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ORIGINAL ARTICLE

# Geoheritage of the São Tomé Island (West Africa)

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**Abstract**
Remote islands are a focus of great interest for biodiversity studies, and it is common to neglect their geodiversity that conditions the composition and evolution of the biotic component of nature. Just like endemic species, which stand out in the composition of the biodiversity of remote islands, geosites are places that represent geological processes and products that characterize the genesis and evolution of these islands. The geological heritage of the island of São Tomé, located in the Gulf of Guinea (West Africa), was previously described based on several selected geosites. The main objective of this work is to present the complete inventory of the geological heritage of São Tomé Island, based on detailed field analysis of its different stratigraphic units, and using an evaluation methodology that considers the specificities of oceanic islands in a low to middle income social context. The results provide an overview of all the geosites on the island, which are described in accordance with its main geological interests and intended for public understanding. Such records allow the dissemination of geosciences in communities with low levels of scientific literacy and can be used to advance geoscience, improve geoeducation, and promote geotourism. In the long term, it is expected that this will have the effect of reducing poverty among the population whose income depends significantly on tourism activity.

**Keywords** São Tomé Island · Cameroon volcanic line · Geological heritage · Geoconservation · Sustainable development

## Introduction

São Tomé is a small Atlantic Island located in the Gulf of Guinea (West Africa) that integrates the set of volcanic islands located at the "Cameroon Volcanic Line". Besides the aesthetic appeal of volcanic landscapes provided by these remote islands (Carrión-Mero et al. 2024), they also represent a privileged area for the comparative study of oceanic volcanism and continental alkaline volcanism (Henriques and Neto 2019), and to understand important concepts and ideas about Darwin´s Coral Reef Theory (Henriques and Neto 2023).

This study builds upon previous research conducted on the archipelago of São Tomé and Príncipe, which enabled the forward-looking inventorying of the geological heritage of the São Tomé Island and the qualitative evaluation of seven selected geosites (Henriques and Neto 2015, 2019; Neto and Henriques 2023).

Detailed field analysis of outcropping geological units of São Tomé Island and laboratorial work of rock and fossil sampling led to the updating of its stratigraphic framework, and to the identification and assessment of 28 geosites with significant heritage value. They allow us to demonstrate and explain the variety of geological phenomena that constitute the island's geohistory and which founded its worldwide known current biodiversity, therefore contributing to achieve a comprehensive overview of the natural heritage of São Tomé and Príncipe.

The geodiversity of volcanic landscapes represents a non-renewable form of heritage (Wang et al. 2014). The obtained results can be utilized as a powerful tool for geoeducation, since the adequate dissemination of São Tomé's geological heritage makes it possible to raise awareness among local communities that geodiversity is an essential condition to protect biodiversity (Gray 2018). Moreover, it can help promote geotourism as a strategic economic

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activity in the island, therefore expanding and diversifying the current tourism offer, whose marketing is based above all on the country's extraordinary biodiversity (Jones 1994; Ceríaco et al. 2022).

This is of particular importance for African countries, where the geoheritage at the global scale is currently underrepresented and remains to be analyzed and uncovered (Neto and Henriques 2022). Moreover, it is part of one of the key aspects of the 2030 Agenda, since geoscience knowledge can contribute to the conservation of geodiversity through awareness and appreciation of geosciences, both by tourists and by the communities that inhabit areas with geological heritage (Gill 2016; Gerbaudo et al. 2023; Senger 2024). Disclosing the geological heritage of São Tomé and Príncipe can contribute to promote geoeducation and geotourism, and foster sustainable development in this tiny African country, dimensions of the utmost importance for Small Island Developing States (SIDS).

## Geology of the Study Area

The Cameroon Volcanic Line (CVL), which includes the islands of São Tomé and Príncipe, is the sole example on Earth of an active intraplate alkaline tectonomagmatic alignment that developed simultaneously in oceanic and continental domains (Fig. 1).

The CVL comprises a series of mountainous regions and active volcanoes, extending over approximately 1,600 km and oriented in a north-to-east direction (N30°E) (Toteu et al. 2010; Adams 2022; Linol et al. 2024). It has been the site of volcanic activity since the Paleocene epoch, approximately 66 Ma, and continues to be so today (Déruelle et al. 1991, 2007). The continental part of the CVL has been volcanically active since approximately 42 Ma, while offshore volcanism commenced approximately 30.4 Ma (Grunau et al. 1975).

The São Tomé Island is primarily composed of volcanic rocks, which can be divided into four main units (Fig. 2): the São Tomé Volcanic Complex (0.15–1.5 Ma), the Phonolitic Basaltic Complexes, which include the Ribeira Afonso Volcanic Complex (2.5-5 Ma) and the Mizambú Volcanic Complex (7–13 Ma), and the Ilhéu das Cabras Volcanic Formation (~13 Ma) (Fitton 1987; Halliday et al. 1988; Caldeira and Munhá 2002; Caldeira et al. 2003; Aka et al. 2004).

On top of the pyroclastic materials corresponding to the first phase of the São Tomé Volcanic Complex (<0.4 Ma) (Fitton 1987; Halliday et al. 1988) outcrops a sedimentary unit (Lagoa Azul Formation) which is visible in several places on the island, from its northern coast to Ilhéu das Rolas islet on the south (Fig. 3; see also Fig. 14). This unit

