
Academic Research Paper

Geotourism Potential in Southern Calabria: Insights from the First Thematic Map of the Southernmost Part of the Italian Peninsula

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Abstract:

Purpose - Southern Calabria represents one of the most geologically complex and diverse regions of the Mediterranean. Despite this exceptional geological richness, its geoheritage remains only partially documented and poorly integrated into structured geotourism strategies. In many Mediterranean regions, geotourism has proven to be an effective tool for sustainable territorial development, environmental education, and heritage protection, yet Southern Calabria still lacks a comprehensive and systematic geotouristic framework. The purpose of this study is to address this gap by presenting the first integrated geotouristic assessment of the southernmost part of the Italian Peninsula. *Design/methodology/approach* - The study is based on more than 10 years of extensive field surveys combined with the construction of a GIS-based geodatabase designed to systematically

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store, organize, and analyze geotouristic information. Nearly 200 geosites were identified and classified according to their geological setting, typology, accessibility, and relationship with human activities. The geodatabase was used to produce a digital geotouristic map and four thematic maps focusing on site density, distribution per municipality, geological environment, and accessibility. Spatial and geostatistical analyses were applied to evaluate clustering patterns, spatial connectivity, and relationships between geosites and major geological domains. *Originality/value* - This work represents the first thematic geotouristic map of Southern Calabria and one of the most comprehensive geoheritage assessments conducted in Southern Italy. The integration of long-term fieldwork, GIS-based analysis, and geoethical principles provides a transferable methodological model for geotourism studies in geologically complex regions. The results offer a solid foundation for future research, including the expansion of the geosite inventory and the development of multi-scalar geotourism networks. *Practical implications* - The results highlight a strongly heterogeneous spatial distribution of geosites, with high densities and easy accessibility along the Tyrrhenian coast, and fewer but more specialized sites in inland and mountainous areas. This configuration supports diversified geotourism strategies, ranging from inclusive coastal itineraries to experiential inland routes. The thematic maps provide practical tools for sustainable geotourism planning, risk awareness, and inter-municipality cooperation, contributing to the responsible valorization and long-term protection of Calabria's geoheritage.

Keywords:

geotourism; geoheritage; Calabria; geosites; geoethics

JEL Codes:

Z32; L83; Q56; R11

1. Introduction

Geotourism enhances sustainable regional development by promoting geodiversity, geoheritage, and public understanding of Earth processes. By integrating conservation, education, and community participation, it generates low-impact economic benefits while strengthening local identity and stewardship (Gray; 2019). Effective geotourism relies on accurate site inventories, clear interpretation, and inclusive planning (Hose; 2011; Ólafsdóttir and Tverijonaite; 2018; Gordon; 2018; Gray; 2019).

In many regions worldwide, geotouristic maps have proven to be effective tools for identifying geoheritage assets, improving public accessibility to geological information, and supporting sustainable tourism planning (Castaldini et al.; 2005; Gustavsson et al.; 2006; Bissig; 2018). Especially in territories where tourism remains underdeveloped and geological resources have not yet been translated into structured visitor experiences, geotouristic mapping provides a strategic framework to reveal hidden assets, organize access, and support territorial valorization.

Southern Calabria, located in the southernmost part of the Italian Peninsula, possesses exceptional geotouristic potential resulting from its complex geodynamic evolution, diverse lithologies, active tectonics, and remarkable coastal–mountain landscapes (Patacca and Scandone; 2007). Despite this geological richness, its geoheritage remains only partially documented from a geotouristic perspective and has not yet been incorporated into a comprehensive geotourism framework. Although previous

studies have investigated the geology and geomorphology of Calabria, no systematic geotouristic assessment, geosite inventory, or dedicated geotouristic map has been developed for Southern Calabria. This represents a significant gap in both the geotourism and geoheritage literature, limiting the effective promotion, conservation, and sustainable use of the region's geological resources.

To address this gap, the present study provides the first comprehensive framework for geotourism development in Southern Calabria. Specifically, we identify and describe the region's principal geotouristic sites through a dedicated geodatabase, produce the first thematic digital geotouristic map of the area, and evaluate its broader geotouristic potential. By integrating geological interpretation, spatial analysis, and tourism-oriented criteria, this work establishes a methodological framework for future geotourism planning and sustainable territorial development in Southern Calabria.

The remainder of this paper is organized as follows. Section 2 presents the theoretical framework of geotourism and reviews the geoheritage and geotourism literature relevant to Calabria. Section 3 describes the materials and methods adopted for geosite identification, database construction, and spatial analysis. Section 4 presents the results, including the geotouristic database and thematic maps. Finally, Section 5 discusses the implications of the findings for geoheritage conservation, geotourism development, and future research directions.

2. Theoretical framework and geological overview

2.1 Theoretical framework

Geotourism is generally defined as a form of sustainable tourism that focuses on the appreciation, interpretation, and conservation of geological and geomorphological features while fostering public understanding of Earth processes (Hose; 2011; Dowling and Newsome; 2018). Over the past three decades, geotourism has evolved from a niche concept primarily associated with geological heritage interpretation into a recognized field of research and territorial planning, attracting increasing attention from geoscientists, tourism scholars, and policy-makers (Ólafsdóttir and Tverijonaite; 2018; Dowling and Newsome; 2018). Its growing relevance reflects the increasing recognition of geoheritage as a valuable resource capable of supporting environmental education, nature conservation, local economic development, and community engagement (Gordon; 2018; Gray; 2019).

