Journal of the Geological Survey of Brazil

The geological heritage of the state of São Paulo: potential geosites as a contribution to the Brazilian national inventory

Ligia Maria de Almeida Leite Ribeiro[1,2*], Maria da Glória Motta Garcia[2], Karina Kawai Higa[2]

[1]Serviço Geológico do Brasil – SGB / CPRM, Rua Costa, 55 - Cerqueira César, São Paulo - SP – Brazil, CEP: 01304-010
[2]Núcleo de Apoio à Pesquisa em Patrimônio Geológico e Geoturismo (GeoHereditas), Instituto de Geociências, Universidade de São Paulo. Rua do Lago, 562, São Paulo - SP, Brazil, CEP: 05508-080

Abstract

Having a national geoheritage inventory is essential to plan effective geoconservation strategies. Since 2017, the Geological Survey of Brazil (CPRM) has been carrying out a project aimed at the Inventory of the Brazilian Geological Heritage and defined state coordinations to propose indicative lists of potential geosites based mainly on the scientific value (SV) according to the GEOSSIT platform. For the state of São Paulo, which was the first in Brazil to have a systematic geoheritage inventory, with 137 geosites already defined, this study intends to analyze them to propose some criteria to select the ones to compound the national list. Fifty-seven geosites were chosen according to both SV (≥ 300, following the requirements of GEOSSIT) and representativeness within each geological framework (when SV < 300). We also evaluated the selected geosites in other national initiatives, such as SIGEP (nine geosites) and the Geoparks Project (five geosites). The GEOSSIT public lists show only three of the 57 geosites already registered, a low number considering that these registrations are relevant indicators for the national inventory. The geosites were also analyzed according to the main thematic classification (eight main thematic categories, with a large number in the petrology theme - 35.10%) and general geological context (73.70% in the Mantiqueira, Paraná, and Tocantins provinces and 26.30% in Emerged Phanerozoic Basins - Paraná, Bauru, and São Paulo), according to the parameters available on GEOSSIT. The sites were also evaluated according to typology, being 33 points, 22 areas, and two sections. Regarding the statutory setting, 30% are in fully protected areas, 36% in public or private areas with non-effective statutory protection (APAs, marine land, paleontological sites, etc.), and 34% comprise public or private areas with no protection.

Article Information

Publication type: Research papers
Received 15 October 2020
Accepted 8 February 2021
Online pub. 4 March 2021
Editor: Marcos Nascimento

Keywords:
Geoconservation,
Geological heritage,
Geosites,
Inventory,
São Paulo State

*Corresponding author
Lígia Maria de Almeida Leite Ribeiro
E-mail address: ligia.ribeiro@cprm.gov.br

1. Introduction

Inventories of geological heritage have long been considered crucial instruments for making the initial diagnosis of geological interest sites in a particular area. The data originated from these investigations are essential as bases for geoconservation planning. The character of their outcomes controls further actions focused on land use (Brilha and Pereira 2014), scientific communication (Stewart and Nield 2013), dissemination of geosciences (Mansur 2009), geotourism (Moreira 2010) or geoparks planning (Nascimento et al. 2015), among others. One of the classical bases of geological heritage conservation is the GEOSITES Project developed by the Working Group linked to the IUGS and promoted by UNESCO (Wimbledon 1996, 2011). The Project had as its prime objective to generate a world-based inventory of geologically relevant sites following a systematization by establishing frameworks that would guide their selection (Wimbledon 2011). The Project officially finished in 2000, and from then on, it was replaced by other actions. However, its conceptualization and methodology were embraced by several countries members of ProGEO (European Association for the Conservation of Geological Heritage) while carrying out their national inventories. Historically, the recognition and the assessment of the sites that may correspond to the geological heritage in Brazil has accomplished in a non-systematic way, and among the pioneering initiatives carried out to identify potential candidates to compound this list is the SIGEP (Brazilian Commission of Geological and Paleobiological Sites), in 1997. Romão and Garcia (2017) investigated 61 geoheritage inventories developed in Brazil until 2017, based on the methods used for geosite selection and quantitative evaluation. The authors observed a growing number of researches, but not homogeneously distributed in the country. Also, many works do not mention the inventory method applied.