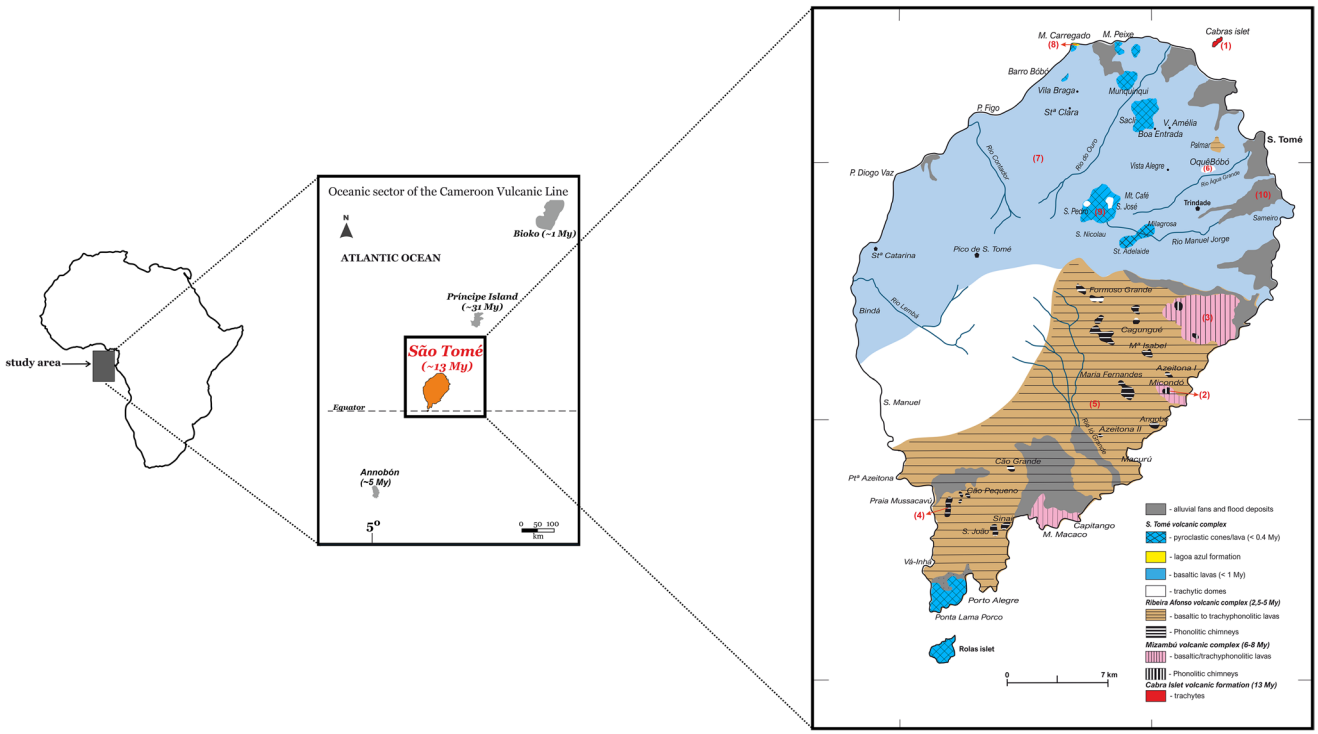


**Fig. 1** Location of São Tomé Island in the Gulf of Guinea and the Cameroon Volcanic Line: Cabras Islet volcanic formation 13 Ma - **(1)** – trachytes; Mizambú volcanic complex 6–8 Ma - **(2)** – Phonolitic chimneys, **(3)** – basaltic/trachyphonolitic lavas; Ribeira Afonso volcanic complex 2.5-5 Ma - **(4)** – Phonolitic chimneys, **(5)** basaltic to trachyphonolitic lavas; S. Tomé volcanic complex < 1 Ma – **(6)** trachytic domes, **(7)** - basaltic lavas, **(8)** – Lagoa Azul formation; **(9)** – pyroclastic cones/lavas (<0.4 Ma); **(10)** – alluvial fans and flood deposits

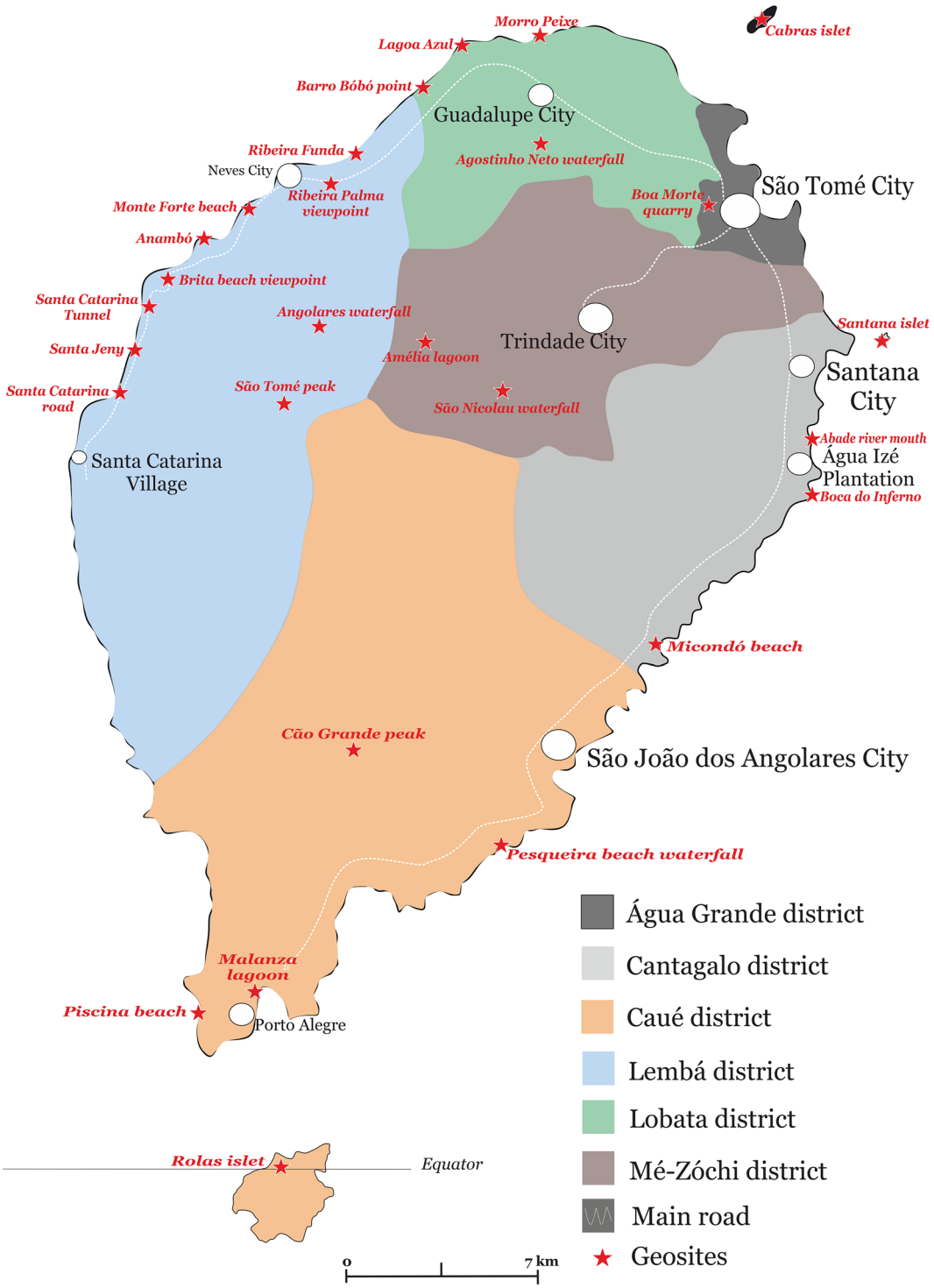


**Fig. 2** Map of district of São Tomé Island indicating geosites´ location (in red star)

is composed by cross-bedded sandstone sequences representing migrating sand dunes (Anambó), which vary laterally to siliceous (Santa Catarina Tunnel, Monte Forte Beach and Santa Jeny), and carbonate cemented conglomerates of well-rounded clasts of volcanic materials and bioclasts, mainly of large abundant crustose coralline red algae. These provide evidence of an ancient platform of a drowned fringing coral reef, and they are particularly visible in Lagoa Azul (Henriques and Neto 2023).

