UNIVERSIDADE DE SÃO PAULO
INSTITUTO DE GEOCIÊNCIAS

Geoconservation strategies as a subsidy to foster interpretation in protected areas: a case study from the Itatiaia National Park, Brazil

VANESSA COSTA MUCIVUNA

Orientadora: Prof. Dra. Maria da Glória Motta Garcia
Coorientador: Prof. Dr. Emmanuel Reynard

TESE DE DOUTORADO

Programa de Pós-Graduação em Geociências (Mineralogia e Petrologia)

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Orientador: Profª. Dra. Maria da Glória Motta Garcia

Tese de Doutorado

Nº 645

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I dedicate this work to the memory of my grandmother Maria Flores Nadilo, a wise illiterate woman, who always supported and encouraged me in my formal education.

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We keep moving forward, opening up new doors and doing new things, because we're curious. And curiosity keeps leading us down new paths.

Walt Disney

We have always been aware of the need to preserve our memories - i.e. our cultural heritage. Now the time has come to protect our natural heritage, the environment. The past of the Earth is no less important than that of human beings. Now it is time for us to learn to protect, and by doing so, to learn about the past of the Earth, to read this book written before our advent: that is our geological heritage.

International Declaration of the rights of the memory of the Earth

I'll interpret the rocks, learn the language of flood, storm and the avalanche. I'll acquaint myself with the glaciers and wild gardens, and get as near the heart of the world as I can.

John Muir

ABSTRACT

Mucivuna, V.C., 2022, **Geoconservation strategies as a subsidy to foster interpretation in protected areas: a case study from the Itatiaia National Park, Brazil** [PhD Thesis], São Paulo, Institute of Geosciences, University of São Paulo, 346 p.

For a long time, protected areas have focused their efforts on conserving biotic aspects of nature. However, since the 2010s, several international initiatives have been undertaken to integrate geodiversity and geoheritage in the management of protected areas through a broader concept of nature. Nevertheless, Brazilian protected areas have not yet included geoconservation and geoheritage in their work programmes despite the advances. Based on this, the main objective of this study was to elaborate the first stages of the geoconservation strategies to serve as a core database to subsidise future interpretation actions in the inventoried geological sites. In this context, the Itatiaia National Park was selected as the study area because it was the first protected area established in Brazil and it has important records of the region's geological history in the rocks and landforms. The following methodological procedures were applied to achieve the objectives of the thesis: (i) systematic literature review on several themes; (ii) data analysis; (iii) geological sites inventory, (iv) quantitative assessment, and (v) products from the previous steps, such as fact sheets of the inventoried sites, proposals to integrate the inventoried geological sites in the management plan, development of interpretative topics, themes and objectives, and methodological guidelines to elaborate interpretation plans for geological sites in National Parks. The results include seventeen geosites, distributed in six geological frameworks, in addition to seven geodiversity sites and three viewpoints. The quantitative assessment showed that they have potential to be integrated into educational and interpretative programmes, as well as in the public use activities, as they have low degradation risk. Furthermore, the management plan analysis provided promising results due to the possibilities of integrating the inventoried geological sites throughout the document. Finally, the results obtained throughout this research made it possible to select sites with the highest interpretative potential in the park and identify interpretative topics, themes, and objectives. These data can (and should) be used in future stages of the interpretative planning to contribute to disseminating the park's geological history for students, visitors, and residents of the surrounding communities.

Keywords: Assessment, Interpretation, Geological Heritage, Geological site, Geomorphosite, Inventory.

RESUMO

Mucivuna, V.C., 2022, **Estratégias de Geoconservação como subsídio para fomentar a interpretação em Unidades de Conservação: um estudo de caso do Parque Nacional do Itatiaia, Brasil** [Tese de Doutorado], São Paulo, Instituto de Geociências, Universidade de São Paulo, 346 p.

Durante muito tempo as áreas protegidas focaram seus esforços na conservação dos aspectos bióticos da natureza. No entanto, desde os anos 2010s, diversas iniciativas internacionais vêm sendo realizadas para integrar a geodiversidade e o patrimônio geológico na gestão das áreas protegidas por meio de um conceito mais amplo de natureza. Apesar dos avanços, as áreas protegidas brasileiras ainda não incluíram a geoconservação e o patrimônio geológico nos seus programas de trabalho. Com base nisso, o principal objetivo deste estudo foi elaborar as primeiras etapas das estratégias de geoconservação para servir como banco de dados primordial para subsidiar as futuras ações de interpretação nos sítios geológicos inventariados. Neste contexto, o Parque Nacional do Itatiaia foi selecionado como área de estudo por ser a primeira área protegida brasileira e por possuir importantes registros da história geológica da região nas rochas e formas de relevo. Os seguintes procedimentos metodológicos foram utilizados para atingir os objetivos da tese: (i) revisão sistemática da literatura em diversos temas; (ii) análise de dados; (iii) inventário de sítios geológicos, (iv) avaliação quantitativa, e (v) produtos provenientes das etapas anteriores, tais como fichas de dados dos sítios inventariados, propostas para integrar os sítios geológicos inventariados no plano de manejo, desenvolvimento de tópicos, temas e objetivos interpretativos, e diretrizes metodológicas para elaborar planos de interpretação para sítios geológicos em parques nacionais brasileiros. Os resultados incluem dezessete geossítios, distribuídos em seis categorias temáticas, além de sete sítios da geodiversidade e três mirantes. As avaliações quantitativas mostraram que eles possuem potencial para ser integrados nos programas educativos e interpretativos, bem como nas atividades de uso público pois eles possuem baixo risco de degradação. Além disso, a análise do plano de manejo forneceu resultados promissores devido as possibilidades de integração dos sítios geológicos inventariados ao longo do documento. Por fim, os resultados obtidos ao longo desta pesquisa permitiram selecionar os sítios com maior potencial interpretativo do parque, bem como identificar os tópicos, temas e objetivos interpretativos. Estes dados podem (e devem) ser utilizados nas futuras etapas do planejamento interpretativo de modo a contribuir com a divulgação da história geológica do parque para estudantes, visitante e moradores do entorno.

Palavras-chave: Avaliação, Geomorfossítio, Interpretação, Inventário, Patrimônio Geológico, Sítio geológico.

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LIST OF ABBREVIATIONS AND ACRONYMS

CAPES	Coordination for the Improvement of Higher Education Personnel
CNPq	National Council for Scientific and Technological
CPRM	Geological Service of Brazil
CRSB	Continental Rift of Southeast Brazil
DR	Degradation risk
EPA	Environmental protection area
GIS	Geographic Information System
GF	Geological framework
GLA	Geological approach
GMA	Geomorphological approach
HD	Hydrological
HG	Hydrogeological
ICMBio	Chico Mendes Institute for Biodiversity Conservation
IUCN	International Union for Conservation of Nature
IUGS	International Union of Geological Sciences
IAM	Itatiaia Alkaline Massif
INP	Itatiaia National Park
MP	Management plan
MT	Metamorphism
NSPA	National System of Protected Areas
PA	Protected area
PE	Paleoenvironmental
PEU	Potential educational use
PTU	Potential touristic use
PL	Plutonism
PNHR	Private natural heritage reserve
PT	Petrological
REE	Rare Earth Element
SD	Sedimentary
SDGs	Sustainable Development Goals
SF	Surface formations
SGI	Sites of geological interest
SV	Scientific value

SIGEP	Brazilian Commission of Geological and Palaeobiological Sites
TC	Tectonics
UNESCO	United Nations Educational, Scientific and Cultural Organization
VLL	Vale dos Lírios Lineament
WCPA	World Commission on Protected Areas

1. INTRODUCTION

1.1 Presentation

The first initiatives to protect geological features such as caves, erratic boulders or specific landforms began in the 17th century (Grube, 1994; Erikstad, 2008; Thomas and Warren, 2008; Reynard, 2012; Gray, 2013); however, such actions were isolated and lacked coordination between conservation and dissemination (Garcia et al., 2022).

From the 19th century onwards, many protected areas (PAs) were designated due to their geological and geomorphological features. For example, Yellowstone National Park in the United States (1872) and Banff National Park in Canada (1885) were created to protect geothermal phenomena, while Tongariro National Park in New Zealand (1887) was created to protect a volcanic landscape (Dingwall, 2000).

Since then, many international institutional initiatives dedicated to nature conservation have been created. The International Union for Nature Conservation (IUCN) stands out for its contribution to the systematic conservation and sustainable use of nature. However, although geoconservation has gained significant prominence in environmental issues since the 1980s (Matthews, 2014), the PA management remained focused mainly on biotic elements of nature and geological features were conserved indirectly due to biological, aesthetic or cultural values rather than for their scientific value (SV) (IUCN, 1994; Dingwall, 2000). This scenario started to change in the 2000s when IUCN created many initiatives to integrate geodiversity and geoheritage into PA management through a broader concept of nature (e.g. Crofts and Gordon, 2015; Díaz-Martínez et al., 2017; Woo, 2017, Crofts et al., 2020, 2021).

Geoconservation is the action taken to conserve and enhance geological, geomorphological and soil features and processes; sites and specimens, including associated promotional and awareness-raising activities; and sites threatened with loss or damage (Prosser, 2013). In the PA context, geoconservation aims to identify, conserve, enhance and promote geodiversity and geoheritage (Crofts et al., 2020). Such objectives are directly related to geoconservation strategies, including inventory, quantitative assessment, conservation, interpretation and promotion, and monitoring (Brilha 2005, 2016, 2018).

Studies focused on the first two geoconservation strategies (inventory and assessment) have been carried out worldwide, considering different scales, extents and frameworks (Reynard and Brilha, 2018). Although these steps are essential for the other ones, only recognising geological sites does not guarantee the protection to safeguard them for future generations (Garcia et al., 2022). Therefore, conservation should include the steps of legal protection, conserving and monitoring (Garcia et al., 2022); however, they are rarely completed and put into practice in research around the world (Prosser et al., 2018). Finally, promotion and interpretation aim to raise awareness of the geological records preserved in rocks and landforms through education and interpretative narrative (Crofts and Gordon, 2015); however, most studies that have developed these steps have focused on the development of interpretative media rather than proposing integrated interpretative planning on geoheritage.

Interpretation is a crucial part of geoconservation and one of the most effective tools for ensuring the conservation of geological sites both inside and outside of PAs (Carcavilla et al., 2007). It should not be carried out based on a didactic approach that provides only information, and with geologists using explanatory boards and leaflets (Crofts and Gordon, 2015), on the contrary, geological interpretation should prioritise communication with diverse audiences to promote scientific knowledge, appreciation and protection of geoheritage (Pacheco and Brilha, 2014).

Considering the need to convey awareness messages about the conservation of geological values and the lack of interpretative planning focused on the abiotic aspects of nature in Brazilian PAs, this work was carried out in the Itatiaia National Park - INP (Brazil) with the aim of contributing to methodological discussions about the need to integrate geoconservation in PAs and the role of environmental interpretation as a tool to introduce geoconservation and geoheritage in these areas.

1.2 Research Justifications and Objectives

The INP is a PA regulated by the National System of Protected Areas (NSPA) (Brasil, 2000) and one of the Brazilian National Parks with the highest number of visitors (ICMBio, 2019). It has tourist attractions recognised for their unique scenic beauty and outcrops and waterfalls that are visited for ecotourism, mountaineering, and hiking (ICMBio, 2013).

Although there is a potential to foster its geodiversity, and the promotion of environmental interpretation is one of the objectives of the NSPA (Brasil, 2000), the park still has no management strategies or environmental interpretation focused on the physical environment. Therefore, information about the formation of the outcrops and landscape remain unknown to the general public.

The lack of geoscientific content in educational and interpretative programmes is not exclusive to this PA. For many years nature conservation policies focused their efforts on biodiversity, while geodiversity was neglected. Some of the reasons for these differences could be explained by the idea that geological features are static and do not need special measures for their conservation, the low awareness within society about the importance of conserving key geological sites and the restricted number of researchers on geodiversity and geoconservation in PAs (Gray, 2013; Crofts et al., 2020, Mucivuna et al., 2022b).

Although abiotic protection of nature still lags behind biotic one, several international efforts have recently been made to integrate geodiversity and geoheritage into PA conservation policies (Crofts and Gordon 2015; Brilha 2018; Crofts 2018; Reynard and Brilha 2018; Crofts et al. 2020). However, many Brazilian PAs have not yet included geoconservation and geoheritage issues in their work programs. In order to change this scenario, the identification and assessment of the geoheritage of PAs and the development of interpretative themes on key geological sites are fundamental tools to raise public awareness about the importance of assessing, conserving and managing abiotic elements in a sustainable way.

Given the above facts, the motivation for this work arose from seeking answers to the following questions:

(i) Which geoheritage assessment method is the most suitable to be applied in areas with a strong correlation between geomorphological and other geological interests?

(ii) What is the current status of geoconservation research in Brazilian National Parks, and which criteria should be applied to evaluate geological sites with scientific, educational, touristic and additional values?

(iii) What are the INP's geological sites, and how can they be integrated into the management and conservation of the park?

(iv) How to use geoheritage inventory to select sites with interpretative potential, and what topics and themes can be covered to help visitors understand the park's geological history?

(v) How to elaborate a geoheritage interpretation plan in Brazilian National Parks?

To answer these questions, the main objective of this thesis is to develop geoconservation strategies in the INP to acquire the primary database to elaborate the interpretation plan of the geological sites. To achieve this general objective, the following specific goals were established:

(i) To review the literature to analyse how qualitative and quantitative assessment methods for geomorphological heritage have been developed and to compare the criteria applied in the studies analysed;

(ii) To make the inventory of geological sites in the INP considering their scientific, educational and touristic values;

(iii) To analyse how the abiotic elements of nature are described in the INP's management plan (MP) and to assess the possibilities of including the inventoried geological sites in its guidelines;

(iv) To review the distribution of geoconservation research in Brazilian National Parks and to discuss the importance of well-defined criteria for selecting geological sites concerning scientific, educational, tourism and additional values;

(v) To quantify and compare the results of the assessment of the SV of inventoried geosites with geomorphological and other geological interests applying general-purpose and special-purpose methods;

(vi) To quantitatively assess all inventoried geosites and geodiversity sites in terms of their SV, degradation risk (DR), potential educational use (PEU) and potential tourism use (PTU);

(vii) To make an interpretative inventory of the INP and to develop interpretative topics, themes and objectives of the selected sites;

(viii) To develop methodological guidelines for elaborating interpretation plans for geological sites in Brazilian National Parks and to apply them to the study area;

(ix) To produce fact sheets of the INP's geological sites with information on identification, characterisation, quantitative assessment, description, use, and management. (appendix)

1.3 Thesis Structure

This doctoral thesis is composed of nine chapters structured into four main parts:

(i) <u>Introductory section</u> (chapters 1 to 3). It presents an overview of the topic, describes the study area and details the methodological procedures applied to achieve the proposed objectives.

(ii) <u>Main body</u> (chapters 4 to 8). These chapters are presented in paper format in partnership with other researchers. Four papers were published in peer-reviewed journals and one is in preparation. Although these chapters have independent sections, such as introduction, methodological procedures, results and discussions, they are linked by the common theme of geoconservation.

(iii) Conclusion section (chapter 9). It deals with the discussion and concluding remarks on the data covered in the previous chapters.

(iv) Additional material section (appendix A). It contains the full description of the geological sites inventoried in the INP.

In order to maintain equivalence to the number of figures and tables published in the papers, they have been numbered separately in each chapter rather than sequentially.

The introductory chapter concerns the main issues related to the theme, research justifications and objectives, and the structure of this work. The second chapter describes the location, historical and environmental aspects, and the geological and geomorphological settings of the area. Finally, the third chapter describes the methodological procedures applied to obtain and treat the data.

The fourth chapter contains the paper "Geomorphosites assessment methods: comparative analysis and typology" published in Geoheritage in collaboration with Emmanuel Reynard and Maria da Glória Motta Garcia (https://doi.org/10.1007/s12371-019-00394-x). The objective of the paper was to analyse how the methods of qualitative and quantitative evaluation of geomorphosites have developed over the years, comparing the criteria used in the studies analysed, and to select the most suitable method to be applied in the study area.

The fifth chapter includes the manuscript "Integrating geoheritage into the management of protected areas: a case study of the Itatiaia National Park, Brazil" published in International Journal of Geoheritage and Parks in collaboration with Maria da Glória Motta Garcia, Emmanuel Reynard and Pedro Augusto da Silva Rosa (https://doi.org/10.1016/j.ijgeop.2022.04.004). The paper highlighted the geology and geomorphology of the study area and their relation with the management by addressing the data of the inventory of geological sites of the INP, discussing and proposing the integration of them into the INP's management plan.

Given the importance of including geoheritage in nature conservation policies, it is necessary to establish the criteria for assessing geological sites in PAs. Based on this, the paper "Criteria for assessing geological sites in National Parks: a study in the Itatiaia National Park, Brazil" published in Geoheritage in collaboration with Maria da Glória Motta Garcia and Emmanuel Reynard is presented in the sixth chapter (https://doi.org/10.1007/s12371-021-00633-0). The manuscript dealt with the distribution of geoconservation research in Brazilian National Parks and discussed the importance of applying well-defined criteria in the inventory of geological sites, illustrating those used in the INP.

The seventh chapter includes the paper “Comparing quantitative methods on the evaluation of scientific value in geosites: analysis from the Itatiaia National Park, Brazil” published in Geomorphology in collaboration with Maria da Glória Motta Garcia and Emmanuel Reynard (https://doi.org/10.1016/j.geomorph.2021.107988). The manuscript discussed the applicability of general- and special-purpose methods in assessing geosites with geomorphological and other geological interests. The application of some methods reviewed in the fourth chapter allowed a discussion of whether the results revealed significant differences that justify using specific methods for geomorphosites.

Following the qualitative and quantitative assessment of the SV of geological sites, the evaluation of the interpretative potential of geoheritage is discussed in the eighth chapter. The chapter “Theory and application of interpretation” discusses the interpretation concepts and methods as a means to have subsidies to apply them in practice. The first part of the chapter presented the theoretical basis of interpretation and the second applied basic elements of interpretation in the paper entitled “Methodological proposal for the interpretative inventory of geological sites: example from the Itatiaia National Park, Brazil” (in preparation). The manuscript addressed how to select interpretative geological sites from the geoheritage inventory based on the scores of the quantitative assessment. Moreover, it provided the first findings on interpretative planning by selecting and developing the sites' interpretative topics, themes, and objectives.

The final chapter integrates the data presented throughout the papers, discusses the results and perspectives on the main findings of this work, and describes the methodological guidelines to prepare interpretation plans for geological sites in Brazilian National Parks.

The appendix contains a series of fact sheets with information on identification, characterisation, quantitative assessment, description, use and management of each geological site of the INP.

2. CHARACTERISATION OF THE STUDY AREA

The INP is located in the Mantiqueira Mountain Range, on the boundary between the states of Rio de Janeiro and Minas Gerais. It covers an area of approximately 280 km² in the cities of Itatiaia and Resende, in Rio de Janeiro, and Bocaina de Minas and Itamonte, in Minas Gerais. The INP is part of the NSPA (Federal Law 9,985/2000) (Brasil, 2000), which is responsible for creating, managing and consolidating these areas in Brazil. They are classified into two groups and subdivided into several categories: (i) strictly protected areas, in which only the indirect use of natural resources is permitted (ecological station, biological reserve, national park, natural monument, and wildlife refuge), and (ii) sustainable-use protected areas, which allow sustainable use of part of its resources (environmental protection area, area of relevant ecological interest, national forest, extractive reserve, fauna reserve, sustainable development reserve, and private natural heritage reserve).

Four strictly PAs border the park area and its buffer zone: the state parks of Serra do Papagaio and Serra Pelada; and the municipal natural parks of Rio Pombo and Cachoeira da Fumaça e Jacuba. Ten sustainable-use protected areas surround the INP, being three of which classified as environmental protection areas (EPA) (Mantiqueira, Serrinha do Alambari and Penedo) and seven as private natural heritage reserves (PNHR) (Mitra do Bispo, Ave Lavrinha, Santo Antônio, Agulhas Negras, Jardim de Mukunda, Chalé Club Alambary and Dois Peões) (ICMBio, 2013).

Due to the large territorial extent of the park, its area has been segmented into three regions to facilitate management (Fig. 2.1): (i) lower region, which includes the tributaries of the Paraíba do Sul river basin, and not includes the plateau area or the Preto river basin; (ii) upper region, which comprises the plateau and the water catchments of the northern slope, and (iii) Visconde de Mauá, which comprises the Preto river’s watershed, except the high plateau area (Tomzhinski, 2012).

The principal access to the INP from São Paulo or Rio de Janeiro is the Presidente Dutra Highway (BR-116). The access to the lower region is done through the city of Itatiaia (exit 318), following 5.5 km along BR-485 through to the main entrance. The upper region can also be accessed by Presidente Dutra Highway (exit 330A), following 26 km along BR-354 to Garganta do Registro, and then 14 km in the unpaved road (BR-485) to Marcão’s station. The access to Visconde de Mauá is made through the city of Itatiaia (exit 311), following 30 km along RJ-163, and then to Maromba Village by RJ-151.

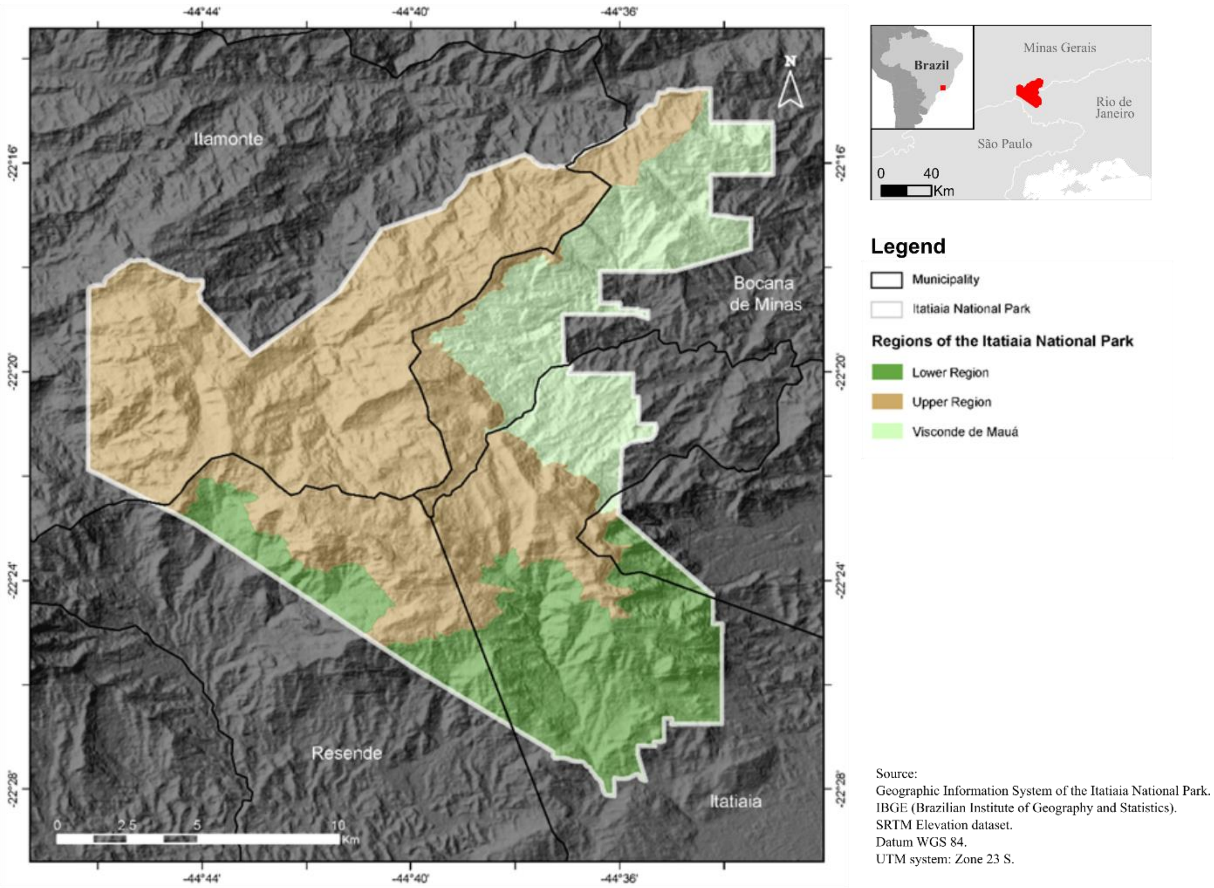

Fig. 2.1 Location map and administrative regions of the Itatiaia National Park.

2.1 Historical Aspects

Puri Indians were the first natives who inhabited the region where the INP is currently located. The name Itatiaia has its origins from the Tupi language, being a hybridisation of the words *Ita* = stone and *tiããi* = tip, meaning the "place of pointed stones" (Teixeira and Linsker, 2007), inspired by the local geodiversity, characterised by very sharp peaks in alkaline rocks. In the sixteenth century, indigenous enslaved people who lived in the region were captured by the *Bandeirantes* (leaders of expeditions into the interior of Brazil in search of mineral wealth or indigenous people to enslave) and, in the seventeenth century, the region became a route to the countryside due to the discovery of gold in the state of Minas Gerais. After the decline of gold exploration, farmers from the Paraíba do Sul River Valley region invested in coffee production using slave labour of Africans, and a significant portion of the Atlantic Forest was destroyed. From 1890, the coffee farms fell into decline, and farmers replaced coffee crops for grazing animals to produce milk (Drummond, 1997; Santos and Zikan, 2000; Teixeira and Linsker, 2007; ICMBio, 2013).

During the nineteenth century, several researchers such as Auguste de Saint-Hilaire (1816-1822), Franklin Massena (1856), Auguste Glaziou (1872), Derby (1889) and E. Ule (1898) visited the region due to scientific interest in several fields of knowledge, such as Biology, Ecology, Geology and Geomorphology (Santos and Zikan, 2000). Glaziou, accompanied by Princess Izabel, was the first botanist to visit the upper region in 1872. He collected several new plant species and climbed the Itatiaia Massif on this occasion. Baker, Fée and other specialists were in charge of describing these plants (Brade, 1956). In 1894, Ule collected data for the first scientific publication about the fauna of the Itatiaia Plateau (Pinto, 1950).

In the late nineteenth century, the engineer André Rebouças visited the region and recommended establishing a natural PA, influenced by the creation of the Yellowstone National Park in the United States (ICMBio, 2013).

In 1908, the federal government acquired 48 km² of a farmland from Irineu Evangelista de Souza's son for the establishment of two colonial centres for Europeans. However, the project was not successful. In 1913, the Swiss naturalist Joseph Hubmayer praised the region's importance and proposed the creation of a national park. As a result, the Itatiaia Forest Reserve was founded on the lands previously occupied by the colonial centre in the following year. In 1929, the Itatiaia Biological Station, subordinated to the Botanical Garden of the state of Rio de Janeiro, was created (Drummond, 1997; Santos and Zikan, 2000; Teixeira and Linsker, 2007; ICMBio, 2013).

The publication of the Forest Code of 1934 (Federal Decree 23,793/1934) (Brasil, 1934), the first legislation to describe the categories of "national park" and "national forest", stimulated the creation of the INP (Federal Decree 1,713/37) as the first Brazilian PA. The park initially covered an area of 119.43 km² (Brasil, 1937), and in 1982 its boundaries were extended to approximately 280 km² (Federal Decree 87,586/82) (Brasil, 1982).

In 1982, its first MP was published (IBDF, 1982), but this version only included the initial boundaries. Other planning documents were developed in order to fill the gap about the expanded area, such as the Emergency Action Plan, in 1994 and the Public Use Plan, in 2001 (Gomes, 2020). The new MP was updated in 2013 (ICMBio, 2013) to replace previous documents, adjust to the NSPA guidelines and the new boundaries, and offer an integrated vision of the park's management.

Since the 2000s, INP has been regulated by the NSPA and administered by the Chico Mendes Institute for Biodiversity Conservation (ICMBio) (Brasil, 2000; ICMBio, 2013).

2.1.1 Development of the geological knowledge of the study area

The first research related to Geology in the region was performed by Silva (1876), who interpreted the area as an igneous terrain developed by volcanic processes. Later, Silva (1882) published an overview of the geology of the Southern region of the state of Minas Gerais and emphasised the aspects associated with the occurrence of a granitic body in the area. The work of Lasaulx (1885) is worth noting for having been the first to describe the existence of alkaline rocks in Brazil by means of the petrographic characterisation of syenites. Derby (1887) described the rocks in the region as foyaite with granitic aspect, phonolite and other nepheline rocks. In 1902, K. H. Dusen developed an integrated study between geological characteristics and vegetation cover (Santos and Zikan, 2000).

By means of geologic and petrographic studies, Lamego (1936) discussed the origin of the Itatiaia Massif, disagreeing with Derby's idea of volcanism. In his published geological map, the massif occupied an area of 1,224 km² and was considered, at that time, the second-largest alkaline province in the world. However, Ab'Saber and Bernardes (1958) and Ribeiro Filho and Penalva (1965) pointed out that the mapping of this alkaline body had been overestimated by Lamego (1936) because the author had not observed the discontinuities between Itatiaia and Passa Quatro alkaline massifs and other surrounding bodies.

According to Freitas (1951), the intrusion of the alkaline rocks was related to the tectonic events responsible for the formation of the Mantiqueira and Serra do Mar mountain ranges, suggesting a plutonic-volcanic origin for the Itatiaia Massif.

Mau and Coutinho (1959) were the first to detect radioactive minerals of thorium enriched with Rare Earth Elements (REE) in a carbonatite vein in the region.

Ribeiro Filho and Penalva (1965), Penalva (1967) and Ribeiro Filho (1967) conducted detailed geological surveys on the Itatiaia Massif and described four rock associations: (i) nepheline syenite and syenite, (ii) quartz syenite, (iii) magmatic breccia and (iv) granite. According to Ribeiro Filho (1967), these rocks were aged between 64.2 and 64.7 Ma. Penalva (1962) stated that magmatic breccia bodies show a fluid texture with a confused and disorganised orientation. On the other hand, Pires et al. (2014) observed the occurrence of fluorocarbonates and rare minerals associated with hydrothermal activity in breccia bodies, suggesting an origin from the interaction between low-temperature alkaline fluids.

The isotopic data published by Brotzu et al. (1997) showed that crustal contamination was notable in the petrogenesis of the silica-oversaturated rocks, while evidence indicating a common parental magma for silica-oversaturated and silica-undersaturated was inconclusive.

Enrich et al. (2005), and Brotzu et al. (2005) reviewed the preceding data in an analysis of petrogenetic models, comparing with the Passa Quatro and São Sebastião alkaline complexes.

Melluso et al. (2017) published new mineral chemical data related to the number of accessory phases with REE distribution in some lithologies of the Itatiaia Alkaline Complex.

Rosa (2017) and Rosa and Ruberti (2018) published recent data and geological mapping of the Itatiaia Alkaline Massif (IAM). They suggest that the massif evolved from a migratory centre, forming ring structures and successive moon-shaped intrusions from SE to NW. These authors segmented the massif into three magmatic events, represented by different sectors according to their particular lithological and geomorphological features and presented U-Pb dating age ranging between 71.3 and 67.5 Ma. The authors also identified 21 units representing successive intrusive bodies of feldspathoid-bearing and quartz-bearing syenites, porphyritic to breccioid trachytes, granite, monzonite, gabbro and trachybasalt. As stated by the authors, the tectonic setting of the massif is manifested by the drainage system, the lineaments and faults that control the landforms, as well as the notable quantity of conjugate shear joins. Three preferential directions of lineaments were observed in the IAM: (i) NW-SE, corresponding to the elongation of the massif, the Vale dos Lírios Lineament (VLL) being the principal example; (ii) ENE-WSW, following the basement and Continental Rift of Southeast Brazil (CRSB) arrangement; and (iii) W-E, less marked and more noticeable in the central sector.

2.1.2 Development of the geomorphological knowledge of the study area

In the study area, research into geomorphology has increased since the 1940s, with the spread of theories about relief formation associated with glacial origin.

De Martonne (1943, 1944) was one of the pioneers of these ideas. He presented evidence about the occurrence of glaciers that would have been responsible for the production of the possible steps in the suspended valleys and of glacial cirques in the region. Following his hypothesis, Ruellan (1943) reported glacial cirques and suspended valleys and discussed that only the action of snow and ice by accumulation and erosion would be able to shape this relief. Domingues (1952) published new data about the geology of the massif; however, he did not introduce any changes in the paradigm of glaciation in the area. Rich (1953) relied on glacial U-shaped valleys and the dispersion of boulders to spread the Pleistocene glaciation theory. Although he had not found any evidence of glacial striae or moraine deposits, the author stated that these features could have been erased due to exposure to the current climate, while moraines could have been hidden in inaccessible or forested areas.

Ödman (1955) was one of the first researchers to present arguments against the hypothesis of Pleistocene glaciation in the area. Based on the fluting formation, the author stated that these features could only result from exposure of the rocks to chemical weathering.

Ab'Saber and Bernardes (1958) described the landforms as a result of glacial processes remodelled by weathering and fluvial and rainfall erosion. In the 1960s, some authors once again supported the Pleistocene glaciation. By studying the Preto river basin deposits, Ebert (1960) described them as being of glacial origin. He also assumed that the landforms of the region would have been resulted from the penultimate Pleistocene glaciation and not from the last one, as assumed by most of the authors.

Since Freitas's (1951) and Teixeira's (1961) works, the landforms have been investigated considering the regional tectonics. However, according to Penalva (1967), the structural components are the main reason for the morphological aspects, particularly due to the intense joints that affect the upper portion of the massif.

Teixeira (1961) suggested the existence of a ring-dyke in the central zone of the plateau composed of tinguaite. On the other hand, Penalva (1967) interpreted the ring structure as a consequence of the subsidence of the top of the intrusion by contemporary circular faults. However, Rosa and Ruberti (2018) found no testimony of caldera subsidence and concluded that sin-plutonic trachytes support the external ring. This structure stands out in the relief and has a diameter of eight by nine kilometres in NW-SE and NE-SW directions. It extends from Serra Negra Hill (NW) to Maromba and Pedra Cabeça de Leão Hills (E) and, after a gap, to the south in the region of Massena shelter and Urubu Hill (Teixeira, 1961). The southern face is depressed, being interpreted by Freitas (1951) as a result of the formation of the CRSB. Teixeira (1961) stressed that the establishment of water-gaps in the ring structure was conducted by the river erosion, Maromba and Aiuruoca rivers being the most prominent.

Teixeira (1961) emphasised that the intrusion of alkaline rocks has caused many changes in the drainage patterns of the region. Initially, a radial pattern formed by rivers that diverge from the central part to NE (Maromba), SE (Campo Belo), SW (Itatiaia) and NW (Aiuruoca) was generated (Ab'Saber and Bernardes, 1958). Later, the establishment of the CRSB produced adjustments in the drainage models, like a switch in the pattern of the main tributaries of the Preto and Aiuruoca rivers, with deposition of clay and peat sediments (Modenesi and Melhem, 1986). The Campo Belo river tributaries, on the other hand, adjusted to radial structures. The rectangular drainage pattern is displayed in the NW of the INP, close to the contact between the alkaline rocks and the basement (Penalva, 1967).

Penalva (1967) stated that the development of CRSB also contributed to the arrangement of Couto-Prateleiras through a fault scarp and the Lírios valley, formed by a fracture in the N60-70W.

De Martonne (1943) named the depressed area, near Agulhas Negras, as a glacial cirque. On the other hand, Teixeira (1961) interpreted it as a local basal level plain, surrounded by the ring structure and filled with peat bogs.

Modenesi (1992) pointed out that the term plateau does not accurately represent the relief, which is marked by hills with steep slopes and rocky peaks that contrast with flat sectors occupied by peaty plains. The plateau morphology is characterised by landforms composed of joints in alkaline rocks associated with erosive and weathering processes. These processes are responsible for the development of boulders fields, fluted and pitted erosion, and others (Modenesi-Gauttieri and Toledo, 1996).

Modenesi (1992) and Modenesi-Gauttieri and Toledo (1996) interpreted the concentration of boulders in the first order valleys as a joint action of rockfall and frost weathering, which are particularly useful in releasing thick debris.