At the international level, the establishment and expansion of the UNESCO Global Geoparks network have demonstrated how geotourism can contribute to sustainable regional development by integrating geological heritage protection with tourism promotion, educational activities, and local entrepreneurship (Farsani et al.; 2011; Dowling and Newsome; 2018). Numerous case studies from Europe, Asia, and Latin America have shown that geotourism can generate significant socio-economic benefits while strengthening awareness of geological heritage and encouraging its long-term conservation (Farsani et al.; 2011; Ólafsdóttir and Tverijonaite; 2018). In this context, the identification, inventory, and spatial analysis of geosites represent essential preliminary steps for effective geotourism planning. Geotouristic maps and GIS-based approaches provide fundamental tools for documenting geoheritage resources, evaluating accessibility and spatial distribution, identifying thematic routes, and supporting evidence-based management strategies (Castaldini et al.; 2005; Bissig; 2018). Consequently, the development of geotouristic mapping frameworks has become a key component of contemporary geotourism research and practice.

2.2 Geological overview of Calabria

Calabria is a peninsular region in Southern Italy forming the southernmost segment of the Italian mainland and acting as a narrow geological bridge between the Tyrrhenian Sea to the west and the Ionian Sea to the east, at the centre of the Mediterranean domain where the African and European plates interact. This geodynamic setting has long attracted geological research, as it offers exceptional exposures of subduction-related, collisional, and post-orogenic processes within the Alpine–Mediterranean system (Ghisetti and Vezzani; 1981; Cirrincione et al.; 2017).

The geological evolution of Calabria reflects its prolonged involvement in the Alpine–Mediterranean orogenic system and results from the long-lived interaction between subduction, continental collision, and post-orogenic extension. The Calabrian Arc, considered the connection between the southern Appennines with the Maghrebide Chain, expose a complex stack of tectonic units belonging to the Alpine Chain (Bonardi; 1982). Extending from the Pollino Massif in northern Calabria to the Peloritani Mountains in northeastern Sicily, is bounded by the Tyrrhenian and Ionian basins to west and east, respectively. Its crystalline core is represented by the Calabria-Peloritani Orogen, which consists of a stack of metamorphic and plutonic units of European affinity, with a series of sedimentary covering (Ghisetti and Vezzani; 1981).

In Northern Calabria, the Catena Costiera preserves oceanic-derived metamorphic units that experienced polyphase deformation during subduction and subsequent exhumation within an accretionary wedge, later overthrust by continental-derived units such as the Sila and Castagna units (Filice et al.; 2014). Toward the south, a series of NW-SE transtensional faults, such as the Lamezia-Catanzaro fault, The Maida-Staletti fault zone, Nicotera-Gioiosa Ionica fault (NGF) or the Palmi-Antonimina fault (PAF), accommodate differential block movements and segment the Calabrian Arc (Brutto et al.; 2016; Tripodi et al.; 2018). In fact, the Serre and Aspromonte Massifs, divided by the NGF and PAF and by the interposed Gioia Tauro Plain, conserve unique conditions from a geological perspective. Clearly examples are the preserved Hercynian crustal section (Angi et al.; 2010) or the so-called Valle delle Grandi Pietre, constituted by several conglomerate monolites, located respectively in Serre and Aspromonte.

Regarding the geological period of the main units, the crystalline basement is constituted by metamorphic and intrusive Paleozoic-Mesozoic complexes, covered by Mesozoic limestones and conglomerates (Critelli et al.; 2017). The Neogene tectonic activity, that led to the counterclockwise rotation and movement of the Calabrian arc southeasternward (Patacca and Scandone; 2007), combined with the progressive uplift and with climatic fluctuations, resulted into the formation of stepped sequences of marine terraces. As consequence, the quaternary landscape evolution, modelled by active tectonic, complex river network and gravity processes, is reflected in the present-day physiography of the region (Sorriso-Valvo and Sylvester; 1993; Monaco and Tortorici; 2000; Scarciglia et al.; 2005; Roda-Boluda and Whittaker; 2017).

From a geotourism perspective, Southern Calabria presents a marked spatial contrast between coastal municipalities, which attract the majority of visitors due to their beaches, seaside resorts, and cultural attractions, and inland mountainous municipalities, where tourism flows remain comparatively limited despite the presence of significant natural and geological assets. The regional tourism economy is therefore strongly concentrated along the Tyrrhenian and Ionian coasts, while many interior areas continue to experience lower visibility within established tourism circuits. This uneven territorial exposure highlights the need for strategies capable of diversifying tourism beyond traditional coastal

destinations. In this context, geotourism offers an opportunity to enhance lesser-known inland areas by promoting their geoheritage, improving territorial connectivity, and creating thematic itineraries that integrate geological, natural, and cultural resources. A systematic inventory and spatial representation of geosites therefore constitute essential tools for identifying areas with untapped geotouristic potential and supporting more balanced and sustainable territorial development.

3. Materials and methods

We started this work by exploring and documenting the Southern Calabria region, then compiling every information in a database, and subsequently using the database to create a thematic map.

3.1. Exploration and database creation

An extensive field-based exploration was carried out in >10 years across Southern Calabria mostly by Nicola Mari, with the aim of identifying sites of geocultural interest, with particular emphasis on geological and geohistorical features. The survey activities were conducted through direct field observations, supported by photograph documentation (Figure 1) and qualitative descriptions collected in situ (including rock types and/or geological features surrounding the site of interest). Most of these sites were already known and present over many touristic local maps (e.g., the Amendolea waterfalls (Figure 1c)), while others were only known for forsaken villages (e.g., Pentidattilo (Figure 1b)).