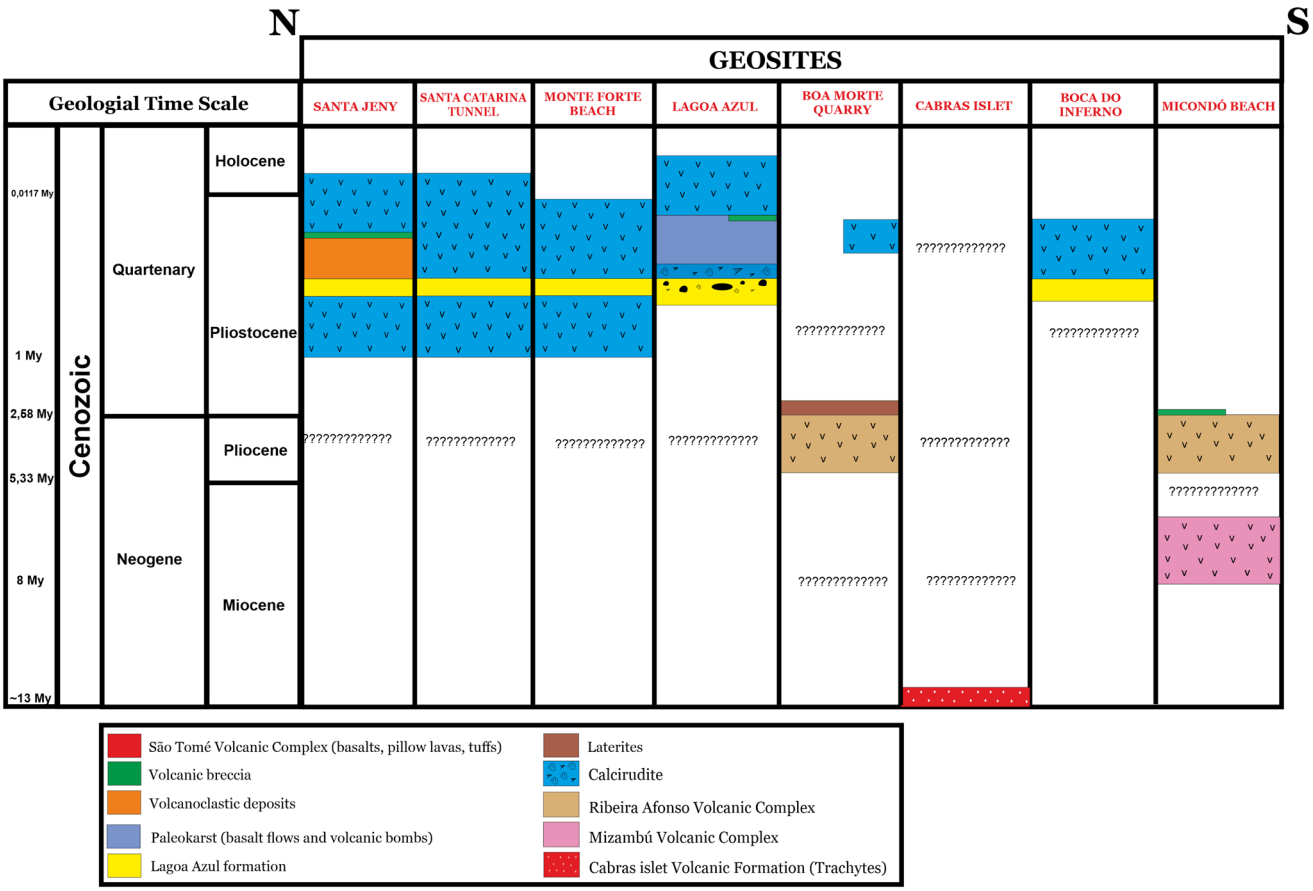


**Fig. 3** Chart of stratigraphic units of São Tomé. Geosites are highlighted in red line

## Theoretical and Methodological Considerations

It is widely acknowledged that the process of assigning values to geological objects inherently involves a certain degree of subjectivity. This is primarily because the very concept of value is shaped by a "human filter" (Coratza and Hobléa 2018), which is influenced by a multitude of individual and social factors, as well as cultural factors. Cultural bias can affect various fields, including research and decision-making processes, and highlights the importance of considering cultural diversity and sensitivity when making assessments or decisions (Cameron 2024). It can be suggested that most, if not all, inventory and evaluation methods may be susceptible to cultural bias, a topic that receives significant attention in the social sciences, as it can affect multiple inventory and evaluation methods, but apparently less so in geoconservation literature (Yadav 2022).

Inventorying and assessment methods in geoconservation include both quantitative and qualitative approaches. The issue of subjectivity becomes particularly critical when it comes to assigning a numerical value to a previously defined parameter as an indicator of any dimension among the many that underpin the concept of geoheritage.

Scales for valuing geological heritage established based on parameters that are relevant for a given socio-economic context may be inappropriate for other contexts (Neto and Henriques 2022), demonstrating how utopian it is to create a universal scale for valuing the geological heritage of the Earth.

Africa is a multi-speed continent, and the issue of size and insularity renders SIDS particularly challenging territories for the implementation of any policy and/or strategy already used within the continent. The African continent itself is characterized by diversity, with varied customs, languages, and ethnic groups within countries. São Tomé and Príncipe belongs to Africa but this SIDS displays a lot of distinctive characteristics stemming from historical and geographical contexts, particularly the influence of colonialism and the absence of robust inter-country connections. Implementing a closed methodological approach to geoconservation in African SIDS is a challenge, given the nature of the method, and it seems more appropriate to use approaches that are more open and adapted to the territory where they have to be implemented, and thus conform to these territories, rather

than the other way around. This perspective is further substantiated by the absence of SIDS territories in Africa on the IUGS list of geological sites (IUGS 2025).

The objective of this study is to validate the application of a tool for inventorying and evaluating geological heritage, which can be utilized throughout Africa. The first approaches to the country's geoheritage were developed in São Tomé Island (Oliveira & Santos 2013; Henriques and Neto 2015, 2019) employing an integrated evaluation system that is qualitative in nature and is based on the geoheritage contents that geosites may display (Pena & Henriques 2009). This method allows for a more holistic appreciation of geosites, reflecting various subjective aspects. It relates the degree of relevance for the scientific community and the public perception of the geological object under evaluation, which stems from the use of geosites by various social groups, particularly in the areas of education, research in geosciences, and geotourism (Henriques and Pena dos Reis 2021).

The same methodology was subsequently employed on a preliminary approach to the geological heritage of Príncipe Island (Neto and Henriques 2023), and it will be used in this paper to benchmark and compare the earlier outcomes and contribute to the compilation of a future inventory of the national geological heritage.

## Geosites Inventorying and Assessment

The geoheritage of São Tomé can be represented through 28 geosites that resulted from the inventory and assessment of its geodiversity, and which allows a narrative to be based on the island's geohistory (Figs. 4 and 5; Tables 1 and 2). The inventory was meticulously designed to identify geological heritage of scientific value and national relevance, employing international methodologies as a framework. The selection of these geosites was based on several well-defined criteria, including their representativeness of the island's geological history (i.e., relevance grade for scientific communities), and abstract perceptiveness (i.e., the public perception of the geological object under evaluation as reflected by its current use; Table 1). In the absence of specific legislation on geoconservation and the incipient state of public awareness of local geological heritage, a