According to Modenesi (1992), two generations of colluvium deposits occur across the Itatiaia plateau. The oldest, from the late Pleistocene, is less than one metre thick and deposited on the weathered rock, being massive and compact, without structures and with rock blocks with varying degrees of alteration. The most recent colluviums, from the Holocene, are up to 240-cm high and have fewer coarse sediments. These deposits were formed at the lowest level and spread over the peat deposits of the floodplains, covering the first-generation colluviums. The differences between these generations suggest distinct processes in their evolutions. The first generation would have been originated by mudflow in humid and perhaps lesser cold climates. In contrast, the second one would have been formed through mudflow or slower processes, capable of mobilising and depositing weathered materials without damaging the superficial deposits.

2.2 Environmental Aspects

The INP's vegetation is characterised by the Atlantic Forest biome. It thus has prime importance considering that it is one of the 25 biodiversity hotspots in the world (Myers et al., 2000). Furthermore, this biome is also recognised as Biosphere Reserve by UNESCO and as natural heritage according to article 225 of the Brazilian Constitution (Brasil, 1988).

Among the priority zones for biodiversity conservation, the INP is considered an area of exceptionally high importance (MMA, 2004). Its flora is categorised as (i) Vegetation

Refuge, above 2,000 m (Ribeiro and Medina, 2002); (ii) Dense High Ombrophilous Montane Forest, above 1,500 m; (iii) Dense Ombrophilous Montane Forest, under 1,500 m; (iv) Mixed Ombrophilous Montane Forest, around 1,200 m, and (v) Semideciduos Montane Forest, under 500 m (ICMBio, 2013). This vegetation has 1,779 inventoried species, including the endemic species *Ferneseea itatiaiae*, *Piper itatiaianum*, *Itatiaia cleistopetala* and *Lycopodium jussiaei* (IBDF, 1982; ICMBio, 2013). The fauna is also quite diverse among arthropods: there are more than 50,000 species of insects, at least 90 of them are exclusive to the upper region (IBAMA, 1994). More than 60 species of amphibians are found, the most popular one being the *Melanophryniscus moreirae*, the symbol of the PA. In addition, about 115 species of mammals and 320 species of birds have been identified (ICMBio, 2013).

In hydrographic terms, the area is drained by the Grande and Paraíba do Sul river basins, the IAM being the water divisor of these regional basins. The sub-basins of Capivari, Aiuruoca and Grande rivers flow to Grande River's watershed, which converges into the Paraná basin and then flows to the Atlantic Ocean. The sub-basins of Salto, Água Branca, Cazunga, Campo Belo, Bonito, Pedras, Alambari, Pirapetinga and Preto rivers flow into the Paraíba do Sul river basin (ICMBIO, 2013).

According to the Köppen-Geiger climate classification, the park has two climates: (i) Cwb (mesothermic, with mild summer and rainy season in summer); and (ii) Cpb (mesothermic, with mild summer without dry season), with rainfall concentrated in summer, with an average precipitation of 2,600 mm in the "upper region" and 1,800 mm in the "lower region". The average temperature of INP is 11.4º C, January being the warmest month (13.6º C) and July, the coldest (8.2º C). From May to October, low temperatures often form frosts (IBDF, 1982; Tomzhinski, 2012).

In the INP, four classes of soils were mapped: (i) dystric cambisol (humic); (ii) dystric litholic neosols; (iii) red-yellow dystric argosols; and (iv) latosols (ICMBIO, 2013).

2.3 Geological Setting

The geological setting of the study area is subdivided into three main compartments: (i) igneous and metamorphic rocks of the Proterozoic age, (ii) syenitic rocks of Meso-Cenozoic age and (iii) sedimentary deposits of Quaternary age that were deposited over both compartments.

2.3.1 Igneous and metamorphic Proterozoic rocks

The area is located in the interference zone between the Brasília and Ribeira Orogens (Fig. 2.2), in the Mantiqueira Province (Almeida et al., 1977, 1981), developed during the Brasiliano-Pan African Orogeny that resulted in the amalgamation of the Western Gondwana Paleocontinent (Heilbron et al., 2004). The province spreads over an area of 700,000 km² and comprises the Araçuaí, Ribeira, Dom Feliciano and São Gabriel Orogens, and the zone of interference between the Brasília and Ribeira Orogens (Heilbron et al., 2004).

According to Heilbron et al. (2004), the southern segment of the Brasília Orogen was formed due to the collision between the S-SW edge of the São Francisco-Congo paleoplate, and the plate located at W-SW, during the Brasiliano-Pan African cycle. This collision, which climax occurred in 630-625 Ma (Collision I), is related to an NNW-SSE structural trend and nappes with tectonic stacking in the E-ESE direction, towards the São Francisco craton. These nappes are grouped in the bottom, which shows paleogeographic relation to the São Francisco craton, and in the top, interpreted as remnants of a cordilleran arc.

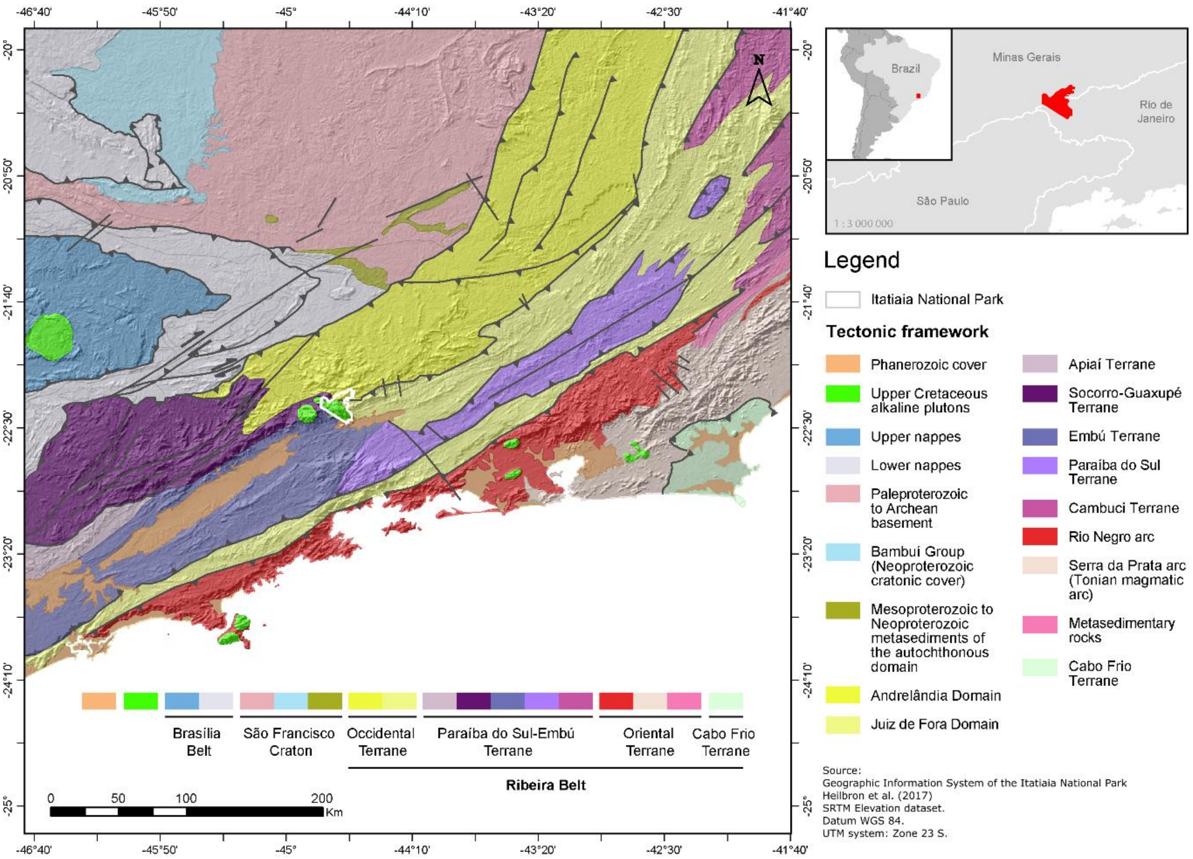

Fig. 2.2 Tectonic framework of the Ribeira Belt and southern Brasília Belt (Heilbron et al., 2017), highlighting the Itatiaia National Park.

The Ribeira Orogen was developed due to the collision between the São Francisco craton, other microplates and terranes and the West Congo craton in 580 Ma (Collision II). This collision produced a NE-SW structural trend due to docking stacking of different terranes from E to W-NW and reaching the newly structured Brasilia Orogen, creating the interference zone among these orogens in the south/southeast of the state of Minas Gerais (Heilbron et al., 2004).

The Brazilian orogeny produced a large volume of pre-, syn- and post-tectonic calcium-alkaline granitic magmatism, with granitic bodies being intruded into basement rocks (Trouw et al., 2003).

In the study area, igneous and metamorphic rocks of Proterozoic age are represented by (Fig. 2.3):

(i) The undifferentiated metagranitoid unit represents the Paleoproterozoic basement (Trouw et al., 2003). According to Junho (1995), the mineralogical composition includes quartz, plagioclase, microcline, biotite and muscovite.

(ii) The gneiss of the Andrelândia Megasequence stands for the Neoproterozoic basement. It was mapped as banded biotite gneiss (Trouw et al., 2003) and garnet-biotite gneiss units (Heilbron et al., 2016). These authors pointed out that the mineralogical composition includes plagioclase, biotite, muscovite, epidote, microcline and garnet, as well as biotite-rich compositional bands.

(iii) The Maromba granitic gneiss unit is a Neoproterozoic, NE-SW-oriented granitic body (Almeida, 1996). The K-feldspar megacrysts show igneous flow orientation, accentuated by the tectonic deformation that generated a gneiss texture in the matrix. The Pb-Pb zircon dating determined the crystallisation age in ca. 590 ±2 Ma (Mendes et al., 2003).

(iv) The Capivara leucogranite and associated diatexite unit is either embedded in the migmatitic orthogneisses of the basement or intruded in the successions of Andrelândia Megasequence (Almeida, 1996). It occurs as a NE-SW lenticular intrusion, composed of quartz, K-feldspar, plagioclase, muscovite and biotite (Trouw et al., 2003). According to Valladares et al. (2000), the Capivara leucogranite was formed during the second syn-collisional stage of the Ribeira Orogen. The U-Pb dating determined the age between 565 and 540 Ma. On the other hand, Pereira et al. (2002) applied the Pb-Pb method in zircon and determined the age of ca. 605 ± 11 Ma, conflicting with the structural geology of the region.

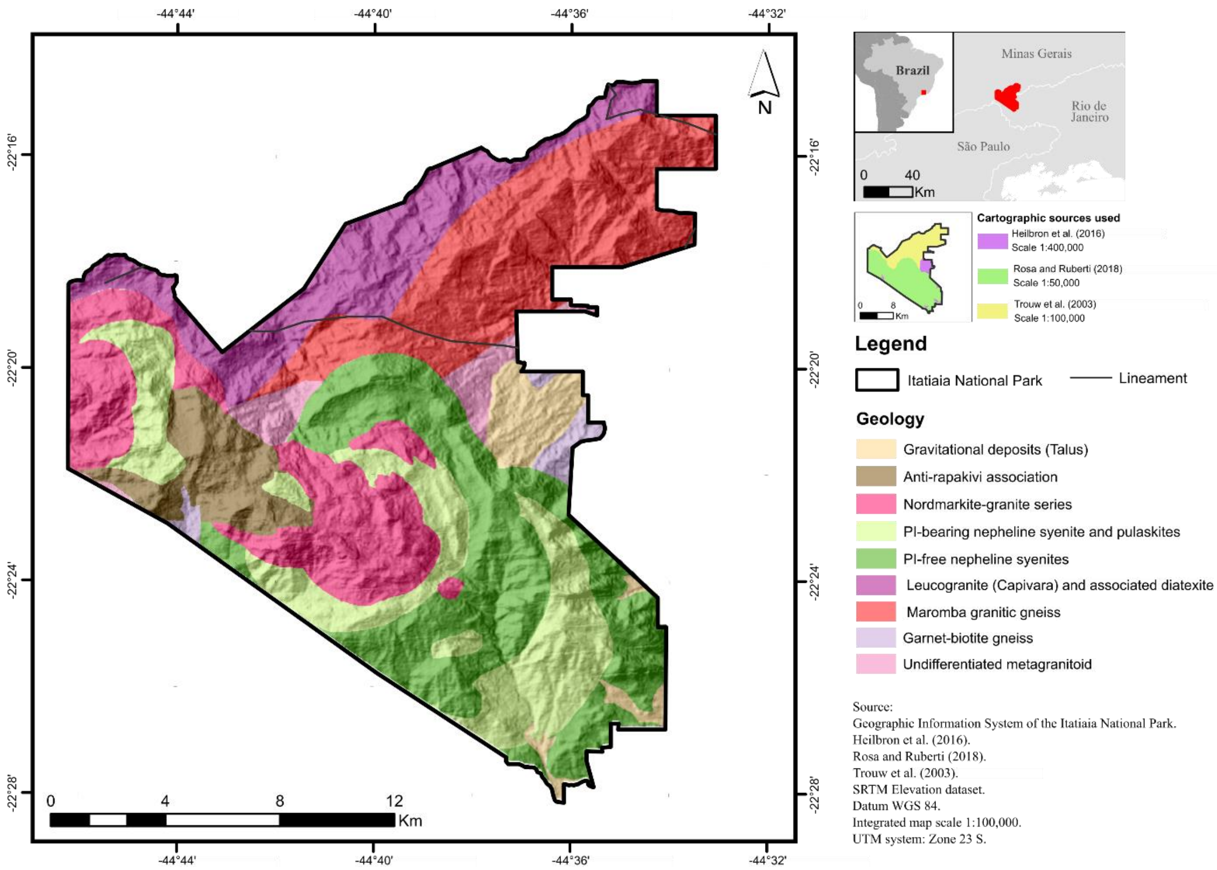

Fig. 2.3 Simplified geological map of the Itatiaia National Park.

2.3.2 Meso-Cenozoic evolution

In the Upper Jurassic, the extensional tectonic resulting from the opening of the South Atlantic Ocean allowed the reactivation of old faults and caused an intense tholeiitic basaltic magmatism in the Paraná Basin, with peak magmatism at ca. 132 Ma (Marques and Ernesto, 2004), as well as dykes swarms along the coastline. These processes caused the reactivation of arcs, flexures and failure zones in the edges of this basin. In this tectonic environment, the alkaline volcanism occurred around the Paraná basin and on adjacent coasts to the Santos basin (Almeida, 1971, 1983; Riccomini et al., 2005).

During the Upper Cretaceous, the development of an epirogenetic mega plateau, responsible for the evolution of the Japi surface, was interpreted as a result of Cenozoic tectonic deformation of a tafrogenic nature, causing the formation of grabens and the mountain ranges of the Serra do Mar and Mantiqueira (Almeida and Carneiro, 1998).

In the Meso-Cenozoic, intense alkaline magmatism occurred in the region and elsewhere on the South American Platform. Most of the resulting alkaline bodies are distributed along the Cabo Frio Magmatic Lineament, associated with a fracture zone in the WNW-ESE trending, including 26 alkaline intrusive centres, with ages ranging between 84 and 49 Ma

(Almeida, 1991; Riccomini et al., 2005). At least two phases of reactivation and associated magmatism, in the Neocretaceous to Paleocene and during the Eocene, were established (Riccomini et al., 2004). The Itatiaia and Passa Quatro massifs are examples of these alkaline intrusive bodies.

During part of the Cenozoic (58-20Ma), the uplifted areas have become isostatically unstable, and the continental crust broke and collapsed into a series of grabens, forming rifts parallel to the coast (Zalán and Oliveira, 2005). The CRSB's main axis orientation is influenced by the shear zones parallel to the coastline, which were reactivated as normal faults during the Paleogene and as strike-slip faults in the Neogene (Riccomini 1989; Riccomini et al. 2004).

In the study area, Meso-Cenozoic syenitic rocks are represented by the IAM (e.g., Ribeiro Filho, 1967; Penalva, 1967; Enrich et al., 2005; Rosa, 2017; Rosa and Ruberti, 2018). Rosa and Ruberti (2018) divided it into three sectors representing different magmatic events.

In the S-SE sector, varieties of nepheline syenite rocks occur, indicating a U-Pb dating age at 71.26 Ma (Rosa, 2017). Most of these lithological units are emplaced into the CRSB; however, they were not strongly affected by the evolution of the rift system.

The S-C sector forms a moon-shaped ring, with an external circular ridge where the rocks vary from nepheline syenite to quartz syenite, including trachyte and a small granite body. The U-Pb dating determined age ranging between 69.65 and 68.65 Ma (Rosa, 2017).

In the S-NW sector occurs nepheline syenites, quartz-bearing syenites, trachytes, monzonite, gabbro and trachybasalt. The U-Pb dating determined age at 67.5 Ma (Rosa, 2017). The lithological relations are the least precise, and an interplay between the unsaturated and supersaturated intrusions in silica was observed.

These rocks were divided into petrographical series (Fig. 2.3): (i) plagioclase-free nepheline syenites, characterised by strong silica-undersaturation; (ii) plagioclase-bearing nepheline syenites and pulaskite, displaying weak silica-undersaturation and increased mafic content; (iii) nordmarkite-granite series, showing progressive variations of quartz content in alkali feldspar quartz syenites and granite; (iv) anti-rapakivi association, distinguished by anti-rapakivi porphyritic to glomeroporphyritic texture; (v) basic rocks, with an unclear association to the syenites (Rosa and Ruberti, 2018).

2.3.3 Sedimentary deposits

Talus deposits were accumulated during the Quaternary period (Fig. 2.3). They are made up of angular rocks debris of any size or shape at the base of steep rock slopes. The accumulated mass of broken loose rocks is formed by falling, rolling or sliding (Trouw et al., 2003; Heilbron et al., 2016). Modenesi and Toledo (1993) stress that these deposits keep records of intense erosion and deposition periods.

Alluvial deposits accumulated during the Quaternary period are composed of mud and peat sediments, coarser grains and centimetre clasts, deposited at the bottom of valleys and depressive areas (Trouw et al., 2003; Rosa and Ruberti, 2018).

2.4 Geomorphological Setting

The regional geomorphological context is linked to the uplift resulting from the tafrogenesis that culminated in the horsts of the Serra do Mar and Serra da Mantiqueira and the graben of Paraíba do Sul (Marques Neto et al., 2015). The development of the CRSB generated a peculiar double escarpment in the continental margin (Hiruma et al., 2010), being this landform one of the most outstanding orographic features on the Atlantic edge of the South American continent (Almeida and Carneiro, 1998).

The evolution of these large relief compartments was conditioned mainly by the Cenozoic tectonic events (Hasui et al., 1982; Modenesi-Gauttieri et al., 2002). According to IBGE (2009), the study area is part of the morphostructural domain of Neoproterozoic Mobile Belts, characterised by plateaus, mountainous alignments and inter-plateau depressions formed in folded and faulted terrains. In the INP, this morphostructural domain is represented by the geomorphological regions of (i) Paraíba do Sul River Depression and (ii) Mantiqueira / Itatiaia Mountain Ranges (IBGE, 2019) (Fig. 2.4).

2.4.1 Paraíba do Sul River Depression

In the study area, this geomorphological region is exemplified by the Middle Paraíba do Sul Depression unit, which is described as a depressed region in relation to the surrounding plateaus, most of which at an altitude between 500 and 600 m. Its genesis is associated with the readjustment of regional tectonic events that were later affected by successive erosive and depositional phases, being elongated and parallel to each other. Such events were responsible for modelling the landforms such as hills, ridges, erosive scarps, and valleys adjusted to the faults and fractures in the NE-SW orientation (RADAMBRASIL, 1983).

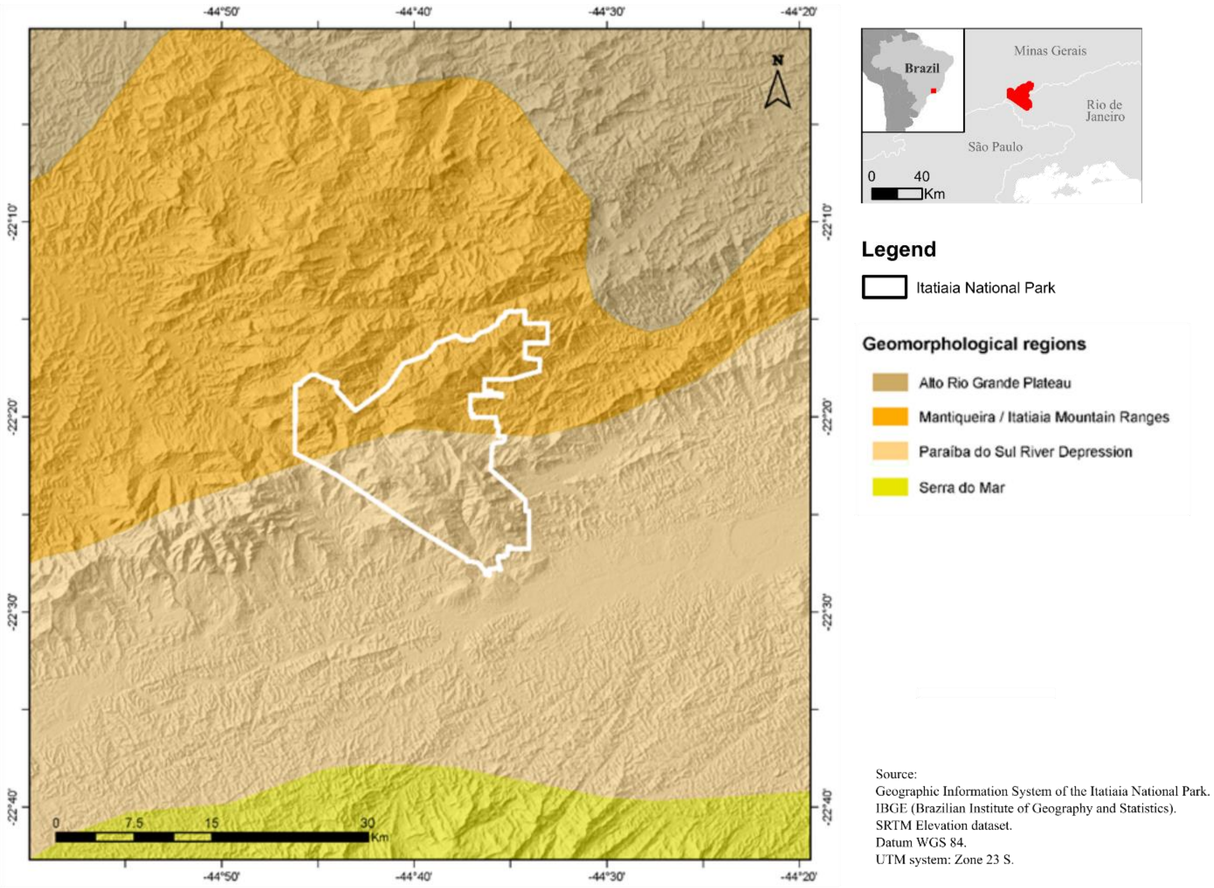

Fig. 2.4 Map of geomorphological regions of the Itatiaia National Park.

2.4.2 Mantiqueira / Itatiaia Mountain Ranges

In the INP, this geomorphological region is illustrated by the Itatiaia Plateau unit, which had its genesis influenced by tectonic activities, uplift and failure of blocks in the NE-SW direction. It is subdivided into (i) Western compartment, which has a relief marked by differential dissection, structural valleys, scarps, symmetrical ridges of long extension and edges of circular structures, and (ii) Eastern compartment, characterised by frontal escarpments in the ENE-WSW orientation, resulting from shear zones (RADAMBRASIL, 1983).

The INP relief has its genesis linked to structural processes, such as (i) landforms of dissection including residual features; (ii) landforms related to tectonic features, and (iii) landforms of undifferentiated genesis (IBGE, 2009).

(i) Landforms of dissection have their genesis associated with structural control, and ridges and structural valleys identify them. The hills may be segmented into (i) symmetric ridge, corresponding to elongated residual landforms, isolated and with steep slopes; and (ii) asymmetric ridge (hogback), indicative of elongated residual relief, which slopes are more than 30° sloping.

(ii) Landforms related to tectonic features are symbolised by (i) fault-adjusted scarp, resulting from headward erosion and accompanied by a fault zone and, (ii) structural valley, corresponding to the valley-shaped incision created by failure, fracture or joint-related to brittle tectonics.

(iii) Landforms of undifferentiated genesis are characterised by the erosive scarp, described as a steep slope or individualised shape resulting from erosive processes with the retreat of hills due to climatic variations.

Besides the geomorphological features described, the IAM stand out in the landscape as one of the highest compartments of the Brazilian Platform (Marques Neto, 2016) and for featuring 12 of the 25 highest peaks in Brazil (Table 2.1), all above 2,400 meters of altitude (the INP ranges between 540 m and 2790.9 m) (IBGE, 2016). The Agulhas Negras peak stands out as the highest peak in the INP and the state of Rio de Janeiro. It is also ranked as the fifth highest peak in Brazil.

Table 2.1 Itatiaia National Park's highest peaks and its rankings in relation to Brazil (IBGE, 2016).

Ranking	Toponym	Height (m)	Latitude	Longitude
5º	Agulhas Negras Peak	2 790,9	- 22°22'49"	- 44°39'42"
8º	Pedra do Couto Hill	2 687,0	- 22°23'07"	- 44°41'34"
9º	Pedra do Sino Hill	2 670,0	- 22°22'13"	- 44°39'42"
11º	Pedra do Altar Hill	2 663,0	- 22°22'27"	- 44°40'27"
15º	Maromba Hill	2 613,0	- 22°22'22"	- 44°37'35"
16º	Massena Hill	2 603,0	- 22°22'13"	- 44°42'01"
19º	Pedra Furada Hill	2 589,0	- 22°21'28"	- 44°43'25"
21º	Serra Negra Hill	2 572,0	- 22°20'07"	- 44°39'53"
22º	Prateleiras Hill	2 536,0	- 22°23'58"	- 44°36'59"
23º	Pedra Cabeça de Leão Hill	2 476,0	- 22°23'13"	- 44°36'59"
24º	Pedra Cabeça de Leoa Hill	2 469,0	- 22°23'10"	- 44°37'00"
25º	Pedra Assentada Hill	2 451,0	- 22°23'59"	- 44°39'45"

2.5 Zoning

Zoning is a land-use planning instrument whose objective is to establish homogeneous land use and occupation sectors or zones to manage a given area better (ICMBio, 2013).

According to the NSPA (Brasil, 2000), the PA zoning is based on the definition of sectors or zones to differentiate each zone's uses based on management objectives and specific rules.

The zoning of the INP was proposed in its MP (ICMBio, 2013) applying the methodological planning guidelines of Galante et al. (2002) and is as follows (Fig. 2.5):

The Intangible Zone is where nature is preserved as intact as possible, no human interference being tolerated, thus representing the highest preservation level. The access to this zone is restricted for purposes of preserving the park's ecosystems, genetic resources and environmental monitoring and limited to research, control and monitoring activities. This zone covers about 23% of the park.

The Primitive zone is where there has been minimal human intervention and where fauna and flora species or natural phenomena of great SV are located. The access to this area is limited to low impact visitation activities, and priority is given to research and environmental interpretation. This area corresponds to about 56% of the park.

The Temporary Occupation Zone includes residential areas. As soon as the population is relocated, this zone will be converted into one of the Permanent Zones. The access to this area is focused on reducing the impacts on the park, and priority is given to control, environmental interpretation and environmental awareness activities targeted at the local population. This zone represents about 10% of the park.

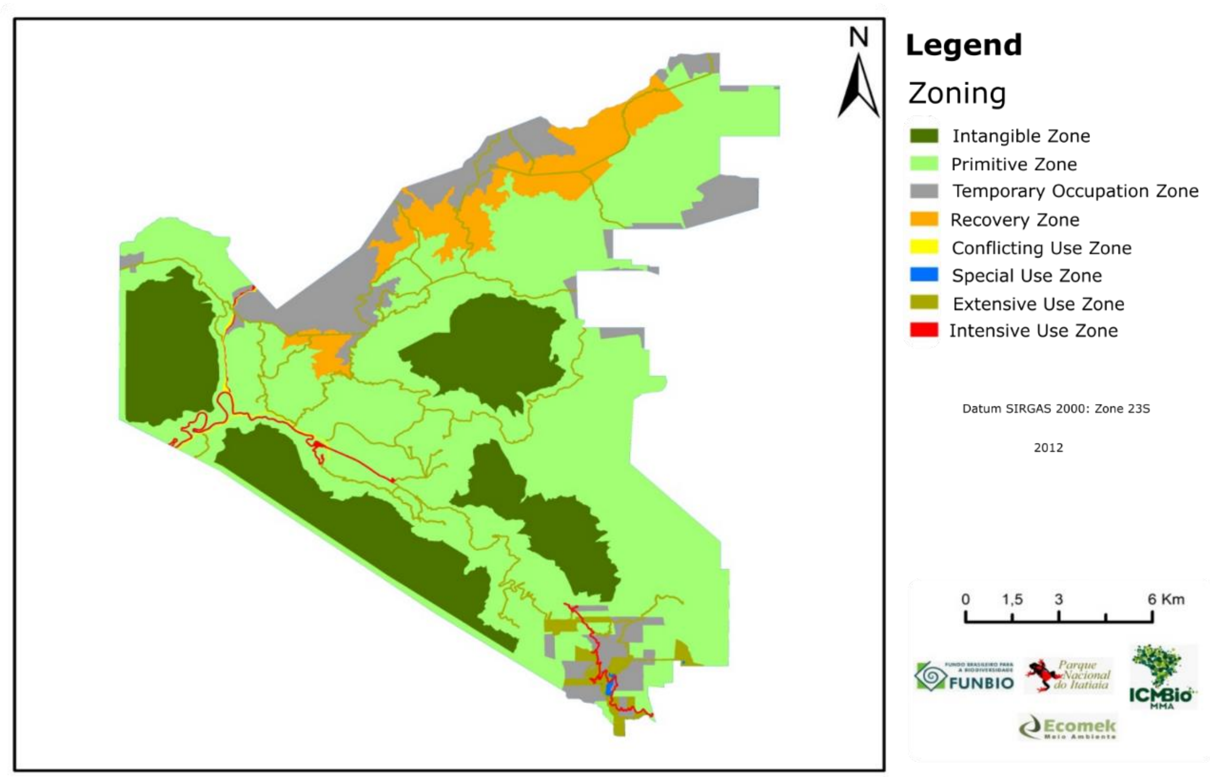

Fig. 2.5 Zoning of the Itatiaia National Park (ICMBio, 2013).

The Recovery Zone has considerable human impacts. It is a transition area, i.e., as soon as the area is recovered, it will be converted into one of the Permanent Zones. The access to this area is restricted for purposes of recovering the park's degraded areas, and research, environmental interpretation and environmental awareness activities targeted at the local population are encouraged. This zone covers about 6% of the INP.

The Conflicting Use Zone includes areas within the park whose uses and objectives, established before its creation, conflict with the PA conservation objectives, such as transmission lines, antennas, roads and water catchment areas. The actions planned for these areas must aim to mitigate the impact of such conflicting activities on the PA. It corresponds to less than 1% of the park.

The Special Use Zone includes the areas necessary to the park's management, maintenance, and services. The access to this zone is limited to employees, and priority is given to administrative, control and monitoring activities. It covers less than 1% of the park.

The Extensive Use Zone comprises natural areas that could have evidence of human activities. The access is not highly restricted, research, visiting and environmental awareness and education activities being permitted, but with minimal human impact on the natural environment. This zone covers about 4% of the park.

The Intensive Use Zone includes natural or anthropic areas maintained as natural as possible. This zone may contain infrastructure, other facilities and services to support public use, such as visitor centres and museums and promote environmental interpretation or intensive visitation activities. This area covers less than 1% of the area.

3. MATERIALS AND METHODS

This chapter is structured into five sections (review of the literature, data analysis, inventory of geological sites, quantitative assessment of the geological sites, and results and products from the previous steps) that describe the materials and methods applied to achieve the general and specific objectives of this thesis. Each section refers to a theme, being the activities conducted therein not presented in the chronological order in which they were performed.

3.1 Review of the Literature

The review of the literature covered the following topics: (i) qualitative and quantitative assessment methods of geomorphological heritage, (ii) INP's management plans, (iii) geoconservation research in Brazilian National Parks, (iv) geology and geomorphology of the study area and (v) general- and specific-purpose methods to assess the SV of geosites.

3.1.1 Methods for assessing geomorphological heritage

The review of the literature on qualitative and quantitative geomorphological heritage assessment methods was carried out (Mucivuna et al., 2019a) to select those that best fit the characteristics of the INP (Mucivuna et al., 2019b).

The papers were selected in international online databases: Web of Science, Science Direct and Journal Citation Reports of the Brazilian Federal Agency for Support and Evaluation of Graduate Education. The search was conducted based on the following criteria: the papers must be (i) written in English; (ii) published in peer-reviewed scientific journals; and (iii) use at least one of the following words on the title: geomorphological heritage, geomorphological site or geomorphosite. Papers were selected from many scientific journals. Therefore, a targeted survey was then conducted on these journals' websites to investigate the manuscripts not added to these international databases.

3.1.2 Management plans of the Itatiaia National Park

There are two versions of the MP: the 1982 version covers its initial boundaries (IBDF, 1982), and the current includes the additional area (ICMBio, 2013). These plans were thoroughly examined with two main objectives: (i) select potential geological sites for the inventory (step 3.3.1.2) (IBDF, 1982; ICMBio, 2013) and (ii) analyse how geodiversity aspects are addressed in the document (ICMBio, 2013) (step 3.2.2) (Mucivuna et al., 2022c).

3.1.3 Geoconservation research in Brazilian National Parks

The literature on geoconservation research in Brazilian National Parks was reviewed to map the coverage of structural provinces (Almeida et al., 1981; Schobbenhaus and Neves, 2003), biomes and coastal marine systems (IBGE, 2019a). After compiling a list of national parks, a literature survey on each of them was carried out (Mucivuna et al., 2022b).

The list of Brazilian National Parks was based on the official webpage of ICMBio (https://www.icmbio.gov.br/portal/unidades-de-conservacao in Portuguese) by using the keyword *Parque Nacional* to get information on name, biome and date of creation.

The literature on each national park was reviewed by consulting (i) the first, second and third editions of the book "*Sítios Geológicos e Paleontológicos do Brasil*" published by the Brazilian Commission of Geological and Paleontological Heritage Sites (SIGEP) (Schobbenhaus et al. 2002; Winge et al. 2009, 2013); (ii) the Geopark proposals outlined by Geological Service of Brazil (CPRM) (Schobbenhaus and Silva 2012; Barros et al. 2014, 2019; Theodorovicz 2014; Ferreira et al. 2017a, b, 2018; Martins et al. 2017; Peixoto 2017; Pereira et al. 2017, 2018; Lages et al. 2018; Freitas et al. 2019); and (iii) the scientific publications provided by Google Scholar.

While the sites in SIGEP and Geopark proposals were chosen considering the description of national parks in the area studied by the authors, the scientific publications were searched on Google Scholar using the keywords *geoconservação* + the name of all national parks. The results were filtered by adopting the following criteria: the publications should (i) be published in complete formats, not in conference proceedings, and (ii) have in their titles the national park's name and at least a word associated with geoconservation such as geodiversity, geoheritage, inventory, geosite or geotourism.

3.1.4 Identification of key geoheritage interests

The research on the geology and geomorphology of the study area was reviewed to define the key geoheritage interests and data about (i) contemporary Earth processes; (ii) representative surface and subsurface features; and (iii) records of past environmental conditions (Crofts et al., 2020).

3.1.5 Methods to assess the scientific value of geosites

The general-purpose (applicable to any geosite) and specific-purpose quantitative methods (designed to assess geomorphosites) for assessing the INP geosites were applied to compare and discuss whether special-purpose methods provide different results that justify their application and whether general-purpose methods cover the needs of the particularities of the geomorphological heritage (Mucivuna et al., 2022a).

General- methods (Brilha, 2016; García-Cortés et al., 2019) were chosen because they feature in several studies in Brazil, while the special-purpose methods (Pereira et al., 2007; Reynard et al., 2016; Santos et al., 2020) were partially chosen based on their impact on the scientific literature (Mucivuna et al., 2019a).

3.2 Data Analysis

This step refers to data analysis of (i) papers discussing qualitative and quantitative assessment methods, (ii) INP's MPs and (iii) geoconservation research in Brazilian National Parks.