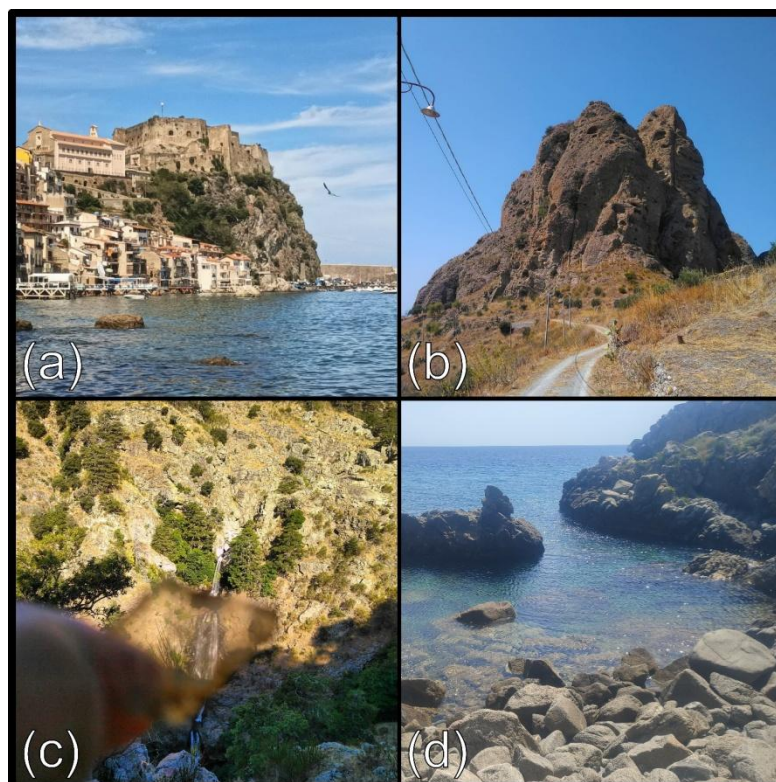


Figure 1. Particular of four identified geosites. (a) The Ruffo's castle of Scilla, built over a promontory. The particularity of this outcrop is that it's cut from a series of faults filled by euhedral

crystals of biotite; (b) the Pentidattilo monolite with the characteristic ‘five-fingers’ shape (from the ancient greek word ‘Πενταδάκτυλο’ - penta-dáktylos - five-fingers); (c) the Amendolea waterfalls - a muscovite crystal collected in the pathway to the waterfall is showed at the center of the picture; (d) Piscina di Venere, located in a creek along the granitic cliffs of Coccorino, in the Capo Vaticano area. Photo credits: Alessandro Luppino (a-c), Giuseppe Luppino (b) and Nicola Mari (d).

Each visited site was georeferenced using geographic coordinated and systematically documented in order to ensure traceability and reproducibility of the dataset. For this purpose, a dedicated database was created in form of spreadsheet.

The database includes both spatial and descriptive attributes, allowing the integration of qualitative and quantitative information. Included parameters comprise the site code, location name, typology, description, accessibility, kind of interest, geology, municipality, geographic coordinates (longitude and latitude), and additional observations. Photographic documentation was also linked to each site to support visual interpretation and validation.

3.2. Data digitalization and GIS implementation

The spreadsheet database was subsequently imported into a Geographic Information System (GIS) environment using the QGIS software. Geographic coordinates stored in the database were used to generate a point vector layer, where longitude and latitude values were assigned respectively to the x and y fields.

To ensure spatial accuracy and consistency, coordinates were projected into the UTM reference system (Zone 33N), generating Easting and Northing values (Easting_UTM33N and Northing_UTM33N). The resulting point layer constituted a connected shapefile, in which each spatial feature was directly linked to its corresponding attributes record.

During the importing process, the attribute table was automatically populated with all descriptive fields previously defined in the spreadsheet (i.e., the database), preserving the original structure. This procedure allowed for seamless integration of field-derived data into the GIS framework, enabling spatial analysis, visualization, and cartographic representation of the surveyed sites.

Following digitalization, the sites were classified based on their typology and thematic relevance, using the attribute fields in the database. The classification scheme integrates multiple criteria, including cultural significance, geological context, accessibility, and branch of interest, allowing for a flexible and multi-layered interpretation of the dataset. This structural approach facilitates both qualitative assessment and spatial querying, supporting comparative analyses and enabling the development of thematic maps.

The attribute table (Figure 2) includes the following sites: *Site code*, *Site name*, *Typology*, *Description*, *Accessibility*, *Branch of interest*, *Geological setting* (if applicable), *Municipality*, *Geographic coordinates* and Projected coordinates (*Easting_UTM33N* and *Northing_UTM33N*), and *Additional notes*. For the most significant category for the first impact on the readers - the *Typology* - we created custom symbols for each group. We opted for the minor possible number of groups in order to: *i*) reduce the confusion that a map full of different elements/symbols could bring to the readers/tourists, and *ii*) to simplify the map legend.