ISSN: 2595-1939
https://doi.org/10.29396/jgsb.2021.v4.SI1.5
Open access at jgsb.cprm.gov.br

In the scope of the Geological Survey of Brazil (CPRM), there are some initiatives related to geoconservation. Among them we can emphasize the Project "*Brazilian Geoparks - Proposals*" and the development of the GEOSSIT Platform (Rocha et al. 2016), an online resource to support the national inventory, and both qualitative and quantitative assessment of geosites and geodiversity sites. During the general meeting of the Commission for the Geological Map of the World (CGMW) held in Paris in February 2018, the geologist Carlos Schobbenhaus, from CPRM, proposed a project aiming to produce the Geological Heritage Map of South America on a scale of 1: 5.000.000. The initiative was stimulated mainly by the publication in 2019 of a new Geological Map of South America (Gómez Tapias et at. 2019). As this project was approved, the task for the identification of potential geosites to be included in the Brazilian Geoheritage Inventory has been inscribed in CPRM's Strategic Plan (2017-2021). The method consists of research and evaluation of geosites of national and international relevance, taken from geological mapping, geoparks proposals, and external contributions (academic works, consultation with experts, etc.). The technical coordination of this task was established in CPRM's regional units, aiming to collect potential geosite data from each state and to integrate them into the National Inventory. The State of Rio de Janeiro was chosen as a pilot area to test this method.

The State of São Paulo, the focus of this work, is the first Brazilian state to complete a systematic inventory of geosites made by the geoscientific community (Garcia et al. 2018). Many of these geosites are potential sites to be included in the national inventory, but their selection raises some questions that are addressed in this paper: i) Considering the National inventory, which criteria should be used to identify these geosites?; ii) Is the quantitative assessment an effective way to select the best examples?; and iii) To what extent and detail can the State geological frameworks be applied at the national level?

1.1 The inventory of geoheritage of the state of São Paulo: an overview

The inventory of geological heritage of São Paulo state has identified, selected, and evaluated geosites with scientific relevance in order to set the bases for future geoconservation actions (Garcia et al. 2018). Its first phase was developed during 2013-1016, as a project based at the Institute of Geosciences, University of São Paulo, and supported by the Science Without Borders Program (Project 075/2012 - MEC/CAPES/CNPq). The method involved the definition of geological frameworks and identification of their scientific coordinators, a preliminary list of potential geosites, fieldwork, a final listing of geosites for each framework, and the quantitative assessment of scientific value and risk of degradation for each geosite (Brilha 2016). The inventory had a general coordination, scientific coordinators for each geological framework, and expert teams. The geoscientific community involvement was one of its main strengths, being the working group composed of researchers from different institutions in various geosciences. As a result, 142 geosites representatives of 11 geological frameworks representing the state's geological history were initially selected (Table 1).

TABLE 1. Geological frameworks of the inventory of geoheritage of the state of São Paulo. From: Garcia et al. (2018).

Geological framework	Description	Number of geosites
Precambrian terranes	It represents the domains included in the Mantiqueira (Ribeira and Apiaí orogens) and Tocantins provinces (southern portion of Brasília Orogen), which have a general configuration related to the events of the Brasiliano–Pan African Cycle, in the Neoproterozoic.	21
Shear zones	It reflects the structural organization of the Precambrian terranes, formed by different units occurring as elongated strips bounded by strike–slip shear zones with local thrust components, in a 1000-km length and 200-km wide megastructure.	09
Granitic rocks	More than 200 kilometric to metric granitic bodies, associated with extensional tectonics and collisional events during the Neoproterozoic occur in the region.	10
Precambrian metallic mineralization	Represented by the Mesoproterozoic metavolcano-sedimentary succession of the Serra do Itaberaba Group, which metamorphism gave origin to tourmalinites and the metamorphic product of Algoma-type iron formation, enriched with syngenetic gold mineralization.	07
Paraná Basin	Formed by volcano-sedimentary rocks ranging from the glacial–interglacial cycle during the Upper Carboniferous – Lower Permian interval to the continental environment at the end of the Permian and arid climates that completed the tendency to continentalization during the Mesozoic.	19
Mesozoic magmatism	It represents the intense tectonic magmatic processes represented by the basaltic flows of the Serra Geral Formation (Paraná Basin), dike swarms and alkaline complexes associated with the evolution of the Paraná Basin.	13
Bauru Basin	It is mainly represented by Upper Cretaceous continental sandstones formed within the South American platform, corresponding to a period of isostatic adjustment subsidence after the breakup of Gondwana and opening of the South Atlantic Ocean.	15
Continental Rift of Southern Brazil	A 900-km long Cenozoic tectonic feature, which evolution is related to the latest stage of the tectonic activation event in the South American Platform, associated with the fragmentation of the Gondwana supercontinent and the formation of the South Atlantic Ocean.	10
Continental and coastal Neogene and Quaternary evolution	It represents the processes that formed the current physiography of the state, resulting from a sequence of events controlled by geological, geomorphological, climatic and oceanographic processes.	06
Geomorphological units and landforms	Represented by two main domains, the Atlantic Shield, with limited sedimentary deposits and Jurassic–Paleocene intrusions and the Platform cover, which reflect the general geological setting of the state.	14
Caves and Karst Systems	Most of the caves are mainly composed of sink-resurgence systems, forming river caves, with high depths, and common vadose shafts. Pseudokarst caves in granite/gneiss and other non-carbonate caves also occur.	14

The second phase (2017-present) is based on updating and systematizing the primary information about the geosites. For this purpose, Higa (2019) carried out the quantitative evaluation of both education and tourism potential, based on GEOSSIT's procedures and the assessment of the statutory framework and diagnoses of the current use and protection of these geosites - Table 2. Effective protection regimes were considered to be those with a management plan. An online map of the inventoried locations with the possibility of suggesting geosites using a public form was also elaborated (https://bit.ly/2EoF6Zg).