3.2.1 Qualitative and quantitative assessment methods for geomorphological heritage

The initial list comprised a total of 110 manuscripts (step 3.1.1), and after removing those that discussed topics unrelated to geomorphosite assessment, the resulting list of 71 papers was analysed in detail regarding the following criteria (Mucivuna et al., 2019a):

(i) General aspects (topic, value, scale, and aim);

(ii) Qualitative evaluation of geomorphological heritage assessment methods (description of the procedures and criteria used in the selection of sites, use of descriptive cards, development of a new method based on previous ones, and application of previous methods);

(iii) Quantitative evaluation of geomorphological heritage assessment methods (description of criteria and values, development of a new method based or inspired by previous ones, application of previous methods, and description of weighting and calculation of the ultimate value of the geomorphosite).

3.2.2 Management plans of the Itatiaia National Park

The MP (ICMBio, 2013) was analysed to check how geodiversity had been addressed and to get subsides to integrate geoheritage and geoconservation into its guidelines (Mucivuna et al., 2022c). The analysis consisted of three stages: (i) MP review, (ii) diagnosis, and (iii) content analysis.

The review of the MP aimed to evaluate it according to the following questions:

- How is geodiversity described?
- Do geological and geomorphological maps show sites associated with geodiversity?
- Is the physical characterisation of geological sites adequate?
- Do the proposals for public use cover sites associated with geodiversity?

The diagnosis consisted of organising the information on abiotic aspects. Finally, the information obtained in the previous steps was analysed and correlated with geodiversity and geoconservation.

3.2.3 Geoconservation research in Brazilian National Parks

A total of 116 SIGEP sites and 31 Geopark proposals were reviewed to check whether they were partially or fully within the boundaries of national parks. In addition, 35 publications (e.g., papers, theses, monographs) were selected. Based on the previously described criteria, a total of 41 studies were analysed in detail on their distribution in Brazilian structural provinces (Almeida et al., 1981), biomes and coastal marine systems (IBGE, 2019a) (Mucivuna et al., 2022b).

3.3 Inventory of Geological Sites

This step describes the methods used to inventory the geological sites, compiling data about their scientific, educational and touristic values, and interpretative potentialities.

3.3.1 Inventory of geological sites with scientific, educational and touristic values

The first step consisted of defining the main objectives of the inventory (Lima et al., 2010). The topic is valuing geoheritage considering scientific, educational and tourism interests; the scale covers the boundaries of the INP, and the aim is to contribute with geoconservation strategies through interpretative tools.

The geosites, geodiversity sites (Brilha, 2016, 2018) and viewpoints (Migoń and Pijet-Migoń 2017) were selected following the four main steps below (Mucivuna et al., 2022c):

3.3.1.1 Establishment of Geological Frameworks

A geological framework (GF) represents the records of the main geological/geomorphological events that took place in a given area (Wimbledon, 2011). To set a framework, the main themes related to the park’s geological and geomorphological features were identified and described by performing the following: (i) review of literature, (ii) analysis of cartographic materials (Trouw et al. 2003; Heilbron et al. 2016; Rosa and Ruberti 2018) and (iii) considering the suggestions of researchers who have conducted studies in the area.

3.3.1.2 Selection of Potential Sites

Once the GFs were established, potential sites were selected based on systematic surveys and comparative assessment (Wimbledon et al. 1999). Then, the method of Mucivuna and Garcia (2017) was applied following these steps:

(i) Review of literature

This review of literature is crucial to geoheritage inventory, particularly when it is taken to assess the SV of sites. In this work, papers, theses, dissertations, books and technical reports were scrutinised to select potential sites. However, despite the valuable geological history of the study area, specific knowledge about some park regions is limited due to the difficulty of access and vegetation cover.

(ii) Analysis of the protected area management plan

The MP was reviewed in order to select potential geological sites in the park.

(iii) Review of sites used in educational activities and tourists advertisement materials

The materials were reviewed to identify sites used in educational and touristic activities with geoscientific importance. Information on these sites was collected from (i) the MP, (ii) the INP leaflet and website; (iii) websites of the Tourism Department of the cities within the study area, and (iv) advertisement materials available online.

(iv) Interviews with researchers who have worked in the area

Interviews were conducted with Geosciences researchers who worked in the study area in order to gather information on potential sites that could be included in the inventory due to scientific, educational and/or tourist values. Data on location, access routes, contents of interest, and other information were requested during the interviews.

(v) Analysis of cartographic materials

Some sites were selected after the analysis and interpretation of maps (geological, geomorphological, pedological, topographical), satellite images and digital elevation models. This step was carried out to recognise the lithostratigraphic and geomorphological units, regional structures and geological contacts (Mucivuna et al., 2015).

The sites selected in this and previous steps were geocoded in geographic information systems (GIS) and then analysed using the following cartographic materials:

- Geological, geomorphological, pedological, vegetation, land-use, public use, and zoning maps (ICMBio, 2013);
- Geological and Mineral Resources Map of the State of Rio de Janeiro in scale 1:400.000 (Heilbron et al., 2016);
- Geological Map of Folha Pouso Alto (SF-23-Z-A-I) in scale 1:100.000 (Trouw et al., 2003);
- Geological Map of the Itatiaia Alkaline Massif in scale 1:50.000 (Rosa and Ruberti, 2018);
- Topographical map Agulhas Negras (SF-23-Z-A-I-4) in scale 1:50.000 (IBGE, 1988);
- Global Digital Elevation Model - ASTER GDEM;
- Satellite images of the study area obtained by Google Earth software;
- Landsat 8 image RGB 754 (U.S. Geological Survey).

(iv) Analysis of access routes and pathways

This step was carried out to find the shortest access routes to the potential sites. As most of the sites have no direct road access, the pathways were found through (i) maps included in the MP; (ii) trails mentioned in the INP folder and (iii) trails included in the Wikiloc application.

3.3.1.3 Field Evaluation

Fieldwork was more complicated than initially planned. Besides the large extension of the INP (~300 km²), the area has dense vegetation, very rugged topography and only a few roads. Therefore, the fieldwork required long trips along trails, contributing to a reduced number of visited sites daily.

This step was carried out not only to assess and to describe potential sites, but also to identify new ones. During field evaluation, each potential geological site was qualitatively assessed using the following criteria: representativeness, integrity, rarity and scientific knowledge (geosites) and didactic potential, variety of geological elements, scenery and interpretative potential (geological sites) (Brilha 2016, 2018). Some potential sites were not found due to incorrect coordinates, inaccessible areas and no geoscientific interest. On the other hand, other geological sites with good interpretative potential were added.

3.3.1.4 Final List and Site Characterisation

After fieldwork, the final list of geological sites was compiled. A summary sheet of each site was elaborated, containing the following data: (i) identification; (ii) characterisation; (iii) quantitative assessment; (iv) description; (v) use and management proposals, and (vi) interpretative elements.

3.3.1.5 Identification of Additional Values in the Inventoried Sites

This step was carried out to recognise the links between geodiversity and additional values. As a result, the following values were identified: (i) ecological value: the importance of geodiversity elements to support fauna and flora, (ii) aesthetic value: relationship of the observation conditions with the scenic value; and (iii) cultural value: relationship of geological sites with historical, religious and artistic values (Mucivuna et al., 2022b).

3.3.2 Inventory of geological sites with interpretative value

The interpretative inventory was carried out to select the best geological sites with interpretative features that can be used to foster geoconservation in the park. It was conducted in three main stages:

3.3.2.1 List of Potential Sites

The potential sites were selected from the data of the inventory of geological sites (Mucivuna et al., 2022c).

3.3.2.2 Assessment of Potential Sites

The assessment of each geological site was based on criteria to evaluate the interpretative potential (Morales and Varela (1986) *apud* Morales (1992)) and its relation to the results of the quantitative assessment of SV, PEU, PTU and DR (Brilha, 2016, 2018).

The following relationship was made: uniqueness criterion to rarity criterion (SV), didactic representativeness criterion to the PEU final score, attractiveness criterion to the PTU final score, and resistance to potential impacts criterion to the DR final score.

These criteria were used to arrive at the final list as follows:

(i) Sites scoring four in the rarity criterion (Brilha, 2016) (in both approaches) were included in the final list, regardless of the scores in the other criteria.

(ii) Sites scoring above the arithmetic mean in SV (geological and/or geomorphological approaches), PEU and PTU, and low DR (Brilha, 2016) were included.

3.3.2.3 Final List and Characterisation of Interpretative Geological Sites

Each interpretative geological site included in the final list was characterised according to the site inventory form: (i) geological site name; (ii) location; (iii) interpretative site description; and (iv) interpretative significance (Veverka, 2015).

3.4 Quantitative Assessment

The inventoried sites were quantitatively assessed to measure the most relevant sites for priority management and conservation. Geosites and geodiversity sites were evaluated for their SV, PEU, PTU and DR (Brilha, 2016). The SV assessment was performed twice, first considering only the geological approach - GLA (geosites were assessed based on geological aspects other than geomorphological ones) and after the geomorphological approach - GMA (geosites were evaluated based only on geomorphological elements).

As most geosites have strong relationships between geomorphological and other geological aspects, they were assessed for their SV (both in GLA and GMA) using general-purpose methods (Brilha, 2016; García-Cortés et al., 2019), i.e., designed to evaluate any geosite and specific-purpose methods (Pereira et al., 2007; Reynard et al., 2016; Santos et al., 2020), i.e., to assess geomorphosites (Mucivuna et al., 2022a). The assessment of other values, potential uses, protection and threats (Pereira et al., 2007; Reynard et al., 2016; García-Cortés et al., 2019, Santos et al., 2020) were not performed in this work.

3.4.1 Brilha (2016)

The SV value was assessed based on seven criteria and scored with 1, 2 or 4 points (Table 3.1). The PEU was assessed based on twelve criteria and the PTU on thirteen (Table 3.2); both had scores ranging from 0 to 4 points. The DR was assessed on five criteria and scored between 0 and 4 points (Table 3.3). The final scores for each value (SV, PEU, PTU and DR) were obtained based on the weighted sum of each set of criteria, ranging from 0 to 400. Subsequently, the DR was classified as: <200 (low), 201-300 (moderate) and > 301 (high).

Table 3.1 Criteria, indicators and weighting used for the quantitative assessment of the scientific value (Brilha, 2016).

Scientific value (SV)	
Criteria, indicators and weighting	**Parameters**
A. Representativeness (30%)	
The geosite is the best example in the study area to illustrate elements or processes, related with the geological framework under consideration (when applicable)	4
The geosite is a good example in the study area to illustrate elements or processes, related with the geological framework under consideration (when applicable)	2
The geosite reasonably illustrates elements or processes in the study area, related with the geological framework under consideration (when applicable)	1
B. Key locality (20%)	
The geosite is recognised as a GSSP (Global Stratotype Sections and Point) or ASSP (Auxiliary Boundary Stratigraphic Section and Point) by the IUGS or is an IMA reference site	4
The geosite is used by international science, directly related with the geological framework under consideration (when applicable)	2
The geosite is used by national science, directly related with the geological framework under consideration (when applicable)	1
C. Scientific knowledge (5%)	
There are papers in international scientific journals about this geosite, directly related with the geological framework under consideration (when applicable)	4
There are papers in national scientific publications about this geosite, directly related with the geological framework under consideration (when applicable)	2
There are abstracts presented in international scientific events about this geosite, directly related with the geological framework under consideration (when applicable)	1
D. Integrity (15%)	
The main geological elements (related with the geological framework under consideration, when applicable) are very well preserved	4
Geosite not so well preserved, but the main geological elements (related with the geological framework under consideration, when applicable) are still preserved	2
Geosite with preservation problems and with the main geological elements (related with the geological framework under consideration, when applicable) quite altered or modified	1
E. Geological diversity (5%)	
Geosite with more than three types of distinct geological features with scientific relevance	4
Geosite with three types of distinct geological features with scientific relevance	2
Geosite with two types of distinct geological features with scientific relevance	1
F. Rarity (15%)	
The geosite is the only occurrence of this type in the study area (representing the geological framework under consideration, when applicable)	4
In the study area, there are two to three examples of similar geosites (representing the geological framework under consideration, when applicable)	2
In the study area, there are four to five examples of similar geosites (representing the geological framework under consideration, when applicable)	1
G. Use limitations (10%)	
The geosite has no limitations (legal permissions, physical barriers,…) for sampling or fieldwork	4
It is possible to collect samples and do fieldwork after overcoming the limitations	2
Sampling and fieldwork are very hard to be accomplished due to limitations difficult to overcome (legal permissions, physical barriers,…)	1

Table 3.2 Criteria, indicators and weighting used for the quantitative assessment of the potential educational and touristic uses. Ten criteria (A-J) are shared between these two types of uses. Two more criteria (K-L) are used to assess PEU and three (K-M) for PTU (Brilha, 2016).

Potential educational and touristic uses (PEU and PTU)	
Criteria, indicators and weighting	**Parameters**
A. Vulnerability (10%)	
The geological elements of the geosite present no possible deterioration by anthropic activity	4
There is the possibility of deterioration of secondary geological elements by anthropic activity	3
There is the possibility of deterioration of main geological elements by anthropic activity	2
There is the possibility of deterioration of all geological elements by anthropic activity	1
B. Accessibility (10%)	
Site located less than 100 m from a paved road and with bus parking	4
Site located less than 500 m from a paved road	3
Site accessible by bus but through a gravel road	2
Site with no direct access by road but located less than 1 km from a road accessible by bus	1
C. Use limitations (5%)	
The site has no limitations to be used by students and tourists	4
The site can be used by students and tourists but only occasionally	3
The site can be used by students and tourists but only after overcoming limitations (legal, permissions, physical, tides, floods, …)	2
The use by students and tourists is very hard to be accomplished due to limitations difficult to overcome (legal, permissions, physical, tides, floods, …)	1
D. Safety (10%)	
Site with safety facilities (fences, stairs, handrails, etc.), mobile phone coverage and located less than 5 km from emergency services	4
Site with safety facilities (fences, stairs, handrails, etc.), mobile phone coverage and located less than 25 km from emergency services	3
Site with no safety facilities but with mobile phone coverage and located less than 50 km from emergency services	2
Site with no safety facilities, no mobile phone coverage and located more than 50 km from emergency services	1
E. Logistics (5%)	
Lodging and restaurants for groups of 50 persons less than 15 km away from the site	4
Lodging and restaurants for groups of 50 persons less than 50 km away from the site	3
Lodging and restaurants for groups of 50 persons less than 100 km away from the site	2
Lodging and restaurants for groups less than 25 persons and less than 50 km away from the site	1
F. Density of population (5%)	
Site located in a municipality with more than 1000 inhabitants/km^2	4
Site located in a municipality with 250-1000 inhabitants/km^2	3
Site located in a municipality with 100-250 inhabitants/km^2	2
Site located in a municipality with less than 100 inhabitants/km^2	1
G. Association with other values (5%)	
Occurrence of several ecological and cultural values less than 5 km away from the site	4
Occurrence of several ecological and cultural values less than 10 km away from the site	3
Occurrence of one ecological value and one cultural value less than 10 km away from the site	2
Occurrence of one ecological or cultural value less than 10 km away from the site	1
H. Scenery (PEU 5%, PTU 15%)	
Site currently used as a tourism destination in national campaigns	4
Site occasionally used as a tourism destination in national campaigns	3
Site currently used as a tourism destination in local campaigns	2
Site occasionally used as a tourism destination in local campaigns	1

(Continue)

Table 3.2 (Continued)

Potential educational and touristic uses (PEU and PTU)			
Criteria, indicators and weighting			**Parameters**
I. Uniqueness (PEU 5%, PTU 10%)			
The site shows unique and uncommon features considering this and neighbouring countries			4
The site shows unique and uncommon features in the country			3
The site shows common features in this region but they are uncommon in other regions of the country			2
The site shows features rather common in the whole country			1
J. Observation conditions (PEU 10%, PTU 5%)			
All geological elements are observed in good conditions			4
There are some obstacles that make difficult the observation of some geological elements			3
There are some obstacles that make difficult the observation of the main geological elements			2
There are some obstacles that almost obstruct the observation of the main geological elements			1
K. Didactic potential (PEU 20%)		**K. Interpretative potential (PTU 10%)**	
The site presents geological elements that are taught in all teaching levels	4	The site presents geological elements in a very clear and expressive way to all types of public	4
The site presents geological elements that are taught in elementary schools	3	The public needs to have some geological background to understand the geological elements of the site	3
The site presents geological elements that are taught in secondary schools	2	The public needs to have solid geological background to understand the geological elements of the site	2
The site presents geological elements that are taught in the university	1	The site presents geological elements only understandable to geological experts	1
L. Geological diversity (PEU 10%)		**L. Economic level (PTU 5%)**	
More than 3 types of geodiversity elements occur in the site (mineralogical, palaeontological, geomorphological, etc.)	4	The site is located in a municipality with a household income at least the double of the national average	4
There are 3 types of geodiversity elements in the site	3	The site is located in a municipality with a household income higher than the national average	3
There are 2 types of geodiversity elements in the site	2	The site is located in a municipality with a household income similar to the national average	2
There is only 1 type of geodiversity element in the site	1	The site is located in a municipality with a household income lower than the national average	1
		M. Proximity of recreational areas (PTU 5%)	
		Site located less than 5 km from a recreational area or tourist attraction	4
		Site located less than 10 km from a recreational area or tourist attraction	3
		Site located less than 15 km from a recreational area or tourist attraction	2
		Site located less than 20 km from a recreational area or tourist attraction	1

Table 3.3 Criteria, indicators and weighting used for the quantitative assessment of the degradation risk (Brilha, 2016).

Degradation risk (DR)	
Criteria, indicators and weighting	**Parameters**
A. Deterioration of geological elements (35%)	
Possibility of deterioration of all geological elements	4
Possibility of deterioration of the main geological elements	3
Possibility of deterioration of secondary geological elements	2
Minor possibility of deterioration of secondary geological elements	1
B. Proximity to areas/activities with potential to cause degradation (20%)	
Site located less than 50 m of a potential degrading area/activity	4
Site located less than 200 m of a potential degrading area/activity	3
Site located less than 500 m of a potential degrading area/activity	2
Site located less than 1 km of a potential degrading area/activity	1
C. Legal protection (20%)	
Site located in an area with no legal protection and no control of access	4
Site located in an area with no legal protection but with control of access	3
Site located in an area with legal protection but no control of access	2
Site located in an area with legal protection and control of access	1
D. Accessibility (15%)	
Site located less than 100 m from a paved road and with bus parking	4
Site located less than 500 m from a paved road	3
Site accessible by bus through a gravel road	2
Site with no direct access by road but located less than 1 km from a road accessible by bus	1
E. Density of population (10%)	
Site located in a municipality with more than 1000 inhabitants/km^2	4
Site located in a municipality with 250–1000 inhabitants/km^2	3
Site located in a municipality with 100–250 inhabitants/km^2	2
Site located in a municipality with less than 100 inhabitants/km^2	1

3.4.2 García-Cortés et al. (2019)

The Geological Survey of Spain developed this method to cover all geological disciplines and include the qualitative and quantitative assessment of Sites of Geological Interest (SGI).

The SV was assessed based on seven criteria and scored between 0 and 4 points (Table 3.4). The final score was obtained from the following expression (divided by 40 to get a number between 0 and 10):

$$\mathbf{SV} = \frac{\mathbf{1}}{\mathbf{40}} \times [\mathbf{30} \times \mathbf{R} + \mathbf{15} \times (\mathbf{K} + \mathbf{A}) + \mathbf{10} \times (\mathbf{T} + \mathbf{C} + \mathbf{O} + \mathbf{D})]^{*}$$

**Note:* * SV: Scientific value, R: Representativeness, K: Degree of scientific knowledge of the site, A: Rarity, T: Type locality, C: State of conservation, O: Visibility, D: Diversity

Table 3.4 Criteria, indicators and weighting used for the quantitative assessment of the scientific value (García-Cortés et al., 2019).

Scientific value (SV)	
Criteria, indicators and weighting	**Points**
Representativeness (R) (Scientific value x 30)	
Little use as a model to represent, even partially, a feature or process	0
Useful as a model to represent part of a feature or process	1
Useful as a model to represent an entire feature or process	2
Best-known example of an entire feature or process in the geological region inventoried.	4
Type locality (T) (Scientific value x 10)	
It does not meet, by default, the following three criteria	0
Regional reference site	1
Reference site (metallogenic, petrological, mineralogical, tectonic, stratigraphic etc.) used internationally, or type locality of fossils, or biozones of wide scientific use	2
Stratotype accepted by the IUGS, or IMA type locality	4
Degree of scientific knowledge of the site (K) (Scientific value x 15)	
There are no published studies or doctoral theses on the site	0
There are published studies and/or doctoral theses on the site	1
The site has been studied by several scientific teams and is the subject of doctoral theses and published papers cited in national scientific journals	2
The site has been studied by several scientific teams and is the subject of doctoral theses and published papers cited in international scientific journals	4
State of conservation (C) (Scientific value x 10)	
Strongly degraded: the site is practically destroyed	0
Degraded: the site shows significant deterioration	0
Altered: the site has damage that prevents the observer from appreciating some characteristics of interest	1
Good with alterations: some damage that does not decisively affect the value or interest of the SGI	2
Good: the SGI in question is practically intact and is well preserved.	4
Visibility (O)) (Scientific value x 10)	
Has elements that almost entirely obscure the characteristics of interest	0
Has elements that obscure the SGI and prevent the observer from appreciating some characteristics of interest	1
Has the occasional element that does not prevent the observer from appreciating the entire SGI	2
Almost the entire SGI is perfectly and easily observable	4
Rarity (A)) (Scientific value x 15)	
There are several similar sites in the geological domain	0
One of the few known examples in the geological domain	1
Only known example in the geological domain	2
Only known example in Spain (or worldwide)	4
Diversity (D) (Scientific value x 10)	
The SGI only presents the primary type of interest	0
The SGI presents another type of interest in addition to the primary type, but it is not relevant	1
The SGI presents 2 other types of interest in addition to the primary type, or only 1, but relevant	2
The SGI presents 3 other types of interest in addition to the primary type, or only 2, but relevant	4

3.4.3 Pereira et al. (2007)

This method was developed to assess geomorphosites; however, it can also be used to evaluate other geosites after some adjustments. The SV value was evaluated based on seven criteria and scored between 0 and 1.5 points, according to each criterion (Table 3.5). The final score is obtained based on the sum of all criteria.

Table 3.5 Criteria and indicators used for the quantitative assessment of the scientific value (Pereira et al., 2007).

Scientific value (maximum 5.5)	
Criteria and indicators	**Points**
Rareness in relation to the area (Ra)	
It is not one of the most important 5	0.00
It is not one of the most important 3	0.25
One of the most important 3	0.50
The most important	0.75
The only occurrence	1.00
Integrity/Intactness (In)	
Highly damaged as a result of human activities	0.00
Damaged as a result of natural processes	0.25
Damaged but preserving essential geomorphological features	0.50
Slightly damaged but still maintaining the essential geomorphological features	0.75
No visible damage	1.00
Representativeness of geomorphological processes and pedagogical interest (Rp)	
Low representativeness and without pedagogical interest	0.00
With some representativeness but with low pedagogical interest	0.33
Good example of processes but hard to explain to non-experts	0.67
Good example of processes and/or good pedagogical resource	1.00
Number of interesting geomorphological features (diversity) (Dv)	
1	0.00
2	0.33
3	0.67
More than 3	1.00
Other geological features with heritage value (Ge)	
Absence of other geological features	0.00
Other geological features but without relation to geomorphology	0.17
Other geological features with relation to geomorphology	0.33
Occurrence of other geosite(s)	0.50
Scientific knowledge on geomorphological issues (Kn)	
None	0.00
Medium: presentations, national papers	0.25
High: international papers, thesis	0.50
Rareness at national level (Rn)	
More than 5 occurrences	0.00
Between 3 to 5 occurrences	0.17
2 occurrences	0.33
The only occurrence	0.50

3.4.4 Reynard et al. (2016)

This method is the updated version of the one proposed by Reynard et al. (2007). The method was designed to evaluate geomorphosites; however, the criteria of the method can be adjusted to assess other types of geosites. The SV was assessed based on four criteria (Table 3.6) and scored between 0 and 1.00 (null, low, medium, high and very high). The final value is obtained based on the arithmetic means of the set of criteria.

3.4.5 Santos et al. (2020)

The method was designed to assess geomorphosites. The SV value was evaluated based on eight criteria and scored between 0 and 1.0 (Table 3.7). The final score is obtained based on the arithmetic means of all criteria.

Table 3.6 Criteria used for the quantitative assessment of the scientific value (Reynard et al., 2016).

Scientific value		
Criterion	**Evaluation**	**Score**
Integrity	State of conservation of the site. Bad conservation may be due to natural factors (e.g., erosion) or human factors	0 - 1.0
Representativeness	Concerns the site's exemplarity Used with respect to a reference space (e.g., region, county, country). The selected sites should cover the main processes, active or relict, in the study area	0 - 1.0
Rareness	Concerns the rarity of the site with respect to a reference space (e.g., region, commune, country) The criterion serves to illustrate the exceptional landforms in the area	0 - 1.0
Palaeogeographical value	Importance of the site for the Earth or climate history (e.g., reference site for a glacial stage)	0 - 1.0

Table 3.7 Criteria, indicators and weighting used for the quantitative assessment of the scientific value (Santos et al., 2020).

Scientific value	
Criteria, indicators and weighting	**Points**
Representativeness	
The site represents a form or process of the regional geomorphological context	0.25
The site is the best example of some geomorphological unit of process of the regional geomorphological context	0.50
The site represents a clear relation between forms and processes or the site has palaeogeographic relevance	0.75
The site represents a clear relation between forms and processes and the site has palaeogeographical relevance	1.00
Integrity	
The forms and/or processes are significantly altered.	0.25
The forms and/or processes are significantly altered, but it is still possible to clearly recognise and analyse them	0.50
The forms and/or processes are not intact, but are not significantly altered	0.75
The forms and/or processes are intact	1.00
Rarity	
The site represents a common form/process in the area	0.25
The site is the best example of a common form/process in the area	0.50
There are few examples of the form/process represented by the site	0.75
The site is the only occurrence of the type in the study area	1.00
Geodiversity	
The site represents a geomorphological complex	0.25
The site represents a geomorphological system	0.50
The site presents relevant elements beyond geomorphology (other aspects of geodiversity)	0.75
The site presents three or more relevant elements beyond geomorphology (other aspects of geodiversity)	1.00
Scientific knowledge	
There is scientific material available (monographs, abstracts, simple reports, etc.)	0.25
The site was used for the development of master dissertations or it is currently used for the development of not yet published research	0.50
There are works about the geomorphological features of the site published in national journals or books with national relevance or the site was used for the development of doctoral theses	0.75
There are works about the geomorphological features of the site published in international journals or books with international relevance	1.00
Observation conditions	
The observation of the elements is very hard, depending on specific conditions	0.25
The observation of the elements is hard, but it does not depend on specific conditions	0.50
There are few difficulties for the observation of the elements	0.75
There are no obstacles for the observation of the elements	1.00
Ecologic value	
The geomorphological unit represented by the geomorphosite has direct relationship with some biotic aspect	0.25
The geomorphological unit represented by the geomorphosite has direct relationship with some special biotic aspect (rare, endemic, threatened, etc.)	0.50
The site shows a clear conditioning of geomorphology over some biotic aspect	0.75
The site represents a special case of relationship between geomorphology and biodiversity	1.00
Cultural value	
There are elements with cultural importance, but not directly related to the geomorphological setting	0.25
There are elements with cultural importance directly related to the geomorphological setting or the site has economic importance	0.50
The site is/was occupied or is highly relevant for some traditional community or the site was used for the development of a geomorphological model	0.75
The main geomorphological feature is anthropic, or represents an icon of a people/region, or is highly relevant for the history of geomorphology	1.00

3.5 Results and products from the previous steps

This section deals with the methods applied to design the products resulting from the data obtained in the previous steps. It includes the (i) typologies for geomorphosite assessment methods, (ii) fact sheet with the characterisation of the inventoried geological sites, (iii) proposals for integrating the inventoried sites into the MP, (iv) development of interpretative stories for the interpretative geological sites and, (v) methodological guidelines to elaborate interpretation plans for geological site in Brazilian National Parks.

3.5.1 Typologies for geomorphosite assessment methods

Based on the investigation into qualitative and quantitative methods for assessing geomorphological heritage (step 3.2.1), a set of typologies was proposed based on the application and description of qualitative and quantitative assessment methods by the authors of the selected papers (Mucivuna et al., 2019a).

3.5.2 Fact sheet with the characterisation of the inventoried geological sites

According to the results of the inventory of geological sites (step 3.3.1), fact sheets for each geological site were prepared based on the descriptive cards published by Serrano and González-Trueba (2005), Reynard (2006), Moura (2018) and Santos et al. (2020).

Each fact sheet included the following information:

(i) Identification: name, municipality, geographic coordinates (UTM coordinates), access/trailhead (ICMBio 2013, 2020; PMG, 2020), typology (Fig 3.1 and 3.2) (Fuertes-Gutiérrez and Fernández-Martínez, 2010; Perret, 2014), and zoning (ICMBio, 2013);

(ii) Characterisation: geological framework (Mucivuna et al., 2022c), geological unit (Trouw et al., 2003; Heilbron et al., 2016; Rosa and Ruberti, 2018), geomorphological unit (IBGE, 2019), main geological interests, specific geomorphological interest, and other elements of interests (CPRM, 2020);

(iii) Quantitative assessment: SV, DR, PEU and PTU (Brilha, 2016);

(iv) Description (Brilha 2016, 2018; Migoń and Pijet-Migoń, 2017);

(v) Figures;

(vi) Use and management: potential uses (Brilha, 2016), security, observing conditions, interpretative potential, infrastructure, DR (García-Ortiz et al., 2014) and use limitations (ICMBio, 2013).

Typology	Definition
Point	
Section	
Area	
Viewpoint	
Complex Area	

Fig. 3.1 Typology categories for spatial classification proposed by Fuertes-Gutiérrez and Fernández-Martínez (2010).

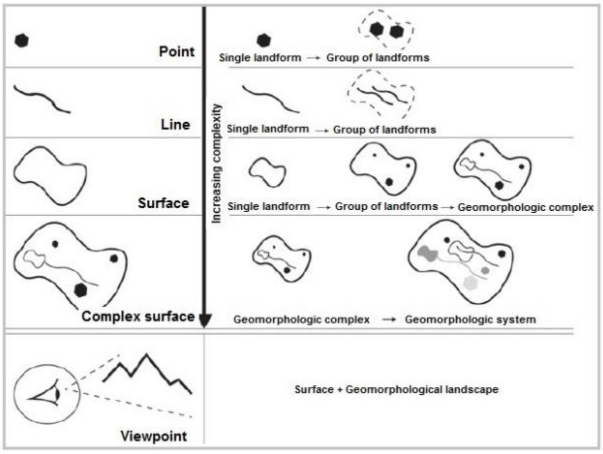

Fig. 3.2 Typology categories for spatial classification proposed by Perret (2014).

3.5.3 Proposals for integrating the inventoried sites into the management plan

Based on the MP analysis (step 3.2.2), recommendations to include geological sites in the MP were performed according to the MP chapters that directly or indirectly describe geodiversity and the inventory of geological sites (Mucivuna et al., 2022c).

3.5.4 Development of the interpretative topics, themes and objectives

With the results of the interpretative inventory (step 3.3.2), each site's interpretative topics, themes, and objectives were conducted based on thematic interpretation. It included the following information: topics and themes (according to Ham, 1992) and interpretative objectives (Veverka, 2015).

3.5.5 Methodological guidelines to elaborate interpretation plans for geological site in Brazilian National Parks

It was carried out based on five main steps: (i) inventory, (ii) fieldwork, (iii) assessment, (iv) interpretative inventory, and (v) development of basic elements of interpretation. The methodological guidelines were designed to be a roadmap to promote the integration of geoconservation within Brazilian National Parks.

4. GEOMORPHOSITES ASSESSMENT METHODS: COMPARATIVE ANALYSIS AND TYPOLOGY[1]

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Abstract

Due to the increase in geoconservation studies, several methods of qualitative and quantitative assessment of geosites have been published since the 1990s. However, the criteria and parameters used in the methods are often unclear and ambiguous. Thus, the aims of this study were to analyse how methods of qualitative and quantitative evaluation of geomorphological heritage developed and to compare them. The analysis resulted in a typology of the works published until now. A literature review was conducted based on three criteria, the papers had to be (i) written in English, (ii) published in peer-reviewed scientific journals and (iii) include at least one of the following keywords in the title: geomorphological heritage, geomorphological site and geomorphosite. Based on these criteria, 71 papers were analysed. Five categories are proposed: (i) application of previous methods, (ii) creation of new methods, (iii) application of previous methods combined with new methods, (iv) comparison of methods and (v) no description of method. The outcomes show that the qualitative evaluation should be more systematic and explicit according to the criteria applied and the main purpose of the evaluation. Quantitative methods should focus on reducing weaknesses associated with the overlapping and lack of clarity of some criteria. The proposed typology allowed us to summarise the papers published so far and to highlight the need to focus on improving existing methods rather than proposing new ones.

Keywords: Geoconservation, Geomorphological heritage, Assessment, Inventory, Typology, Criteria

[1] Paper published on Geoheritage 11, 1799–1815 (2019). https://doi.org/10.1007/s12371-019-00394-x

5. INTEGRATING GEOHERITAGE INTO THE MANAGEMENT OF PROTECTED AREAS: A CASE STUDY OF THE ITATIAIA NATIONAL PARK, BRAZIL [2]

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Abstract

The International Union for Conservation of Nature (IUCN) has created many initiatives to integrate geodiversity and geoheritage into the management of protected areas through a broader concept of nature. However, many protected areas do not have an inventory of geological sites. In view of this fact, this study aims to discuss the inventory of geological sites (including geomorphological, hydrological, petrological, sedimentological, and structural sites) and analyse, through a case study, how geodiversity is described in an existing management plan, prepared before IUCN included geoconservation in the Manual for the Management of Protected Areas. This study was conducted in the Itatiaia National Park, which has outstanding geomorphological and other geological features. To ensure appropriate assessment of geological sites, we carried out an inventory of geological sites and then we analysed how the management plan addressed geodiversity. The inventory includes 17 geosites (distributed in six geological frameworks), seven geodiversity sites and three viewpoints. We concluded that although geodiversity is mentioned in the plan, the inventory of geological sites would facilitate and support the exploration of management possibilities that range from conservation to education. Therefore, we recommend the inclusion of the inventoried sites in the management plan of protected areas because it is a valuable tool for the proper conservation and management of geoheritage.

Keywords: Assessment, Geoconservation, Geodiversity, Geological sites, Inventory, Management Plan.

[2] Paper published on International Journal of Geoheritage and Parks 10, 252–272 (2022). https://doi.org/10.1016/j.ijgeop.2022.04.004

6. CRITERIA FOR ASSESSING GEOLOGICAL SITES IN NATIONAL PARKS: A STUDY IN THE ITATIAIA NATIONAL PARK, BRAZIL[3]

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Abstract

Interest in geoconservation has been growing since the 1990s and, therefore, several actions have been taken to integrate geoheritage in scientific research, public policies and nature conservation. In this context, the International Union for Conservation of Nature (IUCN) has included many initiatives to integrate geodiversity and geoheritage in a broader nature concept in its agenda. In Brazil, the protected areas follow IUCN's guidelines. Thus, this study aimed to map the distribution of geoconservation research in Brazilian National Parks and to discuss the criteria and procedures applied in the inventory of geological sites in the Itatiaia National Park that can be adapted to other Brazilian protected areas. The applied methods were carried out based on the literature review, geoprocessing techniques and application of criteria and parameters to ensure the proper assessment of geological sites. The results show that geoconservation research in national parks has been growing over the years, and the geosites located in them may compound a potential list to be included in the Brazilian geoheritage inventory. Furthermore, the application of pre-established criteria in the selection of geological sites made the qualitative process more transparent, and the identification of additional values showed to be a useful tool to help park managers to integrate geological sites in the management process. Therefore, the criteria and parameters applied in this paper may be replicated in existing Brazilian National Parks and should be considered when assessing potential areas for establishing new protected areas.

