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REVIEW ARTICLE

Pages of Earth History in an Exceptional Uniqueness: The Geo-Heritage of the Sila National Park and its Spheroidal Boulders Geosite (Northern Calabria, Italy)

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Abstract

The knowledge of the territory that people inhabit, the awareness of the geological heritage value and its management are aimed both at the benefit of local socio-economic sustainable development goals and at promoting geopark-inclined geotourism through actions which identify potential geosites or enhance those already assessed. The objective of this study is focused on the geoheritage exploration of the Sila massif area, in southern Italy, in order to illustrate the high “geological diversity” like first step for inherent potential geotourism. The Sila landscape exhibits a rich geodiversity to give value, but it is poorly known to the public, although it has been and is the subject of many national and international scientific works. The focus of this work is to enhance the geological, geomorphological and landscape uniqueness of a Sila area, characterized by the presence of a wide range of weathering products and morphologies as a result of geological and geomorphological events and processes, in a variety of temporal and spatial scales, which have an influence on the development and evolution of reliefs and landscape, giving rise to the three geosites: Sila Spheroidal Boulder Field Geosite, Sila Sand Geosite and Sila Paleosols Geosite. These sites of geological interest were subjected to quantitative assessment in terms of the scientific, educational, touristic values and degradation risk of geosites.

Keywords Granitoid rocks · Weathering products · Boulder field · Geodiversity · Geotourism

Introduction

In recent decades an attempt to achieve a more harmonious balance between environment and human activity has strongly been increased, through a greater and more effective dissemination of environmental education, also thanks to many initiatives promoted by UNESCO (*United Nations Educational Scientific and Cultural Organization*). The "*environmental education*", expression used for the first time in 1969 by W.P. Stapp of the University of Michigan, hosts a pedagogical mission for communities and citizens starting to the UNESCO Tbilisi conference of 1977, and it aims to more responsibility and attention to environmental issues and good territorial governance, intended as knowledge of the natural environment structure and organization, as well as awareness of human beings to must manage their own behaviours in relation to ecosystems so as to living in a sustainable way, avoiding the complete alteration of natural balances, also for the future generations. The “*Geoeducation*”, instead, is a broader cultural concept that, in addition to providing for environmental education of citizens (Henriques and Brilha 2017), contains promotion of the geological-geomorphological heritage (McBriar 1995; Wimbledon 1996; Patzak and Eder 1998; Poli 1999; Vai 1999), its geoconservation (Dowling 2011; Reynard et al. 2016; Brazier et al. 2017; Gordon et al. 2018; Gray 2018; Reynard and Brilha 2018; and many others) and its rational management, also to create opportunities of economic sustainable

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development of local communities (Patzak and Eder 1998; Eder and Patzak 2004; McKeever et al. 2010) and to offer opportunity of geotourism services (Farsani et al. 2011), namely form of nature tourism that specifically focus on landscape and geology. The understanding of Earth sciences and learning geological and geomorphological features and/or processes, represent a resource for geotourism (Dowling and Newsome 2018), that, in turn, could encourage various forms of geoeducation by means of geosites organization open to the public with educational and recreational activities (Hose 2012), and a consequent improvement in the economic and social profile of a certain area.

The geological history of a specific region is represented by different geological environments and geological phenomena, processes, events and forms that shape/shaped the landscape, and allow identification of geosites (area defined by geodiversity-related elements, exposed in situ and on the Earth's surface, having scientific, educational, aesthetic, and cultural values (Brilha 2018)), geomorphosites (Kubalíková 2013), geotopes (Serrano and Ruiz-Flaño 2007), geoparks (EGN 2020), geoheritage (Gray 2018), and geodiversity sites (Brilha 2016). The geological-geomorphological heritage diversity has been object of several attempts/initiatives to evaluate its quality in terms of inventories of natural heritage sites (Serrano and Gonzalez-Trueba 2005), tourist promotion (Pralong 2005) or management of nature parks (Pereira et al. 2007), as well as promoting the geological heritage concept in the scientific community and public, with regard to sustainable development in the areas hosting potential or recognized geosites (Wimbledon 1999) and / or geoparks (Eder 2008).

The inventory is the first step in any geoconservation strategy, coupled to a geosites evaluation according to one of the different methodologies recognized in the literature (for examples Pereira et al. 2007; Brilha 2016, 2018; Reynard et al 2016; Mehdioui et al. 2022 and many others). The universal recognition of a guideline is not possible due to the differences geoconservation objectives and geological context.

The Sila territory (northern Calabria, Italy), which is the focus of this work, contains geodiversity with exceptional scientific value at the regional, national and global scales, as demonstrated by the multiple geological works on the Sila massif present in the literature. From a naturalistic aspects, the vast Sila plateau is an recognized Italian heritage because of it includes various areas (e.g. the forest with multi-century pines called "I Giganti di Fallistro") in the Natura 2000 network, which main instrument of the European Union policy for the conservation of biodiversity, and the tenth Italian Biosphere Reserve MaB (Man and the Biosphere) in the UNESCO World Network of Sites of Excellence. The Sila Biosphere Reserve has very varied landscapes with glacial moraines, lakes and springs and, thanks to its morphological and geographical characteristics, hosts a great variety of natural environments with different microclimates that ensure a very important biodiversity throughout the Mediterranean biogeographical region and is rich in rare endemic species. Only in the latest years (2014) the Sila managed to enter the UNESCO World Heritage tentative list, satisfying the selection criteria under item VIII which include geological uniqueness. Despite a lot of geological works and the probable candidacy of the Sila National Park in the UNESCO World Geopark Network, a complete inventory for this area and related quantitative assessment of geosites, as solid geoconservation strategy (Henriques and Brilha 2017) has never been done. The present work consists in the first step to fill this gap. This paper's aim is to promote geological knowledge of three geosites (Sila Spheroidal Boulder Field Geosite, Sila Sand Geosite and Sila Paleosols Geosite) in the Sila area, spreading an easier understanding of landscapes, morphologies and shapes, as well as processes and environmental conditions that gave rise to them, thus to lay the ground for the future geoconservation actions, management use and geotourism, starting from the geosites inventory and quantitative assessment.

These geosites, reported and catalogued in the National Inventory of Geosites (website that provides information on sites of geological, pedological and geoarcheological interest, collected by ISPRA –Istituto Superiore per la Protezione e la Ricerca Ambientale; http://sgi.isprambiente.it/GeositiWeb), have the potential to be formally recognized by UNESCO, also in the context of the candidacy as a Geopark of the Sila National Park.

The study area, falling within the municipality territories of Serra Pedace, Pedace, Spezzano Piccolo, Spezzano della Sila, Longobucco and San Giovanni in Fiore (Fig. 1), in the province of Cosenza, and located almost entirely in the central sector of the *Sila National Park* (National Park and related institution recognized in 2002) It is configured as a natural (or spontaneous re-naturalization due to reforestation measures, following repeated phases of intense deforestation, settlement and agricultural practices) laboratory both for the study of weathering and morpho-evolutionary processes that led to development of particular landscapes, morphologies and shapes, and for the study of the generation of sand-sized particles deriving from in situ weathering processes of granite and granodiorite rocks, under heavy leaching conditions (Le Pera and Sorriso-Valvo 2000). The unique geological characters take to attribute an intrinsic, didactic and research value to the geological heritage of the area, which, in contrast to a general tendency of considering the abiotic world (mountains and rocks) stable and static, finds itself vulnerable and, therefore, in need of conservation (Gray 2004).

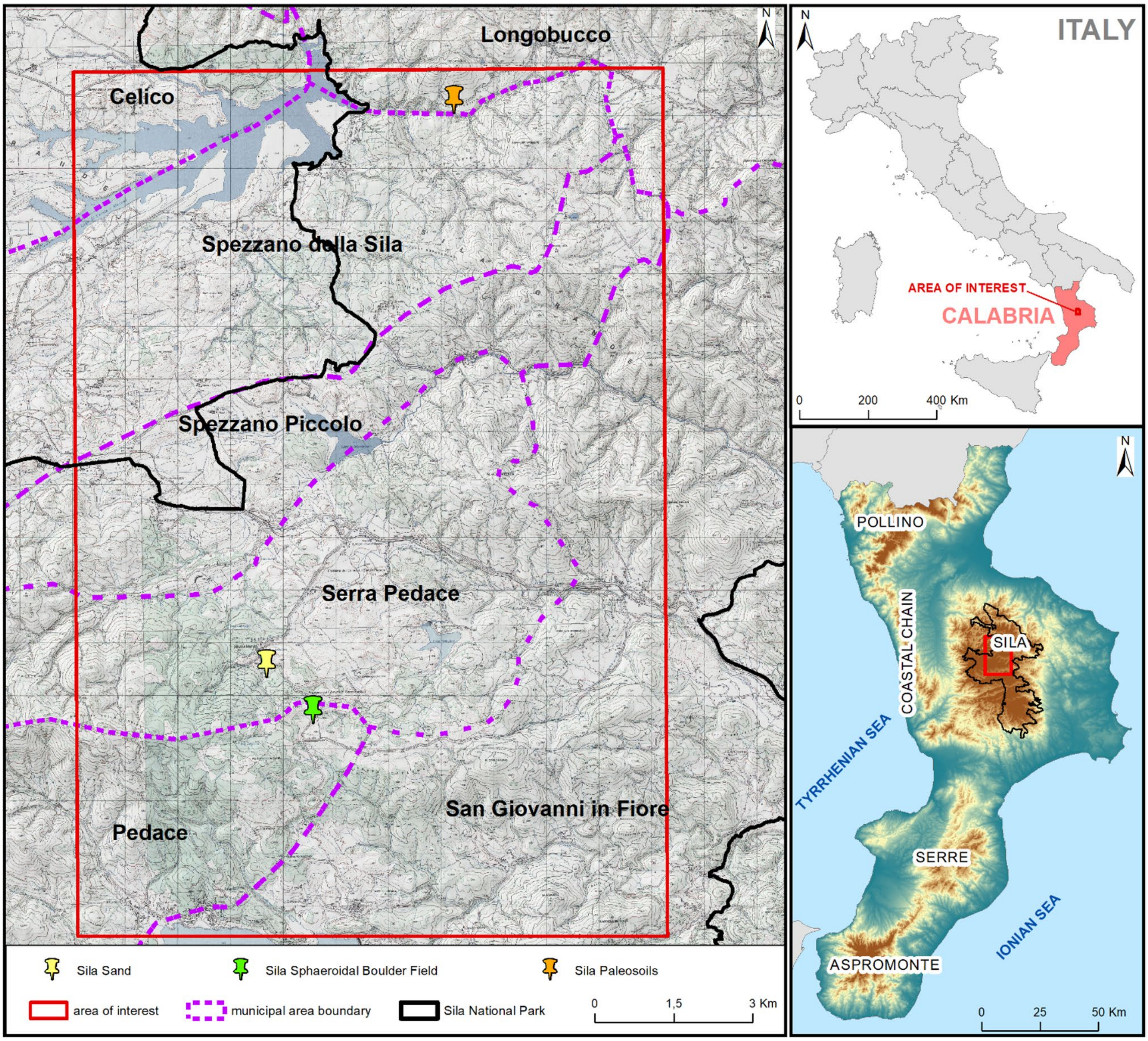


Fig. 1 Location of the study area

Study Area

Geological Framework

The area of this work is located in the northern sector of the Calabria-Peloritani composite terrane, an arched segment which is a key point in the central Mediterranean geodynamics (Fig. 2), as a connecting element between the Sicilian Maghrebid chain, with a W-E trend, and the Southern Apennines, with a NW–SE trend (Amodio-Morelli et al. 1976; Vai 1992; Van Dijk et al. 2000; Bonardi et al. 2001). It is made up of Alpine-type crystalline Hercynian basement nappes thrusted over sedimentary Meso-Cenozoic units of the Southern Apennines during the Miocene (Amodio-Morelli et al. 1976). The Calabria–Peloritani terrane is the result of its tectonic-evolutionary history with a mainly brittle character, which from the middle Miocene to the middle Pleistocene dissected the tectogenetic chain into longitudinal and transversal basins (graben) and highs (horst), because of a regional tectonic phase with left-lateral strike slip kinematics (Van Dijk et al. 2000; Tripodi et al. 2013, 2018). At this last phase are related the structures that delimit the crystalline building (Taormina Line to the south and Sangineto Line to the north) and divide it into a southern and a northern sectors by means of the Catanzaro Trough (Brutto et al. 2016) (Fig. 2). The Sila represents one of the horsts in the northern sector of Calabria and it is configured as a junction area between the Pliocene–Pleistocene Graben of the Crati