As the next steps are the establishment of partnerships with institutions such as CPRM and the State Forest Foundation, the government agency responsible for São Paulo State conservation units, the registration of the geosites on the GEOSSIT platform, the identification of gaps and fragilities in the defined geological categories, and the elaboration of specific management actions in the priority geosites, including their promotion.

TABLE 2. Main statutory protection for the geosites (2018).

Effective legal framework
Fully Protected Units (Law nº 9.985/2000): conservation units of relevant natural characteristics instituted by the Government. Only the indirect use of its natural resources is allowed. They are classified into Ecological Station, National Parks (which can be state and municipal as well), and Natural Monuments among others.
Non-effective legal framework
Sustainable Use Units (Law nº 9.985/2000): conservation units with relevant natural characteristics instituted by the Government. The sustainable use of part of its natural resources is permitted. They are classified as APAs among others.
Sites Listed as Heritage (Decree-Law nº25/1937): set of movable and immovable property of the country whose conservation is of public interest. These areas cannot be destroyed, demolished or mutilated
Marine Terrains (Decree-Law nº 9.760/1946): marine terrains are considered as movable assets of the union, therefore susceptible to the Penal Code Law nº 2,848 / 40, which makes the depredation of public heritage sites a crime.
Paleontological site (Decree-Law nº 4.146/1942): fossiliferous deposits are considered as property of the nation, so their extraction depends on prior authorization and inspection.
Speleological site (Decree nº 6.640/2008): activities considered being effectively or potentially polluting or degrading of underground natural cavities will depend on prior licensing.

2. Methods

2.1 Selection of potential geosites

The selection of geosites of the São Paulo State inventory to be possible candidates for the national inventory was based on two main criteria:

i) Quantitative assessment, using the GEOSSIT platform (Higa 2019).

For this evaluation, we consider the geological frameworks used in the São Paulo State inventory to classify the geosites (Garcia et al. 2018). We follow the concept established by Brilha (2016), which calls geosites those with scientific value (SV). The geosites that achieve SV ≥ 300 within the quantitative assessment of the GEOSSIT platform, were characterized as geosites of international relevance.

ii) Representativeness of the geosite within the state geological framework.

In the GEOSSIT platform, the quantitative assessment of scientific value is based on the quality of scientific publications and the possibility of collecting samples. However, many places show a few number of international scientific publications, despite being representative and rare examples of a specific context. In these cases, geosites with a scientific value of less than 300 but which constitute unique representatives of a particular event or geological element/unit were also selected.

2.2 Characterization of geosites

The selected sites were described regarding the following features:

i) Primary geological interest, according to the parameters described in the GEOSSIT platform, which represent the major geological relevance of the geosite (e.g. paleoenvironmental, geomorphological, or petrological);

ii) General geological framework, also based on the GEOSSIT platform, associated with the main Brazilian geological contexts (e.g., Phanerozoic Emerged Sedimentary Basins and Brazilian Structural Provinces);

iii) Site typology, according to Fuertes-Gutiérrez and Fernández-Martínez (2010): area (>1 ha with just one type of interest), complex area (large areas with several interests), point (<1 ha with only one geological feature), section (<1 ha with elements having a linear spatial development) and viewpoints (an area of geological interest and its better observatory spot);

iv) Brazilian statutory framework, according to which the geosites were classified into areas with no protection and areas with effective and non-effective protection, as described in Table 2.

3. Results

The selection based on the above criteria has resulted in 57 geosites, distributed within the 11 geological frameworks established for the São Paulo State inventory (Figure 1). The range of the Scientific Value of the geosites in each geological framework is presented in Table 4. Among the selected sites, 47 present SV equal to or higher than 300 and 10 show SV lower than 300. Precambrian Terranes is the geological framework with the largest number of selected sites (13), which corresponds to 22,81% of the total number of the sites, followed by Geomorphological Units and Landforms (14,03%), Paraná Basin (10,52%), and Mesozoic Magmatism (10,52%), Bauru Basin (8,77%). Granitic Rocks and Southeastern Continental Rift (7,02% each), Shear Zones, Precambrian Metallic Mineralizations, and Neogene and Quaternary Evolution (5,26% each) and Caves and Karst Systems (3,51%).