Keywords: Geoconservation, Geoheritage, Geosite, Inventory, Protected Area

[3] Paper published on Geoheritage 14, 1 (2022). https://doi.org/10.1007/s12371-021-00633-0

7. COMPARING QUANTITATIVE METHODS ON THE EVALUATION OF SCIENTIFIC VALUE IN GEOSITES: ANALYSIS FROM THE ITATIAIA NATIONAL PARK, BRAZIL[4]

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Abstract

Despite efforts by the scientific community to create a single universal quantitative method to assess geological sites, dozens of methods have been designed and applied around the world with the purpose of assessing geosites with specific interests. Although several studies have already compared quantitative assessment methods with different objectives, there is not yet research that compares the application of general-purpose (method applicable to any geosite) and special-purpose methods (designed to assess geomorphosites) on the assessment of geosites with geomorphological and other geological interest. In view of this fact, this study aims (i) to make a quantitative assessment of the scientific value of the inventoried geosites of the Itatiaia National Park, Brazil, adopting geological and geomorphological approaches, using both general- and special-purpose methods and (ii) to discuss whether special-purpose methods provide different results that justify their application and whether general-purpose methods appropriately assess geomorphological heritage. The methodology procedures consisted of applying two general- and three special-purpose methods adopting the geological and geomorphological approaches to each geosite. The results show two main patterns: (i) different scores in the assessment of the geological and geomorphological approaches when applying the same method and (ii) similar scores in the assessment of each geosite among each method type –general- or special-purpose methods. The comparison of these five methods showed that general- and special-purpose methods could be applied in geosites with geomorphological and other geological interest without strongly affecting the final results.

Keywords: Assessment, Geoconservation, Geoheritage, Geomorphosite, Methods

[4] Paper published on Geomorphology 396, 107988 (2022). https://doi.org/10.1016/j.geomorph.2021.107988

8. THEORY AND APPLICATION OF INTERPRETATION

This chapter aims to discuss the interpretation concepts and methods as a means to have subsidies to apply them in practice. The first part of this chapter presents the theoretical basis of interpretation. It is not intended to exhaust the topic or address all the issues associated with it, since related topics, such as designing interpretative materials, were not discussed because they are not among the objectives of this thesis.

Based on these conceptual and methodological foundations, the second part of the chapter presents the application of geodiversity interpretation in the Itatiaia National Park (INP), Brazil". It was carried out as a paper under preparation named "Methodological proposal for the interpretative inventory of geological sites: example from the Itatiaia National Park, Brazil". The main objective of this paper is to propose a method to select interpretative sites, taking as bases the inventoried geological sites and to identify topics, themes and interpretative objectives based on geological frameworks and features and processes of geological sites. It is intended to provide a basis for selecting interpretative geological sites by applying interpretative and geoconservation criteria.

9. DISCUSSION AND CONCLUDING REMARKS

This chapter seeks to integrate the results presented throughout this research, discussing their contributions to the integration of geoconservation in the INP, and in Brazilian and worldwide protected areas, as well as the role of interpretation as a tool to introduce geoconservation and geoheritage in PAs. The discussion is related to the nine research objectives proposed in the introduction of the thesis.

For this purpose, the following specific themes are addressed: (i) the importance of the assessment, (ii) geoconservation issues in Brazilian PAs, (iii) how to elaborate a geoheritage interpretation plan in Brazilian National Parks, and (iv) the potentials and challenges of including geological site interpretation in National Parks. Finally, highlighting the concluding remarks.

9.1 The importance of the assessment

The assessment was addressed in every chapter of this work with different perspectives, either through the review of literature of methods for assessing geomorphological heritage (Mucivuna et al., 2019a) or through the application and discussion of the geological site diagnosis (Mucivuna et al., 2022a, 2022b, 2022c). In both aspects, the use of reliable methods appropriate to the objectives of the work was highlighted (Mucivuna et al., 2019a, 2022a, 2022b, 2022c), as well as the use of well-defined criteria to guarantee the quality and representativeness of the results (Mucivuna et al., 2022b, 2022c).

The review and comparison of different methods for assessing geomorphological heritage were realised to achieve the first objective of the thesis and proved to be essential regarding two main aspects. First, the site selection method applied in this work (Mucivuna and Garcia, 2017) was none of the ones analysed by Mucivuna et al. (2019a), as the inventory was already in progress when the analysis on geomorphological heritage methods was carried out. However, the analysis of such methods made it possible to identify weaknesses in the method applied in this research and to adapt it according to the needs. For example, the descriptive cards of Serrano and González-Trueba (2005) and Reynard (2006) were used as a model to elaborate the fact sheets for this work. Second, the analysis of geomorphosite assessment methods (Mucivuna et al., 2019a) made it possible to select and apply two quantitative assessment methods in the study area (Mucivuna et al., 2019b; Mucivuna et al., 2022a).

Regarding the diagnosis, until this work was conducted, the park lacked studies about its geological sites. However, as stated by Garcia et al. (2019a), the inventory is the most reliable way to identify the places that best represent the geological history of a given area, as well as being the database for the other steps in geoconservation strategies, such as the qualitative and quantitative assessment (Brilha 2005, 2016).

The review of the literature regarding both geological and geomorphological settings and the selection of potential sites proved to be essential to have sufficient knowledge of the physical aspects of the study area in which the inventory of geological sites was carried out. In contrast, the geomorphological aspects of the INP have not been the subject of many studies in detail. For these reasons, the analysis of the MP, cartographic materials and review of educational and tourist materials, and the interview of researchers who worked in the area were essential to identify the park's main rocks, structures, features, and processes.

The inventory of geological sites was carried out to select scientific representativeness and educational and touristic sites in the INP and was performed to achieve the second objective of the thesis (Mucivuna et al., 2022c). The criteria used to identify the SV were focused on GFs and key geoheritage interests (Mucivuna et al., 2022b, 2022c). This approach was essential to ensure an unbiased selection, recreate the sequence of events in the park, and assess the scientific representativeness of the park's geological history. Furthermore, the use of GFs (Brilha 2016, 2018) in the inventory proved to be pretty promising, as it may allow future data integration and comparison with surrounding areas, with the Brazilian geoheritage inventory, or with a future inventory of Brazilian National Parks (Mucivuna et al., 2022b).

On the other hand, geological sites with educational and tourism value were selected with specific criteria for such uses (Brilha, 2016, 2018). Although the INP is already widely used for tourism purposes and most of its attractions have geological and geomorphological aspects as primary features, the park lacks environmental education and interpretation activities focused on these aspects. Therefore, the diagnosis of geological sites (selection, assessment [qualitative and quantitative] and characterisation) was essential to indicate to managers the best sites with the potential to promote the inclusion of geodiversity and geoheritage in future education and environmental interpretation activities.

The application of quantitative assessment methods proved adequate to assess the geosites following the fifth objective of the thesis (Mucivuna et al., 2022a). As discussed earlier, geological sites are relevant regarding lithostratigraphic units, structures and inherited and active processes. Therefore, applying assessment methods focused on geological and geomorphological heritages was crucial to analyse the differences in methods and inventoried sites and identify the criteria responsible for the low scores in the geomorphological approach.

Likewise, the assessment of the PEU, PTU and DR allowed identifying the priority sites for use, conservation, and interpretation, as stated in the sixth objective of the thesis. Geological sites with the highest PEU and PTU and low DR scores were included in the interpretative inventory of geological sites and should be prioritised in environmental education and interpretation programmes and outreach strategies. On the other hand, geological sites with moderate to high DR must be prioritised in conservation and management actions.

9.2 Geoconservation issues in Brazilian protected areas

Brazilian PAs are regulated by the NSPA (Federal Law 9,985/2,000, Brasil, 2000) and managed by the ICMBio. While the NSPA has several objectives directed to bioconservation, abiotic conservation falls under three objectives (Pereira et al., 2008; Ferreira et al., 2018a). These are (i) to protect natural and unaltered landscapes of remarkable scenic beauty; (ii) to protect relevant geological, geomorphological, speleological, archaeological, palaeontological, and cultural features; and (iii) to protect and restore water and soil resources.

Although geodiversity is included in the NSPA, there is still a lack of national laws or guidelines guiding its conservation and use. ICMBio is a member of the IUCN, and therefore, Brazilian PAs follow its principles and recommendations for management and conservation. However, despite the recent international efforts by IUCN to recognise geodiversity and geoconservation in PAs (e.g., Crofts and Gordon, 2015; Díaz-Martínez et al. 2017; Woo 2017; Gordon et al. 2018; Crofts et al., 2020, 2021), there has not yet been effective integration in Brazilian PAs. On these grounds, the following question arose: How could the NSPA be used as a tool to promote geoconservation in Brazilian PAs?

The NSPA has mechanisms to integrate geoconservation in Brazilian PAs; however, the management of these areas must focus on the effectiveness of its objectives and guidelines. As mentioned above, geodiversity is related to three NSPA objectives; therefore, integrating abiotic aspects in the MP (Mucivuna et al., 2022c), as proposed in the third objective of the thesis, is essential to fostering geoconservation and encouraging integrated management between biodiversity and geodiversity within these areas.

The MPs aim to regulate and guide the general objectives, zoning, rules, and use restrictions (Brasil 2000). Therefore, performing geoconservation research in Brazilian National Parks, as highlighted in the fourth objective of the thesis, is essential to select geological sites to guide and propose their management and use actions. Furthermore, in recent years, research on geoconservation in national parks has been growing (Meira et al., 2018, Mucivuna et al., 2022b). Therefore, integrating geological sites along the PA's MP or in specific zoning brings optimistic perspectives to integrate geoconservation in Brazilian and worldwide PAs. For example, the analysis of the karst system vulnerability contributed to define a specific zoning and buffer zone in the MP of Intervales State Park (Sallun and Sallun Filho, 2019; Sallun Filho et al., 2010), and the geoheritage inventory (Garcia et al. 2019b; MA 2019) supported the creation of the Geobiodiversity Protection Zone in the MP of the Central Coast Marine EPA.

Regarding the use of geoheritage in PAs, the NSPA highlights in its objectives the need to promote environmental education and interpretation, recreation in contact with nature, and ecological tourism (ecotourism) (Brasil, 2000). Based on this, environmental interpretation is an excellent tool to disseminate geoheritage in all categories of PAs. Given these facts, the following section discusses the potentialities and challenges to integrating geodiversity and geoheritage into the interpretative programmes and projects in Brazilian PAs.

9.3 Potentialities and challenges of including geological site interpretation in Brazilian protected areas

Since the 1970s, several efforts have been carried out to include environmental interpretation in the planning and management of Brazilian PAs. From then on, environmental interpretation has been included in the regulations of National Parks (Decree 84,017/1979), the objectives of the NSPA (Law 9,985/2000), MPs, guidelines for visiting PAs, and institutional publications (Brasil, 1979; Brasil, 2000; Caetano et al., 2018).

Around 30% of the Brazilian territory is covered by PAs (Table 9.1). Therefore, environmental interpretation in these areas is a tool that can contribute to their management and conservation. Furthermore, if offered adequately to visitors, it builds connections between these areas and their visitors (Vasconcelos, 2006).

Although environmental interpretation is provided in some Brazilian PAs, the offer of environmental interpretation is still limited (Gomes, 2020). Despite this, some initiatives on environmental interpretation have been developed in Brazilian PAs, such as the publication on environmental interpretation in Federal PAs (Caetano et al., 2018), the interpretative plans of Tapajós National Forest (ICMBio, 2014), Anavilhanas National Park (ICMBio, 2016), Abrolhos Marine National Park (ICMBio, 2018), as well as the guidelines for elaborating interpretative projects (ICMBio, 2021).

Despite the advances to effectively promote environmental interpretation in the management of Brazilian PAs, the number of interpretative plans in PAs is still scarce. Moreover, existing projects and programmes focus mainly on biological, cultural, and historical aspects, while abiotic ones are neglected or only superficially mentioned.

Table 9.1 Summary of distribution of Brazilian protected areas based on their categories and governmental levels. Source: Ministry of Environment. Available in www.mma.gov.br/areas-protegidas/cadastro-nacional-de-ucs.html

		Federal		State		Municipal		Total	
Type	**Category**	**No.**	**Area (km²)**	**No.**	**Area (km²)**	**No.**	**Area (km²)**	**No.**	**Area (km²)**
Strictly protected areas	Ecological station	30	72,112	60	47,626	7	43	97	119,781
	Natural monument	5	115,314	34	964	23	209	62	116,487
	National park	74	268,078	223	95,393	178	848	475	364,320
	Wildlife refuge	9	2,984	55	3,448	13	205	77	6,637
	Biological reserve	31	42,674	27	13,524	8	51	66	56,249
	Total strictly protected areas	149	501,163	399	160,956	229	1,355	777	663,474
Sustainable use protected areas	National Forest	67	178,148	41	135,861	0	0	108	314,009
	Extractive reserve	66	135,091	29	21,126	0	0	95	156,217
	Sustainable development reserve	2	1,026	32	111,250	5	171	39	112,447
	Fauna reserve	0	0	0	0	0	0	0	0
	Environmental protection area	37	897,222	200	342,153	138	59,594	375	1,298,968
	Area of relevant ecological interest	13	341	30	625	16	199	59	1,164
	Private natural heritage reserve	670	4,885	321	1,031	2	-	993	5,917
	Total sustainable use protected areas	855	1,216,713	653	612,046	161	59,964	1169	1,888,723
	Total	1,004	1,717,875	1,052	773,002	390	61,139	2,446	2,552,197

Although the number of inventories of geological sites in PAs has grown in recent years (Meira et al., 2018; Mucivuna et al. 2022b), there are still no interpretative plans and projects focused on geodiversity or geoheritage within these areas. However, considering that abiotic elements are part of nature, the basis for the development of organisms and ecosystems, and the integration of geoconservation in PAs is recommended by the IUCN guidelines (Crofts et al., 2020), the implementation of interpretation can (and should) be carried out exploring geological and geomorphological features and processes (Moreira, 2012). Furthermore, geodiversity and geoheritage in PA's interpretation are of utmost importance for an integrated interpretation of nature (Mucivuna et al. 2021).

Many possibilities and challenges have emerged for integrating geodiversity and geoheritage into environmental interpretation in Brazilian PAs. Among the possibilities, integrating geodiversity and geoheritage in public use activities and key points along trails stand out. Such measures can be very promising, as they would allow an integrated interpretation of nature through biotic and abiotic aspects (Bétard et al., 2017) and would increase visitor understanding and general appreciation of the PA as a whole. Furthermore, emphasising the importance of abiotic aspects in the guidelines for the elaboration of interpretative projects (ICMBio, 2021) would contribute with institutional support to develop interpretative products (e.g., folders, interpretative panels, website content and exhibitions in visitor centres, virtual products) and educational materials (e.g., textbooks, field guides, games, itineraries) focused on geodiversity and geoheritage (Mucivuna et al., 2021). Other possibilities are associated with the training of environmental monitors on abiotic content to act as multipliers and the production of simplified management materials to help them understand geoscientific concepts and terms. Such initiatives can help them focus on the integrated management of biodiversity and geodiversity. These possibilities are directly linked to the public-private partnership of many Brazilian PAs, as these companies can invest more in interpretative research, projects, and materials and staff training to contribute to increasing the visitor experience.

Among the challenges, the difficulty for the public to understand geoscientific terms and the need to translate technical terms on a more straightforward approach stand out. Such measures may be facilitated by integrating guidelines for geoconservation in PAs (Crofts et al., 2020), as these areas are still managed predominantly in terms of biological, historical, and cultural aspects. Furthermore, integrating geodiversity and geoheritage into MPs, strategic planning, and interpretative activities would collaborate with integrated management. Other possibilities are associated with the visitors' engagement to contribute to disseminating and conserving the PAs' geoheritage (Pacheco e Brilha, 2014). These challenges are strongly related to PAs' lack of geoscience staff and their difficulty in selecting, assessing, and managing geomorphological and other geological features and processes.

9.4 How to elaborate a geoheritage interpretation plan in Brazilian National Parks?

As highlighted in section 9.2, all categories of Brazilian PAs can integrate interpretation into their programmes and projects, as it is among the objectives of the NSPA (Brasil, 2000).

Despite the possibilities in both strictly protected areas and sustainable-use protected areas, the national park category stands out because its main objective is to preserve natural ecosystems, develop scientific research, educational and environmental interpretation, and ecological tourism (Brasil, 2000). Furthermore, it is the most numerous category managed by the government authorities (Table 9.1).

In Brazil, there are no interpretation plans that address the abiotic environment. Therefore, this section discusses the methodological guidelines for elaborating interpretation plans for geological sites in Brazilian National Parks, as proposed in the eighth objective of the thesis. The guidelines described here summarise all steps described throughout the thesis and applied in the INP (Fig. 9.1). They were designed to be an essential roadmap and intended to promote the integration of geoconservation within other Brazilian National Parks and the management of PA worldwide.

The first step consists of defining the objectives of the inventory, i.e., the topic, the value, the scale, and the objective (Mucivuna et al., 2022c). It is suggested that the topic integrate all types of geological sites to allow the reconstruction of all steps of the park's geological history. The objective has to consider both the potential use and the SV linked to the park's geological and geomorphological features and processes. The scale is the park area. However, it may also include its buffer zone or be restricted to only the zoning where public use activities are conducted. The objective should be defined considering the needs of the park and its relation with interpretation, either associated with the development of projects and programs or interpretative materials. Subsequently, a review of the literature should be conducted to recognise the park's geological and geomorphological settings and the key geoheritage interests. Potential geological sites should be selected based on scientific materials (e.g., previous inventories, papers, theses, dissertations, books), MPs, educational, tourism and cartographic materials. Finally, fieldwork should be carried out to qualitatively assess and characterise the potential sites. To guarantee an unbiased selection, it is suggested to apply predefined criteria, as stated by Crofts et al. (2020). Site characterisation should focus on the abiotic attributes and may include risks or threats associated with the uses of the sites.

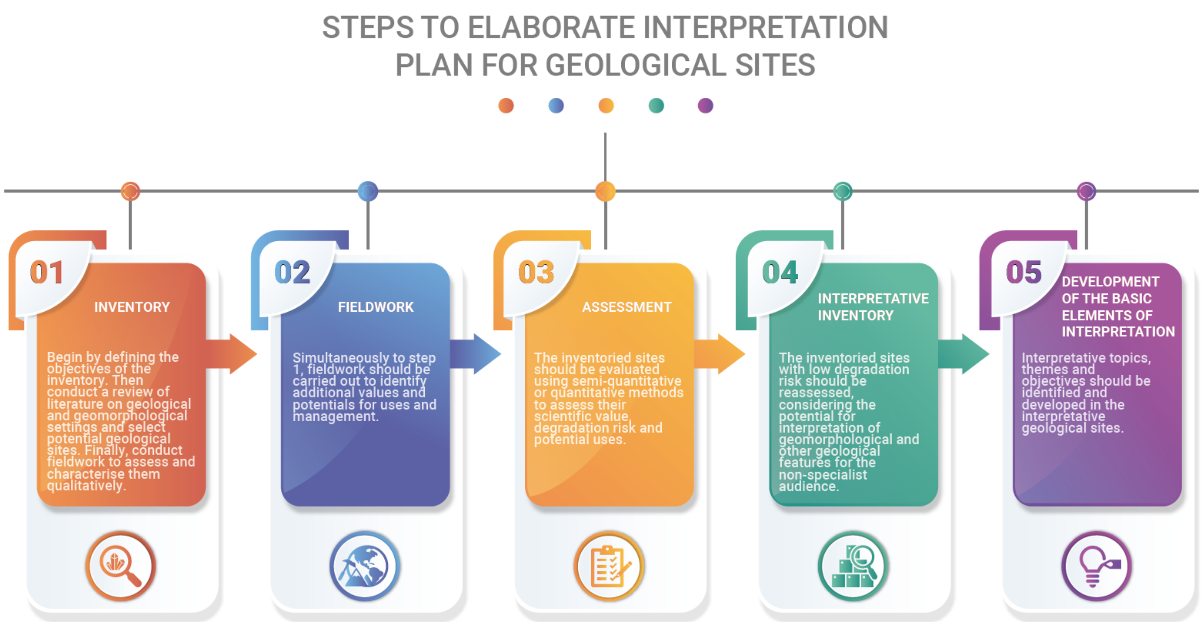

Fig. 9.1 Steps to elaborate interpretation plan for geological sites.

The second step concerns fieldwork. It can be carried out concurrently with the first step or independently (Mucivuna et al., 2022b). The fieldwork should identify additional values (e.g., aesthetic, cultural, ecological, archaeological) and use and management potentials. These values must be correlated to their potential to interpret the geological and geomorphological features and processes.

The third step is the assessment (Mucivuna et al., 2022a; Chapter 8). It should be carried out using systematic methods for semi-quantitative or quantitative assessment. It has to select methods that assess the sites' SV, DR, and potential uses. This assessment aims to reduce the subjectivity associated with the qualitative assessment process and defines priority sites in the other stages of the interpretation plan.

The fourth step involves the interpretative inventory of geological sites (Chapter 8). It consists of defining the objectives of the interpretative inventory based on the outcomes that are intended to be achieved by interpreting the study area and/or each geological site. The interpretative inventory should be carried out in sites with lower DR and higher interpretative potential. Their selection is based on the correlation of the quantitative or semi-quantitative assessments with interpretative criteria (e.g., uniqueness, attractiveness, didactic representativeness, infrastructure facilities) and focused on their interpretative potential. In INP, it was conducted in line with the seventh objective of the thesis and aimed to select the most suitable sites to be the target of future interpretative programmes or projects

The fifth step involves the development of interpretative topics, themes, and objectives (Chapter 8). It focuses on the concepts and methods of interpretation and is part of the interpretative planning of Veverka (2015). The development of topics and themes should be conducted based on the thematic interpretation of Ham (1992) and approached in diverse ways. Instead, the interpretative objectives should be identified considering the correlation of the park's geological history with the objectives (learning, behavioural and emotional) to determine which aspects should be considered in interpretative planning. It is important to stress that such aspects should be better detailed after identifying the target audience.

These five steps correspond to the basic elements for developing an interpretation plan for geological sites in national parks. After these steps, others must be carried out, such as (i) identifying the stakeholders that could contribute to making the planning effective, (ii) identifying and defining the target audience based on data on visitors who frequent the park (Martin et al. 2010) (when applied to the school public, the national curricular bases must be consulted), (iii) integrate the geological sites in the MP and the environmental education and interpretation activities, (iv) define and design interpretative media based on the characteristics of the sites, target audience and available financial resources, (v) manage and monitor and (vi) evaluate the plan.

According to Garcia et al. (2019a), the successful implementation of geoconservation plans depends on proper interaction between (a) the scientific knowledge, which provides the bases for the recognition of geologically relevant sites; (b) the government authorities, responsible for the management of geoheritage; and (c) interpretation, to promote the dissemination of information to different audiences. Considering these three factors, the inventory of geological sites is the first and essential step for the success of all the steps. In the context of the INP, it was carried out based on systematic methods and allowed the selection of representative sites of its geological history (Mucivuna et al., 2022c). According to the second factor, the park managers can integrate geological sites into the management strategies. Therefore, we highlight the integration of inventoried sites into the MP (Mucivuna et al., 2022c), and the use of fact sheets, as stated in the ninth objective of the thesis, should be prioritised in conservation and management actions (Appendix A). Finally, the last factor includes the interpretative inventory (Chapter 8) that intends to build the basic information to allow the dissemination of geomorphological and other geological features and processes for different audiences.

9.5 Concluding remarks

This work addressed the theme of geoconservation to integrate geodiversity through the interpretation of geological sites. It was carried out not only to improve the management in the INP and Brazilian PAs, but also to the management of PAs worldwide. The results were obtained by applying systematic methods and considering four main axes.

The first axis is focused on the discussion of the existing methods. Firstly, the analysis of the geomorphological heritage assessment methods showed that several issues still need to be better discussed and improved, especially the lack of clarity in the selection process and the overlapping of some criteria during the quantitative assessment. Next, the comparison of the quantitative assessment methods in the INP allowed us to conclude that there is not much divergence between the results of general methods (used to assess all types of geosites) and those focused on geomorphological sites. However, this conclusion cannot be extrapolated beyond the conditions studied. Because in areas where geomorphological and other geological features and processes are not so closely interconnected, the results are likely to differ from those found in this research.

The second axis concerns the diagnosis. The inventory was carried out based on GFs and allowed us to include representative geological sites of all events in the park's geological history. Furthermore, this work has made it possible to conduct the first inventory of the park's geological sites, which can serve as a database to safeguard the memory of science and subsidise actions for the conservation, use, and dissemination of the sites. However, the distribution of these GFs in the different park regions is limited in the lower region and Visconde de Mauá. Regarding exploring the geological sites for educational and visiting activities, this issue can be improved by including them in tourism promotion materials, leaflets, websites, and the visitors' centre. Furthermore, the quantitative assessment showed results consistent with the qualitative observations made during the fieldwork. Therefore, the quantitative assessment results can be used together with the fact sheets to prioritise the best sites in future geoconservation strategies in the park.

The third axis included the analysis of geoconservation research in Brazilian National Parks and the analysis regarding the description of abiotic aspects in the INP's management plan. The first analysis allowed us to verify that research on geoconservation has been increasing in Brazilian National Parks in recent years. However, they are concentrated in the diagnosis of geological sites and are sometimes carried out only in part of the park boundaries. Furthermore, it was observed that research associated with SIGEP sites and Geoparks proposals (developed by the Geological Survey of Brazil) were predominantly carried out by *ad hoc* methods focusing on the selection of superlative features. Despite the advances, it was noted that although geodiversity is present in Brazilian PAs, it is still not the main focus of management actions. Therefore, research focused on management and monitoring should be encouraged to contribute to conserving the abiotic aspect of nature. In this context, the elaboration of materials with more accessible language for managers and employees should be done to facilitate the understanding of integrating geodiversity and geological sites in their actions, as most of them have diverse backgrounds from the Earth sciences. Furthermore, it is becoming increasingly urgent to develop a national plan that focuses on developing PAs' inventory of geological sites. Geological sites can only be prioritised in conservation and management actions through such measures. A second approach is associated with the analysis of the MP. The INP's analysis showed that geodiversity is addressed in its guidelines, but it is mainly focused on the regional characterisation of the abiotic aspects and not on use and management aspects. Based on this, the inclusion of geodiversity and geological heritage into the MP guidelines meets the IUCN recommendations for geoconservation in PAs (Crofts et al., 2020). This approach should be extended to worldwide PAs in order to improve the management within these areas. Nevertheless, the scientific community and the agencies responsible for managing PAs need to join efforts to develop conservation and management guidelines that integrate biotic and abiotic aspects in conserving natural heritage. Such actions are necessary because geological sites may suffer partial or total loss even in PAs due to inadequate policies and management.

The fourth axis is the proposal of an interpretation plan in PAs. This stage focused on elaborating two directly interconnected products: the interpretative inventory of geological sites and the guidelines for drawing up interpretative plans for geological sites in Brazilian national parks. The methodological proposal to perform interpretative inventories of geological sites used the information from the diagnosis stage to select and characterise them about their interpretative approach. It was elaborated based on the geoconservation strategies developed in the INP but can be adapted to several contexts, inside or outside PAs. The interpretative inventory consisted of one of the stages of the interpretation plan for Brazilian national parks. In this context, the preparation and application of the interpretative plan should be carried out together with national park managers and is intended to facilitate and systemise the stages of interpretative planning.

The results obtained in this research have the potential to be integrated into the use and management actions of the INP and provide the methodological basis for application in other Brazilian and worldwide PAs. Therefore, this methodology will be translated in the future into a language more accessible to PA managers, as most of them are not used to geoconservation concepts and methods. Thus, communication between the scientific community and decision-makers is essential to implement the proposals of this work.

Moreover, the data and discussions presented throughout this thesis bring unprecedented contributions not only to improve the management and inclusion of geodiversity and geoheritage topics in the INP and Brazilian PAs, but also to the management of PA worldwide. Moreover, the integration of geological sites in the PAs' management plans is quite new and could help the geoconservation community in the progress of research on geoconservation in PAs. Thus, it is expected that such data will be used for planning, conservation, and dissemination of geological sites in the INP, and as a methodological basis for the replication in other Brazilian and worldwide PAs.

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A. APPENDIX A: FACT SHEETS OF THE GEOLOGICAL SITES OF THE INVENTORY OF THE ITATIAIA NATIONAL PARK, BRAZIL

INTRODUCTION

This document contains information on the geological sites that are part of the inventory of the Itatiaia National Park (Brazil). It was designed as a practical guide, so it comprises a series of fact sheets that were prepared based on the descriptive cards published by Serrano and González-Trueba (2005), Reynard (2006), Moura (2018) and Santos et al. (2020). Its main objective is to contribute to the safeguard of the memory of science and support managers in the planning of conservation, management, dissemination and interpretation actions on the abiotic aspects of the protected area. The following sections are included: (i) identification, (ii) characterisation, (iii) quantitative assessment, (iv) description, and (v) use and management.

The identification section includes the following data: name, municipality, geographic coordinates, access or trailhead, typology, and zoning within the management plan. The access or trailhead data includes trail difficulty information based on the classification proposed by the Itatiaia National Park (ICMBio, 2020) and by the Paulista Mountaineering Group (PMG, 2020). As the interest of most sites lies in both geological and geomorphological aspects (except for the Geosite Biotite monzonite quarry), both the spatial classifications of Fuertes-Gutiérrez and Fernández-Martínez (2010) (geological interest) and Perret (2014) (geomorphological interest) were used. For the zoning of the protected area, the ICMBio (2013) mapping was adopted.

The following parameters were used to characterise the sites: geological framework (Mucivuna et al., 2022), geological unit (Trouw et al., 2003; Heilbron et al., 2016; Rosa and Ruberti, 2018), geomorphological unit (IBGE, 2019), geological interests, specific geomorphological interest, and other elements of interests (CPRM, 2020).

The quantitative assessment of the scientific value (geological and geomorphological interest, respectively), degradation risk, and educational and touristic potential use was performed based on Brilha (2016)'s method. This method is described in Chapter 3, while the scores assigned to each site are described in Chapter 7 (scientific value) and Chapter 8 (degradation risk and potential educational and touristic uses). This assessment was not extended to viewpoints as they do not always have intrinsic values, being used as a base from which a landscape is observed.

In the description, the following terms were adopted to identify the sites:

- Geosite – site of scientific relevance, which may also have other interests (Brilha 2016, 2018);
- Geodiversity site – site with high significant educational and/or touristic interest (Brilha 2016, 2018);

- Viewpoints - natural or built surface from where the landscape can be observed. It does not necessarily have an intrinsic value related to geology or geomorphology but offers a view towards features and areas which do have (Migoń and Pijet-Migoń, 2017).

The use and management section includes the following criteria: potential use, security, observing conditions, interpretative potential, infrastructure, degradation risk, and use limitations. Potential uses and observing conditions were analysed considering the concepts of Brilha (2016). Security, interpretative potential, infrastructure, and use limitations were described based on qualitative analyses made during the field work and the descriptions on the management plan (ICMBio, 2013). The degradation risk refers to the possibility of a site being damaged or destroyed, i.e., losing any of the elements of geodiversity that make it valuable. This includes both the threats due to intrinsic (fragility) and extrinsic factors (vulnerability - natural processes or human activities) (García-Ortiz et al., 2014). The risks associated with inappropriate behaviour of visitors were not included.

A total of twenty-seven sites were listed in the inventory, being seventeen geosites, seven geodiversity sites, and three viewpoints.

Identification	**Name:** Geosite Bog of Aiuruoca River.
	Municipality: Itamonte (MG).
	Geographical coordinates (UTM WGS-84): 23K 534151 / 7527107.
	Access / Trailhead: On foot by following the Aiuruoca waterfall trail that starts at Marcão station. This route is approximately 11 km long (round trip), and its difficulty level is considered moderate. The geosite is a few metres from the end of the trail.
	Typology: Area and area (single landform).
	Zoning within the management plan: Primitive zone and extensive use zone.
Characterisation	**Framework:** Quaternary deposits.
	Geological unit: Alluvium sediments (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Surface formation, sedimentary, hydrological and geomorphological.
	Specific geomorphological interest: Organic and fluvial processes.
	Other elements of interest: Ecological, aesthetic and historical.
Quantitative assessment	**Scientific value:** 270, 225.
	Degradation risk: 100.
	Potential educational use: 225.
	Potential touristic use: 185.

Description

The geosite Bog of Aiuruoca River is a depressive area, with an average slope of 4% (ICMBio, 2013), filled with peat sediments (Fig. A.1A) where the accumulated water forms one of the highest springs in Brazil, at an altitude of about 2,380 metres (Teixeira and Linsker, 2007) (Fig. A.1B). On its Western side, sub-rounded to rounded granules and pebbles were observed in the central and upper portions of the profile (Fig. A.1C), and in some areas, these deposits can reach more than two metres above the current water level (Rosa and Ruberti, 2018).

Rosa and Ruberti (2018) point out that the alluvial sediments are mainly composed of mud and peat deposits, with coarser grains and centimetric clasts in the adjacent areas; their formation is associated with a spatial and temporal decrease in water flow velocity and sediment transport rate (Bridge, 2004).

According to Modenesi and Melhem (1986), peat deposits are frequent in the Itatiaia Plateau, and the Aiuruoca River floodplain is one of the most significant peat sediments areas in the INP. They are formed due to biological and geological processes that resulted in the deposition of decomposed plants in wetlands under specific conditions (O’Kelly, 2015).

The morphogenesis of the geosite is linked to sedimentary and hydrographic processes that formed the floodplain and the Aiuruoca river, respectively. As to morphodynamics, sedimentary, fluvial and erosion processes are in progress.

Furthermore, it has great importance for the planning and management of water sources, since the Aiuruoca river has the highest hierarchical level of the park, being ranked number six, and is one of the principal rivers of the Grande river basin (ICMBio, 2013).

Figures

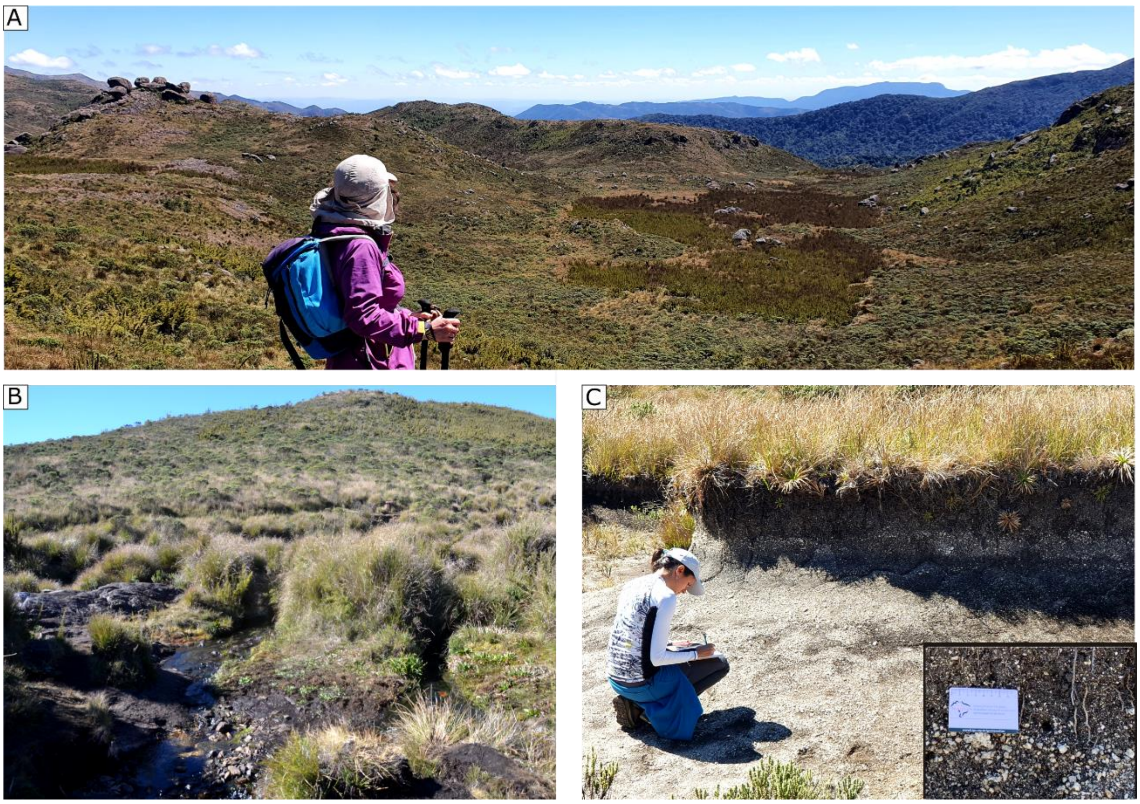


Fig. A.1 Geosite Bog of Aiuruoca River. (A) View of the geosite, highlighting the high-altitude grasslands in the central area. (B) View of the spring of Aiuruoca River surrounded by peat deposits and high-altitude grasslands. (C) Alluvial deposits with sub-rounded to rounded granules and pebbles in the central and upper portion of the profile. (Figure A: photo by Vanessa C. Mucivuna, figures B and C: photos by Maria da Glória M. Garcia).