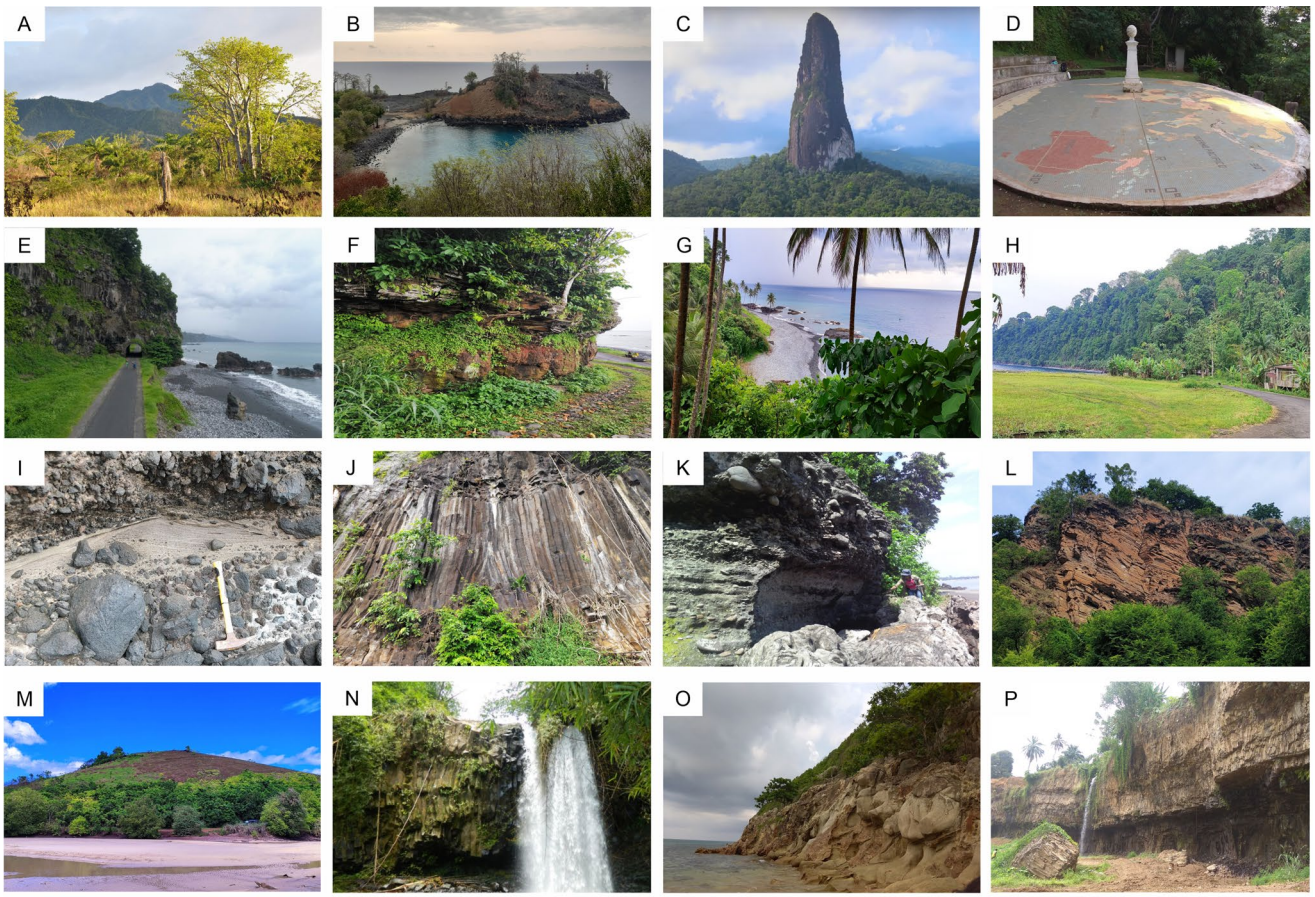


**Fig. 4** Photos of the geosites (**a** – São Tomé peak, **b** – Lagoa Azul, **c** – Cão Grande peak, **d** – Rolas islet (Equator), **e** – Santa Catarina tunnel, **f** – Santa Jeny, **g** – Brita Beach viewpoint, **h** – Santa Catarina road, **i** – Anambó, **j** – Monte Forte Beach, **k** – Ribeira Funda, **l** – Barro Bóbó point, **m** – Morro Peixe, **n** – Agostinho Neto waterfall, **o** – Cabras Islet, **p** – Boa Morte quarry)


**Fig. 5** Photos of geosites (**a** – Queluz Spring, **b** – Angolares waterfall, **c** – São Nicolau waterfall, **d** – Amélia Lagoon, **e** – Santana Islet, **f** – Boca do Inferno, **g** – Micondó Beach, **h** – Pesqueira Beach waterfall, **i** – Malanza Laguna, **j** – Piscina Beach, **k** – Ribeira Palma viewpoint, **l** – Abade river)

qualitative approach to inventorying and evaluating geoconservation, as exemplified by Pena & Henriques (2009), is particularly useful. This method can serve to complement the existing conservation status of areas that are legally protected for non-geological reasons, something that is already happening in São Tomé (e.g., the Obô Natural Park). The inventory was based on previous work and focused on identifying geological heritage of scientific value and national relevance.

This inventory was conducted from a regional perspective with the objective of developing a geoconservation strategy and a geotourism and education program involving the two islands (São Tomé and Príncipe) in the future.

The majority of the selected geosites exhibit a multiplicity of values, thereby conferring upon them a substantially heightened heritage value. The priority of geoconservation measures can be determined according to the heritage value obtained through the overall qualitative assessment of each geosite (sum of obtained scores) and its vulnerability to natural and man-made threats (Tables 1 and 2).

When considering its position in the frame of the CVL the assemblage of São Tomé geosites may be of international significance, as it enables the reconstruction of the geological history of the CVL, a significant geological phenomenon associated with the opening of the South Atlantic Ocean. A thorough analysis was conducted, considering the scientific, educational, and tourist value of all the sites. The most relevant geosites include São Tomé Peak, Lagoa Azul, Cão Grande Peak and Rolas Islet, which are of particular interest to scientific communities due to their unique characteristics and their role in understanding the history of the Earth and the development of Earth sciences (Pena & Henriques 2009). Among them, Cão Grande Peak and Lagoa Azul were recognized as displaying international relevance.

Cão Grande Peak is a remarkable site of profound scientific importance, serving as a point of reference for researchers familiar with its structural features. The Pico do Cão Grande rises dramatically from the lush surrounding rainforest, reaching an impressive height of approximately 663 m (Henriques and Neto 2015, 2019). It is characterized by its vertical walls, which resemble a giant tooth or tusk protruding from the earth. The peak is composed of phonolitic rock, formed by the volcanic activity of the region (Caldeira et al. 2003). It is the most spectacular volcanic peak in the oceanic part of the Cameroon Volcanic Range.

The Lagoa Azul, an emblematic site, merits recognition as a geosite of international importance due to its scientific value, but it also displays considerable educational potential. It is considered one of the most spectacular scenic spots in the country. The northern aspect of the beach is marked by the presence of Carregado Hill, which is composed of pyroclastic materials from the São Tomé Volcanic Complex. These materials occasionally exhibit rhythmic stratification, reflecting the final volcanic phase of the island of São Tomé, dating back 0.4 Ma. The sedimentary units within this region have been identified as containing marine fossils. The sedimentary rock, designated as calcirudite, is of an undetermined age but is believed to be Pleistocene. It

**Table 1** Geosites assessment of São Tomé Island

| Geosite N.º | Geosite | Characterization | Relevance | Abstract perceptiveness | | | | Geoheritage contents | | | | | Geoconservation priority | Qualitative Assessment Rank (s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Material | Demonstrative | Cognitive | Social | Indicial | Iconographic | Symbolic | Documental | Scenic | | |
| 1 | São Tomé Peak | The island features a shield volcano that was carved by fulvial erosion and rises to a height of 2024 meters. | i,r,n | X | | | X | X | | X | | X | 1st | I, II and III |
| 2 | Lagoa Azul | Volcanic cone under marine erosion process. | i,r,n | X | X | | X | X | | X | X | X | 1st | I, II and III |
| 3 | Cão Grande Peak | The Cão Grande peak rises to 663 meters above sea level; it is the most spectacular peak of the oceanic part of the Cameroon Volcanic Line. | i,r,n | | X | | X | | | X | X | X | 1st | II and III |
| 4 | Rolas Islet | Volcanic cone and raised beach. | i,r,n | | | | X | | | X | X | X | 1st | II and III |
| 5 | Santa Catarina tunnel | Volcanic stratigraphic sequence and type section of of São Tomé Volcanic Complex. | r,n | | | X | X | | X | | | X | 1st | I and III |
| 6 | Santa Jeny road | Sequence of basalts, fluvial conglomerates, volcanic sediments and basalts of the São Tomé Volcanic Complex. | n | X | X | | | X | | | X | | 2nd | I and II |
| 7 | Brita Beach Viewpoint | Viewpoint of the Brita beach, beatiful pebble beach. | n | X | | | X | X | | | | X | 3th | I and III |
| 8 | Santa Catarina road | Pillow lavas and a spectacular columnar disjunction of the São Tomé Volcanic Complex. | n | | | | X | | | | | X | 2nd | III |
| 9 | Anambó | Flood deposits interspersed with aeolian material, showing entrenched stratification. | n | X | X | | | X | | | X | | 2nd | I and II |
| 10 | Monte Forte Beach | Pyroclastic material interspersed with basalts with columnar and spheroidal disjunction and at the top with volcanic sediments. | n | | X | | X | | | | X | X | 3th | II and III |
| 11 | Ribeira Funda | River conglomerates overlying volcanic flows of the São Tomé Volcanic Complex. | n | X | | | | X | | | | | 3th | I |
| 12 | Barro Bóbó point | Surtsean coastal cone of the São Tomé Volcanic Complex. | n | X | X | | X | X | | | X | X | 1st | I, II and III |
| 13 | Morro Peixe | Old pyroclastic cone made up of "aa" São Tomé Volcanic Complex type scoriaceous lavas, with channel structures and tombs. | n | X | | | X | X | | | | X | 2nd | I and III |
| 14 | Agostinho Neto waterfall | Stunning waterfall showing basalt with columnar and laminar disjunction of the São Tomé Volcanic Complex. | n | X | X | | X | | | | X | X | 3th | II and III |

