Accepted Manuscript

*Geological Society, London, Special Publications*

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DOI: https://doi.org/10.1144/SP530-2022-110

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Received 31 March 2022
Revised 5 December 2022
Accepted 6 December 2022

# The soil trail of Buscagna Valley, an example of the role of soil science in geodiversity and geoheritage analyses

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**Abstract**

Soil is a component of geodiversity and, for its scientific value, can also be a component of geoheritage, playing a role in reconstructing the environmental evolution of an area. This assumption will be examined here with special reference to mountain environments, where the high variability of soil forming-factors is responsible for a great variety of soil types, contributing to soil diversity and to local geodiversity.

To promote soil as an element of geoheritage, we propose a strategy for creating a trail about soil topics in the small mountain catchment of Buscagna hydrographic basin in the Veglia-Devero Natural Park (Lepontine Alps, Italy).

Geopedological research carried out in the study area has allowed the identification of seven soil profiles as sites of potential pedological interest along already existing hiking paths. The selected soil profiles mirror the main soil types of the area and testify past environmental conditions and geomorphic dynamics. Among these, two soil profiles are also selected as pedosites.

Providing hikers and mountaineers a proper key to read exposed soils along the Buscagna Valley, the trail allows an increase in awareness of geoheritage conservation with a focus on soil in mountain landscapes, where soil characteristics reflect the influence of compound forming-factors.

**Keywords**

Soil heritage, Geoheritage, Pedosites, Soil Trail, Buscagna Valley (Lepontine Alps, Italy)

## *1.* **The state of art on soil in geoheritage studies**

### *1.1 Soil diversity (pedodiversity) in relation to geodiversity*

Soil is defined as "a natural body consisting of layers (soil horizons) that are composed of weathered mineral materials, organic material, air and water. Soil is the ultimate product of the combined influence of climate, topography, organisms (flora, fauna, and human) on parent materials (original rocks and minerals) over time" (FAO, https://www.fao.org/soils-portal/about/all-definitions).

The combination of the five main soil-forming factors (i.e., climate, organisms, relief, parent material and time; Jenny, 1941) originated the huge diversity of soils.

The rich diversity of rocks and sediments provides different parent materials determining the development of a variety of soils (e.g., Temme, 2019). Soil diversity is also favoured by the landscape setting and characteristics, which, mainly through their impact on other variables, affect soil development (e.g., Masseroli et al., 2020 and references therein). The different nature and intensity of the weathering processes, related to climate parameters, influences the evolution of pedogenesis (e.g., Masseroli et al., 2021 a). The climate variability across the Earth's surface also induces a vegetation variability, which in turn causes a variation in soil properties and soil development (e.g., D'Amico et al., 2014). The biotic component, including Man, has a paramount impact on soil processes influencing, for example, organic matter accumulation, biochemical weathering, nutrient cycling, aggregate stability, soil mixing and rates of soil erosion (e.g., Rowley et al., 2018; Arroyo-Kalin, 2012; Compostella et al., 2013). Lastly, soil formation (pedogenesis) needs time to take place. In the proglacial areas, the presence of soils characterized by different ages and by different degrees of development over short distances contributes to increased soil diversity (e.g., Masseroli et al., 2022; Bollati et al., 2023; D'Agata et al., 2020).

Therefore, there is a wide diversity of soils across the Earth's surface, and several properties of soil are subject to variability (e.g., colour, particle size distribution, structure, density, pore spaces, horizonation).

Since the XXI century, the attention paid to the diversity of abiotic elements characterizing the planet Earth (i.e., geodiversity sensu in Gray, 2013) has grown, not only as a counterpart of biodiversity, but also for the intrinsic value of geodiversity itself (Gordon et al., 2012). Soils, and their diversity, are one of the many elements that makes up geodiversity. Indeed, geodiversity is defined as "the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contribution to landscapes" (Gray, 2013, p.12).

In this framework and considering the infinite diversity of soils on Earth, pedodiversity is generally defined as the variation of soil properties (usually characterized by soil classes) within an area (Ibáñez et al., 1995; Mc Bratney, 1995; Mc Bratney and Minasny, 2007).

However, in addition to the taxonomic approach, the genetic, parametric, and functional ones are also used to analyse pedodiversity (Mikhailova et al., 2021).

The soil, in fact, as one component of geodiversity, generates important goods and services (Adhikari and Hartemink, 2016; Comerford et al., 2013; Bollati et al., 2023). Soil is an essential resource and a vital part of the natural environment: it is a medium for plant growth, from it most of the global food is produced and its diversity has an important role for agriculture. At the same time, soil acts as habitat for biota (contributing to biodiversity conservation) and provides living environment for humans, as well as regulating the flow of water and climate and also nutrient cycling, e.g., carbon sequestration and carbon recycler of organic matter (Gray, 2013; Bockheim et al., 2005¸; Bollati et al., 2023). Moreover, soil provides also cultural services acting as environmental archives (e.g., in geoarcheology and geoforensic studies) and can be used to monitor the ecosystem status (Gray, 2013).

Since the soil is an interface between atmosphere, hydrosphere, lithosphere and biosphere, the concept of pedodiversity is complex. It is strictly related to atmospheric diversity, biodiversity, hydrodiversity, lithodiversity and geomorphodiversity, and affected by ecosphere and anthroposphere dynamics (Mikhailova et al., 2021; Ibáñez and Bockheim, 2013; Ibáñez, 2014 and reference therein).

Soil diversity is measured and characterized in several ways but, as underlined by Costantini and L'Abate (2016, p. 244), "the pedodiversity of a territory is highlighted through soil mapping and classification".

Unfortunately, the use of different types of soil classification systems (e.g., WRB - World Reference Base for Soil Resources, IUSS Working Group WRB, 2015; Soil Taxonomy - Soil survey staff of USDA, 1999; CPCS - Commission de Pédologie et des Cartographie des Sols, 1967) and the availability in many areas of small-scale soil maps allows only a partial appraisal of pedodiversity (Costantini and l'Abate, 2016). Furthermore, even if buried, soils compose the soil diversity of an area, however they often do not appear on standard maps.

Among the studies dealing with geodiversity, there are not many papers focused on pedodiversity (Ibanez et al., 2019), although knowing the soil diversity of a country or region is of practical utility for the use and also preservation of the soil as a resource (Costantini and L'Abate, 2016), starting from the assumption that it is a variable and evolving land characteristic, which could be affected by accelerated erosion and invasive human activities (Lo Papa et al., 2011; Costantini and Lorenzetti, 2013; Costantini e L'Abate, 2016).

For this reason, soil could be considered, according to the classification proposed by García-Ortiz et al. (2014), as an abiotic resource, that is potentially fragile to natural processes (e.g., water-driven erosion; Bollati et al., 2017a), and vulnerable to human impact (e.g., soil exploitation for agricultural use; Podwojewski, et al., 2015).

*1.2 Pedosites, pedodiversity sites and sites of potential pedological interest*

As depicted by Brilha (2016), the sites representative of the geodiversity of a region could be named *geodiversity sites*, but when they are recognized to have a high scientific value, they are labelled as *geosites* or *geoheritage elements*. Geosites, if not fragile or vulnerable, are valuable for promotion, although only through sustainable approaches allowing the preservation of their integrity. If they are fragile or vulnerable, geoconservation strategies should be adopted to ensure their integrity, before or instead of promoting them.

