) geological diversity;

- **Potential Touristic Use:** Assessed using the same criteria as the PEU, including three new factors: interpretive potential, economic level, and proximity to recreational areas;
- **Degradation Risk:** Evaluated through five indicators: deterioration of geological elements, proximity to areas or activities that may cause degradation, legal protection, accessibility, and population density.

Each group of criteria has specific weights that sum to 100 points, allowing a geosite to achieve a maximum score of 400 points.

3. RESULTS AND DISCUSSION

3.1. Geological Framework

Cachoeira da Mulada is located within the Paraná-Etendeka Large Igneous Province (PELIP), a continental flood basalt province of the Early Cretaceous, dated between 135.5 and 133.2 Ma, with the peak of magmatism lasting approximately 1.6 to 3 Ma (Gomes & Vasconcelos, 2021). PELIP is structured by large volumes of volcanic rocks, dominated by subaerial mafic lavas, with subordinate acidic volcanic products and intrusive rocks. This magmatic event preceded the breakup of the supercontinent Gondwana and the opening of the South Atlantic Ocean (Gladczenko et al. 1997), resulting in these rocks being found in South America (about 90% in Brazil, Argentina, Uruguay, and Paraguay) and in Africa (approximately 10% in Namibia and Angola) (Piccirillo & Melfi, 1988; Peate, 1997). In South America, the area and volume of the PELIP are estimated at 917,000 km² and around 600,000 km³, respectively, considering both volcanic and intrusive rocks (Frank et al. 2009). Within Brazil, PELIP was emplaced in the Paraná Basin, reaching a maximum thickness of 1,725 m in its central portion (Piccirillo & Melfi, 1988).

In Brazil, PELIP is known as the Serra Geral Group, which, in its southern portion, is formally subdivided, from the base to the top, into the Torres (TF), Vale do Sol (VSF), Palmas

(PF), and Esmeralda (EF) formations (Rossetti et al. 2018). Previous studies in the Cachoeira da Mulada (CM) area have focused on its lithostratigraphic and petrographic aspects (Meucci et al. 2025). Two main formations at the CM can be identified: the VSF forms the lower part, and the PF overlies it. The regional contact between these formations is approximately 650 m above sea level. The waterfall, with a height exceeding 80 m, is structurally defined by the contact between VSF at the base and PF at the top (Figure 1).

At the base, within the VSF, three rubbly pahoehoe basaltic flows can be recognized between 585 and 660 m in elevation. These flows range from 15 to 50 m thick, and are characterized by brecciated tops (5–15 m thick), massive cores (5–35 m thick), and vesicular zones. In the upper portion of the waterfall, at elevations between 670 and 725 m, dacitic lava flows and vertical structures are identified. These flows exhibit a simple tabular morphology with an aphanitic texture, flow foliation, and, when verticalized, tight flow folds. Such vertical structures may correlate with feeder conduits of the Palmas Formation (Lima et al. 2018).

The waterfall's morphology is further highlighted by the contrast between the more resistant, tabular acidic flows and the rubbly pahoehoe flows of the VSF, which exhibit lower resistance due to brecciation (flows top). Four distinct breaks in relief have been identified: one between PF and VSF, and three within the internal contacts of the rubbly pahoehoe flows in the VSF.

Petrographically, the basaltic lithofacies generally display an aphanitic texture characterized by plagioclase and pyroxene microphenocrysts, along with iron oxides and rare larger plagioclase phenocrysts. The matrix consists of highly oxidized, glassy material altered into clay minerals and zeolites. The massive lithofacies (mB) is defined by a fine-grained, holocrystalline texture with a higher degree of crystallinity and rarely exhibits vesicles and amygdaloids. It also presents a diktytaxitic texture filled with zeolites and clay minerals. In contrast, the vesicular lithofacies (vB) shares similar textural characteristics with

mB but contains a greater abundance of vesicles and amygdalae, ranging from 0.1 to 1 mm in size with oval to irregular shapes, and occasionally forms geodes. The brecciated lithofacies (bB) is distinguished by a characteristic reddish color due to lava oxidation and is composed of vesicular to amygdaloidal volcanic fragments commonly filled with zeolites.