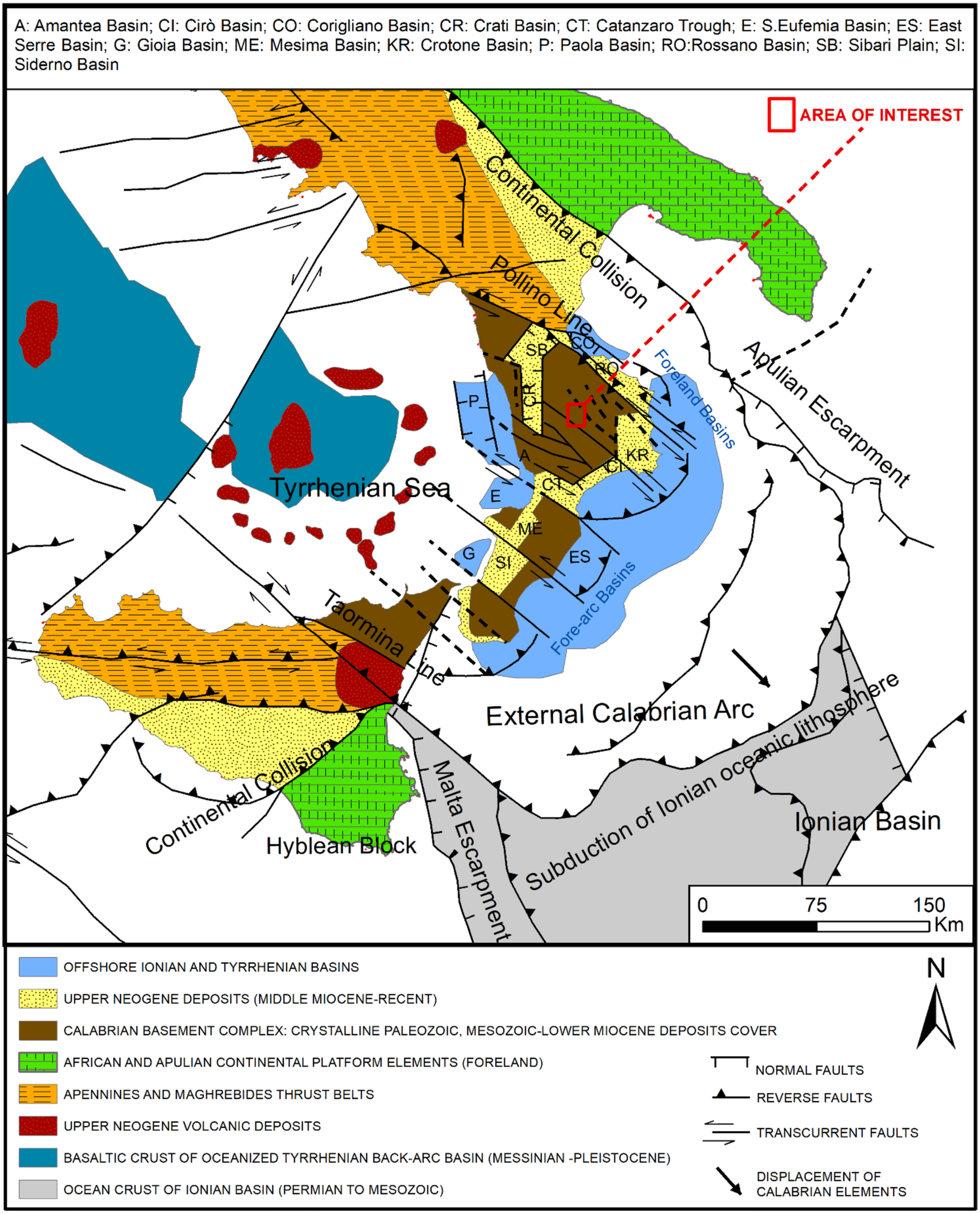


Fig. 2 Geological and tectonic sketch-map of the Central Mediterranean area (modified after Van Dijk et al. 2000; Tansi et al. 2007). In the figure is reported the location of the study area

River valley (Fabbricatore et al. 2014) and the Middle-Late Miocene-Pleistocene Basins of the eastern belt that slopes towards the Ionian coast (Barone et al. 2008; Zecchin et al. 2020; Civile et al. 2022) (Fig. 3).The Sila orogen is made up of the Paleozoic basement of the Sila Unit (Messina et al. 1991, 1994), formed by a large plutonic complex, the Sila Batolith, and by three distinct metamorphic complexes of Gariglione (medium–high metamorphic grade), Mandatoriccio (medium–low grade) and Bocchigliero (low grade complex), locally covered by the Longobucco Mesozoic sedimentary succession (Fig. 3). Middle-Miocene to Pleistocene sedimentary successions unconformably overlap both sedimentary cover and basement rocks of the eastern side of Sila (Critelli 1999). The study area is almost entirely located in the Sila Batolith (Figs. 3 and 4), formed by numerous sin to post tectonic intrusive bodies, different for extension, texture and mineralogy (Festa et al. 2018), with predominant massive texture or tectonic foliation and a compositional range from gabbro to leuco-monzo-granite with a prevalence of tonalitic-granodioritic terms. Limitedly, the site extends into biotitic gneisses, locally granatiferous of the Gariglione Paleozoic Unit, which contain veins and volumes of pegmatite and granite material (Fig. 4).

From a tectonic perspective, the Sila Massif is characterized by three regional fault systems trending NW–SE, N-S, NE-SW. The NW–SE fault system (Fig. 4) is characterized by early Pleistocene left strike slip faults, inherited from pre-existing strike slip zone of regional extension ("Pollino Line", Bousquet 1973). These structures well developed at the boundary between the Apennine and the Calabrian Arc (Van Dijk et al. 2000), reactivated during the last extensional tectonic phase of the Late Pleistocene (Corbi et al. 2009), and still active (Tortorici et al. 1995). The mentioned deformative style allowed an initial identification of intramontane depressions, later becoming lakes in the Sila plateaus thank to tectonic delimitation of structures NW–SE trend, except for Cecita Lake that bordered to the east by N-S fault systems. The N-S fault system developed as normal system during the Middle Pleistocene in response to abrupt regional tectonic uplift, still active and estimated at 0.8 mm/year (Sorriso-Valvo 1993; Sorriso-Valvo and Sylvester 1993; Westaway 1993) for the last million years, produced a generalized lowering of the water course base levels and, consequently, a high local relief along the slopes.

The NE-SW faults system is morphologically less evident and finds its maximum expression in the Sangineto Line (Amodio-Morelli et al. 1976) which borders the Crati Graben to the NW, and its left transcurrent tectonic activity is fundamental in the Crati basin formation (Lanzafame and Tortorici 1981). The faults belonging to the NE-SW system have also been "taken over" by the Quaternary tectonics connected with the late extensional phase (Lanzafame and Tortorici 1981).

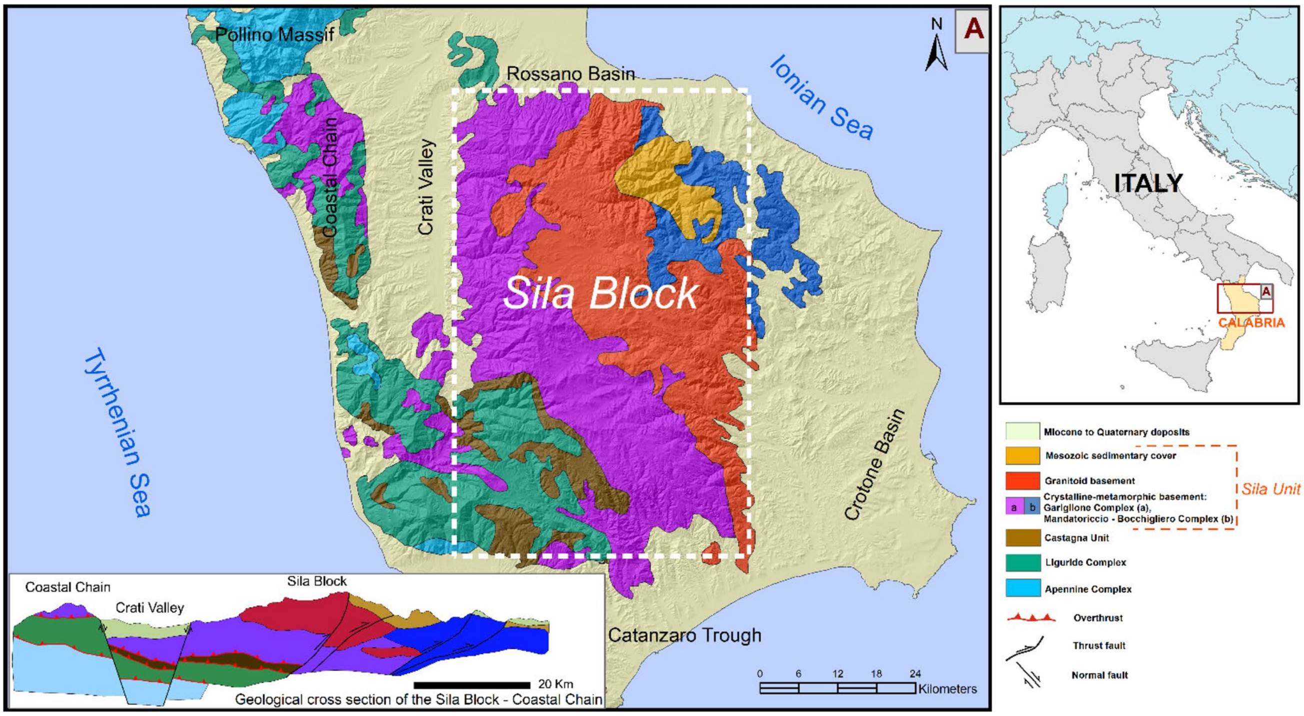
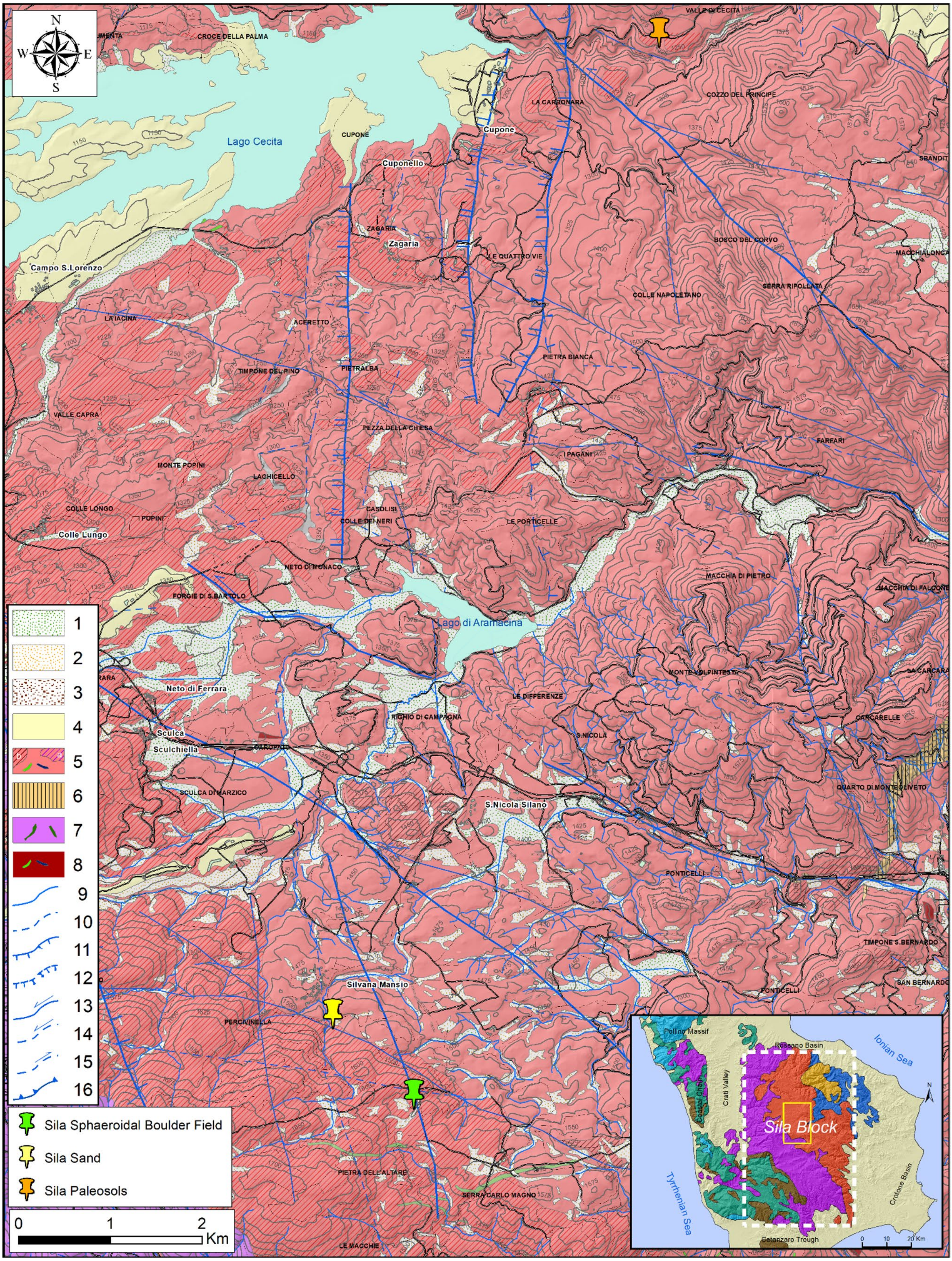