Whereas the *geosite* concept, defined according to its scientific, cultural and socio economic interests, has been already well recognized internationally (i.e., site concept by Wimbledon, 1996), the concept of pedosite is less common. However, soil can possess heritage characteristics, since, as an interface between different spheres, it can contribute to provide knowledge of how the geosphere works and interacts with other Earth subsystems.

A *pedosite* was defined by Costantini and L'Abate (2009, p.143) as a "georeferenced soil having cultural heritage, that is, a soil exposure or a soilscape where an extraordinary cultural interest has been recognised (Costantini, 1999)". Costantini and L'Abate (2009) divided pedosites in two distinct categories: soil profiles (i.e., paleosols, soils from archeological and paleontological sites, soils displaying natural and anthropic processes) and soilscapes (i.e., soils characterizing a defined and important cultural landscape, soils as a panoramic beauty, soils occurring in fragile environmental balance, soils that support fragile ecosystems such as soils related to specific biotopes).

More recently, Bothelo and Brilha (2022) suggested, following Brilha's (2016) approach applied for the geosites, to restrict the term pedosite to soils with high scientific value, whereas pedodiversity site refers to soils with no particular scientific relevance but with educational, touristic, or other values.

Botelho and Brilha (2022) identified soil heritage based on three major aspects: soil diversity, history of pedology and ex-situ soil heritage.

However, Ibáñez and Brevik (2022) pointed out that geodiversity and pedodiversity studies do not follow the same methods and techniques, therefore currently it is not possible to compare the results of geodiversity and pedodiversity research. Geodiversity studies are mainly focused on the preservation and valorization of geological heritage in a perspective of geoconservation (e.g., geosites, geoparks, geotourism), whereas pedodiversity studies principally aim to quantify soil diversity with index and statistical models. Indeed, many geoheritage studies focused on soils take into consideration the soil as a profile (its promotion and valorization) and not the pedodiversity quantification of an area.

In this light, to avoid creating confusion, rather than using the expression "pedodiversity sites" we prefer using "sites of potential pedological interest" to indicate those soils with no particular scientific relevance but with educational, touristic, or other values. We believe that the label "site of potential pedological interest" may be wider then "pedodiversity site", as it can also be referred to the buried soils that, in contrast, are less considered in pedodiversity literature.

Often the soil is only a secondary topic in geosites inventories, and the number of soil sites populating these databases is still low. For example, in the Italian National Inventory geosites, which are categorized according to their pedological interest, are slightly more than 10 out of 2054 (http://sgi.isprambiente.it/GeositiWeb/ricerca_geositi.aspx accessed on March 10th 2022). Internationally, there are few databases dedicated expressly to pedosites (e.g., Botelho and Brilha, 2022) and sometimes they take into consideration only few of the most important paleosols, leaving aside other types of soils possessing cultural heritage (Costantini e L'Abate, 2009). However, as far as Italy is concerned, Costantini and L'Abate (2009) have proposed a national database (available online: https://www.crea.gov.it/web/agricoltura-e-ambiente/-/soilsites-patrimonio-culturale-pedologico-italia), in which the main pedosites are collected.

Even if for geoheritage the methodologies addressed to the quantification of the scientific and additional values of geoheritage sites are several (see a review in Brilha, 2016), for pedosites this kind of quantitative approach is still lacking. Bothelo and Brilha (2022) presents a method to identify pedosites according to established criteria and based on soil database, whereas Costantini and L'Abate (2009) proposed an evaluation of pedosites based on these criteria: (i) level of interest and (ii) type of scientific interest, (iii) state of conservation, (iv) type and (v) intensity of risk, (vi) level of knowledge, (vii) geological age, (viii) protection and (ix) proposed protection, (x) accessibility, (xi) visibility, (xii) exposure, (xiii) observability.

*1.3 Soil heritage promotion and valorisation: the geotrails and soil trail*

Geoheritage promotion and valorisation is often done through the creation of geotrails (e.g., Burlando et al. 2011; Wrede and Mügge-Bartolovic, 2012) and naturalistic and thematic trails, which could have a strong abiotic imprint (e.g., glaciological trails; Martin 2010; Bollati et al. 2013). Geotrails are usually aimed at the general public (e.g., tourists, scholars) for exploring geoheritage, raising awareness on the possible threats caused both by human and natural factors, and for unconventional teaching and field activities (e.g., Bollati et al. 2011; Garavaglia and Pelfini 2011; Bollati et al. 2016).

In this light, soil trails can be a valid tool for promoting soil as a component of the cultural and natural heritage. Although some things have been done to recognize the importance of soil and pedosites in the context of geoheritage, there are still few studies that promote soil among the elements of thematic paths of geoheritage (e.g., Conway, 2010; Prinz, 2008). Whereas geodiversity, geoheritage, geotourism, and geosites are all terms frequently used in literature, papers focused on pedosites or soil trail are rare and the pedologists seems to be more interested in "soil diversity" analysis (Ibanez et al., 2019).

Although the case studies in the literature are few, there are significant examples where the soil trails have been used to make the general public more aware about the soil relevance for the community. Conway (2010), for example, proposed a soil trail in Anglesey focusing on the importance of soil as a crucial landscape element linked to biodiversity and geodiversity. The soil trail offers to the public an itinerary through the soil diversity of the area, starting from the interests related to nature or archaeology, but also concerning some of current environmental issues, such as soil erosion and carbon storage. Whereas, in the geotouristic itinerary in Southern Tierra Del Fuego (Argentina), Schwarz and Migoń (2017) selected soil as georesource illustrating it in one stop of the itinerary: the "Harberton peatbog" is chosen to explain the importance of bogs and how, studying this georesource, paleoclimate history can be reconstructed. In Austria, the national soil internet platform (http://www.bodeninfo.net/) provides soil trail, in order to show the importance of soils for humans and ecosystem and underline the consequences of soil disturbances.

The planning of a soil trail allows single pedological spots to be highlighted, and could become a tool to appreciate the soil diversity of an area, highlighting how the soil variability mirrors the close interaction between the pedosphere and the other spheres. From this perspective, the heritage value of soil as particular archive of Earth's history and evolution emerges.

## *2.* Study case

To promote soil sites as geoheritage sites, we propose a strategy to include pedological topics within a multidisciplinary trail in the small mountain catchment of Buscagna hydrographic basin in the Veglia-Devero Natural Park (Lepontine Alps).

The European Alps are among the key sites for geoheritage, since they are characterized by a high level of geodiversity, as recognized in general for mountain regions (Gordon, 2018). Mountain regions display high variability in time and space of geomorphological processes and related landforms, which is strictly linked to the diverse lithologies and structures occurring short distances and to the environmental variability of the area (Gordon, 2018). In particular, the high variability of the soil-forming factors (i.e., parent material, climate, relief, organism, time; Jenny, 1941) over short distances, induces an important diversity of soils type (e.g., D'Amico et al., 2020; Zanini et al., 2015). This contributes to the pedodiversity and is also part of local and cultural heritage, allowing narration of the evolution of an area (e.g., Rellini et al., 2015; Cremaschi et al., 2015; Masseroli et al., 2021b).