In the dacitic lithofacies, flow structures are either horizontal (haD) or subvertical (saD) marked by alternating bands of devitrified material and bands with a high oxide content. The porphyritic texture features plagioclase and orthopyroxene phenocrysts, while the matrix remains aphanitic with plagioclase microlites. Vesicles and amygdalae are rare within these acidic lithofacies.

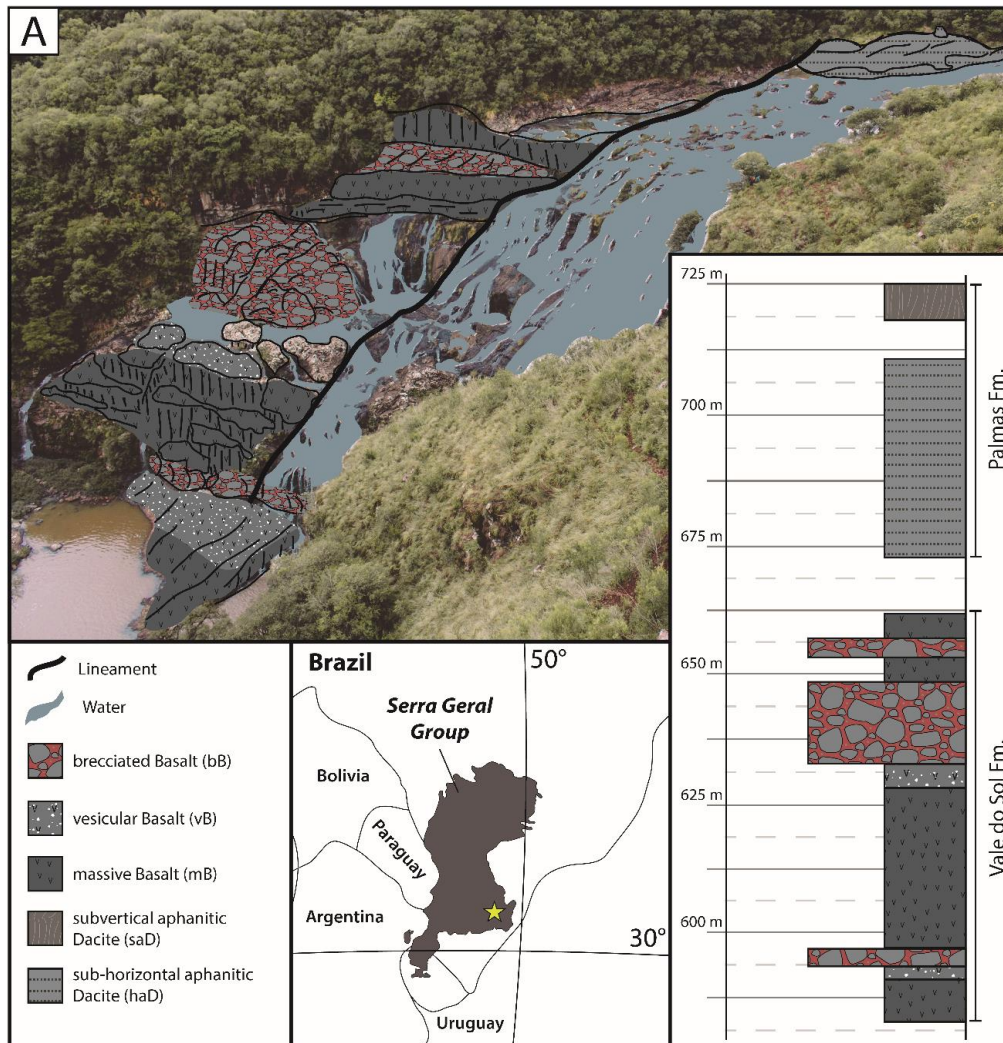


Figure 1 – Cachoeira da Mulada logged section with schematic drawing of the lava flows and the vertical log succession (modified after Meucci et al. 2025)