	Codice	Luogo	Tipologia	Descrizione	Accessibilità	Interesse	Geologia	Comune	Coordinate	Note	Easting_UTM	Northing_UTM	Latitude	Longitude
6	1M	Plaesano Vecchio	Rovine	Resti del vecchio centro abitat...	Facile	Archeologico	Manufatto	Feroleto della C...	38.477045, 16.074202	Vi sono resti di ...	593699,1027	4259292,857	38.4770449999...	16.074202000...
7	31D	Spiaggia della Mando...	Spiaggia	Spiaggia nascosta sotto la fale...	Difficile	Paesaggistico	Sedimentaria	Tropea	38.672870, 15.882429	Vi sono diverse ...	576762,3458	4280845,026	38.6728700000...	15.882429000...
8	37D	Spiaggia di Parghelia	Spiaggia	Spiaggia selvaggia divisa in tre...	Facile	Paesaggistico	Magmatica	Parghelia	38.684554, 15.919279	Verso Sud si ra...	579954,9789	4282173,075	38.6845539999...	15.919279000...
9	28D	Spiaggia Petri i Mulinu	Spiaggia	Spiaggia piccola nascosta dietr...	Media	Paesaggistico	Sedimentaria	Santa Domenic...	38.673070, 15.875872	Sulla spiaggia v...	576191,7316	4280861,75	38.6730700000...	15.875871999...
10	49D	Spiaggia di Rosarno	Spiaggia	Vasta spiaggia con dune	Turistica	Paesaggistico	Sedimentaria	Rosarno	38.506125, 15.918845	Spiaggia localiz...	580115,3246	4262373,043	38.5061249999...	15.918844999...
11	51D	Spiaggia di Eranova	Spiaggia	Spiaggia nascosta molto lunga...	Media	Paesaggistico	Sedimentaria	San Ferdinando	38.464404, 15.904828	Spiaggia localiz...	578938,642	4257731,385	38.4644040000...	15.904828000...
12	21H	Spiaggia di Condoleo	Spiaggia	Spiaggia a blocchi rocciosi	Facile	Paesaggistico	Metamorfica	Scilla	38.255027, 15.741932	Sono presenti n...	564913,8459	4234371,647	38.2550269999...	15.741932000...
13	63D	Spiaggia Tiraju	Spiaggia	Spiaggia remota con acque cri...	Difficile	Paesaggistico	Magmatica	Joppolo	38.597455, 15.863712	Sono presenti d...	575212,9003	4272460,95	38.5974549999...	15.863712000...
14	5I	Roghudi Vecchio	Rovine	Vecchio borgo di Roghudi abb...	Difficile	Archeologico	Manufatto	Roghudi	38.048779, 15.916509	Scendendo in b...	580414,5452	4211623,593	38.0487790000...	15.916509000...
15	11C	Vasche di Cassiodoro	Scogliera	Serie di vasche di acqua calda ...	Facile	Paesaggistico	Magmatica	Copanello	38.760990, 16.571338	Ogni vasca ha l...	636525,2288	4291426,169	38.7609900000...	16.571338000...
16	29D	Grotta dello Scheletro	Grotta	Grotta con due entrate e locali...	Media	Paesaggistico	Sedimentaria	Santa Domenic...	38.673403, 15.876310	Nome dovuto a...	576229,4805	4280899,067	38.6734030000...	15.876310000...
17	13M	Grotta di Santa Cristina	Grotta	Grotta molto spaziosa, con stal...	Facile	Speleologico	Sedimentaria	Filandari	38.617227, 16.034679	Molto ampia e ...	590076,4838	4274808,887	38.6172270000...	16.034679000...
18	15D	Spiaggia di Grotticelle	Spiaggia	Ampia spiaggia di ghiaia fine s...	Turistica	Paesaggistico	Magmatica	Ricadi	38.616425, 15.835741	Molte praterie ...	572757,9581	4274543,442	38.6164250000...	15.835741000...
19	44D	Spiaggia Brace 1	Spiaggia	Spiaggia di sabbia fine con div...	Turistica	Paesaggistico	Magmatica	Briatico	38.726223, 16.023558	Lo Scoglio La V...	588973,2657	4286893,182	38.7262229999...	16.023558000...
20	41D	Spiaggia Paradiso del ...	Spiaggia	Spiaggia selvaggia divisa in du...	Facile	Paesaggistico	Magmatica	Zambrone	38.714774, 15.974247	Lo Scoglio del L...	584700,3051	4285575,938	38.7147739999...	15.974247000...
21	17M	Monte Diavulomani	Montagna	Un rilievo montuoso di forma t...	Facile	Paesaggistico	Metamorfica	Acquaro	38.512028, 16.226825	Leggende locali...	606960,5937	4263341,182	38.5120280000...	16.226825000...
22	14M	Pietra di Liso	Formazione roc...	Un grosso boulder venuto in s...	Facile	Geologico	Sedimentaria	Serrata	38.511959, 16.119785	Leggende locali...	597628,1345	4263214,507	38.5119589999...	16.119785000...
23	32D	Spiaggia di Tropea	Spiaggia	Spiaggia molto turistica localiz...	Turistica	Paesaggistico	Sedimentaria	Tropea	38.679007, 15.893490	Le spiagge son...	577717,9203	4281535,355	38.6790069999...	15.893490000...
24	19H	Grotte di Trachina e d...	Grotta	Maestose grotte con vari reper...	Media	Archeologico	Sedimentaria	Palimi	38.374287, 15.850137	Le grotte si trov...	574259,4358	4247686,289	38.3742870000...	15.850137000...
25	4I	Rocca del Drako	Formazione roc...	Grossa roccia erosa e modellat...	Media	Paesaggistico	Sedimentaria	Roghudi	38.049525, 15.941011	Le Caldaie del L...	582563,5602	4211727,847	38.0495250000...	15.941011000...
26	19D	Spiaggia Praia i Focu	Spiaggia	Ampia spiaggia nascosta dietr...	Molto difficile	Paesaggistico	Magmatica	Ricadi	38.622015, 15.827964	La spiaggia è su...	572075,3022	4275157,609	38.6220149999...	15.827964000...
27	7A	Grotta di Zagaria	Grotta	Lunga grotta, in parte verticale...	Difficile	Speleologico	Sedimentaria	Canolo	38.315415, 16.187023	La grotta si trov...	603771,2291	4241478,416	38.3154150000...	16.187023000...
28	12M	Miniera di Arsenopirit...	Cave e miniere	Una labirintica miniera abband...	Molto difficile	Paesaggistico	Sedimentaria	Roccella Jonica	38.373623, 16.363344	Interno molto p...	619090,7282	4248150,259	38.3736230000...	16.363344000...