The Buscagna hydrographic basin, located in the Lepontine Alps, in the Northwestern Italy (Fig.1a), is characterized by a great variety of geomorphic processes and landforms, due to lithology and structural control. Therefore, this area could be suitable to the structure of a soil trail that highlights how the soils, and their diversity, are closely linked to the geomorphodiversity and lithodiversity characterizing the area. The biological diversity, promoted by the presence of climatically and topographically different zones, favours the soil variability even more.

Therefore, the present work is focused on the importance of soils as an element concurring to the definition of geoheritage in the frame of geodiversity and biodiversity relation, for both geoconservation and promotion purposes.

*2.1 Study area*

The Buscagna stream hydrographic basin is SW-NE elongated and ranges in altitude from 1650 m a.s.l. (Devero plain) to 3237 m a.s.l. (Boccareccio Peak). It belongs to a protected area, the ZSC e ZPS IT1140016, Alpi Veglia e Devero - Monte Giove (151.19 $km^2$), which includes the Veglia-Devero Natural Park (Lepontine Alps; Fig.1a,b).

In the hydrographic basin, the outcropping lithologies, belonging to the upper and lower Pennidic Nappes, are the following (e.g., Bigioggero et al., 2007; Steck et al., 2013): i) orthogneisses with locally intercalated amphibolites, micaschists and paragneiss (Monte Leone Unit); ii) ultramafic rocks, mainly serpentinites (Ultramafic Cervandone-Geisspfad Complex) iii) calcschists and marbles.

The basin is characterized by an evident asymmetry between the valley slopes in terms of lithology (Fig. 1c): calcschists outcrop on the southeastern slope whereas orthogneiss, micaschists and spots of ultramafic rocks outcrop on the northwestern slope. This difference, together with the structural control, is responsible for the great landform variability and the geomorphic dynamic dissimilarities between the slopes (Bollati and Cavalli, 2021).

Glacial modelling of the area is generally evident. The Buscagna valley is a glacial hanging valley over the Devero plain, and it set along the contact between gneisses and calcschists. It was intensely shaped by glaciers as testified by the presence of Pleistocene glacial landforms and deposits, such as morainic ridges and erratic boulders, which are very widespread. More recent Holocene glacial stages are seen in the landscape and the differentiation between slopes of different origin is evident in terms of response to water and gravity related processes. Due to the different behaviour of orthogneisses and calcschists with respect to the superficial processes, the northwestern slope is characterized by a high relief energy, and it is affected by gravity-related processes like rockfalls and debris-flows (Fig. 1c). Whereas calcschists and marbles, cropping out along the southeastern slope and at the valley head, are more suitable to weathering and dissolution being soluble and, hence, affected by karst processes (Fig. 1c). In this context, snow avalanches are also important modelling agents, especially the wet spring avalanches, which, through the debris transport are able to shape avalanche channels and contribute to the debris cone and debris flow fan evolution.

The climate of the Devero area is temperate continental (Garbarino et al., 2013), with cold winters and moderate summer temperatures. The dominant tree species is the European larch (*Larix decidua*), with the Norway spruce (*Picea abies*) as the co-dominant species at lower elevations (Garbarino et al., 2013). A bushy undergrowth, mainly composed of rhododendron (*Rhododendron ferrugineum*) and blueberry bushes (*Vaccinium myrtllus*), characterizes the European larch forest. At higher altitudes, the forest thins out, replaced by shrub and alpine grassland. Human impact has heavily influenced the vegetation cover of the Devero area over time (Garbarino et al., 2013). Cattle grazing has been in this area since approximately 1300, and it is still ongoing, mainly in open pastures, but also in wood pastures (Garbarino et al., 2013).

The soils of the Devero area are mainly Umbrisols (from Leptic to Brunic) and Cambisols (mainly Dystric) (Carta dei Suoli del Piemonte, 1:250.000; IPLA, 2007). Soil with low degrees of development, as Leptosols, Regosols and Fluvisols are common in slope portions affected by active geomorphological processes (e.g., mass movements, running water, and snow avalanches) (Carta dei Suoli del Piemonte, 1:250.000; IPLA, 2007). Whereas Podzols are the most widespread on the more stable surfaces, with a continuous vegetation cover (Carta dei Suoli del Piemonte, 1:250.000; IPLA, 2007).

*2.2 Selection strategy of soil trail sites and pedosites*

The selection process consisted of two phases subdivided in four steps (workflow in the Fig. 2): first, we selected the sites of potential pedological interest for the trail, according to the criteria that will be presented below (i.e., accessibility, soil diversity, pedostratigraphy, visibility), subsequently, among these, the pedosites were chosen according to their scientific value and other criteria.

The profiles selected for the trail were previously studied in detail (Masseroli et al., 2020): the soils were characterized through chemical and physical analyses and micromorphological observations (Step 1). A geomorphological map of the area was also created (Bollati and Cavalli, 2021).

The sites of potential pedological interest in the Buscagna Valley for the soil trail have been selected according to a range of criteria (Step 2):

1. *Accessibility*: profiles are located in safe and accessible places, along already existing hiking paths, in order to directly provide hikers and mountaineers a proper key to read exposed soils and thus to allow increasing awareness towards geoheritage conservation.
2. *Soil diversity*: profiles show the broad diversity of high altitude soils in order to bring the diversity to the attention of the public and to underline that soil diversity is a mirror of the geomorphodiversity and biodiversity of the area.
3. *Pedostratigraphy*: sometimes, profiles are composed of different soil units (i.e., pedostratigraphic levels sensu Costantini and Priori, 2007) that allow to underline that soil can be used as an archive of past environmental conditions and geomorphic dynamics.
4. *Visibility*: profiles are nearly always visible as they are exposed along natural scarps, produced by geomorphological processes (e.g., areas in subsidence, erosion scarp due to watercourse erosion) and/or along artificial scarps, related to anthropic activity (e.g., path, pastures).

In this first phase, the sites of potential pedological interest have been chosen for the purposes of the construction of the soil trail and are not pedosites, which will be selected in the second step of the procedure (Fig. 2) according to their scientific value. Based on the existing literature (Masseroli et al., 2020) we selected, among the soil profiles chosen for the trail, those that had a scientific value and could therefore be defined as pedosites (Step 3). The selection was carried out by using the methodology proposed by Costantini and L'Abate (2009) for the creation of the national database of pedosites (Step. 4). The qualitative evaluation presented by Costantini and L'Abate (2009) is based on the following categories: (i) level of interest and (ii) type of scientific interest, (iii) state of conservation, (iv) type and (v) intensity of risk, (vi) level of knowledge, (vii) geological age, (viii) protection and (ix) proposed protection, (x) accessibility, (xi) visibility, (xii) exposure, (xiii) observability (for more details see Costantini and L'Abate, 2009).

It is worth underlining that some of the parameters are the same as those used in the first step of the procedure, but they could be considered for this specific purpose.

Finally, we proposed a possible promotion strategy for the soil trail and pedosites, through the construction of explanatory panels for each site of potential pedological interest to be also made available online.