Fig. 3 Geological sketch map of the Sila Block and representative geological cross section of the Sila and Coastal Chain with main complexes and related tectonic units (modified after Messina et al. 1994; Ortolano et al. 2020)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Lago Cecita
CUPONE
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Cuponello
LA CARBONARA
COZZO DEL PRINCIPE
SBANDITI
ZAGARIA
Zagaria
LE QUATTRO VIE
BOSCO DEL CORVO
MACCHIALONGA
Campo S.Lorenzo
COLLE NAPOLETANO
SERRA RIPOLLATA
LA IACINA
ACERETTO
PIETRA BIANCA
TIMPONE DEL PINO
PIETRALBA
VALLE CAPRA
PEZZA DELLA CHIESA
FARFARI
I PAGANI
MONTE POPINI
LAGHICELLO
COLLE LONGO
I POPINI
CASOLISI
COLLE DEI NERI
LE PORTICELLE
Colle Lungo
NETO DI MONACO
MACCHIA DI PIETRO
MACCHIA DI FALCONE
FORCIE DI S.BARTOLO
Lago di Ariamacina
MONTE VOLPINTESTA
LA CARCARA
Neto di Ferrara
LE DIFFERENZE
RICHIO DI CAMPAGNA
CARCARELLE
Sculca
Sculchiella
S.NICOLA
SCULCA DI MARZICO
QUARTO DI MONTE OLIVETO
S.Nicola Silano
PONTICELLI
TIMPONE S.BERNARDO
SAN BERNARDO
Silvana Mansio
PERCIVINELLA
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SERRA CARLO MAGNO
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Sila Sphaeroidal Boulder Field
Sila Sand
Sila Paleosols
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Km
Pollino Massif
Rossano Basin
Ionian Sea
Crati Valley
Coastal Chain
Sila Block
Tyrrhenian Sea
Crotone Basin
Catanzaro Trough
0
10
20 Km
N

◂**Fig. 4** Geological-structural map of the study area (Cassa per il Mezzogiorno – Legge speciale per la Calabria del 26/11/1955 n. 1177, modified) Legend 1) alluvial deposits fixed by vegetation or artificially, terraced alluvial deposits (Holocene); Eluvium-colluvial deposits, solifluxion and washout products, sometimes mixed with alluvial material (Holocene); 3) Mass movement deposits, slope deposits (Holocene); 4) Terraced alluvial conglomerates poorly consolidated and easily disintegrated, locally associated with ancient alluvional fans (Pleistocene); 5) Granitoid rocks of the Sila Batholith (diorite quartz, monzonite, granite, tonalite, granodiorite), having massive to stratified structure and veins and pegmatitic small intrusions. Sometimes this rocks are laminated, brecciated and migmatitic (5a) or with a fine-graned texture (5b) (Paleozoic, Permian); 6) Biotite schists and gneisses of the Bocchigliero Complex, with veins and masses of granite (Paleozoic, Cambrian-Devonian); 7) Biotitic gneiss and schists, locally granatiferous of the Gariglione Complex, often containing veins and small cluster of pegmatite and granite material (Paleozoic); 8) Basic rocks with variable composition between gabbro and diorite of the Gariglione Complex (Paleozoic); 9) Generic fault; 10) Inferred generic fault; 11) Normal fault; 12) Inferred normal fault; 13) Left lateral strike slip fault; 14) Inferred left lateral strike slip fault; 15) Inferred right lateral strike slip fault; 16) Thrust fault

Climatic and Environmental Features

With regard to climatic data, the study area today has a humid temperate climate of the mountain Mediterranean type (Csb, sensu Köppen 1936), characterized by hot but short summers and relatively mild winters. The main climatic data summarized below are taken or elaborated by Colacino et al. (1997), Scarciglia et al. (2022) and the database of the Centro Funzionale Multirischi – ARPACAL, Calabria Region, Italy, www.cfd.calabria.it. The average monthly temperatures recorded between January and March, the coldest months, are around values between -2.6 and 0 °C, while in the hottest months (July and August) reach 16–18 °C. From November to April, the daily temperature values can easily reach a few degrees below zero (allowing frequent freeze/thaw cycles), down to lows of -10 °C or lower. Summer absolute maxima can reach 30–32 °C. Average annual rainfall is between about 1400 and 1600 mm, varying according to altitude and exposure, and are distributed throughout the winter season, while in July (and sometimes August) they do not exceed 30 mm. The snow cover affects areas located at altitudes greater than 1400–1600 m a.s.l. in a more stable way, lasting for at least 6 months. The pedoclimate (sensu USDA 2014) is characterized by a soil temperature regime of mesic type associated with an udic moisture regime (ARSSA 2003). The vegetation cover of the Sila plateaus consists of extensive meadows and pastures, high mountain conifers dominated by pine (Pinus nigra subsp. laricio or Pinus nigra subsp. calabrica) and silver fir (Abies alba), beech woods (Fagus silvatica) and fields mainly cultivated with potato and wheat (Moser et al. 2017; Scarciglia et al. 2020).

Weathering Processes and Their Associated Forms

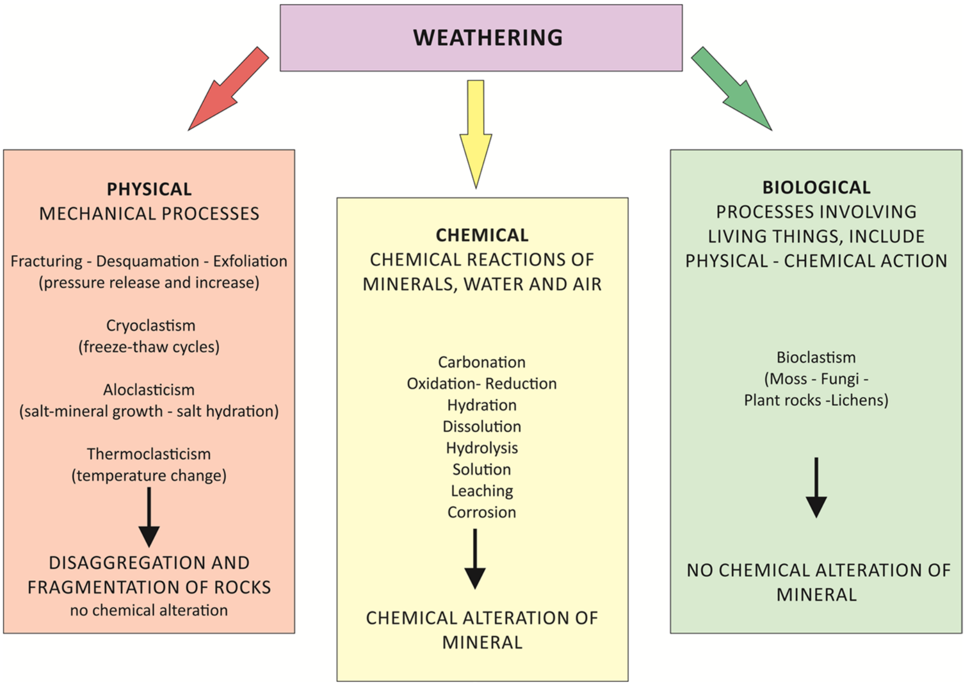
To understand the scientific value of the site as a trace and witness of landscape evolution over the course of geological history, it is necessary to frame it, in a schematic but exhaustive way, in the context of the different processes that have acted over the geological time up to the formation of current particular morphologies. The morphological aspect that distinguishes the area of interest is strongly conditioned by lithological characteristics, intensity of meteoric degradation processes, particularly developed in crystalline lithotypes, Quaternary tectonic structures (Matano 1991) and morpho-evolutionary processes.

The geological context of reference is that of a pervasively fractured crystalline substrate consisting of Paleozoic continental crust rocks, belonging to the granite rocks (granodiorites) of the lower Permian Sila Batolith (Figs. 3 and 4), and limited to the Paleozoic gneissic rocks of the Gariglione unit (Messina et al. 1994).

The crystalline rock masses, over the geological time, have undergone the action of a set of chemical and physical weathering processes (Fig. 5), which through the action of exogenous agents brought the rocks, placed on the surface or near it, to decay leading to the formation of loose debris. The nature and intensity of weathering depend mainly on three conditions (Fookes et al. 1971): environmental factors that control the alterative processes (climate, topography, type of source rock, duration of the processes, hydrological and biological conditions); properties of material constituting the source rock (mineralogical and chemical composition and physical–mechanical characteristics); features of the rock mass (overall pattern of discontinuities: type, nature, size, geometry, filling, etc.). Compositional layering, schistosity and many other anisotropic patterns in structure of rocks, as well as tectonic planes of discontinuity contribute to the mechanical breakdown of rocks and allows the transfer of rainwater in depth according to preferential flow directions, along which weathering processes are concentrated and enhanced.

The physical processes cause a mechanical disintegration of the rock through the formation, propagation and widening of progressively more widespread and pervasive networks of fractures and microfractures. The chemical processes, on the other hand, affect the original rock deeper, producing both modifications in the structure and texture, and a mineralogical imbalance which is reflected in the alteration of the mineralogical paragenesis, with a consequent appearance of weathering products, such as newly formed minerals (mainly clay minerals and Fe–Mn oxy-hydroxides), both as a replacement of the primary phases, which can still be present as in situ relics, and as a filling of voids by illuviation processes (Borrelli et al. 2015; Scarciglia et al. 2016).

Fig. 5 Types of weathering and their main processes



The biological weathering processes are related to direct and indirect effects of living organisms, which affect rock and mineral surfaces through the decomposition products of the vegetable organic substances including humus or more labile compounds, which enhance the chemical attack (e.g., lichens). The climatic parameters that most influence weathering processes are temperature and rainfall, because influence the soil type formation (unstable primary minerals and speed of chemical reactions) and control evaporation, that indirectly affects the removal of the soluble phases, drainage conditions and leaching. The leaching rate, high for the mountain environments of Calabria, coupled to tectonic uplift and erosion, controlling the depth of the weathering due to ability of water to percolate deep into the rock masses (Le Pera and Sorriso-Valvo 2000; Scarciglia et al. 2016).