Figure 2. A small fraction of the attributes table of our database, where it is possible to see the logic and structure that we adopted. Names are displayed in the local language of interest (italian) - Codice (site code); luogo (site name); tipologia (typology); descrizione (description); accessibilità (accessibility); interesse (branch of interest); geologia (geological setting); comune (municipality); geographic and projected coordinates, and additional notes.

4. Results

We generated a GIS database and map with 198 sites of geotouristic interests for Southern Calabria. Among these, many could be considered new geotouristic sites, i.e., never known before or never considered as geotouristic locations. Using our data, several interpretations on the regional geotouristic potential can be made.

4.1. Geotouristic map

The geotouristic map that we obtained is clearly representative of the regional geosites (Figure 3). In total, we obtained 14 categories represented as follows: *beach, canyon, castle, cave, cliff, fall, monument, mountain, quarry, outcrop, river/lake, ruin, thermal bath, wreck* and *woodland*. From the map it is possible to notice that most of the represented sites are constituted by beaches, reflecting the >300 km of coastline that the Southern Calabria boasts.

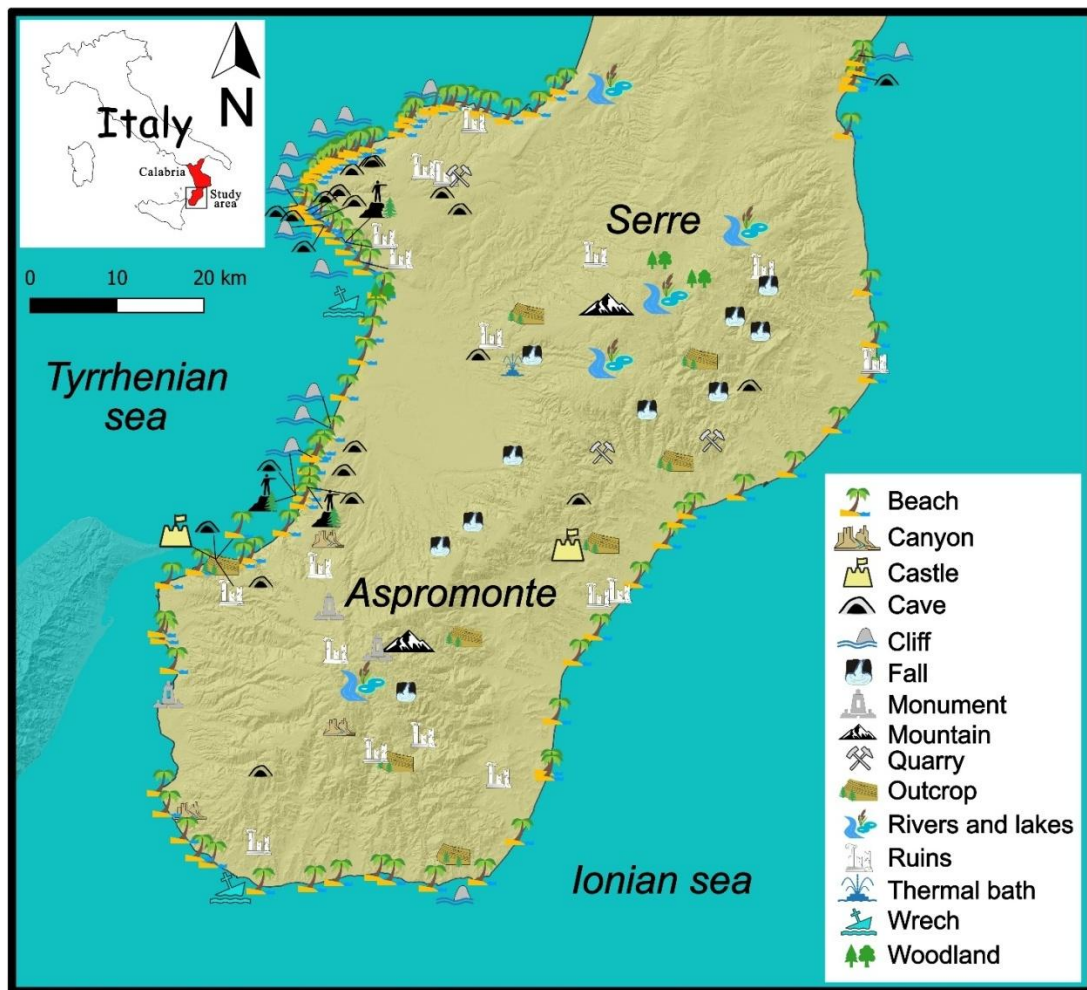


Figure 3. The complete geotouristic map of Southern Calabria (Italy). Base map is obtained from a shaded model and open street maps in transparency. DEM source: Tarquini et al.; (2007).