2.3 *Soil trail structuring*

The proposed soil trail runs along the already existing hiking trail (medium difficulty level) from about 1650 m a.s.l. to 2300 m a.s.l. (with a difference in height of about 700m) and it is about 10 km long. Along this, seven soil profiles have been selected as sites of potential pedological interest (Fig. 3).

Being located in a high-altitude area, the trail can be mainly hiked in summer, when the avalanche risk is absent, the snow cover has melted and the soil profiles are clearly visible. In addition, the potential for debris flows in heavy rain means that the area should be avoided during and after extreme meteorological events. Following the path characteristics, this soil trail will be mainly addressed for hikers and mountaineers passionate about nature. The selected trail is a loop and partly follows the *Grande Traversata delle Alpi* (GTA), in the trait connecting Alpe Devero with Alpe Veglia. Alpe Devero represents the start and end point of the soil trail (Fig. 3).

The profiles selected on the northwestern slope are most useful for describing the close relationship between soil development and geomorphological processes. The presence of sequences of paleosols, often truncated by erosion, frequently overlain by younger soils developing on the debris flow and talus slope deposits, allows us to display how soil has recorded the geomorphological dynamics that affected this part of the slope. These sites challenge people to consider that soil is a useful archive to gather information on the landscape and its evolution.

Moreover, the 4 selected soil profiles belong to four different reference soil groups (IUSS Working Group WRB, 2015) showing that even in a small area the interaction of different soil forming factors can lead to the formation of different soil types.

The 4 stops located on the northwestern slope will be presented below.

1. The first site of potential pedological interest is located in a snow avalanche corridor, often affected by disruptive events (e.g., mass wasting and snow avalanche). In this site, the soil profile is brought to light by the instability event that uprooted some trees exposing a portion of the soil (Fig. 4a). The profile is located at a very short distance from the path.

   This area is an excellent example of the relation between soil profile characteristics and geomorphological context, but also with vegetation disrupted by powerful snow avalanches. The continuous contribution by slope processes of coarse material determines the weak degree of soil development, inducing a continuous profiles rejuvenation that does not allow pedogenesis to take place. The most evident soil characteristic that reflects this phenomenon is the presence of a large amount of coarse material along the profile (Fig. 4a). Moreover, the soil coarse mineral component, clearly visible inside the profile, also provides information on the source of the material transported by the geomorphological processes. In fact, gneiss but also ultramafic rocks, outcropping upslope, are observable. As mentioned before, snow avalanche processes are also highlighted by trees with tilted stem or truncated trees, located nearby where the soil profile was sampled. This first profile represents an example of Leptosol, i.e., a thin soil characterized by a weak degree of development and a large amount of coarse material, typical of mountain regions in area with strongly dissected topography (IUSS Working Group WRB, 2015, p. 163).

2. Located along the path on an inactive debris flow deposit, the second site of potential pedological interest has been selected since it highlights how the soil profile records the instability events. The profile has three different soil units (Fig. 4b). The soil unit 1 and 2 are separated by a stone line, evidence of the occurrence of a slope instability event, probably due to debris accumulation by gravity, a process no longer active at the soil profile location.

   The good degree of development of surface soil units testifies to the current stability conditions of the surface, but the well preserved and unweathered stone line shows that the instability event was quite intense and/or recent. Also in this case, the vegetation that has partially colonized the debris flow deposits can testify to the current stability of the slope.

   In addition, from a geopedological point of view the surficial soil units of this soil profile can be a good example of a Cambisol, i.e., a soil characterized by an incipient subsurface soil formation and parent material transformation, highlighted by structure formation, and mostly brownish discoloration (IUSS Working Group WRB, 2015, p.152), and by the differentiation of the B horizons.

3. The third site of potential pedological interest is located along an erosion scarp on the flat valley bottom, along the Buscagna stream. The soil profile, highlighted by the erosion of the watercourse, is visible from the path that, on the stretch, runs along the Rio Buscagna (Fig 4c). This site demonstrates clearly how soil has recorded the geomorphic dynamics related to the water action, which over time has deposited sediments that have truncated and buried the existing soils, and acted as a parent material for the subsequent pedogenetic phases. The occurrence of multiple buried soils with developed B horizons indicates past surface stability, which would have allowed weathering rates to exceed erosion and deposition rates. The different soil units are identifiable in the field by the presence of grain-size discontinuities and/or a change in colour (Fig. 4c).

   The surface soil units can be classified as Fluvisols, a genetically young soil developed in fluvial deposits with evidence of stratification, characterized by weak horizon differentiation but by a distinct topsoil horizon (IUSS Working Group WRB, 2015 pp. 157-158). Approaching the profile, the different soil units show a comparable mineral composition and texture suggesting a similar material source and depositional processes.

   The area has other similar profiles, albeit less deep, located at the edges of past Buscagna riverbed. These soils record the different depositional events and the subsequent stability phases of the plain. The migration of the watercourse into the plain through time has brought to light different portions of the same soil sequence, thus allowing public to observe the soil.

4. The last site on the northwestern slope is located along the path on glacial deposits on the edge of an inactive debris flow deposit. The soil shows two different units, testifying a past event of instability, and are characterized by a low degree of development (Fig. 4d).

   The surface soil unit can be classified as Regosol (i.e., "weakly developed soils in unconsolidated material", IUSS Working Group WRB, 2015 p. 172), it only shows an incipient pedogenesis that, perhaps due to the past geomorphological processes and today's pasture exploitation, has not yet had the opportunity to take place. This soil is a classic example of an incipient stage of pedogenesis, which, depending on the future influence of the formation factors, could evolve becoming, for instance, a Cambisol.

These first four sites highlight how the soil is more dynamic and variable than people think and that there is a continuous balance with the forming factors that determine its evolution. At the same time, however, it also shows soil resilience, it is a record in time, as characteristics and soil features, of the processes and environmental conditions that took place in the past and in some case, it superimposes the result of new processes on these. Moreover, soils tell us about the occurrence of different geomorphological processes and how these processes have been recorded within the soil in different ways depending on the intensity and degree of activity.

The profiles selected on the southeastern slope testify to a greater slope stability, which allowed the formation and subsequent conservation of two buried Podzols, a typical boreal and temperate soil often associated with a conifer vegetation cover, which are among the most aesthetic and colourful soils in mountainous areas. Also, a soil profile was selected along the slope in order to show the effect on soil record of the various instability events that have characterized the steepest portions of the slope.

5. The sites of potential pedological interest number 5 gives the opportunity to observe, along the path, a profile consisting of two different units: a surficial Cambisol and a noteworthy buried cryptoPodzol (Fig. 5a). In the field, the presence, at about 40 cm of depth, of a grey depleted horizon, identifiable as horizon AE, and the underlying brown horizon Bhs, allows to identify the buried cryptoPodzol (Podzol is a soil characterized by "an illuvial horizon with accumulation of black organic matter and/or reddish Fe oxides. This illuvial horizon is typically overlain by an ash-grey eluvial horizon", IUSS Working Group WRB, 2015 p. 171).