From the sites selected, seventeen are included in other initiatives, directly or indirectly related to the survey of geosites in a national scope (SIGEP, Geoparks Project, and GEOSSIT platform registers). The classification according to typology resulted in 33 geosites classified as points, 22 as areas, and 2 sections (Table 5).

TABLE 3. Criteria and respective parameters in GEOSSIT for quantitative evaluation of Scientific Value (SV).

Scientific Value
A1. Representativeness
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 points The geosite is a good example in the study area to illustrate elements or processes, related with the geological framework under consideration (when applicable) - 2points The geosite reasonably illustrates elements or processes in the study area, related with the geological framework under consideration (when applicable) – 1 point Not applicable - 0
A2. Key locality
It is considered to be a key-locality (location where the geological unit to which it belongs was originally described and / or named) – 4 points Is considered a secondary key-locality – 2 points Not applicable - 0
A3. Scientific Knowledge
There are scientific publications related to the site in books, international scientific journals, directly associated to the geological framework (when applicable) – 4 points There are scientific publications related to the site in national scientific journals, directly associated to the geological framework (when applicable) – 2 points There are abstracts associated to the site published in annals of scientific events, or in unpublished reports, directly related to the geological framework (when applicable) – 1 point Not applicable - 0
A5. Geological Diversity
Geosite with 5 or more different geological elements, with scientific value – 4 points Geosite with 3 or 4 distinct types of geological elements, with scientific value – 2 points Geosite with 1or 2 distinct types of geological elements, with scientific value – 1 point Not applicable - 0
A6. Rarity
The Geosite is the only known example in the study area, associated with the geological framework (when applicable) – 4 points There are 2 to 3 examples known in the study area, associated with geological framework (when applicable) – 2 points There are 2 to 5 examples known in the study area, associated with geological framework (when applicable) – 1 point Not applicable - 0
A7. Use Limitations
The site has no limitations (legal permissions, physical barriers, etc.) for sampling or fieldwork – 4 points It is possible to collect samples and do fieldwork after overcoming the limitations – 2 points Sampling and fieldwork are very hard to be accomplished due to limitations difficult to overcome (legal permissions, physical barriers, etc.) – 1 point Not applicable - 0

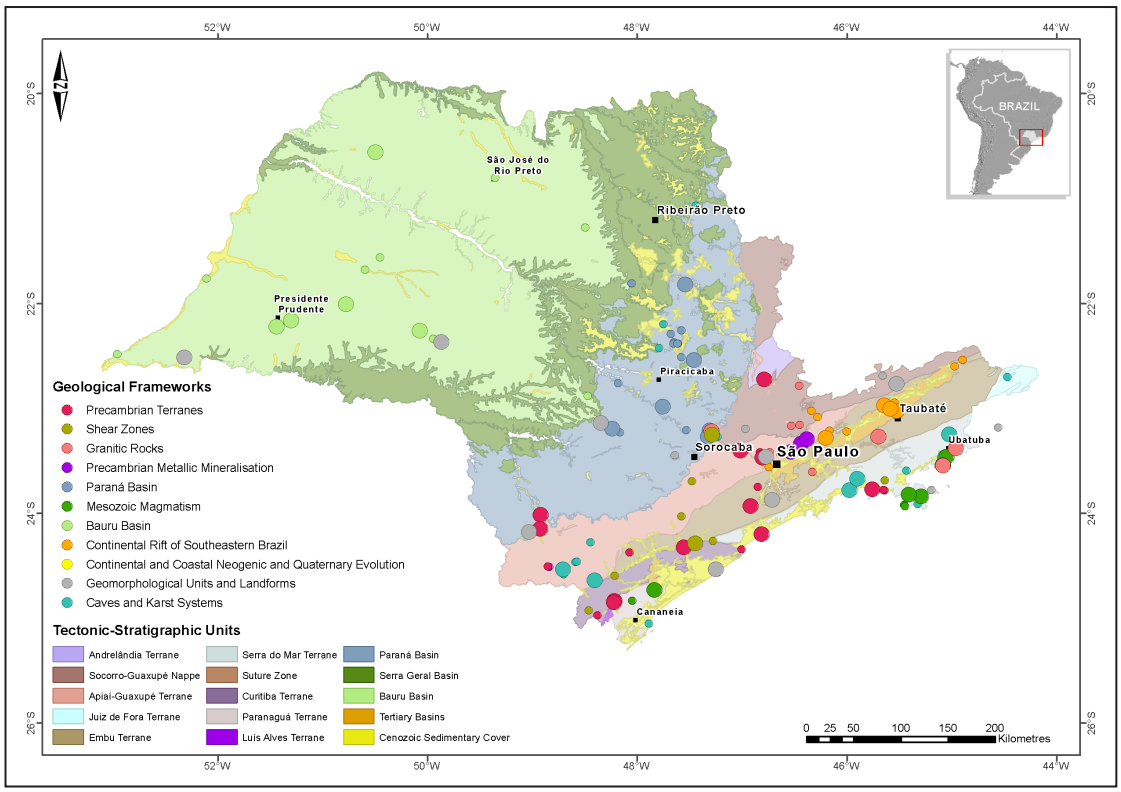

FIGURE 1. Map of the Geological Heritage of the State of São Paulo with the location of the geosites in their respective geological framework. The larger dots correspond to the 57 geosites selected in this work. Modified from Garcia et al. (2018).