3.2 Cultural and Historical Heritage

Criúva has a small, predominantly rural population whose history is closely linked to the “tropeiro” routes in the Campos de Cima da Serra region. Most residents are descendants of Italian and Portuguese immigrants who colonized the area at the end of the 19th century and the beginning of the 20th century (Passos, 1967). Local inhabitants are dispersed across small rural properties,

where family farming is the main economic activity, helping preserve the natural and cultural environment.

The region is rich in natural and cultural attractions, much of which is connected to its geological and geomorphological heritage, particularly its volcanic rock formations. In addition to Cachoeira da Mulada, notable sites in the region include the Palanquinho Canyon, Rio das Antas Valley, Ponte dos Korff, Sepultura Waterfall, and several

archaeological sites featuring caves with burials and fragments of lithics and ceramics (Corteletti et al. 2008).

The area also holds significant historical and cultural importance, bolstered by musician Fioravante Bertussi, who once owned the land where Cachoeira da Mulada is located. In the 1940s, Fioravante and his family were pivotal in popularizing traditional Gaúcho music, forming a musical group that performed at dances and festivals. In the 1950s, his sons Honeyde and Adelar gained prominence with the formation of the "Irmãos Bertussi" duo, considered one of the greatest Gaúcho duos of all time, pioneers of danceable music and the first accordionists in the genre to record albums. Moreover, Fioravante used the local geomorphology to construct a small power plant that supplied the local population until 1982; the remnants of the former engine house and dam can still be seen along local trails.

Today, the Bertussi family maintains the property, dedicating themselves to preserving its touristic, cultural, biological, and geological legacy. Other cultural points of interest include the Bertussi Farm/Museum and a monument honoring the Irmãos Bertussi.

3.3 Adventure Sports and Canyoneering

Cachoeira da Mulada also hosts one of the largest outdoor canyoneering training complexes in Rio Grande do Sul. Its various drops provide an ideal setting for practicing canyoneering techniques safely and repeatedly, reinforcing skill acquisition. Both sectors feature dry and wet rappels, downclimbing techniques, natural pools, and typical canyon anchors.

On the right bank, a sequence of six rappels leads to the base of the cascade, where practitioners can also train in jumps ranging from 1 to 8 m. The major challenge lies on the left bank, where a 50-m drop is encountered. In this sector, a natural anchor supports a

series of rappels, necessitating rope recovery to setup of subsequent rappels. The final 25-m rappel offers a unique panoramic view of the waterfall.

The local geomorphology and arrangement of the lava flows provide exceptional potential for adventure sports. Four distinct relief breaks have been identified—one at the contact between the PF and VSF and three stemming from internal variations within the rubbly pahoehoe flows of the VSF. This configuration creates distinct sectors with varied features, such as large blocks and massifs, natural pools, vertical or inclined rappels, and rope handrails that facilitate safe descents. These variations make the site ideal for training various canyoneering techniques.

3.4 Educational Materials and Interpretive Tools

The investigations were integrated into a thematic map that shows trails, tourist information points, and thematic spots covering geological, botanical, cultural aspects, scenic viewpoints, and canyoneering (Figure 2). Additionally, a 30-page digital tourist guide was produced, detailing key points of interest, five geological, two botanical, four cultural, three scenic, and one canyoneering-specific. Alongside the guide, 13 informative panels (A3 size) were created for installation at these thematic locations.

The local infrastructure further supports tourism with camping areas with barbecue facilities, restrooms with showers, and a restaurant offering on-demand meals. Three main trails serve the area:

1. **Bosque Trail:** Circulates through the camping zones;
2. **Sabão Trail:** Leads to a viewpoint overlooking a small cascade;
3. **Waterfall Base Trail:** Descends to the base of the cascade and is considered the most challenging.