   Observing this profile, the different degree of development of the two soil units shows the past environmental conditions. Since the identified podzolic paleosols have a much stronger pedogenic degree than superficial soils, during their development, the climate conditions and the vegetation cover could be different compared to present-day conditions. For example, the area was probably characterized by a denser vegetation cover, which, perhaps due to human impact (e.g., deforestation due to grazing), is absent today. Therefore, the selected soil profile offers the opportunity to talk about how anthropogenic activity modifies the environment and is a determining factor in soil evolution in a direct or indirect way.

6. Although more stable, the southeast side is affected by erosional and depositional processes. The soil of the sixth site of potential pedological interest narrates the geomorphic dynamics of the slope. The profile is located on an erosion scarp due to the action of an intermittent watercourse, at a short distance from the path.

   Observing the profile, the presence of horizons characterized by different colours and particle size composition underlines the existence of four soil units along the profiles (Fig. 5b), the superficial ones can be classified as Umbrisols (i.e., soil characterized by "a significant accumulation of organic matter in the mineral surface soil" and a dark topsoil, IUSS Working Group WRB, 2015 pp. 178-179).

   As for the profile located on the northwestern slope near the Rio Buscagna, this selected soil profile records processes of water action and to a lesser extent to gravity. In this profile, the deposited material has a coarser texture, this underlines how the different slope steepness affected the solid discharge.

   In addition, this stop leads the public to observe how the overlapping of different processes has contributed to form the soil profile shown at this location.

7. In the last selected area, there are several examples of soils composed of two units made visible by subsidence. Among these, the best preserved and closest to the path was chosen.

   The structure of the profile is very similar to profile 5 as it is composed of a superficial Cambisol and a buried Podzol (Fig. 5c). However, this selected soil has a more expressed and better preserved buried Podzol than the profile 5. At a depth of about 40 cm, it is possible to observe a buried black horizon (AOb), an underlying depleted grey horizon (E) and a red spodic horizon (Bhs) (i.e., "subsurface accumulation of organic matter and/or Fe and Al", IUSS Working Group WRB, 2015 p.7). The buried Podzol of this site has most of the podzolic characteristics, this is a good example to explain the processes that form this soil.

   As for site 5, the difference between the surface soil unit and the buried one could be due to a longer pedogenesis period, and/or different climate conditions (warmer and wetter), and/or different vegetation cover (perhaps linked to different human exploitation) during their development, compared to present-day conditions.

Furthermore, by comparing the buried Podzols of the two different sites (5 and 7), a different expression of the podzolization process is evident, highlighting the different altitude that characterizes the two sites, which in turn influences the microclimatic conditions and the vegetation cover, may have affected soil evolution and it probably will influence the evolution of the surficial soil units too.

Along the trail, in addition to discovering different types of soil, the visitors can better understand the relationship between the soil and its formation factors, concluding that the soil diversity observed along the path reflects the different environmental conditions of Buscagna Valley.

*2.4 Pedosite individuation*

As shown in the previous paragraph, the soil trail is composed of seven soil profiles chosen because they narrate the environmental change and the landscape evolution, and show the soil diversity of the Buscagna hydrographic basin. Among those presented in the soil trail, profiles number 2 and number 7 have been selected as potential pedosites. The soils selected as pedosites were hence classified according to the form proposed by Costantini and L'Abate (2009) for the inclusion in the database (Table 1).

The two selected profiles, in addition to being well preserved, with good accessibility and visibility, are the most suitable examples of the soil variability of the area. Furthermore, both of these profiles clearly testify to the environmental variation in time and space. Profile 2 is characterized by a Cambisol as superficial soil units separated from the buried soil by a stone line, evidence of the past geomorphic dynamics that affected the area (i.e., the slope processes). Therefore, among the profiles located on the northwestern slope, our selected site is the best profile that combines the possibility of observing a soil with a good degree of development as well as the evidence of a geomorphological process (in this case a slope processes).

Profile 7 shows a beautiful, almost entirely preserved buried Podzol allowing the inference of the past environmental conditions that led to its formation, whereas, as in the Profile 2, the superficial soil unit is a Cambisol. The profile 7 was selected instead of the 5 because the buried Podzol is better preserved and shows a more marked soil development in relation to the podzolization processes (e.g., organic horizon, eluvial horizon and spodic horizon). Both profiles have not been selected to avoid repetition, but to complement each other, and profile 5 could be associated with 7 considering them as members of a toposequence (i.e., "a sequence of related soils that differ, one from the other, primarily because of topography as a soil-formation factor", https://www.soils.org/publications/soils-glossary/), but not as a pedosite.

Therefore, the two selected pedosites emphasize how the soil can be useful in reconstructing instability events and the role of soil as an archive of information for reconstructing environmental conditions.

*2.5 Proposal for soil trail promotion*

In order to communicate the information about the soil trail, for each site of potential pedological interest an illustrative panel, containing soil profile characteristics and information about the evolution of the area, will be prepared (Fig. 6). We intend to make available the location of each site and the associated descriptive panel on Google Earth through a link. This favours the reading and the comparison of the information even remotely, and while on the trail depending on the internet connection.

Through this trail, once equipped with illustrative panels, we want to show soil, its characteristics and its variability, and, in addition, we want to show how soil can be used as a useful archive for reconstructing the evolution of a landscape and past environmental conditions.

The soil trail has been designed for hikers and mountaineers passionate about nature, but who are often not familiar with soil topics, even if soil is what they are walking on. The panels provide of texts that use simple and concise language in conjunction with a captivating graphic, done using the software package Canva. As a general rule, the text is written using a Sans Serif font to make it easier to read.

More in detail, the panels are designed following the 3-30-3 scheme (Bruno and Wallace, 2019), as follows:

- the headlines are written in a large font and visitors can read it in a calculated time of 3 seconds;
- the key message is supported with a main image, that is in this specific case the soil profile photo, and medium-font subheadings that can be read in 30 seconds;
- the soil profile sketch, showing the characteristics in more detail, and an explained simplified geomorphological map of the area (e.g., geoboxes; Bollati et al., 2017b; Masseroli et al., 2020) aimed at enhancing the geomorphological processes currently active or no more active to or that were active in the past, are inserted as additional material, which can be read in 3 minutes.

The sketch profile box illustrates the main soil characteristics observable along the profile. In particular, it is drawn to scale and shows the main features of the soil type and the subdivision into horizons (Fig. 6).

To incite curiosity and wonder, non-conventional data are also included in each panel, according to the soil topic illustrated. For instance, in the case of the two buried Podzols a picture of soil thin section was included (Fig. 6). The panels are planned both to be installed in the future on site or preferably made available in pdf file through the web (e.g., website of the protected area, specific apps for planning excursions and QR codes).

**Discussion and Conclusions**

This research illustrates how soil can be an interesting topic enhancing the geoheritage of an area. Although little considered in the framework of scientific discussion on geoheritage, soil can display multiple facets and offer different opportunities.

First, the soil has value as "a profile" inasmuch it is the product of the ongoing and, in some cases, past geopedological processes. Moreover, soil can disclose the environmental and landscape evolution of an area, since it is the result of different forming factors interactions. Beside this scientific application, their peculiar characteristics make the soil a useful tool also in the view of educational and promotional activities.