4.2. Thematic maps

In addition to the geotouristic map, a series of thematic maps was produced to highlight specific spatial and quantitative characteristics relevant to geotourism planning. These maps incorporate geostatistical information and are designed to emphasize key factors for the definition of effective touristic routes, such as the number of sites within restricted areas, their spatial connectivity, and their mutual accessibility. Such information is essential to maximize geotouristic potential by identifying areas where multiple geosites can be efficiently combined into coherent itineraries, while also supporting informed decisions related to logistics and visitor flow management.

Moreover, the thematic maps contribute to the assessment of site accessibility and potential hazards, which is a crucial aspect for geotourism development in Calabria, where several geosites are located in morphologically complex or rugged environments. In some cases, access to these locations may require a certain level of physical preparedness or specific safety considerations. Another

important thematic aspect addressed by these maps concerns the dominant type of interest associated with each site, distinguishing between geosites of strictly geological relevance and those more closely linked to human activities, such as archaeological remains, historical infrastructures, or abandoned mining areas. This distinction is particularly useful for the development of diversified geotouristic experiences tailored to different target audiences.

4.2.1. Sites density

The sites density map (Figure 4a) highlights a heterogeneous spatial distribution of geosites across Southern Calabria, with clear clustering along specific coastal sectors and lower densities in some inland areas. Higher site densities are particularly evident along the Tyrrhenian coast, especially in correspondence with morphologically complex coastal stretches, where the most ancient regional magmatism is present (Bedini et al.; 1990). In contrast, a more scattered distribution characterizes the Ionian side, reflecting its diverse and predominantly sedimentary geological framework compared to the Tyrrhenian margin (Cavazza and Ingersoll; 2005), as well as the internal mountainous sectors, which are mainly composed of metamorphic units (Tripodi et al.; 2018).

This spatial pattern mirrors both the geological diversity of Southern Calabria and the strong observational and interpretative value of its coastal environments. From a geotouristic perspective, areas characterized by higher site density represent strategic zones for concentrated visitor experiences, where multiple geosites can be explored within limited spatial ranges. Such settings are particularly suitable for the development of short thematic itineraries, coastal routes, and educational paths, enhancing the overall efficiency and attractiveness of geotourism initiatives in the region.

4.2.2. Sites distribution per municipality

The number of sites per municipality shows marked variability among administrative units, with some municipalities hosting a significantly higher concentration of geosites compared to others (Figure 4b). Municipalities located along the Tyrrhenian margin - particularly within the Costa degli Dei and Costa Viola sectors - and those situated in structurally complex areas (e.g., Scilla and Reggio Calabria) tend to concentrate a larger number of geosites. In contrast, several inland municipalities and those along the Ionian side display a comparatively lower number of documented sites.

This uneven spatial distribution reflects the fact that geoheritage is not homogeneously embedded within administrative boundaries, but instead closely follows geological, geomorphological, and tectonic controls (Ghisetti and Vezzani; 1981; Roda-Boluda and Whittaker; 2017). Consequently, administrative units do not necessarily correspond to coherent geotouristic systems. This observation highlights the importance of inter-municipality cooperation for effective geotourism development, especially in regions characterized by strong geological heterogeneity such as Southern Calabria. Municipalities with higher site densities may function as geotouristic hubs, providing services, accessibility, and interpretative infrastructure, while municipalities with fewer sites could be integrated into broader, multi-municipality networks to ensure a more balanced and sustainable valorization of regional geoheritage.

4.2.3. Geological environment and site typology

The geological classification of sites (Figure 4c) reveals a clear spatial relationship between site typology and the main geological domains of Southern Calabria. Magmatic geosites are primarily concentrated in the Capo Vaticano area along the Tyrrhenian coast, reflecting the localized exposure of magmatic rocks and their prominent geomorphological expression, often characterized by steep cliffs, rocky headlands, and coastal landforms of high scenic value (Pepe et al.; 2014).

Sedimentary geosites are predominantly distributed along the Ionian coastline, where extensive low-relief coastal sectors preserve well-developed sedimentary successions and depositional features linked to basin evolution and coastal dynamics (Cavazza and Ingersoll; 2005). In contrast, metamorphic geosites are mainly located within the main crystalline massif of the Aspromonte (Tripodi et al.; 2018), as well as along parts of the Tyrrhenian coast, where tectonic uplift and intense erosion have exposed deeper crustal units and complex structural relationships (Cucci and Tertulliani; 2010).

This spatial organization mirrors the long-term geological evolution of Southern Calabria (Patacca and Scandone; 2007). From a geotouristic perspective, however, its main relevance lies in providing a natural framework for the development of thematic routes based on geological environments. Such an approach allows visitors to experience distinct petrological, mineralogical, and geodynamic contexts across relatively short distances, enhancing both educational value and the overall coherence of geotourism itineraries in the region.

4.2.4. Accessibility

The accessibility map (Figure 4d) highlights significant spatial variations in the ease of access to geosites across Southern Calabria. The most easily accessible and tourist-oriented geosites are predominantly located along the coastal sectors, particularly on the Ionian side, where the absence of extensive coastlines with cliffs and the presence of wide coastal plains favor direct access. In these areas, well-developed transportation networks, proximity to urban centers, and the concentration of touristic infrastructure further enhance site accessibility.