<table>
<tr><td rowspan="3">Use and management</td><td>Potential use: Scientific, educational and touristic.</td></tr>
<tr><td>Security: No significant risk.</td></tr>
<tr><td>Observing conditions: The vegetation obstructs the observation of some geological elements.</td></tr>
</table>

	Interpretative potential: High, as the spring is excellent to raise public awareness of the importance of protection and conscious use of water. Moreover, the spring and the floodplain are essential to the maintenance and reproduction of local fauna and flora.
	Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area and toilets at the trailhead.
	Degradation risk: About fragility, the process of rainfall erosion is affecting the stability of the alluvial deposits. Regarding vulnerability, the intense use of the trail, the forest fires (by natural or human activities) and incorrect garbage disposal are the main factors of anthropic vulnerability.
	Use limitations: The geosite can be visited during the park's opening hours. There is no limit to the number of visitors per day. The time limit to start the Aiuruoca Waterfall trail is 10:00 am.

Identification	**Name:** Geosite Bog of Preto River.
	Municipality: Bocaina de Minas (MG) and Itatiaia (RJ).
	Geographical coordinates (UTM WGS-84): 23K 536460 / 7526460.
	Access / Trailhead: On foot by following the trail through the Rancho Caído Crossing that starts at Marcão station. This route is about 30 km long (one way), and its difficulty level is considered hard. The geosite is about halfway along the trail.
	Typology: Area and area (single landform).
	Zoning within the management plan: Primitive zone and extensive use zone.
Characterisation	**Framework:** Quaternary deposits.
	Geological unit: Alluvium sediments (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Surface formation, sedimentary, hydrological and geomorphological.
	Specific geomorphological interest: Organic and fluvial processes.
	Other elements of interest: Ecological, aesthetic and historical.
Quantitative assessment	**Scientific value:** 210, 195.
	Degradation risk: 65.
	Potential educational use: 225.
	Potential touristic use: 185.

Description

The geosite Bog of Preto River stands out as a depressive area, with an average gradient of 4% (ICMBio, 2013), filled with alluvial deposits (Fig. A.2A) where the water flows are the source of the Preto river (Fig. A.2B). A few metres from its left bank, alluvial deposits of up to one-metre high were observed, with sub-rounded granules at the top of the profile (Fig. A.2C). ICMBio (2013) stresses that the evolution of this floodplain is adjusted to the ring-dyke, which forms a barrier fundamental to dam the water and the consequent accumulation of peat deposits; while its upper course is marked by drainage anomalies suggestive of recent tectonism (Modenesi, 1992).

Rosa and Ruberti (2018) state that the alluvial sediments are made up of mud and peat deposits, with coarser grains and centimetric clasts in the adjacent areas, their formation being associated with biological and geological processes through the deposition of decomposed plants in wetlands under specific conditions (O'Kelly, 2015).

According to Modenesi and Melhem (1986) and Teixeira (1961), such deposits are usually marked on the Itatiaia Plateau, and the Preto River floodplain is one of the principal peat deposits areas in the park.

Its morphogenesis is linked to the sedimentary and fluvial processes that created the alluvial deposits and the Preto river, respectively. Regarding morphodynamics, sedimentary, fluvial and erosion processes are still ongoing.

The geosite is of great relevance for water source planning and management. Furthermore, it stands out as the natural border between the states of Minas Gerais and Rio de Janeiro.

Figures

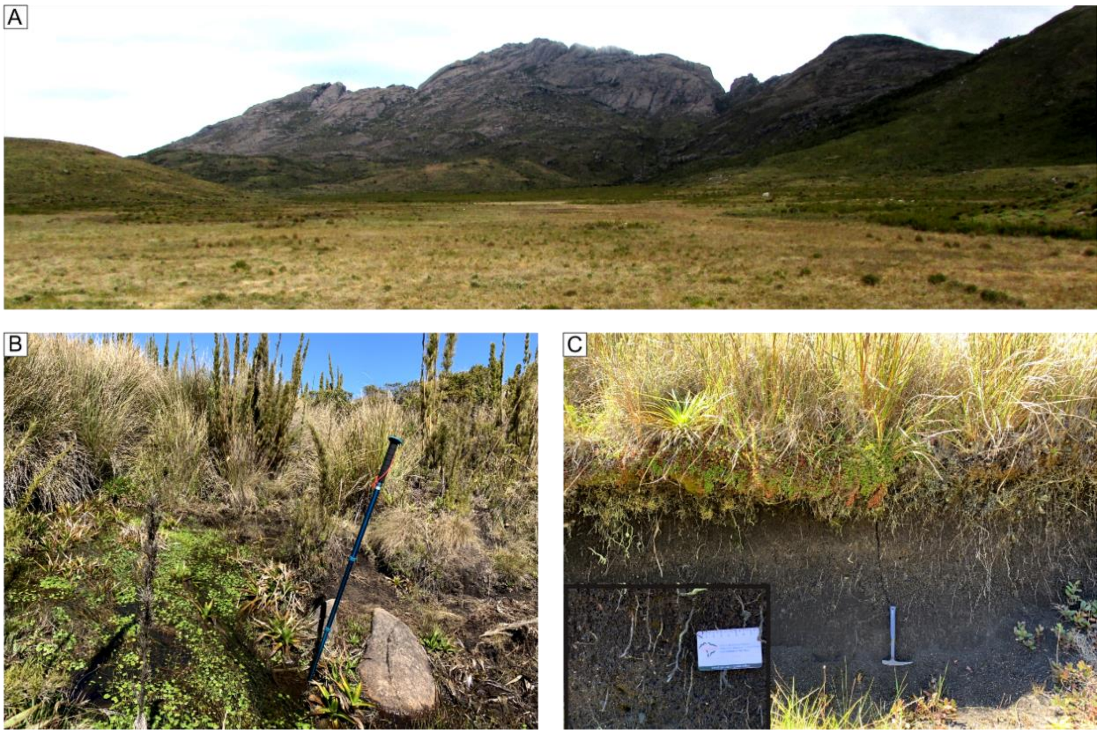


Fig. A.2 Geosite Bog of Preto River. (A) Panoramic view of the Preto River floodplain, highlighting the Agulhas Negras (in the centre) and Pedra do Sino hills (in the right). (B) View of the spring of Preto River surrounded by high-altitude grasslands. (C) Alluvial deposits with sub-rounded granules at the top of the profile. (Figure A: photo by Pedro Augusto S. Rosa, figures B and C: photos by Vanessa C. Mucivuna).

Use and management	**Potential use:** Scientific, educational and touristic.
	Security: No significant risk.
	Observing conditions: The vegetation obstructs the observation of some geological elements.
	Interpretative potential: High, as wetlands and riverheads are excellent to raise public awareness about the importance of the protection and responsible use of water. Furthermore, the view of the

	Agulhas Negras and Pedra do Sino hills are excellent, and these landforms could be included in the interpretation process. These aspects could be explored to offer an integrated interpretation and management, in view of their essential role in biodiversity maintenance and conservation.
	Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area and toilets at the trailhead.
	Degradation risk: About fragility, the process of rainfall erosion is affecting the stability of the alluvial deposits. Regarding vulnerability, the intense use of the trail, the forest fires (by natural or human activities) and incorrect garbage disposal are the main factors of anthropic vulnerability.
	Use limitations: The geosite can be visited during the park's opening hours. The access to Rancho Caído Crossing is restricted to 26 visitors per day. The time limit to start the Rancho Caído Crossing is 9:00 am with advance booking, or 10:00 am without advance booking.

Identification	**Name:** Geosite Fluvial deposits of Lago Azul.
	Municipality: Itatiaia (RJ).
	Geographical coordinates (UTM WGS-84): 23K 539736 / 7517208.
	Access / Trailhead: On foot by following the Lago Azul trail that starts at the Visitor Centre. The route is about 1 km (round trip), and its difficulty level is considered easy. The geosite is located at the end of the trail.
	Typology: Point and point (single landform).
	Zoning within the management plan: Extensive use zone.
Characterisation	**Framework:** Quaternary deposits.
	Geological unit: Gravitational deposits (Talus) (Heilbron et al., 2016).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Hydrological, sedimentary and geomorphological.
	Specific geomorphological interest: Fluvial processes.
	Other elements of interest: Ecological, aesthetic and historical.
Quantitative assessment	**Scientific value:** 260, 255.
	Degradation risk: 120.
	Potential educational use: 295.
	Potential touristic use: 275.

Description

The geosite Fluvial deposits of Lago Azul is a natural pool, in the middle course of the Campo Belo river, with an average gradient of 27% (ICMBio, 2013). It is inserted into an incised valley, in the NW-SE orientation (linked to the preferential lineament of the massif), filled with many boulders and cobbles of alkaline rocks spread along the riverbank (Fig. A.3A). Most of these boulders are rounded up to three metres in diameter (Fig. A.3B). Rounded pebbles, granules and sand are also deposited on its left bank.

According to Heilbron et al. (2016), the gravitational deposits are characterised by large boulders and cobbles in an immature matrix, usually associated with steep slopes.

The morphogenesis of the geosite is related to the intrusion of alkaline rocks, the modelling process that carved the incised valley, the sedimentary deposits and the fluvial processes. Regarding morphodynamics, fluvial and sedimentary processes are in progress and linked to the fragmentation, transport and deposition of sediments along the river. During summer, sudden floods are constant in its riverbeds due to the heavy rains at headwaters.

The size and roundness of sediments are directly linked to the transport from the source area.

Despite the name, the site is not a lake, nor is it blue. The aforementioned natural pool represents one of the curves of Campo Belo River (Teixeira and Linsker, 2007).

Figures

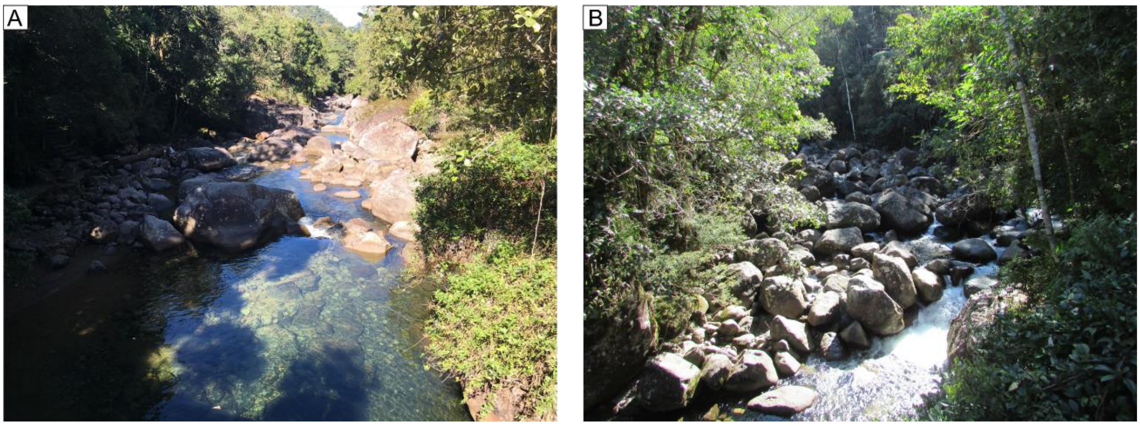


Fig. A.3 Geosite Fluvial deposits of Lago Azul. (A) In the foreground, view of the natural pool; in the background, view of the incised valley. The geosite has rounded rocks scattered along the riverbank and deposited mainly on the left bank. (B) The alkaline rocks are rounded and deposited along the river; their sizes are directly related to the fluvial energy. (Figure A: photo by Vanessa C. Mucivuna and figure B: photo by Debora S. Queiroz).

<table>
<tr><td rowspan="6">Use and management</td><td>Potential use: Touristic, educational and scientific.</td></tr>
<tr><td>Security: No significant risk, but the river speed and level urge caution, especially during summer, when heavy rains at headwaters cause sudden floods on riverbeds.</td></tr>
<tr><td>Observing conditions: All geological elements are observed in good conditions.</td></tr>
<tr><td>Interpretative potential: High, as its features are clearly distinguishable. As the geosite Bog of Aiuruoca River, it has high potential to foster public awareness of the importance of protecting the planet’s freshwater. Moreover, it can be used in sync with the geosite Waterfalls of Campo Belo River basin to correlate rock size with fluvial energy along the river.</td></tr>
<tr><td>Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area, toilets and a snack bar at the trailhead.</td></tr>
<tr><td>Degradation risk: About vulnerability, incorrect waste disposal is the main fact of anthropic vulnerability.</td></tr>
</table>

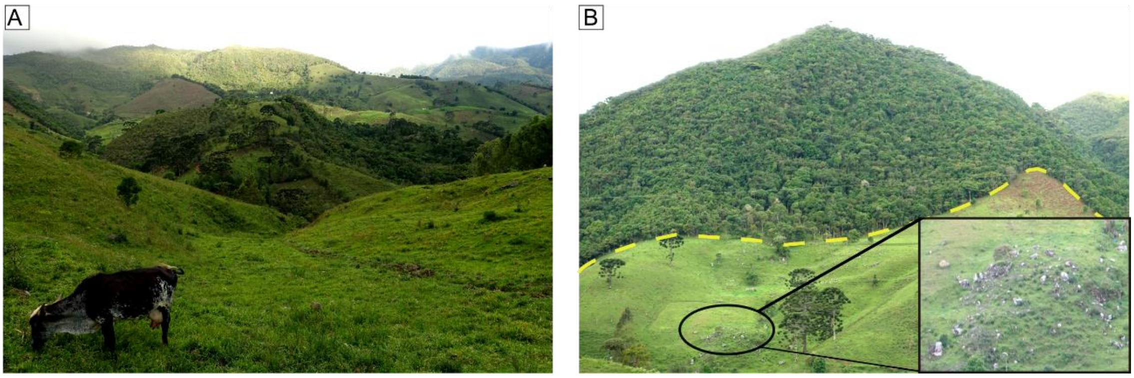
	Use limitations: The geosite can be visited during park’s opening hours. There is no limit to the number of visitors per day.

Identification	**Name:** Geosite Talus deposits of Serra Negra village.
	Municipality: Itamonte (MG).
	Geographical coordinates (UTM WGS-84): 23K 530929 / 7532340.
	Access / Trailhead: By motor vehicle. From Garganta do Registro, follow 8 km along the Flores Highway (BR-485) to Brejo da Lapa, and then 11 km on the unpaved road towards Serra Negra village.
	Typology: Area and area (single landform).
	Zoning within the management plan: Temporary occupation zone.
Characterisation	**Framework:** Quaternary deposits.
	Geological unit: Capivara leucogranite and associated diatexite (Trouw et al., 2003).
	Geomorphological unit: Mantiqueira / Itatiaia Mountain Ranges.
	Geological interests: Geomorphological and surface formations.
	Specific geomorphological interest: Gravitational processes.
	Other elements of interest: Ecological, aesthetic and historical.
Quantitative assessment	**Scientific value:** 235, 235.
	Degradation risk: 230.
	Potential educational use: 245.
	Potential touristic use: 205.

Description

The geosite is formed by talus deposits accumulated under the Capivara leucogranite and associated diatexite unit (Trouw et al., 2003). These deposits are made up of large rock fragments in clay to a sand-clay matrix (ICMBio, 2013). It is characterised by convex tops and slopes, an average gradient of 27% (Fig. A.4A) with little vegetation, while the surroundings are marked by forested areas (ICMBio, 2013). The vegetation contrast is linked to the use of the land for farming. In lower regions, the exposed rocks are related to slope erosion (Fig. A.4B).

Trouw et al. (2003) stress that the Capivara leucogranite and associated diatexite are fine to medium equigranular, with crystals of quartz, K-feldspar, plagioclase, muscovite and biotite. According to ICMBio (2013), it is inserted in the colluvium sediments unit with talus deposits formed due to the dislodged weathered rock fragments from cliffs or free faces and then accumulated at the base of slopes (Jomelli, 2004).

Its morphogenesis is linked to fragments of angular rocks from old mass movements. As to morphodynamics, there is active slope erosion on inherited features. It is an excellent illustrative example of the connection between geodiversity and biodiversity. The scattered vegetation on the slope and the well-developed soils confirm the essential role of geodiversity in supporting and maintaining biodiversity.	
Figures  **Fig. A.4** Geosite Talus deposits of Serra Negra village. (A) View of the convex-shaped talus deposits in the northern region of the park. (B) The yellow dotted line shows the vegetation contrast, which is a result of deforestation for grazing. In the black circle, the concentration of exposed boulders is due to the erosion of slopes. (Figures A and B: photos by Vanessa C. Mucivuna).	
Use and management	**Potential use:** Scientific, educational and touristic.
	Security: The observation of the geosite is made from the road without a parking zone. There is no risk on the geosite itself.
	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: High, as landforms are clearly distinguishable, being possible to create links with geosciences content. Furthermore, this site is easily accessible, so a wider range of visitors, including children, disabled people and the elderly can reach it. It can also be used as a tool to introduce integrated interpretation, explaining the links and role of geodiversity in supporting and maintaining biodiversity.
	Infrastructure: There is no infrastructure on the geosite itself.
	Degradation risk: About fragility, the processes of creep and debris flow is affecting the slopes. Concerning vulnerability, the risks of mass movements are intensified in the summer due to rainfall intensity.
	Use limitations: There is no restriction to access the geosite.

Identification	**Name:** Geosite Structural valley of Campo Belo River.
	Municipality: Resende (RJ).
	Geographical coordinates (UTM WGS-84): 23K 532716 / 7524651.
	Access / Trailhead: By motor vehicle through Flores Highway, from Marcão station.
	Typology: Complex area and complex area (geomorphological system).
	Zoning within the management plan: Primitive zone, extensive and intensive use zones.
Characterisation	**Framework:** Cenozoic tectonism.
	Geological unit: Alluvium sediments (area i and ii), quartz alkali feldspar syenite II (areas iii, iv and v) and microalaskite (area vi) (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Geomorphological, tectonics, surface formation, sedimentary, hydrological, paleoenvironmental and plutonism.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Aesthetic, ecological and historical.
Quantitative assessment	**Scientific value:** 340, 340.
	Degradation risk: 75.
	Potential educational use: 210.
	Potential touristic use: 200.

Description

The geosite comprises a structural valley in the central sector of the IAM (IBGE, 2019), covering an area of about 1.5 km² at altitudes ranging between 2,332 and 2,356 metres (Fig. A.5A). It includes six sub-areas (Fig. A.5B) located in the NW-SE oriented VLL (Rosa and Ruberti, 2018), where the gradient varies from 4% to 27% (ICMBio, 2013).

According to Rosa and Ruberti (2018), the alluvial sediments are mostly composed of mud and peat deposits, with coarser grains and centimetric clasts in the adjacent areas. The quartz-alkali feldspar syenite II is brownish to light grey with a characteristic medium-grained massif-oriented structure and granular texture. The microalaskite has an equigranular structure and a light creamy grey colour, showing 26% of quartz and alkali feldspar intergrowths. Prismatic quartz, ankerite and albite fill the myarolytic cavities.

Its morphogenesis is associated with the Cenozoic tectonic reactivation that gave rise to the VLL and the deposition of sediments at the valley bottom as well as on slopes. As to morphodynamics, most of the events that formed the geosite are inactive. However, there are still erosion and rockfall on the slopes and sedimentary and fluvial processes at the bottom of the valley.

The sub-areas are:

(i) Spring of Campo Belo River - a depressive area filled with peat sediments, where the accumulated water flows at an altitude of 2,350 metres (Fig. A.5C). Modenesi and Melhem (1986) pointed out that it is one of the main depressive areas with peat deposits in the study area. Its morphogenesis is linked to the hydrographic and sedimentary processes that are still in progress.

(ii) Peat deposits of Flores River - described as black sediments, with an apparent high level of humidification and predominance of gellified material. Non-decomposed plant remains were found at the top of the profile (from 15 to 20 cm), forming a thick tangle with a fibrous structure of up to 100 cm. The texture alternates from sandy to sandy-clay (over 30 cm and at the base, weathered rock), silica clay (from 30 to 70 cm and 210 to 255 cm) and clay (from 70 to 210 cm). Although the sediments are predominantly fine and homogeneous, coarse sand, granules and sparse pebbles have been found in small lenses inside the peat deposits (Modenesi and Melhem, 1986). These authors state that pollen grains predominate over spores in all layers of the profile. Its morphogenesis is associated with sedimentary and hydrographic processes that are still active.

(iii) Colluvium deposits - Pleistocene ramps dated 13,000/12,700 BP are less than one-metre thick on the weathered bedrock. They are described by Modenesi (1992) and Modenesi-Gauttieri and Toledo (1996) as massive and compact, lacking structures and having cobbles with different degrees of alteration. Moreover, they have many pebbles (around 25%), cobbles and boulders scattered in a yellowish-brown clay matrix, with whitish and yellowish-red mottles from weathered feldspar and ferruginous nodules. The most recent deposits (Holocene) are at the bottom of the colluvium deposits and extend over the peat deposit of the floodplain. They are up to 240 cm-high, having less coarse sediments and stony appearance with strong colour contrast between the dark matrix and the pebbles of various colours (Modenesi, 1992). According to Modenesi and Toledo (1993), they were deposited between 7,950 ± 100 years BP (220 cm deep) and 2,790 ± 80 years BP (60 cm deep). Modenesi (1992) and Modenesi and Toledo (1993) state that these ages indicate an interdigitation between the second-generation colluvium and floodplain sediments (deposited between 8,200 BP (230 cm deep) and 1,090 BP (50 cm deep)). Its morphogenesis is linked to mudflow in humid and perhaps lesser cold climates due to the weathering of materials on slopes (Modenesi, 1992; Modenesi and Toledo, 1993; Modenesi-Gauttieri and Toledo, 1996). The Holocene colluvium has its morphogenesis linked to mudflow or slower mass movements that would have been able to mobilise and deposit weathered materials without damaging surface deposits (Modenesi and Toledo, 1993). Regarding morphodynamics, slope erosion modifies the inherited features but maintains its main characteristics.

(iv) Talus cones and linear concentration of boulders (stone streams) - represent the inherited features hidden by vegetation, hanging over the current floodplains (Fig. A.5D) (Modenesi-Gauttieri and Nunes, 1998). The size and quantity of boulders in talus deposits and stone streams suggest the influence of seismicity on detaching them from the intensely fractured free faces. On the slopes of the Flores river valley, cobbles and boulders are observed *in situ* (flowing in structural directions) as well as scattered on the slopes (without clear orientation) (Modenesi, 1992). About morphogenesis, coarse-texture deposits would reflect the past processes related to freezing and melting cycles, whereas small weathered cobbles at the bottom of the talus deposits would be associated with older mass movements (Modenesi, 1992). Modenesi-Gauttieri (2000) stresses that cobbles and boulders in talus deposits may have their morphogenesis associated with gravity (rockfall) and seismicity due to tectonic activities in cold-humid environments. Regarding morphodynamics, dislodged weathered rocks from free faces and rockfalls are in progress and contribute to the evolution of the current and inherited features.

(v) Flores Waterfall - formed by the first cascade of Campo Belo River, it is a three-tiered waterfall with approximately seven metres high and a natural pool of about 15 metres in diameter. The natural pool is filled with rock fragments with angular edges and variable sizes (Fig. A.5E). Downstream, the river flows in the NW-SE orientation in an incised valley. Across the plateau, the river is adjusted to a W-WNW oriented fault, being correlated with the second tectonic phase of the development of the Serra do Mar Rift System (Penalva, 1967; Riccomini, 1989). Its morphogenesis is correlated with the intrusion and fracturing of alkaline rocks, tectonic reactivation, as well as fluvial processes that sculpted its features. Concerning morphodynamics, the fluvial process is still active and plays a fundamental role in the weathering of the fracture planes

(vi) Microalaskite - the outcrop is a low elongated hill with a light grey colour. It is located in the VLL, where the conjugate shear joints stand out (Fig. A.5F). Its morphogenesis is linked to the intrusion and fracturing of alkaline rocks and the tectonic reactivation that contributes to the structural pattern of the VLL. About morphodynamics, erosion is acting on the outcrop; nevertheless, the inherited characteristics are well preserved.

Figures

Fig. A.5 Geosite Structural valley of Campo Belo River. (A) View of the geosite, highlighting the NW-SE orientation of the valley and the concentration of boulders on slopes. (B) The white dotted line shows the structural pattern of the geosite and the Roman numerals the approximate location of the sub-areas: [i] Spring of Campo Belo River, [ii] Peat deposits of Flores River, [iii] Colluvium deposits, [iv] Talus cones and linear concentration of boulders, [v] Flores Waterfall and [vi] Microalaskite. (C) View of the spring of Campo Belo river surrounded by peat sediments and high-altitude vegetation. (D) View of talus deposits and concentration of boulders on slopes. (E) View of the Flores waterfall, highlighting the three rock tiers formed by horizontal fracture planes. (F) Detail of the microalaskite outcrop, highlighting the conjugate shear joints in the VLL. (Figures A and D: photos by Maria da Glória M. Garcia, figure B: organised by Vanessa C. Mucivuna based on Google Earth (2021), figure C: photo by Vanessa C. Mucivuna, figure E: photo by Debora S. Queiroz and figure F: photo by Pedro Augusto S. Rosa).

	Potential use: Scientific, touristic and educational.

Use and management	**Security:** No significant risk, but caution is advised on the trail to access Flores Waterfall due to its steep slope, as well as the natural pool’s water level and speed.
	Observing conditions: The vegetation obstructs the observation of some geological elements.
	Interpretative potential: Excellent, as its geological features are clearly distinguishable and linked with two main events: (i) intrusion and fracturing of alkaline rocks and (ii) deposition of sediments at the bottom of the valley and on slopes. It has a high geomorphological interest because besides being inserted in the VLL, it includes features such as talus, colluvium and peat deposits, linear concentration of boulders on slopes, and an incised valley. As other geosites linked to hydrographic processes, this one could also be used to increase awareness of water protection and conscious use.
	Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area and toilets at the trailhead.
	Degradation risk: About fragility, the processes of landslides and debris flow can occur on the slopes. Concerning vulnerability, biological activity of plants is the main factor enhancing the natural vulnerability of the site. The incorrect waste disposal, the trampling in areas off the trail and the use of the highway during the breeding season of the *Melanophryniscus moreirae* (an endemic species of Brazilian amphibian, which is the symbol of the Itatiaia National Park) are the main causes of anthropic vulnerability.
	Use limitations: The geosite can be visited during the park’s opening hours. There is no limit to the number of visitors per day.

<table>
<tr><td rowspan="6">Identification</td><td>Name: Geosite Fault escarpment of Couto-Prateleiras.</td></tr>
<tr><td>Municipality: Resende (RJ).</td></tr>
<tr><td>Geographical coordinates (UTM WGS-84): 23K 532843 / 7524000.</td></tr>
<tr><td>Access / Trailhead: On foot by following the Couto-Prateleiras Crossing trail that starts at Marcão station. The trail is about 12.5 km long (round trip) and the difficulty level is considered moderate, except for the stretch to get to the summit of Prateleiras Hill, considered hard. Its geological interest is along the trail.</td></tr>
<tr><td>Typology: Complex area and complex area (geomorphological complex).</td></tr>
<tr><td>Zoning within the management plan: Primitive zone and extensive use zone.</td></tr>
<tr><td rowspan="6">Characterisation</td><td>Framework: Cenozoic tectonism.</td></tr>
<tr><td>Geological unit: Nordmarkite II (area i), quartz alkali feldspar syenite II (area ii) and quartz alkali feldspar syenite I (areas iii and iv) (Rosa and Ruberti, 2018).</td></tr>
<tr><td>Geomorphological unit: Paraíba do Sul River Depression.</td></tr>
<tr><td>Geological interests: Geomorphological, tectonics and plutonism.</td></tr>
<tr><td>Specific geomorphological interest: Structural processes.</td></tr>
<tr><td>Other elements of interest: Aesthetic, ecological and historical.</td></tr>
<tr><td rowspan="4">Quantitative assessment</td><td>Scientific value: 330, 310.</td></tr>
<tr><td>Degradation risk: 75.</td></tr>
<tr><td>Potential educational use: 215.</td></tr>
<tr><td>Potential touristic use: 240.</td></tr>
<tr><td colspan="2">Description
The Fault escarpment of Couto-Prateleiras is a N70W (Penalva, 1967) oriented fault scarp (IBGE, 2019), covering approximately 2.1 km² at altitudes ranging between 2,541 and 2,687 metres. The geosite has rounded tops, straight slopes with an average gradient of 42% (ICMBio, 2013). It includes four sub-areas across the Itatiaia Plateau, isolated between the VLL and the cliff on the south side of the IAM (Fig. A.6A).
According to Rosa and Ruberti (2018), the nordmarkite II is dark grey, medium-grained inequigranular, and has a slight structure. The quartz-alkali feldspar syenite II is brownish to light grey with a characteristic medium-grained massif-oriented structure and granular</td></tr>
</table>

texture. The quartz alkali feldspar syenite I is medium-to-coarse-grained inequigranular and has a light rose brown colour, with whitish smudges and miarolitic cavities filled with quartz crystals.

Its morphogenesis is linked to both the intrusion of alkaline rocks and the tectonic reactivation that resulted in the development of CRSB (Riccomini, 1989; Riccomini et al., 2004). About morphodynamics, rockfall, spheroidal weathering, fluted and pitted erosion are in progress, contributing to the evolution of the current features while maintaining the inherited features.

The sub-areas are:

(i) Morro do Couto - the second-highest hill in the study area, at 2,687 metres of altitude (Fig. A.6B), is related to a W-E oriented lineament, with a rounded top, steep slopes and fracture planes. Its morphogenesis is linked to the intrusion and fracturing of alkaline rocks. As to morphodynamics, the chemical weathering in the fracture planes resulted in the development of rounded boulders, fluted and pitted erosion, as well as spheroidal weathering.

(ii) Toca do Índio - it refers to a “cave” at 2,542 metres of altitude, located along the Couto-Prateleiras Crossing. It is characterised by metric boulders, locally with shallow flutes, spheroidal weathering (Fig. A.6C) and associated with a NW-SE oriented lineament (elongation of the massif). Its morphogenesis is linked to fracturing, spheroidal weathering, fluted erosion and rockfall processes that are still ongoing.

(iii) Prateleiras - the ninth-highest hill in the study area, at 2,536 metres of altitude (Fig. A.6D), is characterised by rounded tops, comprising cross-orthogonal joint systems, which resulted in the development of boulders (up to 15 m high) with flat faces and rounded to sub-rounded edges. The boulders follow the pattern of the fracture planes and are detached from each other by deep and wide joints (Modenesi, 1992; Modenesi-Gauttieri and Toledo, 1996). Locally, vertical fracture planes contribute to the development and evolution of dissolution flutes. Its morphogenesis is associated with the intrusion and fracturing of alkaline rocks. Regarding morphodynamics, fluted and pitted erosion is caused by the action of microorganisms in association with water in the fracture planes, while spheroidal weathering is related to the disintegration of edges, through the attack of water where two or more joints meet.

(iv) Pedra da Maçã is a nine-metre boulder high and six-metre in diameter, while Pedra da Tartaruga is seven-metres high, 12-metres wide and 20-metres long (Fig. A.6E). Both have rounded edges with fluted erosion on their faces and pitted erosion on their flattened top caused by fracture planes. Their morphogenesis is related to fracturing, spheroidal weathering and fluted erosion that are in progress.

The geosite also stands out as a spectacular viewpoint, as it has a panoramic view of the INP landscape (Antena Hill, Agulhas Negras Hill and Maromba Peak) and its surroundings (Funil Dam, Paraíba do Sul River Valley and Fina Mountain Range).

Figures

Fig. A.6 Geosite Fault escarpment of Couto-Prateleiras. (A) Panoramic view of the geosite from the Agulhas Negras Peak. In the foreground, view of the Prateleiras [1] and Morro do Couto hills [2]. In the background, view of the Bocaina mountain range [3], Paraíba do Sul River valley [4], and Fina mountain range [5]. (B) Detail of Morro do Couto Hill, highlighting the fracture planes on slopes. (C) View of the Toca do Índio with rounded boulders. (D) Detail of Prateleiras Hill, with visible orthogonal joint systems. (E) Pedra da Maçã [1] and Pedra da Tartaruga boulders [2]. (Figures A, B and C: photos by Vanessa C. Mucivuna, figure D: photo by Raquel M. M. Romão and figure E: photo by Eliana Mazzucato).

Use and management	**Potential use:** Scientific, touristic and educational.
	Security: Risk of rockfalls. Some stretches urge caution due to steep slope, slippery grounds and loose rocks.
	Observing conditions: The vegetation obstructs the observation of some geological elements.
	Interpretative potential: High, as its features, such as the fractures and boulders, are essential to illustrate the spheroid exfoliation process. Furthermore, the panoramic view allows visitor to clearly distinguish significant landforms, such as the graben of the Paraíba do Sul and the horsts of the Serra do Mar and Serra da Mantiqueira. It also has tourism value, as it is one of the most visited hills of the park.
	Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area and toilets at the trailhead.
	Degradation risk: Regarding fragility, the process of chemical weathering is producing spheroid exfoliation, fluted and pitted erosion. About vulnerability, some trail stretches have water drainage and erosion issues, and at the summit of Prateleiras, there are some engravings, an irreversible damage to its integrity.
	Use limitations: It can be visited during the park's opening hours. The access to the summit of Prateleiras is restricted to 80 people per day, while the visitation to the base and Pedras da Tartaruga and Maçã is limited to 120 people per day. The time limit to begin the trail to the summit is 11:00 am, while that to the base and Pedras da Tartaruga and Maçã is noon. There is no limit to the number of visitors per day to Morro do Couto Hill. The time limit to start the trail is 2:00 pm.

Identification	**Name:** Geosite Biotite monzonite quarry.
	Municipality: Itamonte (MG).
	Geographical coordinates (UTM WGS-84): 23K 526016 / 7526458.
	Access / Trailhead: By motor vehicle through km 3.8 of Flores Highway (BR-485) towards Marcão station.
	Typology: Point.
	Zoning within the management plan: Intensive use zone.
Characterisation	**Framework:** Third magmatic stage of alkaline intrusion.
	Geological unit: Biotite monzonite (Rosa and Ruberti, 2018).
	Geomorphological unit: Mantiqueira / Itatiaia Mountain Ranges.
	Geological interests: Petrological and plutonism.
	Specific geomorphological interest: -
	Other elements of interest: Cultural and ecological.
Quantitative assessment	**Scientific value:** 230, -.
	Degradation risk: 265.
	Potential educational use: 170.
	Potential touristic use: 180.

Description

The geosite Biotite monzonite quarry stands out for its easy access and for having been described for the first time in the IAM by Rosa and Ruberti (2018). It is representative of the most recent magmatic event in the study area. It is composed of a greenish-grey biotite monzonite, with medium-grained massive crystals and a significant amount of poikilitic biotite, with cleavage planes and no preferential orientation (Fig. A.7A). The geosite is associated with a notable E-W oriented lineament (Rosa and Ruberti, 2018).

Figure

Fig. A.7 Geosite Biotite monzonite quarry. (A) Biotite monzonite showing massive, greenish-grey medium-grained crystals (Figure A: photo by Pedro Augusto S. Rosa).

Use and management	**Potential use:** Scientific and educational.
	Security: No significant risk.
	Observing conditions: The vegetation almost obstructs the observation of the main geological elements.
	Interpretative potential: Low, as only people with specific knowledge of Geology could distinguish its features. It also has geological-historical potential, as its rocks were used as raw material for the building of the *Casa de Pedra* (lodging used by the ex-president Getúlio Vargas during his visits to the INP).
	Infrastructure: There is no infrastructure on the geosite itself.
	Degradation risk: About vulnerability, biological activity of plants, causing weathering of rocks, is the main cause of natural vulnerability.
	Use limitations: Although it is located in the park, the access to the geosite is before Marcão station. Therefore, there is no access restriction.