To better promote soil as component of geoheritage, the planning of a soil trail seems to be the most suitable and common approach. Indeed, a soil trail allows to highlight the diversity of an area from a pedological perspective, and, at the same time, can help in contextualizing the surrounding environmental reconstructions, obtained due to the geopedological research. Moreover, the integration of pedological information with those pertaining to geology, geomorphology or botany, through appropriate explanatory material, will guide the user in a more holistic landscape interpretation.

The soil trail of Buscagna Valley can represent a valid alternative/add on to the more common approach through geotrails and can also be used in other areas in order to promote the soil as a component of geoheritage. Soil has been very rarely used as the main focus of an entire itinerary (Conway, 2010) and also the selected location is particular, since the proposed trail is located in a high-altitude area.

Furthermore, this soil trail is developed within a protected area, the regional park of the Veglia-Devero. Being within a natural park facilitates the promotion, which is also carried out through the park communication channels, and the geoconservation of the site is assured through the park. Indeed, many geo trails are carried out in protected areas, such as the UNESCO Global Geoparks of Mixteca Alta in Mexico (Prieto et al., 2019) or Sesia-Val Grande (Perotti et al., 2020), or even more in the area surroundings geosites of local and national importance (Theodosiou et al., 2010).

In the case of the Veglia-Devero Natural Park, other thematic trails are already present (e.g., The Black Lake and the Buscagna Valley: the forest of the Park - https://www.areeprotetteossola.it/en/excursions) but focused on other topics (e.g., forest dynamics), thus the soil trail of the Buscagna Valley could expand the offer, by presenting themes not yet addressed.

Finally, the Buscagna Valley soil trail corresponds partly to a path usually proposed to families, being the itinerary of limited length and reduced walking times, consequently the whole experience is easily feasible in one single day, depending on the hiker preparation.

Among the seven soils selected for the trail, only the two most representative and with a high scientific value have been chosen as pedosites. However, the official recognition of these two pedosites is desirable and important, allowing the soil to be considered as a geoheritage component, completing the enhancement and protection of the soil of the Buscagna Valley area, inside the Veglia-Devero Natural Park.

As mentioned in the previous paragraphs, the informative-educational tools are fundamental for the correct use and for transmitting knowledge in a touristic trail (Bruno and Wallace, 2019).

The panels, created in the proposed soil trail, aim at the total independence of the visitor: the information is simplified and condensed as much as possible to make it comprehensible to the general public and this including the fundamental concepts. However, before the trail setting up, the panels could be evaluated by the potential users or a representative sample of general public, and eventually modified according to the received feedback.

The choice of proposing a digital trail, as already done in other study case in literature (e.g., Perotti et al., 2020), simplifies its use, allowing the visitor to prepare in advance their visit on the field. The interested visitor can view the digital version not only in advance but also remotely, and the quick sharing of the file through the link allows an equally effective communication of the itinerary. Furthermore, the installation costs are low and the panels in digital version guarantee the possibility of updating information through time, with a potential improvement of the contents and graphics without a new reproduction of the panels, necessary if these are printed and exhibited.

We should also take into consideration that the soil, being the result of the interaction of various forming factors, may over time change its characteristics and the high mountain landscape could be really dynamic. For example, as a result of slope processes, soil could be subject to erosion and/or burial (i.e., formation of buried soils), whereas because of an environmental change (e.g., change of vegetation cover, climate deterioration) the new pedogenetic processes can superimpose on the previous ones (e.g., polycyclic soils). Therefore, also in terms of protection and enhancement, this characteristic of soil must be taken into consideration and the choice to create an online soil trail allow to easily update and modify the scientific content.

**Acknowledgments**

This work was supported by Università degli Studi di Milano, Fondi Potenziamento della Ricerca - Linea 2 - 2017 (entrusted to A. Zerboni) and 2018 (entrusted to I. M. Bollati). The Authors thanks the

Ente Gestione Aree Protette Ossola for the logistic support during the field surveys. We thank editor and two anonymous reviewers for helping us revise the first version of the manuscript.

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**Figure Captions**

Figure.1. Study area; a) geographical setting (modified from https://www.freeworldmaps.net/europe/europe-bw-hd.jpg); b) study area location in the context of Veglia-Devero Natural Park; c) panoramic view of the northwestern slope taken from the southeastern slope (photo courtesy of F. Moraschina).

Figure 2. Analysis workflow. Scheme of soil trail structuring and pedosite selection process composed of two phases subdivided in four steps.

Figure 3. Soil trail path (white line). The red point refers to the location of each site of potential pedological interest; b) soil trail path on altitude contour map, courtesy made available by the Geoportale Nazionale (http://www.pcn.minambiente.it/GN/, WMS service).

Figure 4. Soil profiles of sites of potential pedological interest selected for the trails. a) Soil trail location 1: Leptosol characterized by a lot of coarse materials; b) soil trail location 2: soil profiles composed by different soil units, characterized by a Cambisol as surface unit and the presence of a stone line; c) soil trail location 3: Fluvisol with different soil units; d) soil trail location 4: soil profile composed of a surficial Regosol and one buried soil.

Figure 5. Soil profiles of sites of potential pedological interest selected for the trails. a) Soil trail location 5: Cambisol and buried cryptoPodzol; b) soil trail location 6: soil profiles composed by different soil units due to action of geomorphological processes, the surficial soil is a Umbrisol; c) soil trail location 7: Cambisol and buried Podzol.

Figure 6. Example of illustrative panel that we intend to prepare for the soil trail. The title is placed at the top and centred (time required for reading 3 seconds); the main text is placed under the title in the upper portion of the panel (time required for reading 30 seconds; the two brown boxes and the white bubble contain additional information, written in a smaller font (time required for reading figures and text: 3 minutes). The soil profile sketch and the geomorphological map are modified from Masseroli et al., 2020.

**Table Caption**

Table 1. Qualitative evaluation of the two potential pedosites. The Criteria are taken from Costantini and L'Abate (2009). In few cases, the criteria descriptions are partially modified to better fit to our purpose.

| Criteria | Site 2 | Site 7 |
|---|---|---|
| *Level of interest* | regional interest | regional interest |
| *Types of scientific interest* | paleoenvironmental evidence; pedological evolution model; didactic interest | paleoenvironmental evidence; pedological evolution model; didactic interest |
| *State of conservation* | medium | good |
| *Type of risk to lose natural/cultural heritage* | natural: slope processes; anthropic: grazing activity | natural: subsidence phenomena; anthropic: grazing activity |
| *Degree of risk of losing natural/cultural heritage* | low | low |
| *Level of knowledge* | Scientific publications | Scientific publications |
| *Geological age* | Holocene | Holocene |
| *Protection* | protected (Veglia-Devero Natural Park) | protected (Veglia-Devero Natural Park) |
| *Proposed protection or "measures"* | suggested | suggested |
| *Accessibility* | access on foot along to hiking path | access on foot along to hiking path |
| *Visibility* | partial, it needs to be ameliorated | entirely visible |
| *Exposure* | anthropic | natural |
| *Observability* | summer (without snow) | summer (without snow) |