TABLE 4. Potential geosites in the State of São Paulo to compound the national Inventory.

Geological Framework	Number of Potential Geosites	Number of Geosites with value ≥300	Number of Geosites with value <300	Range of SV values
Pre Cambrian Terranes	13	11	02	250-360
Shear Zones	03	02	01	180-370
Granitic Rocks	04	01	03	200-330
Precambrian Metallic Mineralizations	03	03	00	325-385
Mesozoic magmatism	06	04	02	235-360
Paraná Basin	06	05	01	295-390
Bauru Basin	05	05	00	310-350
Southeast Continental Rift	04	04	00	300-380
Neogene and Quaternary Evolution	03	02	01	270-355
Geomorphologic Units and Landforms	08	08	00	310-390
Caves and Karst Systems	02	02	02	310-320
Total of Potential Geosites	57	47	10	

According to the main thematic classification of the GEOSSIT platform, the geosites are distributed among eight main interest categories: 35,10% geosites classified as Petrology, 14,03% Paleontology, 14,03% Geomorphology, 10,50 Tectonics, 10,50 Stratigraphy, 7,01% Paleoenvironmental, 5,26% Mineralogy and 3,51% Speleology.

Regarding the geological contexts available in GEOSSIT, it was possible to distribute the geosites between the Brazilian Structural Provinces (32 Mantiqueira Province, 9 Paraná Province, 1 Tocantins Province) and Emerged Phanerozoic Basins (6 Paraná Basin, 5 Bauru Basin, 3 Taubaté Basin and 1 São Paulo Basin) - Table 5.

Among the selected geosites, 34% have no protection and, 36% of geosites are located in areas with non-effective statutory protection (APAs, marine terrains, paleontological sites, etc.), and 30% are located in protected areas (Figure 2).

4. Discussion

Pioneering initiatives in geoconservation in Brazil, such as SIGEP, GEOSSIT Platform, and Geoparks Project, developed non-systematic, AD HOC-based inventories. Although these initiatives are useful in tracing an overview of the current status of the geological knowledge of the territory, this type of survey fails in promoting an adequate sampling of the most representative sites according to the national geological contexts. As a result, the proportion of high relevance geosites that are effectively registered is low, which can be observed by the low number of potential geosites selected in this work that is included in these reports.

In this work, the geosites inventoried in the São Paulo state (Garcia et al. 2018) were analyzed regarding their representativeness to compound the national inventory. Being a systematic initiative, this inventory allowed to bring up a considerable number of high relevance geosites, in which high scientific values were calculated with the use of well-defined criteria. From the 57 selected geosites, 47 achieved > 300 on the SV, which, according to GEOSSIT, would indicate an international relevance. The other ten geosites with < 300 SV present low values mostly in the A1 criteria (key-locality), followed by A5 (geological diversity) and A6 (rarity), despite being important examples within their geological framework. It is worth noting that this numerical parameter is not described in the original paper on which the platform was based (e.g., Brilha 2016).

These 57 sites selected in the state of São Paulo (41.6% of the initial inventory) compose a robust indicative list of candidates to form a basis for a systematic inventory of the Brazilian geoheritage. However, it is essential to note the low registration of these geosites in the GEOSSIT platform, which aims to be a relevant indicator for the national inventory project and that was initially created with the goal of being a geosite's database. The broad record of geosites in the platform is essential, once it is considered as a vital tool for building the nationwide inventory and also for the systematic assessment of geological heritage in the country (Schobbenhaus et al. 2015). This will only be possible when the number of geosites on the platform is substantially higher than today. Some topics may be raised as possible reasons for this low registration. One of them is the incompatibility of the platform with local or regional systematic inventories with large numbers of geosites and that do not always comply with national parameters. The input of geosites is made by ad-hoc criteria and does not follow any systematic method, making their comparison with others from the same context difficult. After being registered by a user, the geosite must be evaluated by an internal commission, which has as parameters the description input, the number of publications, or the personal knowledge. This may favor the input of geosites with superlative characteristics without considering their context. Another point that arises from this insertion dynamics is the authorship. Many of the users register a few geosites, normally the ones they have studied personally. In this scenario, how would systematic inventories, with hundreds of geosites, work? These issues may represent an additional challenge for the national inventory.