<table>
<tr><td rowspan="6">Identification</td><td>Name: Geosite Breccia of Pedra Furada Hill.</td></tr>
<tr><td>Municipality: Itamonte (MG).</td></tr>
<tr><td>Geographical coordinates (UTM WGS-84): 23K 528365 / 7527402.</td></tr>
<tr><td>Access / Trailhead: On foot by following Pedra Furada trail that starts at km 11.5 of BR-485, near the Alsene Hotel. This route is approximately 5.5 km long (round trip), and its difficulty level is considered moderate. The geosite is at the end of the trail.</td></tr>
<tr><td>Typology: Point and area (single landform).</td></tr>
<tr><td>Zoning within the management plan: Primitive zone and intensive use zone.</td></tr>
<tr><td rowspan="6">Characterisation</td><td>Framework: Third magmatic stage of alkaline intrusion.</td></tr>
<tr><td>Geological unit: Trachyte I (Rosa and Ruberti, 2018).</td></tr>
<tr><td>Geomorphological unit: Mantiqueira / Itatiaia Mountain Ranges.</td></tr>
<tr><td>Geological interests: Petrological, plutonism and geomorphological.</td></tr>
<tr><td>Specific geomorphological interest: Structural processes.</td></tr>
<tr><td>Other elements of interest: Aesthetic, ecological and historical.</td></tr>
<tr><td rowspan="4">Quantitative assessment</td><td>Scientific value: 255, 175.</td></tr>
<tr><td>Degradation risk: 85.</td></tr>
<tr><td>Potential educational use: 185.</td></tr>
<tr><td>Potential touristic use: 180.</td></tr>
<tr><td colspan="2">Description
The Breccia of Pedra Furada Hill is the seventh highest hill in the study area at 2,590 metres of altitude and an area of approximately 7,500 m² (Fig. A.8A). It is characterised by well-marked fracture planes, top and smooth convex slopes with an average declivity of 42% (ICMBio, 2013).
According to Rosa and Ruberti (2018), the trachyte I unit occurs in the transition between the C-S and NW-S sectors of the IAM. It is described as a breccioid with an aphanitic matrix with millimetre-to-centimetre angular fragments of aphanitic to fine-grained rock, auto-fragments and alkali feldspar megacrysts. These authors suggest that these rocks could symbolize a fourth magmatic stage of alkaline intrusion, corresponding to subvolcanic conducts with epigenetic characteristics.
Its morphogenesis is related to the intrusion and fracturing of alkaline rocks, while morphodynamics is associated with the erosion of slopes over inherited features.</td></tr>
</table>

Despite the name, Pedra Furada Hill is not related to a holed stone, but to the gap between two boulders that resemble a hole (Fig. A.8B), located along the trail, some metres below the summit (Teixeira and Linsker, 2007).

The geosite offers a panoramic viewpoint from its summit, one of the best places to observe the geosite Leucogranite of Pedra Grande Hill, as well as the landforms delineated by convex and less steep slopes, associated with the Proterozoic rocks, and sharp peaks correlated to alkaline rocks (Fig. A.8C). On the trail to Pedra Furada Hill, some outcrops have fluidal textures with deformed fragments.

Figures

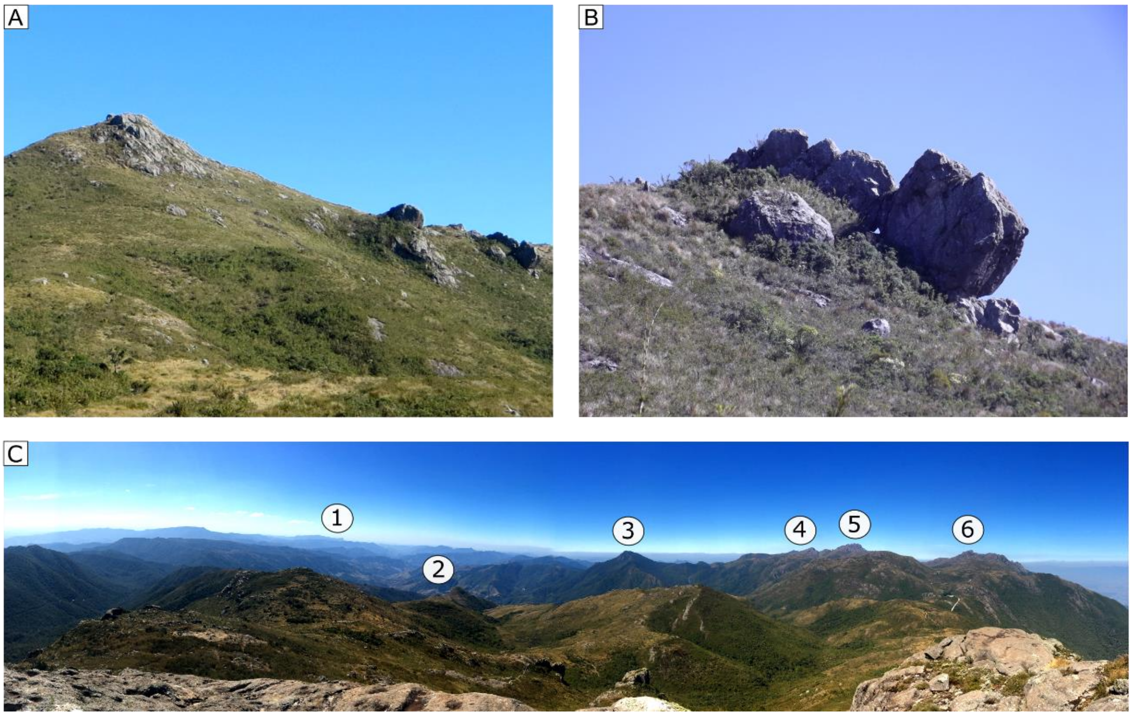


Fig. A.8 Geosite Breccia of Pedra Furada Hill. (A) View of the Pedra Furada Hill. The summit is on the left, and the rock formations are on the right, also shown in figure B. (B) Detail of the set of two boulders and the gap between them. (C) View from its summit of [1] Papagaio Peak (outside of the study area), [2] Pedra Grande Hill, [3] Serra Negra Peak, and [4] Pedra do Sino Hill, [5] Agulhas Negras Peak, and [6] Morro do Couto Hill. (Figures A, B and C: photos by Vanessa C. Mucivuna).

Use and management	**Potential use:** Scientific, touristic and educational.
	Security: No significant risk on the geosite itself. However, the fork on the ridge access trail is not clearly marked, and some stretches could be dangerous because of loose boulders.
	Observing conditions: The vegetation obstructs the observation of some geological elements.
	Interpretative potential: Good, as the features are clearly distinguishable, particularly at the summit, where vegetation is scarcer.

	Although having some distinct features, the interpretative strategy could include the geodiversity site Breccia of Camelo Hill since both are inserted in the same lithological unit (Rosa and Ruberti, 2018).
	Infrastructure: There is no infrastructure on the geosite itself.
	Degradation risk: Concerning vulnerability, forest fires (by natural or human activities) and biological activity of plants, causing weathering of rocks, are the main factors of natural and anthropic vulnerability.
	Use limitations: Although the geosite is located in the park, its trailhead is before Marcão station. Therefore, there is no access restriction.

Identification	**Name:** Geosite Fracture planes of Pedra do Altar Hill.
	Municipality: Resende (RJ).
	Geographical coordinates (UTM WGS-84): 23K 533539 / 7525715.
	Access / Trailhead: On foot, by following the Pedra do Altar Hill trail that starts at Marcão station. The trail is six kilometres long (round trip), and its difficulty level is considered moderate. The geosite is at the end of the route.
	Typology: Area and area (single landform).
	Zoning within the management plan: Primitive zone and extensive use zone.
Characterisation	**Framework:** Second magmatic stage of alkaline intrusion.
	Geological unit: Quartz alkali feldspar syenite II (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Tectonics, plutonism and geomorphological.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Aesthetic, ecological and historical.
Quantitative assessment	**Scientific value:** 240, 230.
	Degradation risk: 75.
	Potential educational use: 235.
	Potential touristic use: 230.

Description

The geosite Fracture planes of Pedra do Altar Hill covers an area of almost 17,000 m² at an altitude of 2,663 metres. The top of the hill is easy to reach on foot, not having any stretch that requires climbing skills. It is an intensely fractured hill, with uneven surfaces, smooth convex top, straight slopes and an average gradient of 42% (ICMBio, 2013). Vertical and sub-vertical fracture planes are arranged on slopes (Fig. A.9A, A.9B and A.9C) and pitted erosion, caused by chemical weathering and reaching up to 20 cm in diameter (Fig. A.9D), are observed on the ridge.

Rosa and Ruberti (2018) stress that the quartz alkali feldspar syenite II is brownish to light grey with a characteristic medium-grained massif-oriented structure and granular texture. The geosite is related to an ENE-WSW oriented lineament, concordant with the tectonic configuration of the basement and the CRSB.

Its morphogenesis is associated with the intrusion and fracturing of alkaline rocks. Regarding morphodynamics, pitted erosion is in progress, producing new features while maintaining the inherited ones.

It also stands out due to its panoramic view of the following geosites: Structural valley of Campo Belo River (Fig. A.5), Fault Escarpment of Couto-Prateleiras (Fig. A.6), Fluted erosion of Agulhas Negras Hill (Fig A.10) and Ring-dyke on Itatiaia Plateau (Fig. A.12).

Figures

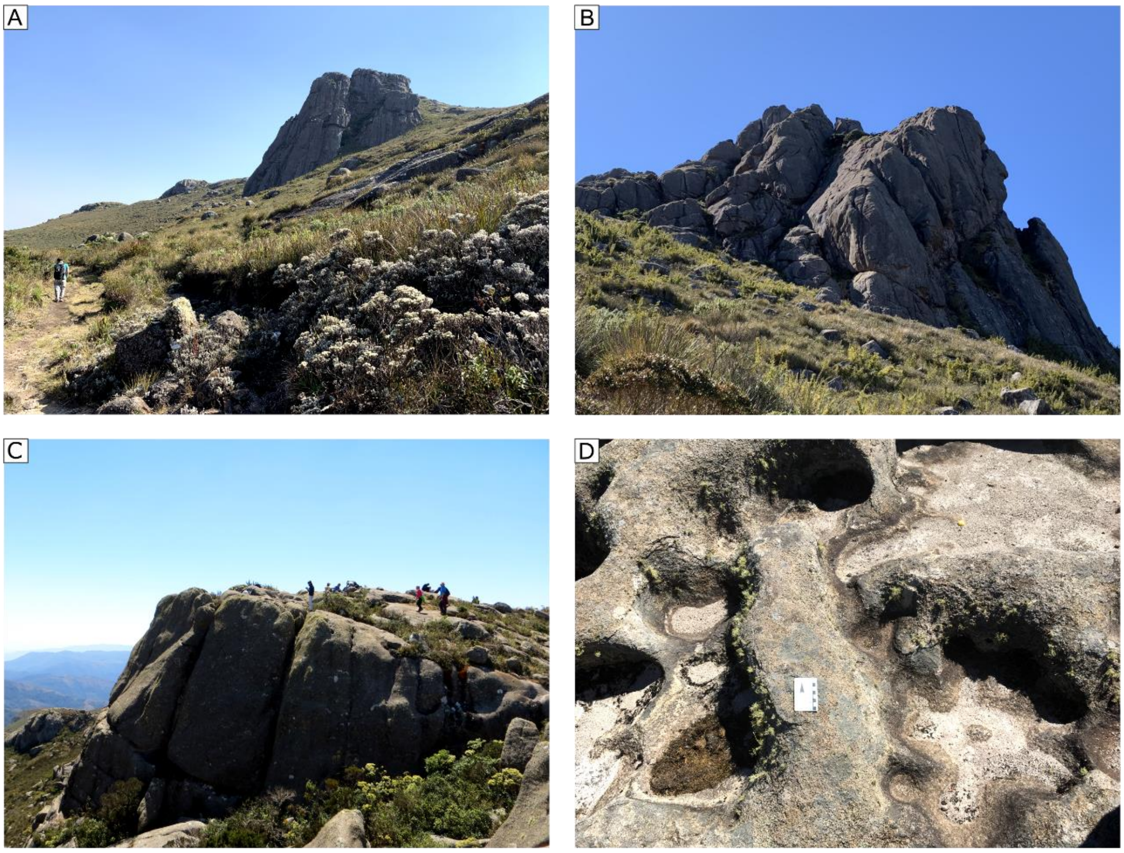


Fig. A.9 Geosite Fracture planes of Pedra do Altar Hill. (A) View of the geosite, highlighting its fracture planes. (B) Details of fractures planes on slopes. (C) Detail of the sub-vertical fracture planes associated with fluted erosion on steep slopes. (D) Detail of the ridge highlighting the deeply pitted erosion (Figures A, B and D: photos by Vanessa C. Mucivuna and figure C: photo by Eliana Mazzucato).

Use and management	**Potential use:** Scientific, educational and touristic.
	Security: No significant risk.
	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: High, as all geological features are clearly distinguishable. On slopes, fracture planes and fluted erosion could be used to illustrate the importance of structures in rock weathering. On the ridge, pitted erosion could be used to illustrate the integrated action

	of geodiversity and biodiversity in the development of these features. The geosite also has a panoramic view of the Itatiaia Plateau and surroundings, in addition to one of the best views of Agulhas Negras Hill.
	Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area and toilets at the trailhead.
	Degradation risk: About vulnerability, the intense use of the trail and biological activity of plants, causing weathering of rocks, are the main factors of anthropic and natural vulnerability.
	Use limitations: The geosite can be visited during the park's opening hours. There is no limit to the number of visitors per day. The time limit to start the Pedra do Altar Hill trail is 11:00 am.

Identification	**Name:** Geosite Fluted erosion of Agulhas Negras Hill.
	Municipality: Bocaina de Minas (MG), Itatiaia and Resende (RJ).
	Geographical coordinates (UTM WGS-84): 23K 534818 / 7525059.
	Access / Trailhead: On foot, by following the Agulhas Negras trail that starts at Marcão station. This route is about 11 km long (round trip), and its difficulty level is considered hard due to the steep and slippery stretches. Climbing equipment is required to reach the peak.
	Typology: Area and area (single landform).
	Zoning within the management plan: Primitive zone and extensive use zone.
Characterisation	**Framework:** Second magmatic stage of alkaline intrusion.
	Geological unit: Quartz alkali feldspar syenite I (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Petrological, tectonics and geomorphology.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Aesthetic, historical and ecological.
Quantitative assessment	**Scientific value:** 330, 330.
	Degradation risk: 65.
	Potential educational use: 250.
	Potential touristic use: 265.

Description

The geosite Fluted erosion of Agulhas Negras Hill covers both the Agulhas Negras and Asa de Hermes hills (Fig. A.10A and A.10B). The geosite is related to the E-W oriented lineament and corresponds to a deeply-dissected hill, with uneven surfaces, sharp peaks, straight slopes, and an average gradient of 42% (ICMBio, 2013).

The quartz alkali feldspar syenite I is a medium-to-coarse grained light rose brown inequigranular lithotype, with whitish smudges and miarolitic cavities filled with quartz crystals (Rosa and Ruberti, 2018).

Several authors have studied the slopes of Agulhas Negras and interpreted their features as a result of different processes, such as glacial (e.g., De Martonne 1943, 1944), karstic (e.g., Talim and Bueno, 2014), and chemical weathering (e.g., Modenesi-Gauttieri and Toledo, 1996). According to Talim and Bueno (2014), chemical dissolution is one of the main factors influencing the features on slopes of Agulhas Negras Hill. This process occurred due to the action of microorganisms in association with water and resulted in fluted (Fig. A.10C) and pitted erosion in the E-W oriented fracture planes. Pitted erosion is observed on steep and middle slopes. It is characterised as a circular depression developed due to the intense action of chemical weathering; the region known as Vale da Lua (Moon Valley) being the best example (Fig. A.10 D). Fluted erosion may be caused by either fracture planes or the evolution of the pitted erosion.

Its morphogenesis is associated with the intrusion and fracturing of alkaline rocks. Regarding morphodynamics, the geosite has inactive processes related to the igneous and tectonic processes that formed it. However, dissolution fluting is in progress and modifies the slope while retaining its inherited features.

Agulhas Negras Hill stands out as the highest peak (Itatiaiaçu) in the study area at an altitude of 2,791 metres and in the state of Rio de Janeiro, being the fifth highest peak in Brazil. Furthermore, it is the watershed divisor of the Grande and Paraíba do Sul rivers.

Its peak also stands out as a highly significant viewpoint, as it has a panoramic view of both geological and geomorphological aspects of the study area and its surroundings. From the Agulhas Negras Peak, it is possible to view Papagaio Peak, in Serra do Papagaio State Park, in the N; Pedra do Altar Hill in the NW; Marombinha and Maromba Peaks in the NE; Prateleiras Hill in the S; Morro do Couto Hill and Fina Mountain Range in the SW; and Três Picos Hill and Paraíba do Sul River Valley in the SE (Fig. A.10E).

Figures

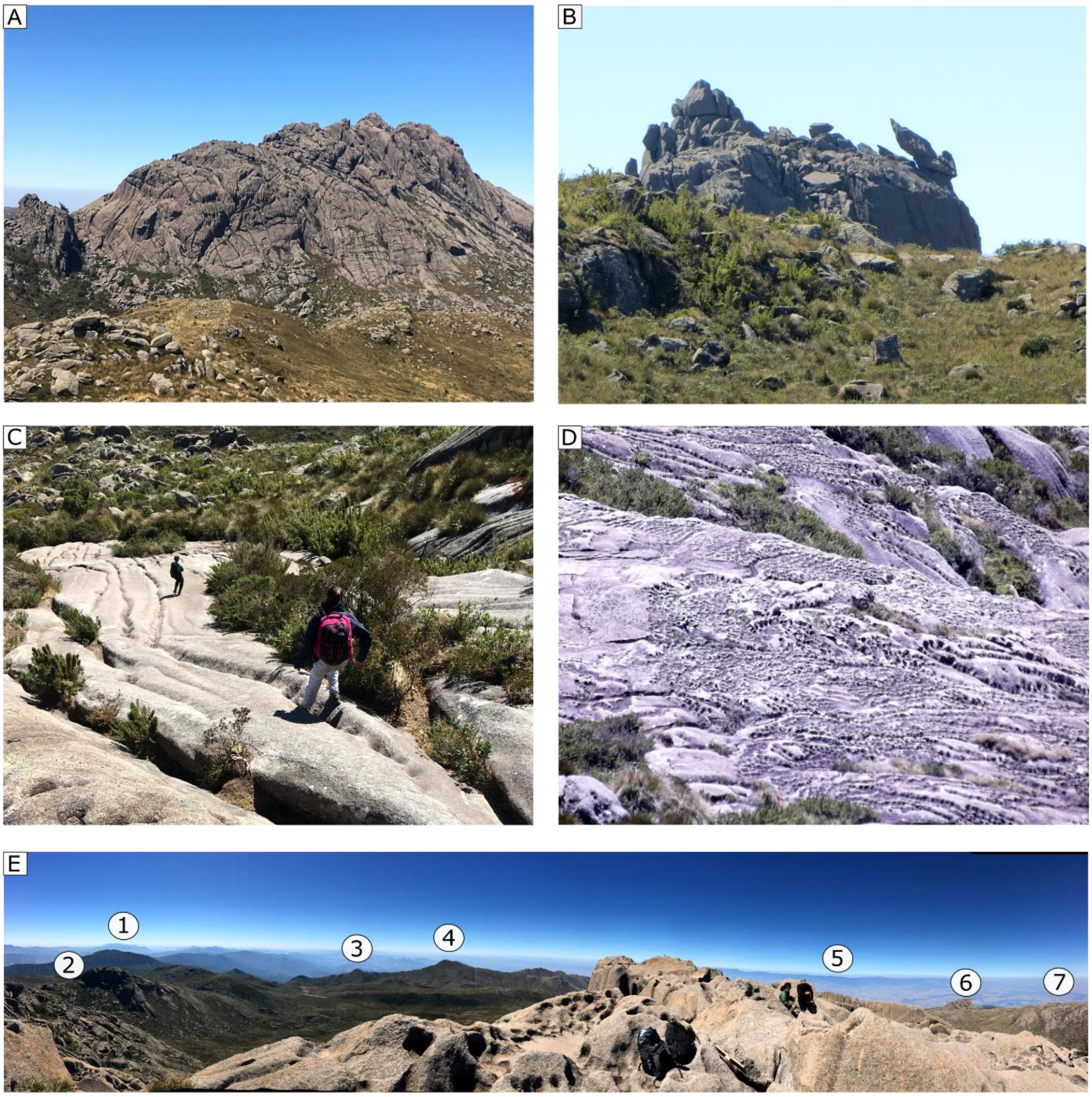


Fig. A.10 Geosite Fluted erosion of Agulhas Negras Hill. (A) The general aspect of the geosite, the vertical and sub-vertical joints. (B) Detail of the Asa de Hermes hill. (C) Dissolution flutes originated from the expansion of fracture planes linked to the chemical and physical weathering process. (D) Detail of the pitted erosion of the Vale da Lua region. (E) View from the geosite of [1] Papagaio Peak, [2] Pedra do Altar Hill, [3] Marombinha Peak, [4] Maromba Peak, [5] Bocaina Mountain Range, [6] Prateleiras Hill and [7] Paraíba do Sul River Valley. (Figures A, D and E: photos by Vanessa C. Mucivuna, figure B: photo by Eliana Mazzucato and figure C: photo by Felipe Guimarães).

Use and management	**Potential use:** Scientific, touristic and educational. It is a popular climbing destination (adventure tourism).
	Safety: There is risk of rockfalls. Some areas urge caution due to steep slope, slippery ground and loose rocks. Moreover, the trail is quite steep, requiring good physical ability. Children's educational activities are not recommended due to the lack of security and the high level of difficulty to reach the peak.

	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: High, as its features are clearly distinguishable. Pitted and fluted erosion can be used to illustrate the role of fracture planes in the development of features. Moreover, the geosite is an extremely significant viewpoint since it has a panoramic view of the landscape of the study area and its surroundings, represented by many rocks and sedimentary deposits of different genesis and ages. However, the difficulty to access it limits the potential for disseminating geosciences. The name Agulhas Negras is directly linked to geodiversity, as the vertical and sub-vertical lines corresponding to fluted erosion, which seems like black needles, then the Toponym.
	Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area and toilets at the trailhead.
	Degradation risk: Regarding fragility, the process of chemical weathering is producing fluted and pitted erosion. About vulnerability, there are some engravings near Agulhas Negras Peak; although they do not affect the identification of the elements of interest, they represent irreversible damage to its integrity.
	Use limitations: The geosite can be visited during the park's opening hours. The access is limited to 80 people per day to Agulhas Negras Peak, 60 people per day to Chapada da Lua, and 30 people per day to the Southern summit. The time limit to start the trail is 10:00 am. There is no limit to the number of visitors per day to Asa de Hermes Hill or the Agulhas Negras base. The time limit to start the trail is 10:30 and 13:00, respectively. The geosite is not accessible by disabled people.

Identification	**Name:** Geosite Ovos da Galinha boulders and trachyte dyke swarm.
	Municipality: Itamonte (MG).
	Geographical coordinates (UTM WGS-84): 23K 535060 / 7526810; 534929 / 7526795.
	Access / Trailhead: On foot by following the Pedra do Sino Hill trail that starts at Marcão station. The route is about 24 km long (round trip), and its difficulty level is considered high. The site is near the end of the trail, and it takes approximately 20 km (round trip).
	Typology: Point and point (group of landforms).
	Zoning within the management plan: Primitive zone and extensive use zones.
Characterisation	**Framework:** Second magmatic stage of alkaline intrusion.
	Geological unit: Biotite hornblende pulaskite (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Plutonism, tectonics and geomorphological.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Aesthetic and historical.
Quantitative assessment	**Scientific value:** 330, 180.
	Degradation risk: 65.
	Potential educational use: 200.
	Potential touristic use: 170.

Description

The Ovos da Galinha Boulders and the trachyte dyke swarm encompasses two sub-areas related to the second magmatic intrusion in the INP. Rosa and Ruberti (2018) state that the biotite hornblende pulaskite unit forms a second C-shaped structure. The lithotype is characterised by a lower feldspathoid content and a slight porphyritic tendency, with some discrepant tabular feldspar crystals and disequilibrium textures. The geosite is associated with a NW-SE oriented lineament, concordant with the elongation of the massif.

(i) The Ovos da Galinha Boulders comprise five NW-SE oriented boulders of up to eight metres in diameter and arranged on a hill (Fig. A.11A). These boulders stand out in the landscape due to their large size and the fluted erosion in their facies.

(ii) The biotite hornblende pulaskite slab is crosscut by trachyte dykes up to one-metre wide and 20 metres long (Rosa and Ruberti, 2018). Some dykes have cooling fractures and sin-plutonic displacement, while others have failed or interconnected intrusive contacts (Fig. A.11B). Both areas have NW-SE orientation, corresponding to the elongation of the massif.

Its morphogenesis is linked to the intrusion of alkaline rocks and the fracture patterns oriented towards the IAM. In area (i), the fracture planes cause boulder fracturing and erosion, while in area (ii), they contribute to the intrusion of dykes in the slab. Regarding morphodynamics, erosion is in progress.

Figures

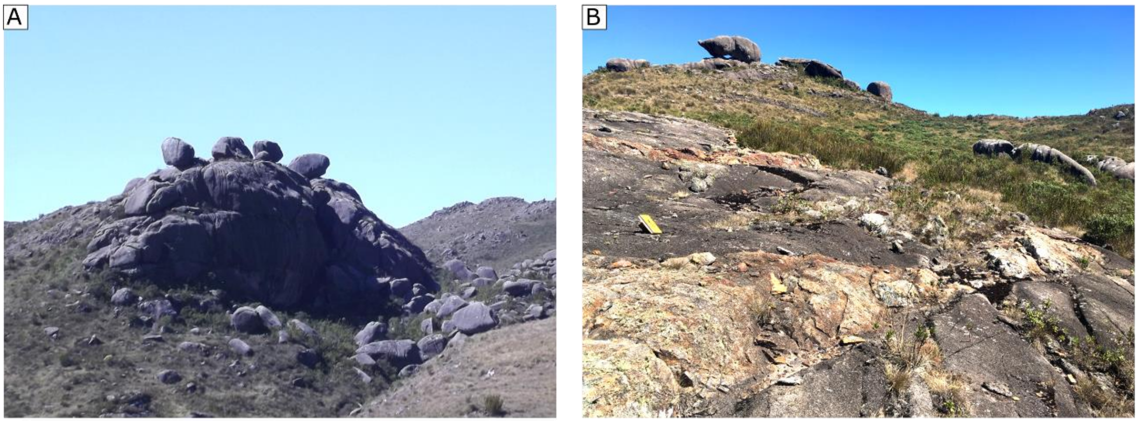


Fig. A.11 Geosite Ovos da Galinha boulders and the trachyte dyke swarm. (A) View of the Ovos da Galinha boulders aligned with NW-SE orientation. (B) Detail of the dyke swarm in a slab to the East of figure A. (Figures A and B: photos by Vanessa C. Mucivuna).

Use and management	**Potential use:** Scientific, educational and tourism.
	Security: No significant risk in the slab, but caution is advised in Ovos da Galinha boulders due to the risk of rockfalls and in-depth fracture planes on the hill.
	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: Moderate since area (i) has geological characteristics that are clearly distinguishable, while area (ii) has features that only people with some Geology knowledge could distinguish. The site can be used to illustrate the role of fracture planes in boulder formation through spheroidal weathering, while the second one could illustrate the role of fracture planes in allowing the dyke intrusion.

	Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area and toilets at the trailhead.
	Degradation risk: About vulnerability, biological activity of plants, causing weathering of rocks, is the main cause of natural vulnerability.
	Use limitations: The geosite can be visited during the park’s opening hours. There is no limit to the number of visitors per day. The time limit to start the Pedra do Sino Hill trail is 10:00 am.

Identification	**Name:** Geosite Ring-dyke on Itatiaia Plateau.
	Municipality: Itatiaia (RJ), Bocaina de Minas and Itamonte (MG).
	Geographical coordinates (UTM WGS-84): 23K 536870 / 7528573.
	Access / Trailhead: The geosite is located on the Itatiaia Plateau. The access to Maromba's summit is by Rancho Caído Crossing and to Serra Negra's summit by the homonymous village or Serra Negra Crossing.
	Typology: Area and area (group of landforms).
	Zoning within the management plan: Primitive zone and extensive use zone.
Characterisation	**Framework:** Second magmatic stage of alkaline intrusion.
	Geological unit: Biotite aegirine-augite nepheline syenite and aegirine nordmarkite (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression and Mantiqueira / Itatiaia Mountain Ranges.
	Geological interests: Petrological, plutonism and geomorphological.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Aesthetic, ecological and historical**.**
Quantitative assessment	**Scientific value:** 330, 295.
	Degradation risk: 65.
	Potential educational use: 230.
	Potential touristic use: 215.

Description

The geosite Ring-dyke on Itatiaia Plateau covers the circular ridge in the IAM centre (Fig. A.12A). It is characterised as a circular crest with eight by nine kilometres in the NW-SE and NE-SW orientations with sinuous sin-plutonic intrusive dykes (Fig. A.12B) and an average gradient of 42% (ICMBio 2013). It extends from Serra Negra Hill (NW) to Maromba and Pedra Cabeça de Leão Hills (E) and, after a gap, to the south in the region of Massena Shelter and Urubu Hill (Teixeira, 1961). It is topographically well defined in its northern and eastern parts; however, it is lower in the south and almost absent in the western region (Fig. A.12C) (Rosa and Ruberti, 2018).

Furthermore, it has water gaps developed by river erosion, Maromba and Aiuruoca Rivers being the most outstanding examples of these features (Teixeira, 1961).

Rosa and Ruberti (2018) point out that the biotite aegirine-augite nepheline syenite unit forms the external ring of the central sector of the IAM. The rock is medium-to-coarse grained, with a slightly oriented-to-massive inequigranular structure, and its colour is grey-to-light grey. The aegirine nordmarkite is medium-grained, massive, with inequigranular texture and is leaden to light grey, with polygonal ochre smudges.
It is represented by dissection landforms linked to an asymmetric ridge, which is indicative of elongated residual relief (IBGE, 2019). Its morphogenesis is related to the intrusion of alkaline rocks and the dyke swarm. On morphodynamics, erosion on slopes is ongoing.
The geosite stands out for including the summits Maromba (2,613 m.), Serra Negra (2,572 m.) and Pedra da Cabeça do Leão (2,476 m.) hills.

Figures

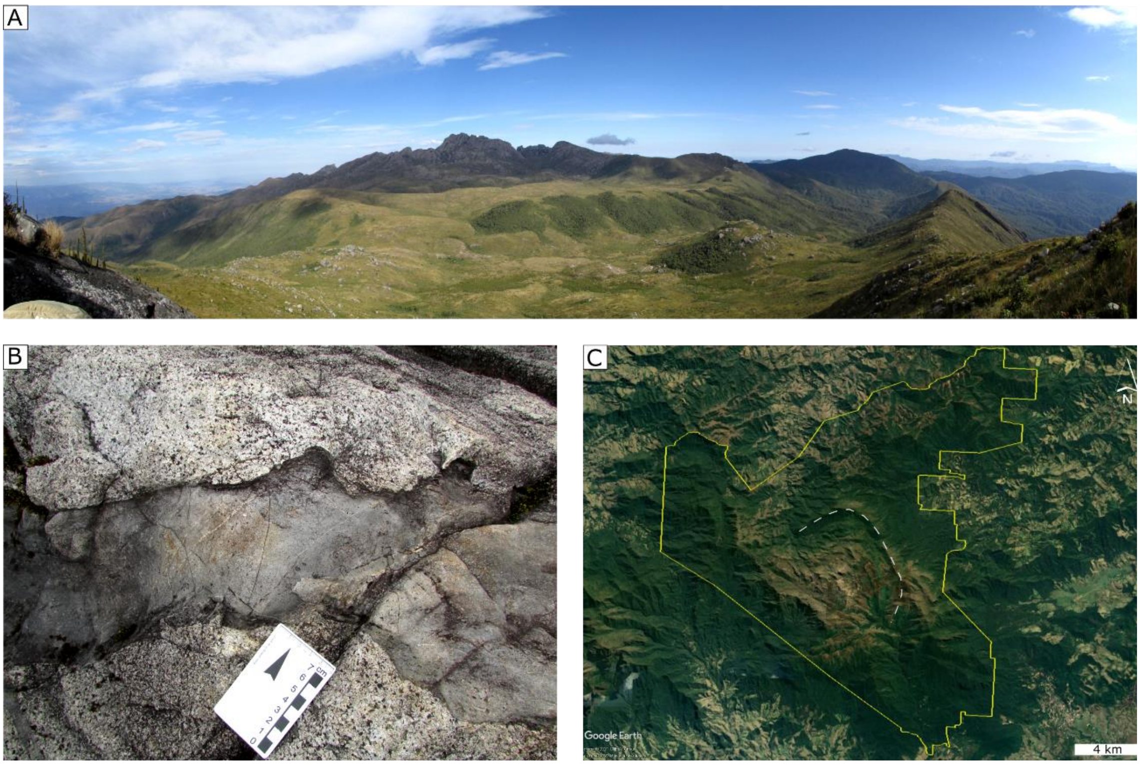


Fig. A.12 Geosite Ring-dyke on Itatiaia Plateau. (A) Panoramic view of the geosite, highlighting its circular ridge. (B) Sinuous sin-plutonic intrusive dyke in the crest of external C-shape ridge. (C) The white dotted line shows its circular geomorphological structure, also shown in figure A. (Figures A and B: photos by Pedro Augusto S. Rosa and figure C: organised by Vanessa C. Mucivuna based on Google Earth (2021)).

Use and management	**Potential use:** Scientific, educational and touristic.
	Security: No significant risk.
	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: High, as its features are clearly distinguishable. Dykes are only spotted at the ridge, while the

	asymmetric circular ridge can be spotted from several Itatiaia Plateau regions. These features show that the central region of the IAM was a volcanic caldera of about 8 km in diameter, i.e., a huge volcano. The site can be used to illustrate the different types of volcanoes and volcanisms. Moreover, its prominent peaks, such as Maromba, Serra Negra, and Cabeça do Leão, provide a panoramic view of the study area and its surroundings.
	Infrastructure: There is no infrastructure in the geosite itself, but there are a parking area and toilets close to Marcão station.
	Degradation risk: Concerning vulnerability, biological activity of plants, causing weathering of rocks, is the main factor of natural vulnerability.
	Use limitations: The geosite can be visited during the park's opening hours.

Identification	**Name:** Geosite Waterfalls of Campo Belo River Basin.
	Municipality: Itatiaia (RJ).
	Geographical coordinates (UTM WGS-84): 23K 538868 / 7520001; 539302 / 7519893; 539161 / 7519592; 539774 / 7518369.
	Access / Trailhead: On foot, Maromba Pool, Véu de Noiva and Itaporani Waterfalls can be reached by the trail that starts at Maromba bridge. The round-trip distance to Maromba Pool is 340 metres, to Véu de Noiva Waterfall is 760 metres, and to Itaporani Waterfall is 1,280 metres. The access to Poranga Waterfall is by a trail that starts at BR-485 and is about 800 metres (round trip). The difficulty level of these trails is considered easy.
	Typology: Area and point (group of landforms).
	Zoning within the management plan: Primitive zone, extensive and intensive use zones.
Characterisation	**Framework:** First magmatic stage of alkaline intrusion.
	Geological unit: Sodalite nepheline syenite (area i) and biotite hornblende nepheline syenite (areas ii, iii and iv) (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Hydrological, surface formation, tectonics and geomorphological.
	Specific geomorphological interest: Fluvial and structural processes.
	Other elements of interest: Aesthetic, ecological and historical.
Quantitative assessment	**Scientific value:** 300, 200.
	Degradation risk: 90.
	Potential educational use: 255.
	Potential touristic use: 240.
Description The Waterfalls of Campo Belo River Basin is a geosite that includes four waterfalls located in the Campo Belo river basin, which spring is in the upper region of the INP at an altitude of 2,350 metres. Three of these waterfalls are in the Campo Belo river (areas i, iii and iv), and one waterfall is in the Maromba river (area ii). They have slopes with a gradient between 27% and 40% and at altitudes ranging between 946 and 1,177 metres (ICMBio 2013). The	

features in these areas are associated with the first magmatic pulse of the IAM and a NW-SE oriented lineament, concordant with the elongation of the massif (Rosa and Ruberti, 2018).