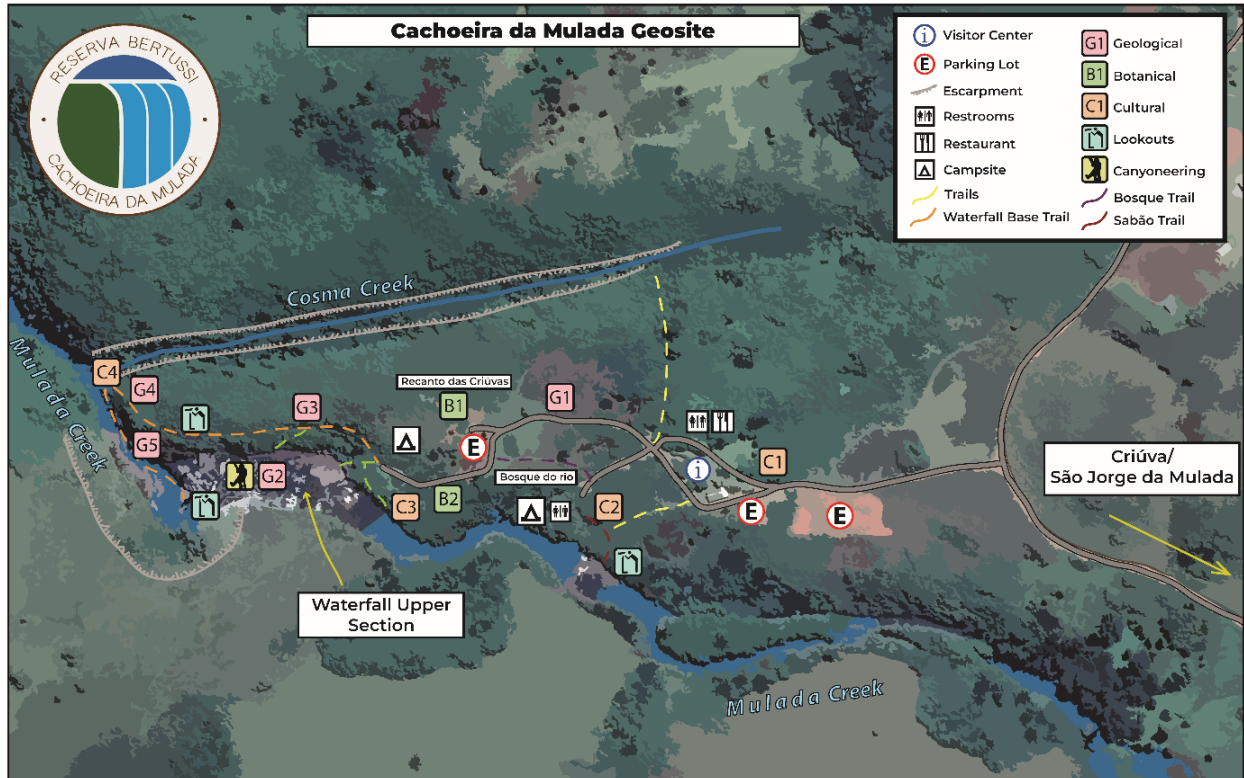


Figure 2 - Thematic map of Cachoeira da Mulada Geosite, displayed on an on-site informational sign, showing trails and points of interest.

3.5 Quantitative Evaluation and Risk Assessment

The quantitative evaluation using the Brilha Method yielded high scores for Cachoeira da

Mulada: 290/400 for scientific potential, 310/400 for touristic potential, and 320/400 for educational potential, with a moderate degradation risk of 150/400 (Table 1).

Table 1 – Quantitative evaluation of Cachoeira da Mulada geosite based on Brilha Method (Brilha, 2016).