The experience with large areas inventories suggests that the use of tectonic domains approaches, such as those performed by Mansur (2010) and Moura (2018), has promising results to classify the geosites according to representative frameworks. This strategy can also be used as a basis for the National Inventory. However, Brazil is a country of continental dimensions and the work of surveying these domains is a complex task still in progress.

TABLE 5. Geosites, typology, primary thematic classification, general geological framework, legal framework/ownership and scientific value.

Nº	Geological Framework / Geosite Name[1]	Tipology[2]	Main Thematic Classification[3]	General Geological Framework[3]	Legal Framework/Ownership[4]	Scientific Value[4]
Precambrian Terranes						
1	Amparo Migmatites	Area	Petrology	Tocantins SPB	APA (Law nº 9.985/2000) – private area	250
2	Nova Campina and Itapeva Stromatolites[A]	Area	Paleontology	Paraná SPB	Paleontological site (Decree-Law nº 4.146/1942) – private area	260
3	Atuba Complex TTG	Point	Petrology	Mantiqueira SPB	Nonexistent – public area	340
4	Guaraú/ Prainha Granulites	Area	Petrology	Mantiqueira SPB	Marine Terrain (Decree-Law nº 9.760/1946) – public area	330
5	Pirapora do Bom Jesus Pillow Lavas	Point	Petrology	Mantiqueira SPB	Nonexistent – public area	325
6	Turvo-Cajati Formation in Serra do Azeite	Point	Petrology	Mantiqueira SPB	APA (Law nº 9.985/2000) – public area	320
7	Migmatites and Gneisses from Cama de Anchieta	Area	Tectonics	Mantiqueira SPB	Marine Terrain (Decree-Law nº 9.760/1946) – public area	320
8	Contact between Itaiacoca Group and Furnas Formation in Itapeva	Area	Stratigraphy	Paraná SPB	Nonexistent – private area	310
9	Metagabbro with injection features of Juqueí	Section	Petrology	Mantiqueira SPB	Marine Terrain (Decree-Law nº 9.760/1946) – public area	310
10	Rodoanel Metaconglomerates	Point	Tectonics	Mantiqueira SPB	Nonexistent – public area	300
11	Embu Complex in São Lourenço da Serra	Point	Petrology	Mantiqueira SPB	Nonexistent – private area	300
12	Atuba Complex in Serra do Azeite	Point	Petrology	Mantiqueira SPB	APA (Law nº 9.985/2000) – public area	330
13	Itapeva Peak	Point	Petrology	Mantiqueira SPB	APA (Law nº 9.985/2000) – public area	370
Shear Zones						
14	Mylonites of Cubatão Shear Zone	Point	Tectonics	Mantiqueira SPB	Nonexistent – public area	180
15	Guaratuba river capture	Area	Tectonics	Mantiqueira SPB	Ecological Station (Law nº 9.985/2000)	370
16	Itapira Complex in Itu Shear Zone	Point	Tectonics	Paraná SPB	Nonexistent – public area	285
Granitic Rocks						
17	Ubatuba Charnockite	Point	Petrology	Mantiqueira SPB	APA, Marine Terrain (Law nº 9.985/2000, Decree-Law nº 9.760/1946) – public area	200
18	Rapakivi granite from Itu Province in Lavras Park	Area	Petrology	Paraná SPB	Municipal Park – public area	255
19	Paleoproterozoic Granitoid form Capivari River	Point	Petrology	Mantiqueira SPB	Nonexistent – public area	230
20	Ilha Anchieta Monzonite	Point	Petrology	Mantiqueira SPB	State Park (Law nº 9.985/2000) – public area	330
Precambrian Metallic Mineralizations						
21	Cabuçu Topazites[B]	Point	Mineralogy	Mantiqueira SPB	Nonexistent – public area	385
22	Fazenda Soledade Tourmalinites	Point	Mineralogy	Mantiqueira SPB	State Park (Law nº 9.985/2000) – public area	330
23	Rocks with anthophyllite and cummingtonite from Itaberaba[B]	Point	Mineralogy	Mantiqueira SPB	State Park (Law nº 9.985/2000) – public area	325
Mesozoic Magmatism						
24	Magmatic Breccia from Anchieta Island	Point	Petrology	Mantiqueira SPB	State Park, APA, Marine Terrain (Law nº 9.985/2000, Decree-Law nº 9.760/1946) – public area	360
25	Mafic Syenite from Pariquera-Açu	Point	Petrology	Mantiqueira SPB	Nonexistent – private area	310
26	Ponta Do Araçá Dykes	Point	Petrology	Mantiqueira SPB	Marine Terrain (Decree-Law nº 9.760/1946) – public area	310
27	Mantle Xenoliths from Northern Praia Vermelha	Point	Petrology	Mantiqueira SPB	Marine Terrain, APA (Decree-Law nº 9.760/1946, Law nº 9.985/2000) – public area	305
28	Diabase with columnar disjunctions of Santa Bárbara do Oeste	Point	Petrology	Paraná SPB	Nonexistent – private area	260
29	Ilhabela's syenitic magmatism	Point	Petrology	Mantiqueira SPB	State Park (Law nº 9.985/2000) – public area	235
Paraná Basin						
30	Giant stromatolites of Santa Rosa de Viterbo[A]	Area	Paleontology	Paraná EPSB	Paleontological site (Decree-Law nº 4.146/1942) – private area	390