According to Rosa and Ruberti (2018), the sodalite nepheline syenite is grey-to-locally rosy and medium-to-coarse inequigranular in texture; and the biotite hornblende nepheline syenite is described as medium-to-coarse-grained, with an inequigranular, slight oriented texture and a light-grey colour.

The areas are as follows:

(i) Itaporani waterfall is 20 metres high, with water flowing down three tiers into a natural pool of approximately 20 metres in diameter (Fig. A.13A). There are metric boulders with rounded edges in its valley, which sizes indicate the high speed of the water to transport sediments from distant source areas.

(ii) Véu de Noiva cascade is 40 metres high, with horizontal unevenness developed by the fracture planes (Fig. A.13B). The different sizes and angular edges of the rocks fragments at its base indicate that they are from the waterfall itself and result of rockfalls associated with fracture planes.

(iii) Maromba Natural Pool includes a five metres high waterfall with two tiers and a natural pool of about 40 metres in diameter (Fig. A.13D). Rounded rocks fragments occur in its valley, and the circular potholes were originated from the abrasion of suspended sediments by the circular movements of water.

(iv) Poranga waterfall includes a ten metres high slide waterfall and a natural pool of about 30 metres in diameter (Fig. A.13C). Two principal fracture planes in the NW-SE and NE-SW orientations crosscut the outcrop. Its valley is filled with rounded boulders between 1.5 metres and 6 metres in diameter.

Its morphogenesis is related to both intrusion and fracturing of alkaline rocks, as well as fluvial processes. Regarding morphodynamics, the igneous and tectonic processes that gave rise to the geosite are inactive. However, fluvial processes are still in progress, as water plays a crucial role in deepening the thalweg, erosion of fracture planes, contributing to the formation of distinct waterfall steps, as well as the fragmentation and transportation of rocks in flowing water.

Figures

Fig. A.13 Geosite Waterfalls of Campo Belo River Basin. (A) View of the Itaporani Waterfall with water flowing in the eroded planes. (B) View of the Véu de Noiva Waterfall with horizontal joints on the slope and fragmented angular rocks at the base. (C) View of the Poranga Waterfall with fracture planes on the slopes. (D) View of the Maromba Natural Pool, highlighting rounded rocks and a well-developed natural pool. (Figures A, C and D: photos by Vanessa C. Mucivuna and figure B: photo by Debora S. Queiroz).

Use and management	**Potential use:** Scientific, touristic and educational.
	Security: No significant risk, but the river speed and level urge caution, especially during summer, when heavy rains at headwaters cause sudden floods on riverbeds.
	Observing conditions: The vegetation obstructs the observation of some geological elements.

	Interpretative potential: High, as its geological features are clearly distinguishable. They are mainly associated with the action of water. For example, rock size and roundness could be correlated with the river energy and the distance from the source area. Erosion processes are seen in both circular potholes and fracture planes where the waterfall flows. As in the Fluvial deposits of Lago Azul, this site could be used to raise public awareness of the importance of protecting the planet's freshwater.
	Infrastructure: There is no infrastructure in the geosite itself. However, most of the route to the Maromba pool consists of a concrete stairway with handrails. The beginning of the route to the Véu de Noiva waterfall has concrete stairs, handrails and bridges, but after the bifurcation to the Itaporani waterfall trail, the route becomes more rugged. The beginning of the Poranga waterfall trail has stairs made of blocks of rocks. There is a parking area for vehicles near the Maromba bridge and at the trailhead of the Poranga Waterfall.
	Degradation risk: There is no risk regarding intrinsic fragility or vulnerability resulting from natural or anthropic action.
	Use limitations: The geosite can be visited during park’s opening hours. There is no access restriction, but disabled people may face difficulties.

<table>
<tr><td rowspan="6">Identification</td><td>Name: Geosite Leucogranite of Pedra Grande Hill.</td></tr>
<tr><td>Municipality: Itamonte (MG).</td></tr>
<tr><td>Geographical coordinates (UTM WGS-84): 23K 529562 / 7529067.</td></tr>
<tr><td>Access / Trailhead: On foot by following the Pedra Grande trail that starts at km 11.5 of Flores Highway (BR-485), near the Alsene hotel. This route is approximately 10 km long (round trip), and its difficulty level is considered moderate. The geosite is at the end of the trail.</td></tr>
<tr><td>Typology: Point and point (single landform).</td></tr>
<tr><td>Zoning within the management plan: Primitive zone and extensive use zone.</td></tr>
<tr><td rowspan="6">Characterisation</td><td>Framework: Proterozoic igneous and metamorphic rocks.</td></tr>
<tr><td>Geological unit: Capivara leucogranite and associated diatexite (Trouw et al., 2003).</td></tr>
<tr><td>Geomorphological unit: Mantiqueira / Itatiaia Mountain Ranges.</td></tr>
<tr><td>Geological interests: Plutonism, tectonics and geomorphological.</td></tr>
<tr><td>Specific geomorphological interest: Tectonics process.</td></tr>
<tr><td>Other elements of interest: Aesthetical, ecological and historical.</td></tr>
<tr><td rowspan="4">Quantitative assessment</td><td>Scientific value: 255, 280.</td></tr>
<tr><td>Degradation risk: 85.</td></tr>
<tr><td>Potential educational use: 215.</td></tr>
<tr><td>Potential touristic use: 190.</td></tr>
<tr><td colspan="2">Description
The geosite Leucogranite of Pedra Grande has top and slopes convex hill, with an average gradient of 27% (ICMBio, 2013) at an altitude of 2,282 metres. The leucogranite shows stretched K-feldspar crystals and intrusion of quartz veins discordant with foliation (Fig. A.14A and A.14B).
Trouw et al. (2003) states that the Capivara leucogranite and associated diatexite is fine-to-medium equigranular with quartz crystals, K-feldspar, plagioclase, muscovite and biotite.
Its morphogenesis is associated with the second syn-collisional stage of the Ribeira Orogen (Valladares et al., 2000). Regarding morphodynamics, the process that formed the geosite is no longer active. However, erosion of slopes is ongoing over inherited features.</td></tr>
</table>

<table>
<tr><td colspan="2">It is also a viewpoint, with panoramic views of the landforms marked by convex and less steep slopes, associated with igneous and metamorphic rocks of Proterozoic age and the rocky peaks related to Meso-Cenozoic alkaline rocks.</td></tr>
<tr><td colspan="2">Figures

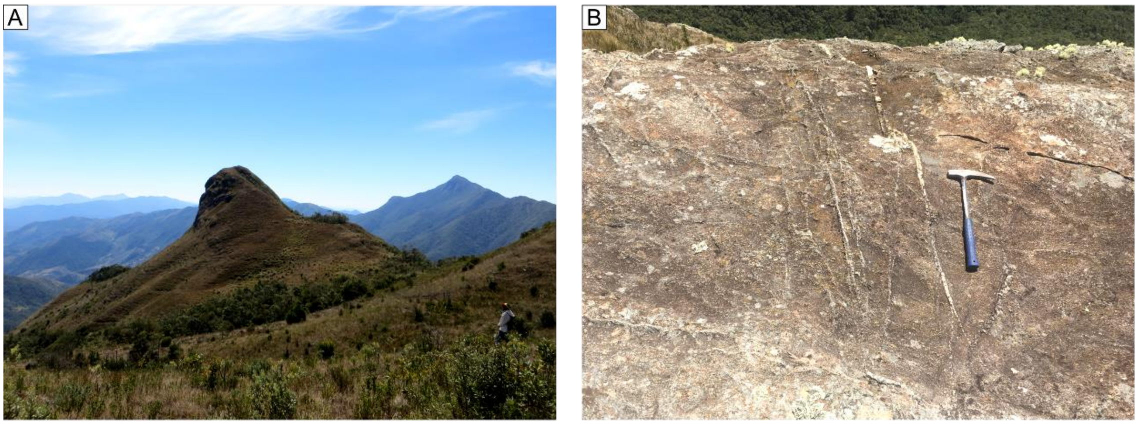



Fig. A.14 Geosite Leucogranite of Pedra Grande Hill. (A) In the centre, the view of the geosite. On the left, view of the convex and less steep slopes and on the right, the rocky slopes. (B) Detail of the rocky ridge of leucogranite with the intrusion of quartz discordant with foliation. (Figure A: photo by Eliana Mazzucato and figure B: photo by: Vanessa C. Mucivuna).</td></tr>
<tr><td rowspan="7">Use and management</td><td>Potential use: Scientific, touristic and educational.</td></tr>
<tr><td>Security: The sloping floor could be slippery, causing the risk of falls. Therefore, educational activities are not recommended for children due to the lack of security on the geosite.</td></tr>
<tr><td>Observing conditions: The vegetation obstructs the observation of some geological elements.</td></tr>
<tr><td>Interpretative potential: Good, because the ridge of Pedra Grande hill has the best exposure of leucogranite with quartz intrusions in the study area. Furthermore, the geosite is near the contact between the Proterozoic igneous and metamorphic rocks and the Meso-Cenozoic alkaline rocks. These lithological varieties are pretty prominent in the landforms and can be very well distinguished from the geosite.</td></tr>
<tr><td>Infrastructure: There is no infrastructure on the geosite itself.</td></tr>
<tr><td>Degradation risk: Concerning vulnerability, biological activity of plants, causing weathering of rocks, is the main factor of natural vulnerability.</td></tr>
<tr><td>Use limitations: Although it is located in the park, the trailhead to reach the geosite is before the Marcão station. Therefore, there is no</td></tr>
</table>

	access restriction. It cannot be visited by many people simultaneously due to its size and sloping floor.

Identification	**Name:** Geosite Tectonic records of Rio Preto Waterfalls.
	Municipality: Bocaina de Minas (MG) and Itatiaia (RJ).
	Geographical coordinates (UTM WGS-84): 23K 539405 / 7530390; 539420 / 7530346.
	Access / Trailhead: On foot by following the trail that starts at Escorrega Waterfall (Escorrega Road). This route is about 0.5 km long (round trip), and its difficulty level is considered easy. Escorrega Waterfall is at the start of the trail, while Macacos Waterfall is at the end.
	Typology: Area and point (group of landforms).
	Zoning within the management plan: Primitive zone.
Characterisation	**Framework:** Proterozoic igneous and metamorphic rocks.
	Geological unit: Garnet-biotite gneiss (Heilbron et al., 2016).
	Geomorphological unit: Mantiqueira / Itatiaia Mountain Ranges.
	Geological interests: Tectonics, metamorphism, hydrological and geomorphological.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Ecological, aesthetic and historical.
Quantitative assessment	**Scientific value:** 300, 195.
	Degradation risk: 170.
	Potential educational use: 230.
	Potential touristic use: 225.

Description

The Tectonic Records of Preto River waterfalls is a geosite that comprises two waterfalls in the Preto river with an average gradient of 27% (ICMBio, 2013). It is included in the banded biotite gneiss unit of Trouw et al. (2003) and garnet-biotite gneiss unit of Heilbron et al. (2016). Despite giving these rocks different names, both authors described that their mineralogical composition included plagioclase, biotite, muscovite, epidote, microcline and garnet, as well as biotite-rich compositional bands. The geosite is also related to an indiscriminate NW-SE oriented shear zone (CPRM, 2006).

(i) Escorrega Waterfall is a slide waterfall located at the natural border between the states of Rio de Janeiro and Minas Gerais. It is approximately 30 metres high, with water flowing on a slab into a natural pool of about 25 metres in diameter (Fig.

A.15A). It is composed mainly of locally garnet-bearing banded paragneiss, showing axial plane foliation to isoclinal to tight folds (Fig. A.15B). The mafic layers appear as *boudins* (Fig. A.15C) that locally preserve the previous foliation plane with internal folded quartz veins. The main foliation has NW-SE orientation, with moderate to high dip angle and linked to an indiscriminate shear zone that crosscuts the region (CPRM, 2006). Fracture planes are locally filled with quartz veins. Sub-rounded boulders of alkaline and metamorphic rocks of up to three metres are scattered along the riverbank (Fig. A.15D).

(ii) Macacos Cascade is about 15 metres high with horizontal fracture planes (Fig A.15E). The banded paragneiss has NW-SE orientation, with a moderate-to-high dip angle. Stretched *boudins* are locally observed in accordance with the orientation of the rocks. It is possible to recognize folded rocks in some areas, whereas in other areas, only the high dip angle foliage is noticeable. Alkaline and metamorphic boulders up to two metres are scattered over the natural pool and along the river (Fig. A.15F).

Its morphogenesis is associated with metamorphic and ductile deformations, as well as hydrographic processes. Regarding morphodynamics, metamorphic and structural processes are no longer active. However, hydrographic processes are ongoing, contributing to the erosion of slopes and the fragmentation and transport of sediments.

The geosite also plays an essential role in the planning and management of water sources.

Figures

Fig. A.15 Geosite Tectonic records of Preto River waterfalls. (A) View of the Escorrega waterfall. (B) Isoclinal to tight folds in the banded paragneiss showing competence contrast between mafic layers. (C) *Boudin* oriented in accordance with the general foliation of the outcrop. (D) Sub-rounded boulders deposited along the riverbed. (E) View of the Macacos Waterfall, highlighting the fracture planes on slopes. (F) Sub-rounded boulders deposited along the river near Macacos Waterfall. (Figures A, B, D and F: photos by Vanessa C. Mucivuna and figures C and E: photos by: Maria da Glória M. Garcia).

Use and management	**Potential use:** Scientific, touristic and educational.
	Security: Risk of falls due to slippery grounds. Also, the river speed and level urge caution, especially during summer, when heavy rains at headwaters cause sudden floods on riverbeds.
	Observing conditions: The vegetation obstructs the observation of some geological elements.

	Interpretative potential: Moderate, because the understanding and correlation of its features require good knowledge of Geosciences. On the other hand, it has a high interpretative potential to demonstrate the contrast of rocks and relief between this region and the upper region of the protected area. Moreover, it could also be used to explain the role of water in sediment transport and raise public awareness of the importance of protection and efficient use of water.
	Infrastructure: There is no infrastructure in the geosite itself, but there are parking zones, restaurants and accommodations at the trailhead of the geosite.
	Degradation risk: There is no risk regarding intrinsic fragility or vulnerability resulting from natural or anthropic action.
	Use limitations: Although it is located in the park, there is no access restriction.

<table>
<tr><td rowspan="6">Identification</td><td>Name: Geosite Metagranitoid of Enamorados Peak.</td></tr>
<tr><td>Municipality: Resende (RJ).</td></tr>
<tr><td>Geographical coordinates (UTM WGS-84): 23K 526108 / 7525221</td></tr>
<tr><td>Access / Trailhead: On foot by following the trail that starts at km 6 of BR-485 towards Marcão station, near Casa de Pedra. The route is about 5 km long (round trip), and its difficulty level is considered easy. The geosite is at the end of the trail.</td></tr>
<tr><td>Typology: Point and point (single landform).</td></tr>
<tr><td>Zoning within the management plan: Primitive zone and extensive use zone.</td></tr>
<tr><td rowspan="6">Characterisation</td><td>Framework: Proterozoic igneous and metamorphic rocks.</td></tr>
<tr><td>Geological unit: Undifferentiated metagranitoid (Trouw et al., 2003).</td></tr>
<tr><td>Geomorphological unit: Paraíba do Sul River Depression.</td></tr>
<tr><td>Geological interests: Metamorphism, geomorphological and tectonics.</td></tr>
<tr><td>Specific geomorphological interest: Structural processes.</td></tr>
<tr><td>Other elements of interest: Aesthetic, ecological and historical.</td></tr>
<tr><td rowspan="4">Quantitative assessment</td><td>Scientific value: 210, 250.</td></tr>
<tr><td>Degradation risk: 95.</td></tr>
<tr><td>Potential educational use: 220.</td></tr>
<tr><td>Potential touristic use: 205.</td></tr>
<tr><td colspan="2">Description
The geosite Metagranitoid of Enamorados Peak is partially within the boundaries of the INP. It is a hill at 2,076 metres of altitude, at the top of which there is an outcrop of approximately 30 metres (Fig. A.16A) with uneven surfaces, straight slopes and an average gradient of 40% (ICMBio 2013). Its foliation has NW-SE orientation, and the fracture planes are concordant with a moderate dip angle.
Trouw et al. (2003) point out that the undifferentiated metagranitoid that composes the unit comprises quartz, plagioclase, microcline, biotite, and muscovite.
Its morphogenesis is linked to metamorphism and ductile deformation processes. Regarding morphodynamics, erosion of slopes is continuous over the inherited features.
It stands out as a great example of the connection between geodiversity and biodiversity (Fig. A.16B), and it also offers a panoramic viewpoint of (1) Itatiaia Massif Alkaline, (2)</td></tr>
</table>

Bocaina Mountain Range, (3) Paraíba do Sul River Valley and (4) Fina Mountain Range (Fig. A.16C).

Figures

Fig. A.16 Geosite Metagranitoid of Enamorados Peak. (A) A. View of the Enamorados Peak, highlighting the very steep slopes. (B) Detail of vegetation on the rock, showing the role of geodiversity in supporting biodiversity. (C) The general aspect of the viewpoint, with emphasis on [1] Itatiaia Massif Alkaline, [2] Bocaina Mountain Range, [3] Paraíba do Sul River Valley and [4] Fina Mountain Range. (Figures A, B and C: photos by Jobson Pereira).

Use and management	**Potential use:** Scientific, touristic and educational.
	Security: The floor is very steep and could be slippery, causing the risk of falls. Therefore, educational activities are not recommended for children due to the lack of security of the geosite.
	Observing conditions: The vegetation obstructs the observation of some geological elements.

	Interpretative potential: High, as the Metagranitoid of Enamorados Peak is one of the geosites that represent the oldest geological events in the study area. A fundamental viewpoint, it has a panoramic view of many landforms that could be used to address landscape formation. It is also a great example of the role of geodiversity in supporting biodiversity.
	Infrastructure: There is no infrastructure in the geosite itself.
	Degradation risk: About vulnerability, biological activity of plants, causing weathering of rocks, is the main cause of natural vulnerability.
	Use limitations: Although it is located in the park, the trailhead is before Marcão station. Therefore, there is no access restriction.

<table>
<tr><td rowspan="6">Identification</td><td>Name: Geosite Mylonitic gneiss of Santa Clara Waterfall.</td></tr>
<tr><td>Municipality: Bocaina de Minas (MG).</td></tr>
<tr><td>Geographical coordinates (UTM WGS-84): 23K 541600 / 7532273.</td></tr>
<tr><td>Access / Trailhead: On foot by following the trail that starts at Santa Clara Road. The route is about 0.5 km long (round trip), and its difficulty level is considered easy. The waterfall is located at the end of the trail.</td></tr>
<tr><td>Typology: Point and point (single landform).</td></tr>
<tr><td>Zoning within the management plan: Primitive zone.</td></tr>
<tr><td rowspan="6">Characterisation</td><td>Framework: Proterozoic igneous and metamorphic rocks.</td></tr>
<tr><td>Geological unit: Undifferentiated metagranitoid (Trouw et al., 2003).</td></tr>
<tr><td>Geomorphological unit: Mantiqueira/Itatiaia Mountain Ranges.</td></tr>
<tr><td>Geological interests: Metamorphism, tectonics, hydrological and geomorphological.</td></tr>
<tr><td>Specific geomorphological interest: Structural processes.</td></tr>
<tr><td>Other elements of interest: Ecological, aesthetic and historical.</td></tr>
<tr><td rowspan="4">Quantitative assessment</td><td>Scientific value: 300, 200.</td></tr>
<tr><td>Degradation risk: 190.</td></tr>
<tr><td>Potential educational use: 255.</td></tr>
<tr><td>Potential touristic use: 230.</td></tr>
<tr><td colspan="2">Description
The geosite Mylonitic Gneiss of Santa Clara Waterfall exemplifies one of the waterfalls of Santa Clara River. It comprises a slide waterfall that is approximately 40 metres high and 15 metres wide, with water flowing down two tiers and finally into a natural pool (Fig. A.17A). The waterfall is formed by mylonitic gneiss with deformed feldspar crystals (Fig. A.17B), suggestive of sinistral movement and NW-SE oriented foliation. The horizontal fracture planes can be noticed on the slope, and they are being eroded due to the action of water (Fig. A.17A). The natural pool and its valley are filled with metric boulders of up to one metre with sub-rounded edges (Fig. A.17C), inferring that they are from the slope itself and also from more distant areas.
Trouw et al. (2003) state that the undifferentiated metagranitoid is mainly composed of quartz, plagioclase, microcline, biotite and muscovite. The geosite is also correlated with an indiscriminate NW-SE oriented shear zone (CPRM, 2006).</td></tr>
</table>

Its morphogenesis is correlated with metamorphic and ductile deformations, as well as with hydrographic processes. Concerning morphodynamics, only hydrographic processes are in progress, contributing to slope erosion and fragmentation and transport of sediments in the flowing water.

Moreover, it has an essential role in the planning and management of water sources.

Figures

Fig. A.17 Geosite Mylonitic gneiss of Santa Clara Waterfall. (A) View of the Santa Clara Waterfall, highlighting the horizontal fracture planes on the slope. (B) Detail of the mylonitic gneiss with deformed feldspar crystals, indicative of sinistral movement. (C) Detail of the natural pool and valley filled with sub-rounded edges boulders. (Figures A, B and C: photos by Vanessa C. Mucivuna).

Use and management	**Potential use:** Scientific, touristic and educational.
	Security: No significant risk, but the river speed and level urge caution, especially during summer, when heavy rains at headwaters cause sudden floods on riverbeds.
	Observing conditions: The vegetation obstructs the observation of some geological elements.
	Interpretative potential: Great, as waterfalls are excellent places to raise public awareness of the importance of protection and efficient use of water. It should be noted that water plays a fundamental role in the erosion process and sediment transport. The deformation and

	orientation of minerals in rocks can be explained by their association with the indiscriminate shear zone that cuts the region. The contrast of rocks and relief between this region and the upper region of the protected area should be included in interpretative proposals.
	Infrastructure: There is no infrastructure in the geosite itself. However, most of the route to the Santa Clara waterfall is a rustic stairway with handrails. There is a parking area at the trailhead.
	Degradation risk: There is no risk regarding intrinsic fragility or vulnerability resulting from natural or anthropic action.
	Use limitations: Although it is located in the park, there is no access restriction.

Identification	**Name:** Geodiversity site Lakes and wetland with peat deposits.
	Municipality: Itamonte (MG).
	Geographical coordinates (UTM WGS-84): 23K 531616 / 7526418.
	Access / Trailhead: On foot by following the Cinco Lagos trail that starts at Marcão station. This route is approximately 12 km long (round trip), and its difficulty level is considered moderate. The geodiversity site is at the beginning of this trail, after hiking approximately 4 km (round trip).
	Typology: Area and area (group of landforms).
	Zoning within the management plan: Primitive zone and extensive use zone.
Characterisation	**Framework:** Quaternary deposits.
	Geological unit: Alluvium sediments (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Surface formation, sedimentary, hydrogeological and geomorphological.
	Specific geomorphological interest: Organic processes.
	Other elements of interest: Ecological, aesthetic and historical.
Quantitative assessment	**Scientific value:** 180, 180.
	Degradation risk: 65.
	Potential educational use: 215.
	Potential touristic use: 195.

Description

The geodiversity site Lakes and wetland with peat deposits comprises two lakes and a wetland located at the Cinco Lagos trail. It is in one of the principal depressive areas with peat sediments in the study area, covering about 80,000 m², at an altitude of 2,277 metres and an average gradient of 4% (Teixeira, 1961; Modenesi and Melhem, 1986; ICMBio, 2013). It is characterised as a wetland with shallow lakes, elongated in the NE-SW orientation, with an average depth of one metre, filled with peat sediments (ICMBio, 2013) and surrounded by steep hills and rocky peaks (Fig. A.18A, A.18B and A.18C).

According to Rosa and Ruberti (2018), the alluvial sediments are primarily composed of mud and peat deposits, coarser grains and centimetric clasts in adjacent areas. In the Itatiaia Plateau region, peat deposits with fossil pollen grains are frequent (Modenesi and Melhem, 1986). These deposits have their genesis related to biological and geological processes and are formed due to the deposition of decomposed plants in wetlands on specific conditions (O'Kelly, 2015).

Its morphogenesis is linked to the sedimentary and hydrographic processes that formed peat deposits and lakes, respectively. Riverheads or underground drains through joints and faults (ICMBio, 2013) are essential elements in the evolution of wetlands, deposition of peat sediments and water accumulation in lakes. About morphodynamics, sedimentary and hydrographic processes are still ongoing.

Moreover, depressive areas allow the growth of an organic horizon within slopes, these areas being covered by high-altitude grasslands, with a high rate of endemic species (Marques Neto et al., 2015).

Besides its geological interest, it is an excellent illustration of the connection between geodiversity and biodiversity since the biota is adapted to particular abiotic conditions (Mucivuna et al., 2021).

Figures

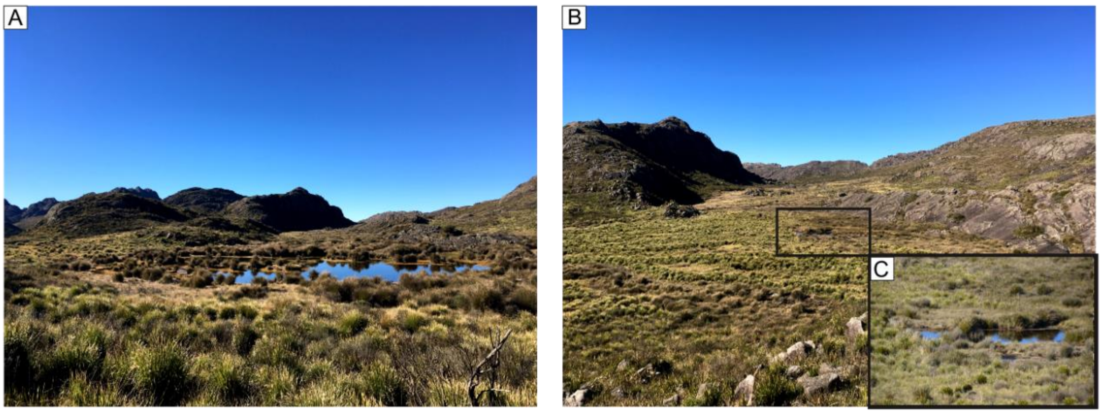


Fig. A.18 Geodiversity site Lakes and wetland with peat deposits. (A) View of the first and largest lake, surrounded by high-altitude grasslands and rocky peaks across the Itatiaia plateau. (B) View of the second and smallest circular-shaped lake and contact between rocky outcrop and wetlands in the background. (C) Detail of the second lake and the high-altitude grasslands over the peat deposits. (Figure A: photo by Vanessa C. Mucivuna, figures B and C: photos by Maria da Glória M. Garcia).

Use and management	**Potential use:** Educational, scientific and touristic.
	Security: No significant risk.
	Observing conditions: The vegetation obstructs the observation of some geological elements.
	Interpretative potential: High, as wetlands, lakes and peat deposits are clearly distinguishable. Moreover, the geodiversity site is surrounded by steep hills and rocky peaks, so interpretation could include both landforms. Furthermore, it could be used as a tool to

	propose integrated interpretation and management, as the geodiversity site is of supreme importance in supporting biodiversity and contributing to the reproduction and conservation of local fauna and flora.
	Infrastructure: There is no infrastructure in the geodiversity site, but there are a parking area and toilets at the trailhead.
	Degradation risk: Regarding vulnerability, the intense use of the trail is the main fact of anthropic vulnerability.
	Use limitations: The geodiversity site can be visited during the park's opening hours. There is no limit to the number of visitors per day. The time limit to start the Cinco Lagos trail is 11:00 am.

Identification	**Name:** Geodiversity site Breccia of Camelo Hill.
	Municipality: Itamonte (MG) and Resende (RJ).
	Geographical coordinates (UTM WGS-84): 23K 529874 / 7526124.
	Access / Trailhead: On foot through km 12 of Flores Highway (BR-485) towards Marcão station, near Alsene Hotel. The summit is reached by following the Morro do Camelo trail, which difficulty level is considered easy and takes about 20 minutes.
	Typology: Area and area (single landform).
	Zoning within the management plan: Primitive zone.
Characterisation	**Framework:** Third magmatic stage of alkaline intrusion.
	Geological unit: Trachyte I (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Petrological, plutonism and geomorphological.
	Specific geomorphological interest: Tectonic processes.
	Other elements of interest: Aesthetic, ecological and historical.
Quantitative assessment	**Scientific value:** 170, 230.
	Degradation risk: 175.
	Potential educational use: 235.
	Potential touristic use: 220.

Description

The geodiversity site Breccia of Pedra do Camelo Hill stands out for having one of the shortest trails to reach the summit. It is on the VLL, in the NW-SE orientation, and corresponds to an intensely dissected hill, with uneven surfaces, smooth convex top, straight slopes, and covers an area of almost 25,000 m² at an altitude of 2,318 metres. It has the shape of a camel, which "head" would be the steep slope with alveolar hollows developed by both differential erosion and rockfalls (Fig. A.19A). The alveolar hollows are more noticeable in the areas corresponding to the "eyes" and "mouth", as well as in the “back”, in the stretch locally known as “skull rock” (Fig. A.19B).

Rosa and Ruberti (2018) state that the trachyte I unit occurs in the transition between the C-S and NW-S sectors of the IAM; it is a breccioid aphanitic matrix with millimetre-to-centimetre angular fragments of aphanitic to fine-grained rock, auto-fragments and alkali feldspar megacrysts. These authors infer that these rocks could represent the fourth magmatic stage of alkaline intrusion, corresponding to subvolcanic conducts with epigenetic characteristics.

Its morphogenesis is linked to the intrusion of alkaline rocks and the modelling processes that sculpted it. On morphodynamics, erosion of slopes, alveolar hollows and rockfall are active, creating new features and modelling the inherited ones.

It is also a viewpoint because its summit provides a good view of the Pedra Furada and Morro da Antena hills as well as Fina Mountain Range.

Figures

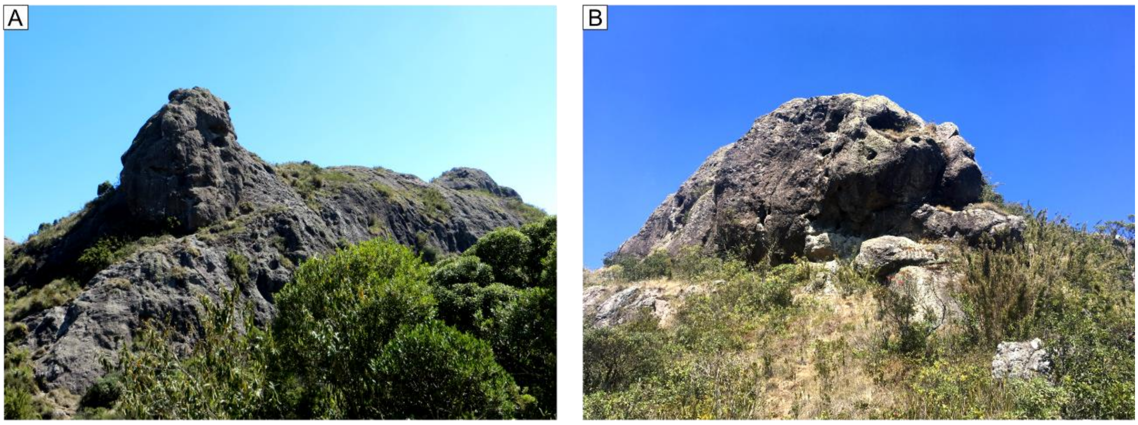


Fig. A.19 Geodiversity site Breccia of Camelo Hill. (A) View of the Pedra do Camelo Hill, highlighting the differential erosion in the steep zones. (B) Detail of the region named "skull rock", where metric alveolar hollows stand out. (Figure A: photo by Eliana Mazzucato and figure B: photo by Vanessa C. Mucivuna).

Use and management	**Potential use:** Touristic, scientific and educational.
	Security: Risk of rockfalls. Some stretches of the geodiversity site urge caution due to a steep slope, slippery grounds and loose rocks.
	Observing conditions: The vegetation obstructs the observation of some geological elements.
	Interpretative potential: Good, considering that this geodiversity site is the best place to observe alveolar hollows in the trachyte unit. The site is currently used for climbing due to its easy access; however, it is under-promoted for visiting. It could potentially attract visitors who do not have much time available or are unwilling to take long walks. Moreover, it could be used as a viewpoint since it offers a panoramic view of the landforms of the study area and its surroundings.
	Infrastructure: There is no infrastructure on the geodiversity site.
	Degradation risk: About fragility, the processes of alveolar hollows and rockfalls are affecting its fragility. Regarding vulnerability, biological activity of plants, causing weathering of rocks, is the main

	cause of natural vulnerability. Moreover, there are swallows' nests on the hill, so activities such as climbing and visits may affect the reproduction of these birds; therefore, further research on this bird species' nesting is required (ICMBio, 2013).
	Use limitations: Although it is located in the park, the trailhead is before Marcão station. Therefore, there is no access restriction.

Identification	**Name:** Geodiversity site Pitted erosion of Pedra do Sino Hill.
	Municipality: Bocaina de Minas and Itamonte (MG).
	Geographical coordinates (UTM WGS-84): 23K 534737 / 7526045.
	Access / Trailhead: On foot by following the Pedra do Sino trail that starts at Marcão station. It is 24 km long (round trip), and its difficulty level is considered hard. The geodiversity site is at the end of the path.
	Typology: Area and area (single landform).
	Zoning within the management plan: Primitive zone and extensive use zone.
Characterisation	**Framework:** Second magmatic stage of alkaline intrusion.
	Geological unit: Quartz alkali feldspar syenite I (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Plutonism, geomorphological and tectonics.
	Specific geomorphological interest: Structural geomorphology.
	Other elements of interest: Aesthetic, ecological and historical.
Quantitative assessment	**Scientific value:** 200, 200.
	Degradation risk: 65.
	Potential educational use: 230.
	Potential touristic use: 215.

Description

The Pitted erosion of Pedra do Sino Hill is the third highest peak in the INP at 2,670 metres of altitude (Fig. A.20A). It is a hill with uneven surfaces, smooth convex top, straight slopes and chemical dissolution linked to the action of microorganisms and water in the fracture planes. Pitted erosion is remarkable on upper slopes and the summit (Fig. A.20B and A.20C), while fluted erosion is more noticeable on middle and upper slopes (Fig. A.20D). Angular boulders with fluted erosion evolved both from pitted erosion and erosion of fracture planes (Fig. A.20E).

Rosa and Ruberti (2018) describe the quartz alkali feldspar syenite I as inequigranular, medium-to-coarse grained, and light rose brown coloured, with whitish smudges and miarolitic cavities filled with quartz crystals. It is linked to a NW-SE oriented lineament, concordant with the elongation of the massif.

Its morphogenesis is related to the intrusion and fracturing of alkaline rocks. About morphodynamics, the processes that formed it are inactive. However, pitted and fluted erosion are ongoing, producing new features and maintaining its main inherited features.

Its summit does not have a clear pattern in the distribution of pitted and fluted erosion, being possible to notice them across the area (Fig. A.20C). It also offers a panoramic viewpoint of the landforms of the study area and its surroundings.

Figures

Fig. A.20 Geodiversity site Pitted erosion of Pedra do Sino Hill. (A) View of the geodiversity site from Agulhas Negras Peak. (B) View of the pitted erosion related to the fracture planes on upper slopes. (C) Detail of the summit with numerous circular depressions formed by pitted erosion of different sizes. (D) Detail of the middle slopes, highlighting the fluted erosion developed in the fracture planes in association with the chemical weathering processes. Some of these features are evolved from the expansion of pitted erosion. (E) Detail of the metric boulders on the middle slopes, highlighting pitted and fluted erosional processes. (Figures A, B, C, D and E: photos by Vanessa C. Mucivuna).

Use and management	**Potential use:** Touristic, scientific and educational.
	Security: Risk of rockfalls. Some stretches of the geodiversity site urge caution due to the steep slope, slippery grounds and loose rocks.