The most active zone in terms of alterative processes is the Critical Zone (Fig. 6) which extends from the base of the altered bedrock to the roof of the vegetation cover, within which the flows of water and energy guide the chemical, physical, biological and geological processes that support life at the Earth's surface (Brantley et al. 2007). Understanding the formation, evolution and

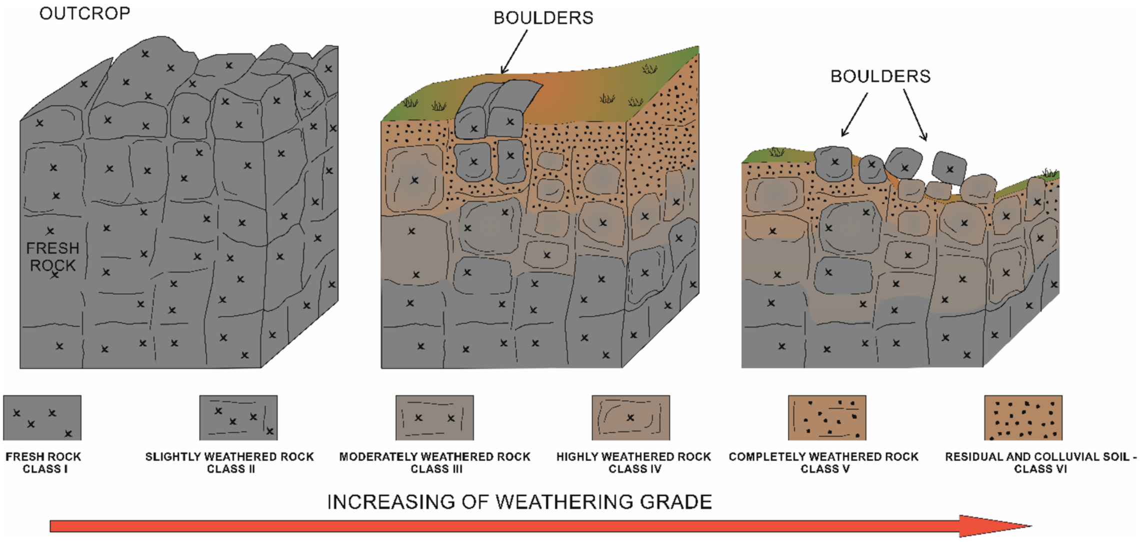


Fig. 6 Typical simple weathering profile developed in granite rocks and weathering form (modified after Little 1969; Anderson et al. 2007)

functioning of the Critical Zone is crucial to predict its response to ongoing changes in climate and land cover (National Research Council 2001). The mechanical rock degradation generally leads to planar jointing with angular mutual intersections and clasts, whereas the subsequent chemical weathering processes tend to smooth and eliminate edges and vertices, where the chemical attack is favoured because of a greater surface area for a preferential water–rock interaction., As far as the chemical transformations develop, they generate increasingly rounded shapes and reduce the size of unaltered rock, also reducing the exposed surface, and create easily removable debris from surface flowing waters. The reduction of the attack surface slows down the modifications that proceed from the periphery towards the central portions (Fig. 6). The intensity of the weathering processes, which can affect different rocks in different ways, and the main relief features (Basu 1985; Palomares and Arribas 1993) control the development of alteration profiles and the production of terrigenous sediments, with consequent landscape modifications in space and time (Ollier 1971; Dixon and Young 1981; Pye 1986; Twidale 1990; Le Pera and Sorriso-Valvo 2000; Scarciglia et al. 2007, 2022). The alteration profiles represent the vertical sequence of thicknesses with different degrees of alteration with respect to the conditions of the rock of unaltered origin. This succession extends from the unaltered bedrock to the topographical surface, with the maximum expression of weathering in the regolith, which normally forms the surface of the territory (Ollier 1988), both with altered rock in place, i.e., the saprolite and/or in situ formed soil, and altered material that has undergone transport (colluvium). The progressive and gradual increase in the degree of weathering towards the surface, where weathering processes commonly start earlier due to interplay with meteoric agents and water infiltration, generates a simple weathering profile. In contrast, if there are juxtapositions of layers showing different degrees of weathering without such a common depth-trend, possibly controlled by lithological changes, within the normal weathering sequence, it may exhibit a complex pattern (Fig. 6) (Baynes et al. 1978; Borrelli et al. 2014). The different stages of alteration, from unaltered bedrock to in situ or colluvial soil (Fig. 6), can be identified by observing geological characters (texture, discoloration/coloration, compactness, grain size and shape) and with the evaluation of simple tests (Schmidt hammer, immersion of samples in water, etc.) related to the mechanical resistance of the rock, according to the classifications of the degree of alteration of crystalline rocks (GCO 1984; Cascini et al. 1992, 1994; GSE-GWPR 1995; Gullà and Matano 1994; Borrelli et al. 2014; Scarciglia et al. 2016) known in the technical scientific literature.

Methodology

Geoconservation strategies provide a sequence of steps (inventory, quantitative assessment, conservation, interpretation, promotion, and monitoring of sites) aiming to achieve a functional management of geoheritage (Brilha 2018). This represents a fundamental tool in order to identify and select representative geosites of geological history of the area, thus address them to protection and value appreciation. Achieving a geosites inventory is needed identify the topic, the value, the scale and the use (Lima et al. 2010). This study concerns the identification, selection, and assessment of geological heritage (topic), with scientific relevance to international, national, and local scales (value), outcropping in the Sila Massif (scope) to encourage and support actions for the protection, management and promotion of this geoheritage by the Sila National Park authority (use). For the purposes of have a general framework, in terms of forms and products of geological processes having geoheritage significance, the present study was articulated in different phases following reported.

In the first stage, the rock type and structural elements identification, as well as the surveying of weathering grade in the study area were carried out on the basis of classical geological techniques of field survey, supported by aerial photo interpretation. The collected lithological, structural and geomorphological mesoscale information stored in a GIS database (Coordinate System WGS 1984 UTM Zone 33N) allowed to obtain the geological-structural map (Fig. 4). Regarding the inventory and evaluation of the geosites, among the different methodologies recognized in the literature, in this work the method proposed by Brilha (2016) and taken up by other authors was adopted. This method can be applied to all types of geological sites according to a selection of geosites that must favour scientific value, regardless of the possibility that educational and tourist values are also relevant. From a list of potential geosites collected after a literature review, field work and background of authors, geosites were selected using the following qualitative criteria: representativeness, integrity, rarity and scientific knowledge. The three selected geosites were assessed for their scientific, educational and tourism values, as well as their risk of degradation. Regarding the quantification process, 26 criteria were used, with numerical scores ranging from 1 to 4, according to the method indicated above (Brilha 2016, Table 1). Each geosite is ranked 1, 2, 3 or 4 points in accordance with the indicators for each criterion (Table 1). An indicator can also be ranked zero if appropriate. For scientific value there is no indicator with 3 points in order to better distinguish geosites ranked with 4 points. The final values are a weighted sum of all used criteria to quantify each one, as expressed in Table 2.

Table 1 Criteria, indicators, and parameters used for the quantitative assessment of the scientific, educational, and touristic values, together with the degradation risk of the geosites (Brilha 2016)

Quantitative Assessment of Scientific Value

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

Table 1 (continued)

Quantitative Assessment of Educational and Potential Touristic Value		
Criteria/indicators		**Parameters**
A	Vulnerability	Point
	The geological elements of the geosite present no possible deterioration by anthropic activity	4
	There is the possibility of deterioration of secondary geological elements by anthropic activity	3
	There is the possibility of deterioration of main geological elements by anthropic activity	2
	There is the possibility of deterioration of all geological elements by anthropic activity	1
B	Accessibility	
	Site located less than 100 m from a paved road and with bus parking	4
	Site located less than 500 m from a paved road	3
	Site accessible by bus but through a gravel road	2
	Site with no direct access by road but located less than 1 km from a road accessible by bus	1
C	Use limitations	
	The site has no limitations to be used by students and tourists	4
	The site can be used by students and tourists but only occasionally	3
	The site can be used by students and tourists but only after overcoming limitations (legal, permissions, physical, tides, floods, …)	2
	The use by students and tourists is very hard to be accomplished due to limitations difficult to overcome (legal, permissions, physical, tides,floods, …)	1
D	Safety	
	Site with safety facilities (fences, stairs, handrails, etc.), mobile phone coverage and located less than 5 km from emergency services	4
	Site with safety facilities (fences, stairs, handrails, etc.), mobile phone coverage and located less than 25 km from emergency services	3
	Site with no safety facilities but with mobile phone coverage and located less than 50 km from emergency services	2
	Site with no safety facilities, no mobile phone coverage and located more than 50 km from emergency services	1
E	Logistics	
	Lodging and restaurants for groups of 50 persons less than 15 km away from the site	4
	Lodging and restaurants for groups of 50 persons less than 50 km away from the site	3
	Lodging and restaurants for groups of 50 persons less than 100 km away from the site	2
	Lodging and restaurants for groups less than 25 persons and less than 50 km away from the site	1
F	Density of population	
	Site located in a municipality with more than 1000 inhabitants/km2	4
	Site located in a municipality with 250–1000 inhabitants/km2	3
	Site located in a municipality with 100–250 inhabitants/km2	2
	Site located in a municipality with less than 100 inhabitants/km2	1
G	Association with other values	
	Occurrence of several ecological and cultural values less than 5 km away from the site	4
	Occurrence of several ecological and cultural values less than 10 km away from the site	3
	Occurrence of one ecological value and one cultural value less than 10 km away from the site	2

Table 1 (continued)

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

Table 1 (continued)

	Site located less than 20 km from a recreational area or tourist attraction	1
Quantitative Assessment of Degradation Risk		
Criteria/indicators		**Parameters**
A	Deterioration of geological elements	Point
	Possibility of deterioration of all geological elements	4
	Possibility of deterioration of the main geological elements	3
	Possibility of deterioration of secondary geological elements	2
	Minor possibility of deterioration of secondary geological elements	1
B	Proximity to areas/activities with potential to cause degradation	
	Site located less than 50 m of a potential degrading area/activity	4
	Site located less than 200 m of a potential degrading area/activity	3
	Site located less than 500 m of a potential degrading area/activity	2
	Site located less than 1 km of a potential degrading area/activity	1
C	Legal protection	
	Site located in an area with no legal protection and no control of access	4
	Site located in an area with no legal protection but with control of access	3
	Site located in an area with legal protection but no control of access	2
	Site located in an area with legal protection and control of access	1
D	Accessibility	
	Site located less than 100 m from a paved road and with bus parking	4
	Site located less than 500 m from a paved road	3
	Site accessible by bus through a gravel road	2
	Site with no direct access by road but located less than 1 km from a road accessible by bus	1
E	Density of population	
	Site located in a municipality with more than 1000 inhabitants/km2	4
	Site located in a municipality with 250–1000 inhabitants/km2	3
	Site located in a municipality with 100–250 inhabitants/km2	2
	Site located in a municipality with less than 100 inhabitants/km2	1

Results

Inventory of Geosites: Sila Spheroidal Boulder Field Geosite, the Sila Sand Geosite and the Sila Paleosols Geosite

The landscape of the Sila plateaus is essentially made up of vast relict strips of ancient planation surfaces, flat or with a weak gradient, shaped on the rocky substrate consisting of granitoids (tonalites, monzogranites and granodiorites) and Paleozoic metamorphic rocks (about 400–270 Ma) of the Sila Batholith (Messina et al. 1991) and/or on a Miocene sedimentary cover during the Pliocene and the Pleistocene, both displaced by block faulting at various altitudes between about 1000 and 1700 m a.s.l. (Sorriso-Valvo and Sylvester 1993; Molin et al. 2004, 2012; Scarciglia et al. 2016). Prevalent flat morphologies in the landscape of the Sila plateaus, formed starting from 5 Ma ago (early Pliocene), has favored the development of about one hundred meters deep weathering mantles, along with a few meters' thick soils, strongly rejuvenated by erosion (Figs. 7 and 8). The characteristics of the alteration profiles, although spatially very variable, can be traced back to some recurring types, in which different degrees of alteration are represented, from unaltered or slightly altered rock (respectively of classes I and II) to completely altered rock or saprolite (class V) up to soil material, colluvium or granular debris (class VI) or their transitions (Borrelli et al. 2014; Perri et al. 2015; Scarciglia et al. 2016; Biondino et al. 2018, 2020). The forms of alteration are often controlled by the primary characters (relating to the genesis and emplacement) of the rock or by secondary discontinuities linked to its evolutionary, geological and tectonic history, such as lithological, compositional, granulometric or textural variations, intrusion of dikes, load release structures, fault or thrust planes, cataclastic zones (Le Pera and Sorriso-Valvo 2000; Scarciglia et al. 2005, 2007). These discontinuities are often very evident, with angular contours and sharp edges, in fresh or lowly-weathered granites, which still show much of the rock structure and faint color variations (Figs. 7 and 8). The latter are generally located on the faces of discontinuities and due to infiltration and subsequent precipitation/accumulation (from the more altered