In contrast, inland and mountainous areas - especially those surrounding the highest peaks of the Aspromonte massif - are characterized by a higher proportion of geosites classified as having medium to difficult (to even very difficult) accessibility. These sites are often located in rugged terrains, along steep slopes, narrow valleys, or structurally complex sectors, where access may require hiking, off-road paths, or favorable weather conditions. As a result, their accessibility is strongly influenced by topography, land use, and seasonal factors.

This spatial distribution emphasizes a clear contrast between coastal and inland geotourism in Southern Calabria. Coastal geotourism is generally more immediate and inclusive, appealing to a broad and heterogeneous audience, including families and casual visitors. Conversely, inland geotourism is more experiential in nature and typically targets motivated, physically prepared, adventurous, and environmentally aware visitors. Although difficult-to-access sites may naturally limit visitor numbers, they also offer high potential for specialized geotourism activities, such as guided hiking itineraries, geo-trekking, and immersive landscape experiences, where the geological context is closely intertwined with natural scenery and a strong sense of place.

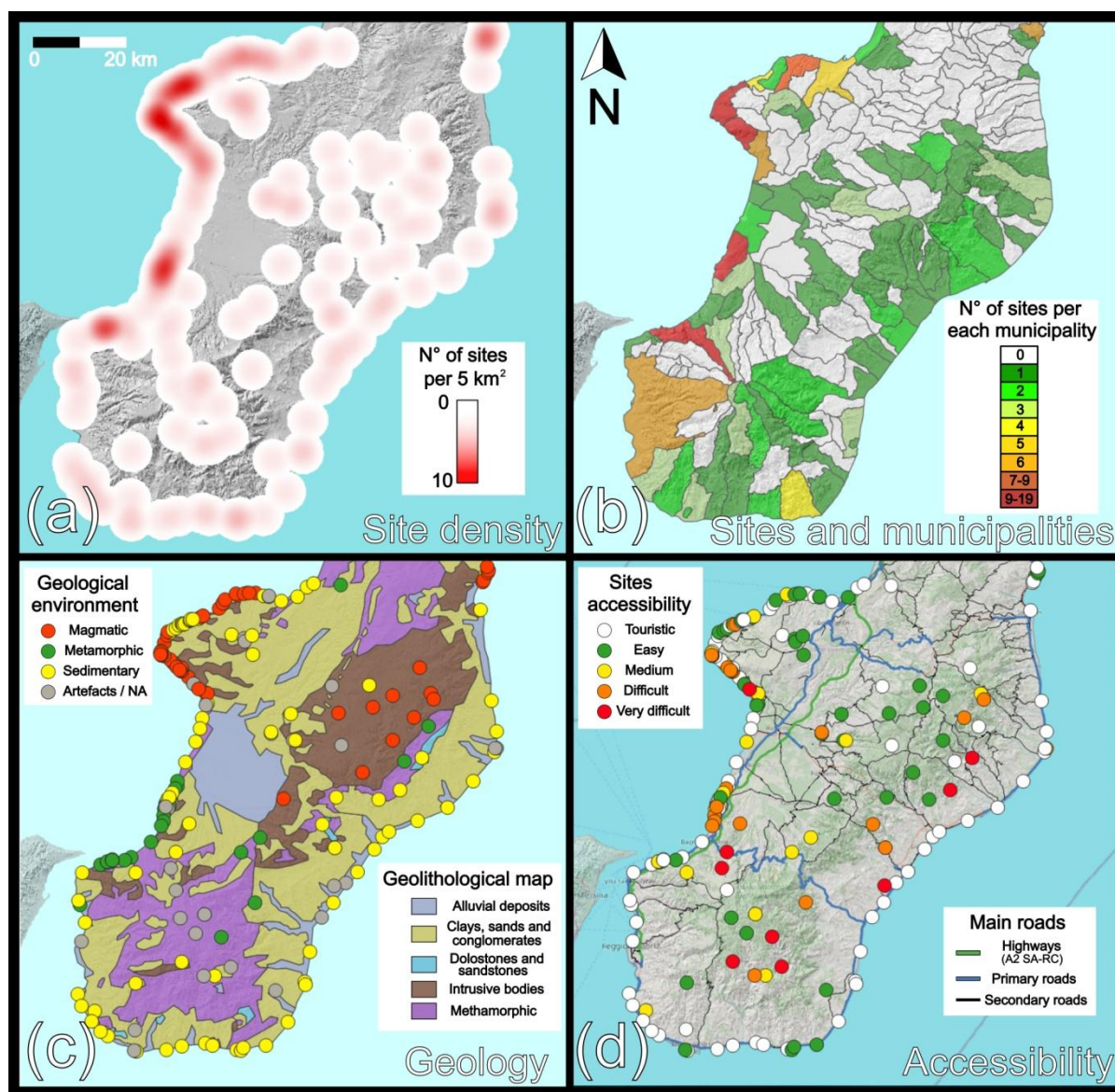


Figure 4. Thematic maps obtained from our database. (a) Shows the site density per unit of area (5 km²) while (b) shows the number of site per each municipality. Map in (c) represent the geological branch of each site (magmatic, metamorphic, sedimentary, or not applicable for human artifacts), and (d) represent the difficulty of access for each site, from touristic (reachable with a normal car or by public transport) to very difficult, which requires adventurous skills and materials such as ropes, or climbing expertise. Base maps are a combination between shaded models (a) and municipality limits (b), simplified geolithological map (c, source: <https://gn.mase.gov.it/portale/servizio-di-consultazione-wms>) and Open Street Map (d, <https://www.openstreetmap.org/>) DEM source: Tarquini et al.; (2007).