Scientific Value – Total: 290/400					
Representativeness	120	Integrity	60	Use limitations	20
Key locality	20	Geological diversity	20		
Scientific knowledge	20	Rarity	30		
Potential Touristic Use – Total: 310/400					
Vulnerability	30	Density of population	15	Interpretative potential	30
Accessibility	30	Association	20	Economic level	20
Use limitations	15	Scenery	30	Proximity	20
Safety	40	Uniqueness	20		
Logistics	20	Observation conditions	20		
Potential Educational Use – Total: 320/400					
Vulnerability	30	Logistics	20	Uniqueness	10
Accessibility	30	Density of population	15	Observation conditions	40
Use limitations	15	Association	20	Didactic potential	60
Safety	30	Scenery	10	Geological diversity	40
Degradation Risk – Total: 150/400					
Deterioration	35	Legal protection	20	Density of population	30
Proximity	20	Accessibility	45		

Regarding scientific potential, the region and Cachoeira da Mulada have recently been studied for their lithostratigraphic, petrological, and morphological characteristics (Meucci, 2025). The site exhibits well-preserved and varied geological features, offering excellent opportunities for observation and study. Nonetheless, further multidisciplinary research, particularly in geomorphology, hydrology, and local fauna and flora studies, is needed to understand the region's environmental dynamics fully.

The waterfall's high touristic potential is due to its scenic beauty, ease of access, and robust infrastructure, which includes parking, a camping area, a restaurant, and restrooms with showers. Although it is relatively distant from major urban centers, its location allows for day trips, making it accessible to local tourists and visitors from nearby cities. Additionally, the site offers a variety of activities, from adventurous trails and sports to areas for bathing. While it is not the only waterfall with this morphology in the region, it stands out for its impressive aesthetics and diverse attractions. This significance was further recognized when it was voted the second most beautiful waterfall in Rio Grande do Sul in a contest by the Repórter Farroupilha blog (2024), which garnered nearly 200,000 votes among 10 finalists.

The geosite also holds strong educational potential, catering to audiences such as tourists, school excursions, and academics. Informative panels at the site help communicate scientific concepts in an accessible manner, using comparative illustrations to clarify the geological formations and natural processes on display.

Concerning degradation risk, the geosite was classified as having a moderate risk according to the Brilha Method (Brilha, 2016). However, part of this rating may be slightly overestimated due to the methodology. For instance, the geosite is located in Caxias do Sul, with a population density between 250 and 1,000 inhabitants per km². Yet, the specific site lies in the Criúva district, more precisely in São Jorge da Mulada village, where the density is under 100 inhabitants per km². Other criteria

indicate a low risk of degradation for the geosite's geological, geomorphological, and aesthetic elements. Environmental impact is minimal, as the area lacks nearby industrial facilities, with family farming being predominant. The geosite is located on private property, with controlled visitor access and infrastructure in place to accommodate tourism. Although access is via a dirt road, nearby paved roads ease tourist arrival.

4. CONCLUSION

Cachoeira da Mulada geosite demonstrates significant potential for classification and inclusion in the System for Registration and Quantification of Geosites and Geodiversity Sites (GEOSSIT - Sistema de Cadastro e Quantificação de Geossítios e Sítios da Geodiversidade), as well as for recognition through legal protection mechanisms within the municipality of Caxias do Sul and the state of Rio Grande do Sul.

The site combines geological importance with a well-developed infrastructure for tourist reception. Its diverse and clearly defined geological features facilitate observation, especially with the aid of informative panels. Additionally, the geosite boasts high educational and touristic potential, appealing to a wide range of visitors.

Integrating the conservation of geological, cultural, and natural heritage with regional development is essential to empowering local communities and promoting the education of tourists, schools, and guides, thereby contributing to the region's overall sustainability.

Funding: The authors acknowledge financial support by CNPq (406980/2021-7).

Acknowledgments: We thank Samantha Bertussi and the team at Reserva Bertussi – Cachoeira da Mulada for their collaboration, and Mateus Meucci for his valuable contribution to the canyoneering section.

5. REFERENCES

BRILHA, J. Inventory and quantitative assessment of geosites and geodiversity sites: a review. *Geoheritage*, v. 8, p. 119-134, 2016. Disponível em: <https://doi.org/10.1007/s12371-014-0139-3>.