TABLE 5. Geosites, typology, primary thematic classification, general geological framework, legal framework/ownership and scientific value. (Continuação)

31	Itu's Varvite[A]	Area	Stratigraphy	Paraná EPSB	Listed as Heritage Site (Decree--Law nº25/1937), Municipal Park – public area	370
32	Itararé Group's temperate forest record	Point	Paleontology	Paraná EPSB	Paleontological site, APA (Decree--Law nº 4.146/1942, Law nº 9.985/2000) – public area	340
33	Clastic dykes in Bandeirantes Highway	Section	Stratigraphy	Paraná EPSB	Nonexistent – public area	300
34	Asphaltic sands from Betumita Farm	Point	Petrology	Paraná EPSB	Nonexistent – public area	300
35	Moutoneé Rock in Salto[A]	Point	Paleoenvironmental	Paraná EPSB	Municipal Park – public area	295
			Bauru Basin			
36	Presidente Prudente Fm. Type--section	Point	Stratigraphy	Bauru EPSB	Nonexistent – public area	350
37	Fossil Reptiles from General Salgado[A]	Area	Paleontology	Bauru EPSB	Paleontological site (Decree-Law nº 4.146/1942) – private area	345
38	Pirapozinho Fossiliferous Site[A]	Point	Paleontology	Bauru EPSB	Paleontological site (Decree-Law nº 4.146/1942) – public area	330
39	Vale do Rio do Peixe Fm. in its Type-section	Point	Stratigraphy	Bauru EPSB	Nonexistent – public area	320
40	Calcretes from Marília Formation	Point	Stratigraphy	Bauru EPSB	Nonexistent – public area	310
			Continental Rift of Southeastern Brazil			
41	Tremembé Paleo Lake in Santa Fé Farm[A]	Area	Paleontology	Taubaté EPSB	Paleontological site (Decree-Law nº 4.146/1942) – private area	380
42	Phyto Fossils and palynomorphs from Itaquaquecetuba	Point	Paleontology	São Paulo EPSB	Paleontological site (Decree-Law nº 4.146/1942) – private area	350
43	Tremembé Paleolake in Quiririm[A]	Area	Paleontology	Taubaté EPSB	Paleontological site (Decree-Law nº 4.146/1942) – public area	330
44	Post-Sedimentary faults from Taubaté	Point	Tectonics	Taubaté EPSB	Nonexistent – public area	300
			Neogenic and Quaternary Evolution			
45	Ubatuba Beachrock	Point	Paleoenvironmental	Mantiqueira SPB	APA, Marine Terrain (Law nº 9.985/2000, Decree-Law nº 9.760/1946) – public area	355
46	Holocene marine terraces from Itaguaré Beach	Point	Paleoenvironmental	Mantiqueira SPB	State Park, Marine Terrain (Law nº 9.985/2000, Decree-Law nº 9.760/1946) – public area	350
47	Pleistocene marine terraces from Praia Vermelha do Norte	Point	Paleoenvironmental	Mantiqueira SPB	State Park, Marine Terrain (Law nº 9.985/2000, Decree-Law nº 9.760/1946) – public area	270
			Geomorphological Units and Landforms			
48	Furnas structural escarpment [A]	Area	Geomorphology	Paraná SPB	Nonexistent – private area	390
49	Morro do Diabo (Devil Hill's)[C]	Area	Geomorphology	Paraná SPB	State Park (Law nº 9.985/2000) – public area	360
50	Juréia Massif	Area	Geomorphology	Mantiqueira SPB	Ecological Station (Law nº 9.985/2000)	360
51	Colônia Impact Crater[A]	Area	Geomorphology	Mantiqueira SPB	Listed as Heritage Site, APA, Municipal Park (Decree-Law nº25/1937, Law nº 9.985/2000) – public area	355
52	Marília Plateau	Area	Geomorphology	Paraná SPB	Nonexistent – private area	320
53	Jaragua Peak	Area	Geomorphology	Mantiqueira SPB	State Park (Law nº 9.985/2000) – public area	320
54	Itapeva Peak	Area	Geomorphology	Mantiqueira SPB	APA (Law nº 9.985/2000) – public area	310
55	Basaltic Cuestas from Pardinho	Area	Geomorphology	Paraná SPB	APA (Law nº 9.985/2000) – private area	310
			Caves and Karst Systems			
56	Devil's Cave[B]	Area	Speleology	Mantiqueira SPB	Speleological site, State Park (Decree nº 6.640/2008, Law nº 9.985/2000) – public area	320
57	Santana's Cave[ABC]	Area	Speleology	Mantiqueira SPB	Speleological site, State Park (Decree nº 6.640/2008, Law nº 9.985/2000) – public area	310