	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: Good, since the geological features are clearly distinguishable. On slopes, fracture planes could illustrate the evolution of both pitted and fluted erosion features, mainly formed by chemical weathering. At the summit, pitted and fluted erosion are more profound than those observed in slopes, but there is no clear pattern in the distribution of these processes. Besides, the geodiversity site could also be explored as viewpoint, as it has a panoramic view of the study area and surroundings.
	Infrastructure: There is no infrastructure in the geodiversity site, but there are a parking area and toilets at the trailhead.
	Degradation risk: About fragility, the process of chemical weathering is producing fluted and pitted erosion.
	Use limitations: The geodiversity site can be visited during the park's opening hours. There is no limit to the number of visitors per day. The time limit to start the Pedra do Sino Hill trail is 9:00 am

Identification	**Name:** Geodiversity site Aiuruoca Waterfall.
	Municipality: Itamonte (MG).
	Geographical coordinates (UTM WGS-84): 23K 534128 / 7527224.
	Access: On foot by following the Aiuruoca Waterfall trail that starts at Marcão station. The route is about 11 km long (round trip), and its difficulty level is considered moderate. The geodiversity site is situated at the end of the trail.
	Typology: Point and point (single landform).
	Zoning within the management plan: Primitive zone and extensive use zone.
Characterisation	**Framework:** Second magmatic stage of alkaline intrusion.
	Geological unit: Biotite hornblende pulaskite (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Plutonism, tectonics, hydrological and geomorphological.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Aesthetic, ecological and historical.
Quantitative assessment	**Scientific value:** 200, 180.
	Degradation risk: 65.
	Potential educational use: 240.
	Potential touristic use: 220.

Description

The geodiversity site Aiuruoca Waterfall is the first waterfall of the Aiuruoca River. It includes a cascade waterfall that is 20 metres high and has a natural pool of about seven metres in diameter. The waterfall is connected to an E-W oriented lineament, near the contact with alluvial sediments (ICMBio, 2013). Horizontal fracture planes can be recognised on both the unevenness of the slope (Fig. A.21A) and upstream of the riverbed (Fig. A.21B). The natural pool is filled with rock fragments with angular edges of variable sizes, suggesting that they originated from the slope itself, the fractures planes being fundamental to their fragmentation and fall (Fig. A.21C).

Rosa and Ruberti (2018) point out that the biotite hornblende pulaskite unit forms the second C-shaped structure. This rock is described as having low feldspathoid content with some discrepant tabular feldspar crystals and disequilibrium textures. Nevertheless, the site is inserted in facies with a more prominent medium-to-fine-grained porphyritic texture.

Its morphogenesis is linked to intrusion and fracturing of alkaline rocks and hydrographic processes since water plays a crucial role in weathering fracture planes. About morphodynamics, the igneous and tectonic processes are no longer active. However, hydrographic processes are ongoing, contributing to the development of different waterfall steps and the fragmentation and transport of rocks in the flowing water.

Moreover, the geodiversity site has a vital role in the planning and management of water sources since the Aiuruoca River is a very significant river of the Grande river basin.

Figures

Fig. A.21 Geodiversity site Aiuruoca Waterfall. (A) View of the Aiuruoca Waterfall, highlighting the horizontal fracture planes on the slope. (B) Fractures planes on the riverbed, a few metres before the waterfall. (C) The natural pool filled with rocks of different sizes and angular edges. (Figure A: photo by Raquel M. M. Romão, figures B and C: photos by: Maria da Glória M. Garcia).

Use and management	**Potential use:** Touristic, scientific and educational.
	Security: The trail downhill the waterfall is extremely steep. There is no significant risk at the geodiversity site, but the natural pool's water level urges caution.
	Observing conditions: All geological elements are observed in good conditions.

	Interpretative potential: Good, as its geological features are clearly distinguishable. Its geological features are associated with two main events: (i) intrusion and fracturing of alkaline rocks, and (ii) weathering of rocks by action of water, which interpretation could be integrated. For example, rocks with angular edges were formed by water on fracture planes, causing fragmentation and rockfalls. As other geosites connected to hydrographic processes, this geodiversity site could be used to raise awareness of the preservation and conscious use of water.
	Infrastructure: There is no infrastructure in the geodiversity site, but there are a parking area and toilets at the trailhead.
	Degradation risk: About vulnerability, the intense use of the trail, the forest fires (by natural or human activities), and incorrect garbage disposal are the main factors of anthropic vulnerability.
	Use limitations: The geodiversity site can be visited during the park's opening hours. There is no limit to the number of visitors per day. The time limit to start the Aiuruoca Waterfall trail is 10:00 am.

Identification	**Name:** Geodiversity site Nepheline syenite of Três Picos Hill.
	Municipality: Itatiaia (RJ).
	Geographical coordinates (UTM WGS-84): 23K 542910 / 7519982.
	Access / Trailhead: On foot by following the Três Picos trail that starts at Simon Hotel. The route is about 14 km long (round trip), and its difficulty level is considered high. The geodiversity site is situated at the end of the trail.
	Typology: Area and area (single landform).
	Zoning within the management plan: Extensive use zone.
Characterisation	**Framework:** First magmatic stage of alkaline intrusion.
	Geological unit: Nepheline syenite I (Rosa and Ruberti, 2018).
	Geomorphological unit: Paraíba do Sul River Depression.
	Geological interests: Geomorphological and plutonism.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Ecological, aesthetic and historical.
Quantitative assessment	**Scientific value:** 185, 175.
	Degradation risk: 75.
	Potential educational use: 240.
	Potential touristic use: 195.

Description

The Três Picos Hill is inserted in the oldest and the most silica-undersaturated alkaline rocks of INP. The geodiversity site is characterised as a nepheline syenite hill, with a hilltop, convex slopes and an average gradient of 40% (ICMBio, 2013) (Fig. A.22A). On the peak, an outcrop approximately two metres long and one metre wide can be observed (Fig. A.22B).

Rosa and Ruberti (2018) point out that the nepheline syenite I has a fine-to-medium-grained texture and grey-to-dark grey colour with whitish portions and mafic enclaves. Aluminous assemblages with significant plagioclase, biotite, muscovite, hercynite, corundum and rutile stand out in the border facies.

The morphogenesis is linked to the intrusion of alkaline rocks, while its morphodynamics is associated with the erosion of slopes.

<table>
<tr><td colspan="2">The geodiversity site also stands out as a viewpoint since it offers the views of the Paraíba do Sul river valley, Funil hydroelectric plant dam, Bocaina and Mantiqueira mountain ranges (Fig. A.22C).</td></tr>
<tr><td colspan="2">Figures

Fig. A.22 Geodiversity site Nepheline syenite of Três Picos Hill. (A) View of the Três Picos hill. (B) In the foreground, view of the Paraíba do Sul river valley and the Funil hydroelectric plant dam; in the background, view of the Bocaina mountain range. (C) Detail of the summit with a metric outcrop of nepheline syenite (Figure A: Itatiaia National Park, available in http://www.parquedoitatiaia.tur.br/portfolio/trilha-dos-tres-picos/, figure B: available in https://www.tripadvisor.com/Attraction_Review-g2348871-d10786504-Reviews-Trilha_dos_Tres_Picos-Itatiaia_State_of_Rio_de_Janeiro.html and figure C: photo by Maria da Glória M. Garcia).</td></tr>
<tr><td rowspan="4">Use and management</td><td>Potential use: Touristic, educational and scientific.</td></tr>
<tr><td>Security: No significant risk. However, to reach the summit, some rivers have to be crossed. During rainy seasons, higher water volume and risks of sudden floods on riverbeds urge caution.</td></tr>
<tr><td>Observing conditions: The vegetation obstructs the observation of some geological elements.</td></tr>
<tr><td>Interpretative potential: Good, as it represents the oldest exposure of alkaline rocks in the study area. The geodiversity site could also be explored as a viewpoint since its summit has a panoramic view of the study area’s landforms and its surroundings.</td></tr>
</table>

	Infrastructure: There is no infrastructure in the geodiversity site, but there is a parking area at the trailhead.
	Degradation risk: There is no risk regarding its intrinsic fragility or vulnerability resulting from natural or anthropic action.
	Use limitations: The geodiversity site can be visited during the park's opening hours. There is no limit to the number of visitors per day. It is required to fill out and sign a Waiver of Liability Agreement at the park's entrance, Visitor Centre or Maromba Complex.

<table>
<tr><td rowspan="6">Identification</td><td>Name: Geodiversity site Granitic Gneiss of Alcantilado Waterfall.</td></tr>
<tr><td>Municipality: Bocaina de Minas (MG).</td></tr>
<tr><td>Geographical coordinates (UTM WGS-84): 23K 545202 / 7534632.</td></tr>
<tr><td>Access / Trailhead: On foot by following the trail that starts at Alcantilado waterfalls farm (Km 10 of the Mauá-Mirantão Road). This route is 3 km long (round trip), and its difficulty level is considered easy. The geodiversity site is at the end of the trail.</td></tr>
<tr><td>Typology: Point and point (single landform).</td></tr>
<tr><td>Zoning within the management plan: Temporary occupation zone.</td></tr>
<tr><td rowspan="6">Characterisation</td><td>Framework: Proterozoic igneous and metamorphic rocks.</td></tr>
<tr><td>Geological unit: Maromba granitic gneiss (Trouw et al., 2003).</td></tr>
<tr><td>Geomorphological unit: Mantiqueira / Itatiaia Mountain Ranges.</td></tr>
<tr><td>Geological interests: Plutonism, tectonics, hydrological and geomorphological.</td></tr>
<tr><td>Specific geomorphological interest: Structural processes.</td></tr>
<tr><td>Other elements of interest: Aesthetic, ecological and historical.</td></tr>
<tr><td rowspan="4">Quantitative assessment</td><td>Scientific value: 180, 175.</td></tr>
<tr><td>Degradation risk: 65.</td></tr>
<tr><td>Potential educational use: 235.</td></tr>
<tr><td>Potential touristic use: 205.</td></tr>
<tr><td colspan="2">Description
The Granitic gneiss of Alcantilado Waterfall is the highest waterfall of the Alcantilado river in the study area (Fig. A.23A). The cascade waterfall is about 40 metres high with NW-SE oriented foliation, moderate dip angle and concordant with the regional shear zone that crosscuts the area (Fig. A.23B and A.23C) (CPRM, 2006). Two fracture systems can be recognised, the first one oriented NE, mainly noticed in the Alcantilado Waterfall, and the second one oriented NW, being represented by the waterfalls downstream.
According to Trouw et al. (2003), the Maromba granitic gneiss is mainly composed of K-feldspar, plagioclase, quartz and biotite. K-feldspar megacrysts are marked by an igneous flow orientation, emphasised by the tectonic deformation that resulted in a gneiss texture in the matrix. The Pb-Pb zircon dating provided crystallisation age at ca. 590 ±2 Ma (Mendes et al., 2003).</td></tr>
</table>

Its morphogenesis is linked to igneous origin, ductile deformation and hydrographic processes. Concerning morphodynamics, hydrographic processes are active, contributing to the erosion of the fracture planes and the fragmentation and transport of sediments.

Besides, it plays a vital role in the planning and management of water sources and is a viewpoint of the Visconde de Mauá region and Alcantilado river valley (Fig. A.23D).

Figures

Fig. A.23 Geodiversity site Granitic gneiss of Alcantilado Waterfall. (A) View of the geodiversity site and its surroundings. (B) View of the Alcantilado waterfall, highlighting the water flowing in the NE orientation. (C) Detail of the outcrop at the base of the waterfall with a moderate dip angle. (D) View from the geodiversity site of Visconde de Mauá's region and Alcantilado River Valley (Figures A and D available in https://www.cachoeirasdoalcantilado.com.br/, figures B and C: photos by Maria da Glória M. Garcia).

Use and management	**Potential use:** Touristic, educational and scientific.
	Security: No significant risk.
	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: Very high, as its geological features are clearly distinguishable. Even outside the boundaries of the INP, the other waterfalls of the Alcantilado Waterfall farm should be included in an integrated interpretation project to contribute to both conservation of geological features and water preservation. Besides,

	the contrast of rocks and relief between Visconde de Mauá's region and the upper region of the protected area should be included in the interpretative proposals.
	Infrastructure: There are rustic staircases, handrails and protective parapets on site. At the trailhead, there are a parking area, toilets, restaurants and accommodations.
	Degradation risk: There is no risk regarding intrinsic fragility or vulnerability resulting from natural or anthropic action.
	Use limitations: The geodiversity site can be visited during the Alcantilado Waterfall Farm's opening hours. The farm charges a preservation and maintenance fee to visit the Alcantilado waterfall at the farm's entrance.

Identification	**Name:** Geodiversity site Gneiss of Cristais Waterfall.
	Municipality: Itatiaia (RJ).
	Geographical coordinates (UTM WGS-84): 23K 540397 / 7528736.
	Access / Trailhead: On foot by following the Cachoeira dos Cristais trail that starts at Cruzes Valley. This route is about six kilometres long (round trip), and its difficulty level is considered moderate. The geodiversity site is at the end of the trail.
	Typology: Point and point (single landform).
	Zoning within the management plan: Primitive zone.
Characterisation	**Framework:** Proterozoic igneous and metamorphic rocks.
	Geological unit: Gravitational deposits (Talus) (Heilbron et al., 2016).
	Geomorphological unit: Mantiqueira / Itatiaia Mountain Ranges.
	Geological interests: Metamorphism, tectonics, hydrological and geomorphological.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Aesthetic, ecological and historical.
Quantitative assessment	**Scientific value:** 170, 185.
	Degradation risk: 95.
	Potential educational use: 245.
	Potential touristic use: 215.

Description

The site is represented by one of the waterfalls of the Cruzes river and is located at 1,493 metres of altitude. It is about 30 metres high, with water flowing down three tiers and finally into a natural pool of almost eight metres in diameter (Fig. A.24A). According to the geological map of Heilbron et al. (2016), it is located in the gravitational deposits unit. However, the rock that composes the waterfall follows the banded biotite gneiss characteristics (Trouw et al., 2003) or garnet-biotite gneiss units (Heilbron et al., 2016). The above authors defined this unit as a paragneiss with plagioclase, biotite, muscovite, epidote, microcline and garnet, as well as biotite-rich compositional bands.

There is a natural pool with metamorphic and alkaline boulders at the bottom of the waterfall that are up to two metres and have rounded edges, suggesting that they originated from the slope itself and more distant areas. Its second tier has a natural pool of about five metres in diameter (Fig. A.24B). These rocks are locally folded, and their main foliation has NW-SE orientation, with a low dip angle (Fig. A.24C) and concordant with the regional shear zone that crosscuts the region. Well-formed, centimetric quartz crystals are also locally observed (Fig. A.24D).

Its morphogenesis is associated with metamorphic and ductile deformation, as well as with hydrographic processes. About morphodynamics, hydrographic processes are ongoing, contributing to the erosion of the slopes and the fragmentation and transport of sediments.

Furthermore, the geodiversity site plays an essential role in the planning and management of water sources.

Figures

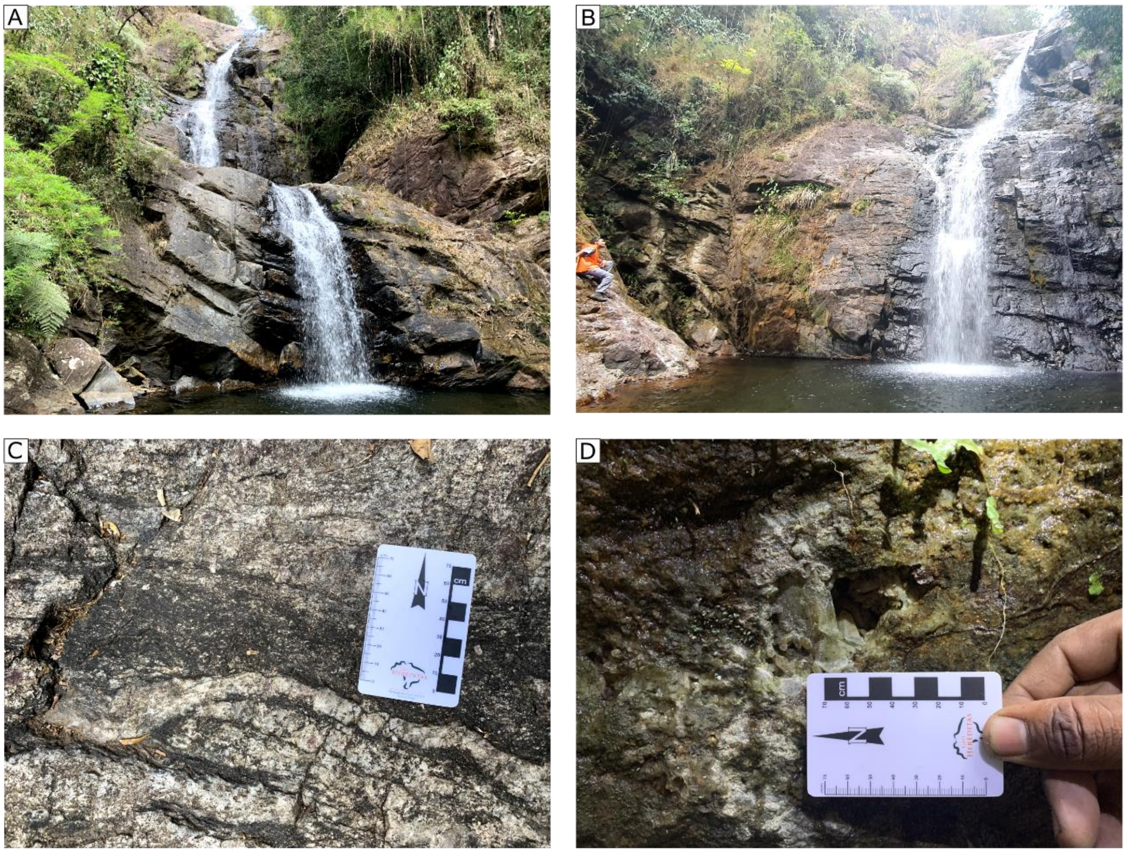


Fig. A.24 Geodiversity site Gneiss of the Cristais Waterfall. (A) View of the Cristais waterfall with water flowing down three tiers. (B) View from the second tier of the waterfall with a natural pool of about five metres in diameter. (C) Detail of the garnet-biotite gneiss unit with a concentration of mafic minerals and folded felsic minerals. (D) Detail of the centimetric quartz crystals. (Figures A and C: photos by Maria da Glória M. Garcia, figures B and D: photos by Vanessa C. Mucivuna).

Use and management	**Potential use:** Touristic, educational and scientific.
	Security: No significant risk, but caution is advised on the trail to reach the second tier of the waterfall due to its steep slope, as well as with the river speed and level, especially during summer, when heavy rains at headwaters cause sudden floods on riverbeds.

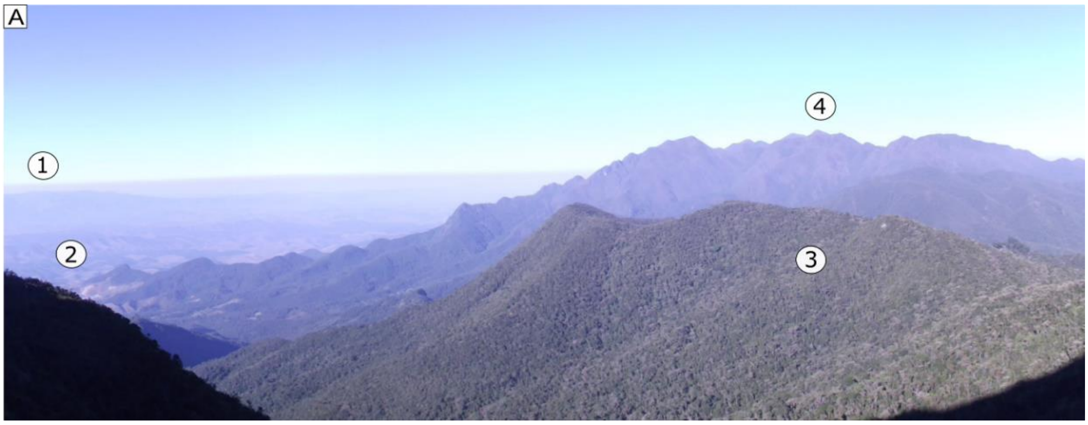
	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: High, since some features are clearly distinguishable by any audience. As other geosites linked to hydrographic processes, this site could be used to raise awareness of the importance of protection and conscious use of water. As the waterfall rocks had been heavily mined for quartz crystals in the past, educational activities should address the sustainable use of natural resources since geodiversity has finite and non-renewable dimensions. Moreover, it could be used to illustrate the contrast of rocks and relief between this region and the upper region of the protected area.
	Infrastructure: There is no infrastructure on the geodiversity site.
	Degradation risk: Regarding vulnerability, the process of water erosion increases natural vulnerability due to the weathering of rocks. The intense use of the trail and mining for minerals are the main factors of anthropic vulnerability.
	Use limitations: Although it is located in the park, there is no access restriction.

Identification	**Name:** Viewpoint Flores Highway.
	Municipality: Resende (RJ).
	Geographical coordinates (UTM WGS-84): 23K 528107 / 7526791.
	Access / Trailhead: By motor vehicles from Garganta do Registro (border between the states of Rio de Janeiro and Minas Gerais), following 13.3 km along the Flores Highway (BR-485). The viewpoint is on the right of the highway towards Marcão station.
	Typology: Viewpoint and viewpoint.
	Zoning within the management plan: Intensive use zone.
Characterisation	**Framework: -**
	Geological unit: -
	Geomorphological unit: -
	Geological interests: Geomorphological and tectonics.
	Specific geomorphological interest: Structural processes.
	Other elements of interest: Aesthetic, ecological and historical.
Quantitative assessment	**Scientific value:** Not applicable.
	Degradation risk: Not applicable.
	Potential touristic use: Not applicable.
	Potential educational use: Not applicable.

Description

The viewpoint is located at 2,173 metres of altitude in the Mantiqueira mountain range, its principal value being associated with the landforms that can be distinguished in its surface. From the viewpoint, it is possible to observe the following features: (1) the horst of the Serra do Mar, represented in the area by Bocaina Mountain Range; (2) the graben of the Paraiba do Sul; (3) Itatiaia Alkaline Massif, and; (4) Passa Quatro Alkaline Massif, of which the following should be highlighted: Pedra da Mina Peak, the fourth highest peak in Brazil, and Três Estados Peak, the triple border between the states of Minas Gerais, Rio de Janeiro and São Paulo (Fig. A.25A) (Mucivuna and Garcia 2018).

Besides its geological interest, the viewpoint has a high aesthetic value due to the colour contrast and topographic variation resulting from the geological and geomorphological characteristics of the landscape.

Figure	
 **Fig. A.25** Viewpoint Flores Highway. (A) General aspect with emphasis on [1] Bocaina Mountain Range, [2] Paraíba do Sul River Valley, [3] Itatiaia Alkaline Massif, and [4] Passa Quatro Alkaline Massif. (Figure A: photo by Vanessa C. Mucivuna).	
Use and management	**Potential use:** Touristic and educational.
	Security: The viewpoint is located on the right of the Highway towards Marcão station. The parking lot has space for two cars only; furthermore, there is no security infrastructure such as fences, handrails, parapets, among others.
	Observing conditions: The vegetation makes difficult the observation of the main geological elements.
	Interpretative potential: The geomorphological characteristics are clearly distinguishable. The viewpoint allows the correlation between the two alkaline massifs (Itatiaia and Passa Quatro). Besides, it is possible to approach the graben and horst system formation by observing the Bocaina and Mantiqueira mountain ranges and the Paraíba do Sul river valley. Furthermore, the importance of protected areas could be addressed by pointing out the difference in vegetation between the Bocaina and Mantiqueira mountain ranges, covered by protected areas, and the Paraíba do Sul river valley, which is not a protected area.
	Infrastructure: There is no infrastructure on the viewpoint itself.
	Degradation risk: There is no risk regarding intrinsic fragility or vulnerability resulting from natural or anthropic action.
	Use limitations: There is no official access restriction, but it cannot be visited by many people at the same time due to its size.

<table>
<tr><td rowspan="6">Identification</td><td>Name: Viewpoint Último Adeus.</td></tr>
<tr><td>Municipality: Itatiaia (RJ).</td></tr>
<tr><td>Geographical coordinates (UTM WGS-84): 23K 540414 / 7516328.</td></tr>
<tr><td>Access / Trailhead: By motor vehicle. From the main entrance at the lower region, following 2.3 km along the Flores Highway (BR-485) towards the head office. The viewpoint is on the left of the road towards the administrative office.</td></tr>
<tr><td>Typology: Viewpoint and viewpoint.</td></tr>
<tr><td>Zoning within the management plan: Extensive and intensive use zone.</td></tr>
<tr><td rowspan="6">Characterisation</td><td>Framework: -</td></tr>
<tr><td>Geological unit: -</td></tr>
<tr><td>Geomorphological unit: -</td></tr>
<tr><td>Geological interests: Geomorphological, tectonics and hydrological.</td></tr>
<tr><td>Specific geomorphological interest: Structural and fluvial processes.</td></tr>
<tr><td>Other elements of interest: Aesthetical, ecological and historical.</td></tr>
<tr><td rowspan="4">Quantitative assessment</td><td>Scientific value: Not applicable.</td></tr>
<tr><td>Degradation risk: Not applicable.</td></tr>
<tr><td>Potential touristic use: Not applicable.</td></tr>
<tr><td>Potential educational use: Not applicable.</td></tr>
<tr><td colspan="2">Description
From this viewpoint, it is possible to view two main geomorphological landforms, one related to the morphology of the IAM and the other linked to the Paraíba do Sul river valley (IBGE, 2019). Its principal value is connected to a panoramic view of the following: (i) Serra da Mantiqueira, represented by IAM and the incised valley of Campo Belo River (Fig. A.26A), and (ii) graben of Paraiba do Sul Valley, represented by the dam of Funil hydroelectric power plant, and Bocaina Mountain Range (Fig. A.26B) (Mucivuna and Garcia, 2018).
Besides its geological interest, it has high aesthetic value due to the colour contrast and high cultural value. Before the creation of the national park, this viewpoint could be seen from the main office of Mont-Serrat Farm, which is today the park's administration. The last record that the Último Adeus viewpoint could be observed from the administrative office dates back to the 1950s (ICMBio, 2013); since then, the vegetation of the park has</td></tr>
</table>

<table>
<tr><td colspan="2">recovered, confirming the crucial role of the protected area in the conservation of local vegetation.</td></tr>
<tr><td colspan="2">Figures

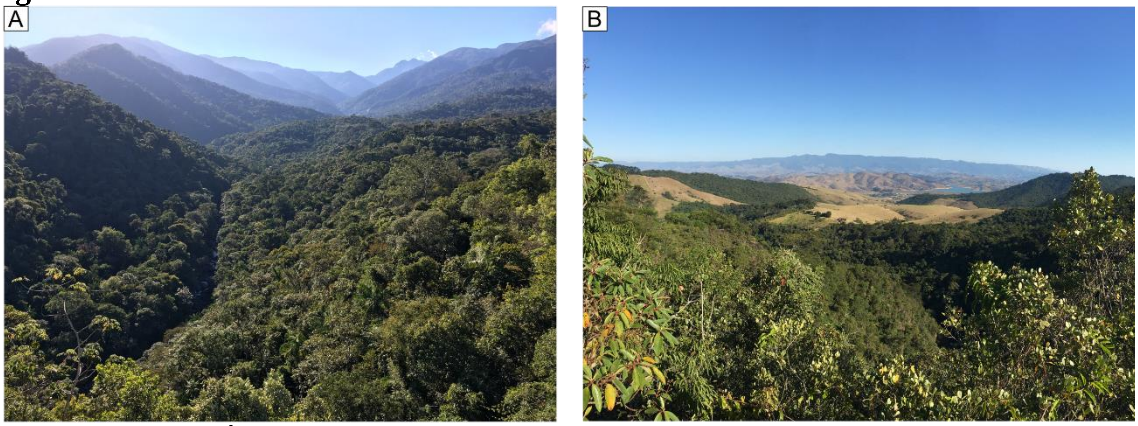



Fig. A.26 Viewpoint Último Adeus. (A) In the foreground, view of the incised valley of Campo Belo river. In the background, view of the IAM. (B) View of the Paraíba do Sul river valley and the Funil hydroelectric plant dam. In the background, view of the Bocaina mountain range. (Figures A and B: photos by Vanessa C. Mucivuna).</td></tr>
<tr><td rowspan="7">Use and management</td><td>Potential use: Touristic and educational.</td></tr>
<tr><td>Security: No significant risk.</td></tr>
<tr><td>Observing conditions: All geological elements are observed in good conditions.</td></tr>
<tr><td>Interpretative potential: High, since it allows the correlation between two geomorphological regions (Paraíba do Sul River Depression and Mantiqueira/Itatiaia Mountain Ranges). Just as in the viewpoint of Flores Highway, this one is important to understand the features linked to the horst and graben system, examples of this system being the Serra do Mar and Serra da Mantiqueira, as well as Paraíba do Sul. Moreover, it is excellent to explain the importance of protected areas to nature conservation, as it is possible to note the contrasts with deforested areas outside the park.</td></tr>
<tr><td>Infrastructure: There are a parking area, handrails and stairs to access the viewpoint.</td></tr>
<tr><td>Degradation risk: There is no risk regarding intrinsic fragility or vulnerability resulting from natural or anthropic action.</td></tr>
<tr><td>Use limitations: The viewpoint can be visited during the park's opening hours. The access is via a stairway, so people who have physical impairment may have problems to reach it. There is no limit to the number of visitors per day, but it cannot be visited by many</td></tr>
</table>

	people simultaneously due to its size, a study on its carrying capacity being required.

<table>
<tr><td rowspan="6">Identification</td><td>Name: Viewpoint Alto dos Brejos Hill.</td></tr>
<tr><td>Municipality: Bocaina de Minas and Itamonte (MG).</td></tr>
<tr><td>Geographical coordinates (UTM WGS-84): 23K 539869 / 7535397.</td></tr>
<tr><td>Access / Trailhead: On foot by following the Alto do Brejos trail that starts at the Ecological Park of the Sanctuary Waterfalls (Santa Clara Valley). This trail is approximately seven kilometres long (round trip), and its difficulty level is considered moderate. The viewpoint is at the end of the trail.</td></tr>
<tr><td>Typology: Viewpoint and viewpoint.</td></tr>
<tr><td>Zoning within the management plan: Primitive zone, extensive use zone, and recovery zone.</td></tr>
<tr><td rowspan="6">Characterisation</td><td>Framework: -</td></tr>
<tr><td>Geological unit: -</td></tr>
<tr><td>Geomorphological unit: -</td></tr>
<tr><td>Geological interests: Geomorphological and tectonics.</td></tr>
<tr><td>Specific geomorphological interest: Structural processes.</td></tr>
<tr><td>Other elements of interest: Aesthetic, ecological and historical.</td></tr>
<tr><td rowspan="4">Quantitative assessment</td><td>Scientific value: Not applicable.</td></tr>
<tr><td>Degradation risk: Not applicable.</td></tr>
<tr><td>Potential touristic use: Not applicable.</td></tr>
<tr><td>Potential educational use: Not applicable.</td></tr>
<tr><td colspan="2">Description
The viewpoint is at 1,988 metres of altitude at the border of Bocaina de Minas and Itamonte. The Alto dos Brejos hill is characterised by asymmetric slopes, with an average gradient of 40% (ICMBio, 2013) and adapted to a NE-SW oriented fault scarp (IBGE, 2019). Its principal value is linked to the landforms that can be recognised from the summit of Alto dos Brejos Hill. From the viewpoint, the following features can be viewed: (1) Serra do Mar Mountain Range (Bocaina Sector); (2) Paraíba do Sul River Valley and Mares de Morros landforms; (3) talus deposits with smoother slopes; (4) asymmetric slopes; (5) convex section slope (Fig. A.27A); (6) Gavião Peak; and (7) Pedra Selada, in the State Park of Pedra Selada (Fig. A.27B).</td></tr>
</table>

Its morphogenesis is linked to igneous origin and ductile deformation. Concerning morphodynamics, erosion processes such as rill are ongoing and derive from soil erosion by the action of flowing water (Fig. A.27C).

The viewpoint has a high aesthetic value due to the colour variation and topographic contrast. It also has high cultural value, as this trail has been used for hundreds of years by residents who come from Minas Gerais to sell traditional products such as cheese, sweets, jams and honey in the Santa Clara Valley region.

Figures

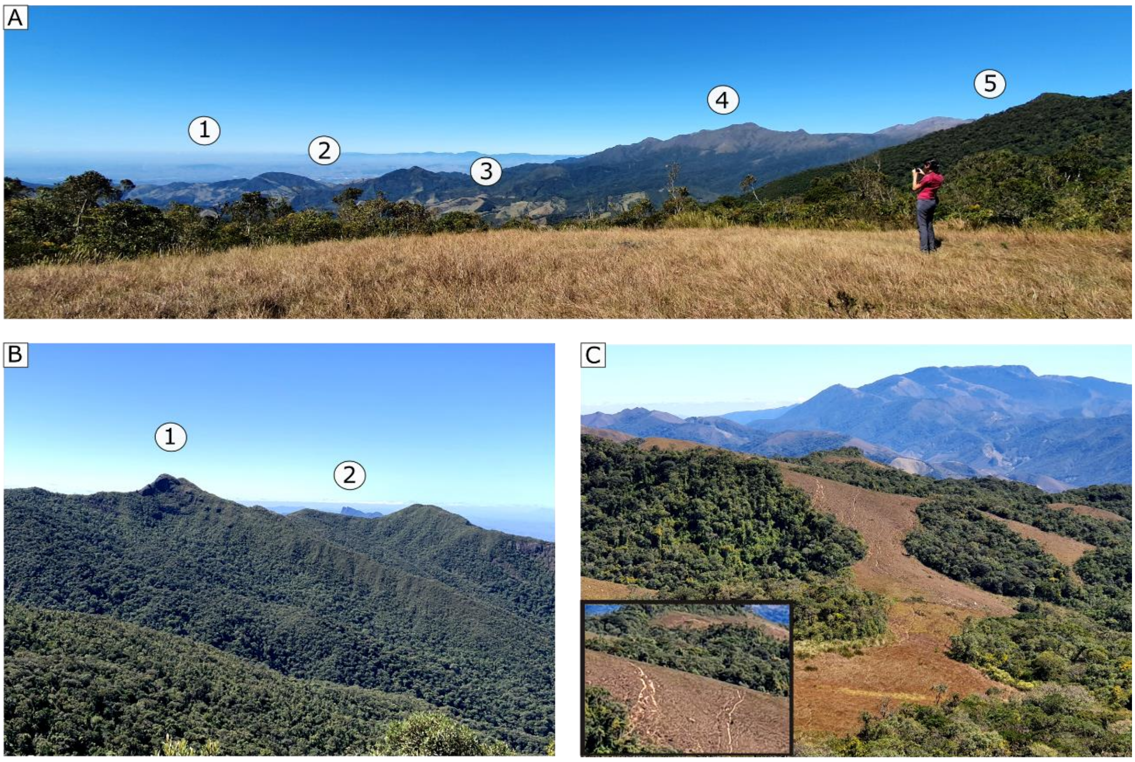


Fig. A.27 Viewpoint Alto dos Brejos Hill. (A) The general aspect of the viewpoint, highlighting [1] Serra do Mar Mountain Range; [2] Paraíba do Sul River Valley and Mares de Morros landforms; [3] talus deposits; [4] asymmetric slopes; [5] convex section slope. (B) In the foreground, view of the Gavião peak [1] and, in the background, view of the Pedra Selada peak [2]. (C) Detail of the erosion process caused by water surface runoff. (Figure A: photo by Maria da Glória M. Garcia, figures B and C: photos by Vanessa C. Mucivuna).

Use and management	**Potential use:** Touristic and educational.
	Security: No significant risk.
	Observing conditions: All geological elements are observed in good conditions.
	Interpretative potential: High, since it allows the association of the landforms inside (Visconde de Mauá region and upper region) and outside of the INP. The different geomorphological regions (Paraíba do Sul River Depression and Mantiqueira/Itatiaia Mountain Ranges) support the interpretation of the formation of the graben and horst

	system through the Bocaina, and Mantiqueira mountain ranges and the Paraíba do Sul river valley.
	Infrastructure: There is no infrastructure in the viewpoint, but there are a parking area, toilets and a snack bar at the trailhead.
	Degradation risk: About fragility, neither the landscape nor the surface could be degraded from the viewpoint. Concerning vulnerability, the intense use of the trail and forest fires (by natural or human activities) are the main factors of anthropic vulnerability.
	Use limitations: The viewpoint can be visited during the opening hours of the Ecological Park of the Sanctuary Waterfalls. However, to reach the viewpoint, the park charges a preservation and maintenance fee at entrance.

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