5. Discussion, conclusions, and future implications

5.1. Discussion

The results of this study provide a spatially explicit framework for understanding geotouristic potential in Southern Calabria, confirming and extending key concepts introduced in Section 2 regarding geotourism as a tool for sustainable territorial planning and geoheritage valorization. In line with previous studies (e.g., Dowling and Newsome; 2018; Ólafsdóttir and Tverijonaite; 2018), our findings reinforce the idea that geotourism effectiveness is strongly dependent on the integration of geological diversity, accessibility, and spatial organization of geosites.

The four thematic maps (Figure 4) highlight that geotouristic potential is not uniformly distributed, but instead reflects a strong structural control imposed by the region's geodynamic evolution and its resulting physiography (Ghisetti and Vezzani; 1981; Cirrincione et al.; 2017). This spatial heterogeneity advances previous conceptual models by showing how tectono-geomorphological inheritance directly translates into differentiated tourism potential, where coastal zones concentrate accessibility and visitor flows, while inland mountainous sectors preserve higher geoheritage integrity but remain less integrated into tourism networks.

The observed segregation of geological environments supports the construction of narrative-based geotourism itineraries, consistent with the interpretative approaches proposed in the geotourism literature (Hose; 2011; Gordon; 2018). However, unlike many previous studies that treat geosites as isolated attractions, the present results demonstrate the importance of network-based spatial planning, where geosites gain enhanced value through functional and thematic connectivity at the municipal scale. This represents a key advancement over traditional site-based approaches, aligning more closely with contemporary GIS-driven territorial planning frameworks (Castaldini et al.; 2005; Bissig; 2018).

The strong contrast between coastal and inland areas further refines the conceptual framework introduced in Section 2. Coastal municipalities act as high-accessibility nodes embedded in consolidated tourism circuits, while inland areas function as low-accessibility but high-potential geotourism reservoirs. This dual structure provides empirical support for differentiated geotourism strategies, ranging from high-flow interpretative tourism in coastal zones to low-impact, educational, and geoscience-oriented experiences in inland areas.

Importantly, this spatial differentiation has direct implications for territorial planning and geoheritage management. The results suggest that effective geotourism development in Southern Calabria requires coordinated inter-municipality strategies, capable of linking coastal and inland geosites into integrated networks supported by shared interpretation systems, accessibility improvements, and joint governance frameworks.

Overall, the integration of spatial analysis with geoheritage interpretation provides a transferable framework for other geologically complex regions, where similar coastal–inland asymmetries and structural controls are expected to shape geotouristic development potential.

5.2. Conclusions

This study presents an integrated approach to the exploration and valorization of Southern

Calabria, combining field surveys, GIS-based geodatabase construction, and the development of a digital geotouristic map accessible to a broad audience. The heterogeneous spatial distribution of geosites reflects both the complex geological evolution of the region and the long-term interaction between natural processes and human activities, demonstrating that territorial value cannot be assessed solely through economic indicators but is deeply rooted in geological, cultural, and historical heritage.

Southern Calabria records millions of years of geological evolution and millennia of human history, expressed through a wide range of geosites, from globally unique localities to sites representative of widespread geological processes. Their preservation is the result of both the relative naturalness of large areas and a growing geoethical awareness, shared by local communities, researchers, and institutions, that recognizes geoheritage as a non-renewable common good requiring responsible protection, communication, and use.

The spatial distribution of geosites reflects the complex geological evolution of the Calabria region and the long-term interaction between natural processes and human activities, confirming that territorial value must be interpreted beyond purely economic indicators and instead include geoheritage as a key component of landscape identity and sustainable development.

From an applied perspective, geological diversity, spatial distribution, and accessibility are the main factors controlling geotouristic potential. The spatial segregation of geological environments supports the development of thematic, narrative-based itineraries across sedimentary, magmatic, and metamorphic landscapes, highlighting the importance of spatial connectivity and coordinated planning.

Importantly, the coexistence of highly accessible coastal geosites and more remote inland sites enables diversified geotourism strategies tailored to different visitor profiles. Coastal areas are suited to high-accessibility, experience-rich tourism flows, while inland areas support low-impact, educational, and geoscience-oriented tourism. This dual structure has clear implications for territorial planning, requiring integrated strategies that connect coastal and inland municipalities through coordinated geotourism networks, shared interpretation systems, and joint management actions.

Although the mapped sites represent only part of the geoheritage of Calabria, this work provides a solid methodological baseline for future geotourism research and planning, and a practical geoethical framework for enhancing, managing, and safeguarding the geological heritage of this geologically complex and largely wild land.

Acknowledgments

Authors are grateful to everyone who explored some of these sites with us during all these years. We also note that some of the locations included in the database, although identified as geosites, are accessible only with prior permission from the respective landowners.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary

The resulting GIS database represents a comprehensive and reproducible tool for the analysis and dissemination of cultural and geological heritage in Southern Calabria. For this reason, the complete geotourism database used to generate the map and the interactive geotourism map is available in the Supplementary of this work (at the link:), and will also be made available through the future website www.geocosmos.com or upon request by contacting the corresponding author.

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