[1]Garcia et al. (2018); [2]Higa (2019, according to Fuertez-Gutierrez and Fernández-Martínez 2010); [3]GEOSSIT (https://www.cprm.gov.br/geossit/), [4]Higa (2019), [A]Geosites with registration in Sigep Volumes, [B]Geosites from Geoparks's Project, [C]Geosites with public register in GEOSSIT's platform.

In this work the selected geosites were distributed according to the geological frameworks as currently available on the GEOSSIT platform, which may allow future comparison with other geosites within the same structural province in contiguous states. Some other characteristics, such as main geological interest, may constitute useful guides for a further diagnosis regarding use and management of these geosites. Although not perfect, the GEOSSIT platform seems to be the most suitable tool for integrating national data on geoheritage sites.

5. Conclusions

The selection of exceptionally relevant geosites that can be included in a broader geoheritage inventory is a task that includes, primarily, questions on the adequacy of the criteria and the methods used. In the case of the Brazilian National Inventory, which will be part of a survey that will include other South American countries, this mission may be challenging due to two main factors: its continental size and heterogeneous geological knowledge. One of the options to achieve this objective is to use both geological limits and administrative division as bases for this selection. The national geological frameworks would guide geosites representativeness regarding the main geological events and processes that shaped Brazilian geology. On the other hand, being the National geological survey, CPRM has offices in several states of Brazil and geologists specialized in distinct geological contexts, which can be a great advantage to compatibilized the state contexts.

Previous systematic information regarding potential geosites provides an excellent starting point for such a broad initiative. The data obtained in these surveys should be taken into account and serve as a guide in selecting the complementary sites. This is the case of the State of São Paulo, in which national and international geosites, defined according to well-defined and solid criteria with the participation of the geosciences community, are potential candidates for an initial national list.

Acknowledgements

The authors thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) - Processes 2016/18652-2 and 2017/50177-5. M. G. M. Garcia thanks the National Council for Scientific and Technological (CNPq), Grant 309964/2018-0.

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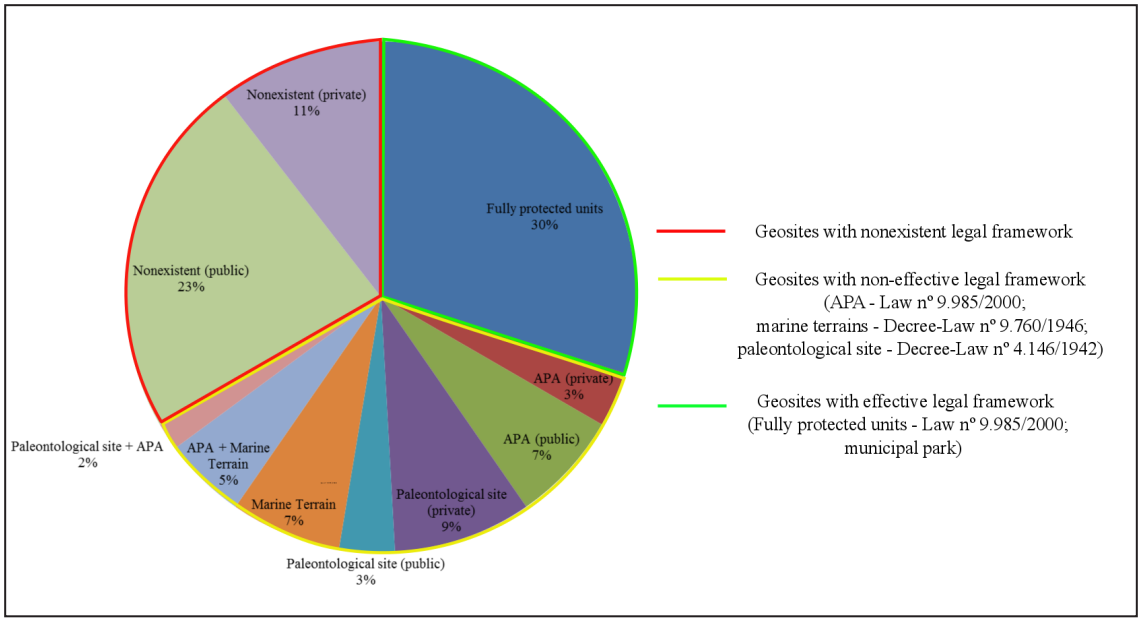

FIGURE 2. Distribution of the geosites regarding their protection regime.

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