is composed primarily of fossil shells, becoming less fossiliferous towards the top. The uppermost layer consists of a compact limestone that does not contain any identifiable fossils, but the whole sequence provides evidence of an ancient platform with abundant crustose coralline red algae representing one of the various stages of coral reef development within the CVL according to Darwin's subsidence hypothesis (Henriques and Neto 2023).

The public's understanding of the meanings assigned to a geological object or abstract perceptiveness encompasses a range of scales (Fig. 6), from the individual, such as the physical entity or object itself like a volcanic cone, to the social scale, which encompasses collectively accepted ideas related to geological objects, like an outstanding landscape. The abstract perceptiveness of such objects is directly related to their social fruition and may influence political decisions that support their geoconservation (Pena & Henriques 2009).

Most of the recognized geosites display intense social use once they have facilitated access, an essential condition for becoming a tourist attraction. This is an issue of the utmost importance in territories covered by intense vegetation, which prevents the observation of a large part of the island's geological record. For the same reasons, the same geosites may also have educational potential, while the scientific potential is limited to geosites that are relevant in the frame of the island's location in the CVL, i.e., geosites requiring specialized knowledge of geological phenomena to be perceived (Fig. 7). In this sense the recognized geosites display geological characteristics, which fall into different types of geoheritage: volcanic, sedimentary, stratigraphical, paleontological, geomorphological, pedological (laterite crusts), and economic (quarries) (Fig. 8) (Habibi et al. 2018).

Typical features of geoheritage of volcanic type include columnar and spheroidal disjunctions, volcanic breccia, pillow lavas and volcanic bombs easily observed in several geosites of the island (Fig. 9). Geoheritage of paleontological type refers to the occurrence of different fossil remains collected at Lagoa Azul geosite, located at Lobata Municipality, which includes bivalve mollusks, coralline

**Table 2** Geosites assessment of São Tomé Island

| Geosite N.º | Geosite | Characterization | Relevance | Abstract perceptiveness | | | | Geoheritage contents | | | | | Geoconservation priority | Qualitative Assessment Rank (s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Material | Demonstrative | Cognitive | Social | Indicial | Iconographic | Symbolic | Documental | Scenic | | |
| 15 | Cabras Islet | Trachyte volcanic chimneys exhumed by marine erosian, the oldest known unit on the island of São Tomé. | n | | X | | X | | | | X | X | 2nd | II and III |
| 16 | Boa Morte quarry | Contact between the Ribeira Afonso Volcanic Complex and the lateritic paleosol horizon | n | | X | | X | | | | X | X | 3th | II and III |
| 17 | Queluz Spring | Spring of carbonated water related to the most recent volcanic phase of the São tomé Volcanic Complex; it belongs to a cluster of similar springs scattered in the island. | r,n | X | | | X | X | | X | | | 2nd | I and II |
| 18 | Angolares waterfall | Gorge entrenched between two tunnels and known as the «bat kingdom". | n | X | | | X | X | | | | X | 3th | I and III |
| 19 | São Nicolau waterfall | Waterfall along the Manuel Jorge River representing a fault front; it is a popular attraction of the island. | n | X | | | X | X | | | | X | 2nd | I and III |
| 20 | Amélia Lagoon | Phreatomagmatic crater. | r,n | X | X | | | X | | | X | | 2nd | I and II |
| 21 | Santana Islet | Large volcanic massif with coastline sculpted by marine erosion displaying spectacular columnar and slab disjunction; it is one of the best spots for diving. | n | | | | X | | | | | X | 3th | III |
| 22 | Boca do Inferno (Hell's Mouth) | Narrow channel formed by the marine erosion of basaltic lavas with columnar disjunction and pillow lavas. | n | | X | X | X | | X | X | X | X | 1st | I,II and III |
| 23 | Micondó Beach | Basalts of the Ribeira Afonso Volcanic Complex showing columnar disjunction eroded by marine abrasion. | n | | X | | X | | | | X | X | 2nd | II and III |
| 24 | Pesqueira Beach waterfall | Costal waterfall in basalts with slab and columnar disjunction providing shell-like structure to the rocks. | n | X | | | X | X | | | | X | 2th | I and III |
| 25 | Malanza Laguna | The Rolas Islet currently separed from the main island as a result of the sea level rise that flooded the depressed areas and created the Malanza lagoon. | n | | | | X | X | | | | X | 2nd | I and III |
| 26 | Piscina Beach | Natural pool formed by coastal erosion with basalts showing a structure resembling "broad bark". | n | X | | | X | X | | | | X | 2nd | I and III |
| 27 | Ribeira Palma viewpoint | Viewpoint of the river fan where Neves city was settled. | n | | | | X | | | | | X | 3th | III |
| 28 | Abade river | Abade River Structure separating the São Tomé Volcanic Complex and the Ribeira afonso Complex. | n | X | | | X | X | | | | X | 2nd | I and III |

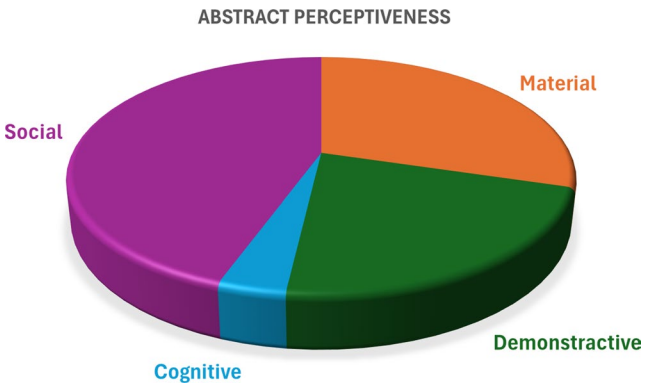


**Fig. 6** The public understanding of the São Tomé geosites

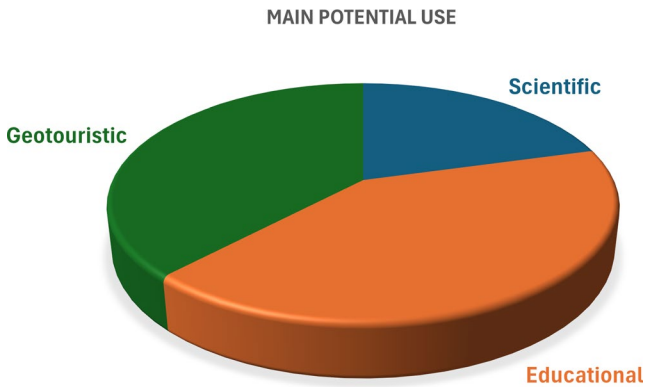


**Fig. 7** Main potential use of São Tomé Island geosites

algae, equinoid, and miliolid foraminifera (Henriques and Neto 2023) (Fig. 10). Examples of geoheritage of economic type include quarries where lateritic soil, and basaltic rocks currently explored for construction (Fig. 11). The rugged character of the island is reflected in the occurrence of peaks, islets and hills of high scenic content, which represent its geomorphological geoheritage (Fig. 12). The sedimentological geoheritage refers to the occurrence of conglomerates, flood deposits and volcanic sediments in several geosites (Fig. 13). Geoheritage of stratigraphic type includes geosites where the lithostratigraphic boundaries between the island stratigraphic units are particularly well exposed (Fig. 14).