Table 2 Weights for the different criteria used for the assessment of the scientific, educational, touristic values and degradation risk of geosites (Brilha 2016)

Scientific value (SV)		**Degradation Risk (DR)**	
Criteria	Weight (%)	Criteria	Weight (%)
Representativeness	30	Deterioration of geological elements	35
Key locality	20	Proximity to areas/activities with potential to cause degradation	20
Scientific knowledge	5	Legal protection	20
Integrity	15	Accessibility	15
Geological diversity	5	Density of population	10
Rarity	15	Total	100
Use limitations	10		
Total	100		
Educational value (EV)		**Touristic value (TV)**	
Criteria	Weight (%)	Criteria	Weight (%)
Vulnerability	10	Vulnerability	10
Accessibility	10	Accessibility	10
Use limitations	5	Use limitations	5
Safety	10	Safety	10
Logistics	5	Logistics	5
Density of population	5	Density of population	5
Association with other values	5	Association with other values	5
Scenery	5	Scenery	5
Uniqueness	5	Uniqueness	5
Observation conditions	10	Observation conditions	10
Didactic potential	20	Interpretative potential	10
Geological diversity	10	Economic level	5
Total	100	Proximity of recreational areas	5
		Total	100

upper portions) of iron and/or manganese oxides/hydroxides, of yellow-reddish to blackish or brownish color, or clay particles (Scarciglia et al. 2016). The intersection of different discontinuity surfaces determines the isolation of blocks of rock (from decimetric to metric sizes), occasionally subject to tilting, detachment and gravity-driven collapse (landslides), with phenomena of fall, toppling and sometimes translational sliding along high-slope planes (Scarciglia et al. 2007, 2022). Furthermore, where physical–mechanical meteoric degradation processes prevail, triggered by cycles of freezing and thawing or variations in temperature, further fragmentation of the rock is observed with angular decimetric to centimetric clasts (Scarciglia et al. 2022). As the degree of chemical alteration due to hydrolysis, dissolution and oxidation processes increases, there is a progressive change of color, no longer localized only on the surfaces but with a pervasive character, gradually more extensive, linked to the disruption of primary minerals and neogenesis of clay minerals and Fe–Mn oxides. Granite partially and then completely loses its internal microstructure (Fig. 8), its original color and high initial consistency (breaking strength), until it becomes strongly disintegrated and divided into polycrystalline clasts or single crystals, with dimensions ranging from centimeters to millimeters, which constitute the typical "granite sand" of Sila (granular disintegration or arenization; Butzer 1976; Power and Smith 1994). Despite the old age of the crystalline basement (Paleozoic) and the maturity of the paleo-landscape, due to the intense erosion that occurred since the middle-upper Pleistocene in response to tectonic uplift and climate shifts, and more recently enhanced by historical to modern human impact (Olivetti et al. 2012; Scarciglia 2015; Raab et al. 2018; Scarciglia et al. 2020), soil sand paleosols evolved on granite rocks or sediments derived from them are generally quite young, poorly differentiated and structured, shallow (locally with considerable proximity or local outcrop of the granite substrate to the topographic surface(Fig. 8), and occasionally buried by river and/or slope deposits or by younger soils (Scarciglia et al. 2005, 2008, 2016). The main characters are the accumulation of humus due to the decomposition of plant tissues by bacterial attack, the development of a pedogenic structure and neogenesis of clay minerals and oxides (Lulli and Vecchio 2000; ARSSA 2003; Scarciglia et al. 2005; Moser et al. 2017). The superficial brown horizon, locally buried, extends with similar characteristics with great lateral continuity on the Sila plateaus and is enriched in fine ash of volcanic origin, probably sourced from late-Pleistocene and/or Holocene explosive eruptions of the Aeolian Islands

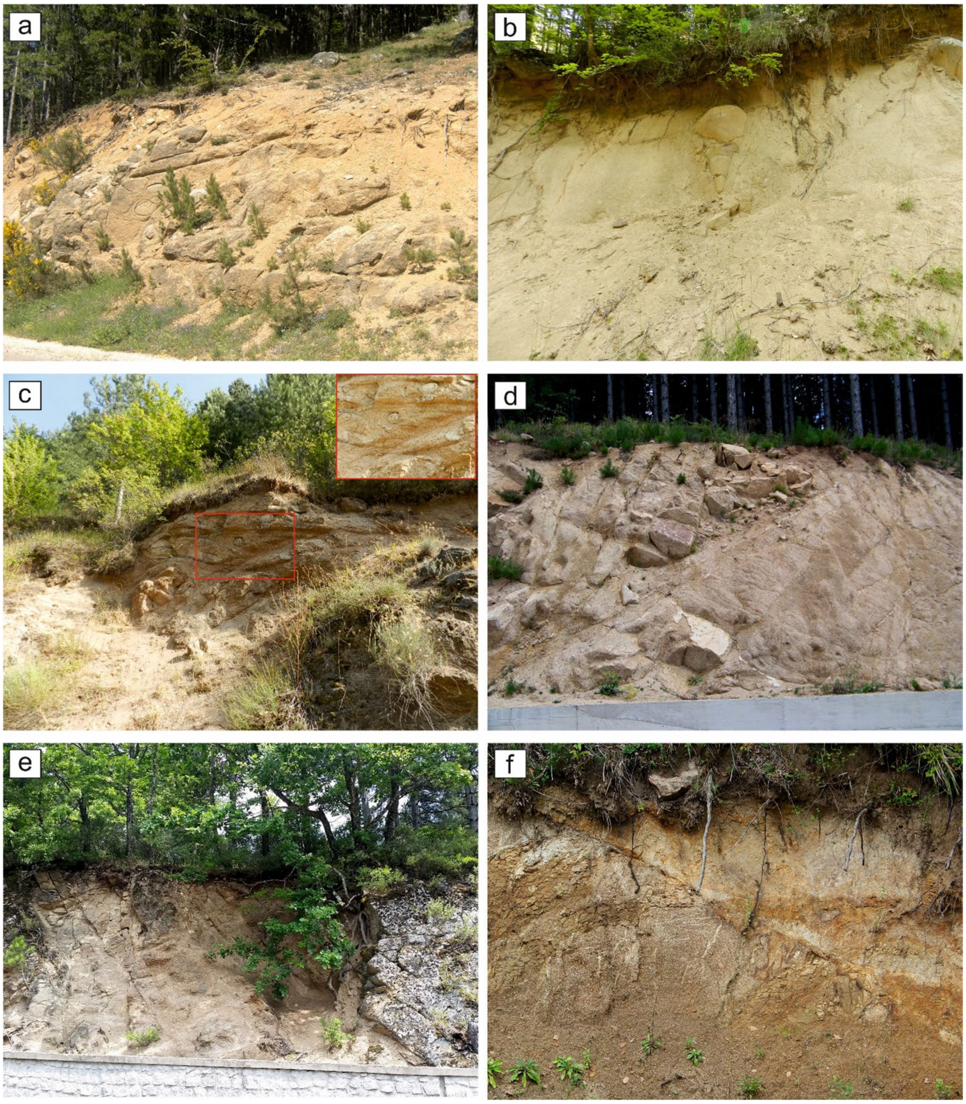


Fig. 7 Weathering profile types and the spheroidal chemical alteration (a), with formation of isolated spheroidal boulder (b, c) and complexity of vertical sequence caused by tectonic activity (d, e, f)

(Scarciglia et al. 2008; Raab et al. 2017; Vingiani et al. 2014). Thanks to this volcanic input, its consistent stratigraphic position and traceability, this soil can be considered a pedostratigraphic marker of the area (Scarciglia et al. 2008). On the edges of the most ancient paleosurfaces, generally (but not exclusively) located at higher altitudes, there are tors, spheroidal boulders and blocks (Figs. 9, 10 and 11), in particular in the area between Silvana Mansio – Carlo Magno (Fig. 4) and San Giovanni in Fiore (Le Pera and Sorriso-Valvo 2000; Scarciglia et al. 2005, 2007, 2008; Raab et al. 2019). These boulders and blocks appear scattered on the topographical surface or "emerge" from it and are locally grouped or piled on top of each other, aligned along ridges or hills or associated with isolated or castellated peaks, giving rise to domiform residual reliefs with typical morphologies of born hardts, inselbergs or tors (Twidale 1986, 2002; Migoń 2013; Migoń et al. 2018) (Fig. 9). Sometimes the boulders form extensive boulder fields or can be mobilized by rolling along the slopes(Fig. 10).These spheroidal boulders (from 2–3 m up to about 6 m in diameter) and similar smaller blocks of the order of 30–60 cm (spheroidal blocks and corestones) are the result of chemical alteration processes thanks to infiltration of rainwater, which occurred at depths of several tens of meters in the alteration profile of the granite rock (Figs. 7 and 8) (Butzer 1976; Ollier 1967, 1971, 1988; Scarciglia et al. 2005, 2007, 2008). The shapes that characterize the Sila geosite landscape result from the action of weathering processes, starting from a parent rock affected by a more or less pervasive fracturing that isolated volumes of rock, subsequently infiltrated by water and subject to chemical attack and alteration, with consequent and progressive widening of the fractures/surfaces of discontinuity linked to geological history (lithological contacts, fault and thrust surfaces, pressure drop fractures, magma-derived rock cooling, dike intrusions, etc.), and smoothing and rounding of the roughness of the granite rock surfaces

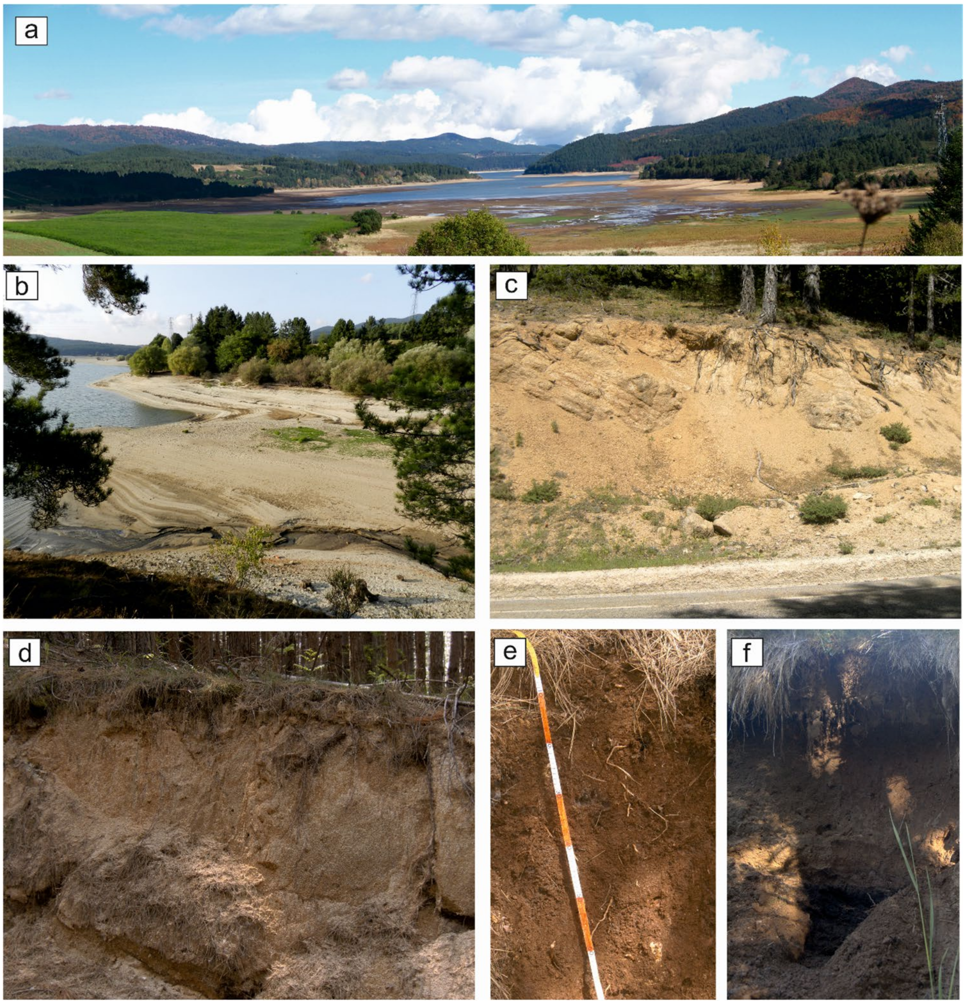


Fig. 8 Extensive outcrop of the "Lake Cecita geosoil" in the south-western area of the lake (a, b); soils (class VI) on top of the weathered profile (c, d); Soil profiles with brown upper horizons rich in humus developed on natural granite river sediment (e); Soil profile with brown upper horizons rich in humus (with the presence of volcanic inputs) overlying horizons of alteration by iron oxides/hydroxides, developed on an altered substrate in granodiorite rock (f)