**Table 1**

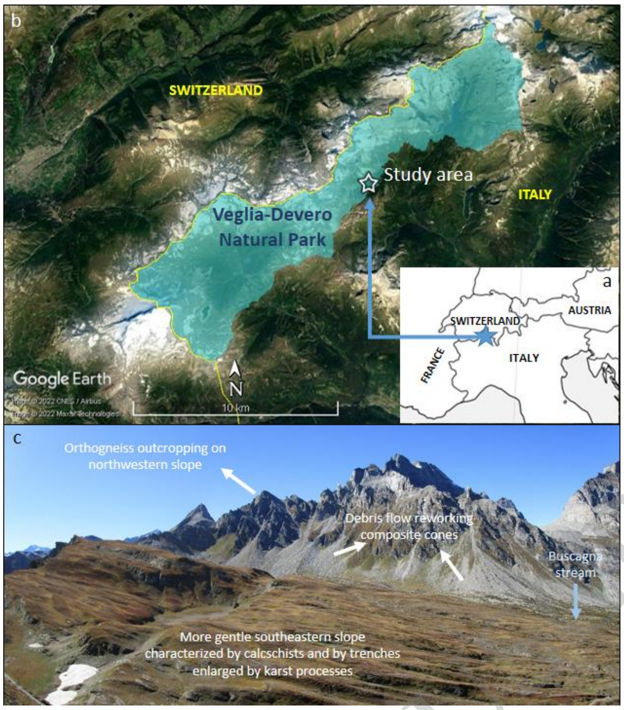
b
SWITZERLAND
Study area
ITALY
Veglia-Devero
Natural Park
a
AUSTRIA
SWITZERLAND
ITALY
FRANCE
Google Earth
N
10 km
c
Orthogneiss outcropping on
northwestern slope
Debris flow reworking
composite cones
Buscagna
stream
More gentle southeastern slope
characterized by calcschists and by trenches
enlarged by karst processes



**Figure 1**

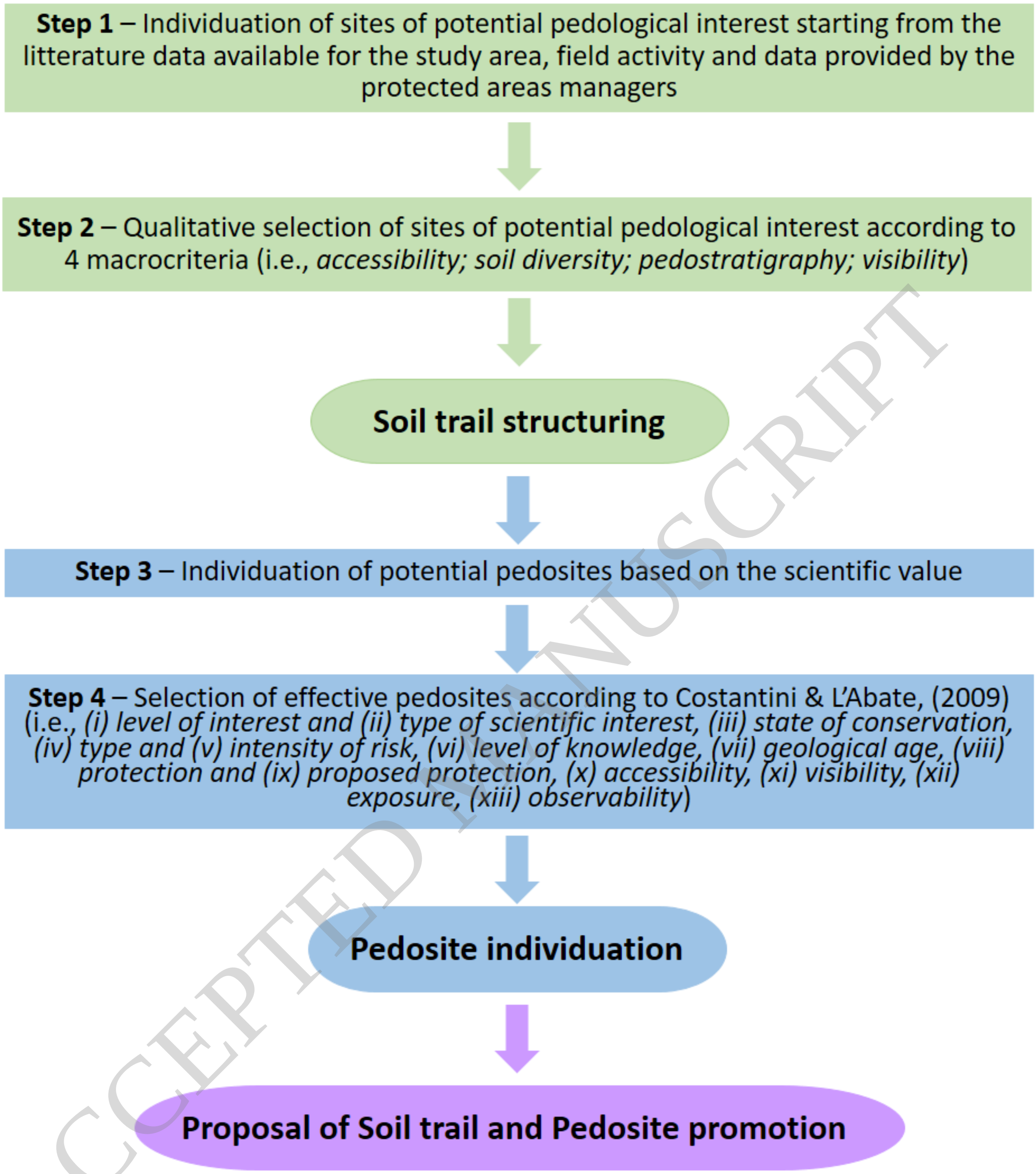
**Step 1** – Individuation of sites of potential pedological interest starting from the litterature data available for the study area, field activity and data provided by the protected areas managers
**Step 2** – Qualitative selection of sites of potential pedological interest according to 4 macrocriteria (i.e., *accessibility; soil diversity; pedostratigraphy; visibility*)
Soil trail structuring
**Step 3** – Individuation of potential pedosites based on the scientific value
**Step 4** – Selection of effective pedosites according to Costantini & L'Abate, (2009) (i.e., *(i) level of interest and (ii) type of scientific interest, (iii) state of conservation, (iv) type and (v) intensity of risk, (vi) level of knowledge, (vii) geological age, (viii) protection and (ix) proposed protection, (x) accessibility, (xi) visibility, (xii) exposure, (xiii) observability*)
Pedosite individuation
Proposal of Soil trail and Pedosite promotion