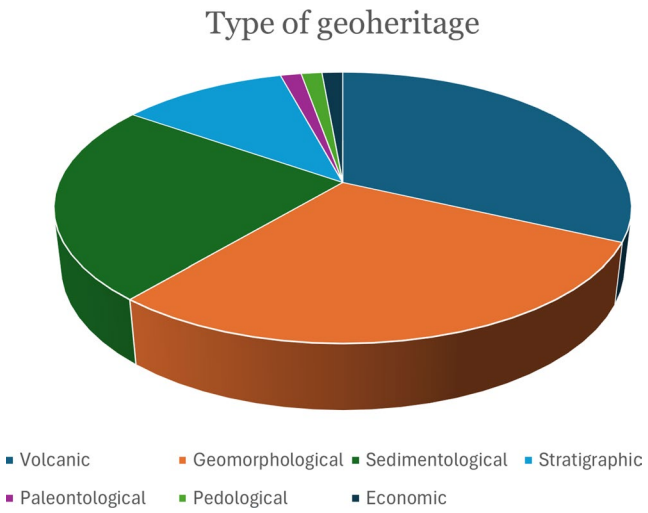


**Fig. 8** Geoheritage types recognized in São Tomé Island

The global geosites inventorying and assessment of the São Tomé Island highlights the dominance of scenic content over other types of geoheritage contents, reflecting the island's remarkable beauty and potential for geotourism purposes. This is followed by documental content, which chronicles significant episodes of the island's geological history, and indicial content, which is directly related to the island's volcanic origin (Fig. 15).

Recognizing the geoconservation priorities of a territory is extremely important in justifying political options regarding the respective development strategies. São Tomé Peak, Lagoa Azul, Cão Grande Peak, Rolas Islet, Santa Catarina Tunnel, Barro Bóbó Point, and Boca de Inferno geosites show the highest assessment rank therefore requiring the highest level of geoconservation priority (Fig. 16). It is not exactly the risk of land degradation that is at stake in most of these geosites, but rather the pressing need to enhance and monitor them. However, given its popularity, ease of access and consequent intense use, Lagoa Azul presents an increased risk of physical degradation.

## Discussion

The African continent, particularly sub-Saharan Africa, is lagging other continents in terms of geoconservation research. This results in the waste of the continent's geological heritage as a tool for fostering sustainable development of local communities (Henriques et al. 2013a, b; Neto and Henriques 2022).

However, the promotion of geotourism in Africa requires a deepening of geoconservation studies on the continent. Unlike other regions of the world, research on geoconservation in Africa is still very limited, which hinders the promotion of geotourism and, consequently, jeopardizes the promotion of sustainable development among African communities (Dowling and Newsome 2018; Ngwira 2019a, b; Neto and Henriques 2022; Matshusa and Leonard 2023).

Conversely, the implementation of methodologies intrinsic to this field, which are already employed in the Western world, are not sufficient to obtain a representative picture of Africa's geological heritage. The socio-economic circumstances of most African countries diverge significantly from those of countries where geoconservation has reached a high level of development (Matshusa et al. 2021). In African countries, priorities and levels of scientific literacy vary considerably. Nevertheless, Africa possesses a rich geological heritage that requires comprehensive study and dissemination (Errami et al. 2015; Ngwira 2019a, b).

This study focuses on a limited geographical area with a relatively small number of geosites, where a quantitative assessment may not be the most appropriate approach (Brilha 2016). Geoheritage assessment methods must be scale-independent, encompassing local to global levels, in alignment with contemporary interpretations of sustainable development, as exemplified by geotourism. This is a crucial consideration when discussing the geological heritage of territories with markedly disparate dimensions, such as Mauritius (Newsome and Johnson 2013) and São Tomé and Príncipe (Henriques and Neto 2015, 2019).

The advantage of employing a qualitative approach to geoheritage assessment allows us to consider not only the scientific relevance of a given geological object, but also the local communities' perception of it (Pena & Henriques 2009). This issue is particularly important, not least because some geosites, being places of worship, have a high symbolic value for the communities that interact with them. Their conservation is guaranteed for non-geological reasons, representing a good example of positive collaboration between scientists and local communities.

A qualitative approach is rather helpful for complementing the current conservation status of areas that are already legally protected for non-geological reasons, being particularly relevant when dealing with the so diverse African socio-cultural contexts and represent a key factor to a successful community involvement in geoconservation (Tavares et al. 2015).

The instruments currently employed to assess the heritage value of geosites have been designed and tested in contexts that are entirely distinct from the socio-geographic environment of São Tomé and Príncipe. The initial approaches to the country's geoheritage were developed in São Tomé Island (Oliveira & Santos 2013; Henriques and Neto 2015, 2019; Neto and Henriques 2023) employing an integrated evaluation system that is qualitative in nature and is based on the geoheritage contents that geosites may display (Pena & Henriques 2009). The same methodology was


**Fig. 9** Typical features of volcanic geoheritage outcropping in São Tomé Island: **a**) Spheroidal disjunctions – Anambó, **b**) Spheroidal disjunctions – Rolas Islet, **c**) Volcanic breccia – Lagoa Azul, **d**) Volcanic breccia – Micondó Beach, **e**) Columnar disjunctions – São Nicolau waterfall, **f**) Columnar disjunctions – Monte Forte Beach, **g**) Columnar disjunctions – Boca de Inferno, **h**) Pillow lavas – Santa Catarina road, **i**) Volcanic bomb – Lagoa Azul, **j**) Surtsean cone – Barro Bóbó point, and **k**) Pillow lavas - Santa Catarina road

subsequently employed at Príncipe Island (Neto and Henriques 2023), thus enabling a comparative analysis between the two islands, and contributing to the compilation of a future inventory of the national geological heritage. This instrument is perfectly suited to the entire heritage of the archipelago of São Tomé and Príncipe, as well as the oceanic part of the Cameroon Volcanic Line (Henriques and Neto 2023).

Of the 28 geosites inventoried in São Tomé, two geosites merit particular attention due to their international relevance: São Tomé Peak and Lagoa Azul. These sites hold significant value for scientific communities, as their distinctive characteristics and role in understanding the history of the Earth and the development of Earth sciences make them of particular interest (Pena & Henriques 2009). In fact, both geosites can help to understand the geological history of CVL and the opening of the South Atlantic.