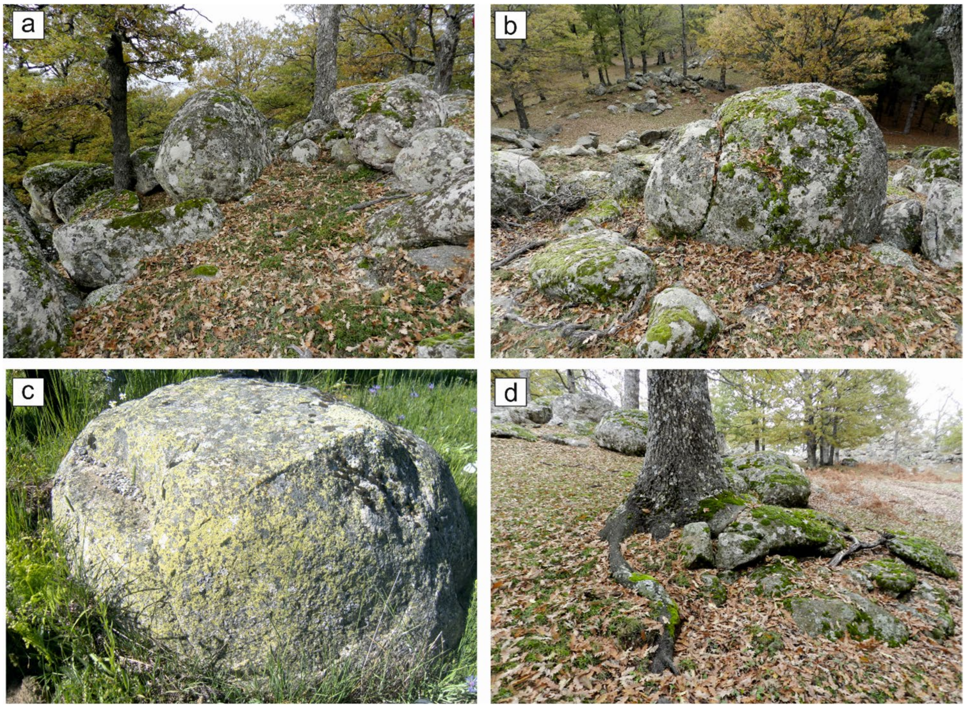


Fig. 9 Examples of granitic spheroidal boulders, exposed out of the weathering profile up to the ground surface due to intense erosion processes that progressively have removed loose disintegrated material (c); often the boulders are grouped along ridges and on hills (a,b, d)

Fig. 10 Different forms of boulder in large fields of the study area, exposed on surface

(especially granodioritic) through progressive chemical alteration processes of primary minerals, such as hydrolysis, dissolution, oxidation and argillification. The progressive penetration of alteration, from outside towards inside of the rock, tends to occur concentrically along the initial discontinuities, isolating portions of spheroidal rock often characterized by an "onion" structure, where the outermost levels are more altered, while the internal portion (corestone) is less or not at all altered. The latter generally falls within the alteration classes I-II (Fig. 7) (Scarciglia et al. 2016), according to different classification variants based on visual observations and physical–mechanical tests in situ (Gullà and Matano 1994; Borrelli et al. 2014). The depths at which boulders and spheroidal blocks are currently found within the alteration profile (saprolite or grus) in the Sila range from a few meters to about fifteen meters (Scarciglia et al. 2005), but in the literature the depths of discovery or formation vary from this range to a few tens of meters (Wright 1997; Patino et al. 2003; Buss et al. 2008) up to hundreds of meters (Ollier 1971). The deep spheroidal alteration was probably active from the Miocene (20 Ma) to the late Pliocene (3 Ma) and the early Pleistocene (about 1 Ma). The tectonic activity that affected the Sila during the Pleistocene, characterized by various phases of uplift, triggered intense erosion processes (Molin et al. 2012; Olivetti et al. 2012), probably at least partially controlled by late Quaternary climatic variations, which have led to the progressive exhumation of these boulders and spheroidal blocks, out of the alteration profile up to the topographical surface, following the removal of loose detrital material (Figs. 9 and 10). After their exhumation, the spheroidal boulders were affected (and still are) by further physical disintegration processes, especially thermo-clastism and cryo-clastism (favoured by strong cyclical, diurnal or seasonal thermal excursions), and ongoing chemical alteration processes, which give rise to phenomena of superficial concentric exfoliation (with an

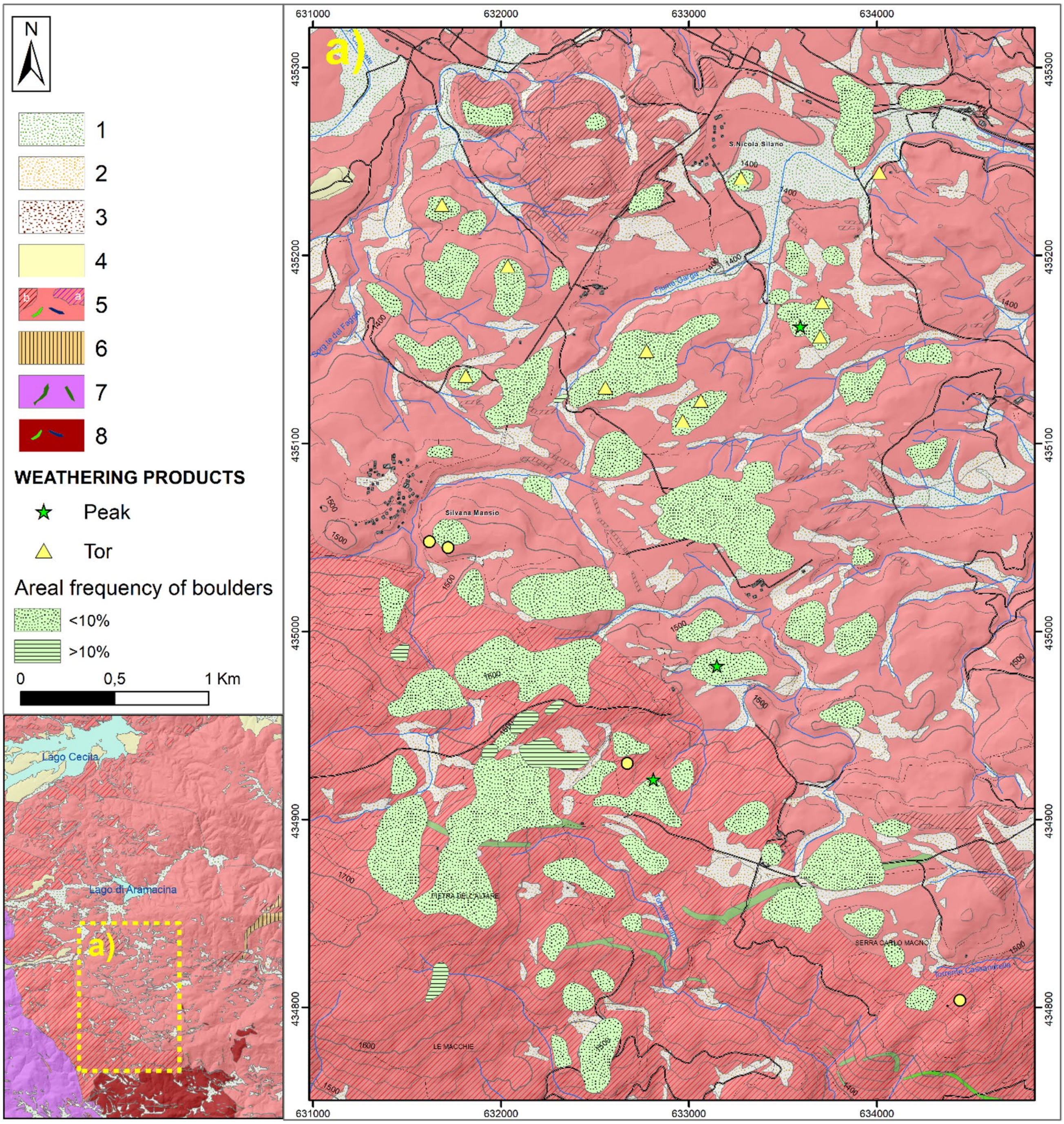


Fig. 11 Geomorphological sketch-map (modified from Le Pera and Sorriso-Valvo 2000) of the study area affected by weathering processes and their products such as rounded form, tor and boulder camps. Geological legend in Fig. 4

"onion" pattern), dislocation of thick slices of rock, gravity-triggered phenomena and/or local disintegration into sand-size detritus(Figs. 8, 9 and 10) (granular sandstone)(Butzer 1976; Power and Smith 1994; Le Pera and Sorriso-Valvo 2000; Scarciglia et al. 2005, 2007, 2008, 2016, 2022). In addition to the effects of the aforementioned meteoric degradation there are often also processes of biological alteration, induced by colonization by lichens (Fig. 12) (Scarciglia et al. 2007, 2012). One evidence that the spheroidal boulders formed in depth and only subsequently were exhumed by erosive processes is the abundant presence of extensive films of illuvial clay (i.e. resulting from the alteration of upper pedogenetic horizons from which neogenic clay migrated in depth thanks to the infiltration waters) that