CORTELETTI, R. Patrimônio arqueológico de Caxias do Sul. Porto Alegre: Nova Prova, 2008. 200 p.

FRANK, H. T.; ELISA, M.; GOMES, B.; LUIZ, M.; FORMOSO, L. Review of the areal extent and the volume of the Serra Geral Formation, Paraná Basin, South America. *Pesquisas em Geociências*, v. 36, n. 1, p. 49-57, 2009. Disponível em: <https://doi.org/10.22456/1807-9806.17874>.

GLADCZENKO, T. P.; HINZ, K.; ELDHOLM, O.; MEYER, H.; NEBEN, S.; SKOGSEID, J. South Atlantic volcanic margins. *Journal of the Geological Society*, v. 154, p. 465-470, 1997. Disponível em: <https://doi.org/10.1144/gsjgs.154.3.0465>.

GOMES, A. S.; VASCONCELOS, P. M. Geochronology of the Paraná-Etendeka large igneous province. *Earth-Science Reviews*, v. 220, p. 103716, 2021. Disponível em: <https://doi.org/10.1016/j.earscirev.2021.103716>.

LIMA, E. F.; WAICHEL, B. L.; ROSSETTI, L. M. M.; SOMMER, C. A.; SIMÕES, M. S. Feeder systems of acidic lava flows from the Paraná-Etendeka Igneous Province in southern Brazil and their implications for eruption style. *Journal of South American Earth Sciences*, v. 81, p. 1-9, 2018. Disponível em: <https://doi.org/10.1016/j.jsames.2017.11.004>.

MEUCCI, M. C.; LIMA, E. F.; ROSSETTI, L. M. M.; PASQUALON, N. G.; MOHR, I. M.; BROSE, G. C. Stratigraphy and petrophysical properties of the volcanic rocks of the Serra Geral Group: A case study in the Antas River Valley region, Rio

Grande do Sul, Brazil. *Journal of South American Earth Sciences*, v. 154, p. 105376, 2025. Disponível em: <https://doi.org/10.1016/j.jsames.2025.105376>.

PASSOS, A. A. P. História de Criúva: uma leitura das interações culturais. Caxias do Sul: Educus, 2018.

PEATE, D. W. The Paraná-Etendeka province. In: MAHONEY, J. J.; COFFIN, M. F. (ed.). *Large Igneous Provinces: Continental, Oceanic, and Planetary Flood Volcanism*. Washington: American Geophysical Union, 1997. p. 217-245. (Geophysical Monograph, v. 100). Disponível em: <https://doi.org/10.1029/GM100p0217>.

PICCIRILLO, E. M.; MELFI, A. J. The Mesozoic Flood Volcanism from the Paraná Basin (Brazil): Petrogenetic and Geophysical Aspects. São Paulo: IAG-USP, 1988.

REPORTER FARROUPILHA. Concurso que elegeu a "cachoeira mais bela do RS" faz aumentar visitaç o à vencedora e às finalistas. 2024. Disponível em: <https://g1.globo.com/rs/rio-grande-do-sul/blog/reporter-farroupilha/post/2024/03/05/concurso-que-elegeu-a-cachoeira-mais-bela-do-rs-faz-aumentar-visitacao-a-vencedora-e-as-finalistas.ghtml>. Acesso em: 26 mar. 2025.

ROSSETTI, L.; LIMA, E. F.; WAICHEL, B. L.; HOLE, M. J.; SIMÕES, M. S.; SCHERER, C. M. S. Lithostratigraphy and volcanology of the Serra Geral Group, Paraná-Etendeka igneous province in southern Brazil: towards a formal stratigraphical framework. *Journal of Volcanology and Geothermal Research*, v. 355, p. 98-114, 2018. Disponível em: <https://doi.org/10.1016/j.jvolgeores.2017.05.008>.

Editado por Inan Guilherme Senter (PET-GEOLOGIA/UFPR)