The results presented above demonstrate the island's need for geoconservation policies that could assist in the promotion of tourism, a significant contributor to the nation's economy. São Tomé, being a volcanic island, has, due to its geographical circumstances and separation from the African

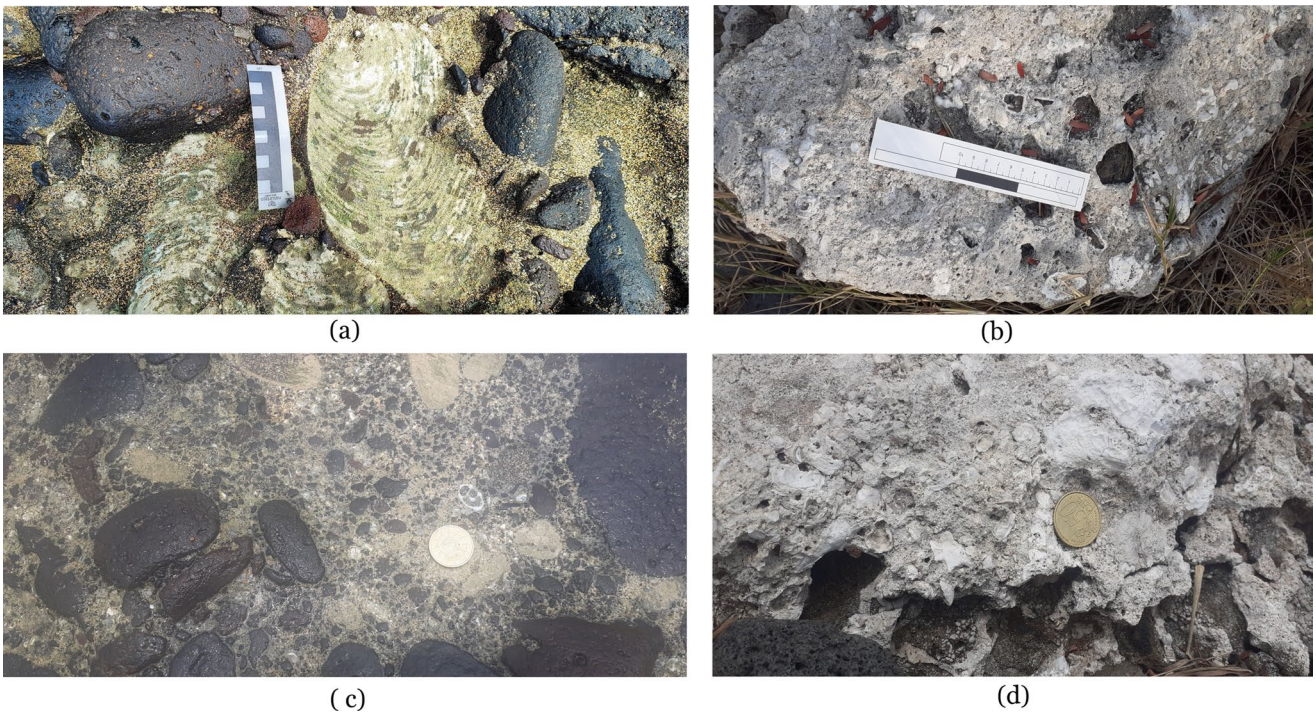


**Fig. 10** Typical features of paleontological geoheritage outcropping in São Tomé Island: **a**) Coraline algae, **b**) Coquina, **c**) Bivalve fossil, and **d**) Coquina – (Lagoa Azul)

**Fig. 11** Boa Morte quarry at Palmar geosite represents geoheritage both of pedological and economic types. Lateritic soil is highlighted in red

continent, been capable of establishing the conditions for one of the world's most significant endemic hotspots. These conditions have been brought about by the island's geological characteristics and the highly fertile soil that has been formed through the weathering of volcanic rock. As so, the island's biodiversity, which is rich at all levels, is a key asset that should be emphasized through its geodiversity and its role in the ecosystem, as well as its potential as an educational resource.

The qualitative geoheritage assessment has already been tested in São Tomé and Príncipe and has been demonstrated to be relevant for use in SIDS. This tool will facilitate a deeper understanding of the geological heritage of Africa, which is crucial for advancing two areas where knowledge is currently limited: geoeducation and geotourism. In addition, this work has enriched knowledge about the island's geology, convincingly illustrating the social relevance that geological heritage studies can have, not only in education, geotourism, nature conservation and land-use planning, but also in research (Henriques et al. 2011).


**Fig. 12** Typical features of geomorphological geoheritage outcropping in São Tomé Island: **a**) Morro Carregado (Lagoa Azul), **b**) São Tomé Peak – Lagoa Azul, **c**) Cão Grande Peak – Caué river bridge, **d**) Santa Catarina tunnel – Santa Catarina road, **e**) Morro Peixe – Namorado Beach and **f**) Santana Islet–Santana Club

## Conclusion

The geological heritage of the island of São Tomé, located in the Gulf of Guinea (West Africa), was previously described based on several selected geosites. The main objective of this work is to present the complete inventory of the geological heritage of São Tomé Island, based on detailed field analysis of its different stratigraphic units, and using an evaluation methodology that considers the specificities of oceanic islands in a low to middle income social context.

The geological heritage of São Tomé Island can be represented through 28 geosites that resulted from the inventory and qualitative assessment of its geodiversity, and which allows a narrative to be based on the island's geohistory. The recognized geosites display geological characteristics, which fall into different types of geoheritage, mainly volcanic, geomorphological, and pedological; sedimentary,


**Fig. 13** Typical features of sedimentological geoheritage outcropping in São Tomé Island: **a**) Lagoa Azul formation – Lagoa Azul, **b**) Flood deposits – Anambó, **c**) Conglomerate (red line) – Monte forte Beach, **d**) Volcanic sediments on the conglomerates – Santa Jeny Road and **e)** Fluvial conglomerate – Ribeira Funda village

stratigraphical, paleontological, and economic types can also be recognized.

Two geosites of international importance were recognized, Cão Grande Peak and Lagoa Azul. When analyzed collectively within the framework of the CVL, they can contribute to supporting conceptions and ideas about the geological history of the CVL and the opening of the South Atlantic.

Some of the recognized geosites display intense social use once they have facilitated access, an essential condition for becoming a tourist attraction and an educational resource. Scenic content prevails over other types of geoheritage contents, an important asset when analyzing the island's potential for geotourism purposes. São Tomé Peak, Lagoa Azul, Cão Grande Peak, Rolas Islet, Santa Catarina Tunnel, Barro Bóbó Tip, and Boca de Inferno geosites