**Figure 2**

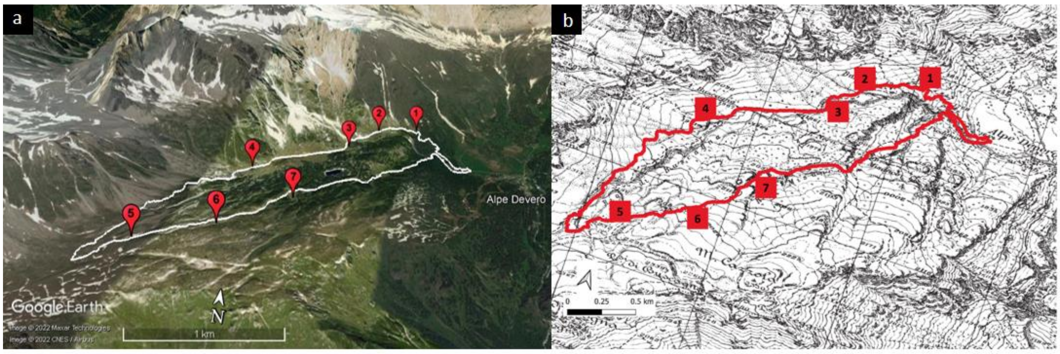




**Figure 3**


a
coarse
mineral
component
b
Cambisol
stoneline
2 different
buried soil
units
c
Fluvisol
4 different buried soil units
d
Regosol
buried
soil
unit



**Figure 4**

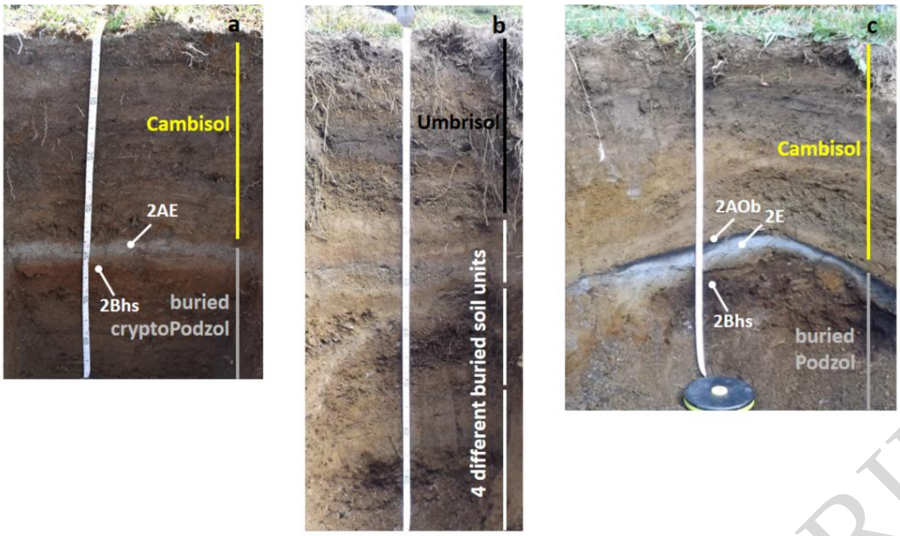
a
Cambisol
2AE
2Bhs
buried
cryptoPodzol
b
Umbrisol
4 different buried soil units
c
Cambisol
2AOb
2E
2Bhs
buried
Podzol



**Figure 5**

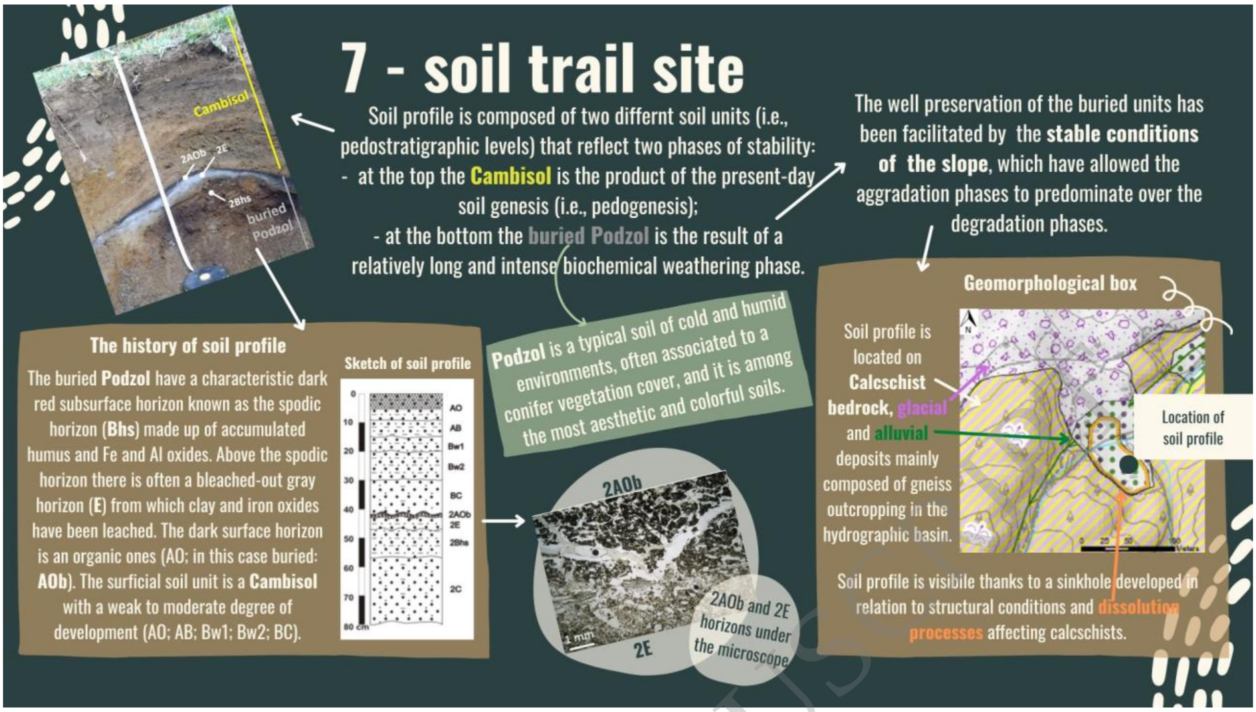
7 - soil trail site
Soil profile is composed of two diffrent soil units (i.e., pedostratigraphic levels) that reflect two phases of stability:
- at the top the Cambisol is the product of the present-day soil genesis (i.e., pedogenesis);
- at the bottom the buried Podzol is the result of a relatively long and intense biochemical weathering phase.
The well preservation of the buried units has been facilitated by the stable conditions of the slope, which have allowed the aggradation phases to predominate over the degradation phases.
Cambisol
2AOb
2E
2Bhs
buried Podzol
The history of soil profile
The buried Podzol have a characteristic dark red subsurface horizon known as the spodic horizon (Bhs) made up of accumulated humus and Fe and Al oxides. Above the spodic horizon there is often a bleached-out gray horizon (E) from which clay and iron oxides have been leached. The dark surface horizon is an organic ones (AO; in this case buried: AOb). The surficial soil unit is a Cambisol with a weak to moderate degree of development (AO; AB; Bw1; Bw2; BC).
Sketch of soil profile
AO
AB
Bw1
Bw2
BC
2AOb
2E
2Bhs
2C
Podzol is a typical soil of cold and humid environments, often associated to a conifer vegetation cover, and it is among the most aesthetic and colorful soils.
2AOb
2E
1 mm
2AOb and 2E horizons under the microscope
Geomorphological box
Soil profile is located on Calcschist bedrock, glacial and alluvial deposits mainly composed of gneiss outcropping in the hydrographic basin.
Location of soil profile
Soil profile is visibile thanks to a sinkhole developed in relation to structural conditions and dissolution processes affecting calcschists.



**Figure 6**