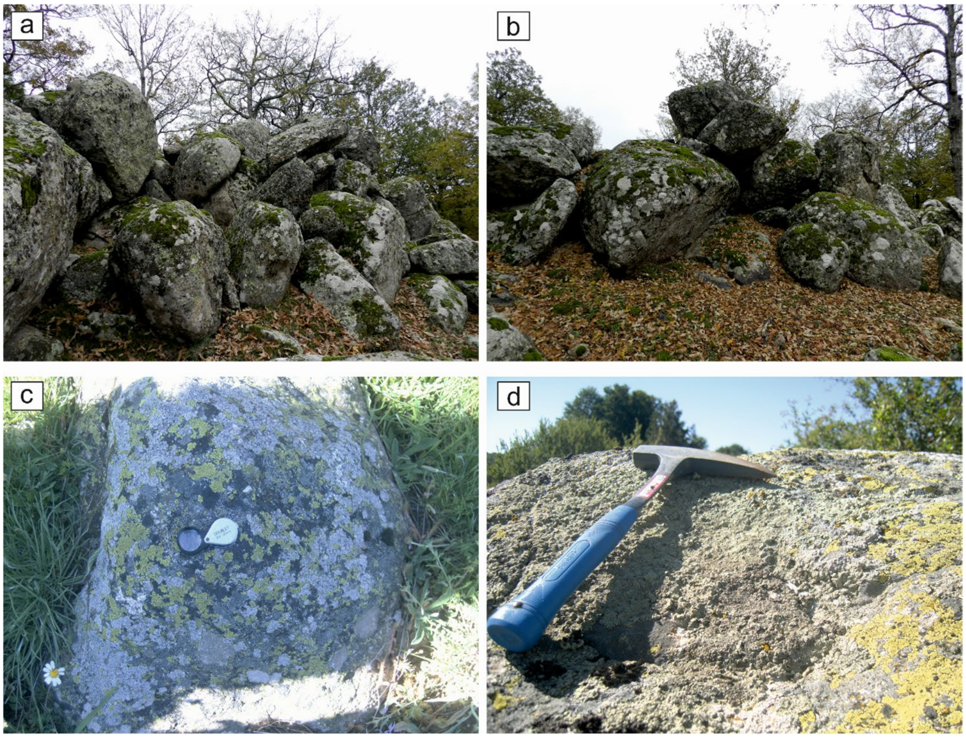


Fig. 12 Biological processes of weathering and examples of lichens attack

covered them (Fig. 13). Even where the prolonged exposure of the boulders to the topographical surface has resulted in the removal of these films, they have occasionally been identified to a lesser extent within some fractures of the rock (Scarciglia et al. 2005). Preliminary data based on geomorphological and pedological observations and exposure age analyses using cosmogenic nuclides (^{10}Be) carried out in collaboration with the University of Zurich (Raab et al. 2018, 2019) allow us to estimate that long-term erosion rates, which occurred during the upper Pleistocene, has removed at least a few tens of meters of altered and/or pedogenized material overlying the boulders currently exposed on the surface. The activity of very recent and probably current surface erosion processes is also provided by the basal exhumation of tors, boulders and blocks from the brown-colored surface soil, clearly highlighted by the "dirty" and brownish aspect of the rock along a layer of about 10–20 cm from the ground level and the contextual absence of lichen cover therein (Fig. 10), further supported by fallout isotope($^{239+240}$Pu) analyses (Raab et al. 2018). In the Sila plateaus the landscape shaped across the granitoid masses can be typically expressed by isolated boulders and extensive boulder fields, often reworked by natural processes or anthropogenic activities (Figs. 9 and 10) or, in places tor-type morphologies, emerging from the ground surface, which have neither undergone transport processes nor have been subject to mobilization and stacking (Figs. 14 and 15). These peculiar landforms represent fascinating remnants of paleo-landscapes that record the geological and geomorphological evolution of the Sila uplands and are unique witnesses of the geodiversity and geological heritage in the whole Mediterranean area.

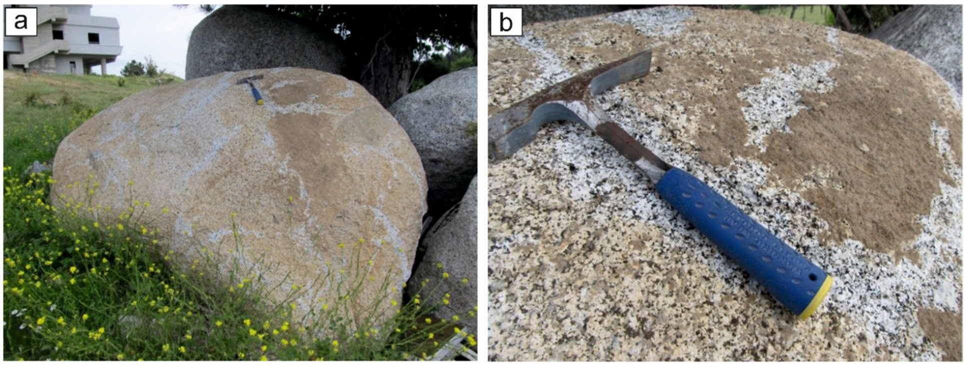


Fig. 13 Presence of extensive films of illuvial clay on boulders surface

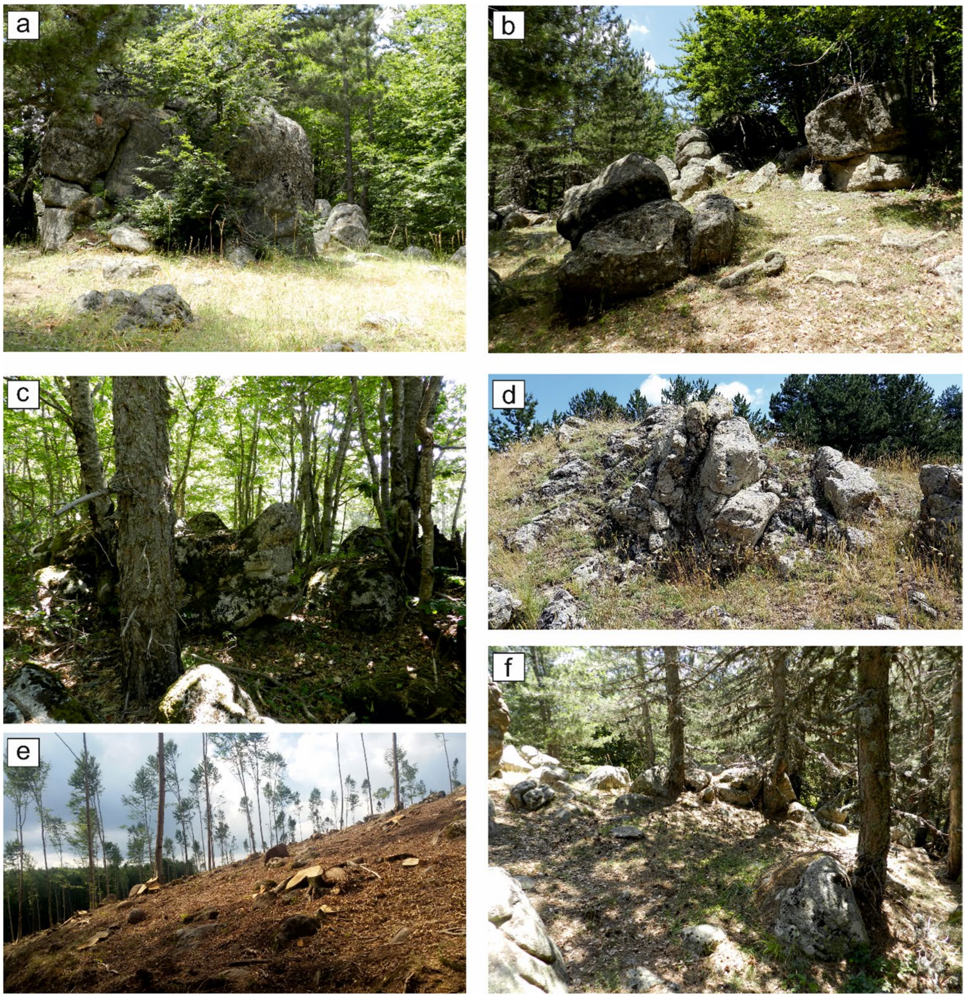


Fig. 14 Examples of boulder fields in the study area

Quantitative Assessment of Geosites

The geological framework for entire study area exhibits a singular natural scenario where action of weathering processes combined with exogenous ones (exhumation and erosion) on the Paleozoic crystalline rocks masses, belonging to Sila batholith, can be easily observed.

The geosites naming reflects the prevailing weathering product of the area. Overall, it witnesses the presence of intense weathering profiles, composed of rocks with different weathering stages, from fresh rocks up to soils, as well as typical morphologies like spheroidal boulders exhumed by erosive processes, also forming fields. The before described geosites exhibit a diverse and a rich geodiversity that allow the understanding and knowledge of geological history of the study area, especially in view of a possible management touristic targeting of the sites.

The quantitative assessment of the 3 geosites is presented in Table 3 and in Figs. 16, 17, and following a summary of the results is reported. The results show that Sila Spheroidal Boulder Field Geosite is the geosite having greater score in all values, in particular it is characterized by a medium–high scientific value (points 250), and moderate educational (points 230) and touristic (points 215) values. The Sila Paleosols Geosite and the Sila Sand Geosite scored the same in educational (points 175) and touristic (points 170) values, while the scientific value it is slightly higher for the second (points 175) geosite than the first (points 155). To regarding the degradation risk is constant in all geosites (points 205). The criteria that most influence the scientific value score are representativeness, scientific knowledge and use limitation. Below is a brief excursus that led to assigning the scores as shown in the Table 3 and in Fig. 17.

The geosites under consideration are a good/best example in the study area illustrate elements or processes that generated them, especially in the case of the Sila Spheroidal Boulder Field Geosite that, although also present in other places of Calabria, only on the Sila plateaus they constitute real spheroidal boulder fields covering a very large territory. Furthermore, given the absence of granitic rocks along the rest of the Apennine chain, they represent a geomorphological unicum throughout peninsular Italy. At present the

Fig. 15 Examples of boulder fields in the study area

Geosite characterized by a low level of protection because it totally natural mode without anthropic intervention, thus, to have a medium probability of human impact and natural deterioration, consequently, can shows some preservation problems given by geological elements altered, modified or subjected to natural/anthropic movement or activity, despite currently all geological elements are observed in good conditions. In order to analyse the evolution of weathering stage in crystalline granitic rocks, this site was object of many research works, enclosed do fieldwork, collect samples and laboratory analysis, even thank to easy accessibility. In fact, the geosite is used by international and national science, even as paper topic in international scientific journals, in relation to deep and/or spheroidal weathering, geomorphology, landscape evolution and soil erosion, exhumation.

A uniqueness value for Sila Paleosols Geosite is given by being the first large area at a regional level in which a volcanic contribution to soil pedogenesis has been well documented.

The fine cinerites of volcanic origin, probably coming from late-Pleistocene and/or Holocene explosive eruptions of effusive systems of the central Mediterranean (Aeolian Islands and Greece), represent an input that gives it the role of pedostratigraphic marker (compositional stratigraphic archive value) in a peri-volcanic area. For this reason, the geosite has mainly attracted the attention of national science, with papers in international scientific journals, such as Scarciglia et al. 2008. As demonstrated by scientific article of literature and dissertations, it has been and can will be a place to collect samples and do fieldwork, because has elements suited to university teaching and for this reason, potential public should need to have solid geological background to understand the geological elements of the site, as well as their conservation importance. Regarding the educational value and tourist potential there are not limitations to be used by students and tourists, on the contrary, exist good possibilities to exploit the site thanks to its location close to the road, easily accessible although there are ordinary road arrangements for tourist purposes, as well as thanks to the presence of a recreational area in a territorial surrounding.