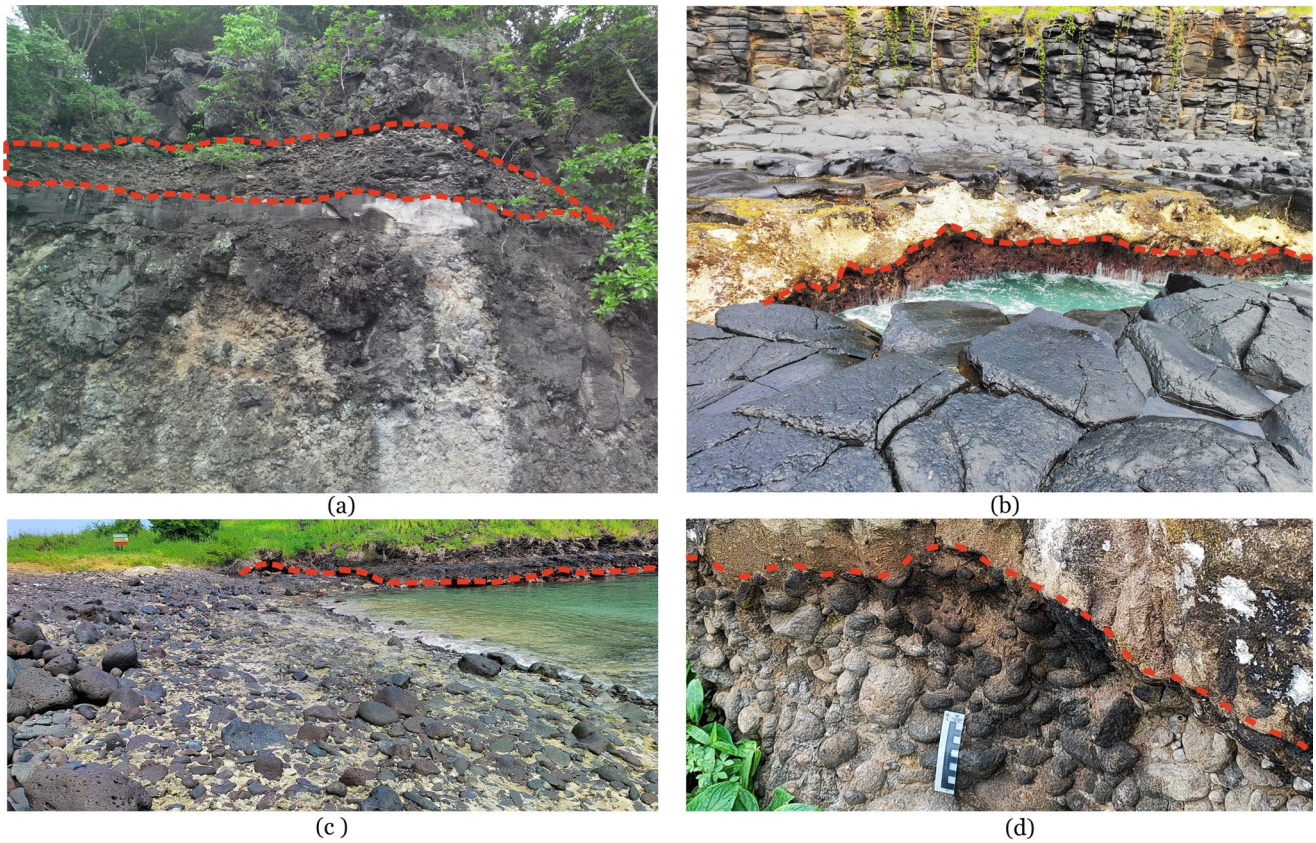


**Fig. 14** Stratigraphic contact between São Tomé volcanic complex and Lagoa Azul formation (**a** – Lagoa Azul, **b**– Boca do Inferno and **c** – Monte Forte Beach, **d** – Santa Jenny)

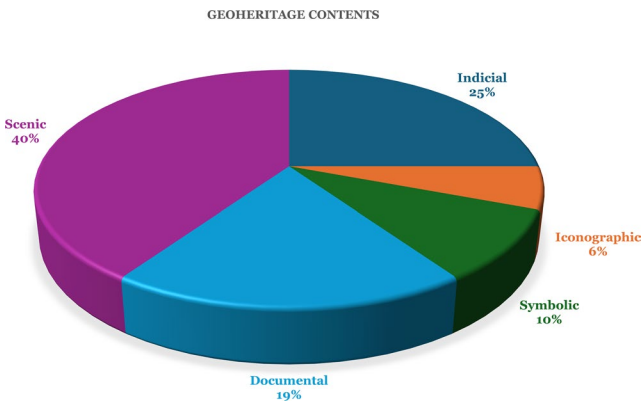


**Fig. 15** Types of geoheritage contents recognized in São Tomé geosites

display the highest rank in terms of geoheritage qualitative assessment and should be the focus of priority geoconservation measures. All these geosites require valuation measures (in terms of accessibility and the installation of information panels, for example). The ease of access and the intense use of the Lagoa Azul geosite as a beach justify the need to take measures to guarantee its physical integrity.

The results of this work provide an overview of all the geosites of the island, which are described in accordance with its main geological interests and intended for public understanding. This work fulfills the initial phase of a typical geoconservation process, paving the way for the formulation of a geoconservation strategy at the national level. The overview of the geology of São Tomé Island represented by the 28 geosites here described and evaluated will allow the dissemination of geosciences in communities with lower levels of scientific literacy and can be used to advance geoscience, improve geoeducation, and promote geotourism. It also facilitates the creation of a geotourism narrative in line with the Strategic and Marketing Plan for Tourism in São Tomé and Príncipe (2018–2025), which identifies the primary factors that attract tourists to the country (natural beauty, gastronomy, history, and farm culture). In the long term, it is expected that this will lead to a decrease in poverty levels among those whose livelihoods are heavily reliant on tourism.

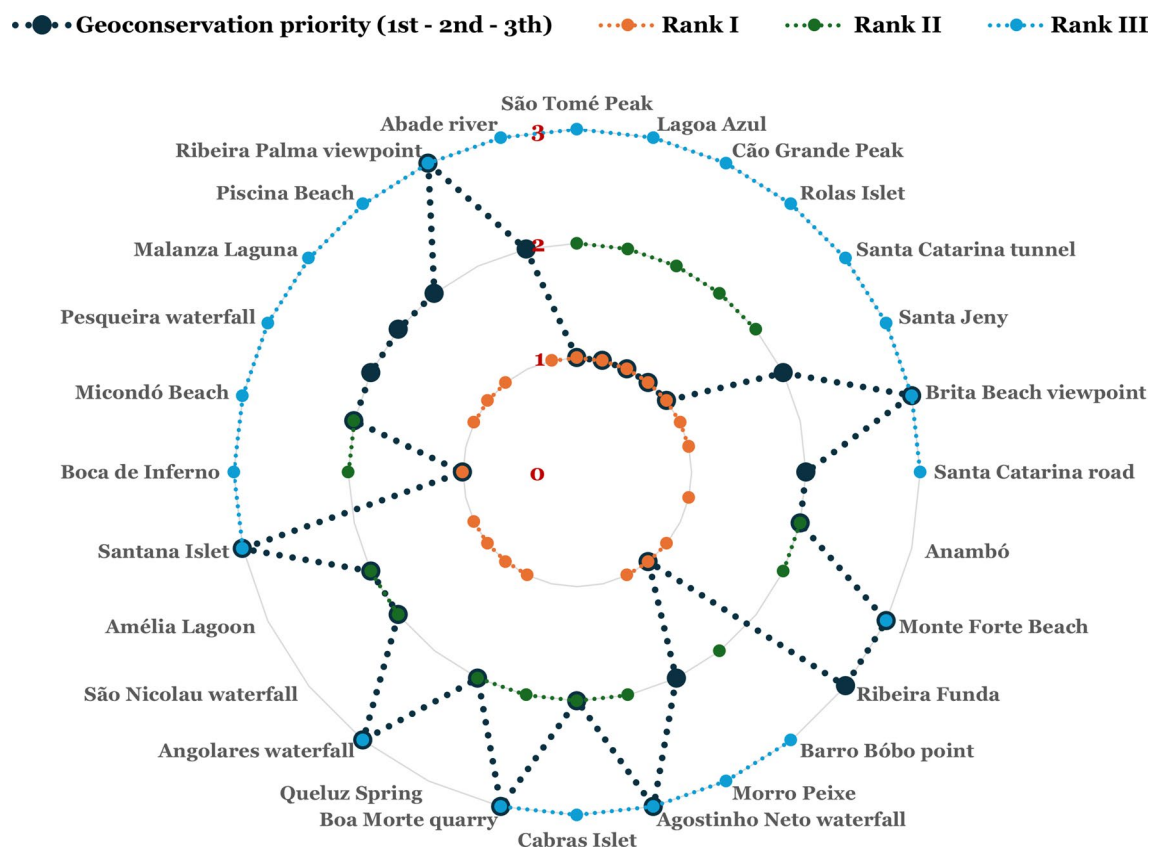


**Fig. 16** Qualitative assessment of the São Tomé Island geoheritage

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## Declarations

**Conflict of interest** The authors declare no conflict of interests.



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