Regarding the conservation state of the "Sila Paleosols Geosite", it is important to underline that these are dynamic systems in continuous evolution and subject to meteoric

Table 3 Quantitative assessment of the scientific, educational, touristic values and degradation risk of Sila geosites according to Brilha 2016 method

Criteria/indicators	Sila Spheroidal Boulder Field Geosite	Sila Sand Geosite	Sila Paleosols Geosite
Scientific Value			
Representativeness	4	2	2
Key locality	2	2	1
Scientific knowledge	4	4	4
Integrity	1	1	1
Geological diversity	1	1	1
Rarity	2	1	1
Use limitations	2	2	2
Educational Value			
Vulnerability	3	2	2
Accessibility	3	3	3
Use limitations	4	4	4
Safety	1	1	1
Logistics	3	3	3
Density of population	1	1	1
Association with other values	1	1	1
Scenery	1	1	1
Uniqueness	4	3	3
Observation conditions	4	2	2
Didactic potential	1	1	1
Geological diversity	4	2	2
Touristic Value			
Vulnerability	3	2	2
Accessibility	3	3	3
Use limitations	4	4	4
Safety	1	1	1
Logistics	3	3	3
Density of population	1	1	1
Association with other values	1	1	1
Scenery	1	1	1
Uniqueness	4	3	3
Observation conditions	4	2	2
Interpretative potential	3	2	2
Economic level	1	1	1
Proximity of recreational areas	2	2	2
Degradation Risk			
Deterioration of geological elements	2	2	2
Proximity to areas/activities with potential to cause degradation	1	1	1
Legal protection	3	3	3
Accessibility	3	3	3
Density of population	1	1	1

degradation, thanks to the peculiar climatic conditions of the area, favorable to a vast range of physical and chemical processes. and organic. These processes also determine the occasional removal of the mobile material thus produced, through the triggering of landslides and surface water erosion. In particular, with regard to soil with volcanic contribution, it should be underlined that it presents an intrinsic fragility and susceptibility to erosion, determined by its peculiar characteristics and general exposure to the topographic surface. This fragility is especially accentuated in areas without tree cover, used for pasture and crops (especially cereals and potatoes), even more so where the plowing

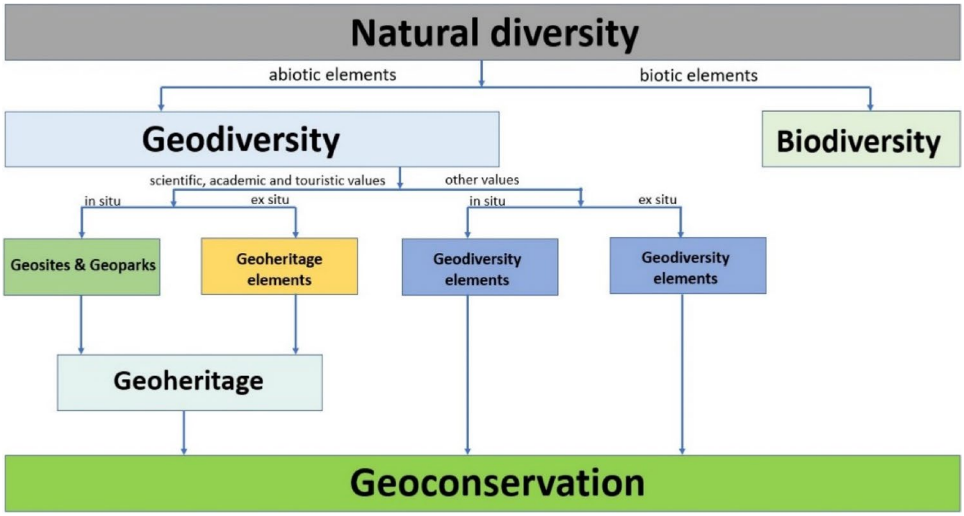


Fig. 16 Conceptual scheme of geodiversity, geological heritage and geoconservation (modified after Lazzari 2013); see text for explanation

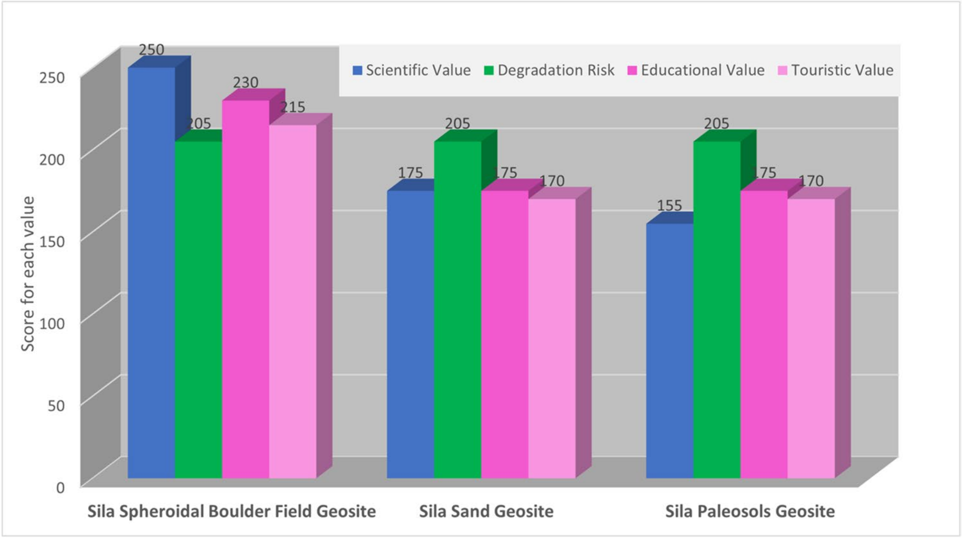


Fig. 17 Final score of geosites obtained according to Brilha 2016 method

furrows follow the lines of maximum slope, or along the banks of the Sila lakes, subject to frequent level fluctuations and wave motion. Therefore, there is a problem about preservation of its main geological elements both caused by anthropic activity or natural course of decay.

Also, the Sila Sand Geosite is characterized by geological relevance proven by paper of international scientific journals science. Its exceptional nature is given by large extension of crystalline rocky outcrops that constitute Sila massif, as well as coexistence of a rocky substrate and rocks originally crystalline and lithoid consistency was transformed over geological time into a loose rock similar to sand that led to a paleolandscape, characterized by ancient alteration profiles but strongly rejuvenated by erosion. This geological peculiarity was favoured by the prevalence of flat morphologies in landscape of the Sila plateau, formed starting 5 million years ago (Pliocene) affecting crystalline rocks, mainly granitoids (tonalites, monzogranites and granodiorites), through the development phases of deep weathering thicknesses, generally exposed in natural and anthropic outcrops and/or cut slopes, which extend in depth up to about a hundred meters from the topographic surface.

With regard to the state of conservation of the “Sila Sand Geosite" it should be underlined that it is inside a dynamic system in continuous evolution, so subject to meteoric degradation, thanks to the peculiar climatic conditions of the area, favourable to a vast range of physical, chemical and biological processes. These processes also determine the occasional removal of the mobile material thus produced, through the triggering of landslides and surface water erosion.

Discussion

The public attention for environment from geological and geomorphological point of view is generally dictated by the occurrence of violent natural events and/or man-made disasters that caused damage to people and property, sometime irrecoverable. Therefore, it's necessary to strengthen the idea that the territory is not simply the place where one is born or lives, but the physical support of human activities, a precious historical, emotional, economic resource, and above all one of the founding values of human identity (Peppoloni and Di Capua 2021). The protection and conservation of the geological heritage stems from the awareness of the geodiversity in a territory, understood as a set of all the abiotic elements (Fig. 16) and evolutionary processes that contribute to the creation and development of the Earth (Gray 2004), and sustain biodiversity and constitute with it the natural diversity of our planet. The knowledge and awareness about geology as testament of landscape history and of all the events that gave rise to the morphology that characterized it, are important for scientific community but also should be for generic public, also in the capacity of potential tourists. The recent past has seen a growing attention for the sustainable use of environmental resources, a bit less for the concept of geoconservation, as an activity or set of actions that have the goal to identify, protect and manage the precious elements of geodiversity, with particular regard to environmental management, geological risks and sustainable development (Prosser et al. 2011). The conservation, rational management and protection of geological features and structures showing iconic geodiversity, can be exploited for educational, scientific, and legacy purposes (Semeniuk 1996; Semeniuk and Semeniuk 2001), thank to their scientific and didactic value (Brocx and Semeniuk 2007). The current educational system does not highlight the importance of the geological heritage, consequently, it is essential to make geological knowledge more widely available and to carry out scientific dissemination in various educational institutes of all levels, as well as to the entire population through targeted events and informative tools. A greater interest for geological heritage and, thus, a positive impact on its protection and geoturism can be inspire by sensorial, empathic and emotional experience related to geosites exploration, namely of the resources, risks, forms, history and evolution of the territory of which they are part (Migoń et al. 2018; Rypl et al. 2021). Geotourism goes together with geodiversity, as well as uniqueness of some geological morphologies/products that confer a high scientific value.

The geological heritage of the study area (Sila massif, Calabria) lends itself optimally to the dissemination of geological knowledge of the territory, both in terms of a pivotal sector in the context of the geodynamics of the Mediterranean and of all those geological processes which, over time, have brought about the transformations of the landscape up to the current conformation. In fact, the sites of this work are identified by a geological or geomorphological interest for conservation, according to geosite definition (Wimbledon 1996) and show several geological peculiarities to be able to function in its entirety as a geosite, within a potential geopark (Patzak and Eder 1998), and have special significance for research, education and geotourism (Poli 1999; Vai 1999).

The geological singularity is due to peculiar coexistence of a rocky substrate and a paleo-landscape, characterized by ancient weathering profiles but strongly rejuvenated by erosion.

The particular morphologies (spheroidal boulders, tors and fields of boulders, as well as soils and paleosols with predominant sandy granulometry) associated with the weathering processes that have affected the crystalline rocks constituting the Sila high plateau, represent fascinating remains of the geological and geomorphological evolution of the Sila and testify a true uniqueness in the geodiversity and geological heritage of the entire Mediterranean area. In fact, they record the mechanical fracturing moments following the placement and later cooling phase of the Sila Batolith and subsequent deep chemical alteration, their displacement and/or fracturing after tectonic uplift phases, further physical, chemical and biological weathering processes once exhumated at the ground surface, and the erosion that occurred with different intensity in different periods of the Pleistocene and the Holocene (still in progress), also in relation to the glacial-interglacial climatic oscillations that occurred during the Quaternary (Raab et al. 2018, 2019).

The granodiorite boulders of the Sila Spheroidal Boulder Field Geosite are very peculiar, because, although present also in other sectors of Calabria, only on the Sila plateaus they constitute real boulder fields and cover a very large extent of the territory, consequently they benefit peculiar beauty and suggestion from a visual point. Furthermore, given the absence of granite rocks all along the remaining close Apennine chain to the north, this weathering forms represent a unique geomorphological site of the entire peninsular Italy.

Another uniqueness of the study area is given being a large area at regional level having a well-documented volcanic contribution in the pedogenesis of soils and paleo sols. Thanks to the pyroclastic input, together with the climatic conditions, these soils and paleo sols also have a high fertility, well in line with the agricultural vocation of the Sila area.

As regards the state of conservation the Sila Spheroidal Boulder Geosite is quite good, thanks to the prevailing naturalness of the area associated with non-invasive tourism.

It is important to emphasize that these are dynamic systems in continuous evolution and their further evolution, thanks to the peculiar climatic conditions of the area favourable to a wide range of physical, chemical and biological processes, is slowly destined to degrade them in a natural way. In addition, the triggering of landslides and surface water erosion can further affect the morphologies and products of weathering. In particular, in the case of spheroidal boulders, where still included within alteration profiles or soil, the surface erosion in progress will lead to their exhumation and locally to a gravity-controlled rearrangement and/or rolling phenomena, further fracturing and fragmentation, and occasionally partial or total removal in the case of mobile material such as soil. Concerning soils and paleo sols with volcanic ash input, it should be emphasized that they have an intrinsic fragility and susceptibility to erosion, determined by their peculiar characteristics and by the general exposure to the topographical surface. This fragility is especially accentuated in areas without an arboreal plant cover, affected by severer anthropogenic activities or along the shores of the Sila lakes, subject to frequent level fluctuations and wave motion. Conversely, the fact that the geosite is almost entirely located within the Sila National Park, largely in an area with purely wooded land use, and in places buried and thus naturally protected by overlying sediments, tends to mitigate possible human impact.

Conclusions

This work started with the acquisition of data from classic geological field surveys and by comparison between the authors thanks to previous information about the geological uniqueness that distinguishes the study area, thus to obtain the identification of geosites followed by their quantitative assessment. The results allow, for each geosites, to have an exhaustive general framework about the scientific, educational and touristic value, and their degradation risk. The three geosites are characterized by a medium–high scientific value, while they have a moderate educational and touristic values, as well as the degradation risk. The most important geosite is the Sila Spheroidal Boulder Geosite with an international relevance. The obtained results, also considering the other two geosites, show a significant geodiversity and a potential geotourism, to date largely ignored, to support the possible future candidature project of the Sila National Park as geopark. To strengthen tourism potential, in addition to scientific dissemination, in agreement with the Sila National Park and based on accessibility and trekking opportunities, connecting itineraries through the geosites could be proposed, equipped with explanatory and informative panels, not only in the three areas identifying the geosites but also in correspondence with significant geological evidence along their entire route.

To examining the tourism potential of geological heritage has a key role in the strategic approach and the planning tool that encourages and aims local development through the dissemination and knowledge of a territory in its geological, geomorphological, landscape and pedological aspects. The applied method can help decision makers regarding geoconservation, geotourism and regional sustainable development strategies.

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